Multi-hazard Loss Estimation Methodology

Flood Model

Hazus®-MH

Technical Manual

Developed by:
Department of Homeland Security
Federal Emergency Management Agency
Mitigation Division
Washington, D.C.

This manual is available on the FEMA Hazus website at www.fema.gov/plan/prevent/hazus.

To order the Hazus software visit www.msc.fema.gov and go to the Product Catalog to place your order.

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Message to Users

Hazus is designed to produce loss estimates for use by federal, state, regional and local governments and private enterprises in planning for risk mitigation, emergency preparedness, response and recovery. Hazus comes complete with methodology to analyze earthquakes, flood and hurricane winds. The methodology deals with nearly all aspects of the built environment, and a wide range of different types of losses. Extensive national databases are embedded within Hazus, containing information such as demographic aspects of the population in a study region, square footage for different occupancies of buildings, and numbers and locations of bridges. Embedded parameters have been included as needed. Using this information, users can carry out general loss estimates for a region. The Hazus methodology and software are flexible enough so that locally developed inventories and other data that more accurately reflect the local environment can be substituted, resulting in increased accuracy.

Uncertainties are inherent in any loss estimation methodology. They arise in part from incomplete scientific knowledge concerning each of the three hazards and their effects upon buildings and facilities. They also result from the approximations and simplifications that are necessary for comprehensive analyses. Incomplete or inaccurate inventories of the built environment, demographics and economic parameters add to the uncertainty. These factors can result in a range of uncertainty in loss estimates produced by Hazus, possibly *at best* a factor of two or more.

The methodology has been tested against the judgment of experts and, to the extent possible, against records from several past earthquakes, floods and hurricanes. However, limited and incomplete data about damage from these events precludes complete calibration of the methodology. Nevertheless, when used with embedded inventories and parameters, Hazus has provided a credible estimate of such aggregated losses as the total cost of damage and numbers of casualties. Hazus has done less well in estimating more detailed results - such as the number of buildings or bridges experiencing different degrees of damage. Such results depend heavily upon accurate inventories. Of course, the geographic distribution of damage may be influenced markedly by local conditions. In the few instances where Hazus has been partially tested using actual inventories of structures plus correct local condition maps, it has performed reasonably well.

Users should be aware of the following specific limitations:

- While Hazus can be used to estimate losses for an individual building, the results must be considered as average for a group of similar buildings. It is frequently noted that nominally similar buildings have experienced vastly different damage and losses during a natural hazard.

- When using embedded inventories, accuracy of losses associated with lifelines may be less than for losses from the general building stock. The embedded databases and assumptions used to characterize the lifeline systems in a study region are necessarily incomplete and oversimplified.

- The Flood Model performs its analysis at the census block level with small numbers of buildings. Damage analysis of these small numbers makes the Flood Model more sensitive to rounding errors. These results should be used with suitable caution.

Hazus should still be regarded as a work in progress. Additional damage and loss data from actual earthquakes, wind or flood events, and further experience in using the software will contribute to improvements in future releases. To assist us in further improving Hazus, users are invited to submit comments on methodological and software issues by letter, fax or e-mail to:

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Chapter 1. Introduction to FEMA Flood Loss Estimation Methodology

1.1 Hazus: FEMA's Multi-Hazard Loss Estimation Methodology & Software

In the early 1990's, FEMA embarked on an ambitious undertaking to expand the Nation's capacity to estimate losses from major types of natural hazards, including earthquakes, floods, and severe winds. This enhanced capacity for estimating losses from natural hazards will be embodied in Hazus, an integrated software package. Within Hazus, there will be a separate module for estimating the losses from each hazard. The earthquake and flood modules are now operational, and are undergoing continual improvements. The wind module is currently under development.

This expanded analytical capacity will assist public officials at all levels of government in preparing estimates of losses from natural hazards, and in facilitating emergency response, planning, and hazard mitigation. One can envision numerous private-sector applications as well, particularly by the insurance and construction industries and others interested in economic development.

From a natural hazards policy perspective, the capacity of Hazus to generate consistent loss estimates for these multiple hazards is particularly significant. To achieve this consistency, Hazus, to the extent possible, draws on shared national databases. The national inventory of housing and commercial and industrial facilities is perhaps the best example of a shared database. Because of the unique nature of each hazard, however, different attributes of the shared data are most critical in determining loss estimates from individual hazard. For example, for flood loss estimation, knowing a building's first floor elevation and specific location within a community is more critical than in estimating earthquake losses. In contrast, knowing the height of the building and certain of its structural characteristics is more critical in estimating earthquake losses.

Within Hazus, care is also being taken to guarantee that the loss estimation methodologies are consistent across modules. The flood and wind committees, for example, are coordinating their efforts so that the separate methodologies do not double count the losses due to wind and storm surge during coastal storms.

Another unique feature of Hazus is its capacity to accommodate additional data and methods that are often available at the state and local level. It is through this capacity of Hazus that localities can use the tool to refine loss estimates for local emergency planning and to determine the effects of hazard mitigation strategies. Where no current data on the flood hazard exist, Hazus can also be used by localities as a platform for increasing awareness of the flood hazard and for generating interest in estimating losses based on these readily available "default" data and methods. It provides other states and localities a platform for estimating losses based on readily available data bases, and can serve to demonstrate effectively the benefits of developing better data at the local level for hazard loss estimation, emergency response and mitigation planning. Perhaps in contrast to some other hazards, this capacity within Hazus is particularly critical for floods, given the local nature of the hazard and the capacity to affect the nature of the hazard through local structural works.

From a national policy perspective, FEMA is responsible for providing national estimates of annualized losses due to these various natural hazards. At the most general level, these loss estimates document the magnitude of the natural hazards problems, as well as provide a benchmark against which progress toward reducing losses due to natural hazards through public policy can be assessed. In its first application of Hazus for this purpose, FEMA published a report in February 2001 entitled: ***HAZUS99: Estimated Annualized Earthquake Losses for the United States***. As other modules in Hazus become available, FEMA anticipates using Hazus to provide estimates of annualized losses from other major hazards on a basis consistent with those for earthquakes.

1.2 Technical Manual Background

The Flood Technical Manual describes the methods for performing flood loss estimation. It is based on a multi-year project to develop a nationally applicable methodology for estimating potential flood losses on a regional basis. The project has been conducted for the National Institute of Building Sciences (NIBS) under a cooperative agreement with the Federal Emergency Management Agency (FEMA).

The primary purpose of the project is to develop guidelines and procedures for making flood loss estimation at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks associated with flooding and to prepare for emergency response and recovery. A secondary purpose of the project is to provide a basis for assessing nationwide risk of flood losses.

The methodology development and software implementation has been performed by a team of flood loss experts composed of engineers, hydraulic and hydrology modelers, emergency planners, economists, social scientists, geographic information systems analysts, and software developers. The Flood Oversight Committee has provided technical direction and review of the work.

1.3 Technical Manual Scope

The scope of the Flood Technical Manual includes documentation of all methods and data that are used by the methodology. Loss estimation methods and data are obtained from referenced sources tailored to fit the framework of the methodology, or from new methods and data developed when existing methods and data were lacking or not current state of the art.

The Flood Technical Manual is a comprehensive, highly technical collection of methods and data covering a broad range of topics and disciplines, including hydrology and hydraulics, structural engineering, floodplain management, social science, and economics. The Flood Technical Manual is written for readers who are expected to have some degree of expertise in the technical topic of interest, and may be inappropriate for readers who do not have this background.

As described in Chapter 2, a separate User Manual describes the flood loss estimation methodology in non-technical terms and provides guidance to users in the application of the methodology. The methodology software is implemented using Geographic Information Systems (GIS) software (specifically ArcGIS 10 with SP1 with the Spatial Analyst extension as developed by Environmental System Research Institute (ESRI)) as described in the Flood Technical Manual.

1.4 Technical Manual Organization

The Hazus-MH Flood Technical Manual organization has been established by the existing Earthquake Technical Manual and so in some cases, it may not be as clear as a flood specific organization may have been. This section has been written to help the flood user wade through the Flood Technical Manual and locate items of interest. The Flood Technical Manual Chapters are as follows:

Forward: A short paragraph providing legal disclaimers and copyright information regarding the protection and rights of FEMA and the National Institute of Building Sciences (NIBS) with respect to this document and the Hazus-MH model.

Message to Users: This section provides some caution and guidance to the users on how the results of the three models can be used and issues related to uncertainty resulting from using the default data and the assumptions necessary to produce functioning methodology.

Acknowledgements: A listing of people and organizations who committed their time and effort in the development of the Hazus-MH Flood Model.

Chapter 1: Introduction to FEMA's flood loss estimation methodology. This chapter provides a history of Hazus and the development of Hazus. This section introduces the reader to the Flood Technical Manual's scope and organization.

Chapter 2: This chapter provides the user with an overview of the Hazus-MH framework, the project vision and the objectives. This chapter will provide the reader with an understanding of key concepts related to Hazus-MH such as the levels of analysis.

Chapter 3: Chapter 3 provides the reader with a description of the baseline or default data provided within Hazus-MH. The chapter is organized to follow the menu organization within the three models with a discussion of the General Building Stock (GBS), Essential Facilities, High Potential Loss Facilities, User Defined Facilities, Transportation Systems, and Utility Systems. The three models share a common valuation discussion and demographics data. The Flood Model has unique data discussed in the sections on Agriculture Products and Vehicles.

Chapter 4: The Potential Earth Science Hazards (PESH) is the chapter where the user will find descriptions on hazard methodology. In other words, this section will describe for the user how the methodology that has been coded within the Flood Model to develop the flood depth grids that are used in estimating losses. This chapter will address the riverine and coastal hazards and the 'What-if?" modeling that is available for the user. A brief section will discuss other flood hazards that may be addressed in future versions of the Flood Model.

Chapter 5: This chapter addresses the heart of the loss estimation methodology, the damage analysis for the General Building Stock. In this chapter, the methodology for estimating the losses associated with the depth grids developed from the hazard models discussed in Chapter 4 is described. This chapter includes a discussion of the building damage functions, the function library and the application of these functions to the occupancy classifications.

Chapter 6: Similar to Chapter 5, this chapter discusses the application of the depth damage functions to the Essential Facilities. This chapter will discuss the classification of the essential facilities, the default damage curves, and the facility functionality.

Chapter 7: The reader will find a detailed discussion of the development and application of damage functions for transportation facilities (Bridges only for the Flood Model) and the utility systems. As with the previous two chapters, this section will describe the analysis capabilities of the flood model.

Chapter 8: This chapter provides a detailed discussion on the vehicle damage analysis. Unique to the flood model, this chapter discusses the development of the damage functions for vehicles and the application of the functions to the vehicle inventory.

Chapter 9: Another Flood Model unique analysis, this chapter provides a detailed discussion of the damage methodology for agricultural products. The chapter will provide an overview of the AGDAM models modified for use within the flood model.

Chapter 10: Although the Flood Model does not perform any direct analysis for the hazardous materials inventory, this chapter has been included to remain consistent with the earthquake model.

Chapter 11: While the earthquake model performs several analyses for induced damages, the Flood Model only analyzes debris related to building damages. This chapter will describe the overall process for the debris analysis and the methodology associated with the analysis.

Chapter 12: The Flood Model does not perform any direct analysis in support of casualty estimation, but this chapter provides a detailed discussion on the research performed for the Hazus Flood Model and the resulting document available for the users review.

Chapter 13: Like the earthquake model, the Flood Model provides the user with an estimate of the shelter requirements. The Flood Model does not make use of all the parameters the earthquake model does and accounts for the likelihood of evacuations due to flood warning. This chapter provides a detailed summary of the methodology created for the Flood Model.

Chapter 14: This chapter provides the reader with a detailed discussion on how the Flood Model transforms the damages estimated for buildings and contents into direct economic impacts such as the building, content, and inventory losses.

Chapter 15: The Indirect Economic Loss Module (IELM) is a standalone module closely related to the module within the earthquake model. This chapter will provide the user with an understanding of the IELM and the applied methodology.

Chapter 16: This section provides the reader with a detailed discussion on the capabilities of the Flood Model and how the user can manipulate both Level 1 and Level 2 data to perform policy analyses.

Chapter 2. Overall Approach and Framework of Methodology

2.1 Vision Statement

As stated previously, the overall objective of the Hazus-MH project is to develop nationally applicable standardized multi-hazard methodologies for estimating potential wind, flood, and earthquake losses on a regional basis. The multi-hazard Hazus is intended to be used by local, state, and regional officials for planning and stimulating mitigation efforts to reduce losses from hurricanes, severe floods and earthquakes and preparing for emergency response and recovery following these events. Depending on the capability built in for each hazard, the multi-hazard Hazus may also be used to prepare a real time (rapid loss) estimate following an event.

Hazus-MH is capable of loss estimation for each of three hazards noted below, and has the following major features:

1. A Hurricane Preview Model, a complete Flood Model, and a complete Earthquake Model

2. Capability to run both deterministic and probabilistic scenarios. In the case of the Flood Model, there is no real distinction between the two as flood return periods are by definition probabilistic in nature.

3. A single, fully integrated set of functions for scenario creation, default inventory and reporting functions for the three models

4. Geographic Information System (GIS) functions

5. Capability to receive user-supplied input for all three models to generate more refined loss estimations

6. Varying degrees of real-time analysis for each hazard

7. State-of-the-Art software, fully documented with metadata and data dictionaries for all databases

2.2 Project Objectives

The Hazus-MH Flood Model is being developed for use by floodplain managers and other users who have the responsibility of protecting citizens and property from the damaging affects of flooding. It is an integrated system for identifying and quantifying flood risks based on advanced science and engineering technology. It is meant to provide an analytic, decision support tool to help communities make informed decisions regarding land use within flood prone areas.

The overall features and functionality of the Flood Model are, to a large extent, based upon capabilities found in the HAZUS99 Earthquake Model. Thus, the same general approach to applying the overall methodology was used in development of the Flood Model. An overall schematic of the Hazus-MH Flood Model methodology is presented in Figure 2.1 below.

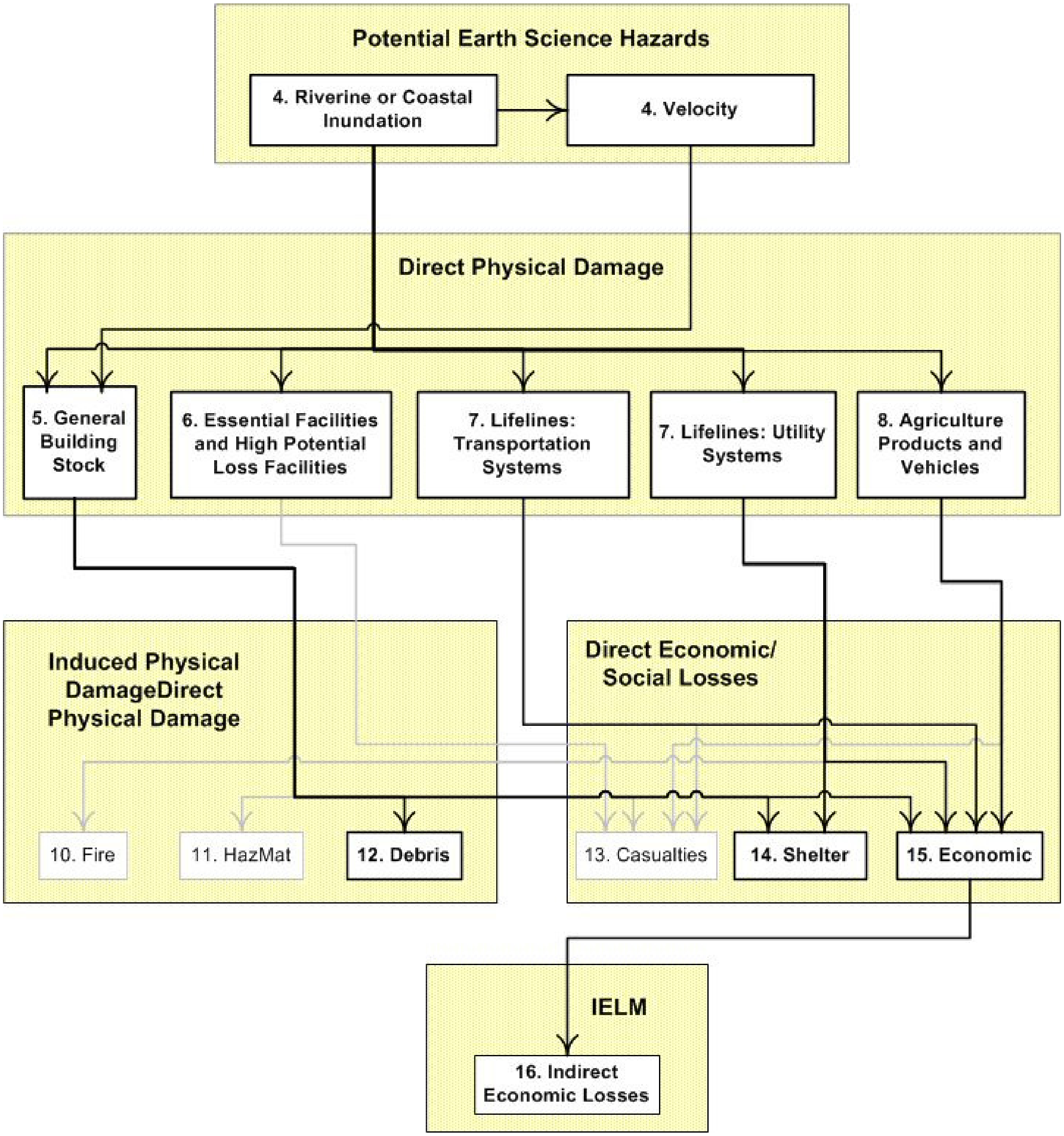


Figure 2.1 Flood Model Schematic

At this time, some features of the Flood Model are not being implemented because additional research and development was required to construct effective models. In those cases, the models are shown in grey boxes and the connections leading to those components are also in grey. As shown in Figure 2.1, the Flood Model methodology consists of two basic analytical processes: flood hazard analysis and flood loss estimation analysis. In the hazard analysis phase, characteristics such as frequency, discharge, and ground elevation are used to model the spatial variation in flood depth, and velocity. During the loss estimation phase, structural and economic damage is calculated based on the results of the hazard analysis through the use of vulnerability curves. Model results can then be conveyed to the user via a series of reports and maps. Those features that are not implemented in this version of the Hazus-MH Flood Model are grayed out in Figure 2.1 including Fire Following Flood, Hazardous Materials Release, and Casualties.

Users will implement the methodology using the GIS-based software application provided by NIBS. After initial inventory entry, the program will run efficiently on a desktop computer. The system requirements for the software are defined in the Hazus-MH Flood User Manual. The ArcGIS technology provides a powerful tool for displaying outputs and permits users to "see" the effects of different flood scenarios and assumptions. The Flood User Manual will guide users in program manipulation, input of new data, and changes to existing data.

Certain users may not wish to use the software application, or may want to augment the results with supplementary calculations. In such cases, users can refer to the Flood Technical Manual for a complete description of models and data of each module. The Flood Technical Manual is useful to technical experts, such as those engineers and scientists that have conducted previous flood loss studies, but might be inappropriate for non-technical users.

Both technical and non-technical users are guided in the application of the methodology by the Flood User Manual, which addresses important implementation issues, such as:

1. Selection of scenario floods and other PESH inputs

2. Selection of appropriate methods (modules) to meet different user needs

3. Collection of required inventory data, i.e., how to obtain necessary information

4. Costs associated with inventory collection and methodology implementation

5. Presentation of results including appropriate terminology, etc.

6. Interpretation of results including consideration of model/data uncertainty.

The three project deliverables are shown in Figure 2.2.

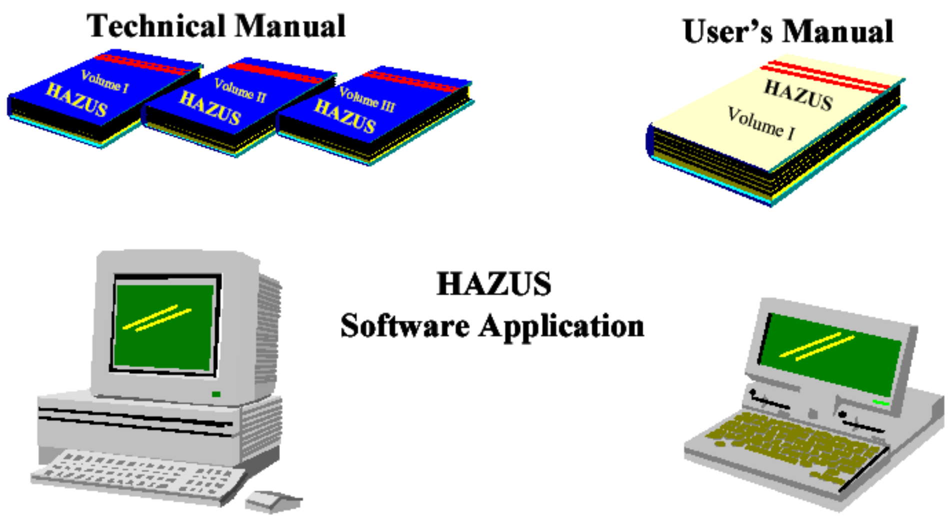


Figure 2.2 Project Deliverables

2.2.1 Accommodation of User Needs

The methodology utilizes a modular approach with different modules addressing different user needs. This approach avoids the need to decide on who is the designated user. The needs of most, if not all, users are accommodated by the flexibility of a modular approach.

The GIS technology permits easy implementation by users on desktop computers. The visual display and interactive nature of a GIS application provides an immediate basis for exchange of information and dialog with end-users of the results. The Flood User Manual provides appropriate terminology and definitions, and user-oriented descriptions of the loss estimation process.

2.2.2 State-of-the-Art

The methodology incorporates available state-of-the-art models in the flood loss estimation methodology. For example, users can develop their depth grids based on their hydrologic and hydraulic models and use the most current depth damage functions. Modules include damage loss estimators not previously found in most studies, such as indirect economic loss. A nationally applicable scheme is developed for classifying buildings, structures and facilities.

2.2.3 Balance

The methodology permits users to select methods (modules) that produce varying degrees of precision. The Flood User Manual provides guidance to users regarding the selection of modules that are appropriate for their needs and which have a proper balance between different components of flood loss estimation.

2.2.4 Uses of Methodology Data

The Flood User Manual provides recommendations for collecting inventory data that will permit use of the data for non-flood purposes. Inventory information will come from databases supplied with the methodology and/or collected in databases compatible with the software. Such data will be available to users for other applications.

2.2.5 Accommodation of Different Levels of Funding

The methodology includes modules that permit different levels of inventory collection and associated levels of funding. For example, the methodology permits simplified (Default Data Analysis) estimates of damage and loss, using primarily default data supplied with the software application. These estimates of damage/loss do not require extensive inventory collection and can be performed on a modest budget. More precise damage/loss (User-Supplied Data Analysis) estimates require more extensive inventory information at additional cost to the user. The Flood User Manual provides guidance to users regarding trade-offs in cost and accuracy of results.

2.2.6 Standardization

The methodology includes standard methods for:

1. Inventory data collection based on census block areas or site specific data collection

2. Using database maps of terrain elevations

3. Classifying occupancy of buildings and facilities

4. Classifying building structure type

5. Developing building damage functions

6. Grouping, ranking and analyzing lifelines

7. Using technical terminology

8. Providing output

2.2.7 Non-Proprietary

The methodology includes only non-proprietary loss estimation methods. The software application is non-proprietary to the extent permitted by the ESRI (ArcGIS) related requirements.

2.3 Description of Flood Loss Estimation Methodology

Depending on the expertise of the user, the Flood Model is designed to operate with minimal user interface and data, or the user can pre-process higher quality data and perform more rigorous analyses. Users are required to have ESRI's Geographic Information System (GIS) called ArcGIS version 10 with SP1 and the associated extension Spatial Analyst in order to perform flood loss estimation. All users will be required to supply a Digital Elevation Model (DEM) since floods are inherently dependent on the terrain. The Flood Model has been designed to ease the process of bringing in a DEM. The Flood Model has been designed to allow the user to easily define the DEM required for their study region and to obtain the National Elevation Dataset (NED) from the USGS website. The user can also use the information to provide their own DEM that meets the needs of the model. Once a DEM is supplied, the user can then start developing estimates of damage and losses due to their flood hazard. A user who may have better terrain data and improved data that defines their flood hazard may decide to use the Flood Information Tool (FIT) to pre-process their data and import it into the Flood Model. The FIT requires the user to have the following data:

- Flood surface data such as Coastal Base Flood Elevations (BFE), digital stream cross sections attributed with flood elevation, or digitized BFE lines from the Flood Insurance Rate Map (FIRM). These will need to be in the form of a polyline,

- Digitized floodplain boundaries such as those shown on a FIRM (i.e., a paper map digitized either in house or by a contractor), a Digital Flood Insurance Rate Map (DFIRM), a Q3 map, or any other floodplain map. This will be in the form of a polygon,

- Ground elevation in a grid format. This may be built from contours, Triangular Irregular Networks (TINs) or other formats that the user may have.

The FIT is designed to operate as an extension within ArcGIS. The FIT allows the user to produce depth grids for one or more return periods, skew angles, and other data required by the Flood Model. Figure 2.3 shows the input data requirements for the FIT, and how the output results from the FIT is integrated into the Hazus Flood Model.

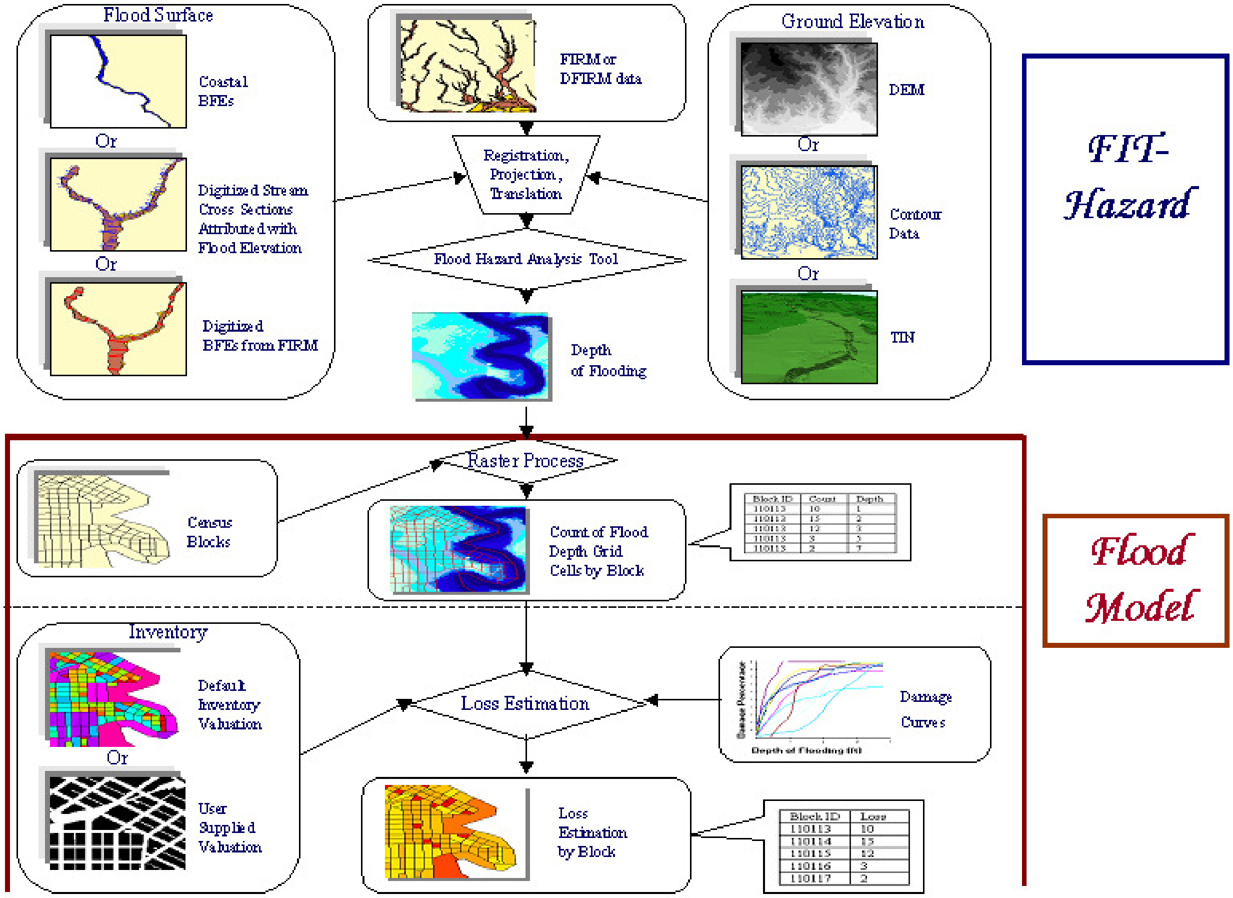


Figure 2.3 Overview of the Integration of the FIT and the Hazus Flood Model

The Comprehensive Data Management System (CDMS) tool was developed to assist users in collecting and generating building inventory data for Hazus-MH. While every effort has been made to preserve and utilize fields and data from the existing Earthquake Model, the physical nature of the flood hazard and differences in damage functions cause differences in data requirements and detail.

The CDMS tool is designed to take existing large format data and import the data into Hazus. The user interface for the program is not complex and requires only moderate modifications to account for different fields necessary for flood loss estimation (such as foundation type and garage). CDMS itself has been modified to support the proposed Hazus Software Architecture and the Flood Model is the first model developed according to the proposed architecture.

The CDMS tool is also site specific in nature and is somewhat more suitable to the flood hazard. CDMS has features that make the collection of data regarding repetitive loss structures or structures within a particular census block fairly easy.

2.3.1 Level of Analysis

Following the HAZUS99 format, the Hazus-MH Flood Model will permit three levels of analysis:

Level 1 This is the simplest type of analysis requiring minimum effort by the user as it is based mostly on input provided with the methodology (e.g., census information, broad regional patterns of floodplain code adoption, etc.). The user is not expected to have extensive technical knowledge. While the methods require some user supplied input to run, the type of input required could be gathered by contacting government agencies or by referring to published information. At this level, estimates will be crude, and will likely be appropriate only as initial loss estimates to determine where more detailed analyses are warranted.

Some components of the methodology cannot be performed in a Default Data Analysis since they require more detailed inventory than that provided with the methodology. The following are not included in the Default Data Analysis: damage/loss due to ground failure or erosion (riverine), damage/loss due to earthquake driven flooding such as tsunamis or seiche, damage/loss due to dam failure. At this level, the user has the option (not required) to enter information about site-specific facilities such as hazardous materials sites or essential facilities among others. One week to a month would be required to collect relevant information depending on the size of the region and the level of detail the user desires.

Level 2 analysis is intended to improve the results from Level 1 by considering additional data that are readily available or can easily be converted or computed to meet the methodological requirements. In Level 2, the user may need to determine parameters from published reports or maps as input to the model. It requires more extensive inventory data and effort by the user than Default Data Analysis. The purpose of this type of analysis is to provide the user with the best estimates of flood damage/loss that can be obtained using the standardized methods included in the methodology. Flood Model users will need to use the FIT to pre-process their flood hazard data for use in the Flood Model. It is likely that the user will need to employ consultants to assist in the implementation of certain methods. For example, knowledgeable users of hydrology and hydraulics models would likely be required to define flood elevations.

All components of the methodology can be performed at this level and loss estimates are based on locally (user) developed inventories. At this level, there are standardized methods of analysis included in the software, but there is no standardized User-Supplied Data Analysis study. As the user provides more complete data, the quality of the analysis and results improve. Depending on the size of the region and the level of detail desired by the user, one to six months would be required to obtain the required input for this type of analysis.

Level 3 analysis will require extensive efforts by the user in developing information on the flood hazard and the measure of exposure. This type incorporates results from engineering and economic studies carried out using methods and software not included within the methodology. At this level, one or more technical experts would be needed to acquire data, perform detailed analyses, assess damage/loss, and assist the user in gathering more extensive inventory. It is anticipated that at this level there will be extensive participation by local utilities and owners of special facilities.

There is no standardized Advanced Data and Models Analysis study. The quality and detail of the results depend upon the level of effort. Six months to two years would be required to complete an Advanced Data and Models Analysis. Each subsequent level builds on and adds to the data and analysis procedures available in previous levels.

Figure 2.4 provides a graphic representation of the various levels of analysis and the subsequent user sophistication to achieve that level of analysis.

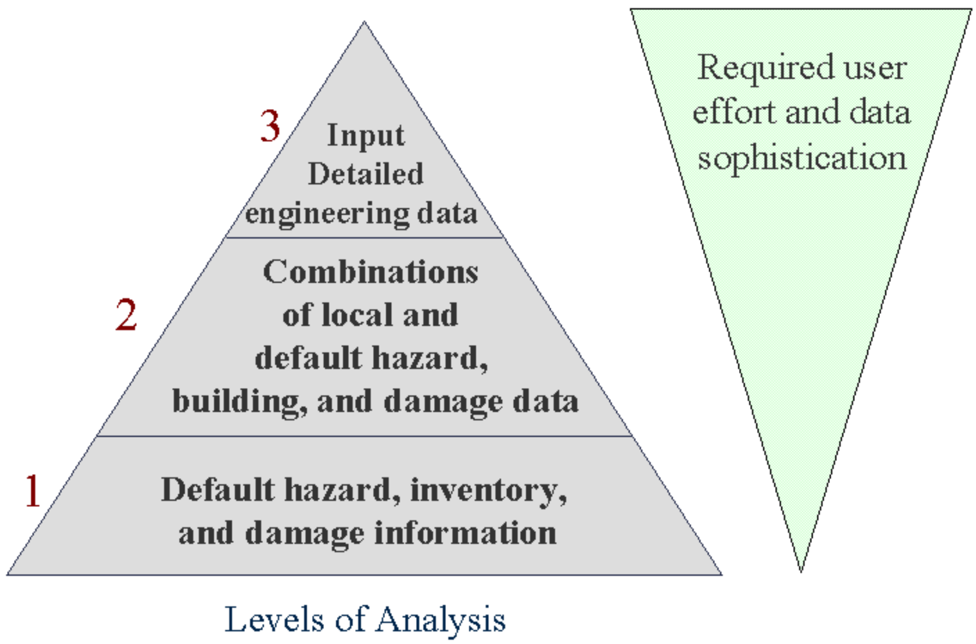


Figure 2.4 Levels of Analysis and User Sophistication

The attributes of the model for each level of analysis and examples of typical applications are presented in Table 2.1.

Table 2.1 Attributes of the Hazus Flood Model

	Level 1	Level 2	Level 3
Hazard	Users supply Digital Terrain Model (DEM), typically the USGS 30-meter DEM. The Flood Model will use default hazard data including Hydraulic Unit Codes, and accumulation methodology to develop approximate stream centerlines. USGS regression equations and gage records will be used to determine discharge frequency curves.	User supplied hazard data pre-processed in the FIT or user supplied depth grid. User will supply improved DEM, flood hydraulic and hydrology results including stream cross-sections attributed with elevations, or lines of BFE. Coastal users will supply polygons attributed with the BFE. A flood boundary of some form is required.	Similar to Level 2 although the user will likely work with Hydraulic models outside of the Flood Model and the FIT.
Inventory	Present Hazus default data methodology, enhanced for flood needs. Allocation of census block data via statistical analysis, and broad assumptions for first floor elevation. General land use, Lifelines, Agriculture, Vehicles inventory, Essential facilities.	User supplies inventory data either through Tax Assessor data processed through CDMS. Users enhance the first floor elevation information and other attributes necessary for flood loss estimation.	High quality data regarding building values, flood vulnerabilities, contents, occupancies, etc., extended to industrial and other high-value facilities.
Damage Curves	Broad regional default curves consistent with level of detail of inventory, based on available FIA or USACE depth damage curves. Library of curves available for user selection. User may create their own damage curves using internal guides.	User provides their own functions or specifically modifies the existing curve library for local practices.	User-input curves based on detailed building surveys, specific crop conditions etc.

Table 2.1 Attributes of the Hazus Flood Model (Continued)

	Level 1	Level 2	Level 3
Damage Estimation	Area weighted damage estimates based on the depth of flooding within a given census block. Losses developed for General Building Stock, Vehicles, Agricultural products, select transportation and utility features.	Consistent with Level 1, estimation enhanced by improved hazard data and detail in inventory data and modification to damage curves.	Consistent with Level 1, estimation enhanced by improved hazard data and detail in inventory data and modification to damage curves.
Direct Loss/ Impacts	Cost or repair / replacement, human casualties and shelter needs, temporary housing, vehicles, crop & livestock losses.	Consistent with Level 1, estimation enhanced by improved hazard data and detail in inventory data and modification to damage curves.	Consistent with Level 1, estimation enhanced by improved hazard data and detail in inventory data and modification to damage curves.
Indirect Loss/ Impacts	Sectoral economic impacts.	Sectoral economic impacts.	Sectoral economic impacts.
Typical Applications	• Flood mitigation / regulatory policy-making, regional, state, federal levels • Pre-feasibility studies • Real-time emergency response with no warning	• Planning, zoning, development… • Mitigation alternatives selection • Engineering pre-feasibility studies • Emergency planning and real-time response • Environmental impact analysis • Education	• Analysis for essential, cultural, high-loss potential facilities • Emergency planning and real-time response • Mitigation and engineering research • Scientific research

2.3.2 Loss Estimation Analysis

The Flood Model allows the user to utilize a default general building stock to estimate the direct physical damages to buildings and contents, the exposure of essential facilities to flooding, the consequential direct economic losses, and the number of people displaced by evacuation and inundation.

The Flood Model also allows the user to import the tabular results from the FIT and access the default inventory and valuation data. The model then estimates the resultant damage in terms of dollars and units impacted as well as the estimation of the number of units impacted by the flood that would then lead to an estimation of the displaced population. Results are presented in summary reports aggregated to the study region level and tabular results at the census block or site specific depending on input data. The Flood Model comes with a suite of damage functions including most of the available curves from the Federal Insurance Administration (now known as the Federal Insurance and Mitigation Administration within the Department of Homeland Security) and the US Army Corps of Engineers.

The Flood Model will be composed of five interrelated components used to estimate flood losses. These components are:

- Inventory Data
- Flood Hazard
- Direct Physical Damage
- Induced Physical Damage
- Economic and Social Impacts

For each of the major components such as flood hazard, inventory, and direct damage, one or more alternative methods were selected for potential use in the module. Each method was then employed in one or more of the "proof-of-concept" communities to estimate a parameter (i.e., results) in as similar a manner as would be done in the Hazus Level 1 analysis. An example of parameter (the result) would be depth of flooding in a census block. These results were then compared to the best available measure of the same parameter (termed "ground truth"). Each alternative evaluated and the results of the evaluation are presented in the next sections. Note that not all alternatives were evaluated in each community.

The following guidelines were used during the proof-of-concept evaluation:

- Where possible, based on the quality of available data, two alternative methods for each component of the flood loss model were evaluated in each community, with the contingency to evaluate as many as four;

- Evaluate at least one alternative method that may be available in the near future, such as the use of remote sensing (e.g., satellite imagery) to produce inventory data;
- Utilize "what if" scenarios to evaluate the results produced by the various alternatives;
- Explore alternatives that can improve the Hazus default databases; and
- Follow a general procedure of trial-and-comparison in evaluating each of the alternatives. The selected alternative was then enhanced and incorporated into the Hazus Flood Model methodology.

2.4 Integration of the three Hazus Loss Estimation Models

The Hazus release, called Hazus, will be comprised of a three-tiered framework consisting of a:

- Presentation Layer with the display for user interface and overall control
- Application Layer with the three models for hazard-specific calculations
- Data Access Layer with common and hazard-specific databases and input/editing functions

Hazus will be supported by component-based implementation for Geographic Information Systems (GIS) using ArcObjects9.3 or better to handle spatial data and mapping functions. GIS programs will add the following functionality:

- Query functions for inventory and loss estimation
- Thematic mapping capabilities
- Raster GIS tools for flood hazard characterization
- Potential for future web enablement

Crystal Reports will be used for report generation including detailed numerical and graphical output and summary reports.

Software in Hazus will be:

- Implemented to run on an IBM-compatible personal computer
- Written in Microsoft Visual C++, but can use Visual Basic/VBA as needed
- Documented to industry standards
- Supported by metadata describing default hazard and inventory databases

- Contained on DVDs for each hazard by region. The number of regions for each hazard will depend on the file size after development of the software

Hazus-MH manuals will consist of:

- User's manuals for the Hurricane Preview, Flood, and Earthquake models will explain each hazard methodology to local, state, and regional officials and other users. Each manual will include information on using the Hazus shell.

- Technical manuals for the Hurricane Preview, Flood, and Earthquake models will describe the methodologies' background for use by technical professionals.

Users GIS Environment:

As a result of methodology and product requirements, the software shall be developed using ESRI's ArcGIS product. This will require the users to have licenses for ArcView Version 10.0 or better and Spatial Analyst Version 10.0 or better. ESRI will update ArcObjects and other ArcGIS related products on a regular basis. Users will need to refer to the current Hazus-MH release documentation for the latest ArcGIS version compatibility.

The Flood Model will share a common overall modular software architecture with the Earthquake and Wind Models. The user interface screens shall vary to some degree for each model, but have a common look and feel. An overview of the Hazus architecture and the various hazard components is provided in Figure 2.5.

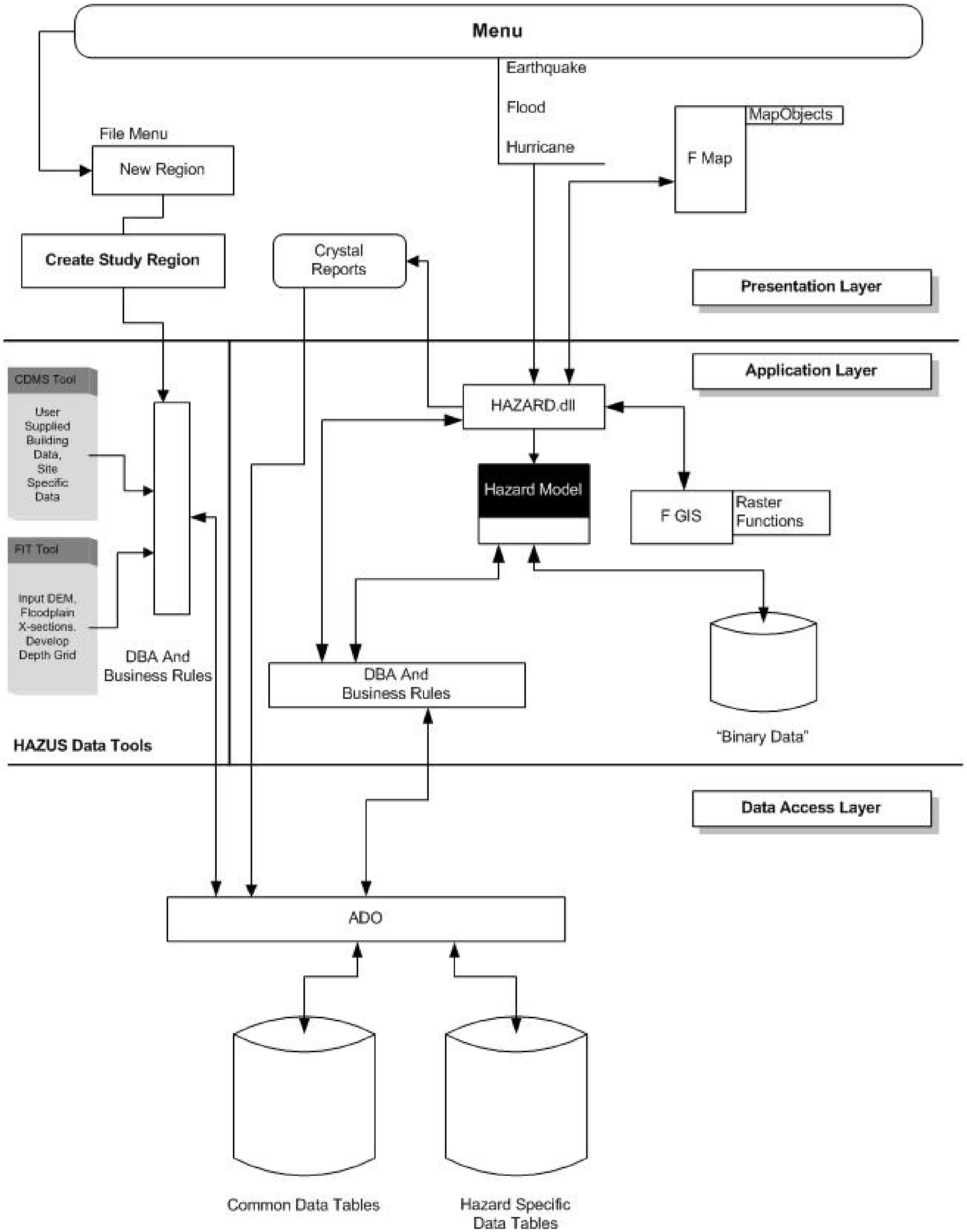


Figure 2.5 Hazus Software Architecture with Hazus Data Tools

Chapter 3. Inventory Data: Collection and Classification

3.1 Introduction

An important requirement for estimating losses from floods is the identification and valuation of the building stock, infrastructure, and population exposed to flood hazard i.e., an inventory. Consequently, the Hazus Flood Model uses a comprehensive inventory in estimating losses. This inventory serves as the default when the users of the model do not have better data available. The inventory consists of a proxy for the general building stock in the continental United States, Hawaii and the U.S. held Territories. Additionally, the model contains national data for essential facilities, high potential loss facilities, selected transportation and lifeline systems, demographics, agriculture, and vehicles. This inventory is used to estimate damage and the direct economic losses for some elements (i.e., the general building stock) or the associated impact to functionality for essential facilities.

The Earthquake Model's general building stock is currently available at the census tract level but increased resolution is needed to support the Flood Model. The census block was chosen as the level of aggregation due to its relatively small geographic size and the capability of the census to identify data at that level of detail. The census only provides information for the development of the residential structures data. Similar to the Earthquake Model, Dun & Bradstreet (D&B) has provided data for non-residential structures at the census block level.

3.2 Direct Damage Data – Buildings and Facilities

3.2.1 General Building Stock

The General Building Stock (GBS) includes residential, commercial, industrial, agricultural, religious, government and education buildings. Damage is estimated in percent and is weighted by the area of inundation at a given depth for a given census block. The entire composition of the general building stock within a given census block is assumed to be evenly distributed throughout the block. The inventory information necessary for determining a given percent damage for the inundated area is given by relationships between the specific occupancy classifications and the building types. The square foot occupancy table is the table from which all the other tables are based.

All three models (Earthquake, Wind and Flood) use key common data to ensure that the users do not have inventory discrepancies when switching from hazard to hazard. Generally the Flood Model displays GBS data at the census block while the Hurricane and Earthquake Model displays GBS data at the census tract level. In order to allow for future alignment between the Hurricane and Flood Models, the Hurricane Model will display and perform analysis at the census block level if the user has included the Flood Model in the study region. Whenever the Flood Model is included in the study region, all three models require the user to edit the common inventory data at the census block level. The key GBS databases include the following:

- **Square footage by occupancy.** These data are the estimated floor area by specific occupancy (e.g., COM1). For viewing by the user, these data are also rolled up to the general occupancies (e.g., Residential).

- **Full Replacement Value by occupancy.** These data provide the user with estimated replacement values by specific occupancy (e.g., RES1). For viewing by the user, these data are also rolled up to the general occupancies (e.g., Commercial).

- **Building Count by occupancy.** These data provide the user with an estimated building count by specific occupancy (e.g., IND1). For viewing by the user, these data are also rolled up to the general occupancies (e.g., Government).

- **General Occupancy Mapping.** These data provide a general mapping for the GBS inventory data from the specific occupancy to general building type (e.g., Wood). Generally, all three models will agree, however, a user can modify the general occupancy mapping at the census block level in the Flood Model thereby requiring them to select an "average" value at the tract level in the other two models, which will result in variances. This should not be an issue for users making this type of change.

- **Demographics.** This table provides housing and population statistics for the study region.

3.2.1.1 Classification

In HAZUS99, 28 specific occupancy classifications were used in the baseline inventory. The primary purpose of building classifications is to group buildings with similar valuation, damage and loss characteristics into a set of pre-defined groups for analysis. For example, the damage and loss models represent a typical response of the occupancy classification to inundation. During the development of the Hazus-MH and the Flood Model, it was recommended that the number of specific occupancy classifications increase from 28 to 33 to allow for an enhanced classification of the multi-family dwellings. This was accepted by all three Hazus contractors and therefore, all three models are using the same specific occupancy classifications.

With respect to classifying buildings by their construction types, where Earthquake Model uses 36 specific construction types (e.g., S1L), the Flood Model uses the five general construction classifications: Wood, Concrete, Masonry, Steel, and Manufactured Housing (aka Mobile Home). Table 3.1 shows the resulting specific occupancy classifications and the label used throughout the Hazus Flood Model. The table also shows the SIC code classification used in the development of the non-residential facilities.

Table 3.1 Hazus Building Occupancy Classes

Hazus Label	Occupancy Class	Standard Industrial Codes (SIC)
Residential		
RES1	Single Family Dwelling	
RES2	Mobile Home	
RES3A	Multi Family Dwelling - Duplex	
RES3B	Multi Family Dwelling – 3-4 Units	
RES3C	Multi Family Dwelling – 5-9 Units	
RES3D	Multi Family Dwelling – 10-19 Units	
RES3E	Multi Family Dwelling – 20-49 Units	
RES3F	Multi Family Dwelling – 50+ Units	
RES4	Temporary Lodging	70
RES5	Institutional Dormitory	
RES6	Nursing Home	8051, 8052, 8059
Commercial		
COM1	Retail Trade	52, 53, 54, 55, 56, 57, 59
COM2	Wholesale Trade	42, 50, 51
COM3	Personal and Repair Services	72, 75, 76, 83, 88
COM4	Business/Professional/Technical Services	40, 41, 44, 45, 46, 47, 49, 61, 62, 63, 64, 65, 67, 73, 78 (except 7832), 81, 87, 89
COM5	Depository Institutions	60
COM6	Hospital	8062, 8063, 8069
COM7	Medical Office/Clinic	80 (except 8051, 8052, 8059, 8062, 8063, 8069)
COM8	Entertainment & Recreation	48, 58, 79 (except 7911), 84
COM9	Theaters	7832, 7911
COM10	Parking	
Industrial		
IND1	Heavy	22, 24, 26, 32, 34, 35 (except 3571, 3572), 37
IND2	Light	23, 25, 27, 30, 31, 36 (except 3671, 3672, 3674), 38, 39
IND3	Food/Drugs/Chemicals	20, 21, 28, 29
IND4	Metals/Minerals Processing	10, 12, 13, 14, 33
IND5	High Technology	3571, 3572, 3671, 3672, 3674
IND6	Construction	15, 16, 17
Agriculture		
AGR1	Agriculture	01, 02, 07, 08, 09
Religion/Non-Profit		
REL1	Church/Membership Organizations	86

Table 3.1 Hazus Building Occupancy Classes (Continued)

Hazus Label	Occupancy Class	Standard Industrial Codes (SIC)
Government		
GOV1	General Services	43, 91, 92 (except 9221, 9224), 93, 94, 95, 96, 97
GOV2	Emergency Response	9221, 9224
Education		
EDU1	Schools/Libraries	82 (except 8221, 8222)
EDU2	Colleges/Universities	8221, 8222

The Earthquake Model provided the initial guidelines for the development of the building classifications by building type. As stated earlier, the Flood Model does not require the two-dimension matrix for the building types as seen in the Earthquake Model. With the exception of the velocity damage, for which the damage functions utilize the general building type, all of the Flood Model damage and loss calculations are performed based on the 33 specific occupancies and the foundation distribution that is discussed later in this chapter. Results for by building type are post-processed from the specific occupancy results.

Table 3.2 shows the general building types as defined in the three models and the range of heights (number of stories) for these building types. Because the damage functions are only marginally dependent on the number of floors, the typical floor information provided in the Earthquake Model Technical Manual is not provided here.

Table 3.2 Hazus Building Occupancy Classes

Number	Label/Description	Height Name	Range of Stories
1	Wood Frame	All	All
2	Steel Frame	Low-Rise	1 –3
3		Mid-Rise	4 – 7
4		High-Rise	8 and up
5	Concrete Frame	Low-Rise	1 – 3
6		Mid-Rise	4 – 7
7		High-Rise	8 and up
8	Masonry	Low-Rise	1 –3
9		Mid-Rise	4-7
10		High-Rise	8 and up
11	Manufactured Housing		All

3.2.1.2 The Default General Building Stock Database

The general building stock inventory was developed from the following information:

- Census of Population and Housing, 2000: Summary Tape File 1B Extract on CD-ROM / prepared by the Bureau of Census.

- Census of Population and Housing, 2000: Summary Tape File 3 on CD-ROM / prepared by the Bureau of Census.

- Dun & Bradstreet, Business Population Report aggregated by Standard Industrial Classification (SIC) and Census Block, May 2006.

- Department of Energy, Housing Characteristics 1993. Office of Energy Markets and End Use, DOE/EIA-0314 (93), June 1995.

- Department of Energy, A Look at Residential Energy Consumption in 1997, DOE/EIA-0632(97), November 1999.

- Department of Energy, A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures, DOE/EIA-0625(95), October 1998.

The US Census and the Dun & Bradstreet data were used to develop the general building stock inventory. The three reports from the Department of Energy (DOE) helped in defining regional variations in characteristics such as number and size of garages, type of foundation, and number of stories. The inventory's baseline floor area is based on a distribution contained in the DOE's Energy Consumption Report. An approach was developed using the same report for determining the valuation of single-family residential homes by accounting for income as a factor on the cost of housing.

Initially the methodology created the opportunity for the user to develop conflicting or discrepant square footage totals for single-family residential structures within a census block between the inventory database and the valuation database. The solution was to integrate the regional DOE distributions with the income factors developed for determining valuation. To do this, default values for typical square footage per single-family home were developed from Energy Information Administration (EIA) data on heated floor space. These default data, shown in Table 3.3, are provided by region and income group. The breakdown reflects not only how typical housing size varies across the U.S., but also how in general, higher income areas tend to contain larger single-family homes.

Consequentially, the default typical square footage data was derived from a detailed, unpublished database provided by the EIA. Only information on families in single-family residences, aggregated across all foundation/basement types, was used. The raw database included information on the number of households by region, income category, and housing floor space. Regional data were available by 9 multi-state census divisions (e.g., New England).

The very nature of the default data, both in occupancy classifications and extent of coverage (national) requires the use of a baseline database collected in a consistent manner for the nation. The data source changes depending on the general use of the inventory being explored. For example, to determine the total floor area (square feet) of single-family residences by census block, one uses a data source like the Census data. While sufficient for residential occupancy, the Census data does not address non-residential occupancy classifications.

The development of the default inventory required two major datasets for the two main elements of the built environment. To create the default inventory for residential structures, the US Department of Commerce's Census of Housing was used. For commercial and industrial structures, a commercial supplier, Dun & Bradstreet (D&B) was contacted. The project team performed the aggregation to the census data, while D&B performed the aggregation to their own data (due to its proprietary nature).

The STF1B census extract at the census block level allows for the quick quantification of the single-family residential environment. When combined with the STF3A census extract at the census block group level, the STF1B can provide a better proxy of the multi-family environment than using one extract alone. In both the single-family and multi-family proxies, the proposed methodology represents an improvement over using single "average" values similar to the existing HAZUS99 data.

The STF3A extract also provides information that is useful in developing distributions for the age of buildings within each census block group as well as valuable demographic data. The age distribution, for example, can be used to infer the Pre-FIRM and Post-FIRM distribution which has an impact on the loss estimation.

The D&B provides a realistic representation of the non-residential environment. Based on the site specific data contained within their database, D&B's data is used to provide a reasonable assessment of the non-residential environment. The processing of the D&B data is discussed in more detail in Section 3.2.1.2.1.

3.2.1.2.1 Specific Occupancy Square Footage by Census Block

Single-Family Residences (RES1)

The following discussion highlights the data development effort for the RES1 square foot values by block. The Census Extract STF1B provides estimates of the single family attached and detached housing units on a block-by-block basis. Several other sources of information were used to develop distributions of square footage relative to the income of the census block group. The DOE distributions of income factors were used to develop a ratio of the census block group income (STF3A field P08A001) and the average income for the region (the nine multi-state census divisions.

The EIA data provided information regarding the heated floor area in relationship to income. Income was reported in 25 categories (e.g., $20,000-$22,499) that were converted into five relative income groups for consistency with the inventory valuation methodology. Housing floor space data were provided in 7 categories (e.g., 2,000-2,399 sq. ft.), which, for purposes of computing typical floor space, were represented by the midpoint of the range (e.g., 2,200 sq. ft.). This enabled average floor space to be calculated for the 9 census divisions and 5 relative income categories.

Table 3.3 Typical Square Footage Per Unit (Main Living Area) by Census Division (R)[1]

***R* = New England**

Income Ratio:	Basement	
	No (j=1)	*Yes[2] (j=2)*
$I_k < 0.5$	1300	975
$0.5 \le I_k < 0.85$	1500	1125
$0.85 \le I_k < 1.25$	1800	1350
$1.25 \le I_k < 2.0$	1900	1425
$I_k \ge 2.0$	2200	1650

***R* = Middle Atlantic**

Income Ratio:	Basement	
	No (j=1)	*Yes[2] (j=2)*
$I_k < 0.5$	1300	975
$0.5 \le I_k < 0.85$	1500	1125
$0.85 \le I_k < 1.25$	1700	1275
$1.25 \le I_k < 2.0$	1900	1425
$I_k \ge 2.0$	2200	1650

***R* = East North Central**

Income Ratio:	Basement	
	No (j=1)	*Yes[2] (j=2)*
$I_k < 0.5$	1300	975
$0.5 \le I_k < 0.85$	1600	1200
$0.85 \le I_k < 1.25$	1700	1275
$1.25 \le I_k < 2.0$	1800	1350
$I_k \ge 2.0$	2500	1875

Table 3.3 Typical Square Footage Per Unit (Main Living Area) by Census Division (R)[1] (Continued)

***R* = West North Central**

Income Ratio:	Basement	
	No (j=1)	*Yes[2] (j=2)*
$I_k < 0.5$	1300	975
$0.5 \leq I_k < 0.85$	1500	1125
$0.85 \leq I_k < 1.25$	1800	1350
$1.25 \leq I_k < 2.0$	1800	1350
$I_k \geq 2.0$	2300	1725

***R* = South Atlantic**

Income Ratio:	Basement	
	No (j=1)	*Yes[2] (j=2)*
$I_k < 0.5$	1400	1050
$0.5 \leq I_k < 0.85$	1600	1200
$0.85 \leq I_k < 1.25$	1700	1275
$1.25 \leq I_k < 2.0$	2000	1500
$I_k \geq 2.0$	2300	1725

***R* = East South Central**

Income Ratio:	Basement	
	No (j=1)	*Yes[2] (j=2)*
$I_k < 0.5$	1300	975
$0.5 \leq I_k < 0.85$	1400	1050
$0.85 \leq I_k < 1.25$	1700	1275
$1.25 \leq I_k < 2.0$	1900	1425
$I_k \geq 2.0$	2500	1875

***R* = West South Central**

Income Ratio:	Basement	
	No (j=1)	*Yes[2] (j=2)*
$I_k < 0.5$	1300	975
$0.5 \leq I_k < 0.85$	1700	1275
$0.85 \leq I_k < 1.25$	1800	1350
$1.25 \leq I_k < 2.0$	1900	1425
$I_k \geq 2.0$	2500	1875

Table 3.3 Typical Square Footage Per Unit (Main Living Area) by Census Division (R)[1] (Continued)

***R* = Mountain**

Income Ratio:	Basement	
	No (j=1)	***Yes[2] (j=2)***
$I_k < 0.5$	1200	900
$0.5 \le I_k < 0.85$	1500	1125
$0.85 \le I_k < 1.25$	1700	1275
$1.25 \le I_k < 2.0$	1800	1350
$I_k \ge 2.0$	2600	1950

***R* = Pacific**

Income Ratio:	Basement	
	No (j=1)	***Yes[2] (j=2)***
$I_k < 0.5$	1300	975
$0.5 \le I_k < 0.85$	1500	1125
$0.85 \le I_k < 1.25$	1700	1275
$1.25 \le I_k < 2.0$	1900	1425
$I_k \ge 2.0$	2100	1575

Notes:

1 *based on data from the Energy Information Administration, Housing Characteristics 1993;*

2 *(Area of main living area if basement present) = 0.75 x (Area of main living area if no basement). This adjustment allows consistent application of the Means cost models, in which basement areas are added-on, and are assumed to be 1/3 of main living area.*

While the US Census data does have data defining the median income for each census block, there is data for the median income for each census block group. This value will be applied to each block within the block group. With the median income for each census block, and the median income for the census region, it is possible to define an Income Ratio that can be used to determine the square footage for buildings with and without basements. Table 3.4 below shows the 9 census regions, the states within those regions and the values used to compute the Income Ratio. The value from the Census STF3A field P08A001 is the median income for the census block group that will be applied to every census block within the group. The distribution of basements is a summation or roll-up of the foundation type distribution discussed later in this section.

Table 3.4 Income Ratio and Basement Distribution by Census Region

Region (States)	Income Ratio	Percent with Basement	Percent without Basement
AL	P053001 / 36,268	25	75
AK	P053001 / 52,492	13	87
AZ	P053001 / 39,653	32	68
AR	P053001 / 30,082	5	95
CA	P053001 / 45,070	13	87
CO	P053001 / 49,216	32	68
CT	P053001 / 50,647	81	19
DE	P053001 / 47,438	23	77
DC	P053001 / 38,005	23	77
FL	P053001 / 37,305	23	77
GA	P053001 / 41,481	23	77
HI	P053001 / 45,657	13	87
ID	P053001 / 37,760	32	68
IL	P053001 / 46,649	68	32
IN	P053001 / 41,315	68	32
IA	P053001 / 41,560	75	25
KS	P053001 / 38,393	75	25
KY	P053001 / 36,826	25	75
LA	P053001 / 32,500	5	95
ME	P053001 / 39,815	81	19
MD	P053001 / 52,846	23	77
MA	P053001 / 45,769	81	19
MI	P053001 / 46,034	68	32
MN	P053001 / 50,088	75	25
MS	P053001 / 31,963	25	75
MO	P053001 / 44,247	75	25
MT	P053001 / 32,553	32	68
NE	P053001 / 39,029	75	25
NV	P053001 / 43,262	32	68
NH	P053001 / 48,029	81	19
NJ	P053001 / 51,739	76	24
NM	P053001 / 34,035	32	68
NY	P053001 / 40,822	76	24
NC	P053001 / 38,413	23	77
ND	P053001 / 33,769	75	25

Table 3.4 Income Ratio and Basement Distribution by Census Region (Continued)

Region (States)	Income Ratio	Percent with Basement	Percent without Basement
OH	P053001 / 41,972	68	32
OK	P053001 / 34,020	5	95
OR	P053001 / 41,915	13	87
PA	P053001 / 41,394	76	24
RI	P053001 / 43,428	81	19
SC	P053001 / 36,671	23	77
SD	P053001 / 35,986	75	25
TN	P053001 / 35,874	25	75
TX	P053001 / 39,296	5	95
UT	P053001 / 46,539	32	68
VT	P053001 / 40,908	81	19
VA	P053001 / 47,701	23	77
WA	P053001 / 46,412	13	87
WV	P053001 / 29,217	23	77
WI	P053001 / 45,441	68	32
WY	P053001 / 38,291	32	68

Once the parameters above had been defined, it is possible to develop an algorithm that allows for the estimation of the RES1 or single-family residential square footage for the entire nation. This algorithm is:

RES1 (sq. ft.) = Total Single Family Units (STF1B H1BX0002) *[(Percent of units with basement) * (floor area w/basement based on income ratio and region) + (Percent of units without basement)*(floor area w/o basement based on income ratio and region] where Income Ratio = STF3A P08A001/regional income

For a sample New England census block, 81% Basement 19% no basement and an I_k of 0.67:

RES1 (sq. ft.) = [STF1BX0002] * [(0.81)*(1,125) + (0.19)*(1,500)]

Multi-Family and Manufactured Housing (RES3 and RES2)

Developing the multi-family (RES3A through RES3F) and manufactured housing (RES2) inventory requires additional information and effort compared to the single-family occupancy classification. In the 1999 census extract, the STF1B (census block data) extract identifies only those housing units within the 10 or more unit classification, unfortunately, the 2000 census extract no longer provided that information. Therefore in order to define of the multi-family units, it is necessary to utilize the STF3A extract. The multi-family definition in the STF3A extract identifies Duplex, 3-4 Unit, 5-9 unit, 10-19 unit, 20-49 unit, and 50+ dwellings. Additionally the STF3A census data provides a definition of the Manufactured Housing (MH) units within a block group and therefore the RES2 was processed at the same time. The census data has an "other" classification for that will be ignored since this classification represent a very small portion of the universe of housing units and there is no "other" damage functions that can be assigned to these facilities. Examples of the "Other" Census classification include vans and houseboats.

Unlike the single family residential that used the Housing Characteristics 1993 to define heated floor area, assessor data from around the United States, including that from the six Proof-of-Concept (POC) communities, was reviewed to develop preliminary estimates of average floor area for multi-family housing. This data was then peer reviewed by engineering experts to develop an average floor area per number of units for the unit ranges provided by the census data. Table 3.5 shows the distribution of the floor area by unit. The associated equations provide an example of the calculations that have taken place.

Table 3.5 Floor Areas for Multi-Family Dwellings (RES2 & RES3A-RES3F)

Units	Duplex	3-4	5-9	10-19	20-49	50+	Manufactured Housing	Other
Floor Area	1,500	750	800	750	700	650	Single Wide – 950 Double Wide – 1,350	Not Required

Previously, the Flood Model team had a complex process that allowed for a more accurate block level distribution. However, when the US Census Bureau modified the SF1 extract to eliminate information regarding the single-family and large multi-family fields, it became necessary to modify the data manipulation process. The multi-family data was still available in the SF3 extract at the census block group level. The only available process was to distribute the census block group data homogeneously throughout the census blocks. The distribution process is facilitated by finding the ratio of total housing units per census block (H1BX0001) with respect to the total housing units per census block group (H0010001). This ratio was then used to as a multiplier to distribute the census block group level multi-family data into each census block.

<u>Step 1:</u> Develop the ratio of total housing units for each census block"

Unit Ratio = (H1BX0001)/(H0010001)

<u>Step 2:</u> Distribute the multi-family housing units throughout each census block

For example:

Duplex units per block = H0200003*Unit Ratio

<u>Step 3:</u> Derive Floor area per occupancy classification

Manufactured Housing (sq. ft.) = Census Block RES2 (from Step 2)* (0.75 * 950 + 0.25 * 1,400)

Duplex (sq. ft.) = (Census Block Duplex from Step 2) * 1,500

3-4 Units (sq. ft.) = (Census Block 3-4 units from Step 2) * 750

5-9 Units (sq. ft.) = (Census Block 5-9 units from Step 2) * 800

10-19 Units (sq. ft.) = (Census Block 10-19 units from Step 2) * 750

20-49 Units (sq. ft.) = (Census Block 20-49 units from Step 2) * 700

50+ Units (sq. ft.) = (Census Block 50+ units from Step 2) * 700

By using the above distribution, the valuation can be more specifically tailored to each floor plan. This has the potential future benefit of allowing the user to modify the floor area for multi-family units. For example in future releases, it may be possible to provide the user the capability to modify the average floor area for duplexes to 2,000 square feet per unit if this more closely reflected the users' community. This should then lead to a net decrease in the total number of units for the RES3A occupancy classification.

The floor areas presented for manufactured housing are based on review of various internet websites for manufactured housing sales (new and used), housing manufacturers, and finally additional US Census Bureau data. There was a great deal of information regarding sales and shipment of manufactured housing since the 1970's, but there was very little information regarding the attrition rate experienced over the same 30-year span. Charting information from the Manufactured Housing Institute, Figure 3.1 shows that there has been a general growth trend in the size of the units since the 1980's for both the single wide and doublewide (also known as single-section and multi-section) manufactured housing.

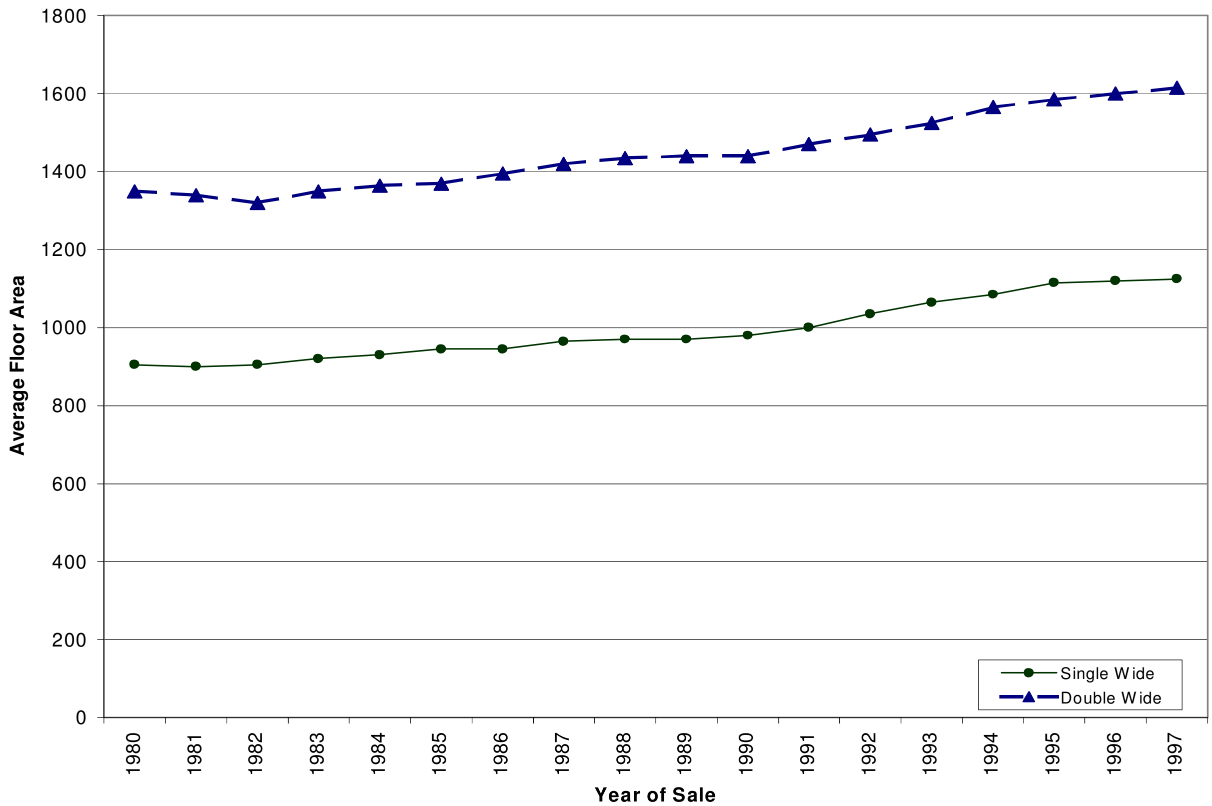


Figure 3.1 Manufactured Housing Growth Over Time

The recently released American Housing Survey for the US, 1997[1] (September, 1999) contained estimated floor areas for manufactured housing (labeled Mobile Home in the Census tables) based on a surveyed population of over 8 million manufactured homes across the United States. The survey does not differentiate between single-section and multi-section units, but when the values are charted the distribution presents natural points to estimate these dimensions. Figure 3.2 shows the distribution of floor area by number of structures from the survey. Using this distribution, it is possible to estimate representative values for single-section and multi-section units of 950 square feet and 1,400 square feet, respectively.

1 US Department of Housing and Urban Development and US Census Bureau, American Housing Survey for the United States H150/97, Office of Policy Development and Research and the US Census Bureau, September 1999.

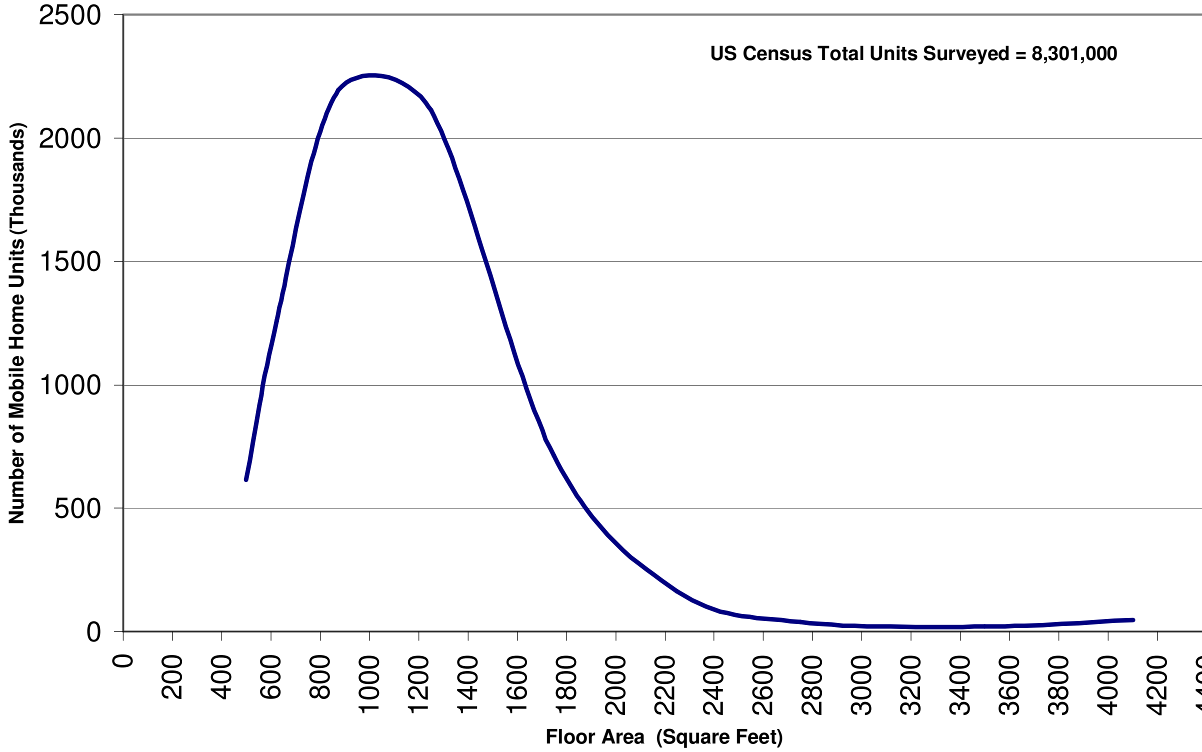


Figure 3.2 Number of Mobile Home Units by Floor Area – 1990 US Census Data Housing Characteristics

Non-Residential Occupancy Classifications

The HAZUS99 Earthquake Model inventory used the D&B business inventory at the census tract level for all non-residential structures and those facilities that are commercial in nature but provide housing for people such as hotels (RES4) and nursing homes (RES6). The D&B data represents approximately 76 percent (approximately 14 million) of the total estimated businesses in the United States (approximately 19 million). While initially this might seem like a low representation, the D&B database accounts for 98 percent of the gross national product. D&B states that the remaining businesses are likely to be smaller and home-based. If true, the proxy inventory established for the residential dwellings will account for these businesses in the total damage estimates.

D&B provided the data aggregated on the SIC definitions used previously in the development of the HAZUS99 Earthquake Model (HAZUS99 Users Manual, 1997 Table Appendix A.19, page A-23). The D&B data obtained for the Flood Model provided floor area for businesses at the census block level. It should be noted that D&B performs regular random sampling of businesses in their database to obtain the actual floor area. D&B then utilizes proprietary algorithms to estimate the floor area for the remaining businesses. According to D&B, floor area is sampled for approximately 25 percent of their business database and the remainder is modeled.

With their data, D&B provided a count of businesses, the total floor area (modeled and sampled), and the total number of employees. During a review of the data, it was discovered that D&B had some data aggregated at the census block groups and tracts level. Review of the data determined that these errors were consistent with automated georeferencing processes and are likely to represent those businesses where the addresses did not match directly with D&B's reference street base. D&B performed an additional review and ascertained that this was in fact the cause of this aggregation. It was felt, however, that the tract and block group data could be safely distributed to the census blocks based on weighted averages of commercial development within the blocks. Review of the results of this effort showed little net impact and continued agreement with ground truth data.

The D&B data contained information on all non-residential uses including some agricultural facilities, general government offices, schools, and churches. Again, comparison with POC data and other available data showed relatively good agreement.

Building Height (Number of Stories)

Table 3.6 provides a distribution of the single-family residential structures by census region. When reviewing the new data within the Residential Energy Consumption 1997 report, there was sufficient data to develop the distributions in Table 3.5. As can be seen in this table, the Northeast region has a larger percentage of 2-story single-family homes than any other census region with the South and West having a preponderance of 1-story single-family homes.

Table 3.6 Distribution of Floors for Single Family Residences

US Census Region	States within the Region	Number of Stories (% of Structures)			
		1-Story	2-Story	3-Story	Split Level
Northeast	CT, MA, ME, NH, NJ, NY, PA, RI, VT	29	61	8	2
Midwest	IA, IL, IN, KS, MI, MN, MO, NE, ND, OH, SD, WI	44	45	5	6
South	AL, AR, DE, DC, FL, GA, KY, LA, MD, MS, NC, OK, SC, TN, TX, VA, WV	72	23	3	2
West	AK, AZ, CA, CO, HI, ID, MT, NV, NM, OR, UT, WA, WY	68	26	3	3

Data Source – A Look at Residential Energy Consumption in 1997 (Nov 1999) Table HC1-13a converted to percent of total single family dwellings.

For the multi-family residences, the Housing Characteristics 1993 report did not provide any distribution by number of floors. This information was enhanced in the Residential Energy Consumption 1997 report with a broad distribution of number of floors that is best represented in Table 3.7. The actual data is provides a little more detail than that seen in the table, but based on the current damage functions available, there is no real value in providing additional definition above 5 floors.

Table 3.7 Distribution of Floors for Multi-Family Residences

US Census Region	States within the Region	Number of Stories (% of Structures)		
		1-2 Stories	3-4 Stories	5+ Stories
Northeast	CT, MA, ME, NH, NJ, NY, PA, RI, VT	29	26	45
Midwest	IA, IL, IN, KS, MI, MN, MO, NE, ND, OH, SD, WI	49	29	22
South	AL, AR, DE, DC, FL, GA, KY, LA, MD, MS, NC, OK, SC, TN, TX, VA, WV	66	21	13
West	AK, AZ, CA, CO, HI, ID, MT, NV, NM, OR, UT, WA, WY	58	25	17

Data Source – A Look at Residential Energy Consumption in 1997 (Nov 1999) Table HC1-13a converted to percent of total multi-family dwellings.

For commercial and industrial structures it is possible to develop a distribution of floors based on the Commercial Building Characteristics[2] (1997). **The Commercial Building Characteristics Table 10 – Year Constructed, Number of Buildings,** 1995 provides for Low, Medium and High rise ranges (approximately consistent with the current Hazus distributions) based on year built. The range of dates provided do not align exactly with the US Census ranges, but when aligned as seen in Table 3.8 it is possible to create a working relationship that will allow for the creation of a distribution of low, medium and high rise.

Table 3.8 Association of US Census "Year Built" with Commercial Building Characteristics "Year Constructed"

US Census Year Built Ranges for Residential Units	Corresponding Commercial Building Characteristics Year Constructed Ranges
1939 or Earlier and 1940-1949	1919 or Before and 1920-1945
1950-1959	1946-1959
1960-1969	1960-1969
1970-1979	1970-1979
1980-1988	1980-1989
1989-Mar 1990	1990-1992 1993-1995

When using Table 3.8 as the basis for relating the commercial development with the physical characteristic of number of floors, Table 3.9 is developed.

[2] Department of Energy, 1995. A Look At Commercial Buildings in 1995 DOE/EIA-0625(97), Washington, D.C., Energy Information Administration Office of Energy Markets and End Use, US Department of Energy, October, 1998.

Table 3.9 Distribution of Number of Floors by Year Built Commercial Buildings

Census Year Built	Low Rise	Mid-Rise	High Rise
1939 or Earlier and 1940-1949	92	7	1
1950-1959	98	1	1
1960-1969	96	3	1
1970-1979	98	1	1
1980-1989	96	3	1
Post 1990	96	3	1

Data Source - Commercial Building Characteristics Table 10 – Year Constructed, Number of Buildings, 1995

3.2.1.2.2 Building Foundation Type

The distribution of foundations, the associated first floor heights, and the Pre/Post-FIRM relationships are the key controlling parameters affecting flood damage within the model. The Flood Model allows the user to define or control these parameters in the Flood Specific Occupancy Mapping dialogs, which are discussed in further detail in Section 5.2 of this Technical Manual. This section will focus on the process by which the foundation distributions and the first floor heights were defined.

To properly develop a distribution of foundation types, the following foundation definitions are used:

- **Pile:** An open foundation, composed of tall and slender members, embedded deeply into the ground. A pile is a single element, not built-up on site like a pier. For our purposes, cast-in-place columns supported by a deep foundation (pile cap, or mat or raft below the anticipated scour depth) will be classified as a pile foundation. In some pile-supported buildings, shear walls may be used to transfer shear from the upper building to the embedded foundation elements.

- **Pier:** An open foundation (no load-bearing perimeter walls), usually built of masonry units and supported by shallow footings. Piers usually range from approximately 2 ft to 8 ft in height.

- **Solid Wall:** Load-bearing perimeter walls greater than 4 ft in height, usually supported by shallow footings. Floor beams or joists usually rest atop the walls, and may or may not be supported by interior piers or columns.

- **Basement or Garden Level Basement:** Any level or story, which has its floor subgrade on all sides. Usually load bearing, masonry or concrete walls around the perimeter of the building, supported on shallow footings. Floor beams or joists rest atop the walls. Shallow basements with windows slightly above grade are defined as a garden level basement.

- **Crawlspace:** Usually short (less than 4 ft high), load bearing, masonry or concrete walls around the perimeter of the building footprint, supported on shallow footings. Floor beams or joists rest atop the walls and may also rest on interior piers.

- **Fill:** Soil built up above the natural ground elevation and used to support a slab or shallow footings.

- **Slab-on-Grade:** Concrete slab resting on the ground. It may have its edges thickened or turned down, but does not rely on other walls or footings for support.

Riverine Building Foundation Types

Foundation type can be determined from either the Housing Characteristics report (1993) or the Residential Energy Consumption report (1997) with the exception of those areas subjected to coastal flood hazards. Foundation types such as pilings are not considered or mentioned in the either report, but this information can be derived from the H. John Heinz III Center data collected for their report "The Hidden Cost of Coastal Hazards" (2000). Coastal hazard areas will be discussed later in this section.

When the two reports were compared there seemed to be only moderate differences in the total percentages. For this reason, the Residential Energy Consumption (1997) census division reporting was used to enhance accuracy of the foundation distributions available to the user. While the Residential Energy Consumption report does not consider multi-family residences of five units or less, it will be assumed that this distribution can be applied to these structures since the numbers are so similar to the distributions found in the Housing Characteristics.

For non-coastal development Table 3.10 provides the recommended distribution of foundation types (basement, crawlspace, or slab on grade) for single family and multi-family residences of less than 5 units. Riverine foundation distributions do not vary by Pre-FIRM or Post-FIRM.

Table 3.10 Distribution of Foundation Types for Single Family and Multi-Family* Residences

US Census Region	States within the Region	Foundation Types						
		Pile	Pier/ post	Solid Wall	Basement/ Garden Level	Crawl-space	Fill	Slab-on-Grade
Northeast – New England	CT, MA, ME, NH, RI, VT	0	0	0	81	10	0	9
Northeast – Mid Atlantic	NJ, NY, PA	0	0	0	76	10	0	14
Midwest – East North Central	IL, IN, MI, OH, WI	0	0	0	68	21	0	11
Midwest – West North Central	IA, KS, MN, MO, NE, ND, SD	0	0	0	75	13	0	12

Table 3.10 Distribution of Foundation Types for Single Family and Multi-Family* Residences (Continued)

US Census Region	States within the Region	Foundation Types						
		Pile	Pier/ post	Solid Wall	Basement/ Garden Level	Crawl-space	Fill	Slab-on-Grade
South – South Atlantic	DE, DC, FL, GA, MD, NC, SC, VA, WV	0	0	0	23	35	0	42
South – East South Central	AL, KY, MS, TN	0	0	0	25	49	0	26
South – West South Central	AR, LA, OK, TX,	0	0	0	5	38	0	57
West-Mountain	AZ, CO, ID, MT, NV, NM, UT, WY	0	0	0	32	29	0	39
West – Pacific	AK, CA, HI, OR, WA	0	0	0	13	45	0	42

Data Source: – A Look at Residential Energy Consumption in 1997 (Nov 1999) Table HC1-9b through HC1-12b as percent of single-family housing units.

Riverine Building Floor Height Above Grade

With the distribution of default foundation types determined it is necessary to determine what this means in terms of first floor elevation. For the sake of consistency, it was determined that the measurement of floor height from grade to the top of the finished floor for both Pre-FIRM and Post-FIRM would be a good basis for default values. Table 3.11 provides the default pre-FIRM or Post-FIRM elevations for each foundation type in riverine flood hazard areas.

Table 3.11 Default Floor Heights Above Grade to Top of Finished Floor (Riverine)

ID	Foundation Type	Pre-FIRM	Post-FIRM
1	Pile	7 ft	8 ft
2	Pier (or post and beam)	5 ft	6 ft
3	Solid Wall	7 ft	8 ft
4	Basement (or Garden Level)	4ft	4 ft[1]
5	Crawlspace	3 ft	4 ft
6	Fill	2 ft	2 ft
7	Slab	1 ft	1 ft[1]

Source Data: Expert Opinion

Notes:

1 *Typically not allowed, but may exist*

Note the heights shown here are default values. In most cases, regulations are written to include a freeboard above the Base Flood Elevation (BFE). Additionally typical engineering design will shift from one foundation type to another depending on the height necessary to elevate the structure above BFE. Therefore the user is recommended to use the following guidelines for Post-FIRM foundation distributions:

- **Piles:** Utilized when the BFE plus freeboard is 8 feet or greater.
- **Piers:** Utilized when the BFE plus freeboard is less than 6 feet. If BFE plus freeboard is greater than 6 feet, typical construction practice is to use other foundation types such as solid walls or piles.
- **Solid Walls:** Utilized when the BFE plus freeboard is less than 8 feet. If the BFE plus freeboard is greater than 8 feet, typical construction practice is to use piles.
- **Basements:** Typically not allowed in Post-FIRM development within the mapped floodplain. The user should establish the Post-FIRM distribution to match what is actually occurring in the regulated areas.
- **Crawlspaces:** Utilized when the BFE plus freeboard is less than 4 feet. If BFE plus freeboard is greater than 4 feet, typical construction practice is to use other foundation types such as piers, solid walls, or piles.
- **Fill:** Utilized when the BFE plus freeboard is less than 2 feet. If the BFE plus freeboard is greater than 2 feet, typical construction practice is to use other foundation types such as crawlspace, piers, solid walls, or piles.
- **Slab-on-Grade:** Typically not allowed in Post-FIRM development within the mapped floodplain. The user should establish the Post-FIRM distribution to match what is actually occurring in the regulated areas.

Coastal Building Foundation Types

The H. John Heinz III Center for Science, Economics and the Environment has developed a report discussing coastal erosion along the US coastline. Part of this effort entailed collecting data from several coastal communities for the areas that front the actual coastline. Their study included site visits to survey the areas of interest. While the data they developed was collected for a different task, it contained detailed information on the structures that front coastlines from around the US. For additional information regarding the methodology of data collection and the complete metadata discussion, please refer to the Heinz Center's report[3].

[3] The Heinz Center. 2000. Evaluation of Erosion Hazards. Washington, D.C.: The H. John Heinz III Center for Science, Economics and the Environment.

The Heinz Center's data was supplied with the necessary metadata to allow for analysis to identify potential usefulness for the Hazus Flood Model. The data contained information regarding foundation types and the structures flood zone (i.e., A Zone, V Zone, etc.). The data was graphically plotted in order to find distinct construction features by geographic region and flood zone appropriate for the development of a modifier table. Table 3.12 shows the table for Pre-FIRM structures that is applied to those census blocks that are within or intersect with the coastal FIRM zones.

Table 3.12 Distribution of Pre-FIRM Foundation Types

Coastline	Pile	Pier	Solid Wall	Basement	Crawl	Fill	Slab
Pacific	7	7	1	2	46	0	37
Great Lakes	0	1	0	0	29	0	70
North Atlantic	47	7	2	0	34	0	10
South Atlantic	34	7	2	0	20	0	37
Gulf of Mexico	34	7	1	1	21	0	36

Source Data: The H. John Heinz III Center for Science, Economics and the Environment study data, and expert opinion

Table 3.12 shows that the Heinz Center did not find any structures that were located on elevated fill in any of their sample communities. The field for elevated fill was kept so users could modify the foundation types to include this classification if it exists within their community. The flood team felt that the communities investigated by the Heinz Center had an unusually high number of pile foundations due to modern hurricane experiences. To accommodate this concern, the North Atlantic, South Atlantic and Gulf Coast V-zones were modified slightly to increase the use of pier foundations and reduce the pile foundations. The team also reduced the slab-on-grade foundations and increased the use of the crawlspace foundations for the Great Lake A-zone.

For Post-FIRM structures, Table 3.13 provides the default distribution for the Flood Model. It should be noted that the Heinz Center data includes some foundation types that should not have been utilized within the flood zones indicated. For example, the North Atlantic V-zone data includes some slab-on-grade structures. This may be an indication that some of the structures were built just before or were under construction while the ordinances were being put in place.

It is important to note that the Flood Model will apply the A-zone and V-zones throughout a given census block based on the zone information available in the Q3.

Table 3.13 Distribution of Post-FIRM Foundation Types by Coastal Zones

Coastline	Post-FIRM Distribution of Coastal Foundation Type						
	Pile	Pier	Solid Wall	Basement	Crawlspace	Fill	Slab on Grade
V-Zone							
Pacific	60	25	0	0	10	0	5
Great Lakes	5	0	10	0	30	0	55
North Atlantic	75	15	5	0	0	0	5
South Atlantic	80	15	2	0	1	0	2
Gulf of Mexico	85	10	2	0	1	0	2
A-Zone							
Pacific	20	5	0	0	55	0	20
Great Lakes	5	0	10	0	30	0	55
North Atlantic	40	10	5	0	30	0	15
South Atlantic	50	15	2	0	20	0	13
Gulf of Mexico	50	15	2	0	20	0	13

Source Data: The H. John Heinz III Center for Science, Economics and the Environment study data and expert opinion

Coastal Building Floor Height Above Grade

For coastal flood areas a consistent measure of floor height from grade to the top of the finished floor was selected for both A-zone and V-zone heights. While the FIA looks to the bottom of the lowest horizontal member it is believed that utilizing a constant reference point in the structures made the table clearer and easier for the user. Within the Flood Model the floor height will automatically be adjusted to reference the lowest horizontal floor member to make the height consistent with the damage curves, which all follow the FEMA coastal approach.

Table 3.14 provides the default elevations for each foundation type in coastal flood hazard areas. This table also shows the changes in foundation type and height by flood hazard zone and pre-FIRM or Post-FIRM. Typically, foundations like slab-on-grade, fill, and crawlspaces are not allowed in V-zone construction, but there will be occasions within communities that these foundations exist in some numbers due to map revisions or delays in compliance enforcement. For this reason V-zone elevations are provided for these foundation types.

Table 3.14 Default Floor Heights Above Grade to Top of Finished Floor (Coastal)

ID	Foundation Type	Pre-FIRM	Post-FIRM	
			A zone	V zone
1	Pile (or column)	7 ft	8 ft	8 ft
2	Pier (or post and beam)	5 ft	6 ft	8 ft
3	Solid Wall	7 ft	8 ft	8 ft
4	Basement (or Garden Level)	4ft	4 ft[1]	4 ft[1]
5	Crawlspace	3 ft	4 ft	4 ft[1]
6	Fill	2 ft	2 ft	2 ft[1]
7	Slab	1 ft	1 ft[1]	1 ft[1]

Source Data: Expert Opinion

Notes:

1 Typically not allowed, but may exist

Note, the heights shown here are default values for coastal areas. In most cases, regulations are written to include a freeboard above the Base Flood Elevation (BFE). Additionally typical engineering design will shift from one foundation type to another depending on the height requirements to elevate the structure above BFE. Therefore the user is recommended to use the following guidelines for Post-FIRM foundation distributions:

- **Pile:** Typically this foundation is utilized when the BFE plus freeboard is 8 feet or greater.

- **Pier:** Typically this foundation is utilized when the BFE plus freeboard is less than 6 feet (A-zone) and 8 feet (V-zone). If BFE plus freeboard is greater than these heights, typical construction practice is to use other foundation types such as solid walls or piles.

- **Solid Wall:** Typically this foundation is utilized when the BFE plus freeboard is less than 8 feet. If the BFE plus freeboard is greater than 8 feet, typical construction practice is to use piles.

- **Basement:** This is typically not allowed in Post-FIRM development. The user should establish the Post-FIRM distribution to match what is actually occurring in the regulated areas.

- **Crawlspace:** Typically this foundation is utilized when the BFE plus freeboard is less than 4 feet. If BFE plus freeboard is greater than 4 feet, typical construction practice is to use other foundation types such as piers, solid walls, or piles. This foundation type is typically not allowed in areas identified as V-zone.

- **Fill:** Typically this foundation is utilized when the BFE plus freeboard is less than 2 feet. If the BFE plus freeboard is greater than 2 feet, typical construction practice is to use other foundation types such as crawlspace, piers, solid walls, or piles. This foundation type is typically not allowed in areas identified as V-zone.

- **Slab-on-Grade:** This is typically not allowed in Post-FIRM development. The user should establish the Post-FIRM distribution to match what is actually occurring in the regulated areas.

As with the values in Table 3.11, the foundation results in Table 3.12 were slightly modified to account for the unusually high percentage of pile foundations.

First Floor Elevations

Due to lack of geographic variance of the First Floor Elevations (FFE) by Pre-/Post- FIRM, Census Block controlling hazard type, Flood Zone, and Foundation type, the Flood Model development team factored out FFE from the Flood Mapping Schemes. FFE is now available from the Flood Model GUI by following *Inventory > General Building Stock > First Floor Elevations*. The Default FFE set for the whole United States is shown in Table 3.15. The Default FFE set is read-only. Users can customize the User-defined FFE set (located on the next tab). The 168 combinations yield 56 independent FFE IDs, please refer to the notes for FFE ID description.

Table 3.15 Default First Floor Elevation (FFE) Set

FFE ID	FIRM	Block Type	Zone	Foundation	Basement	First Floor Height	Notes
1	Pre-	Riverine	A Zone Coastal	Pile	N	7	PRE-FIRM construction in census blocks with Riverine construction (e.g., HazardType = 1)
1	Pre-	Riverine	CA Zone Coastal	Pile	N	7	
1	Pre-	Riverine	Riverine	Pile	N	7	
1	Pre-	Riverine	V Zone Coastal	Pile	N	7	
2	Pre-	Riverine	A Zone Coastal	Pier	N	5	
2	Pre-	Riverine	CA Zone Coastal	Pier	N	5	
2	Pre-	Riverine	Riverine	Pier	N	5	
2	Pre-	Riverine	V Zone Coastal	Pier	N	5	
3	Pre-	Riverine	A Zone Coastal	Solid Wall	N	7	
3	Pre-	Riverine	CA Zone Coastal	Solid Wall	N	7	
3	Pre-	Riverine	Riverine	Solid Wall	N	7	
3	Pre-	Riverine	V Zone Coastal	Solid Wall	N	7	
4	Pre-	Riverine	A Zone Coastal	Basement/Garden	B	4	
4	Pre-	Riverine	CA Zone Coastal	Basement/Garden	B	4	
4	Pre-	Riverine	Riverine	Basement/Garden	B	4	
4	Pre-	Riverine	V Zone Coastal	Basement/Garden	B	4	
5	Pre-	Riverine	A Zone Coastal	Crawl Space	N	3	
5	Pre-	Riverine	CA Zone Coastal	Crawl Space	N	3	
5	Pre-	Riverine	Riverine	Crawl Space	N	3	
5	Pre-	Riverine	V Zone Coastal	Crawl Space	N	3	
6	Pre-	Riverine	A Zone Coastal	Fill	N	2	
6	Pre-	Riverine	CA Zone Coastal	Fill	N	2	
6	Pre-	Riverine	Riverine	Fill	N	2	
6	Pre-	Riverine	V Zone Coastal	Fill	N	2	

Table 3.15 Default First Floor Elevation (FFE) Set (Continued)

FFE ID	FIRM	Block Type	Zone	Foundation	Basement	First Floor Height	Notes
7	Pre-	Riverine	A Zone Coastal	Slab on Grade	N	1	
7	Pre-	Riverine	CA Zone Coastal	Slab on Grade	N	1	
7	Pre-	Riverine	Riverine	Slab on Grade	N	1	
7	Pre-	Riverine	V Zone Coastal	Slab on Grade	N	1	
8	Post-	Riverine	A Zone Coastal	Pile	N	8	POST-FIRM construction in census blocks with Riverine construction (e.g., HazardType = 1)
8	Post-	Riverine	CA Zone Coastal	Pile	N	8	
8	Post-	Riverine	Riverine	Pile	N	8	
8	Post-	Riverine	V Zone Coastal	Pile	N	8	
9	Post-	Riverine	A Zone Coastal	Pier	N	6	
9	Post-	Riverine	CA Zone Coastal	Pier	N	6	
9	Post-	Riverine	Riverine	Pier	N	6	
9	Post-	Riverine	V Zone Coastal	Pier	N	6	
10	Post-	Riverine	A Zone Coastal	Solid Wall	N	8	
10	Post-	Riverine	CA Zone Coastal	Solid Wall	N	8	
10	Post-	Riverine	Riverine	Solid Wall	N	8	
10	Post-	Riverine	V Zone Coastal	Solid Wall	N	8	
11	Post-	Riverine	A Zone Coastal	Basement/Garden	B	4	
11	Post-	Riverine	CA Zone Coastal	Basement/Garden	B	4	
11	Post-	Riverine	Riverine	Basement/Garden	B	4	
11	Post-	Riverine	V Zone Coastal	Basement/Garden	B	4	
12	Post-	Riverine	A Zone Coastal	Crawl Space	N	4	
12	Post-	Riverine	CA Zone Coastal	Crawl Space	N	4	
12	Post-	Riverine	Riverine	Crawl Space	N	4	
12	Post-	Riverine	V Zone Coastal	Crawl Space	N	4	
13	Post-	Riverine	A Zone Coastal	Fill	N	2	
13	Post-	Riverine	CA Zone Coastal	Fill	N	2	
13	Post-	Riverine	Riverine	Fill	N	2	
13	Post-	Riverine	V Zone Coastal	Fill	N	2	
14	Post-	Riverine	A Zone Coastal	Slab on Grade	N	1	
14	Post-	Riverine	CA Zone Coastal	Slab on Grade	N	1	
14	Post-	Riverine	Riverine	Slab on Grade	N	1	
14	Post-	Riverine	V Zone Coastal	Slab on Grade	N	1	
15	Pre-	Coastal	A Zone Coastal	Pile	N	7	PRE-FIRM construction in census blocks with Coastal construction (e.g., HazardType = 2)
15	Pre-	Coastal	CA Zone Coastal	Pile	N	7	
15	Pre-	Coastal	Riverine	Pile	N	7	
15	Pre-	Coastal	V Zone Coastal	Pile	N	7	
16	Pre-	Coastal	A Zone Coastal	Pier	N	5	
16	Pre-	Coastal	CA Zone Coastal	Pier	N	5	
16	Pre-	Coastal	Riverine	Pier	N	5	
16	Pre-	Coastal	V Zone Coastal	Pier	N	5	
17	Pre-	Coastal	A Zone Coastal	Solid Wall	N	7	
17	Pre-	Coastal	CA Zone Coastal	Solid Wall	N	7	
17	Pre-	Coastal	Riverine	Solid Wall	N	7	
17	Pre-	Coastal	V Zone Coastal	Solid Wall	N	7	

Table 3.15 Default First Floor Elevation (FFE) Set (Continued)

FFE ID	FIRM	Block Type	Zone	Foundation	Basement	First Floor Height	Notes
18	Pre-	Coastal	A Zone Coastal	Basement/Garden	B	4	PRE-FIRM construction in census blocks with Coastal construction (e.g., HazardType = 2)
18	Pre-	Coastal	CA Zone Coastal	Basement/Garden	B	4	
18	Pre-	Coastal	Riverine	Basement/Garden	B	4	
18	Pre-	Coastal	V Zone Coastal	Basement/Garden	B	4	
19	Pre-	Coastal	A Zone Coastal	Crawl Space	N	3	
19	Pre-	Coastal	CA Zone Coastal	Crawl Space	N	3	
19	Pre-	Coastal	Riverine	Crawl Space	N	3	
19	Pre-	Coastal	V Zone Coastal	Crawl Space	N	3	
20	Pre-	Coastal	A Zone Coastal	Fill	N	2	
20	Pre-	Coastal	CA Zone Coastal	Fill	N	2	
20	Pre-	Coastal	Riverine	Fill	N	2	
20	Pre-	Coastal	V Zone Coastal	Fill	N	2	
21	Pre-	Coastal	A Zone Coastal	Slab on Grade	N	1	
21	Pre-	Coastal	CA Zone Coastal	Slab on Grade	N	1	
21	Pre-	Coastal	Riverine	Slab on Grade	N	1	
21	Pre-	Coastal	V Zone Coastal	Slab on Grade	N	1	
22	Post-	Coastal	A Zone Coastal	Pile	N	8	POST-FIRM construction in census blocks with Coastal construction (e.g., HazardType = 2), subjected to A-Zone type flooding, including both Riverine and Coastal A-Zones (e.g., ZoneTypeID = 1)
22	Post-	Coastal	CA Zone Coastal	Pile	N	8	
22	Post-	Coastal	Riverine	Pile	N	8	
23	Post-	Coastal	A Zone Coastal	Pier	N	6	
23	Post-	Coastal	CA Zone Coastal	Pier	N	6	
23	Post-	Coastal	Riverine	Pier	N	6	
24	Post-	Coastal	A Zone Coastal	Solid Wall	N	8	
24	Post-	Coastal	CA Zone Coastal	Solid Wall	N	8	
24	Post-	Coastal	Riverine	Solid Wall	N	8	
25	Post-	Coastal	A Zone Coastal	Basement/Garden	B	4	
25	Post-	Coastal	CA Zone Coastal	Basement/Garden	B	4	
25	Post-	Coastal	Riverine	Basement/Garden	B	4	
26	Post-	Coastal	A Zone Coastal	Crawl Space	N	4	
26	Post-	Coastal	CA Zone Coastal	Crawl Space	N	4	
26	Post-	Coastal	Riverine	Crawl Space	N	4	
27	Post-	Coastal	A Zone Coastal	Fill	N	2	
27	Post-	Coastal	CA Zone Coastal	Fill	N	2	
27	Post-	Coastal	Riverine	Fill	N	2	
28	Post-	Coastal	A Zone Coastal	Slab on Grade	N	1	
28	Post-	Coastal	CA Zone Coastal	Slab on Grade	N	1	
28	Post-	Coastal	Riverine	Slab on Grade	N	1	
29	Post-	Coastal	V Zone Coastal	Pile	N	8	POST-FIRM construction in census blocks with Coastal construction (e.g., HazardType = 2), subjected to V-Zone type flooding (e.g., ZoneTypeID = 2)
30	Post-	Coastal	V Zone Coastal	Pier	N	8	
31	Post-	Coastal	V Zone Coastal	Solid Wall	N	8	
32	Post-	Coastal	V Zone Coastal	Basement/Garden	B	4	
33	Post-	Coastal	V Zone Coastal	Crawl Space	N	4	
34	Post-	Coastal	V Zone Coastal	Fill	N	2	
35	Post-	Coastal	V Zone Coastal	Slab on Grade	N	1	

Table 3.15 Default First Floor Elevation (FFE) Set (Continued)

FFE ID	FIRM	Block Type	Zone	Foundation	Basement	First Floor Height	Notes
36	Pre-	Lake	A Zone Coastal	Pile	N	7	PRE-FIRM construction in census blocks with Lakes construction (e.g., HazardType = 3)
36	Pre-	Lake	CA Zone Coastal	Pile	N	7	
36	Pre-	Lake	Riverine	Pile	N	7	
36	Pre-	Lake	V Zone Coastal	Pile	N	7	
37	Pre-	Lake	A Zone Coastal	Pier	N	5	
37	Pre-	Lake	CA Zone Coastal	Pier	N	5	
37	Pre-	Lake	Riverine	Pier	N	5	
37	Pre-	Lake	V Zone Coastal	Pier	N	5	
38	Pre-	Lake	A Zone Coastal	Solid Wall	N	7	
38	Pre-	Lake	CA Zone Coastal	Solid Wall	N	7	
38	Pre-	Lake	Riverine	Solid Wall	N	7	
38	Pre-	Lake	V Zone Coastal	Solid Wall	N	7	
39	Pre-	Lake	A Zone Coastal	Basement/Garden	B	4	
39	Pre-	Lake	CA Zone Coastal	Basement/Garden	B	4	
39	Pre-	Lake	Riverine	Basement/Garden	B	4	
39	Pre-	Lake	V Zone Coastal	Basement/Garden	B	4	
40	Pre-	Lake	A Zone Coastal	Crawl Space	N	3	
40	Pre-	Lake	CA Zone Coastal	Crawl Space	N	3	
40	Pre-	Lake	Riverine	Crawl Space	N	3	
40	Pre-	Lake	V Zone Coastal	Crawl Space	N	3	
41	Pre-	Lake	A Zone Coastal	Fill	N	2	
41	Pre-	Lake	CA Zone Coastal	Fill	N	2	
41	Pre-	Lake	Riverine	Fill	N	2	
41	Pre-	Lake	V Zone Coastal	Fill	N	2	
42	Pre-	Lake	A Zone Coastal	Slab on Grade	N	1	
42	Pre-	Lake	CA Zone Coastal	Slab on Grade	N	1	
42	Pre-	Lake	Riverine	Slab on Grade	N	1	
42	Pre-	Lake	V Zone Coastal	Slab on Grade	N	1	
43	Post-	Lake	A Zone Coastal	Pile	N	8	POST-FIRM construction in census blocks with Lakes construction (e.g., HazardType = 3), subjected to A-Zone type flooding, including both Riverine and Coastal A-Zones (e.g., ZoneTypeID = 1)
43	Post-	Lake	CA Zone Coastal	Pile	N	8	
43	Post-	Lake	Riverine	Pile	N	8	
44	Post-	Lake	A Zone Coastal	Pier	N	6	
44	Post-	Lake	CA Zone Coastal	Pier	N	6	
44	Post-	Lake	Riverine	Pier	N	6	
45	Post-	Lake	A Zone Coastal	Solid Wall	N	8	
45	Post-	Lake	CA Zone Coastal	Solid Wall	N	8	
45	Post-	Lake	Riverine	Solid Wall	N	8	
46	Post-	Lake	A Zone Coastal	Basement/Garden	B	4	
46	Post-	Lake	CA Zone Coastal	Basement/Garden	B	4	
46	Post-	Lake	Riverine	Basement/Garden	B	4	

Table 3.15 Default First Floor Elevation (FFE) Set (Continued)

FFE ID	FIRM	Block Type	Zone	Foundation	Basement	First Floor Height	Notes
47	Post-	Lake	A Zone Coastal	Crawl Space	N	4	POST-FIRM construction in census blocks with Lakes construction (e.g., HazardType = 3), subjected to A-Zone type flooding, including both Riverine and Coastal A-Zones (e.g., ZoneTypeID = 1
47	Post-	Lake	CA Zone Coastal	Crawl Space	N	4	
47	Post-	Lake	Riverine	Crawl Space	N	4	
48	Post-	Lake	A Zone Coastal	Fill	N	2	
48	Post-	Lake	CA Zone Coastal	Fill	N	2	
48	Post-	Lake	Riverine	Fill	N	2	
49	Post-	Lake	A Zone Coastal	Slab on Grade	N	1	
49	Post-	Lake	CA Zone Coastal	Slab on Grade	N	1	
49	Post-	Lake	Riverine	Slab on Grade	N	1	
50	Post-	Lake	V Zone Coastal	Pile	N	8	POST-FIRM construction in census blocks with Lakes construction (e.g., HazardType = 3), subjected to V-Zone type flooding (e.g., ZoneTypeID = 2)
51	Post-	Lake	V Zone Coastal	Pier	N	8	
52	Post-	Lake	V Zone Coastal	Solid Wall	N	8	
53	Post-	Lake	V Zone Coastal	Basement/Garden	B	4	
54	Post-	Lake	V Zone Coastal	Crawl Space	N	4	
55	Post-	Lake	V Zone Coastal	Fill	N	2	
56	Post-	Lake	V Zone Coastal	Slab on Grade	N	1	

3.2.1.2.3 Building Year Built and Pre-FIRM/Post-FIRM Designation

The U.S. Congress established the National Flood Insurance Program (NFIP) with the passage of the National Flood Insurance Act of 1968. Therefore, all buildings built before the community entered the NFIP should be designated as Pre-FIRM. Post-FIRM designation should be based on the year that the community (viewed by Census Block in the Flood Specific Occupancy Mapping) started participating in the NFIP. Users can edit the entry date and modify Pre-FIRM/Post-FIRM designations.

The Comprehensive Data Management System (CDMS) tool will provide a more accurate Pre-FIRM/Post-FIRM distribution within the Census Blocks based on Tax Assessor's data aggregation. This percentage, if available for the community, will automatically override the default entry dates in Hazus.

The NFIP entry dates were updated for all communities in the United States. Using the 24,000+ community boundaries and IDs of all communities in the United States and Census Blocks centroids, a community ID was assigned to each Census Block. The community IDs were related to the Flood Map Status Information Service (FMSIS, 2007) database, which contains the NFIP entry dates. The flSchemeMapping tables were updated in the state data.

3.2.1.2.4 Garage Distributions

The development of a distribution of garages within a census block assists in the assignment of valuation functions to the dwellings. These valuation functions determine whether or not the structure is luxury, custom, average home, or economy. Once again, both DOE reports were reviewed to determine if the data provided differed and if changes in the methodologies impacted the reporting of this information. This review showed that percentages presented in the report are slightly different, but the methodology did not seem to have an impact on the quality of the reporting and therefore the data from the Residential Energy Consumption Report (1997) will be used. Initially it was hoped that the census divisions could be utilized, but upon review of the data it showed that some data was not reported because either not enough units were interviewed to properly report results or the Relative Standard of Error was greater than 50%. It was therefore determined that Census regions would be used as seen in Table 3.16. The user will have the option to modify the results.

As with some of the other housing characteristics tables, multi-family housing units were not asked about garages, but the totals are reported as a portion of the universe of housing. It is therefore necessary to adjust the table to represent a percentage of single family and small multi-family homes. Again, the housing characteristics tables provide the percentages of multi-family units not asked so this adjustment could be made.

Table 3.16 Distribution of Garages for Single Family Residential Structures

US Census Region	States within the Region	Garage Types				
		1-Car	2-Car	3-Car	Covered Carport	None
Northeast	CT, MA, ME, NH, NJ, NY, PA, RI, VT	32	30	3	2	33
Midwest	IA, IL, IN, KS, MI, MN, MO, NE, ND, OH, SD, WI	21	47	6	3	23
South	AL, AR, DE, DC, FL, GA, KY, LA, MD, MS, NC, OK, SC, TN, TX, VA, WV	16	29	1	13	41
West	AK, AZ, CA, CO, HI, ID, MT, NV, NM, OR, UT, WA, WY	17	45	5	10	23

Data Source: – A Look at Residential Energy Consumption in 1997 (Nov 1999) Table HC1-9b through HC-12b as percent of single-family housing units.

3.2.1.2.5 Building Count by Specific Occupancy

Single-Family Residences and Manufactured Housing (RES1 and RES2)

In Hazus-MH MR2 and earlier versions, building count data for each occupancy was estimated by dividing the total square footage for each census block (or tract) and occupancy by a single typical or standard value of building square foot by occupancy. For example, RES1 structures were assumed to be 1,600 sq. ft., while COM1 structures were assumed to be 110,000 sq. ft., etc. Since the square footage for residential structures was originally derived from housing unit count data available in the U.S. Census, it made sense to utilize these housing unit counts directly for RES1 and RES2 occupancies, rather than to utilize data derived from a two step proxy (estimating square footage from housing unit count, then estimating building count from square footage).

For Hazus-MH MR3 and on, revised building count data were generated for RES1 and RES2 occupancies from block group and block level census data:

- block group level census data - total count of all housing units, including the count of housing units in each housing category (1 unit detached, 1 unit attached, 2 units, 3 or 4 units, 5 - 9 units, 10 - 19 units, 20 - 49 units, 50+ units, and mobile home)
- block level data - total count of all housing units.

For each census block group, the percent of all housing units assumed to be single family (RES1) was estimated as the sum of "1 unit detached" and "1 unit attached" counts, divided by total census block group housing unit count. Similarly, the percent of all housing units assumed to be manufactured housing (RES2) was taken as the ratio of "mobile home" counts divided by total census block group housing unit count. This assumes that construction across the census block group is homogeneous - the same assumption that was made in developing the original Hazus square footage databases. To estimate census block RES1 and RES2 counts, the census block group ratios identified above were multiplied by the total census block housing unit count to arrive at census block RES1 and RES2 counts.

All Other Occupancy Classifications

The building count data for all other occupancy classifications are derived by dividing total square footage (by occupancy and by census block/tract) by an assumed typical building size for each occupancy. The assumed building sizes are given in Table 3.17 below.

Table 3.17 Assumed Typical Building Square Footage by Specific Occupancy

Occupancy	Square Footage
RES3A	3,000
RES3B	3,000
RES3C	8,000
RES3D	12,000
RES3E	40,000
RES3F	60,000
RES4	135,000
RES5	25,000
RES6	25,000
COM1	110,000
COM2	30,000
COM3	10,000
COM4	80,000
COM5	4,100
COM6	55,000
COM7	7,000
COM8	5,000
COM9	12,000
COM10	145,000
IND1	30,000
IND2	30,000
IND3	45,000
IND4	45,000
IND5	45,000
IND6	30,000
AGR1	30,000
REL1	17,000
GOV1	11,000
GOV2	11,000
EDU1	130,000
EDU2	50,000

3.2.1.3 Specific Occupancy-to-Model Building Type Mapping

Default mapping schemes for specific occupancy classes (except for RES1) to model building types by floor area percentage are provided in Tables 3A.2 through 3A.16 of Appendix 3A. Table 3A.2 through 3A.10 provide the suggested mappings for Western U.S. buildings and are based on information provided in ATC-13 (1985). Tables 3A.11 through 3A.16 provide the mapping for buildings in the rest of the United States and are based on proprietary insurance data, opinions of a limited number of experts, and interferences drawn from tax assessor's records. Table 3B.1 in Appendix 3B provides regional classification of the states. Table 3A.17 through 3A.21 provide model building distribution for the specific occupancy class "RES1" on a state-by-state basis. Tables 3A.2 through 3A.10 provide the mapping based on the height of buildings and the age of construction. The user must provide, for census tracts on the west coast, the proportion of buildings in low, mid, and high rise categories, and the proportion of buildings in the three categories according to age (pre-1950, 1950-1970, and post-1970). These proportions are used to compute a weighted sum of matrices in Table 3A.2 through Table 3A.10 to arrive at the default specific occupancy class to model building type mapping. For the rest of the United States, Tables 3A.11 through 3A.16 provides the mapping based on the height of buildings only and the user must provide the proportion of buildings in low-, mid-, and high-rise categories to compute the default specific occupancy class to model building type mapping. The default mapping provided in Tables 3A.2 through 3A.16 should be considered as a guide: Accurate mapping may be developed based on the particular building type distribution within the study region.

3.2.2 Essential Facilities

Essential facilities are those facilities that provide services to the community and should be functional after a flood. Essential facilities include hospitals, police stations, fire stations and schools. The damage for essential facilities is determined on a site-specific basis (i.e., the depth of flooding at the location of the facility based on the latitude and longitude provided). The purpose of the essential facility module is to determine the expected loss of functionality for these critical facilities. The data required for the analysis include mapping of essential facility's occupancy classes to model building types or a combination of essential facilities building type and design level. The Flood Model has attempted to mirror the Earthquake Model as much as possible with this approach. Since the Flood Model does provide results in damage states, rather the inventory is simplified and the user can define the construction classification of the building to improve the model.

3.2.2.1 Classification

The essential facilities are also classified based on the building structure type and occupancy class. The building structure types of essential facilities are the same as those for the general building stock presented in Table 3.1. The occupancy classifications are broken into general occupancy and specific occupancy classes. For the methodology, the general occupancy classification system consists of three groups (medical care, emergency response, and schools). Specific occupancy consists of fourteen classes. The occupancy classes are given in Table 3.18, where the general occupancy classes are identified in over each section.

Table 3.18 Essential Facilities Classification

Hazus Label	Occupancy Class	Description
Medical Care Facilities		
MDFLT	Default Hospital	Assigned features similar to EFHM
EFHS	Small Hospital	Hospital with less than 50 Beds
EFHM	Medium Hospital	Hospital with beds between 50 & 150
EFHL	Large Hospital	Hospital with greater than 150 Beds
EFMC	Medical Clinics	Clinics Labs Blood Banks
Emergency Response		
FDFLT	Default Fire Station	
EFFS	Fire Station	
PDFLT	Default Police Station	
EFPS	Police Station	
EDFLT	Default EOC	
EFEO	Emergency Operation Centers	
Schools		
SDFLT	Default School	Assigned features similar to ESF1
EFS1	Grade Schools Primary/ High Schools	
EFS2	Colleges/Universities	

Unlike the Earthquake Model, which had to deal with damage states and probabilities of having a certain building type, the Flood Model methodology is designed to allow the user to select he general building type for the facility and control the critical input for the estimation of losses. At Level 1, the model will use the basic location information (name, latitude, longitude, general facility information) and identify the depth of flooding at the site. The Flood Model has assigned a default building type, which the user can easily modify. Additionally, an assumed foundation type is also presented to the user for their review and modification.

Since the user can easily modify the foundation type, building type and other key parameters to match the actual facility, the Flood Model does not define a facility as Pre- or Post-FIRM. The user can, however, identify if there is any flood protection surrounding the facility such as floodgates that prevent water from entering a basement.

Critical assumptions are as follows:

- **Basement (Y/N):** The assumption developed from expert opinion is that EFFS, EFS1, and EFS2 do not have basements. All other essential facilities are assumed to have basements. The user can modify this field if their facility is incorrect using the table dialog.

- **First Floor Elevation:** Assume EFEO, EFFS, EFS1, and EFS2 are at grade. Assume all other facilities are 3 feet above grade. The user can adjust this field using the table dialog.

- **Number of Stories:** Assume all ESF1, EFHS, EFMC, EFFS, EFPS, and EFEO are all low rise structures, and the EFHM, and EFHL are mid rise. The user can adjust this field using the table dialog.

- **Damage Functions:** Comparable damage functions from the General Building Stock should be used to determine the estimated damage (percent) from which a loss of function for essential facilities can be developed. The user can change the damage functions in the analysis parameters dialogs.

Using the information presented in Table 3.19 below, it is possible to determine an estimated damage for the facility in the baseline inventory. Unlike earthquake damage, where the facility may remain functional even after some damage has been sustained, the depth of flooding dictates whether a facility remains in operation or not and then clean-up time dictates when functionality is restored. As Table 3.19 shows, the general assumption is that when the depth of flooding at the facility reaches half a foot, typically the facility is closed and people evacuated. In the case of some hospitals, this does not always mean the patients are evacuated, but the trauma center will typically refuse new patients.

Since the essential facility is a point site, the depth can be determined from the grid cell in which the facility falls. Based on the first floor elevation and the existence of a basement, the damage can be estimated and the functionality determined. The user can override the basement, number of stories, and use an alternative damage function by changing the assignment. This approach removes the need for an occupancy mapping for essential facilities.

Table 3.19 Essential Facilities Inventory Occupancy Classification and Flood Model Default Parameters

Hazus Label	Occupancy Class	Default Building Type	Base-ment	First Floor Height (ft)	No. of Stories	Functionality Depth (ft)
Medical Care Facilities						
MDFLT	Default Hospital	Concrete	Yes	3	Mid	0.5
EFHS	Small Hospital	Concrete	Yes	3	Low	0.5
EFHM	Medium Hospital	Concrete	Yes	3	Mid	0.5
EFHL	Large Hospital	Concrete	Yes	3	Mid	0.5
EFMC	Medical Center	Concrete	Yes	3	Low	0.5
Emergency Centers						
FDFLT	Default Fire Station	Concrete	No	0	Low	0.5
EFFS	Fire Station	Concrete	No	0	Low	0.5
PDFLT	Default Police Station	Concrete	Yes	0	Low	0.5
EFPS	Police Station	Concrete	Yes	0	Low	0.5
EDFLT	Default Emergency Center	Concrete	Yes	0	Low	0.5
EFEO	Emergency Center	Concrete	Yes	0	Low	0.5
Schools						
SDFLT	Default School	Masonry	No	0	Low	0.5
EFS1	School	Masonry	No	0	Low	0.5
EFS2	University	Concrete	No	0	Low	0.5

3.2.3 High Potential Loss Facilities

High potential loss facilities were defined during the development of the Earthquake Model as those facilities that are likely to cause heavy earthquake losses if damaged. For the earthquake methodology, high potential loss (HPL) facilities include nuclear power plants, dams, and some military installations. The inventory data required for HPL facilities include the geographical location (latitude and longitude) of the facility.

The dam classifications are based on the National Inventory of Dams (NATDAM) database (FEMA 1993).

Table 3.20 High Potential Loss Facilities Classifications

Hazus Label	General Occupancy	Specific Occupancy
Dams		
DDFLT	Dam Default	Default
HPDA	Dams	Arch
HPDB	Dams	Buttress
HPDC	Dams	Concrete
HPDE	Dams	Earth
HPDG	Dams	Gravity
HPDM	Dams	Masonry
HPDR	Dams	Rock fill
HPDS	Dams	Stone
HPDT	Dams	Timber Crib
HPDU	Dams	Multi-Arch
HPDZ	Dams	Miscellaneous
Nuclear Power Plants		
NDFLT	Nuclear Plant Default	Default
HPNP	Nuclear Power Facilities	Nuclear Power Facilities
Military Installations		
MDFLT	Military Default	Default
HPMI1	Military Installations	Barracks/Group Quarters
HPMI2	Military Installations	Officer/Enlisted Quarters - Multi-Unit
HPMI3	Military Installations	Officer/Enlisted Quarters - Detached
HPMI4	Military Installations	Maintenance/Operations Shops
HPMI5	Military Installations	Administrative Offices
HPMI6	Military Installations	Mess Halls
HPMI7	Military Installations	Officer/Enlisted Clubs
HPMI8	Military Installations	Gymnasiums/Armory
HPMI9	Military Installations	Gas/Services Stations
HPMI10	Military Installations	PX/Retail Stores
HPMI11	Military Installations	Arsenals
HPMI12	Military Installations	Other

Damage and loss estimation calculation for high potential loss facilities are not performed as part of the flood methodology. The user can map the locations of the facilities over the flood hazard grid and ascertain the potential for problems associated with the scenario flood conditions and the facility.

3.2.4 User Defined Facilities

By default, there is no baseline inventory for User Defined facilities within Hazus. The user will be provided with a table definition and structure and the opportunity to either import a table that matches that structure, or to add individual records within the data table. The Flood Model will use the damage functions from the General Building Stock damage library. The damage functions are associated by the Occupancy code and key fields, such as "Num of Stories" and "Foundation." For example, RES1 with 2 stories and a basement would be listed under R12B and a COM1 that is mid rise and has no basement would be listed under C1MN. The user can select another damage function from the Flood Model damage function library or build a function and assign it to the user-defined facility. It is recommended that the user utilizes this functionality when they have facilities that do not fall within the normal occupancy classifications. An example of this might be those users who would like to perform a more detailed analysis on structures related to a railway system. The user can create a listing of railway stations, assign the appropriate damage functions and perform the analysis. It is recommended that the user utilizes the User Defined facilities feature when the CDMS tool has been used to collect the inventory data.

Damage and loss estimation calculation for User Defined facilities are performed as part of this methodology and are displayed in results tables, but are not aggregated in a summary report.

3.3 Direct Damage Data - Transportation Systems

The inventory classification scheme for lifeline systems separates components that makeup the system into a set of pre-defined classes. The classification system used in this methodology was developed to provide an ability to differentiate between varying lifeline system components with substantially different damage and loss characteristics. Transportation systems addressed in the methodology include highways, railways, light rail, bus, ports, ferries and airports. The classification of each of these transportation systems is discussed in detail in the following sections. The inventory data required for the analysis of each system is also identified in the following sections.

Effort has been made to classify the components based on their vulnerability to flooding. At this time, the Flood Model does not account for flood borne debris impact or the loads resulting from flood borne debris trapped against transportation features such as bridges. The initial release of the Flood Model will estimate the level of damage to the bridge network and the subsequent functionality of the bridge, but other transportation components have been deferred to later versions.

The Flood Model comes with a baseline bridge database compiled from the National Transportation Atlas and was last updated in 2001. The Flood Model uses the scour field within the database as discussed later in Section 7 of this document. The user can add or remove bridges from this database.

3.3.1 Highway Systems

A highway transportation system consists of roadways, bridges and tunnels. The inventory data required for analysis include the geographical location, classification, and replacement cost of the system components. The Flood Model has tailored the classification system to meet the needs of the flood community and reduce the overall data collection effort.

The Flood Model has delayed the assessment of losses to street segments and other highway components, but will produce an estimate of the percent damage to a bridge and the probability of the bridge being functional depending on the estimated damage.

3.3.1.1 Classification

The classes of highway systems are presented in Table 3.21. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.21 Highway System Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
HRD1	Highway Roads	Major Roads (1km 4 lanes))	10,000
HRD2	Highway Roads	Urban Roads (1 km 2 lanes)	5,000
HTU	Highway Tunnel	Highway Tunnel	20,000
HWBM	Highway Bridge	Major Bridge	20,000
HWBO	Highway Bridge	Other Bridge (include all wood)	1,000
HWBCO	Highway Bridge	Other Concrete Bridge	1,000
HWBCC	Highway Bridge	Continuous Concrete Bridge	5,000
HWBSO	Highway Bridge	Other Steel Bridge	1,000
HWBSC	Highway Bridge	Continuous Steel Bridge	5,000

Notes:

1 All dollar amounts are in thousands of dollars.

3.3.2 Railway Systems

A railway transportation system consists of tracks, bridges, tunnels, stations, fuel, dispatch and maintenance facilities. The inventory data required for analysis include the geographical location, classification and replacement cost of the system components. The Flood Model has tailored the classification system to meet the needs of the flood community and reduce the overall data collection effort.

The Flood Model has delayed the assessment of losses to railway segments and other railway components, but will produce an estimate of the percent damage to a bridge and the probability of the bridge being functional depending on the estimated damage.

3.3.2.1 Classification

The classes of railway systems are presented in Table 3.22. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.22 Railway System Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
RTR	Railway Tracks	Railway Tracks (per km)	1,500
RBRU	Railway Bridge	Railway Bridge Unknown	5,000
RBRC	Railway Bridge	Concrete Railway Bridge	5,000
RBRS	Railway Bridge	Steel Railway Bridge	5,000
RBRW	Railway Bridge	Wood Railway Bridge	5,000
RTU	Railway Tunnel	Railway Tunnel	10,000
RSTS	Railway Urban Station	Steel Railway Urban Station	2,000
RSTC	Railway Urban Station	Concrete Railway Urban Station	2,000
RSTW	Railway Urban Station	Wood Railway Urban Station	2,000
RSTB	Railway Urban Station	Brick Railway Urban Station	2,000
RFF	Railway Fuel Facility	Railway Fuel Facility (Tanks)	3,000
RDF	Railway Dispatch Facility	Railway Dispatch Facility (Equip)	3,000
RMFS	Railway Maintenance Facility	Steel Railway Maintenance Facility	2,800
RMFC	Railway Maintenance Facility	Concrete Railway Maintenance Facility	2,800
RMFW	Railway Maintenance Facility	Wood Railway Maintenance Facility	2,800
RMFB	Railway Maintenance Facility	Brick Railway Maintenance Facility	2,800

Notes:

1 *All dollar amounts are in thousands of dollars.*

3.3.3 Light Railway Systems

A light railway transportation system consists of tracks, bridges, tunnels, stations, fuel, dispatch and maintenance facilities. The major difference between light rail and rail systems is the power supply, where light rail systems operate with DC power substations. The inventory data required for analysis include the geographical location, classification and replacement cost of the system components. The Flood Model has tailored the classification system to meet the needs of the flood community and reduce the overall data collection effort.

The Flood Model has delayed the assessment of losses to railway segments and other light rail components, but will produce an estimate of the percent damage to a bridge and the probability of the bridge being functional depending on the estimated damage.

3.3.3.1 Classification

The classes of light rail systems are presented in Table 3.23. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.23 Light Rail System Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
LTR	Light Rail Track	Light Rail Track (per km)	1,500
LBRU	Light Rail Bridge	Light Rail Bridge Unknown	5,000
LBRC	Light Rail Bridge	Concrete Light Rail Bridge	5,000
LBRS	Light Rail Bridge	Steel Light Rail Bridge	5,000
LBRW	Light Rail Bridge	Wood Light Rail Bridge	5,000
LTU	Light Rail Tunnel	Light Rail Tunnel	10,000
LDC	DC Substation	DC Substation (equip)	2,000
LDF	Dispatch Facility	Dispatch Facility (equip)	3,000
LMFS	Maintenance Facility	Steel Maintenance Facility	2,600
LMFC	Maintenance Facility	Concrete Maintenance Facility	2,600
LMFW	Maintenance Facility	Wood Maintenance Facility	2,600
LMFB	Maintenance Facility	Brick Maintenance Facility	2,600

Notes:

1 All dollar amounts are in thousands of dollars.

3.3.4 Bus Systems

A bus transportation system consists of urban stations fuel facilities, dispatch and maintenance facilities. The inventory data required for analysis include the geographical location, classification and replacement cost of the system components. The Flood Model has tailored the classification system to meet the needs of the flood community and reduce the overall data collection effort.

The Flood Model has delayed the assessment of losses to bus systems.

3.3.4.1 Classification

The classes of bus systems are presented in Table 3.24. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.24 Bus System Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
BPTS	Bus Urban Station	Steel Bus Urban Station	1,000
BPTC	Bus Urban Station	Concrete Bus Urban Station	1,000
BPTB	Bus Urban Station	Brick Bus Urban Station	1,000
BPTW	Bus Urban Station	Wood Bus Urban Station	1,000
BFF	Bus Fuel Facility	Bus Fuel Facility (tanks)	150
BDF	Bus Dispatch Facility	Bus Dispatch Facility (equip)	400
BMFW	Bus Maintenance Facility	Wood Bus Maintenance Facility	1,300
BMFS	Bus Maintenance Facility	Steel Bus Maintenance Facility	1,300
BMFC	Bus Maintenance Facility	Concrete Bus Maintenance Facility	1,300
BMFB	Bus Maintenance Facility	Brick Bus Maintenance Facility	1,300

Notes:

1 All dollar amounts are in thousands of dollars.

3.3.5 Ports and Harbors

Port and harbor transportation systems consist of waterfront structures, cranes/cargo handling equipment, warehouses and fuel facilities. The inventory data required for analysis include the geographical location, classification and replacement cost of the system components. The Flood Model has tailored the classification system to meet the needs of the flood community and reduce the overall data collection effort.

The Flood Model has delayed the assessment of losses to ports and harbors.

3.3.5.1 Classification

The classes of ports and harbors are presented in Table 3.25. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.25 Ports and Harbors Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
PWS	Waterfront Structures	Waterfront Structures	1,500
PEQ	Cranes/Cargo Handling Equipment	Cranes/Cargo Handling Equipment	2,000
PWHW	Warehouses	Wood Port Warehouses	1,200
PWHS	Warehouses	Steel Port Warehouses	1,200
PWHC	Warehouses	Concrete Port Warehouses	1,200
PWHB	Warehouses	Brick Port Warehouses	1,200
PFF	Fuel Facility	Port Fuel Facility	2,000

Notes:

1 All dollar amounts are in thousands of dollars.

3.3.6 Ferry Transportation Systems

A ferry transportation system consists of waterfront structures, passenger terminals, warehouses, fuel facilities, and dispatch and maintenance facilities. The inventory data required for analysis include the geographical location, classification and replacement cost of the system components. The Flood Model has tailored the classification system to meet the needs of the flood community and reduce the overall data collection effort.

The Flood Model has delayed the assessment of losses to ferry transportation systems.

3.3.6.1 Classification

The classes of ferry transportation systems are presented in Table 3.26. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.26 Ferry System Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
FWS	Water Front Structures	Ferry Waterfront Structures	1,500
FPTW	Ferry Passenger Terminals	Wood Ferry Passenger Terminals	1,000
FPTS	Ferry Passenger Terminals	Steel Ferry Passenger Terminals	1,000
FPTC	Ferry Passenger Terminals	Concrete Ferry Passenger Terminals	1,000
FPTB	Ferry Passenger Terminals	Brick Ferry Passenger Terminals	1,000
FFF	Ferry Fuel Facility	Ferry Fuel Facility	400
FDF	Ferry Dispatch Facility	Ferry Dispatch Facility	200
FMFW	Piers and Dock Facilities	Wood Piers and Dock Facilities	520
FMFS	Piers and Dock Facilities	Steel Piers and Dock Facilities	520
FMFC	Piers and Dock Facilities	Concrete Piers and Dock Facilities	520
FMFB	Piers and Dock Facilities	Brick Piers and Dock Facilities	520

Notes:

1 All dollar amounts are in thousands of dollars.

3.3.7 Airports

An airport transportation systems consist of control towers, runways, terminal buildings, parking structures, fuel facilities, and maintenance and hanger facilities. The inventory data required for analysis include the geographical location, classification and replacement cost of the system components. The Flood Model has tailored the classification system to meet the needs of the flood community and reduce the overall data collection effort.

The Flood Model has delayed the assessment of losses to airports.

3.3.7.1 Classification

The classes of airport transportation systems are presented in Table 3.27. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.27 Airports Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
ACTW	Airport Control Towers	Wood Airport Control Towers	5,000
ACTS	Airport Control Towers	Steel Airport Control Towers	5,000
ACTC	Airport Control Towers	Concrete Airport Control Towers	5,000
ACTB	Airport Control Towers	Brick Airport Control Towers	5,000
APTR	Airport Runway	Airport Runway (total)	28,000
AFF	Fuel Facilities	Fuel Facilities	5,000
AFO	Seaport/Stolport/Gliderport/etc.	Seaport/Stolport/Gliderport/etc.	500
AFH	Heliport Facilities	Heliport Facilities	2,000
APS	Airport Parking Structure	Airport Parking Structure	1,400
AMFW	Airport Maintenance & Hangar Facility	Wood Airport Maintenance & Hangar Facility	3,200
AMFS	Airport Maintenance & Hangar Facility	Steel Airport Maintenance & Hangar Facility	3,200
AMFC	Airport Maintenance & Hangar Facility	Concrete Airport Maintenance & Hangar Facility	3,200
AMFB	Airport Maintenance & Hangar Facility	Brick Airport Maintenance & Hangar Facility	3,200
ATBW	Airport Terminal Buildings	Wood Airport Terminal Buildings	8,000
ATBS	Airport Terminal Buildings	Steel Airport Terminal Buildings	8,000
ATBC	Airport Terminal Buildings	Concrete Airport Terminal Buildings	8,000
ATBB	Airport Terminal Buildings	Brick Airport Terminal Buildings	8,000
ATBU	Airport Terminal Unknown	Airport Terminal Buildings Unknown	8,000

Notes:

1 *All dollar amounts are in thousands of dollars.*

3.4 Direct Damage Data – Lifeline Utility Systems

The inventory classification scheme for lifeline systems separates components that makeup the system into a set of pre-defined classes. The classification system used in this methodology was developed to provide an ability to differentiate between varying lifeline system components with substantially different damage and loss characteristics. Utility systems addressed in the methodology include potable water, wastewater, oil, natural gas, electric power, and communication systems. The classification of each of these utility systems is discussed in detail in the following sections. The inventory data required for the analysis of each system is also identified in the following sections.

Effort has been made to classify the components based on their vulnerability to flooding. At this time, the Flood Model does not account for flood borne debris impact, or water borne debris loads, which can cause significant clean-up efforts for utility systems. The Flood Model is analyzing those system components that are more vulnerable or costly to clean-up, repair or replace since they are likely to control the overall recovery costs and time.

3.4.1 Potable Water Systems

A potable water system consists of pipelines, water treatment plants, control vaults and control stations, wells, storage tanks and pumping stations. The inventory data required for potable water systems analysis include the geographical location and classification of system components. The analysis also requires the replacement cost for facilities and the repair cost for pipelines.

The Flood Model will estimate damage, losses and functionality for select vulnerable components of the potable water system. These include treatment plants, control vaults and control stations, and pumping stations.

3.4.1.1 Classification

The classes of potable water systems are presented in Table 3.28. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.28 Potable Water System Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
PWPE	Pipelines	Exposed Transmission Pipeline Crossing	1
PWPB	Pipelines	Buried Transmission Pipeline Crossing	1
PWP	Pipelines	Pipelines (non-crossing)	1
PWSO	Water Treatment Plants	Small Water Treatment Plants Open/Gravity	30,000
PWMO	Water Treatment Plants	Medium Water Treatment Plants Open/Gravity	100,000
PWLO	Water Treatment Plants	Large Water Treatment Plants Open/Gravity	360,000
PWSC	Water Treatment Plants	Small Water Treatment Plants Closed/Pressure	30,000
PWMC	Water Treatment Plants	Medium Water Treatment Plants Closed/Pressure	100,000
PWLC	Water Treatment Plants	Large Water Treatment Plants Closed/Pressure	360,000
PPSB	Pumping Plants	Pumping Plants (Small) Below Grade	150
PPMB	Pumping Plants	Pumping Plants (Med/Large) Below Grade	525
PPSA	Pumping Plants	Pumping Plants (Small) Above Grade	150
PPMA	Pumping Plants	Pumping Plants (Med/Large) Above Grade	525
PCVS	Control Vaults and Stations	Control Vaults and Stations	50
PSTC	Water Storage Tanks	Water Storage Tanks At Grade Concrete	1,500
PSTS	Water Storage Tanks	Water Storage Tanks At Grade Steel	800
PSTW	Water Storage Tanks	Water Storage Tanks At Grade Wood	30
PSTE	Water Storage Tanks	Water Storage Tanks Elevated	800
PSTB	Water Storage Tanks	Water Storage Tanks Below Grade (all)	1,500
PWE	Wells	Wells	400

Notes:

1 *All dollar amounts are in thousands of dollars.*

3.4.2 Wastewater Systems

A wastewater system consists of pipelines, wastewater treatment plants, control vaults and control stations, and lift stations. The inventory data required for wastewater systems analysis include the geographical location and classification of system components. The analysis also requires the replacement cost for facilities and the repair cost for pipelines.

The Flood Model will estimate damage, losses, and functionality for select vulnerable components within the wastewater system including treatment plants, control vaults and stations, and lift stations.

3.4.2.1 Classification

The classes of wastewater systems are presented in Table 3.29. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.29 Wastewater System Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
WWPE	Sewers & Interceptors	Exposed Collector River Crossings	1
WWPB	Sewers & Interceptors	Buried Collector River Crossings	1
WWP	Sewers & Interceptors	Pipes (non-crossings)	1
WWTS	Wastewater Treatment Plants	Small Wastewater Treatment Plants	60,000
WWTM	Wastewater Treatment Plants	Medium Wastewater Treatment Plants	200,000
WWTL	Wastewater Treatment Plants	Large Wastewater Treatment Plants	720,000
WWCV	Control Vaults and Control Stations	Control Vaults and Control Stations	50
WLSW	Lift Stations	Lift Station (Small) Wet Well/Dry Well	300
WLMW	Lift Stations	Lift Station (Med/Large) Wet Well/Dry Well	1,050
WLSS	Lift Stations	Lift Station (Small) Submersible	300
WLMS	Lift Stations	Lift Station (Med/Large) Submersible	1,050

Notes:

1 All dollar amounts are in thousands of dollars.

3.4.3 Oil Systems

An oil system consists of pipelines, refineries, control vaults and control stations, and tank farms. The inventory data required for oil systems analysis include the geographical location and classification of system components. The analysis also requires the replacement cost for facilities and the repair cost for pipelines.

The Flood Model will estimate damage, losses and functionality for select vulnerable system components within the oil system. This is limited to refineries and control vaults and stations.

3.4.3.1 Classification

The classes of oil systems are presented in Table 3.30. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.30 Oil System Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
OIPE	Pipelines	Exposed Transmission Pipelines River Crossings	1
OIPB	Pipelines	Buried Transmission Pipelines River Crossings	1
OIP	Pipelines	Pipelines (non-crossing)	1
OPP	Pumping Plant	Pumping Plant	1,000
OTF	Tank Farm	Tank Farm	2,000
OCV	Oil Control Vault & Control Station	Oil Control Vault & Control Station	50
ORFS	Oil Refinery	Small Oil Refinery	175,000
ORFM	Oil Refinery	Medium Oil Refinery	750,000
ORFL	Oil Refinery	Large Oil Refinery	750,000

Notes:

1 All dollar amounts are in thousands of dollars.

3.4.4 Natural Gas Systems

A natural gas system consists of pipelines, control vaults and control stations, and compressor stations. The inventory data required for natural gas systems analysis include the geographical location and classification of system components. The analysis also requires the replacement cost for facilities and the repair cost for pipelines.

The Flood Model will estimate loses to select vulnerable system components within the natural gas system. This includes the control vaults, control stations and compressor stations.

3.4.4.1 Classification

The classes of natural gas systems are presented in Table 3.31. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.31 Natural Gas System Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
NGPE	Pipelines	Exposed Transmission Pipelines River Crossings	1
NGPB	Pipelines	Buried Transmission Pipelines River Crossings	1
NGP	Pipelines	Pipelines (Non-crossing)	1
NGCV	Control Valves and Control Stations	Control Valves and Control Stations	50
NGC	Compressor Stations	Compressor Stations	1,000

Notes:

1 All dollar amounts are in thousands of dollars.

3.4.5 Electric Power Systems

An electric power system consists of generating plants, substations, distribution circuits, and transmission towers. The inventory data required for electric power systems analysis include the geographical location and classification of system components. The analysis also requires the replacement cost for facilities and the repair cost for transmission lines.

The Flood Model will perform a limited analysis on select vulnerable electric power system components. These components include the generating plants and substations.

3.4.5.1 Classification

The classes of electric power systems are presented in Table 3.32. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.32 Electric Power System Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
ESSL	Substations	Low Voltage Substation	10,000
ESSM	Substations	Medium Voltage Substation	20,000
ESSH	Substations	High Voltage Substation	50,000
EDCE	Distribution Circuits	Distribution Circuits Elevated Crossings	3
EDCB	Distribution Circuits	Distribution Circuits Buried Crossings	3
EDC	Distribution Circuits	Distribution Circuits (non-crossing)	3
EPPS	Generation Plants	Small Power Plants	100,000
EPPM	Generation Plants	Medium Power Plants	500,000
EPPL	Generation Plants	Large Power Plants	500,000

Notes:

1 All dollar amounts are in thousands of dollars.

3.4.6 Communication Systems

A communication system consists of communications facilities, communications lines, control vaults, switching stations, Radio/TV station, weather station, or other facilities. The inventory data required for communications systems analysis include the geographical location and classification of system components. The analysis also requires the replacement cost for facilities and the repair cost for communications lines.

The Flood Model has deferred estimating damage and losses for communications facilities.

3.4.6.1 Classification

The classes of communications systems are presented in Table 3.33. The table also provides a comparison of the Flood Model classification scheme to the Earthquake Model classification scheme to allow those users who have an earthquake database to aggregate the data appropriately into the flood requirements.

Table 3.33 Communication System Classifications

Flood Label	General Occupancy	Specific Occupancy	Hazus Valuation[1]
CCTE	Communications Lines	Exposed Communications Lines River Crossings	N/A
CCTB	Communications Lines	Buried Communications Lines River Crossings	N/A
CCT	Communications Lines	Communications Lines (non-crossings)	N/A
CCSV	Control Vault	Control Vault	50
CCS1	Switching Stations	Central Offices/Switching Stations Below Grade	5,000
CCS2	Switching Stations	Central Offices/Switching Stations At or Above Grade	5,000
CBR	Radio/TV Station	Radio Station/TV Station	2,000
CBW	Weather Station	Weather Station	2,000
CBO	Other Communication Facility	Other Communication Facility	2,000

Notes:

1 All dollar amounts are in thousands of dollars.

3.5 Direct Damage Data Agricultural Products

Based on the results from the proof-of-concept exercise and direction from the Hazus Flood Model Oversight Committee, the methodology for developing the agriculture products inventory has been established. Additionally, the Flood Model project team took the opportunity to review additional crop loss estimation approaches currently used by the US Army Corps of Engineers (USACE). This includes the current development within the Hydraulic Engineering Center's (HEC) Flood Impact Analysis (FIA) and Flood Damage Assessment (FDA) models. The project team also reviewed a program called Computerized Agricultural Crop Flood Damage

Assessment System (CACFDAS). None of these models varied significantly from the Agriculture Flood Damage Analysis (AGDAM) approach tested in the proof-of-concept effort, which has been selected for implementation. The methodology discussed in the Final Task 2 report combines two nationally available datasets that provide sufficient data to develop a general distribution of crops by type, average yield by NRI polygon, the unit price, and the harvest price. As mentioned in the report, the two datasets are the National Resources Inventory (NRI) and the National Agriculture Statistical Service (NASS).

The NRI dataset was created to allow the US Department of Agriculture (USDA) to "…assess the status, conditions and trends of resources at 5-year intervals." The NRI has conducted their survey in 1977, 1982, 1987, 1992 and 1996 and 2001. The data for 2001 is not available for inclusion into the Hazus Flood Model, but this does not pose any issue for the model based on the chosen approach. The NRI data is compiled and presented at the sub-county level. The NRI data consists of point sample data taken throughout the county. This is associated with soils data and "expansion factors" that identify what each sample point represents in terms of acres.

The 1992 NRI dataset was used to develop sub-county polygons (essentially an intersection of the county boundary with the USGS 8-digit Hydrologic Unit codes or HUCS). For example Story County, Iowa and the county are subdivided into six polygons (one of which had no data). For the entire nation, this resulted in an average of six polygons per county. The NRI data also provides sample points taken throughout the county. Each sample point is associated with specific HUC and county polygon, soils data and "expansion factors", statistical weighting factors that establish the total crop acreage and yields represented by the sample point. The NRI data is averaged over each collection interval (5 intervals since 1977) to smooth variations in agriculture yields. These variations include changes in crop types, crop rotation and seasonal or weather related changes in yield. As with every inventory dataset within Hazus, the user can modify or adjust the values based on more accurate local information. The total yields for each polygon are then summed over the 5 collection intervals and averaged to produce the "average yield" that will be supplied to the user. The user will be able to edit the value to account for their estimated or actual yields. The NRI data provides definition of the units of measure for each crop type (such as bushels). Due to data limitations, the agriculture inventory will not be available for Alaska and the US territories; however, the Flood Model is being developed such that users in those areas could easily input locally available data as needed.

The NASS data is compiled annually by the NASS, a branch of the USDA, and covers nearly every aspect of the agriculture industry. This rigorous collection of data is used primarily to assess and estimate crop yields and future industry planting. The data is collected through a variety of sources. The key limitation of this data is that the crop yields are developed for the entire county and do not assess regional variations in crop types or yields. It is believed that the NASS data is more perishable due to the variations in crop yields from year to year. Additionally, the countywide distribution limits the accuracy of the data. The NASS data, however, provides the most up to date estimate on the unit price for each crop type since the data is collected annually. With the strong variations in crop price this field can easily be updated by the user with data from the NASS website. The User Manual will recommend that the user check the NASS website prior to performing an agriculture loss assessment.

By associating the crop types from the NASS data to the NRI, the project team was able to obtain the crop price per unit (e.g., $ per bushel). The NASS data is compiled annually, and the most recent values were used. It is anticipated that the crop price per unit will be the data field most likely modified by users since this value fluctuates annually. The software will make this data field easy to locate, identify, and modify.

Based on conversations with various districts within the USACE and based on review of the previously mentioned crop loss models (FIA, AGDAM, and CACFDAS) used by the USACE, crop losses are substantially affected by the duration of the flood. Since the Flood Model is not developing a hazard duration factor, the solution is to provide a table of results to the user for a range of durations. The USACE has a set of duration functions with factors for 0, 3, 7, and 14 days of duration. The Flood Model will provide a single table of losses by crop type for each duration period.

The USACE has provided damage functions for several different crop types and the Flood Model will use many of these functions as the default. A damage function library is being developed based on curves collected from the various USACE Districts. Damage and duration curves have been obtained from the Sacramento, St. Paul, and Vicksburg Districts. All the curves are based on a Julian calendar to account for the changing potential to loss from planting to harvest. The user will need to provide a date for the flood scenario, and the Flood Model will determine the Julian date and identify the loss potential from the damage function. The loss will be increased by the duration factors as discussed above.

3.6 Direct Damage Data – Vehicles

In order to utilize Hazus to estimate flood damage of motor vehicles, procedures are required to: (1) calculate vehicle inventory within a study area; (2) allocate vehicles by time of day to different locations; (3) estimate the value of vehicles; and (4) apply a percent loss damage function according to the flood depth. These steps are divided into two parts. The first part is a vehicle location estimator, and the other part is the value of damage calculator. The vehicle location estimator is summarized in Figure 3.3.

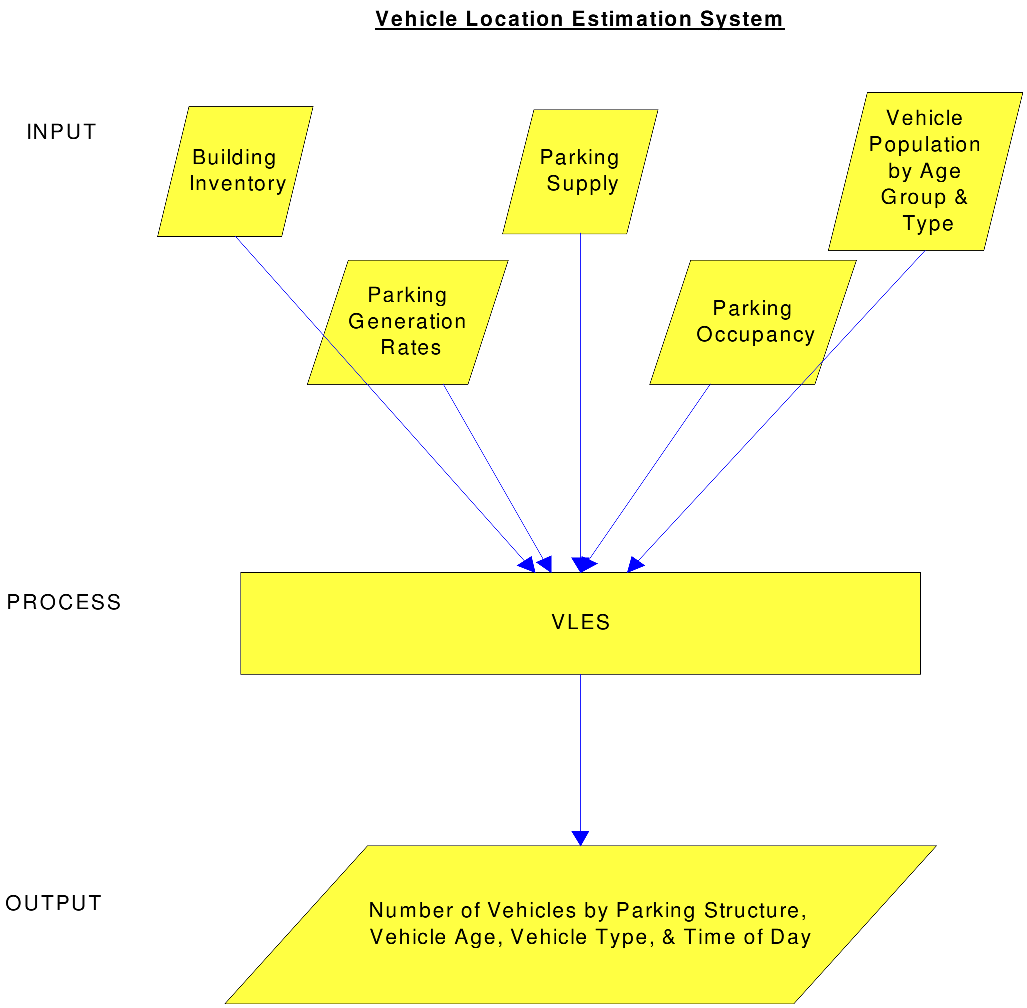


Figure 3.3 Vehicle Location Estimation System

3.6.1 Building inventory

Building inventory in a study area is provided in Hazus, which categorizes all building structures into 33 occupancy groups. Among those major occupancy groups, 11 are residential, 10 are commercial, and 6 are industrial.

3.6.1.1 Parking Generation Rates

Parking generation rates are used to associate number of parked vehicles to square footages of different types of occupancy groups in Hazus during a flood event. Vehicle distributions are estimated for daytime and nighttime, with daytime assumed to be normal business hours. The Institute of Transportation Engineers (ITE) has compiled the most comprehensive parking generation study. The latest version of the ITE Parking Generation manual was dated 1987, however, and a new edition is expected in early 2002. Another comprehensive source of parking in relation to land use is the Off-Street Parking Requirements manual compiled by the American Planning Association (APA). For the purpose of this report, various regional parking studies are referenced to update the ITE study and help determine the parked vehicle distribution according to time of day. These regions include Austin, Denver, Indianapolis, Seattle, and Westfield.

The following examples illustrate the process of assigning parked vehicles to specific occupancy groups. The first example is related to retail trade, which belongs to the Hazus occupancy group COM1. The ITE parking generation report devotes land use code 810-850 and 870-890 to retail trade, which includes shopping centers, restaurants, supermarkets, and so on. The ITE updated parking generation rate (data through April 2001) for shopping centers is available in a report from DKS Associates that utilizes results of 940 parking studies to characterize generalized retail trade activities. During regular business hours, average vehicles per 1,000 square feet of shopping center space generally fall between 3-4; during nighttime, observations are limited and the rate falls sharply to between 0-1 vehicles per 1,000 square feet. Corresponding numbers for the 85 percentile are between 4.5-6 for the daytime and also between 0-1 during nighttime, as seen in Figure 3.4.

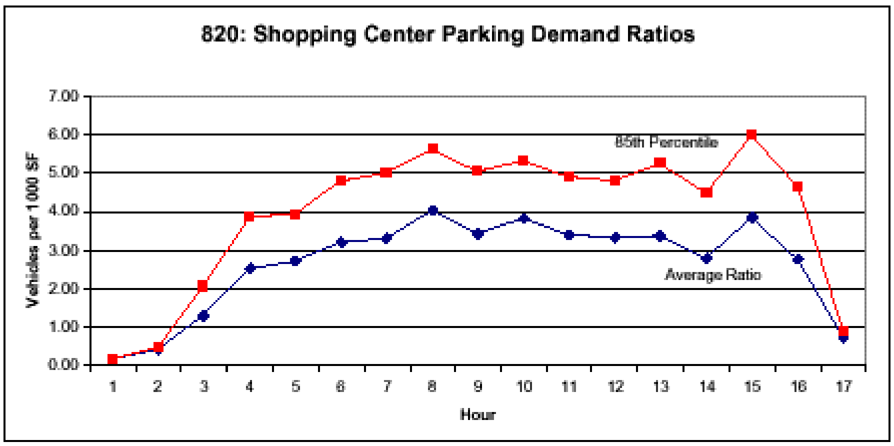


Figure 3.4 Commercial Shopping Center Parking Demand Ratios

Results from various parking studies show 2.5 (mid-day) at Austin, 1.74 at Indianapolis (for all land uses regardless of time), 1.2-3.8 (1.76-6.23 supplied, with 40%-67% utilization rate) at Puget Sound, 1.7 at Seattle, and 3 (mid-day, 3.33 in zoning) at Westfield.

The 1995 Dollars and Cents Guide to Shopping Centers found median amount of parking supplied by developers to be 5.1 spaces per 1,000 square feet gross land area in American neighborhood and community-sized shopping centers; the Urban Land Institute recommends 4, 4.5, and 5 spaces per 1,000 square foot of retail for shopping centers under 400, 400-600, and over 600 thousand square feet.

The off-street parking requirements manual from APA also indicates 5 spaces per thousand square feet floor area, while the minimum requirements for metro areas of Seattle, Portland, Tacoma, and San Francisco are 1-2.86, 2.5, 3, and 1-2, respectively.

Considering this information, 2.4 vehicles per 1,000 square feet is selected to be used as the mid-day rate, while 0.68 is selected as the night rate. Suppose that 4 is the peak parking demand, then parking utilization rates would be 60% and 17% of the peak rate respectively. The expected utilization rates corresponding to time of day are developed from the updated parking generation informational report and the Westfield comprehensive parking plan. The latter is shown in Table 3.34.

Table 3.34 Expected Daily Utilization Commercial Parking

Hour of Day	% of Peak
6:00	0%
7:00	8%
8:00	18%
9:00	42%
10:00	68%
11:00	87%
12:00	97%
13:00	100%
14:00	97%
15:00	95%
16:00	87%
17:00	79%
18:00	82%
19:00	89%
20:00	87%
21:00	61%
22:00	32%
23:00	13%
24:00	0%

The second example deals with the multi-family dwelling, Hazus category RES3. Since parking generation studies generally relate parked vehicles to residential units, average square footage of floor area shared by a unit needs to be estimated for the conversion. For this purpose, multifamily properties owned by Associated Estate Realty Corporation are referred. The company owns garden, townhome, ranch, mid-rise, and high-rise style properties across 12 Midwest states including Indiana, Michigan, and Ohio. Average unit size of these properties is slightly over 900 square feet, excluding those with government assistance, which is generally smaller. This estimated parking requirement is compared with various residential construction projects and zoning requirements. After taking into account the shared public space of multifamily dwellings, 1,000 square feet per unit is assumed.

Peak parking generation per unit shown in ITE's study is around 1, while the Westfield study uses 0.88 with mid-day estimate of 0.75. The range of minimum parking requirements for Seattle, Portland, Tacoma, and San Francisco is 0.25-2. If we consider the fact that the number of average vehicles per household stabilizes around 1.8, these numbers seem low. This phenomenon may be due to the bias found in urban areas, where crowded lands, convenient public transportation, and high-rise structures are prevalent. For our estimation purpose, 1.5 (for 5-49 units) is chosen as this rate is closer to what is used in planning parking demand for new development.

The distribution of vehicle occupancy for residential dwellings with regard to the time of day assumed in Westfield study is around 90% during daytime and 100% during nighttime, while the same study assumes 50% daytime occupancy for hotels. The seemingly high occupancy during daytime may be due to the bias of urban areas, where people utilize other means of travel than personal vehicles and parking of vehicles attracted by businesses. Summing up the factors for multifamily parking generation, 0.3 is used for the daytime, while 1.35 is used for the nighttime. Similar processes were applied for each of the remaining occupancy groups in Hazus. More information is available for some of the groups than for others. Generally, ITE, parking studies of metropolitan areas, the National Personal Travel Survey (NPTS), and related projects of private organizations, are combined to develop a best estimate for this purpose. The table for parking generation, column by column, contains labels and classes of occupancy groups in Hazus, units other than thousand square foot, conversion factors that turn other units into square footage, peak parking rate used, and percentage of peak parking rates as average daytime/nighttime rate

3.6.2 Parking Supply and Parking Occupancy

Once the numbers of vehicles potentially at risk are determined, these vehicles are further distributed to various parking facilities, such as on-street, surface lot, garage, or underground, in order to determine the impacts of flood water levels on vehicles. This distribution is irrelevant to non-urban areas, where all vehicles can be assumed to be on the surface. In urban areas, population density and land values result in underground and multi-story parking facilities. The elevation of the parked vehicle will determine the level of damage, with below ground vehicles having no salvage value and above ground vehicles being afforded a level of added protection.

Parking supplied by each source and its respective occupancy in an area are taken together to distribute vehicles among four parking facility types. After consulting various parking studies, Table 3.35 shows the estimated distribution:

Table 3.35 Estimated Parking Distribution by Parking Area Type

Urban	On-Street	Surface Log	Garage	Underground
Parking Spaces	12.5%	31.5%	33.6%	22.4%
Occupancy	78%	65%	45%	45%
Distribution	18%	37%	27%	18%

While the actual number of levels varies, a parking garage can be represented by a five-floor structure, with the roof also available for parking.

To estimate the impact of flood damage to vehicles in urban areas, it is assumed that 18% of vehicles are below ground level and under water during all flood events and, therefore, total losses. Another 60% of the vehicles (18% (on-street) + 37% (surface lot) + 5% (first floor from garage)) are subject to damage based on the appropriate flood damage equation. The remainder is located at least one level above ground and are assumed to receive no damage.

3.6.3 Vehicle Population by Age Group and Type

To estimate the probability of damage and vehicle value, vehicles are further assigned to three vehicle types: automobiles, light trucks and heavy trucks. Vehicle class estimates are developed by compiling data from the National Automobile Dealers Association (NADA), the US Department of Transportation's comprehensive Truck Size and Weight Study (TSWS), and the 1995 National Personal Transportation Survey (NPTS). The distribution of vehicle age and percentage of trucks versus cars were taken from NADA, with further distribution among trucks by size from TSWS. The 1995 NPTS data is shown in Table 3.36 to fill in the details of vehicle age and type.

Table 3.36 Vehicle Age Distribution by Vehicle Classification

Percentage Distribution

Age	Car	LiteTrk	HvyTrk	Total
0-2	8.438%	4.631%	0.459%	13.53%
3-6	17.500%	6.703%	1.969%	26.17%
7-10	15.625%	5.241%	0.919%	21.78%
10+	20.938%	7.800%	9.778%	38.52%
Sum	62.500%	24.375%	13.125%	100%

3.6.4 Vehicle Value Estimation

In order to calculate the dollar loss from vehicle damages from flood events, research was done to calculate the average price of new and used vehicles under the three categories. According to the 2001 NADA data, the average selling price of a new light vehicle is $24,923, while that of a used light vehicle is $13,648. Thus the value of an average used vehicle is approximately 55% of the value of a new vehicle. Consider the fact that vehicles sold at the dealership tend to be younger than the whole vehicle population. As such, average used vehicle values are assumed to be 50% of the value of average new vehicle.

The vehicle values given by NADA data do not differentiate between cars and trucks. The NADA estimates are actual dealer selling prices for NADA members and include all accessories and options sold with the vehicle.

New vehicles are estimated to be seven percent for cars and nine percent for light- and heavy-duty trucks of all vehicles sold. These estimates are obtained by dividing new vehicles by total vehicles in use between 1990-2000 in Car/Truck Scrappage and Growth in the US table of 2001 Ward's Automotive Yearbook. From the same yearbook, the tables of US Light Vehicle Sales by Segment (2000) and Ward's '01 Light Vehicle US Market Segmentation and Prices are put together to come up with the average prices of new cars and light trucks, which are $22,618.47 and $20,969.21 respectively. These new car prices are applied in the vehicle value estimate.

Using the table of US Truck Shipments by GVW by Make from the Ward's Automotive Yearbook and researching websites such as Truck Paper, Truck Trader Online, Working Wheels, Trucks.com, and numerous individual dealers' inventory lists, each Make and Class (4-8) category was assigned a value to calculate average price of a new heavy duty truck. The estimate is $76,087.67.

To compute the total value of vehicles in an area, the number of total vehicles will be multiplied by the percentage of car/light truck/heavy truck, percentage of new/used vehicles, and the average value of vehicles that match both categories.

3.7 Hazardous Materials Facilities

Hazardous material facilities contain substances that can pose significant hazards because of their toxicity, radioactivity, flammability, explosiveness or reactivity. Significant casualties or property damage could occur from a small number or even a single hazardous materials release induced by a flood, and the consequence of a flood-caused release can vary greatly according to the type and quantity of substance released, meteorological conditions and timeliness and effectiveness of emergency response. Similarly to the case of critical faculties with a potential for high loss, such as large dams, the methodology does not attempt to estimate losses caused by flood, which caused hazardous materials releases. Thus, the hazardous materials module of Hazus is limited to inventory data concerning the location and nature of hazardous materials located at various sites. Section 10.1.2 describes the scheme used to define the degree of danger of hazardous materials.

3.8 Direct Economic and Social Loss

In this section, information related to inventory data required to determine direct economic and social loss is presented. The two main databases used to determine direct economic and social loss are demographic and building square footage databases.

3.8.1 Demographics Data

The census data are used to estimate direct social loss due to displaced households, casualties due to floods, and, as discussed in previous sections, estimation quality of building space (square footage) for certain occupancy classes. The Census Bureau collects and publishes statistics about the people of the United States based on the constitutionally required census every 10 years, which is taken in the years ending in "0" (e.g., 2000). The Bureau's population census data describes the characteristics of the population including age, income, housing and ethnic origin.

The census data were processed for all of the census blocks in the United States, and 37 fields of direct importance to the methodology were extracted and stored. These fields are shown in Table 3.37 and are supplied as default information with the methodology. The population information is aggregated to a census block level. As stated previously, census blocks are divisions of land that are based on hard geographic features that allow for the designation of territory. Examples of these hard features include roads, rivers, and railway tracks. Census blocks are the smallest unit of aggregation for the census data. This small unit of aggregation was better suited for the Flood Model damage analysis because of its general, small area of coverage (typically one square mile or smaller). In those cases where the census data is aggregated to the census block group (20-40 census blocks) rather than the census block, the data is smoothed over every census block within the block group. Generally, it is conceived that census blocks contain populations or land uses that have relatively homogeneous population characteristics, economic status and living conditions.

Census block divisions and boundaries change once every ten years. Census block boundaries never cross county boundaries, and all the area within a county is contained within one or more census blocks. This characteristic allows for a unique division of land from country to state to county to census tract to census block group to census block. Each Census block is identified by a unique 15-digit number. The first two digits represent the block's state (called the State FIPS), the next three digits represent the block's county (when combined with the State FIPS is called the County FIPS), the next 6 digits identify the census tract within the county, another 2 digits are used to identify the block group and the final two - three digits identify the census block. For example, a census block numbered 06037575900702 would be located in California (06) in Los Angeles County (037), in census tract (575900), in census block group (7), Block (02).

Table 3.37 Demographics Data and Utilization within Hazus

Description of Field	Module Usage			
	Shelter	Casualty	Occupancy Class	Lifelines
Total Population in Census Block	*	*		*
Total Household in Census Block	*			*
Total # of People in General Quarter	*			
Total # of People < 16 years old	*	*		
Total # of People 16-65 years old	*			
Total # of People > 65 years old	*			
Total # of People – White	*			
Total # of People – Black	*			
Total # of People - Native American	*			
Total # of People – Asian	*			
Total # of People – Hispanic	*			
Total # of Households with Income < $10,000	*			
Total # of Households with Income $10 - $15K	*			
Total # of Households with Income $15 - $25K	*			
Total # of Households with Income $25 - $35K	*			
Total # of Households with Income > $35,000	*			
Total in Residential Property during Day		*		
Total in Residential Property at Night		*		
Total Working Population in Commercial Industry		*		
Total Working Population in Industrial Industry		*		
Total Commuting at 5 PM		*		
Total Owner Occupied - Single Household Units	*		*	
Total Owner Occupied - Multi-Household Units	*		*	
Total Owner Occupied - Multi-Household Structure	*		*	
Total Owner Occupied - Mobile Homes	*		*	
Total Renter Occupied - Single Household Units	*		*	

Table 3.37 Demographics Data and Utilization within Hazus (Continued)

Description of Field	Module Usage			
	Shelter	Casualty	Occupancy Class	Lifelines
Total Renter Occupied - Multi-Household Units	*		*	
Total Renter Occupied - Multi-Household Structure	*		*	
Total Renter Occupied - Mobile Homes	*		*	
Total Vacant - Single Household Units			*	
Total Vacant - Multi-Household Units			*	
Total Vacant - Multi-Household Structure			*	
Total Vacant - Mobile Homes			*	
Structure Age <40 years			*	
Structure Age >40 years			*	
Median Income			*	
Median Age of Housing Units			*	

3.9 Indirect Economic Data

The indirect economic data refers to the post-flood change in the demand and supply of products, change in employment and change in tax revenues. The user can specify the levels of potential increase in imports and exports, supply and product inventories and unemployment rates.

3.10 References

1. Department of Energy, 1995. A Look At Commercial Buildings in 1995 DOE/EIA-0625(97), Washington, D.C., Energy Information Administration Office of Energy Markets and End Use, US Department of Energy, October, 1998.

2. The Heinz Center. 2000. Evaluation of Erosion Hazards. Washington, D.C.: The H. John Heinz III Center for Science, Economics and the Environment.

3. US Department of Housing and Urban Development and US Census Bureau, American Housing Survey for the United States H150/97, Office of Policy Development and Research and the US Census Bureau, September 1999.

APPENDIX 3A
General Building Stock

Table 3A.1: Distribution Percentage of Floor Area for Specific Occupancy Classes within each General Occupancy Class♦

Specific Occupancy Class			General Occupancy Class						
			RES	COM	IND	AGR	REL	GOV	EDU
No.	Label	Occupancy Class	1	2	3	4	5	6	7
1	RES1	Single Family Dwelling	♦						
2	RES2	Mobile Home	♦						
3	RES3	Multi Family Dwelling	♦						
4	RES4	Temporary Lodging	♦						
5	RES5	Institutional Dormitory	♦						
6	RES6	Nursing Home	♦						
7	COM1	Retail Trade		♦					
8	COM2	Wholesale Trade		♦					
9	COM3	Personal and Repair Services		♦					
10	COM4	Professional/Technical		♦					
11	COM5	Banks		♦					
12	COM6	Hospital		♦					
13	COM7	Medical Office/Clinic		♦					
14	COM8	Entertainment & Recreation		♦					
15	COM9	Theaters		♦					
16	COM10	Parking		♦					
17	IND1	Heavy			♦				
18	IND2	Light			♦				
19	IND3	Food/Drugs/Chemicals			♦				
20	IND4	Metals/Minerals Processing			♦				
21	IND5	High Technology			♦				
22	IND6	Construction			♦				
23	AGR1	Agriculture				100			
24	REL1	Church					100		
25	GOV1	General Services						♦	
26	GOV2	Emergency Response						♦	
27	EDU1	Schools							♦
28	EDU2	Colleges/Universities							♦

♦ The relative distribution varies by census tract and is computed directly from the specific occupancy class square footage inventory. For Agriculture (AGR) and Religion (REL) there is only one specific occupancy class, therefore the distribution is always 100%.

Table 3A.2: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, Low Rise, Pre-1950, West Coast* (after ATC-13, 1985)

No.	Specific Occup. Class	Model Building Type															
		1	**2**	**3**	**6**	**9**	**10**	**13**	**16**	**19**	**22**	**25**	**26**	**29**	**31**	**34**	**36**
		W1	W2	S1L	S2L	S3	S4L	S5L	C1L	C2L	C3L	PC1	PC2L	RM1L	RM2L	URML	MH
1	RES1	For State-Specific "RES1" Distribution, Refer to Table 3A.17															
2	RES2																100
3	RES3	73		1	1	1		6		3	3			1		9	2
4	RES4	34		2	1	2	1	19		16	3			4		18	
5	RES5	20		5	1		1			28	18			6		21	
6	RES6	45				10		5		10				20		10	
7	COM1		22	2		6	3	20		17	1			6		23	
8	COM2		8	3		4	2	41		18	1	3		5	2	13	
9	COM3		28	1	1	3		18		7		1		8		33	
10	COM4		27	2	1	3		19		15				7		26	
11	COM5		27	2	1	3		19		15				7		26	
12	COM6		8	5	2	11		11		27	2	1		27		6	
13	COM7		25	5	2	10		10		15	2	1		20		10	
14	COM8		8	12	1	2	3	16		27	4			5	1	21	
15	COM9		5	20	7			15		20	3			10		20	
16	COM10				8		8	18		43	7		1	6	3	6	
17	IND1		3	29	13	2	2	15		14	7	1		4	2	8	
18	IND2		4	14	8	22	1	18		16	1	1		2		13	
19	IND3		1	18	8	3	3	20		22		2		3		20	
20	IND4		2	24	12	7	2	13		16		2		2	6	14	
21	IND5			21	5	5		3		35	2	10	2	15		2	
22	IND6		32	3	2	10		18		8	7					13	7
23	AGR1	56		3	2	14		2		9					1	13	
24	REL1	22		8		2		21		15	5			8		19	
25	GOV1		9	8	1	3	4	12		42	4			6		11	
26	GOV2	45					2			37				3		13	
27	EDU1	11		6		3	3	21		21	4			9		22	
28	EDU2	2		5	10		5	15		20				20	5	18	

* Refer to Table 3B.1 for states' classifications.

Table 3A.3: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, Low Rise, 1950-1970 , West Coast* (after ATC-13, 1985)

No.	Specific Occup. Class	Model Building Type															
		1	**2**	**3**	**6**	**9**	**10**	**13**	**16**	**19**	**22**	**25**	**26**	**29**	**31**	**34**	**36**
		W1	W2	S1L	S2L	S3	S4L	S5L	C1L	C2L	C3L	PC1	PC2L	RM1L	RM2L	URML	MH
1	RES1	For State-Specific "RES1" Distribution, Refer to Table 3A.18															
2	RES2																100
3	RES3	72		1	2	2		1		6	2			8		3	3
4	RES4	55		1	2	2	2	3		11	2			18	1	3	
5	RES5	39		3	3		1	8		16	6			18	1	5	
6	RES6	70				3	1	1		5				20			
7	COM1		34	3	1	3	2	4		13	5	10	1	18	2	4	
8	COM2		12	4	5	5	3	3		18		22	1	19	4	4	
9	COM3		12	3	5	5	2	3		23	4	12	1	22	4	4	
10	COM4		34	3	3	1	2	3		17	5	3		23	4	2	
11	COM5		34	3	3	1	2	3		17	5	3		23	4	2	
12	COM6		32	5	2	4	3			16	6			28	4		
13	COM7		46	13	1	3	3			9				20		5	
14	COM8		13	17	12	3	3			13	6			30	3		
15	COM9		10	10	30			5		10		5		30			
16	COM10			5	8		20			34			5	20	6	2	
17	IND1		10	25	30	3			7	14				9	2		
18	IND2		8	5	14	17	4			10	5	22	3	12			
19	IND3			14	16	6	1		5	17		28	1	10	2		
20	IND4			18	25	9			11	10		7		15	3		2
21	IND5			4	9	3	2		4	20		35	3	15	4		1
22	IND6		30		1	15				7		4		20	3		20
23	AGR1	51		4	8	12				2		10		11	2		
24	REL1	20		4	1	3	3			24		4		37	4		
25	GOV1		21	6	3	2	2			26	5	4	2	27	2		
26	GOV2	50								13		7		20	10		
27	EDU1	25		3	4	5	4			20		4	2	29	4		
28	EDU2	5		2	12		5			20				50	6		

* Refer to Table 3B.1 for states' classifications.

Table 3A.4: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, Low Rise, Post-1970, West Coast* (after ATC-13, 1985)

No.	Specific Occup. Class	Model Building Type															
		1	2	3	6	9	10	13	16	19	22	25	26	29	31	34	36
		W1	W2	S1L	S2L	S3	S4L	S5L	C1L	C2L	C3L	PC1	PC2L	RM1L	RM2L	URML	MH
1	RES1	For State-Specific "RES1" Distribution, Refer to Table 3A.19															
2	RES2																100
3	RES3	73				2	3			6	1		1	9			5
4	RES4	53		3		2	3		4	13				20	2		
5	RES5	33		3	3		6		5	24				23	3		
6	RES6	70								5		5		20			
7	COM1		26	9	1	2	1		6	10	1	15	5	21	3		
8	COM2		8	4	1	3	4		2	12		41	3	19	3		
9	COM3		13	3	2	2	3		3	13		20	5	34	2		
10	COM4		35	3	2	1	3		4	15		8	3	24	2		
11	COM5		35	3	2	1	3		4	15		8	3	24	2		
12	COM6		31	6	1	1	7		4	13		7		28	2		
13	COM7		47	16			5		4	6		2		20			
14	COM8		4	23	8	1	3		2	15		4	1	32	7		
15	COM9		5	27	20					12		4		27	5		
16	COM10			8	8		6		3	49		3	13	7	3		
17	IND1		11	19	28	3	2		1	9		11	3	11	1		1
18	IND2		3	13	9	6	3			10		41	3	12			
19	IND3		2	15	10	5	3			12		28	7	18			
20	IND4		1	26	18	5	4		1	11	1	12	5	15	1		
21	IND5		1	12	8	2	3			10		38	7	17	1		1
22	IND6		30	4	6	11				8		16	6	14			5
23	AGR1	40		8	11	8				3		11	1	15	1		2
24	REL1	23		12	3	1	6			26		1	3	22	3		
25	GOV1		8	15	4	3	7		2	32			4	16	9		
26	GOV2	40		3	7		23			10			7	3	7		
27	EDU1	24		9	6	1	5		3	16	3	4	3	21	5		
28	EDU2	5		10	10		5			20		5		40	5		

* Refer to Table 3B.1 for states' classifications.

Table 3A.5: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, Mid Rise, Pre-1950, West Coast* (after ATC-13, 1985)

No.	Specific Occupancy Class	Model Building Type										
		4	7	11	14	17	20	23	27	30	32	35
		S1M	S2M	S4M	S5M	C1M	C2M	C3M	PC2M	RM1M	RM2M	URMM
3	RES3	15	4	5		1	19	25		8		23
4	RES4	18	4	12		1	20	20		8		17
5	RES5	16	1	5			40	20				18
6	RES6	20		5			35	20		10		10
7	COM1	8	6	3			21	34		11	1	16
8	COM2	8					27	53		5		7
9	COM3	18					22	42		5		13
10	COM4	25	7	10		2	22	16		9		9
11	COM5	25	7	10		2	22	16		9		9
12	COM6	18	4	6		1	35	19		8		9
13	COM7	20	5	5			30	20		10		10
14	COM8	25		20			40	5				10
15	COM9	30		10			40	10				10
16	COM10		10	5		2	55	18		3	2	5
17	IND1											
18	IND2			10			5	75				10
19	IND3	32	3	1		1	14	41		3		5
20	IND4	25	3	1			9	52				10
21	IND5	35	10				30	5		20		
22	IND6						20	80				
23	AGR1						25	75				
24	REL1						10	90				
25	GOV1	30	15	5		3	23	10		4		10
26	GOV2											
28	EDU2	10		20			60	3		5		2

* Refer to Table 3B.1 for states' classifications.

Table 3A.6: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, Mid Rise, 1950-1970, West Coast* (after ATC-13, 1985)

No.	Specific Occup. Class	Model Building Type										
		4	**7**	**11**	**14**	**17**	**20**	**23**	**27**	**30**	**32**	**35**
		S1M	S2M	S4M	S5M	C1M	C2M	C3M	PC2M	RM1M	RM2M	URMM
3	RES3	10	15	6		4	37		1	21	6	
4	RES4	9	24	9		5	34	1		14	4	
5	RES5	6	1	11		9	45			18	10	
6	RES6	15	10	15		5	25			25	5	
7	COM1	7	25	5		3	31			22	7	
8	COM2	21	3			2	34		1	34	5	
9	COM3	10	3				28			54	5	
10	COM4	17	18	9		9	18		2	23	4	
11	COM5	17	18	9		9	18		2	23	4	
12	COM6	14	10	14		5	23		3	23	8	
13	COM7	15	10	15		5	25			25	5	
14	COM8	5		28			52			10	5	
15	COM9	5		30			50			10	5	
16	COM10	5	8	8		7	39		8	18	7	
17	IND1		10	20			40			20	10	
18	IND2		15	10			50			20	5	
19	IND3	11	4	10		30	20		1	15	9	
20	IND4					100						
21	IND5	10	5	13			32			30	10	
22	IND6											
23	AGR1											
24	REL1						80			10	10	
25	GOV1	15	6	15		11	28		2	18	5	
26	GOV2	5	10	10		5	60				10	
28	EDU2	20		15		5	35			15	10	

* Refer to Table 3B.1 for states' classifications.

Table 3A.7: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, Mid Rise, Post-1970, West Coast* (after ATC-13, 1985)

No.	Specific Occupancy Class	Model Building Type										
		4	7	11	14	17	20	23	27	30	32	35
		S1M	S2M	S4M	S5M	C1M	C2M	C3M	PC2M	RM1M	RM2M	URMM
3	RES3	9	23	8		10	28		7	12	3	
4	RES4	16	28	8		11	18		3	13	3	
5	RES5	9	10	11		16	34		4	11	5	
6	RES6	25	10	15		10	35			5		
7	COM1	34	9	3		12	17		5	15	5	
8	COM2	20	17			15	10		8	15	15	
9	COM3	11	17	3		10	17		12	17	13	
10	COM4	37	10	12		9	15		3	9	5	
11	COM5	37	10	12		9	15		3	9	5	
12	COM6	25	9	15		10	33		1	6	1	
13	COM7	25	10	15		10	35			5		
14	COM8		10			90						
15	COM9		10			90						
16	COM10	4	8	3		4	66		8	6	1	
17	IND1											
18	IND2											
19	IND3	62	5	1		23	4		1	3	1	
20	IND4	100										
21	IND5	18	14	3		34	13		5	10	3	
22	IND6											
23	AGR1											
24	REL1		5			90					5	
25	GOV1	25	11	15		22	12		4	9	2	
26	GOV2	25	20	35			20					
28	EDU2	20	5	10		25	25			10	5	

* Refer to Table 3B.1 for states' classifications.

Table 3A.8: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, High Rise, Pre-1950, West Coast* (after ATC-13, 1985)

No.	Specific Occupancy Class	Model Building Type								
		5	8	12	15	18	21	24	28	33
		S1H	S2H	S4H	S5H	C1H	C2H	C3H	PC2H	RM2H
3	RES3	39	1	2		8	24	23	3	
4	RES4	45	3	3		8	20	18	3	
5	RES5	15	5	10			30	40		
10	COM4	47	10	4		1	21	16	1	
11	COM5	47	10	4		1	21	16	1	
12	COM6	56	9	1		1	24	8	1	
13	COM7									
16	COM10									
23	AGR1									
25	GOV1	53	5	5		3	30	3	1	
28	EDU2	5	5	35			40	15		

* Refer to Table 3B.1 for states' classifications.

Table 3A.9: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, High Rise, 1950-1970, West Coast* (after ATC-13, 1985)

No.	Specific Occupancy Class	Model Building Type								
		5	8	12	15	18	21	24	28	33
		S1H	S2H	S4H	S5H	C1H	C2H	C3H	PC2H	RM2H
3	RES3	30	21	6		13	24		3	3
4	RES4	48	10	9		12	19		1	1
5	RES5	20	15	25		30	5			5
10	COM4	40	26	18		6	7		1	2
11	COM5	40	26	18		6	7		1	2
12	COM6	35	27	17		4	15		1	1
13	COM7									
16	COM10									
23	AGR1									
25	GOV1	46	13	22		10	8			1
28	EDU2	35	20	20		25				

* Refer to Table 3B.1 for states' classifications.

Table 3A.10: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, High Rise, Post-1970, West Coast* (after ATC-13, 1985)

No.	Specific Occupancy Class	Model Building Type								
		5	**8**	**12**	**15**	**18**	**21**	**24**	**28**	**33**
		S1H	S2H	S4H	S5H	C1H	C2H	C3H	PC2H	RM2H
3	RES3	44	6	5		18	20		5	2
4	RES4	56	10	6		16	9		2	1
5	RES5	25	18	20		37				
10	COM4	56	10	14		14	5		1	
11	COM5	54	10	15		15	5		1	
12	COM6	45	6	19		13	17			
13	COM7									
16	COM10									
23	AGR1									
25	GOV1	52	14	14		14	6			
28	EDU2	30	10	10		50				

* Refer to Table 3B.1 for states' classifications.

Table 3A.11: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, Low Rise, Mid-West*

No.	Specific Occup. Class	Model Building Type															
		1	2	3	6	9	10	13	16	19	22	25	26	29	31	34	36
		W1	W2	S1L	S2L	S3	S4L	S5L	C1L	C2L	C3L	PC1	PC2L	RM1L	RM2L	URML	MH
1	RES1	For State-Specific "RES1" Distribution, Refer to Table 3A.20															
2	RES2																100
3	RES3	75												2		23	
4	RES4	50												3	2	45	
5	RES5	20							4	13	2	22	4	2		33	
6	RES6	90														10	
7	COM1		30	2	4	11	6	7		5		5		2		28	
8	COM2		10	2	4	11	6	7	2	10	2	14	2	2		28	
9	COM3		30	2	4	11	6	7		5		5		2		28	
10	COM4		30	2	4	11	6	7		5		5		2		28	
11	COM5		30	2	4	11	6	7		5		5		2		28	
12	COM6				2	4	2	2	6	21	4	33	6	2		18	
13	COM7		30	2	4	11	6	7		5		5		2		28	
14	COM8		30	2	4	11	6	7		5		5		2		28	
15	COM9			2	6	14	8	10	4	13	2	22	4			15	
16	COM10			2	4	11	6	7	6	21	4	33	6				
17	IND1			5	10	25	13	17	2	7	2	12	2			5	
18	IND2		10	2	4	11	6	7	2	10	2	14	2	3		27	
19	IND3		10	2	4	11	6	7	2	10	2	14	2	3		27	
20	IND4			5	10	25	13	17	2	7	2	12	2			5	
21	IND5		10	2	4	11	6	7	2	10	2	14	2	2		28	
22	IND6		30	2	4	11	6	7		5		5		2		28	
23	AGR1		10	2	4	11	6	7	2	10	2	14	2	2		28	
24	REL1	30			3	5	3	4		5		5		2	2	41	
25	GOV1		15	14	21				7	6		4		3		30	
26	GOV2		14	7	17				4	12					3	43	
27	EDU1		10	5	12				5	7				11		50	
28	EDU2		14	6	12			2	8	11					10	37	

* Refer to Table 3B.1 for states' classifications.

Table 3A.12: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, Mid Rise, Mid-West*

No.	Specific Occupancy Class	Model Building Type										
		4	7	11	14	17	20	23	27	30	32	35
		S1M	S2M	S4M	S5M	C1M	C2M	C3M	PC2M	RM1M	RM2M	URMM
3	RES3		10	7	3	14	39		7		2	18
4	RES4		10	7	3	14	37	2	7		2	18
5	RES5					25	62	2	11			
6	RES6											
7	COM1	3	20	16	6	11	27	2	5		2	8
8	COM2		7	3		14	37	2	7		3	27
9	COM3	3	20	16	6	11	27	2	5		2	8
10	COM4	3	20	16	6	11	27	2	5		2	8
11	COM5	3	20	16	6	11	27	2	5		2	8
12	COM6	3	20	16	6	12	30	2	6			5
13	COM7	3	20	16	6	11	27	2	5		2	8
14	COM8	3	20	16	6	11	27	2	5		2	8
15	COM9											
16	COM10	2	14	10	4	17	43	2	8			
17	IND1											
18	IND2		7	3		14	37	2	7		3	27
19	IND3		7	3		14	37	2	7		3	27
20	IND4											
21	IND5		7	3		14	37	2	7		3	27
22	IND6											
23	AGR1		7	3		14	37	2	7		3	27
24	REL1	3	20	16	6	11	27	2	5		2	8
25	GOV1	20	24			11	9				5	31
26	GOV2											
28	EDU2	7	14			9	13				13	44

* Refer to Table 3B.1 for states' classifications.

Table 3A.13: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, High Rise, Mid-West*

No.	Specific Occup. Class	Model Building Type								
		5	8	12	15	18	21	24	28	33
		S1H	S2H	S4H	S5H	C1H	C2H	C3H	PC2H	RM2H
3	RES3	3	13	4		16	44	7	7	6
4	RES4	3	13	4		16	44	7	7	6
5	RES5					26	74			
10	COM4	7	29	9		12	32	4	4	3
11	COM5	7	29	9		12	32	4	4	3
12	COM6	7	29	9		13	36	2	2	2
13	COM7	7	29	9		12	32	4	4	3
16	COM10	5	19	6		18	52			
23	AGR1	2	6	2		16	44	11	11	8
25	GOV1									
28	EDU2									

* Refer to Table 3B.1 for states' classifications.

Table 3A.14: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, Low Rise, East Coast*

No.	Specific Occup. Class	Model Building Type															
		1	2	3	6	9	10	13	16	19	22	25	26	29	31	34	36
		W1	W2	S1L	S2L	S3	S4L	S5L	C1L	C2L	C3L	PC1	PC2L	RM1L	RM2L	URML	MH
1	RES1	For State-Specific “RES1” Distribution, Refer to Table 3A.21															
2	RES2																100
3	RES3	62			3				2	2				5	4	22	
4	RES4	48		5	4			4	8	4		3	3	3	3	15	
5	RES5	7		7	6			6	17	6	3	8	6	5	5	24	
6	RES6	22		11	8			8	8	3	2	4	3	5	4	22	
7	COM1		14	20	15	5		16	3	2		2		4	2	17	
8	COM2		10	21	15	7		16	3	2		2		3	4	17	
9	COM3		25	7	5	11		5	3	2		2		6	4	30	
10	COM4		26	11	8	4		9	4	2		3		5	4	24	
11	COM5		13	13	9	13		10	5	3		2	2	5	3	22	
12	COM6		2	22	15			18	10	4	2	5	4	3	2	13	
13	COM7		24	10	7	15		8	3	2		3		4	4	20	
14	COM8		19	19	13	6		15	3	2		2		3	3	15	
15	COM9		5	20	13	12	2	16	7	2		3	3	3	2	12	
16	COM10			10	7			8	30	11	6	14	12			2	
17	IND1		5	22	15	4	2	17	7	3		3	3	3	3	13	
18	IND2		10	15	9	15		11	5	3		2	2	4	5	19	
19	IND3		7	25	18	3		19	4	2		2	2	3	2	13	
20	IND4		7	26	19	3		20	3	2		2		2	3	13	
21	IND5		5	25	17	3	2	20	7	3		3	3		2	10	
22	IND6		10	21	14	7	2	16	5	2		2	2	2	3	14	
23	AGR1		48	8	6	12		7	2					3	2	12	
24	REL1	36		4	4			3	2	2		2		7	6	34	
25	GOV1		7	24	16	3		19	5	3		2	1	3	3	13	
26	GOV2		8	16	11	4		13	8	3	2	4	3	4	5	19	
27	EDU1		13	17	13			13	5	3		2	2	5	5	22	
28	EDU2		4	18	13			14	8	3	2	4	3	5	4	22	

* Refer to Table 3B.1 for states' classifications.

Table 3A.15: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, Mid Rise, East Coast*

No.	Specific Occupancy Class	Model Building Type										
		4	7	11	14	17	20	23	27	30	32	35
		S1M	S2M	S4M	S5M	C1M	C2M	C3M	PC2M	RM1M	RM2M	URMM
3	RES3	3	4			6	3		14		13	57
4	RES4	9	12		3	18	9	2	11		7	29
5	RES5	7	10		3	23	11	3	12		5	26
6	RES6											
7	COM1	23	29	2	8	5	3		5		5	20
8	COM2	23	30	3	8	4	3		5		5	19
9	COM3	10	13		3	5	4		11		10	44
10	COM4	14	19	2	5	7	4		9		7	33
11	COM5	15	21	2	6	8	5		8		6	29
12	COM6	21	27	2	8	12	6	2	7		2	13
13	COM7	15	20	2	5	7	4		9		6	32
14	COM8	22	30	3	8	5	3		5		5	19
15	COM9											
16	COM10	10	13		3	38	17	6	11			2
17	IND1											
18	IND2	22	28	2	8	10	5	2	6		3	14
19	IND3	25	32	3	9	6	4		4		3	14
20	IND4											
21	IND5	24	32	3	9	9	6		5		2	10
22	IND6											
23	AGR1	19	25	2	7	4	2		7		6	28
24	REL1	5	9		2	4	3		12		12	53
25	GOV1	24	30	3	9	7	5		5		3	14
26	GOV2											
28	EDU2	17	23	2	6	10	5	2	8		4	23

* Refer to Table 3B.1 for states' classifications.

Table 3A.16: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, High Rise, East Coast*

No.	Specific Occup. Class	Model Building Type								
		5	8	12	15	18	21	24	28	33
		S1H	S2H	S4H	S5H	C1H	C2H	C3H	PC2H	RM2H
3	RES3	8	21	8		34	17	2	5	5
4	RES4	8	21	8		34	17	2	5	5
5	RES5	6	16	6		40	20	3	5	4
10	COM4	15	36	15		15	8		2	9
11	COM5	15	36	15		15	8		2	9
12	COM6	14	35	14		17	8	2	2	8
13	COM7	15	38	15		14	8		2	8
16	COM10	5	12	5		43	21	4	6	4
23	AGR1	7	4	18		20	42			9
25	GOV1									
28	EDU2									

* Refer to Table 3B.1 for states' classifications.

Table 3A.17: Distribution Percentage of Floor Area for Model Building Types within "RES1" Building Occupancy Class, Pre-1950, West Coast

State FIPS*	State Abbreviation	State	Model Building Type					
			1	9	13	19	29	34
			W1	S3	S5L	C2L	RM1L	URML
02	AK	Alaska	99			1		
04	AZ	Arizona	60				25	16
06	CA	California	99				1	0
08	CO	Colorado	76				15	9
15	HI	Hawaii	92			1	4	3
16	ID	Idaho	95				3	2
30	MT	Montana	98				1	1
35	NM	New Mexico	74				16	10
32	NV	Nevada	97				2	1
41	OR	Oregon	99				1	
49	UT	Utah	82				11	7
53	WA	Washington	98				1	1
56	WY	Wyoming	92				5	3

* State FIPS are two digit unique number representative of each state and U.S. territory. Refer to Table 3B.1 of Appendix B for a complete list of State FIPS.

Table 3A.18: Distribution Percentage of Floor Area for Model Building Types within "RES1" Building Occupancy Class, 1950-1970, West Coast

State FIPS	State Abbreviation	State	Model Building Type 1 W1	9 S3	13 S5L	19 C2L	29 RM1L	34 URML
02	AK	Alaska	99			1		
04	AZ	Arizona	60				36	4
06	CA	California	99				1	0
08	CO	Colorado	76				21	3
15	HI	Hawaii	92			1	6	1
16	ID	Idaho	95				4	1
30	MT	Montana	98				2	
35	NM	New Mexico	74				23	3
32	NV	Nevada	97				3	
41	OR	Oregon	99				1	
49	UT	Utah	82				16	2
53	WA	Washington	98				2	
56	WY	Wyoming	92				7	1

Table 3A.19: Distribution Percentage of Floor Area for Model Building Types within "RES1" Building Occupancy Class, Post-1970, West Coast

State FIPS	State Abbreviation	State	Model Building Type 1 W1	9 S3	13 S5L	19 C2L	29 RM1L	34 URML
02	AK	Alaska	99			1		
04	AZ	Arizona	60				40	
06	CA	California	99				1	0
08	CO	Colorado	76				24	
15	HI	Hawaii	92			1	7	
16	ID	Idaho	95				5	
30	MT	Montana	98				2	
35	NM	New Mexico	74				26	
32	NV	Nevada	97				3	
41	OR	Oregon	99				1	
49	UT	Utah	82				18	
53	WA	Washington	98				2	
56	WY	Wyoming	92				8	

Table 3A.20: Distribution Percentage of Floor Area for Model Building Types within "RES1" Building Occupancy Class, Mid-West

State FIPS	State Abbreviation	State	Model Building Type		
			1	19	34
			W1	C2L	URML
05	AR	Arkansas	87		13
19	IA	Iowa	92		8
17	IL	Illinois	77	1	22
18	IN	Indiana	80		20
20	KS	Kansas	91		9
21	KY	Kentucky	88		12
22	LA	Louisiana	89		11
26	MI	Michigan	86		14
27	MN	Minnesota	95	1	4
29	MO	Missouri	76		24
28	MS	Mississippi	94		6
38	ND	North Dakota	98		2
31	NE	Nebraska	89	1	10
39	OH	Ohio	76		24
40	OK	Oklahoma	71		29
46	SD	South Dakota	97		3
47	TN	Tennessee	90		10
48	TX	Texas	100		
55	WI	Wisconsin	90		10

Table 3A.21: Distribution Percentage of Floor Area for Model Building Types within "RES1" Building Occupancy Class, East Coast

State FIPS	State Abbreviation	State	Model Building Type		
			1	19	34
			W1	C2L	URML
01	AL	Alabama	95		5
09	CT	Connecticut	96		4
11	DC	District of Columbia	21	3	76
10	DE	Delaware	71	1	28
12	FL	Florida	25	5	70
13	GA	Georgia	93		7
25	MA	Massachusetts	96		4
24	MD	Maryland	71	1	28
23	ME	Maine	99		1
37	NC	North Carolina	90		10
33	NH	New Hampshire	97	1	2
34	NJ	New Jersey	91		9
36	NY	New York	85	1	14
42	PA	Pennsylvania	66		34
44	RI	Rhode Island	98		2
45	SC	South Carolina	92		8
51	VA	Virginia	75		25
50	VT	Vermont	96	2	2
54	WV	West Virginia	72		28

APPENDIX 3B

States' Classifications

Table 3B.1: Regional Distribution of States

State Fips	State Abbreviation	State Name	Group
02	AK	Alaska	West
01	AL	Alabama	East
05	AR	Arkansas	Mid-West
04	AZ	Arizona	West
06	CA	California	West
08	CO	Colorado	West
09	CT	Connecticut	East
11	DC	District of Columbia	East
10	DE	Delaware	East
12	FL	Florida	East
13	GA	Georgia	East
15	HI	Hawaii	West
19	IA	Iowa	Mid-West
16	ID	Idaho	West
17	IL	Illinois	Mid-West
18	IN	Indiana	Mid-West
20	KS	Kansas	Mid-West
21	KY	Kentucky	Mid-West
22	LA	Louisiana	Mid-West
25	MA	Massachusetts	East
24	MD	Maryland	East
23	ME	Maine	East
26	MI	Michigan	Mid-West
27	MN	Minnesota	Mid-West
29	MO	Missouri	Mid-West
28	MS	Mississippi	Mid-West
30	MT	Montana	West
37	NC	North Carolina	East
38	ND	North Dakota	Mid-West
31	NE	Nebraska	Mid-West
33	NH	New Hampshire	East
34	NJ	New Jersey	East
35	NM	New Mexico	West
32	NV	Nevada	West
36	NY	New York	East
39	OH	Ohio	Mid-West
40	OK	Oklahoma	Mid-West
41	OR	Oregon	West
42	PA	Pennsylvania	East
44	RI	Rhode Island	East

Table 3B.1: Regional Distribution of States (Continued)

State Fips	State Abbreviation	State Name	Group
45	SC	South Carolina	East
46	SD	South Dakota	Mid-West
47	TN	Tennessee	Mid-West
48	TX	Texas	Mid-West
49	UT	Utah	West
51	VA	Virginia	East
50	VT	Vermont	East
53	WA	Washington	West
55	WI	Wisconsin	Mid-West
54	WV	West Virginia	East
56	WY	Wyoming	West
60	AS	American Samoa	West
66	GU	Guam	West
69	MR	Northern Mariana Islands	West
72	PR	Puerto Rico	East
78	VI	Virgin Islands	East

Chapter 4. Potential Earth Science Hazards (PESH)

4.1 Flood Hazard

Given the location of a point how does one determine the flood hazard at that point? In different contexts, flood hazard may have different meanings. Hazard can mean risk in some contexts and it can mean a source of danger in others. The hazard may be that an area is inundated about once every 10 years (risk) or it may be that an area is subject to flood depths ranging from 5 to 10 feet (source of danger). Flood frequency studies combine those ideas and define flood hazard in terms of the chance that a certain magnitude of flooding is exceeded in any given year.

Flood magnitude is usually measured as a discharge value or elevation or depth. For example one may refer to the 100-year flood elevation. It is the elevation, at the point of interest, that has a 1-percent annual chance of being exceeded by floodwater. Using the flood frequency convention, flood hazard is defined by a relation between depth of flooding and the annual chance of inundation greater than that depth. The relation is called a depth-frequency curve and is the primary output of the Hazus-MH flood hazard modeling.

The flood loss estimation methodology consists of two basic analytical processes: flood hazard analysis and flood loss estimation analysis. Hazard characterization in the Hazus Flood Model produces estimated flood depths for riverine and coastal flooding sources. The Level 1 user, with a minimum of input, has the capability of producing flood depth grids along any river reach or shoreline. The Level 2 user is required to use the Flood Information Tool (FIT) to develop the flood depth grids required by the model. The FIT is an ArcGIS extension designed to process user-supplied flood hazard data into the format required by the Hazus Flood Model. The FIT**,** when given user-supplied inputs (e.g., ground elevations, flood elevations, and floodplain boundary information), computes the extent, depth and elevation of flooding for riverine and coastal hazards.

While using the FIT, the user is expected to have a greater knowledge of the local flood hazard and a working knowledge of Geographic Information Systems, specifically ESRI's ArcGIS.

Fundamentally, the methodology for Level 1 is very similar to the one developed for FIT, except for the fact that the only requirement on the user will be to provide the Digital Elevation Model (DEM -- typically assumed to be the USGS 30-meter National Elevation Dataset or NED).

4.2 Riverine Flood Hazard

The flood hazard identification portion of the Model accommodates user-supplied data. The goal is to accept user-supplied data, develop flood depth and/or flood depth frequency information, and establish the spatial distribution of that information. The result of the analysis is a Geographic Information System (GIS) model in a grid format with each cell attributed with flood depth information. That information can be either a given flood depth or depth frequency information such as the mean, standard deviation, and coefficient of skew of the probability density function that describes the depth-frequency relation.

Flood depth is the difference between flood and ground surface elevations at each grid cell. The ground surface model is a grid-cell based Digital Elevation Model (DEM). The flood surface model is also grid-cell based. Algorithms have been developed to define the extent of the floodplain and to interpolate flood elevations between user-supplied digital cross sections. The algorithms were developed to accommodate the most detailed digital topographic and flood elevation data available to the user while minimizing the user interaction required.

The approach finds the elevation difference between two surfaces, the flood surface and the ground surface, at each cell in the grid. Cells where the flood surface elevation exceeds the ground surface elevation are within the floodplain. The collection of cells where the flood elevation equals the ground elevation forms the floodplain boundaries.

Level 1 methodology discussion describes the methods to identify the stream reaches, the hydrologic and hydraulic analysis to be performed, the identification of non-conveyance or backwater areas, and exploring what-ifs scenarios.

4.2.1 Identifying Stream Reaches

For the purposes of this discussion, a DEM is a grid of evenly spaced ground elevation data. The spacing between the elevation data is referred to as the posting or cell size. A DEM with 10-meter posting is a grid containing 10-by-10-meter cells. That is, each cell has an area of 100 square meters.

Except at the DEM boundaries, each cell has eight neighbors: one on each of its four sides and one on each of its four corners. Identifying the neighbor where a straight line has the greatest descending slope establishes a flow direction for each cell. Creating a grid with each cell attributed with a flow direction allows for the determination of flow paths throughout the entire grid and the computation of the number of cells that “flow to” or, the accumulation at, a particular cell. An accumulation grid is created by attributing each cell with its accumulation, or, the number of cells that “flow” through it. Similar to the accumulation grid, a flow distance grid is created with each cell attributed with the distance, in terms of flow direction, to an outlet (a grid outlet).

Multiplying the accumulation at a cell by the area of a cell gives the size of the drainage area associated with the cell. The collection of cells that exceed a given accumulation value defines a network of streams that drain more than a given threshold area. Each such network is composed of reaches, or stream segments, the end points of which are referred to as nodes. The composition of a stream network is shown on Figure 4.1.

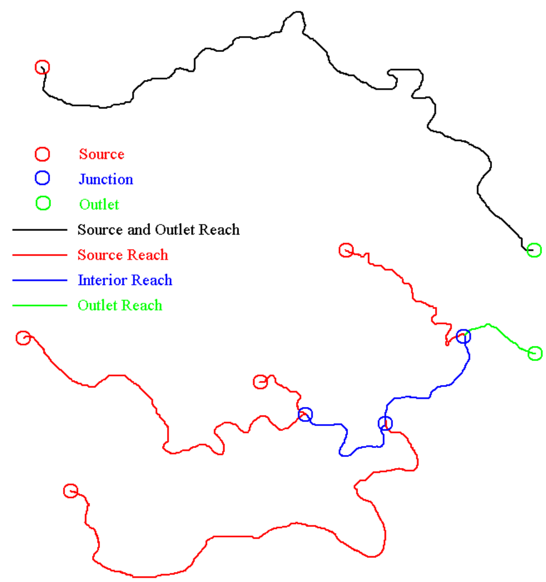


Figure 4.1 Stream Network Nomenclature

There are three types of nodes: sources, junctions, and outlets. Junctions are points where two reaches join (confluence). Sources are the "upper-most" points in a network. There are no reaches upstream of sources. An outlet is the "lower-most" point in a network. A network contains one outlet. There are no reaches downstream of an outlet. Note that a network can be a single reach (no junctions). Also note that, if no more than two reaches join to form junctions and there are N sources, there are 2N-1 reaches. That is, one-half of the nodes are sources. Because more than two reaches can share the same downstream point forming a junction, 2N-1 is an upper limit on the number of reaches.

The term drainage area is used to denote either the size, in square miles, or the spatial extent of the drainage basin above a given point. The drainage area at a cell is the collection of cells that "flow" to or through the cell. Its size is the accumulation at the cell times the area (size) of one cell.

For the purposes of this discussion, a watershed is the drainage area at a node less the drainage area at the next upstream node. Thus, watersheds are associated with either reaches or source nodes. If there are N sources, there are (no more than) 3N-1 watersheds. Drainage areas are the union of all watersheds upstream of the node. Note that watersheds and drainage areas are the same at sources. Watershed grids are created by attributing each cell in the grid with the nearest, in the sense of flow direction, feature.

Using a DEM with approximately 400-meter posting, the continental United States was subdivided into watersheds by creating accumulation grids and using a 100-square-mile threshold for defining stream reaches. Those watersheds and the nodes and reaches associated with them are contained in databases within Hazus. The watersheds and reaches are stored in shape files; the drainage areas and default discharge values corresponding to the nodes are stored in a table.

For example, the stream networks draining 100 or more square miles in the mid-Atlantic region of the eastern United States is shown in Figure 4.2. The major systems are (from north to south): the Delaware, Susquehanna, Potomac, and James. The Potomac River basin is shown in red. There are 421 reaches shown in Figure 4.2. Of those, 65 are within the Potomac River basin upstream of Washington, D.C. The drainage area of the Potomac River at Washington D.C. is 11,560 square miles.

The watersheds associated with the Potomac River network are shown in Figure 4.3. There are 98 watersheds associated with that network, 33 of which are source watersheds.

Except for the stream reach associated with each (non-source) watershed, the drainage areas of all streams within a watershed are contained in the watershed. Therefore, all information necessary to determine the flood hazards affecting a study region are geographically contained in the set of watersheds that cover the study region and the network reaches associated with those watersheds.

After a study region has been chosen, those watersheds that cover the study region are identified and saved in a feature table. Hazus looks for a DEM that contains those watersheds. Hazus will calculate the coordinates of the smallest rectangle containing the watersheds and advise the user of, in the absence of another DEM, the portion of the National Elevation Dataset (NED) prepared by and obtained from the U.S. Geological Survey (USGS) needed to cover the study region. NED has a posting of approximately 30 meters. Once the DEM is loaded into Hazus, the user may set the threshold drainage area for the network of possible study reaches.

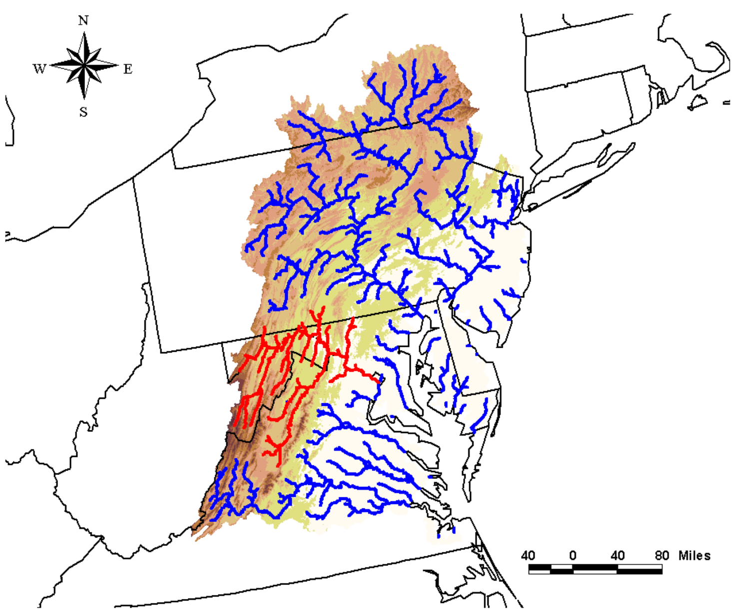


Figure 4.2 Stream Networks in the Mid-Atlantic Region

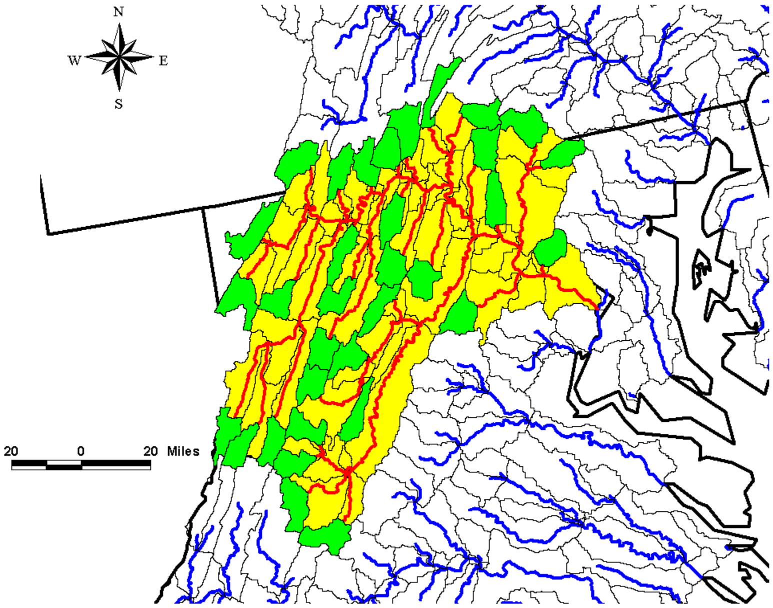


Figure 4.3 Potomac River Basin Watersheds

Figure 4.4 shows the 10 watersheds in Figure 4.3 that cover Shenandoah County, Virginia. The major drainage feature in the county is the North Fork Shenandoah River. The North Fork joins the South Fork Shenandoah River to form the Shenandoah River just downstream of the county line. The Shenandoah River continues northeast and flows into the Potomac River at Harpers Ferry, West Virginia.

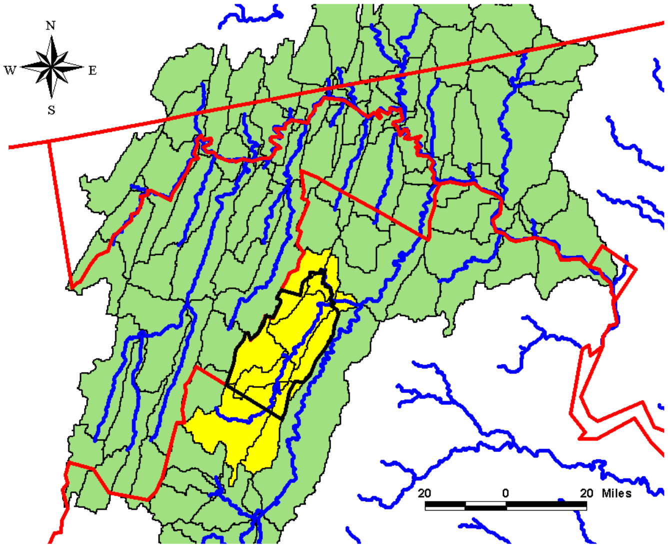


Figure 4.4 Watersheds Covering Shenandoah County

The portion of the NED that covers the watersheds is shown on Figure 4.5. The stream network shown within the watersheds was determined using the DEM information within the watersheds to create flow direction and accumulation grids. The network is based on a threshold drainage area of 10 square miles.

Because of the decrease in the threshold drainage area, the drainage density has increased. Differences in detail of the stream alignments are a consequence of the increased resolution (posting and elevation) of the NED over that of the 400-meter posting DEM.

Using the more detailed network and associated watersheds, the reaches affecting the study area and their drainage areas can be identified for hydrologic and hydraulic analyses. The watersheds associated with the reaches shown in Figure 4.5 are shown on Figure 4.6. Those reaches affecting Shenandoah County are depicted in red.

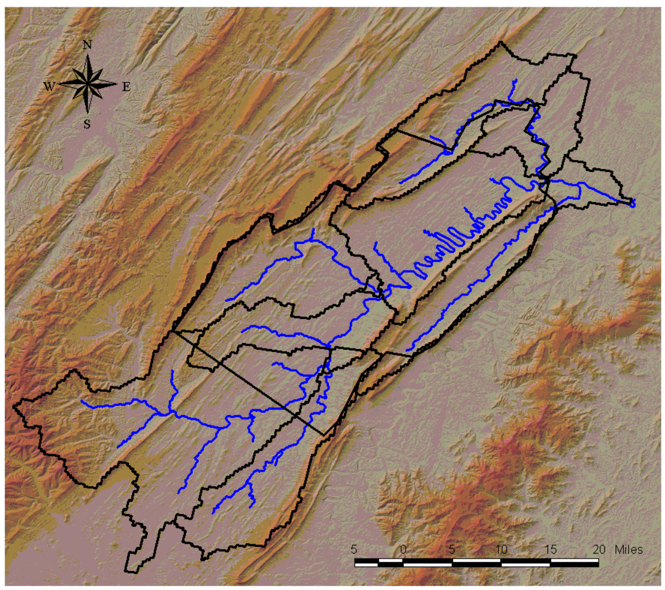


Figure 4.5 Drainage Pattern from a 10-square-mile Threshold

There are 41 stream reaches shown on Figure 4.5. The total stream length is approximately 310 miles. Figure 4.6 indicates that 24 of those reaches have floodplains that affect Shenandoah County. The total length of those reaches is approximately 225 miles.

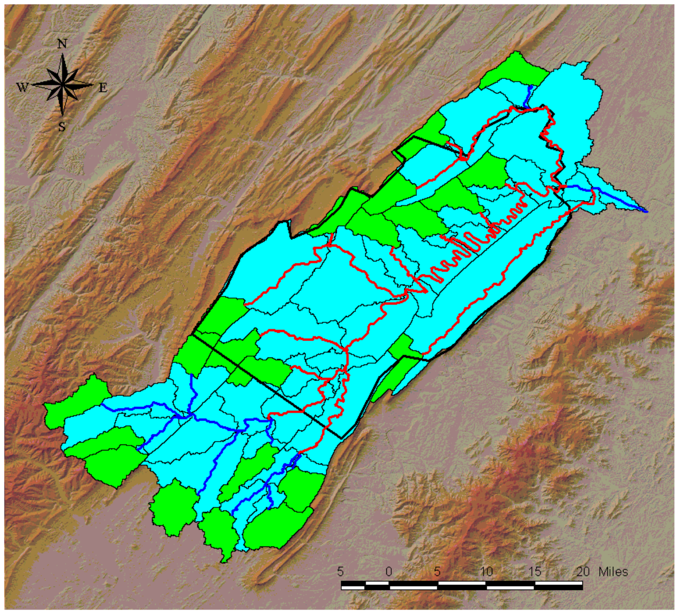


Figure 4.6 Reaches Affecting Shenandoah County

The threshold drainage area for identifying stream reaches is limited only by the resolution of DEM covering the study area. For example, if the user in our example is interested in streams draining a smaller area, the pattern in Figure 4.5 would be preserved with many more reaches included as tributaries to that pattern.

After choosing the threshold drainage area, the stream reaches are shown, as in Figure 4.5, and the user is prompted to select the reaches for hydrologic analyses. Figure 4.6 indicates that the user chose all streams affecting the county. The hydrologic analyses begin after the reaches are selected.

The first step is to identify reaches and associated watersheds that flow into the chosen reaches; the reaches into which the chosen reaches flow; and the watersheds associated with those reaches. When created, each reach is attributed with an upstream node identifier and a downstream node identifier. Figure 4.7, shows the upper portion of the North Fork Shenandoah River. The numbers denote nodes.

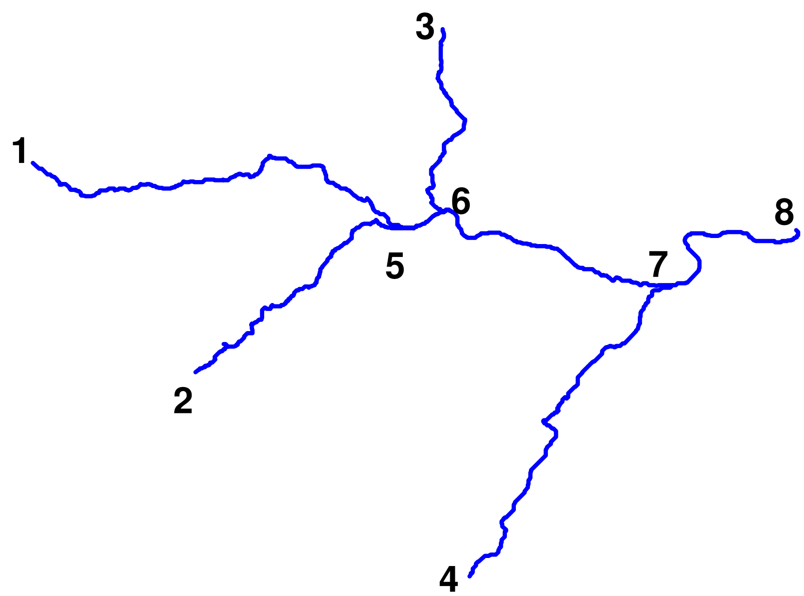


Figure 4.7 Reaches and Nodes

There is a reach that “flows” from node 1 to node 5; a reach that flows from node 5 to node 6; and so on. Using the “from node, to node” data we can construct a one-step transition matrix, $\mathbf{T_1}$, for navigating up- and downstream in the network. If we identify each reach by the number of its upstream node then each entry, (r,c), for row r and column c in $\mathbf{T_1}$ is 1 if the downstream node of stream r is the upstream node of stream c and 0 otherwise.

The entry (r,c) in $\mathbf{T_1}$ can be thought of as the probability that reach r flows into reach c. The probability that reach r flows through reach k into reach c is the value at (r,k) times the value at (k,c), either 1 or 0. If t_{rc} is the value of $\mathbf{T_1}$ at (r,c), the probability that reach r flows through another reach into reach c is the sum $P = \sum_{k=1}^{N} t_{r,k} t_{k,c}$, where N is the number of reaches. P is either 1 or 0. It is the value at (r,c) of the matrix $\mathbf{T_1}$ multiplied by itself. The matrix $\mathbf{T_2=2T_1^2}$, where the superscript 2 denotes matrix multiplication with itself, is a two-step matrix with (r,c)=2 if the downstream node of reach r is the upstream node of any reach having a downstream node that is the upstream node of reach c. Otherwise (r,c)=0. For the network shown in Figure 4.7, rows 1 and 2 of $\mathbf{T_2}$ will have 2 in column 6 and 0 in all other columns. Likewise, the n-step, $\mathbf{T_n = nT_1^n}$. Summing the n matrices, when n is large enough, yields a transition matrix that contains all information needed to readily navigate through the network.

Note that, if there are 2N+1 reaches, no reach is more than N steps from an outlet. The transition matrix, $\mathbf{T}$, for the network shown in Figure 4.7 is:

0	0	0	0	1	2	3
0	0	0	0	1	2	3
0	0	0	0	0	1	2
0	0	0	0	0	0	1
0	0	0	0	0	1	2
0	0	0	0	0	0	1
0	0	0	0	0	0	0

Note that columns 1 through 4 contain all zeros. They are source reaches. No reaches (rows) flow into them. Also note that row 7 contains all zeros. It is the outlet. There are no reaches downstream of reach 7. In general, reach k flows through all reaches, c, for which the value in row k, column c, (k,c) is non-zero; and drains all reaches, r, for which (r,k) is non-zero.

Rather than multiplying $\mathbf{T_1}$ by itself n times, **T** is constructed by initially setting all values to "0" and making lists from the feature table of reaches. Entries in the first list are the records of the downstream reach. If there is no downstream reach, the entry is the location in the list. In our example, given the list starts at record 1, the first list would be {5,5,6,7,6,7,7}. The "last" list is a copy of the first list.

Each record in the "next" list gets the value found in the record of the first list corresponding to the value in the same record (as we started with in the "next" list) in the "last" list. Thus, the first entry in the "next" list in our example is the fifth entry in the first list. The third entry in the "next" list is the sixth entry in the first list. The "last" list is saved in a list of lists and, then, the "next" list becomes the "last" list. The process continues until the "next" list is identical to the "last" list (i.e., n is large enough). In our example, that happens when the last and next lists are both {7,7,7,7,7,7,7}.

Each list in the list of lists is retrieved and used to set values in T. Those values are equal to position of each list in the list of lists. The values associated with the first list are all 1; those associated with the second list are all 2. If the value for a record in a list (i.e., flows-to-in-n-steps record), does not equal the corresponding value in the previous list, then the number of the position of the list is put in the row corresponding to the record in the column corresponding to the value.

A transition matrix is created for all reaches meeting the threshold drainage area requirement. The rows and columns of the matrix associated with the selected reaches are searched to identify up- and downstream reaches. Corresponding lists are made.

Watersheds in the reduced default watershed feature table that do not intersect any of the selected reaches or the reaches draining to selected reaches are deleted from the feature table, leaving only watersheds that drain to the selected reaches. The union of those watersheds defines a polygon that is used to cull the default reaches. If the midpoint of a default reach is not contained in the polygon, that reach is deleted from the reduced default reach feature table.

The default reaches that fall within the watersheds of the selected reaches and those draining to the selected reaches are shown in Figure 4.8. The reaches are the four on the North Fork Shenandoah River and three tributaries, shown in red.

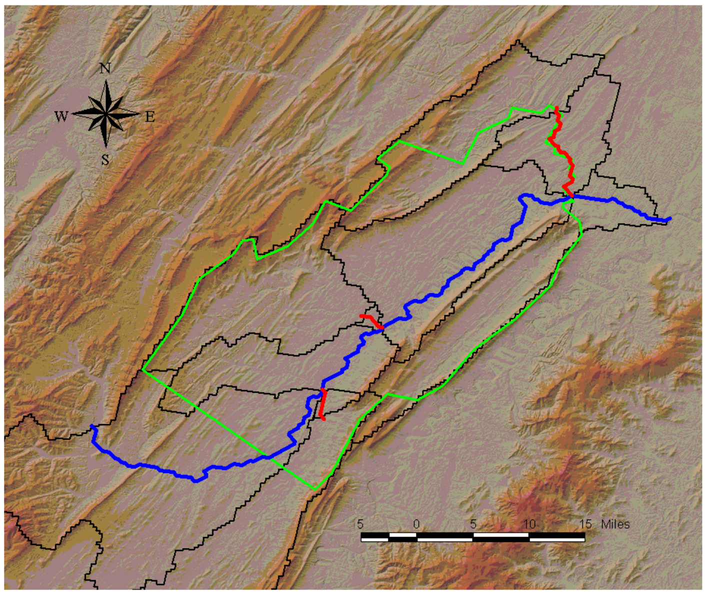


Figure 4.8 Default Reaches Affecting Study Area

The remaining default reaches that have no remaining reaches upstream are identified as potential source reaches. The upstream node of those reaches is found in the default node table and those that are source reaches are deleted from the feature table. A list is made of the potential source reaches that are not identified as source reaches. They are the default reaches that drain areas beyond the polygon. That is, they are parts of streams that originate outside of the study area.

The upstream nodes of all three tributaries shown in Figure 4.8 are contained within the polygon defined by the union of the watersheds covering the selected reaches. That is, those tributaries are source reaches and, therefore, deleted from the feature table.

Deleting the source reaches creates another network that may, unlike the situation depicted in Figure 4.8, contain new "sources." Those new sources are deleted. The potential sources saved in the list of reaches on streams that originate outside of the polygon are not deleted. The process continues until no new sources are created at which point, all default reaches are parts of streams that originate outside of the study area. Those streams will be referred to as main streams. All other streams, including the default reaches deleted in the culling process, drain areas contained within the polygon.

Figure 4.9 shows the various default reaches involved. The area depicted is in the vicinity of Clackamas County, Oregon. The major stream in Clackamas County is the Willamette River, which flows into the Columbia River at Portland. The Clackamas River flows from the southeast corner of the county to the Willamette River in the northwest corner. It is the shown in red on Figure 4.9. The reach on the Tualatin River and the upstream reach of the Willamette River shown in dark blue and the reaches shown in yellow are potential default source reaches that affect Clackamas County. Only the yellow reaches are “true” source reaches.

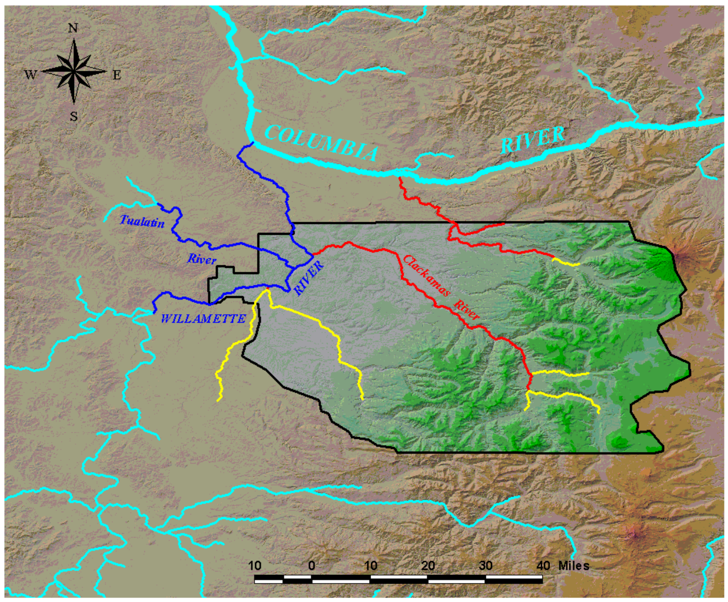


Figure 4.9 Identifying Main Streams

After the yellow reaches are deleted, the reach on the Tualatin River and the upstream reach of the Willamette River shown in dark blue and the upstream reaches shown in red are the potential default sources among the remaining reaches that affect Clackamas County. Those shown in dark blue were flagged and, so, only the potential sources shown in red are deleted. After the culling process is completed, only reaches shown in dark blue (Tualatin and Willamette Rivers) remain.

In addition to the reaches meeting the threshold drainage area that have been selected, there are, at this stage, three other categories of reaches:

Reaches meeting the threshold drainage area that flow to the selected reaches

Reaches meeting the threshold drainage area to which the selected reaches flow

Default reaches that are on main streams

Each category is used differently with the selected reaches to compute discharge values for the selected reaches. Upstream reaches are used to determine drainage areas and identify upstream gages. Downstream reaches are used to identify downstream gages. The default flood frequency information must be used for reaches on the main streams.

Cell values in the watershed grid created with the threshold reaches that are not associated with the selected or upstream reaches are set to null. Thus, the watershed grid only contains watersheds that are within the drainage areas associated with the selected reaches.

The selected reaches that are on main streams must be identified. As described earlier, collection of default reaches comprising the main stream differs from the collection of selected reaches on the main stream both in number of reaches and configuration or detail. The difference is evident for the North Fork Shenandoah River, the main stream shown in Figure 4.10. The red stream in Figure 4.10 is comprises four default reaches; the blue meandering main stream comprises 15 of the selected reaches.

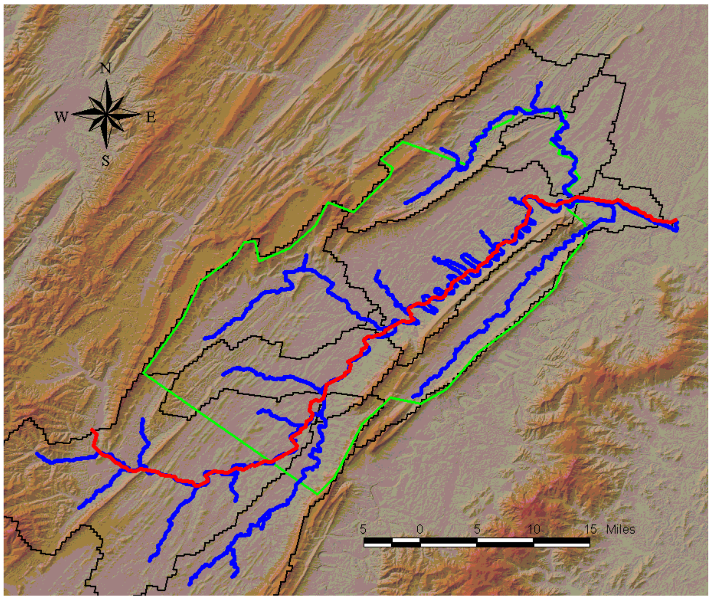


Figure 4.10 Main Stream Differences

A transition matrix is created for the remaining default reaches. The "sources" of the networks defined by the remaining default reaches are identified using the transition matrix. The watersheds remaining in the watershed grid are converted to polygons. The union of those polygons is a polygon covering the area draining to the selected reaches. Note that because the DEM is not the same DEM as used to create the default reaches, the watershed boundaries may not coincide where expected. The covering polygon is buffered inward one cell size. The boundary of the resulting polygon intersects the source reaches in the remaining default reaches. If the "source" reach and boundary intersect at more than one point, the most downstream of the intersections is identified and stored in a list.

Using the flow direction grid, the flow path is determined from each of the points in that "source" points list. That path will intersect the selected reaches and coincide with selected reaches from that intersection downstream (to the outlet of the selected reaches). Each path is buffered one-half a cell size. Lists are made of the selected reaches contained in each of the buffered paths. Thus, any selected reach that is on a main stream is contained in one or more of those main stream lists. The default flood frequency information is used on the reaches in the main stream lists.

The next step is to define the drainage area associated with each node in the networks of selected reaches and the reaches up- and downstream of the selected reaches. The step begins with defining the transition matrix for the selected reaches. Recall that a watershed grid is created when the threshold is chosen and the threshold reaches created. The cells in that grid are attributed with the nearest (in flow direction) reach. The groups of cells having (associated with) the same attributes (reaches) are converted to polygons. The conversion process may create more than one polygon for a given watershed.

Each polygon in the resulting collection of polygons is compared to every other polygon in the collection. Whenever the two polygons have the same attribute (are associated with the same reach), one is replaced with their union the other is placed in a list for removal. After each polygon has passed through the process, the polygons in the removal list are removed from the polygon feature table. The resulting feature table contains one polygon for each reach. Those polygons are the drainage areas associated with the corresponding reaches.

Note that the polygons associated with the source nodes have not been found at this point in the algorithm. That is, the watersheds associated with source reaches include the watersheds draining to the upstream points of the source reaches. They are not watersheds but are, instead, the drainage areas of the downstream nodes of the source reaches.

The source reaches are identified using the transition matrix. For each source reach, the upstream point (actually a point 0.1 percent of the reach length along the reach) is found. A watershed grid is created by identifying the groups of cells that flow to each of the source points and associating each cell with the corresponding point. Those groups are converted to polygons the same way as were the watersheds associated with the reaches. The number of cells in each group is divided by the number of cells in one square mile, yielding the watershed area. The polygon and area for each source point is stored as the upstream watershed and drainage area for the corresponding reach. The same process is applied to the watersheds associated with the reaches. The resulting polygons and areas are the watersheds and watershed areas associated with each of the reaches.

The drainage area of the downstream node of each reach is the sum of the watersheds upstream of the node. The reaches that flow through each downstream node are identified using the transition matrix. The sum of the watershed areas associated with those reaches plus the watershed area associated with the reach being analyzed is the drainage area of the downstream node. The union of the polygons associated with those watersheds is the polygon associated with the drainage area of the node. The resulting polygons and areas are stored as the downstream drainage area polygon and value for the reach.

Samples of the polygons described in the process are shown on Figure 4.11. The drainage areas associated with the upstream nodes of a source reach and an interior reach are shown in yellow. The watershed areas are shown in light blue.

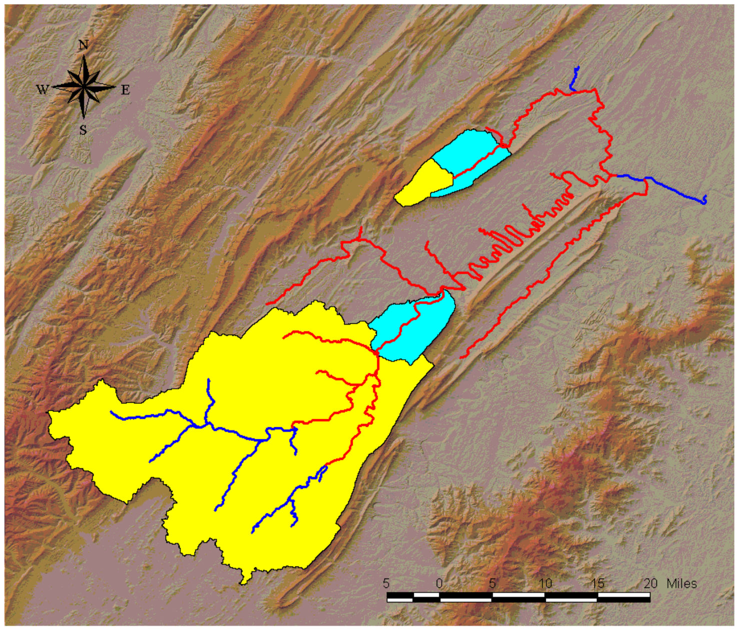


Figure 4.11 Drainage and Watershed Areas

At this point in the algorithm, the drainage areas associated with the upstream nodes of the source reaches and those associated with the downstream nodes of all of the reaches have been determined. Note that the drainage areas associated with the downstream nodes are the union of the blue and yellow polygons shown in Figure 4.11.

The drainage areas of the upstream nodes of the interior (non-source) reaches are determined by subtracting the area associated with the watershed of corresponding reach from the drainage area of the corresponding downstream node. Similarly, if a reach is an interior reach, the polygon associated with the drainage area of its upstream node is the difference between the polygons associated with drainage area and watershed at the downstream node.

Before moving to the algorithms that perform the hydrologic analyses, the default gage dataset is reduced to the gages that may be used those analyses. Using the transition matrix of the reaches meeting the threshold requirement (i.e., selected reaches and those up- and downstream), the outlet reaches are identified. The union of the drainage area polygons associated with the downstream nodes of the outlet reaches contains all gages that will be used in the hydrologic analyses. Note that gages affecting the analyses of the main streams were accounted for in developing the default reaches and watersheds files.

The union of drainage areas covering the study reaches and the gages within and near that area are shown in Figure 4.12. Each gage within the identified area is associated with the nearest reach (the reach feature table is spatially joined to the gage feature table). That association is checked using drainage areas.

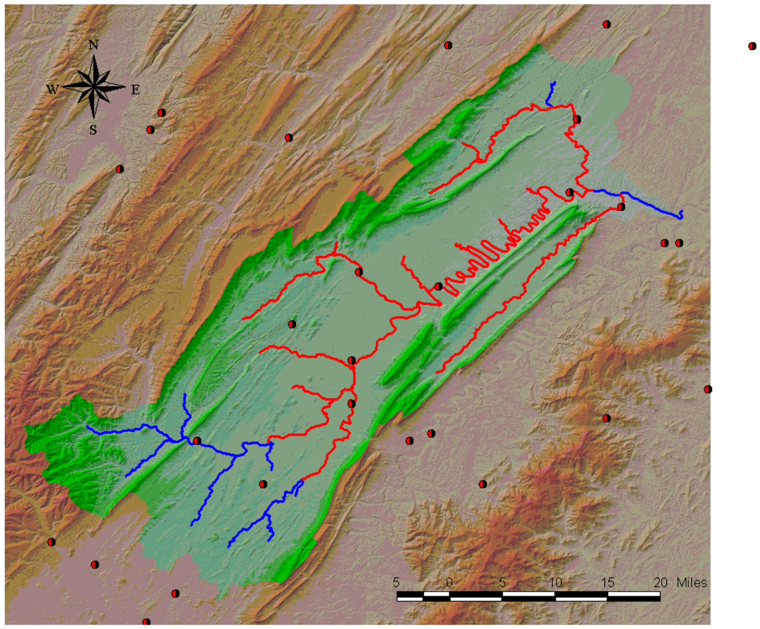


Figure 4.12 Gages In and Near Study Area

The points representing the gage locations are attributed with total and contributing drainage areas and the mean, standard deviation, and coefficient of skew of the flood frequency curve at the gage. If the total drainage area of the gage is less than the drainage area of the upstream node and greater than the drainage area of the downstream node of the reach associated with the gage, the gage is assumed to be on that reach. If not, the gage is removed from the gage feature table. That is, the gage is not used in subsequent analyses. For example, no gages with less than the threshold drainage are used in subsequent analyses.

Note there are two categories of reaches for which the algorithms have or may have underestimated the drainage areas. Drainage areas for reaches on the main streams do not include the area beyond the study region that drain to the reaches. Drainage areas associated with those reaches are underestimated by at least 100 square miles (the default drainage area threshold). Therefore, gages located on main streams will not be used in subsequent hydrologic analyses. Recall that the default flood frequency data incorporates the gage information and will be used for reaches on the main streams.

Drainage areas associated with reaches downstream of the selected reaches may be underestimated. Tributaries that are not selected but flow into reaches that are downstream of the selected reaches do not survive the culling algorithm. Drainage area calculations on down stream reaches do not include areas draining to those tributaries. Before comparing the gage drainage areas with the reach drainage areas, the drainage areas associated with downstream reaches identified as containing a gage are adjusted.

The adjustment uses the watershed grid and the accumulation grid. A new grid is created. Cells in the new grid corresponding to cells contained in the group in the watershed grid that are associated with the reach are given the value of the corresponding cell in the accumulation grid. All other cells in the new grid are given a value of zero. The maximum cell value of the new grid is the number of cells draining to the downstream node of the reach. That number minus the number of cells in the group identified in the watershed grid is the number of cells draining to the upstream node. Dividing each of those numbers by the number of cells in one square mile yields the respective drainage areas.

Those drainage areas are compared to the drainage areas at the gages associated with the reach. Gages not satisfying the drainage area test are deleted from the feature table, leaving only those gages that will be used in the hydrologic analyses.

4.2.2 Hydrologic Analysis

Hydrologic analyses are performed for each node using the regional regression equations developed by the USGS. The results of applying the equations are adjusted using stream gage data where the drainage area at the gage is between 50- and 150-percent of the drainage area of the node. Discharge values for reaches on main streams are interpolated from the corresponding values in the default flood frequency database.

The USGS has divided each state into hydrologic regions and developed a set of regional regression equations for each region. The equations are generally of the form

$$Q_T = Cf_i(P_1)f_2(P_2)...f_n(P_n)$$

where Q_T is the discharge value with a return period of T; C is a constant; and $f_i(P_i)$ denotes a function of the i^{th} parameter of the equation. The number and types of parameters vary from one equation to another. With few exceptions, the fs are power functions, such as the drainage area raised some exponent.

A shape file of polygons representing the hydrologic regions is included in Hazus. Tables included with Hazus contain the information necessary to apply the equations. There is a table for each return period computed. Each record in a table is associated with a region and each field is associated with a function. For example, the first field in every record is the constant, C, the second field is the exponent of the drainage area. If a region does not use a particular function, the corresponding field contains a zero. The hydrologic regions in the vicinity of Shenandoah County are shown in Figure 4.13.

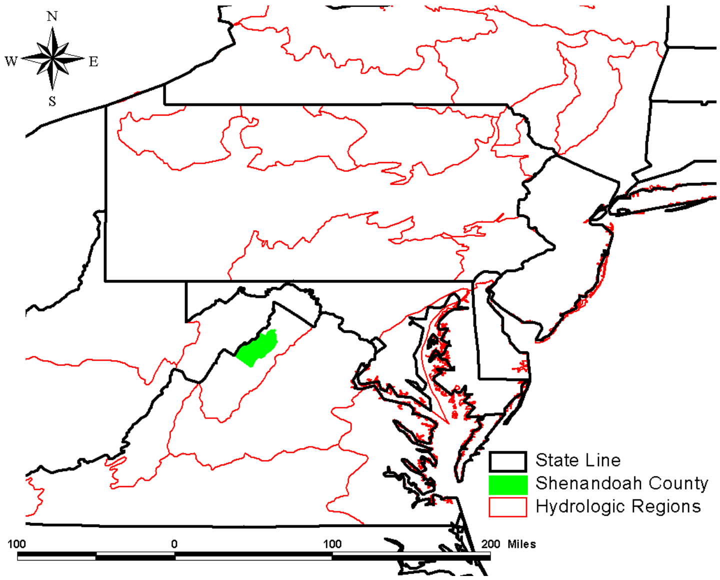


Figure 4.13 Hydrologic Regions Near Shenandoah County

A list is made consisting of the reaches to be analyzed. Because the algorithm for adjusting discharge value estimates with information from stream gages involves applying the regional regression equations for the drainage area at the gage, reaches containing gages are included in the list. Reaches that are on main streams are not included in the list. Thus, the list consists of reaches not on a main stream that were either selected for study or are located up- or downstream of a selected reach and contain a gage.

Topographic Parameters

At each node of each reach in the list, topographic parameters required for the regression equations are derived and stored in a temporary table. This table is deleted once the hydrologic analysis is complete. Each record in the table corresponds to a node. Fields in the table correspond to:

- The record number of the reach in the reach feature table.
- A value denoting whether the node is at the upstream or downstream end of the reach (0 or 99, respectively).
- The drainage area at the node.
- The average elevation of the drainage area (mean basin elevation).
- The average slope in the drainage area (mean basin slope).
- The straight line distance between the outlet of the basin and the point farthest away as measured along the drainage network (basin length).

- The length (channel length) of the longest drainage path, i.e., between the two points used to define basin length.

- The elevation at a point located at a distance along the longest drainage path 10 percent of its length from the outlet.

- The elevation at a point located at a distance along the longest drainage path 85 percent of its length from the outlet.

After the table is created but before data is added, the size of the to-be-analyzed list is investigated. If the list is empty, all of the selected reaches are on main streams and flood frequency data comes from the default databases. In that situation processing skips to the last algorithm, adding data using the default reaches. If the list is not empty, topographic parameters are derived from the DEM and associated grids.

A grid can be thought of as a sequence of numbers. The position within the sequence defines the coordinate of a cell; the number at that position is the value of the cell. Finding statistics of a grid is, essentially, finding the statistics of a large set of numbers. Thus, statistics such as the maximum, minimum, or mean value of the cells in a grid are readily available.

Recall that the direction grid was created by finding, for each cell, the neighboring cell to which a straight line has the greatest descending slope. A slope grid is defined by attributing each cell with that slope.

The point farthest away, in terms of flow direction, from the outlet is determined for each drainage area associated with a source node. Recall that a length grid, containing flow distances to outlets, was created when the accumulation grid was created. The polygon representing the drainage area associated with a source node is used to extract cells from the length grid.

The extracted cells form a grid. The maximum (cell) value of that grid is identified. All cells in the grid that have values less than 0.999999 times the maximum value are set to nil. The resulting grid is converted to a feature table of points. All points in the feature table are the maximum flow distance from the node drainage area to the outlet of the network (that the node belongs to) of reaches meeting the threshold drainage area requirement. Because all flow paths within that drainage area pass through the node, the points are also the maximum flow distance from the node.

The first (usually the only) point in the feature table is saved in a list. That list contains the upstream point of the longest flow path to every source of interest. It is assumed in the algorithm for finding the longest flow path that, within any drainage area, the longest flow path originates at one of the points in the list.

The upstream points of the longest flow paths in the Shenandoah County example are shown in Figure 4.14.

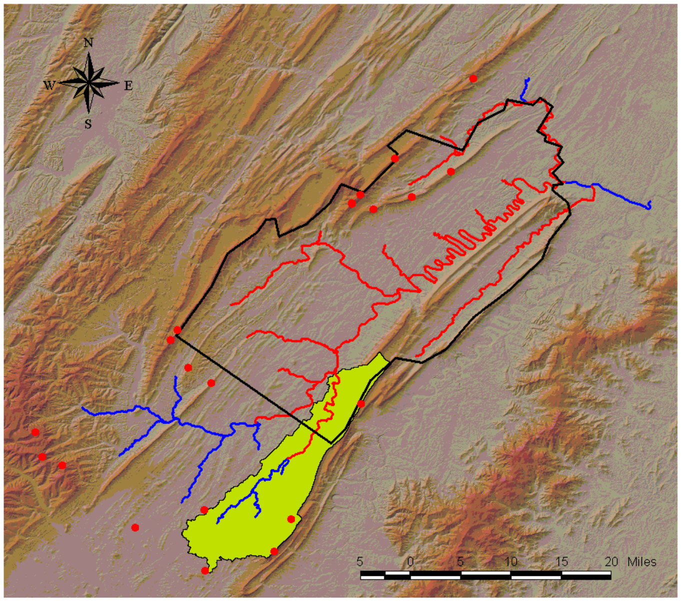


Figure 4.14 Points Farthest from Outlets

After the list of potential farthest upstream points is complete, the topographic parameters are assigned. For each reach in the to-be-analyzed list, a record is added to the topographic parameter table and the record number corresponding to the record of the reach in the reach feature table is put in the reach record number field. The up-or-down field is set to zero, denoting that the node is the upstream end of the reach. The drainage area computed after the study reaches were selected is put in the drainage area field.

The polygon representing the drainage area is used to form grids by extracting cells from the DEM and slope grids. The average values of those grids are determined and put in the fields corresponding to the mean basin elevation and mean basin slope.

The length parameters are found by sampling the paths from those points in the points-farthest-from-the-source-nodes list that fall within the drainage area of the reach. The path from each such point is found and its length is determined. The path with the greatest length is identified as the longest stream. The straight line between the end points of the longest path is created and identified as the basin length line. The lengths of those two lines are put into the channel and basin length fields, respectively.

Points are identified at distances of 15 and 90 percent of the total length as measured from the upstream end and along the line longest stream. Note that, following convention, the parameter name indicates length from outlet whereas measurements in the GIS are in percentage from the uppermost point on the stream. The elevations at those points are found from the DEM and the difference between the up- and downstream elevations is computed. If that difference is positive, the elevation values are put into the elevation 85 and elevation 10 fields.

If the difference is not positive, the elevation of the point at 89 percent of the total length is determined and used instead of the elevation of the point at 90 percent. If the difference is still not positive, the downstream sample point is moved upstream another percentage. The process continues until either the difference between the elevation of the upstream (15 percent) point and that of the point being moved is positive or the sample point has moved to within 85 percent of the length from the upstream end. If the difference is not positive after those iterations, the elevation fields are set at 1.0 foot above and below the average of the last two elevations tested (i.e., at 15 and 85 percent of the total length from uppermost point).

Setting the elevation 10 and elevation 85 fields completes the first record for the reach. A new record is formed. The reach record number field is again set to the record of the reach in the reach feature table. The up-or-down field is set to 99, denoting a downstream node. The process just described is repeated to set the values for the remainder of the parameters.

After records have been added for all of the reaches (two each), the transition matrix is used to find reaches that are not source reaches. The values in up-or-down field in the topographic parameter table for records corresponding to the upstream nodes of those reaches are changed from 0 to 1, thereby distinguishing between interior and source upstream nodes.

Flood Frequency Table

A table containing flood frequency information associated with the default reaches is included with Hazus. The table contains a record for each node in the default (drainage area greater than 100 square miles) reach shape file. Each record has fields denoting a node identification number, the drainage area at the node, and the 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year flood the discharge values. If a particular frequency flood was not computed, the field associated with that frequency contains a zero.

A similar table is created for the nodes contained in the topographic parameter table. That is, the nodes at the ends of reaches from the to-be-analyzed list. The node identification number is formed by adding the up-or-down value divided by 100 to the reach record number. For example, 44.99 would be the downstream node of the reach in the 44th record of the (culled threshold) reach feature table. If a source, the upstream node of that reach would be identified as 44.00; if not a source it would be identified as 44.01. The drainage area is copied from the topographic parameter table.

Discharge values are calculated for each return period. The calculation begins by identifying the hydrologic regions that cover the drainage area at the node being analyzed. The intersection of the drainage and each region is found. The result of applying each regional regression equation is weighted by the portion of the drainage area within the region. The algorithm calculates the ratios of the area of the intersection divided by the drainage area and the area of the intersection divided by the area of the hydrologic region. If both ratios are less than one percent, the drainage area is assumed to be outside of the hydrologic region.

If either ratio is greater than one percent, the drainage area is partially within the hydrologic region and regression equation from that region will be used. The region identification is added to a list of regions covering the drainage area. Additionally, the polygon defined by the intersection of the hydrologic region and the drainage area is added to a list and the ratio of the areas of the intersection and the drainage area is added to a weighting list. A sum of the ratios in the weighting list is kept to calculate the final weights given to the results of each equation applied.

Discharge values are computed for each region in the region list. As mentioned earlier, a table is included with Hazus for each return period. Each table contains the hydrologic region identifiers and information regarding the functions in the regression equation. The tables are labeled with "Q" plus a three-digit return period identifier. Q025 is the table associated with a 25-year flood. The record corresponding to the first region in the region list is found in the appropriate return period (Q) table.

Some hydrologic regions have more than one set of equations. The different sets pertain to different ranges of drainage area. For example, the regions in south-central and southeast Pennsylvania each have one set of equations for drainage areas less than 15 square miles and one set for drainage areas greater than 15 square miles. Connecticut has a set of equations for drainage areas less than 10 square miles; a set for drainage areas between 10 and 100 square miles; and a set for drainage areas greater than 100 square miles.

Two fields in the Q tables contain threshold drainage areas, allowing for three sets of equations for each region (record). Depending on where the drainage area falls within those thresholds, the algorithm sets a range of fields that contain the correct function data. If the drainage area is less than 15 square miles and a portion of it is in region PA06 (south-central Pennsylvania), the algorithm locates the threshold field and, finding the value 15, locates the next threshold field. Finding zero in that field (there are only two ranges, greater or less than 15) the algorithm sets the appropriate range of fields to be sampled. If the drainage area is greater than 15 square miles, a different range is set.

The first field in the range contains the constant, *C*. The discharge value is set equal to the constant. If the discharge value is zero, the region does not have a regression equation for the return period being investigated. In that situation, the remaining fields are not read and the discharge value for the portion of the drainage area contained in the region is zero.

If the discharge value is greater than zero, the next field in the range is read. That field contains the exponent used in the power function of drainage area. The drainage area value is raised to that power and the result is multiplied by the discharge value (the constant at this point in the process). The discharge value is set equal to the resulting product and the next field in the range is read.

Subsequent fields correspond to different functions in the regression equation. The position of the field in the table (first field, second field, third field, ...) identifies a subroutine that solves the function. If the 18^{th} field is read and contains a nonzero value, the subroutine BsnChr18 is called. Each subroutine corresponds to a basin or climatic characteristic.

If the characteristic is topographic, the parameters needed to solve the function are contained in the topographic parameters table. For example, the 100-year flood discharge value in Shenandoah County, Virginia is proportional to the slope of the longest stream raised to the

0.21 power. The slope is in feet per mile as measured at points 10 and 85 percent of the total stream length from the outlet of the drainage area being analyzed. There is a field in the Q100 table with a value of 0.21 in the record corresponding to region VA03. Reading that value, the algorithm calls the subroutine associated with the field. The routine finds the values in the elevation 10, elevation 85, and longest stream length fields in the topographic parameters table, and calculates the slope (the difference in the elevations divide by 85 percent of the length). The routine returns the slope. The result of the subroutine, slope in this example, is raised to the exponent found in the Q100 table.

If the parameter is not topographic, the routine obtains a measure of the parameter within the intersection (of the drainage area and hydrologic region) polygon. The parameters are measured from grids or shape files similar to the way the topographic parameters were derived. If a parameter is represented as a grid, the intersection polygon is used to extract cells from the grid. The parameter, such as the mean annual precipitation or the percent of area of a particular soil type, is measured from the extracted cells. The value of the parameter is returned and raised to the exponent found in the Q table in the corresponding field.

If the parameter is represented by a shape file, the intersections of the intersection polygon and the features in the shape file are used to measure the parameter. For example, Hazus includes a shape file of polygons representing lakes, ponds, and other storage areas used in the regression analyses. The percentage of storage in an area is computed as the 100 times sum of the areas of the intersections of those polygons and the intersection polygon, divided by the area of the intersection polygon. The value of the parameter is returned and raised to the exponent found in the Q table in the corresponding field.

A value of 1.0 is used in the Q tables for functions that cannot be expressed as a power function. The subroutine corresponding to those functions measures the parameter, applies the function and returns the result. The result is raised to the power 1.0 and, therefore, is unchanged.

Some functions of parameters are treated as parameters themselves being used in power functions. Constants are added to parameters measured as percentages, such as percentage of area of a particular soil type or percentage of area covered in forest. Those functions (parameters plus constants) are treated as different parameters in the program. For example, the value1.0 is added to the percentage of drainage area in lakes and ponds (storage percentage) in regions in western Oregon; the value 0.5 is added to the storage percentage in regions in Vermont. There are two fields in the Q tables and, therefore, two corresponding subroutines, representing those values: one for storage plus 0.5; another for storage plus 1.0.

As each subroutine is called and completed, the returned value is raised to exponent found in the Q table and that result is multiplied by the (continuously increasing) discharge value. After all of the fields in the range have been visited, the discharge value represents the contribution from the hydrologic region. If that value is zero (e.g., no regression equation in that region for that return period), the sum of the region weights is reduced by the weight given to that particular region. If the discharge value is greater than zero, the value is multiplied by the region weight. The weighted discharge value is added to a sum being kept until values from all regions in the region list have been added.

If the resulting sum of the region weights, the net sum, is less than 60 percent of the original sum of region weights, the discharge value is set to zero indicating that there is not a regression equation for the return period under investigation. If the net sum is equal to or greater than 60 percent of the original sum, the discharge value is divided by the net sum, completing the weighting process. That quotient, the discharge value, is put in the flood frequency table in the record corresponding to the node, and the field corresponding to the return interval.

Stream Gage Adjustment

Reaches up- and down stream of each node are searched for gage information. The maximum upstream gage area is initially set to zero as each new node is investigated. Upstream reaches are identified using the transition matrix. Note that if the node identification ends in 0.99, the node is a downstream node and, therefore, the reach associated with the node is also identified as upstream of the node. If a reach is upstream of the node, it is checked against the list of reaches containing gages. If the reach is in the gage list and the drainage area of the gage is greater than the maximum upstream gage area, the reach is identified as the upstream gage reach and the drainage area at the gage becomes the maximum. After the last upstream reach is checked, the upstream reach with gage having the greatest drainage area has been identified. Of course it may not exist, in which case the corresponding drainage is, as initially set, zero.

The reach downstream of the node containing the gage with smallest drainage area is found similarly. The minimum area is initially set to 1,000,000 square miles and the downstream reaches are identified using the transition matrix. The reach associated with an upstream node is also identified as downstream of that node. As the reaches are checked against the list of reaches with gages, the reach containing the gage with the smallest drainage area is identified.

If there is an upstream reach with a gage that drains more than 50 percent of the drainage area of the node and there is a downstream reach with a gage that drains less than 150 percent of the drainage area of the node, the discharge values at the node are interpolated.

The discharge value corresponding to each return period is determined at both gages.

Hazus contains a table of normalized random variables corresponding to various probabilities of being exceeded. The variables are Pearson Type III distributed, covering a range of skew coefficients differing by 0.1. The normalized random variable corresponding to a return interval T is the number of standard deviations between the mean and the value of the random variable that has, in the context of flood frequency, a probability 1/T of being exceed in any given year.

Recall that the feature table of gage locations contains the mean, standard deviation, and coefficient of skew of the flood frequency curve at the gage. For each return interval, the algorithm searches a list corresponding to the probability values of the normalized random variable table. The list is arranged in descending order. The search ends when a probability is encountered that is less than the reciprocal of the return period. A normalized random variable corresponding to the reciprocal of the return period is linearly interpolated using that probability and the probability located just before that probability in the list, and the normalized random variables corresponding to those probabilities.

Multiplying the normalized random variable by the standard deviation and, then, adding the mean, yields the value of the random variable. It is the base 10 logarithm of the discharge value, corresponding to the return period, T. The T-year discharge value is equal to10 raised to that value. Having calculated the T-year discharge at the up- and downstream gage locations, the value at the node is interpolated as a power function of the drainage area. That is,

$$Q_{node} = A_{node}^{\alpha}. \tag{4-1}$$

where Q_{node} is the discharge value at the node; A_{node} is the drainage area at the node; and the exponent, α, equals the base 10 logarithm of the ratio of the discharge values at the gages divided by the base 10 logarithm of the ratio of the drainage areas at the gages:

$$\alpha = \frac{\log_{10}(Q_{up}) \big/ \log_{10}(Q_{down})}{\log_{10}(A_{up}) \big/ \log_{10}(A_{down})}. \tag{4-2}$$

The value, Q_{node}, is put in the field associated with the return period of the record associated with the node.

If there is <u>either</u> an upstream reach with a gage that drains more than 50 percent of the drainage area of the node <u>or</u> there is a downstream reach with a gage that drains less than 150 percent of the drainage area of the node, but not both, the discharge values at the node are weighted with the values associated with the gage. As with the previous case, the discharge values corresponding to the return intervals at the gage are determined using statistics from the gage record (mean, standard deviation and coefficient of skew). Additionally, discharge values at the gage location are interpolated, as a power function of drainage area, using the values computed with the regression equations at the up- and downstream nodes of the reach containing the gage. A weighting parameter, R_W, is computed:

$$R_W = R - \frac{2\left|A_{gage} - A_{node}\right|(R-1)}{A_{gage}}. \tag{4-3}$$

Where, R is the discharge value determined from the statistics divided by the interpolated value; A denotes drainage area; the subscripts denote values associated with the gage location or node; and | | denotes the absolute value. If the discharge value at either end of the reach containing the gage is zero, $R_W = 1.0$.

The discharge value in the field associated with the return period and the record associated with node is multiplied by the weighting parameter and replaced by that product.

Adding Main Stream Reaches

Discharge values for nodes on mainstreams are interpolated as power functions of drainage area similar to the procedure used for nodes with gages up- and downstream. The drainage areas and discharge values at the nodes of the default reaches are used to interpolate the discharge values for the selected reaches.

Recall that when the study reaches were selected, the default (meeting a 100-square-mile-drainage-area threshold) reaches were culled to a collection consisting of reaches within the study -region that drain areas beyond the study region. The "source" reaches of the networks defined by that collection were used to identify the selected reaches that are on main streams. The drainage area calculations for those reaches did not consider portions of the drainage areas beyond the study region. Those portions are the drainage areas of the upstream nodes of the source reaches in the remaining default networks.

There are two sets of reaches for each main stream: a set of default reaches and a set of selected reaches. Lists of default "source" reaches and the selected reaches that are on the main streams were created when the main streams were identified. Corresponding lists of default reaches are identified using the list of default "source" reaches and the transition matrix for the remaining default reaches.

Using the numbers of steps in the transition matrix, the default reaches are arranged from upstream to downstream in each list. Recall that, in the record for a given reach, there is a 1 in the field corresponding to the reach one step downstream, a 2 in the field of the reach two steps downstream, and so on. As a consequence, the reaches are arranged by increasing drainage area.

Using the default flood frequency table, the list of source reaches from the remaining default reaches is arranged by drainage area. Pairing the lists of selected reaches that are on mainstreams with the default source reaches creates a list of lists of selected reaches arranged by the unaccounted for drainage area. That is, the first list corresponds to the main stream with the largest drainage area; the next list corresponds to the main stream with the next largest drainage area. That arrangement establishes a sense of which main streams are tributary to other main streams.

For each list of selected reaches on main streams, the unaccounted for drainage area is added to the drainage area of each node of each reach in the list. Because main streams are defined from the upstream node to the outlet of the study region, several main streams may coincide (if they are in the same network within the study region). Selected reaches on portions of main streams that coincide are members of each of the coinciding main streams' reach lists. The drainage area associated with one of those reaches is increased the appropriate amount each time the reach is found in one of the lists. The idea is illustrated in Figure 4.15.

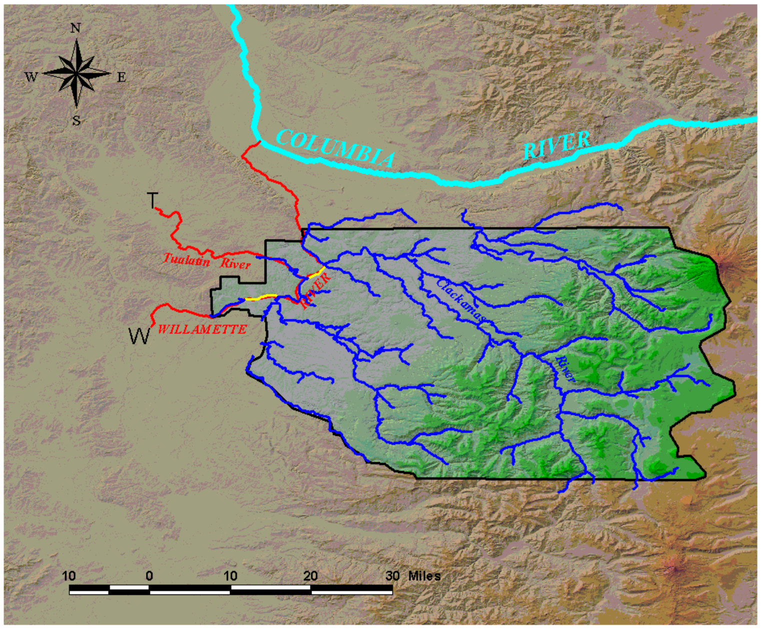


Figure 4.15 Selected Reaches on Main Streams

Figure 4.15 shows the remaining default reaches in Clackamas County and the reaches affecting Clackamas County that meet a 10-square mile drainage area threshold. The two reaches shown in yellow are on the Willamette River: one upstream of and one downstream of the confluence with the Tualatin River. Recall both of those rivers were main streams.

The drainage area in the default flood frequency table at the node labeled W (the upstream end of the Willamette River "source") in the figure is added to both of the selected reaches shown in yellow. Additionally, the drainage area at the node labeled T (the upstream end of the Tualatin River "source") is added to the downstream reach shown in yellow.

After the drainage areas are adjusted, reaches contained in more than one list are deleted from all lists except the list associated with the largest drainage area. Culling the lists that way establishes a unique stream (list) for each selected reach and, consequently, node. Discharge drainage area interpolations are confined to the stream (list) unique to the node being analyzed.

The algorithm addresses one main stream at a time, making parallel lists of drainage areas at nodes of selected reaches and node identifier numbers from the default reach flood frequency table. One pair of lists is made for upstream nodes; another pair is made for downstream nodes. A reach is read from the main stream list and the drainage area at its upstream node is added to the upstream drainage area list.

Default reaches are read (in downstream order) from the default reach list corresponding to the same main stream. If the drainage area at upstream node of the default reach is greater than the drainage area of the selected reach node, the node identification number is added to the upstream node identification number list. If not, the downstream node of the default reach is test. If its drainage area is greater than the drainage area of the selected reach node, its identification number is added to the upstream node identification number list. If not, the process is repeated using the next default reach in the list. If no default node tested has a drainage area greater than the target drainage area, the node identification number of the downstream node of the last reach in the default reach list is added to the upstream node identification number list. In that situation, the discharge values for the node will be extrapolated.

Next, the drainage area at the downstream node of the selected reach is added to the downstream drainage area list. Starting with the reach containing the node just added to the upstream node identification number list, the default reaches are searched for the node with a drainage area greater than the target downstream drainage area. When that node is found its identification number is added to the downstream node identification number list. If no default node tested has a drainage area greater than the target drainage area, the node identification number of the downstream node of the last reach in the default reach list is added to the downstream node identification number list. The discharge values for the node will be extrapolated.

Note that the algorithm does not determine which selected reaches fall within which default reaches. Instead, the algorithm uses the default flood frequency table to establish discharge-drainage area relations for each main stream and, as just described, finds the positions, within the domain of drainage areas, of each node of a selected reach on a main stream. The discharge values at each node is interpolated assuming the discharge-drainage area relations are piecewise log-linear (power functions).

Records are added to the flood frequency table for selected reaches starting with the first entries in the pair of upstream lists just created. The identification number of the first node added is the record of the reach in the feature table of reaches in the study region meeting the threshold drainage area requirement plus 0.01. Any reach on a main stream cannot be a source reach. The drainage area from the drainage area list is put in the drainage area field.

The record in the default flood frequency table containing the node identification number from the upstream node identification number list and the record just before that record are identified. The drainage areas in those records are, respectively, the smallest drainage area greater than and the greatest drainage area smaller than that at the node of the selected reach (unless the latter drainage area is greater than those at all default nodes associated with the main stream). The ratio of the difference of the base 10 logarithms of the three areas is used to interpolate. That ratio is:

$$R = \frac{\log_{10}\left({}^{A_{selected}}\!\big/\!{}_{A_{smaller}} \right)}{\log_{10}\left({}^{A_{greater}}\!\big/\!{}_{A_{smallerr}} \right)} \tag{4-4}$$

where A denotes drainage area and the subscripts denote drainage areas from the node on the selected reach, or nodes on the default reaches having the smaller or greater drainage area. Note that if $A_{selected}$ is greater than $A_{greater}$, R is greater than 1.0.

Discharge values are read from the default flood frequency table records for each return interval. If either of the values (smaller or greater) are zero, a zero is put in the corresponding field in the flood frequency table for selected reaches. If both values are greater than zero, the base 10 logarithm of the discharge value for the node on the selected reach is

$$\log_{10}\left(Q_{selected}\right) = \log_{10}\left(Q_{smaller}\right) + R\log_{10}\left(Q_{greater} \big/ Q_{smaller} \right) \tag{4-5}$$

where Q denotes discharge and the subscripts are as above. If R is greater than 1.0 $\log_{10}(Q_{selected})$ is extrapolated (beyond the largest default value).

Raising 10 to the $\log_{10}(Q_{selected})$ power yields the discharge value that is placed in the appropriate field in the flood frequency table for selected reaches. The process is repeated for each return interval completing the record for the upstream node.

The next node is the downstream node of the first selected reach in the mainstream list being analyzed. The node identification number is the reach record in the feature table plus 0.99. The drainage area is the first drainage area in the downstream drainage area list. The discharge values are assigned using the same procedure as used for the upstream node.

The remaining nodes in the two lists are processed in order to complete the main stream. The lists are emptied and new pairs of lists are created to analyze the next main stream (with the next largest drainage area). The flood frequency table is complete when the nodes of last main stream list of selected reaches have been included.

4.2.2.1 Reach Identification and Watershed Association

The model identifies reaches and associated watersheds that flow into the chosen reaches; the reaches into which the chosen reaches flow; and the watersheds associated with those reaches. When created, each reach is attributed with an upstream node identifier and a downstream node identifier. Figure 4.16, shows the upper portion of the North Fork Shenandoah River. The numbers denote nodes.

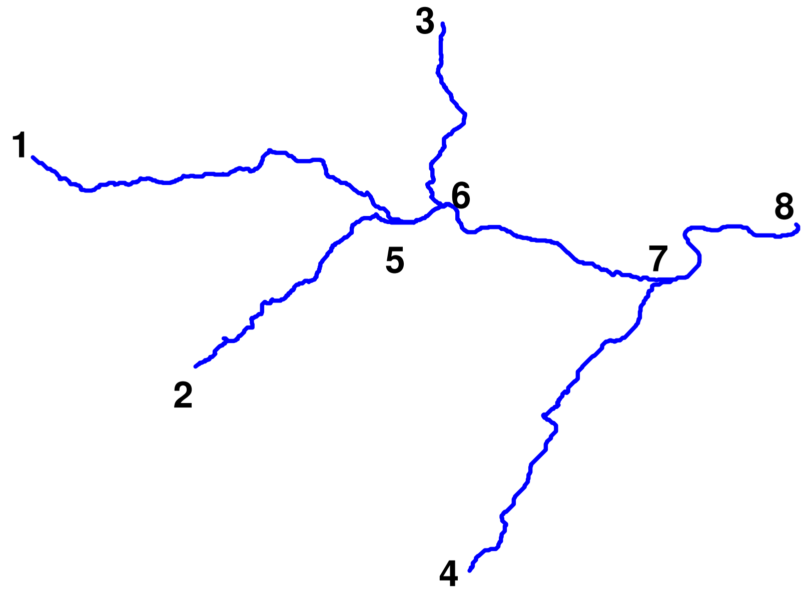


Figure 4.16 Reaches and Nodes

There is a reach that "flows" from node 1 to node 5; a reach that flows from node 5 to node 6; and so on. Using the "from node, to node" data the model constructs a one-step transition matrix, for navigating up- and downstream in the network. If the model identifies each reach by the number of its upstream node then each entry, (r,c), for row r and column c in the matrix is 1 if the downstream node of stream r is the upstream node of stream c and 0 otherwise.

A transition matrix is created for all reaches meeting the threshold drainage area requirement. The rows and columns of the matrix associated with the selected reaches are searched to identify up- and downstream reaches. Corresponding lists are made.

Watersheds in the reduced default watershed feature table that do not intersect any of the selected reaches or the reaches draining to selected reaches are deleted from the feature table, leaving only watersheds that drain to the selected reaches. The union of those watersheds defines a polygon that is used to cull the default reaches. If the midpoint of a default reach is not contained in the polygon, that reach is deleted from the reduced default reach feature table.

The default reaches that fall within the watersheds of the selected reaches and those draining to the selected reaches are shown in Figure 4.17. The reaches are the four on the North Fork Shenandoah River and three tributaries, shown in red.

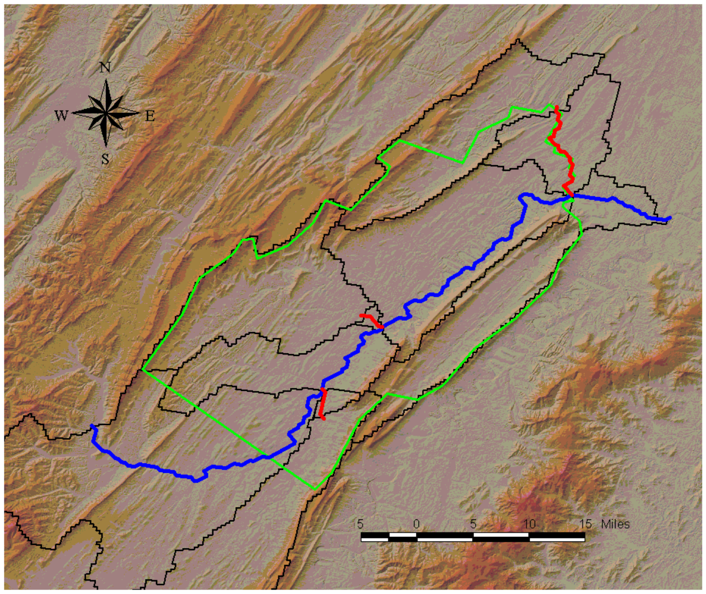


Figure 4.17 Default Reaches Affecting Study Area

The remaining default reaches that have no remaining reaches upstream are identified as potential source reaches. The upstream node of those reaches is found in the default node table and those that are source reaches are deleted from the feature table. A list is made of the potential source reaches that are not identified as source reaches. They are the default reaches that drain areas beyond the polygon. That is, they are parts of streams that originate outside of the study area.

The upstream nodes of all three tributaries shown in Figure 4.17 are contained within the polygon defined by the union of the watersheds covering the selected reaches. That is, those tributaries are source reaches and, therefore, deleted from the feature table.

Deleting the source reaches creates another network that may, unlike the situation depicted in Figure 4.17, contain new "sources." Those new sources are deleted. The potential sources saved in the list of reaches on streams that originate outside of the polygon are not deleted. The process continues until no new sources are created at which point, all default reaches are parts of streams that originate outside of the study area. Those streams will be referred to as main streams. All other streams, including the default reaches deleted in the culling process, drain areas contained within the polygon.

For example, Figure 4.18 shows the various default reaches involved. The area depicted is in the vicinity of Clackamas County, Oregon. The major stream in Clackamas County is the Willamette River, which flows into the Columbia River at Portland. The Clackamas River flows from the southeast corner of the county to the Willamette River in the northwest corner. It is the shown in red on Figure 4.19. The reach on the Tualatin River and the upstream reach of the Willamette River shown in dark blue and the reaches shown in yellow are potential default source reaches that affect Clackamas County. Only the yellow reaches are "true" source reaches.

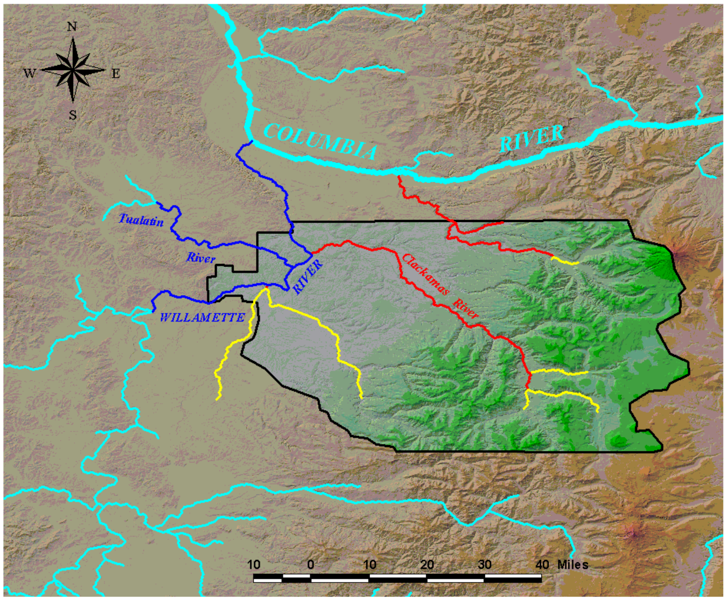


Figure 4.18 Identifying Main Streams

After the yellow reaches are deleted, the reach on the Tualatin River and the upstream reach of the Willamette River shown in dark blue and the upstream reaches shown in red are the potential default sources among the remaining reaches that affect Clackamas County. Those shown in dark blue were flagged and, so, only the potential sources shown in red are deleted. After the culling process is completed, only reaches shown in dark blue (Tualatin and Willamette Rivers) remain.

In addition to the reaches meeting the threshold drainage area that have been selected, there are, at this stage, three other categories of reaches:

1. Reaches meeting the threshold drainage area that flow to the selected reaches

2. Reaches meeting the threshold drainage area to which the selected reaches flow

3. Default reaches that are on main streams

Each category is used differently with the selected reaches to compute discharge values for the selected reaches. Upstream reaches are used to determine drainage areas and identify upstream gages. Downstream reaches are used to identify downstream gages. The default flood frequency information must be used for reaches on the main streams.

Cell values in the watershed grid created with the threshold reaches that are not associated with the selected or upstream reaches are set to null. Thus, the watershed grid only contains watersheds that are within the drainage areas associated with the selected reaches.

The selected reaches that are on main streams must be identified. As described earlier, collection of default reaches comprising the main stream differs from the collection of selected reaches on the main stream both in number of reaches and configuration or detail. The difference is evident for the North Fork Shenandoah River, the main stream shown in Figure 4.19. The red stream in Figure 4.19 is comprises four default reaches; the blue meandering main stream comprises 15 of the selected reaches.

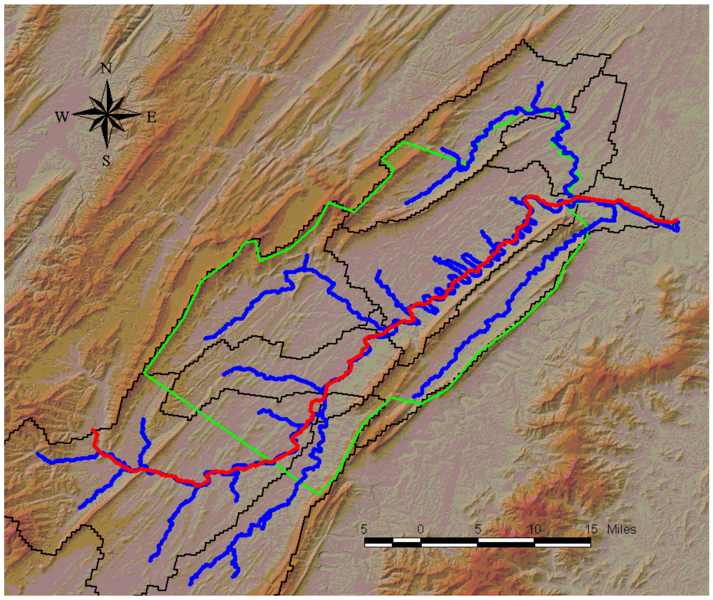


Figure 4.19 Main Stream Differences

A transition matrix is created for the remaining default reaches. The "sources" of the networks defined by the remaining default reaches are identified using the transition matrix. The watersheds remaining in the watershed grid are converted to polygons. The union of those polygons is a polygon covering the area draining to the selected reaches. Note that because the DEM is not the same DEM as used to create the default reaches, the watershed boundaries may not coincide where expected. The covering polygon is buffered inward one cell size. The boundary of the resulting polygon intersects the source reaches in the remaining default reaches. If the "source" reach and boundary intersect at more than one point, the most downstream of the intersections is identified and stored in a list.

Using the flow direction grid, the flow path is determined from each of the points in that "source" points list. That path will intersect the selected reaches and coincide with selected reaches from that intersection downstream (to the outlet of the selected reaches). Each path is buffered one-half a cell size. Lists are made of the selected reaches contained in each of the buffered paths. Thus, any selected reach that is on a main stream is contained in one or more of those main stream lists. The default flood frequency information is used on the reaches in the main stream lists.

4.2.2.2 Define Drainage Area

The next step is to define the drainage area associated with each node in the networks of selected reaches and the reaches up- and downstream of the selected reaches. The step begins with defining the transition matrix for the selected reaches. Recall that a watershed grid is created when the threshold is chosen and the threshold reaches created. The cells in that grid are attributed with the nearest (in flow direction) reach. The groups of cells having (associated with) the same attributes (reaches) are converted to polygons. The conversion process may create more than one polygon for a given watershed.

Each polygon in the resulting collection of polygons is compared to every other polygon in the collection. Whenever the two polygons have the same attribute (are associated with the same reach), one is replaced with their union the other is placed in a list for removal. After each polygon has passed through the process, the polygons in the removal list are removed from the polygon feature table. The resulting feature table contains one polygon for each reach. Those polygons are the drainage areas associated with the corresponding reaches.

Note that the polygons associated with the source nodes have not been found at this point in the algorithm. That is, the watersheds associated with source reaches include the watersheds draining to the upstream points of the source reaches. They are not watersheds but are, instead, the drainage areas of the downstream nodes of the source reaches.

The source reaches are identified using the transition matrix. For each source reach, the upstream point (actually a point 0.1 percent of the reach length along the reach) is found. A watershed grid is created by identifying the groups of cells that flow to each of the source points and associating each cell with the corresponding point. Those groups are converted to polygons the same way as were the watersheds associated with the reaches. The number of cells in each group is divided by the number of cells in one square mile, yielding the watershed area. The polygon and area for each source point is stored as the upstream watershed and drainage area for the corresponding reach. The same process is applied to the watersheds associated with the reaches. The resulting polygons and areas are the watersheds and watershed areas associated with each of the reaches.

The drainage area of the downstream node of each reach is the sum of the watersheds upstream of the node. The reaches that flow through each downstream node are identified using the transition matrix. The sum of the watershed areas associated with those reaches plus the watershed area associated with the reach being analyzed is the drainage area of the downstream node. The union of the polygons associated with those watersheds is the polygon associated with the drainage area of the node. The resulting polygons and areas are stored as the downstream drainage area polygon and value for the reach.

Samples of the polygons described in the process are shown on Figure 4.20. The drainage areas associated with the upstream nodes of a source reach and an interior reach are shown in yellow. The watershed areas are shown in light blue.

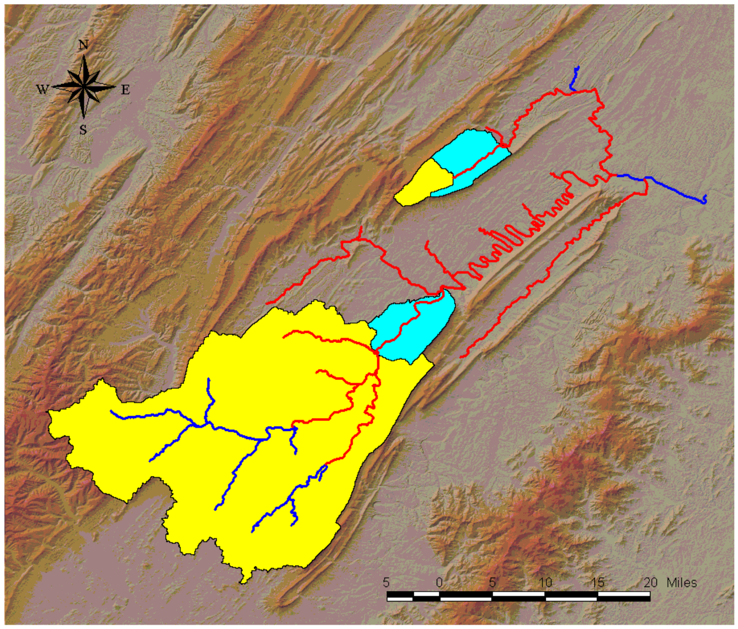


Figure 4.20 Drainage and Watershed Areas

At this point in the algorithm, the drainage areas associated with the upstream nodes of the source reaches and those associated with the downstream nodes of all of the reaches have been determined. Note that the drainage areas associated with the downstream nodes are the union of the blue and yellow polygons shown in Figure 4.20.

The drainage areas of the upstream nodes of the interior (non-source) reaches are determined by subtracting the area associated with the watershed of corresponding reach from the drainage area of the corresponding downstream node. Similarly, if a reach is an interior reach, the polygon associated with the drainage area of its upstream node is the difference between the polygons associated with drainage area and watershed at the downstream node.

4.2.2.3 Default Gage Identification

Before moving to the algorithms that perform the hydrologic analyses, the default gage dataset is reduced to the gages that may be used those analyses. Using the transition matrix of the reaches meeting the threshold requirement (i.e., selected reaches and those up- and downstream), the outlet reaches are identified. The union of the drainage area polygons associated with the downstream nodes of the outlet reaches contains all gages that will be used in the hydrologic analyses. Note that gages affecting the analyses of the main streams were accounted for in developing the default reaches and watersheds files.

The union of drainage areas covering the study reaches and the gages within and near that area are shown in Figure 4.21. Each gage within the identified area is associated with the nearest reach (the reach feature table is spatially joined to the gage feature table). That association is checked using drainage areas.

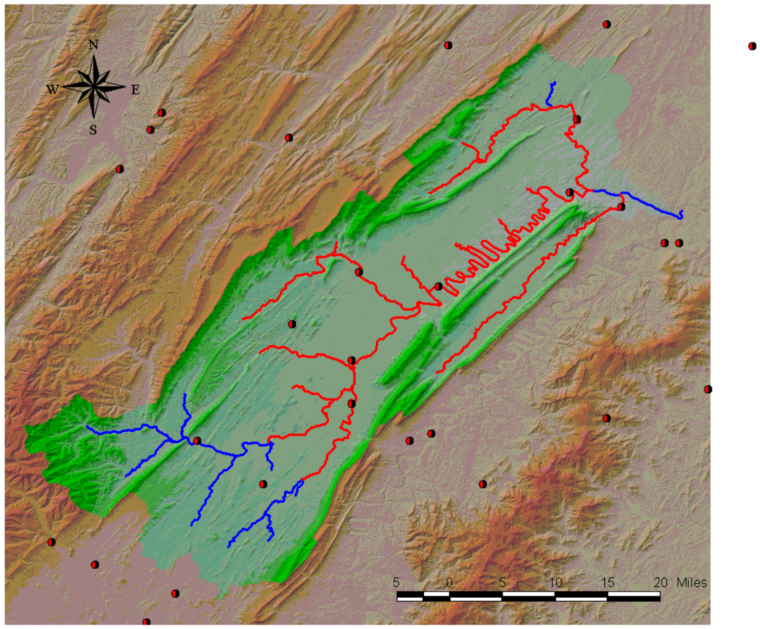


Figure 4.21 Gages In and Near Study Area

The points representing the gage locations are attributed with total and contributing drainage areas and the mean, standard deviation, and coefficient of skew of the flood frequency curve at the gage. If the total drainage area of the gage is less than the drainage area of the upstream node and greater than the drainage area of the downstream node of the reach associated with the gage, the gage is assumed to be on that reach. If not, the gage is removed from the gage feature table. That is, the gage is not used in subsequent analyses. For example, no gages with less than the threshold drainage are used in subsequent analyses.

4.2.2.4 Automated Adjustments

Note there are two categories of reaches for which the algorithms have or may have underestimated the drainage areas. Drainage areas for reaches on the main streams do not include the area beyond the study region that drain to the reaches. Drainage areas associated with those reaches are underestimated by at least 100 square miles (the default drainage area threshold). Therefore, gages located on main streams will not be used in subsequent hydrologic analyses. Recall that the default flood frequency data incorporates the gage information and will be used for reaches on the main streams.

Drainage areas associated with reaches downstream of the selected reaches may be underestimated. Tributaries that are not selected but flow into reaches that are downstream of the selected reaches do not survive the culling algorithm. Drainage area calculations on down stream reaches do not include areas draining to those tributaries. Before comparing the gage drainage areas with the reach drainage areas, the drainage areas associated with downstream reaches identified as containing a gage are adjusted.

The adjustment uses the watershed grid and the accumulation grid. A new grid is created. Cells in the new grid corresponding to cells contained in the group in the watershed grid that are associated with the reach are given the value of the corresponding cell in the accumulation grid. All other cells in the new grid are given a value of zero. The maximum cell value of the new grid is the number of cells draining to the downstream node of the reach. That number minus the number of cells in the group identified in the watershed grid is the number of cells draining to the upstream node. Dividing each of those numbers by the number of cells in one square mile yields the respective drainage areas.

Those drainage areas are compared to the drainage areas at the gages associated with the reach. Gages not satisfying the drainage area test are deleted from the feature table, leaving only those gages that will be used in the hydrologic analyses.

4.2.3 Hydraulic Analyses

Hydraulic analyses are performed to determine the flood depths along the reach. Flood depths are determined by defining a flood surface grid and subtracting the ground elevations at corresponding cells in the DEM. The resulting grid defines the spatial distribution of flood depths. Cells with positive values form the floodplain. The idea is illustrated in Figure 4.22.

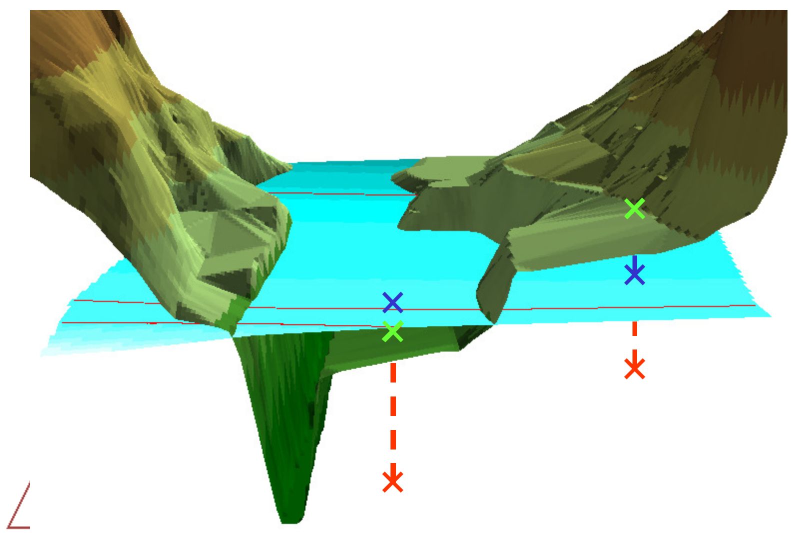


Figure 4.22 Surfaces Used to Develop Flood Depth Grid

The description of the hydraulic analyses begins with a description of the flood surface mapping algorithms. Those algorithms create a flood surface grid using a DEM, a polygon representing a floodplain, two line segments representing the up- and downstream limits of the study reach, and a set of line segments representing cross sections attributed with flood elevations. Those data can be user supplied or determined by Hazus using the default databases and the DEM.

4.2.3.1 Mapping the Flood Surface

There are default (level 1) options in Hazus that approximate the floodplain associated with a stream reach, find the up- and downstream limits of that approximation, generate a set of cross sections within the reach, and attribute those cross sections with flood elevations and discharge values. There are also options to import the results of applying the Flood Information Tool (FIT) to more detailed, user supplied floodplains, limits, cross sections, and flood elevation data. Creating the flood surface for the Model requires a means to interpolate flood elevations between the cross sections.

Consider the sample reach and set of cross sections shown in Figure 4.23.

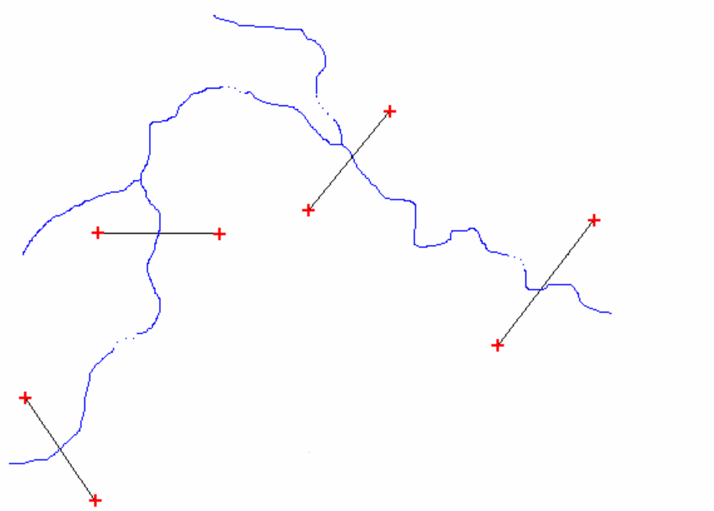


Figure 4.23 Sample Reach and Cross Sections

In many cases connecting the end points of the cross sections would suffice for enveloping the lateral extent of the floodplain and interpolating flood elevations. In some cases, such as that illustrated in Figure 4.24, simply connecting the end points of the cross sections creates obvious errors. A large portion of the floodplain between the middle two cross sections was not captured by the interpolation scheme. The two middle cross sections need to be extended or, alternatively, one or more intermediate cross sections need to be added and attributed with the appropriate elevation information. Note also that the interpolation scheme missed a portion of the floodplain between the left two cross sections.

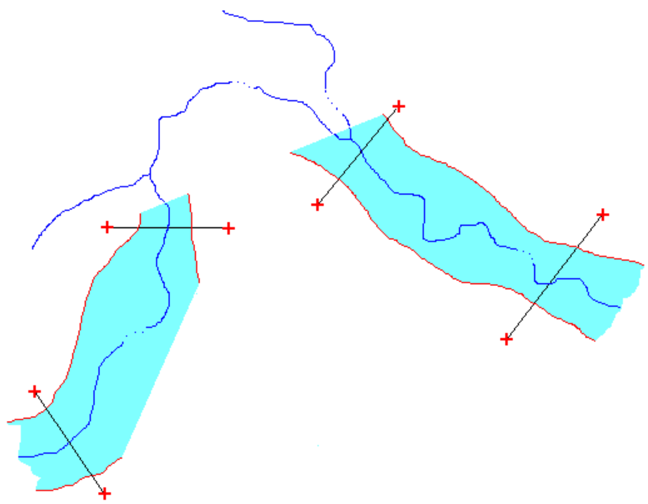


Figure 4.24 Interpolation Error

To avoid those problems, the algorithm in Hazus uses an estimate of the floodplain to define lines along which elevations are interpolated. In particular, for any polygon representing a floodplain, Hazus uses up- and downstream limits of the polygon to define right and left boundaries and a "centerline." The bounding polygon is defined by buffering the centerline. Flood elevations are interpolated between cross sections along the centerline.

The algorithms that create flood surface data in FIT and Hazus are, essentially, the same. Defining the centerline of the floodplain is fundamental to those algorithms.

The following example is from an application of FIT. Note that the "reach" in the example is defined by up- and downstream limits not necessarily located at nodes in the stream network. Users of FIT may define reaches of any length.

Figure 4.25 shows a portion of the floodplain contained on the Q3 map for Travis County, Texas. The source of flooding is Williamson Creek. The study reach is within the City of Austin. The flow direction is from west to east. Figure 4.25 also shows the base flood elevation (BFE) lines digitized from the Flood Insurance Rate Map (FIRM). The base flood is the flood magnitude having a 1-percent annual chance of being exceeded.

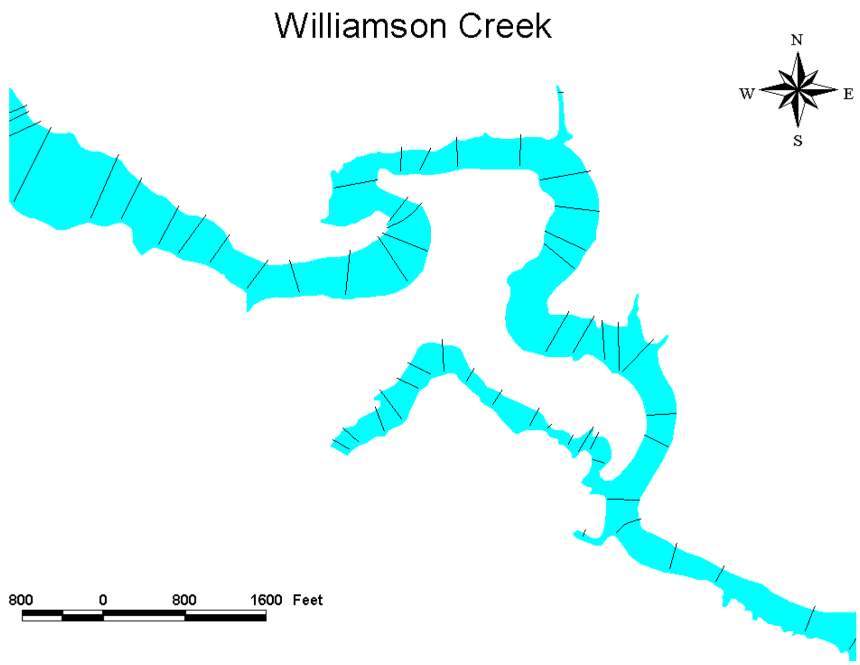


Figure 4.25 Example Data: Floodplains from Q3 Map and Cross Sections from FIRM

The tributary entering from the west is labeled Williamson Creek Tributary 4 on the FIRM. The floodplain associated with the tributary is part of the same polygon as Williamson Creek on the Q3 map. The BFE lines associated with the tributary are contained in the list of cross sections for Williamson Creek. That is, the input data does not distinguish between Williamson Creek and Williamson Creek Tributary 4. The distinction is accomplished by defining a centerline through the study reach.

Defining the up- and downstream study limits establishes study reach, its flow direction and, consequently, the right and left sides of the floodplain. The study reach shown in Figure 4.26 is approximately 2 miles long.

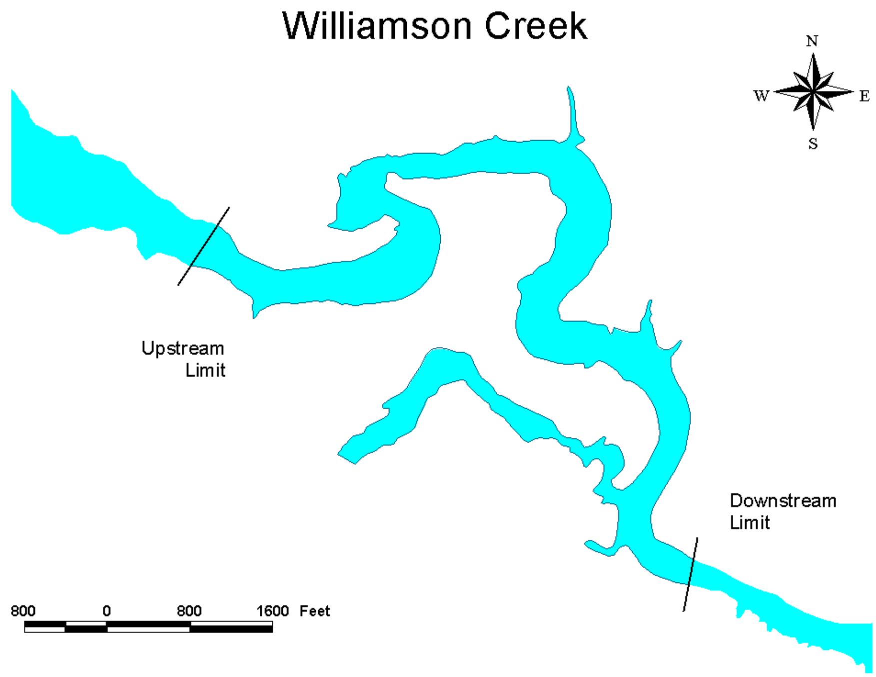


Figure 4.26 Up- and Downstream Study Limits

The boundary of the polygon containing the study reach is defined by converting the polygon to a polyline. In that case the resulting polyline is a continuous line that starts and ends at the same point. The process is illustrated in Figure 4.27. Note that the polygon includes its interior. The polyline is the boundary of the polygon. Even though the polyline starts and ends at the same point, it is not recognized as a closed line.

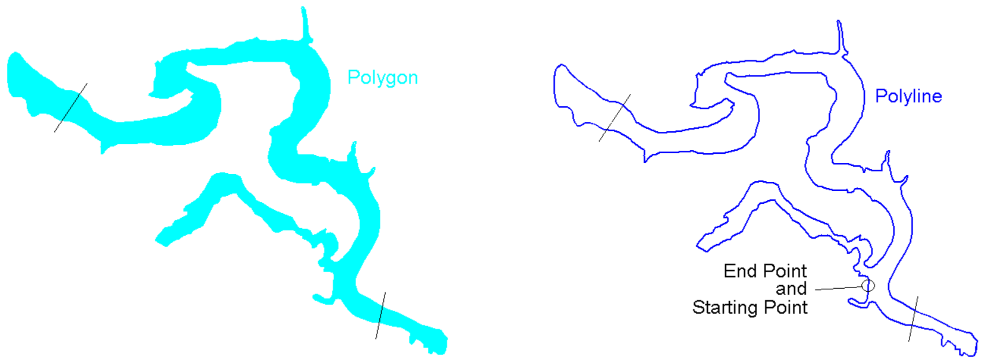


Figure 4.27 Converting a Polygon to a Polyline

The algorithms for finding the left and right boundaries and the centerline manipulate polygons with no holes, or islands, in their interiors. Before applying the algorithms to polygons with islands (doughnut-shaped, for example) the islands must be removed. To accomplish that, the polygon is converted to polylines, the polylines are converted to lists of points, and polygons are made from those lists. The union of those polygons forms the floodplain polygon without islands.

The polyline is split, or clipped, into four or five polylines by the up- and downstream limits. If the starting point and end point fall on one of the limits the split results in four polylines, otherwise it results in five polylines. The clipping is illustrated in Figure 4.28.

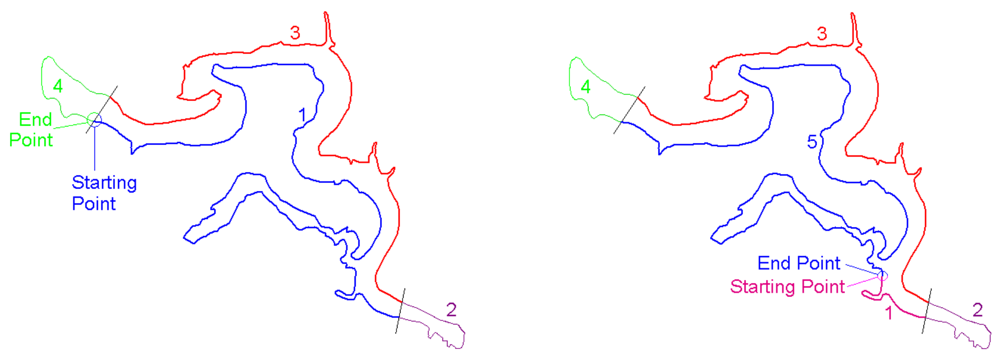


Figure 4.28 Clipping the Polyline

The floodplain boundaries within the reach are found by assessing the intersections between the limits and the polylines from the polygon. Each polyline that intersects both the up- and downstream limits is a floodplain boundary. There is at least one such polyline. If two such polylines are identified, the starting and end point is located either on a limit (four polylines) or outside (up- or downstream) of the reach. In either case, the two polylines intersecting both limits are the floodplain boundaries.

If only one polyline intersects both limits, there are five polylines. Two of those polylines intersect one of the limits twice. Those two polylines are outside of the reach. The remaining two polylines are merged to form the other floodplain boundary.

Polylines have direction. Both boundaries are checked to ensure that the direction is from upstream to downstream. If the direction of a boundary does not meet that convention, the boundary is “flipped.” One boundary is compared to other to set a convention for right and left. Is the second boundary is right of the first boundary, the first boundary is the left boundary; otherwise it is the right boundary.

Just as the polyline that is the boundary of the floodplain polygon was split into several polylines, the up- and downstream limits are split into three polylines. For each limit, that polyline segment whose midpoint is contained in the polygon is identified. The segments are checked and, if necessary, flipped to ensure that the direction of each is from the left boundary to the right boundary. The segments are stored as the clipped limits.

Once the right and left boundaries are defined, a "centerline" of the study reach can be defined. The idea is to define a path that captures the overall flow direction within the floodplain. The portion of the floodplain that conveys floodwater can be estimated by tracing the boundaries of the floodplain "smoothing" out the areas of backwater and omitting the tributaries. Here, "backwater" areas mean areas where water is not conveyed but, rather, pond at the elevation of the main stream. The center of those smoothed boundaries defines a path that preserves a sense of flow direction and (relative) distance within the floodplain.

Imagine a circle centered somewhere on the upstream limit and with a radius such that it just touches the right and left floodplain boundaries. That is, the circle is inscribed in the floodplain. As the circle moves downstream, adjusting its size and position so that it is always inscribed in the floodplain, its center follows the path we seek.

A property of that path is every point on the left side of the path is closer to the left floodplain boundary than the right floodplain boundary. Every point on the right side of the path is closer to the right floodplain boundary than the left floodplain boundary. The path is, in some sense, a centerline. The algorithm to define the centerline exploits that property.

The algorithm begins by defining a polygon using the up- and downstream limits and the right and left boundaries. To do that, the up limit and right boundary are flipped, making the direction continuous. The vertices of the polylines are added to a list in order (left, down, right, up) and that list is used to define the clipped polygon. The smallest rectangle that contains the clipped polygon is found and expanded five cell sizes. A cell size is the posting of the DEM.

A grid is created with a posting equal to the DEM posting and bounded by the rectangle. Each cell in the grid is closer to one floodplain boundary or the other. Attributing each cell with the closest floodplain boundary partitions the rectangle into two regions. The boundary between those regions is the centerline.

One of the regions is converted to a polygon which, subsequently, is converted to a polyline. That polyline is divided by the clipped polygon. The resulting polyline segments that are contained in the clipped polygon are identified and merged. The resulting polyline is the centerline. It is checked and, if necessary, flipped to ensure that its direction is upstream to downstream. Applying that algorithm to the Williamson Creek reach results in the centerline shown in Figure 4.29.

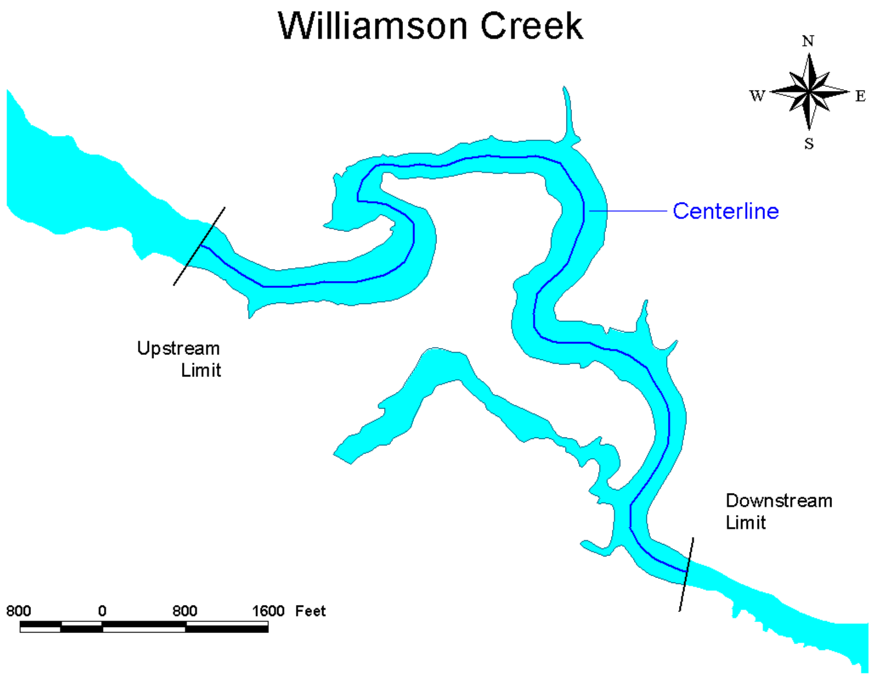


Figure 4.29 Define Centerline

As shown in Figure 4.30, the BFE lines associated with the study reach are those lines that intersect the centerline. The BFE lines are ordered from up- to downstream by measuring the distance to their intersections with the centerline along the centerline. The centerline is also used to establish the right side-left side convention (looking downstream).

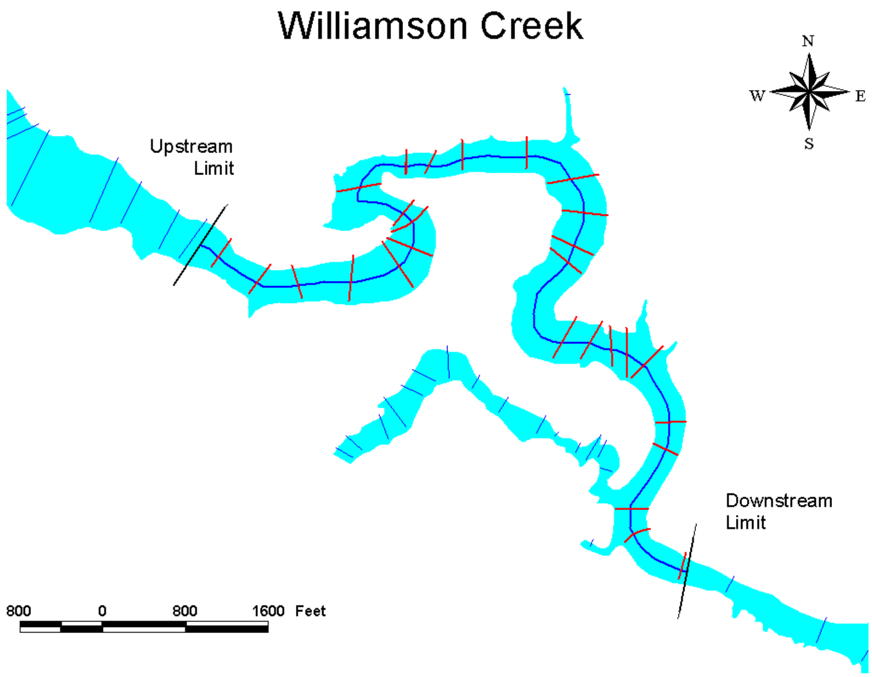


Figure 4.30 Identify Cross Sections with Centerline

A buffer around the centerline is created. A buffer is a polygon that is everywhere the same distance from the object it buffers. Moving a circle of radius r along the centerline from one end point to the other traces a buffer of distance or size.

The buffer is used to define the bounding polygon. In Level 1 analyses, the buffer size is ten times the square root of the largest discharge value determined for the reach. The user selects the buffer size in FIT. The flood surface computations will be confined to the bounding polygon. The flood surfaces around tributaries and backwater areas are added later.

If necessary, the up- and downstream study limits are extended to the edges of the buffer. In FIT, the limits are extended with the orientation at their endpoints. That is, the extension is a straight line passing through the end point being extended and the closest point to that end point. The ramifications of extending the limits in a straight line should be considered when using FIT. The limits derived for Level 1 analyses are the most upstream and downstream cross sections (derived by Hazus). They are extended as cross sections.

As with the floodplain, the buffer polygon is converted to a polyline and clipped using the extended limits. The clipped buffer and extended limits form the bounding polygon. The results of the process for the Williamson Creek example are shown in Figure 4.31.

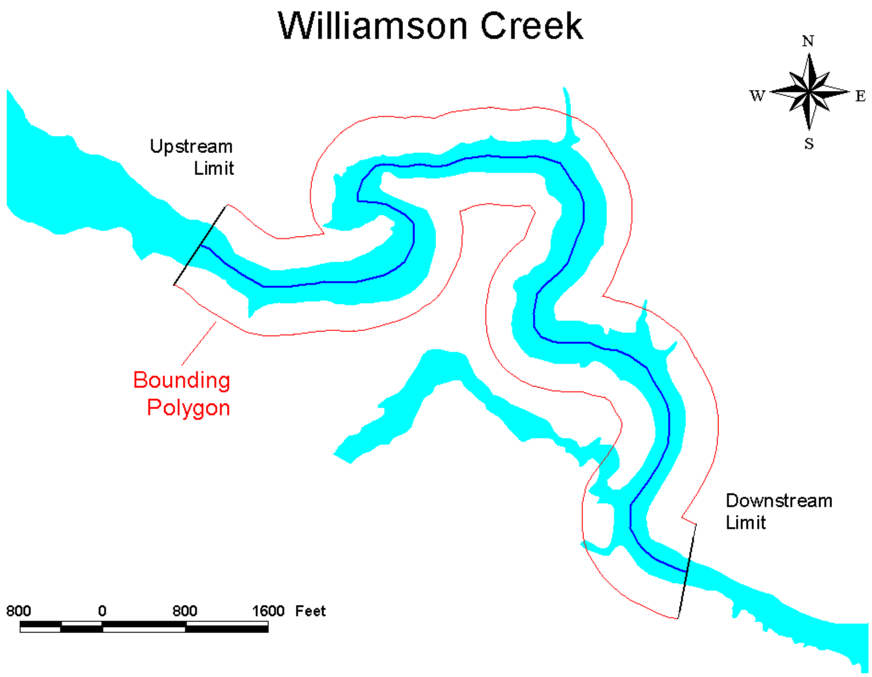


Figure 4.31 Bounding Polygon

A series of buffers is created at regularly spaced intervals between the centerline and the bounding polygon. Each buffer is converted to a polyline and clipped at the up- and downstream study limits. The result is a partitioning of the bounding polygon into semi-parallel flow corridors similar to dividing the conveyance area of the floodplain into flow tubes.

As each buffer is created, the end points of each BFE line are checked to determine whether they are contained within the buffer. If not, the cross section is extended to the point on the edge of the buffer closest to end point of the BFE line. Extending the BFE lines that way aligns the extended portions perpendicular to the flow corridors.

The flow corridors and extended BFE lines for Williamson Creek are shown in Figure 4.32. Note that, on the "inside" portions of the meanders, several extensions can coincide.

The width of each "corridor" in the figure is exaggerated for illustrative purposes. The actual spacing for computations is the cell size chosen for the flood surface grid.

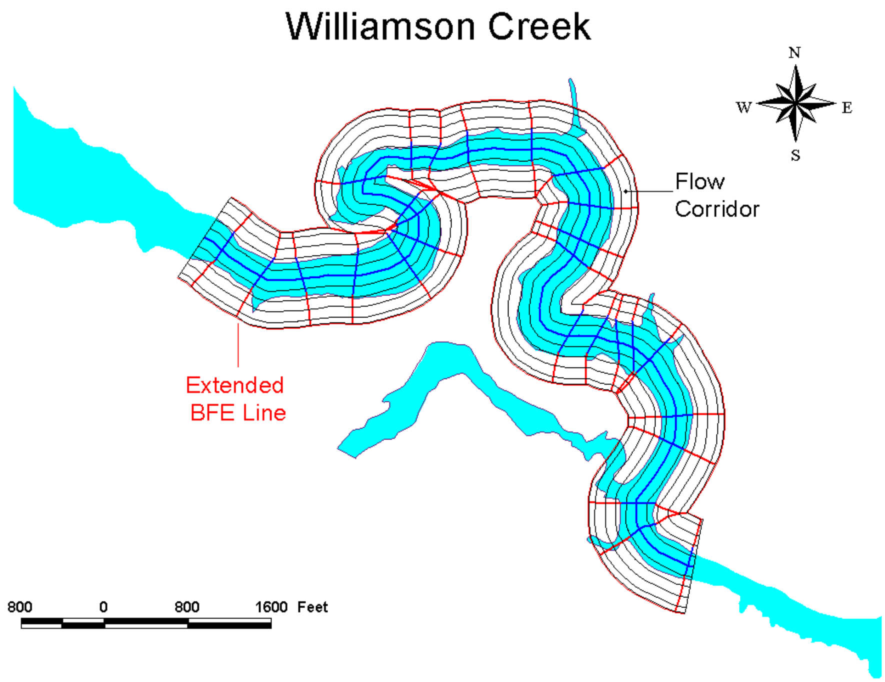


Figure 4.32 Extended Cross Sections

Between BFE lines, elevations are interpolated. Points are identified at regular intervals, equal to the flood surface grid spacing, along the centerline. At each point, the ratio of the distance, along the centerline, to the upstream BFE line and the distance between the up- and downstream BFE lines is determined. The difference in elevations associated with the up- and downstream BFE lines is determined and multiplied by that ratio. Subtracting the result from the elevation associated with the upstream BFE line yields the interpolated elevation at the point on the centerline.

The process applied to the centerline is repeated at each flow corridor edge. That is, rather than interpolating BFE lines to determine the location of an interpolated elevation, the interpolated elevations are evenly spaced along each flow corridor edge. In general, the number of interpolated points between cross sections varies from corridor to corridor and from left side to right side of the centerline.

The result is an irregularly spaced grid of points formed along the flow corridors. The elevation information is stored in the feature table for the collection of points. In addition to the flood elevation, each point is attributed with the interpolation ratio and the identification (record number) of the upstream cross section (BFE line in the example).

Figure 4.33 shows the grid for Williamson Creek. Consistent with Figure 4.32, the point spacing shown in the figure is exaggerated. The actual spacing for computations is the cell size chosen for the flood surface grid.

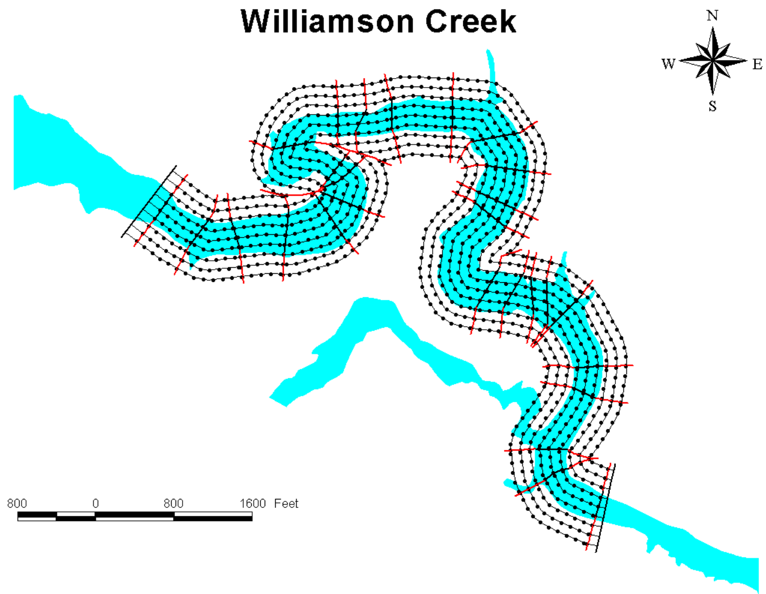


Figure 4.33 Irregularly Spaced Elevation Grid

A surface is created from the points in Figure 4.33. The surface is stored in a regularly spaced grid. The elevation at each cell in the grid is a weighted average of the elevations of all points in the irregular grid (Figure 4.33) within a distance equal to 1.5 times the cell size chosen for the surface grid. The average is weighted by the inverse of the distance to each such point.

The flood surface cell size used to develop the Williamson Creek example is 10 feet. There are actually over 97,000 points in the irregular grid represented by Figure 4.33. The flood surface developed using the process is shown in Figure 4.34. Flood elevation contours are shown on Figure 4.34 to help visualize the surface.

The flood depth grid is created by subtracting (cell-by-cell) the ground elevation, contained in the DEM grid, from the flood elevation. The flood depth grid for Williamson Creek is shown on Figure 4.35. Note that a few backwater areas and, in particular, Tributary 4 are not entirely covered by the grid. Algorithms for analyzing such areas are described in Section 4.2.3.2.9, Nonconveyance Areas.

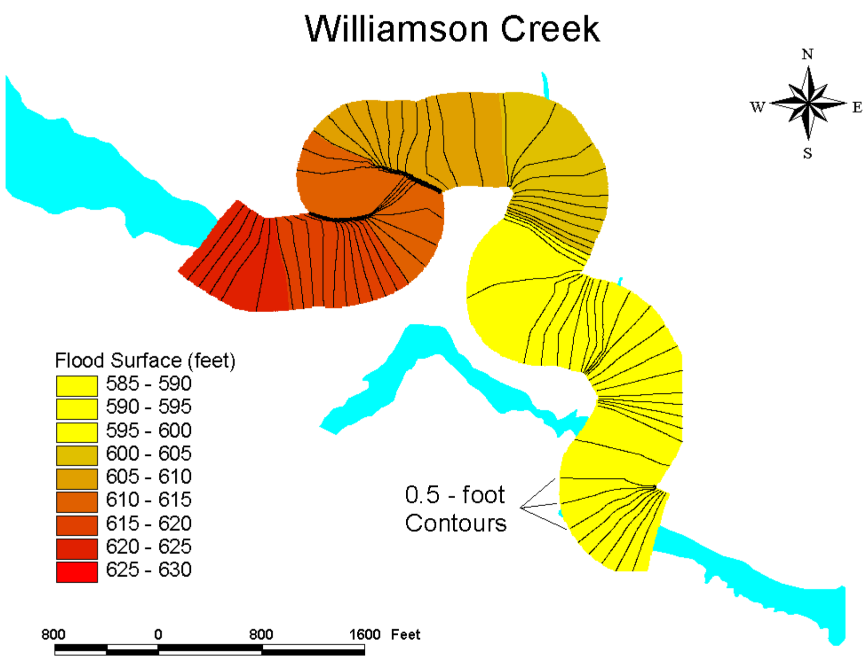


Figure 4.34 Flood Surface

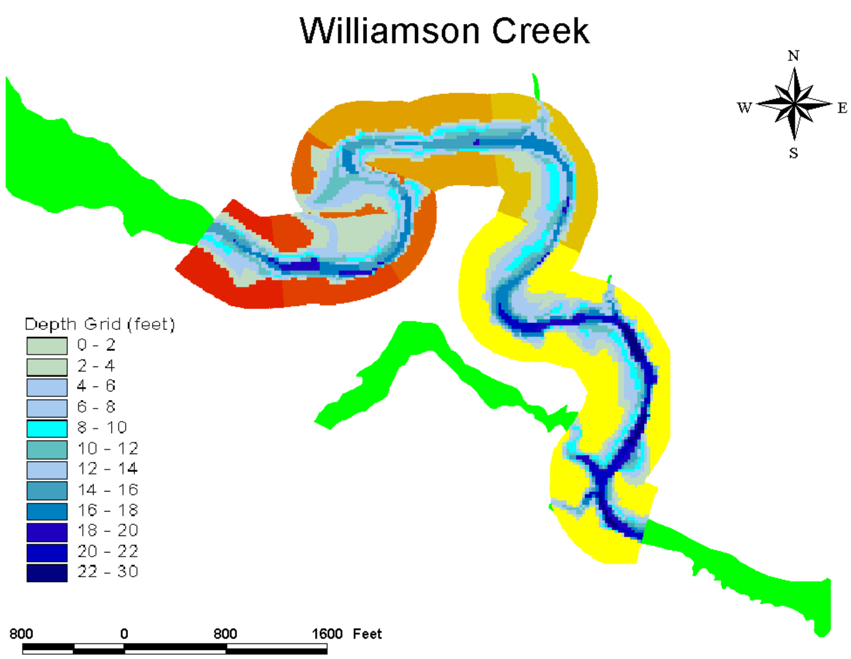


Figure 4.35 Flood Depth Grid

4.2.3.2 Default Hydraulic Analyses

The default or Level 1 hydraulic analyses are performed through a series of estimates of the floodplain. Floodplain limits are estimated and, then, used to define a set of cross sections that are, subsequently, used to refine the floodplain estimate. Flood elevations are estimated using Manning's equation with a friction slope equal to the slope of the reach (i.e., normal depth calculations). The flood elevations are used to redefine the floodplain limits; the new limits are used to adjust the cross section alignments; and so on.

Manning's equation relates the velocity of a unit mass of floodwater to the friction slope, s_f, the roughness, expressed as a coefficient, n, and the hydraulic radius, R, of the floodplain. The hydraulic radius is the area divided by the perimeter of the submerged portion of the cross section. Multiplying that equation by the submerged area, A, yields the discharge value,

$$Q = \frac{1.486}{n} A R^{2/3} \sqrt{s_f}. \tag{4-6}$$

The discharge values used in Manning's equation are interpolated as power functions of drainage area, A, between the up- and downstream nodes of each study reach:

$$Q = \alpha A^{\beta}. \tag{4-7}$$

The two parameters, α and β, that define the power function are stored in two tables: the alpha and beta tables. In the flood frequency table created by the hydrologic analysis algorithms, pairs of records, n and n+1, where n is even starting with zero, represent the up- and downstream nodes of a reach selected for study. Each field other than the first (the reach identification field) and second (the drainage area field) represents a specific frequency.

For each pair of records in the flood frequency table, a record is created in the alpha and beta tables. The integer part of the reach identification in the flood frequency table is put in the first field of the alpha and beta tables. The remaining (frequency) fields are populated as follows.

The difference between the base 10 logarithms of the values in the drainage area fields is computed (downstream area minus upstream area). For each frequency, if the discharge values at both the up- and downstream nodes are not greater than zero, zeros are put in the corresponding fields in the alpha and beta tables. Otherwise, the difference (downstream minus upstream) between the base 10 logarithms of those values is computed. If the difference between the base 10 logarithms of the areas is zero, a zero is put in the frequency field of the beta table. Otherwise, the ratio of the two differences, β, (the difference between the base 10 logarithms of the discharges divided the difference of the base 10 logarithms of the drainage areas) is put in the frequency field of the beta table.

At each node, the base 10 logarithm of α is computed as the base 10 logarithm of the corresponding discharge value minus beta times the base 10 logarithm of the corresponding drainage area. The final value of α is 10 raised to the average of the two α. That value is put in the frequency field of the alpha table.

Using the alpha and beta tables, the discharge value of a given frequency can be readily calculated for cross sections placed arbitrarily along the chosen reaches. The point at which the cross section intersects the reach is identified and the drainage area is computed using the value of the corresponding cell in the accumulation grid. The drainage area is raised to the value in the beta table corresponding to the reach and frequency. Resulting value is multiplied by the value in the alpha table corresponding to the reach and frequency. That product is the discharge value at the point in question corresponding to the frequency being investigated.

The hydraulic analyses are performed on individual reaches, one at a time. One of the selected reaches is chosen. The chosen reach is identified in the feature table representing the reaches selected from those meeting the drainage area threshold (see *Section 4.2.1 Identifying Stream Reaches*) and the reaches draining to the selected reaches. The downstream reach is identified. It is the reach attributed with an upstream node identifier that equals the downstream node identifier of the study reach. If a downstream reach exists, the study reach is extended into the downstream reach to create an "overlap" with the downstream reach.

The reach is extended downstream. The point on the downstream reach 450 feet or one-half of its length from the upstream node, whichever is less, is identified. The portion of the downstream reach upstream of that point is added to the downstream end of the study reach. That is, the "extension" follows the same path as the downstream reach. If no downstream reach exists, the study reach is an outlet reach and the "extended" reach is the same as the study reach.

The first flood depth grid created is associated with the frequency having the largest discharge value. The point 90 percent of the length of the study reach from its upstream node is identified. The value from the flow accumulation grid at that point is determined and drainage area there computed. A list of discharge values is made using the alpha and beta tables. The maximum discharge value is determined and inserted at the beginning of the list. That value is the reference discharge value used to estimate the extent of a polygon, the bounding polygon that will contain the conveyance portions of the floodplains associated with all frequencies analyzed in the hydrologic analysis. As mentioned in the previous section, the default "buffering distance" of the bounding polygon is set at ten times the square root of the reference discharge value.

4.2.3.2.1 Initial Cross Sections

A buffer is created around the extended reach. The buffering distance is two times the cell size (posting) of the DEM. Up- and downstream limits of the buffer are created using the extended reach. An example of a buffered extended reach is shown in Figure 4.36. For illustrative purposes, the buffer distance in Figure 4.36 is much greater than two cell sizes.

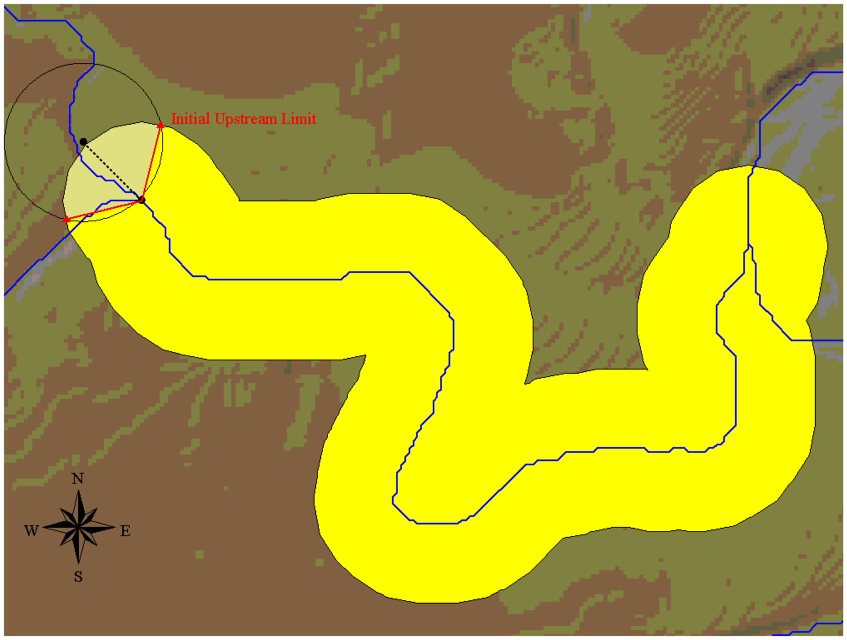


Figure 4.36 Buffered Reach

A line is projected from the upstream node through the buffer. The projection is along the same bearing as the most-upstream section of the extended reach. A circle is created centered where the projection intersects the buffer with a radius equal to the buffer distance. A polyline is created using the points where that circle intersects the buffer and the upstream point of the extended reach. That polyline is the upstream limit. The process is shown in Figure 4.36. The downstream limit is defined the same way.

Islands are removed from the buffer, it is converted to a polyline, clipped, and the centerline of the buffer is determined. That centerline is not the extended reach. In general, the centerline of a buffer about a polyline is not that polyline.

Cross sections are equally spaced along the centerline at intervals no greater than 1000 feet. The number of cross sections is, therefore, two plus the integer value of the length of the centerline divided by 1000. The first cross section is located at the upstream end of the centerline; the remaining cross sections are located at intervals, measured along the centerline, equal to the length of the centerline divided by one less than the number of cross sections. The last cross section is the located at the downstream end of the centerline. Thus, if the centerline is less 2000 feet long, the number of cross sections is three: the up- and downstream ends and one more at the midpoint of the extended reach. The cross sections are, at this point, stored in a list.

Each cross section is oriented by connecting the centerline point to the points on the right and left boundaries, closest to the centerline point. Specifically, the points that define the polyline representing the cross section are arranged form the left boundary to the centerline to the right boundary, assuring a left-to-right direction. The first and last cross sections become the up- and downstream limits, respectively.

The cross sections are extended by buffering the centerline a number of times at equally spaced buffering distances ranging from three cell sizes to the buffering distance of the bounding polygon (ten times the square root of the reference discharge value). The buffering distance is increased one cell size until the bounding polygon is exceeded.

For each buffer created, the algorithm removes the islands and, then, connects the end points of the up- and downstream limits to the nearest points on the (polyline) boundary of the buffer. The polyline is clipped and the end points of each cross section are extended to the closest points on the respective boundaries (of the clipped polyline). That is, the left end point is extended to the left boundary; the right end point is extended to the right boundary. The points defining the cross section polylines are arranged to ensure a left-to-right direction. The first and last cross sections become the up- and downstream limits and the process is repeated at the next buffering distance.

The buffering and extending algorithms create limits that tend away from the floodplain. The initial upstream limit shown in Figure 4.36, for example, is “v-shape” tending “away” from the buffer. After the cross sections have been extended, the end points of the downstream limit are check to ensure they are within the coverage of the DEM. The downstream cross section (limit) of an outlet reach oriented somewhat perpendicular to the edge of the DEM may not be covered by the DEM. If both end points of the downstream cross section are not within the DEM coverage, that cross section is deleted from the list making the next cross section upstream the most downstream cross section and, therefore, the downstream limit.

4.2.3.2.2 Initial Flood Elevation Estimates

A feature table is made to store the cross sections from the cross section list.

Flood elevations are computed using Manning’s equation. In addition to cross section geometry, two parameters are needed for Manning’s equation: a roughness coefficient, or n-value, and a friction slope. The default n-value is 0.08. The friction slope is calculated using the DEM. It is determined by fitting a straight line through data obtained at 101 points, evenly spaced at 1 percent intervals along the reach (not centerline and not the extended reach).

The data are stored in two lists. One list stores the distances to the points along the reach from upstream to downstream. The first entry in that list is zero (upstream). The other list stores the values (elevations) of the cells in the DEM that contain the points. The line is fit to that data by the method of least squares. The slope of that line is used as the friction slope for all cross sections in the reach.

Recall Manning’s equation times area:

$$Q = \frac{1.486}{n} AR^{2/3} \sqrt{s_f} \,. \tag{4-8}$$

Given the discharge value, Q, N-value, n, and friction slope, sf, the only unknown parameters are functions of the flood depth or elevation. Because the geometry of a natural floodplain cross section is not regular, those functions are unknown and, therefore, the algorithm to solve Manning's equation is iterative. That is, one starts with an elevation, computes the area, A, and hydraulic radius, R, below that elevation, and calculates the discharge value. The elevation is adjusted by comparing the calculated discharge value with the known value.

In Hazus, the first elevation is computed by adding a depth to the elevation at the point on the cross section where it intersects the extended reach. That depth is estimated by assuming the floodplain is an isosceles triangle. Assuming that geometry the functions relating area, hydraulic radius, and depth are known. Given the other parameters, Manning's equation can be solved directly.

The average elevation of the right and left boundaries is computed. Similar to the slope calculations, 101 points are sampled at intervals equal to one-percent of the length of each side of the bounding polygon. The "depth" of the triangle is the average of the elevations at those 202 points minus the average elevation of the least-square-fit line used to define the slope.

The points at the intersections of each cross section and the reaches (study reach or downstream reach) are found. At each point the value of the flow accumulation grid is determined and the drainage area associated with that value is calculated (i.e., the value times the number of cells per square mile). The reference discharge value is computed using the drainage area and the interpolation coefficients in the record associated with reach in the alpha and beta tables. Those discharge values are stored in a list.

The values of the DEM at those points are also determined and stored in a list. Those values are the "streambed" elevations.

The length of each cross section is determined and the average of those lengths is computed. That average is the "topwidth" of the triangle. Twice the depth of the triangle divided by its topwidth is the side-slope, Ss, of the triangle. Assuming the topwidth is much greater than the depth (small side-slope) the perimeter is only slightly greater than the topwidth. In that case the hydraulic radius is approximately equal to the average depth or one-half the triangle depth. To summarize, the depth, d, in an isosceles triangle cross section can be approximated as,

$$d \cong \left(\frac{1.07 n Q S_s}{\sqrt{s_f}} \right)^{3/8}. \tag{4-9}$$

A reference depth is computed by adding a (arbitrary) "channel" depth of three feet to the depth estimate from applying the above equation using the maximum value in the list of reference discharge values. The flood elevation estimate is the "streambed" elevation of the cross section plus the reference depth.

Each cross section is attributed with the elevation estimate, the n-value, the slope, and the reference discharge value.

4.2.3.2.3 Revised Flood Elevation Estimates

The elevation estimate is revised by defining the "true" geometry of the cross section using the DEM. For each cross section, points are added to the list of vertices that define the polyline. In particular, points are added between vertices so that there is a point every cell size along the polyline. Two lists are made from that augmented list of points. One list stores the distance from the left most (starting) point of the polyline (i.e., the station). The other list, the ground elevation list, stores the elevation from the DEM.

The algorithm maintains a list of polygons representing areas below the flood elevation that are isolated from the extended reach by expanses of DEM cells with elevations greater than the flood elevation. Those polygons represent pools of floodwater not "hydraulically" connected to the conveyance portion of the floodplain. For purposes of defining cross section geometry, the elevations of points contained in one of those pool polygons are stored in the ground elevation list as very high (over 1,000,000 feet). The list is empty at this point in the analysis.

Maximum and minimum flood elevations are set by adding and subtracting 50 feet, respectively, from the initial estimate. The stations at which the flood elevation estimate equals the ground elevation on the DEM are found and stored with the other elevation-station data. For each point on the cross section, the station is stored in another list, an expanded station list. The difference between the flood elevation estimate and the ground elevation is stored in a list, the difference list. If the difference has a different sign (plus or minus) than the previous point, the station at which the difference is zero is calculated. That station is added to the expanded station list and a zero is added to the difference list. The station and difference at the point being investigated are then added to their respective lists.

Values from the difference list are read sequentially. If two adjacent values (depths) are greater than or equal to zero the area under water between the two points is average of the values times the difference in the corresponding stations from the expanded station list. The wetted perimeter between the two points is the square root of the sum of the squares of the depth difference and the station difference. The sum of those pair-wise areas and wetted perimeters are kept. After reaching the ends of the lists, the total area and wetted perimeter are used to calculate the hydraulic radius and the discharge value associated with estimated flood elevation.

If the calculated discharge value is less than the reference discharge value at the cross section, the minimum flood elevation is replaced by the estimated flood elevation. Otherwise the maximum flood elevation is replaced by the estimated flood elevation. The mean of the minimum and maximum flood elevations is used as the revised flood elevation estimate. If the difference between the minimum and maximum flood elevations is greater than 0.01 feet, the process is repeated up to 20 times. If the process has been repeated 20 times or the difference between the maximum and minimum flood elevations is less than 0.01, cross section is attributed with the last flood elevation estimate. The estimate is the reference flood elevation. The initial elevation estimates in the cross section feature table are replaced with the reference flood elevation.

4.2.3.2.4 Remove Pools

With a centerline, bounding polygon, and set of cross sections identified, the mapping algorithms create the irregular spaced grid of points and the regularly spaced flood elevation grid. Subtracting the DEM from the flood elevation grid yields a difference (depth) grid. The difference values (depths) less than zero are set to "no value." That is accomplished by taking the square root of the difference grid and squaring the result. A function operating on a grid returns "no value" for cells attributed with values for which the function is not defined, square root of a negative number, for example.

Setting the cells in the depth greater than zero to one and the remaining cells to zero creates a floodplain grid. The floodplain grid is converted to a polygon feature table. The polygons in that table may be a collection several disconnected polygons. If a bridge crossing a stream is reflected in the DEM, the floodplain could be divided into an upstream portion disconnected from the downstream portion. Because the flood elevation grid covers the entire bounding polygon, any depressions in the ground surface lower than the flood elevation and reflected in the DEM will be included in the floodplain polygon. Areas of ponds or "pools" that do not convey floodwater must be removed from the cross section geometry used in the flood elevation calculations.

Each polygon in the feature table is tested. If it does not intersect the centerline, the polygon is added to a list of pools and removed from the feature table. As mentioned earlier, as the each point is selected for defining cross section geometry, the algorithm checks if it is contained in any of the polygons in the list of pools. The elevation of any point contained in a pool is set very high, thereby omitting it from the area (and, therefore, conveyance) calculations.

Figure 4.37 shows the initial cross sections assigned to a tributary of Irwin Creek in Charlotte, North Carolina. Note the deep gravel mining operation north and east of the upstream portion of the study reach. The gravel pit affects the three most upstream cross sections. The first estimate of the flood depth grid from that data is shown on Figure 4.38. Without removing the area of the gravel pit from the calculations, the submerged area and wetted perimeter are at the bottom of the pit. The flood elevation interpolation between the most upstream cross section not in the pit and most downstream of the cross sections affected by the pit results in a flood surface 50 feet and more below the ground surface at the stream channel. The latter cross section is shown in Figure 4.39.

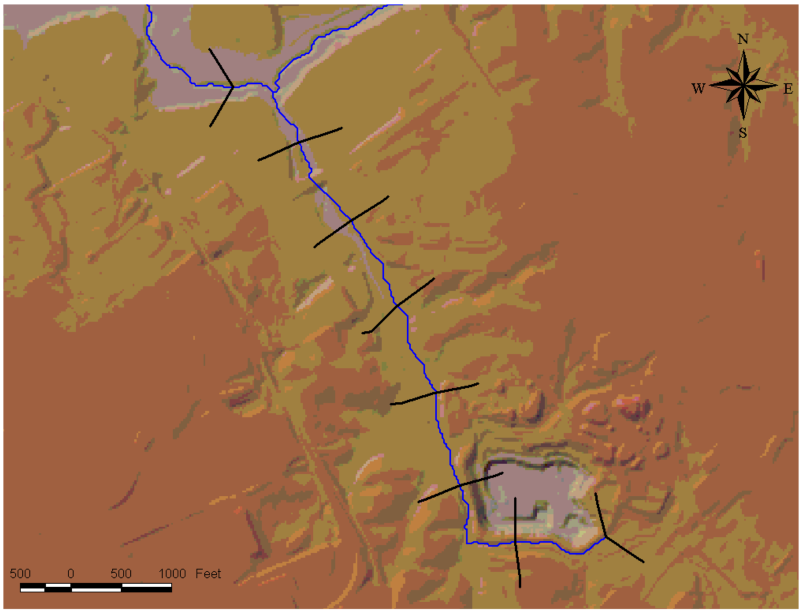


Figure 4.37 Initial Cross Sections along Tributary to Irwin Creek

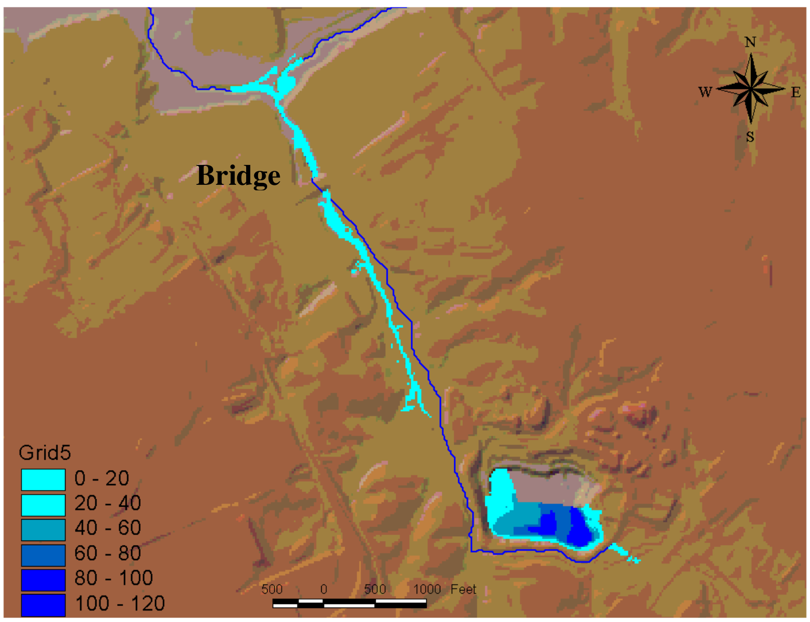


Figure 4.38 Pool in Gravel Pit along Tributary to Irwin Creek

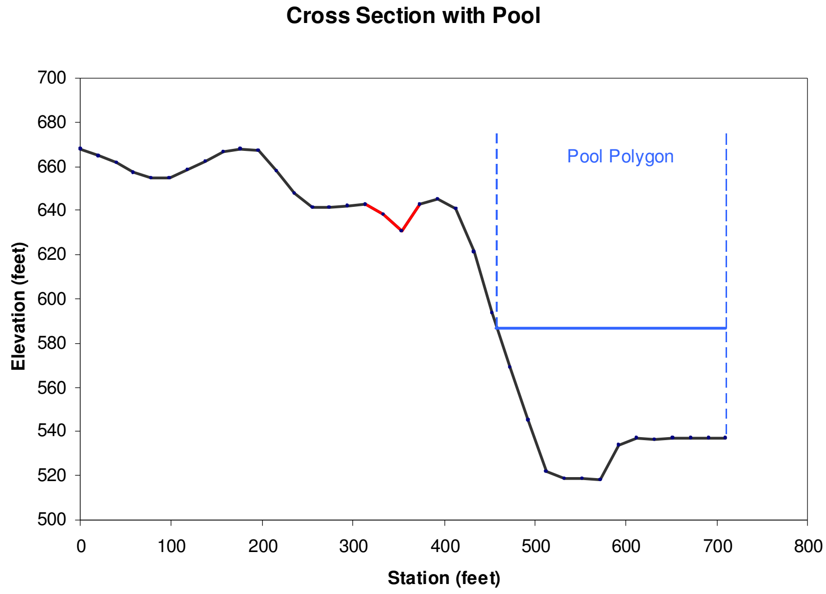


Figure 4.39 Cross Sections Affected by Gravel Pit

The true channel in Figure 4.39 is shown in red. Because the centerline does not intersect the polygon representing the pool in the gravel pit, that polygon is added to the pool list. The flood elevation estimates are recalculated with all points on the cross section shown on Figure 4.39 between the blue dashed vertical lines assigned very high elevation values. The cross sections are attributed with those new estimates.

Each point in the irregular grid (see Figure 4.33, for example) is attributed with a new elevation. Because each point was attributed with the interpolation ratio and the identification of the upstream cross section, the grid need not be reconstructed. The new elevation at each point is the elevation of the downstream cross section plus the difference between the up- and downstream cross sections times the interpolation ratio.

Removing the pools tends to increase the flood elevation estimates and may create more pools. Additional, the polygons associated with deep pools may not cover enough of the pool to eliminate its affects. Note that as in Figure 4.39 only that portion of the pool at elevations less than the flood elevations are contained in the polygon. There may be portions of the pool with ground elevations greater than the first flood elevation estimate but less than the revised flood elevation estimate. The portion of the cross section just left of the left dashed line in Figure 4.39 is such an area. Those portions should be omitted from the flood elevation calculations.

The difference between the last flood elevation calculation and the previous estimate is determined at each cross section. If the sum of the squares of those differences is less than one, the pools have been successfully removed. Otherwise, the latest depth grid is converted to floodplain grid and, then, a polygon, increasing the list of pools. The flood elevation estimates are recalculated, first at the cross sections, then at each of the points in the grid of irregularly spaced points. A new depth grid is created from the points and the sum of the squares of the differences in the flood elevation estimates is computed. The process continues until that sum is less than one, signaling that all pools have been removed (from the calculations).

The result of the algorithm applied to the tributary of Irwin Creek is shown in Figure 4.40. Note that the floodplain now includes the stream channel on the upper portion of the study reach.

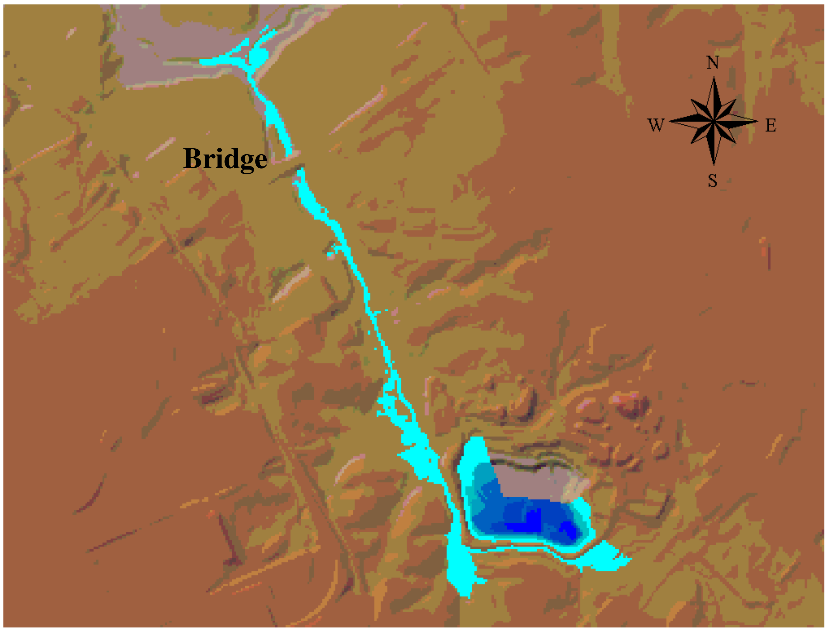


Figure 4.40 Floodplain along Tributary to Irwin Creek

Because Figure 4.40 shows the flood depth grid, the pool is included. It has depths greater than zero. The grid is converted into floodplain grid and, then, a polygon. The pool is not included in the polygon feature table representing the floodplain. Recall that as pools are added to the list of pools, the corresponding polygons are removed from the feature table.

The collection of polygons, without pools, defines the floodplain associated with the flood elevations calculated as described. There are at least two polygons representing the floodplain calculated for the tributary. Note the break in the floodplain at the location labeled "bridge" in Figure 4.40. The placement and orientation of the cross sections used to calculate the flood elevations are not necessarily compatible with the floodplain. A new set of cross sections is defined.

4.2.3.2.5 New Limits and Centerlines

Centerlines are defined for each polygon. Up- and downstream limits are determined for each polygon and, then, the centerline of each polygon is determined. The new centerlines are used to define the new set of cross sections. Figure 4.41 shows a possible configuration of floodplain polygons, centerline, and cross sections.

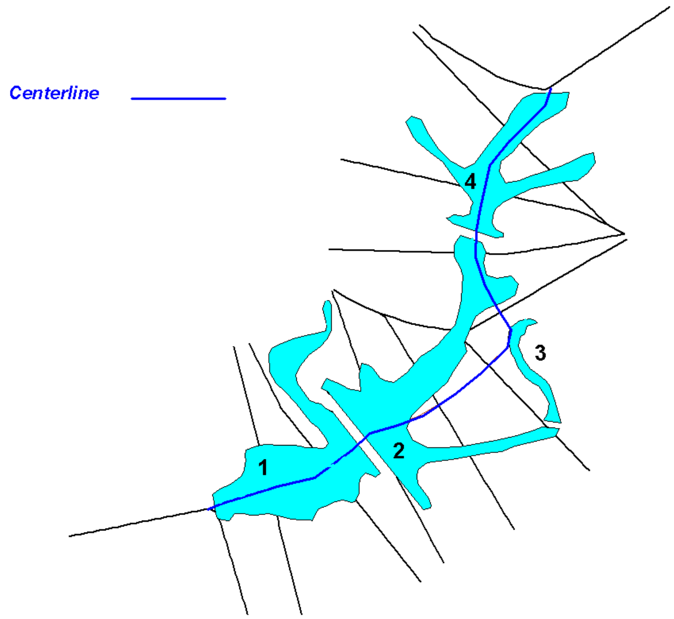


Figure 4.41 Floodplain Polygons

Because of the apparent road crossing between Polygons 1 and 2, the algorithm that created the direction grid (see *Section 4.2.1 Identifying Stream Reaches*) increased the DEM cells in the region upstream of the crossing until all cells had a downstream neighbor. Doing so misaligns the reach and, consequently the centerline, in the vicinity of that region. Note that the floodplain follows the “true” path. The situation was not mentioned earlier but can be seen in Figure 4.38 upstream of the bridge.

For each polygon, a list is made of all cross sections that intersect the polygon. The list is ordered from upstream (first entry) to downstream (last entry). If the first cross section in the list is the most upstream cross section for the reach, it is the upstream limit of the polygon. Likewise, if the last cross section in the list is the most downstream cross section for the reach, it is the downstream limit of the polygon. Note that each cross section intersects at least one polygon and can intersect more than one polygon (i.e., appear in more than one list). Also, flood plain polygons may exist that do not intersect any cross section.

If the first cross section in the list is not the most upstream cross section for the reach, the cross section in the reach just upstream of the first cross section in the list is identified. It is the closest (in terms of centerline distance) cross section to the upstream limit of the polygon that does not intersect (is outside of) the polygon. The points where those cross sections intersect the centerline are identified as the “in” point and “out” point, respectively. The point along the centerline midway between those points is identified.

The points on the left and right bounding polygon boundaries that are nearest that centerline point are identified and a new cross section is created with the three points. If that new cross section does not intersect the polygon, its intersection with the centerline becomes the out point. If it does intersect the polygon, that intersection becomes the in point. Ten such cross sections are created so that the distance between the in point and out point is less than one foot.

After ten iterations, a cross section is made from the three points defined by the in point and the closest points on the bounding polygon. If that cross section intersects the polygon, it is the upstream limit of the polygon. If that cross section does not intersect the polygon, the in point is the original in point from the first cross section in the list (the most upstream original cross section that intersects the polygon). The situation occurs when that in point is not contained in the polygon. The cross section made from three points may not intersect the polygon. The first cross section in the list does. That cross section is the upstream limit.

If the last cross section in the list is not the most downstream cross section in the reach, the downstream limit is determined the same way as just described for the upstream limit.

If no cross sections intersect a polygon, the center point of the section of centerline contained in the polygon is identified. A cross section is created at that point as just described, and that cross section becomes both the first and last cross section in the list. The limits are determined using the same algorithm.

Lists are made to assign a sense of order or direction among the polygons. Consider a polygon that intersects cross sections 3 through 10; and another polygon that intersects cross sections 4 through 8. Which polygon is the "upstream" polygon?

A list of the floodplain polygons is made from the feature table. As the up- and downstream limits are determined for each polygon, the points (up point and down point) at which those limits cross the centerline are added to one of two lists corresponding to the polygon list. The information in the up point and down point lists records the extent or "length" of the polygons as projections onto the centerline, thus recording a sense of direction. The projection of a polygon onto the centerline is the portion of the centerline between the up point and the down point.

To ensure that each limit intersects the polygon exactly twice, the polygon is modified slightly. A buffer at a distance of one cell size is created around each limit. A new polygon is formed from the union of those buffers and the polygon. The islands are removed from the polygon resulting in a slightly modified polygon that the limits intersect exactly twice each.

Centerlines are created between the limits as described in *Section 4.2.3.1 Mapping the Flood Surface*. Some of the polygons within a reach may be quite narrow (in terms of number of DEM cells). In those situations the centerline may not be continuous and/or it may not intersect both limits. The centerline is checked. If it is not continuous or it does not traverse the entire polygon, the polygon is modified slightly.

The modified polygon is the union of the polygon and a one-cell-size buffer around the centerline. The centerline of the new polygon is created and checked. The algorithm is repeated until the centerline is continuous and it intersects both limits. Note that the only difference from the original polygon is that the new polygon is two cells "wider" at locations where the original polygon was originally one or two cells wide.

4.2.3.2.6 Conveyance Limits

Associated with each polygon in the reach is a left boundary, right boundary and centerline. Those lines are used to define left and right "conveyance" limits within the floodplain limits. The conveyance limits are "smooth" boundaries within which floodwater is conveyed. The limits are used to determine whether the bounding polygon (buffer) is large enough.

Points are identified along the centerline spaced at a distance of one cell size. Two lists of points, one for each side of the floodplain, are created. Each list consists of the points on the floodplain boundary closest to the points on the centerline. Because the centerline points are ordered from upstream to downstream, the lists created along the boundaries are ordered from upstream to downstream. A polyline is created from each list.

Connecting the upstream end points of the left conveyance limit polyline (point 1), the polygon centerline (point 2), and the right conveyance limit polyline (point 3) creates an upstream limit. Similarly, a down stream limit is created by connecting the downstream end points. The conveyance limit polylines are combined with the up- and downstream limits to make a polygon.

Circles are created, centered at each of the points on the centerline and having a radius equal to the average minimum distance to the left and right boundaries (i.e., to the points contained in the aforementioned lists). The union of those circles and the polygon discussed in the preceding paragraph defines the conveyance polygon. Two parts of the boundary of the conveyance polygon are the conveyance limits.

Before clipping the boundary with the up- and downstream limits, a couple of details must be checked.

The limits are checked to ensure that both "sides" of each limit intersect the boundary of the polygon. A side in this context is the portion of the limit polyline connecting two points: points 2 and 1 or points 2 and 3. If any side does not intersect the polygon, the point on the polygon boundary closest to end point of the side is identified. In that situation, the limit is revised by replacing the end point (either point 1 or 3) with that closest point.

If the up- and downstream limits share an end point, either the right or left conveyance limit (or both) does not exist. In that situation, a circle with a radius of one-half a cell size is centered on the common end point. The up- and downstream limits are redefined by replacing the common end point with the closest point on the intersection of that circle and the conveyance polygon.

The boundary of the conveyance polygon is clipped with the revised up- and downstream limits resulting in a left conveyance limit and a right conveyance limit. Those limits are essentially, the boundaries traced by a circle, inscribed in the floodplain, traversing the (extended) reach. The conveyance limits for a typical floodplain are shown in Figure 4.42.

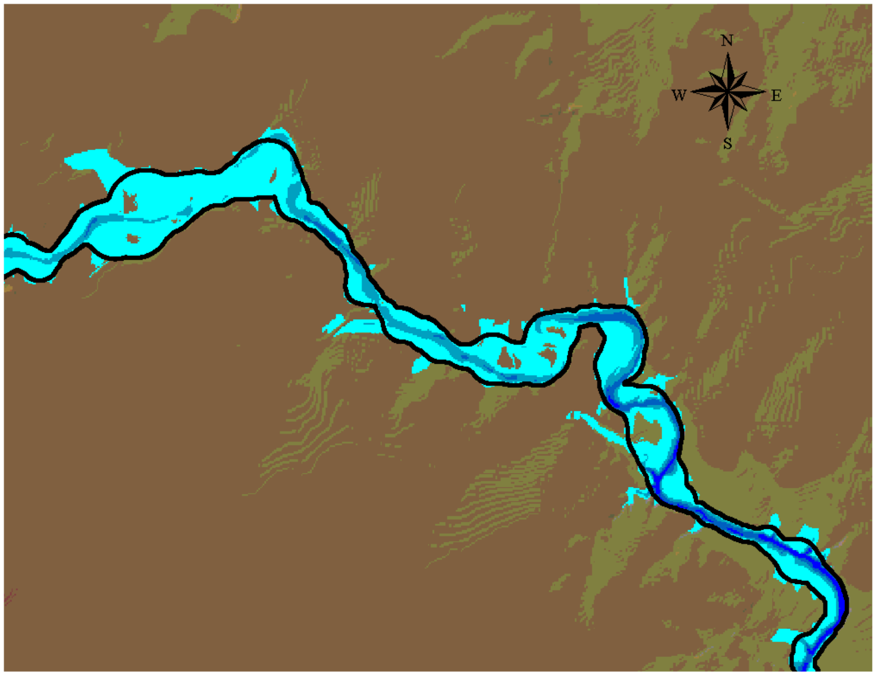


Figure 4.42 Conveyance Limits

If the bounding polygon is everywhere "wider" than the conveyance polygon, the bounding polygon is wide enough. Because the polygons will probably intersect at the up- and/or downstream limits, the "wide enough" test compares left and right boundaries. Specifically, the left and right boundaries of the bounding polygon are buffered one cell size. If neither the left nor the right conveyance limit intersects those polygons (the buffered boundaries) the bounding polygon is wide enough. Failing that test, the bounding polygon is increased.

Increasing the bounding polygon is, in effect, adding more points to the irregularly spaced grid of points. The Minimum distance between the centerline and the right or left boundary defined by the outermost clipped buffer used to create the irregularly spaced points is the bounding polygon buffer distance. If the bounding polygon is not wide enough, more buffers (around the centerline) are added, one at a time, at buffering distances increasing by one cell size. Buffers are added until the buffering distance is 15 percent greater than the bounding polygon buffering distance.

The mapping algorithms are applied (see *Section 4.2.3.1 Mapping the Flood Surface*). As each buffer is added, any islands are removed and the boundary is defined as a polyline. The up- and down stream limits (first and last cross sections) are extended to the boundary; the boundary is clipped by the extended limits; and each cross section is extended to the right and left (clipped) boundaries. Points are located along both boundaries at one-cell- size intervals. The reference flood elevations are interpolated and each point is attributed with the reference flood elevation, the upstream cross section identifier, and the interpolation ratio.

The points are converted to a flood surface grid. The DEM is subtracted creating a flood depth grid that is converted to a floodplain grid. The floodplain grid is converted to floodplain polygons (only polygons that intersect the centerline). The boundaries and the up- and downstream limits of each polygon are found; the boundaries are clipped and the conveyance limits are defined. The conveyance limits are compared with the outermost buffer to check if the new bounding polygon is wide enough. The process is repeated until the bounding polygon is wide enough or its width is double its original width (five iterations).

The flood elevations are not recalculated while testing the width of the bounding polygon. As the area available (bounding polygon) for conveyance is increased the conveyance will, if anything, increase, thereby decreasing the flood elevation estimate. Decreased flood elevation estimates will not increase the estimated floodplain width and, consequently, the width between the conveyance limits. Thus, if the bounding polygon is wide enough for the current flood elevation estimates, it is wide enough for recalculated estimates based on a wider floodplain.

4.2.3.2.7 Final Estimates

The centerline is redefined using the centerlines of the floodplain polygons. Recall that three lists were made storing the polygons and the up- and downstream points of projections of the polygons onto the centerline. The lists are associated with each other through their order. For example, the location of the upstream point of the second polygon in the polygon list is the second number in the up point list. The centerlines of the polygons in shown in Figure 4.41 are shown in Figure 4.43.

A fourth list is created to store a reordering sequence, upstream to downstream, of records of the other three lists. The record of the smallest value in the upstream point list is the first entry in the reordering list; the record next smallest value is the second entry; and so on. In Figure 4.43 the order of polygons is **4,2,3,1**.

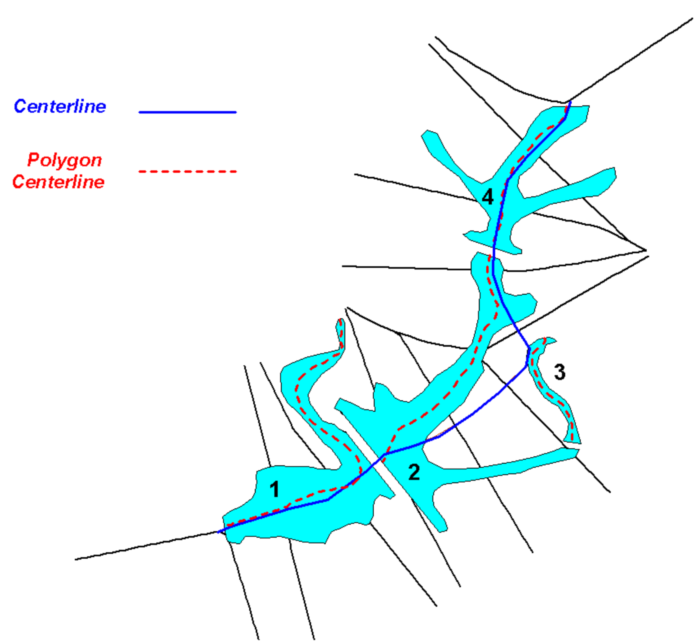


Figure 4.43 Polygon Centerlines

The projection of each polygon centerline onto the centerline is compared with the other projections. The record numbers of polygons whose projections are contained in another's projection are identified. Those polygons and their associated data are removed from the four lists. Polygon **3** in Figure 4.43 meets that criterion. That is, the location (on the centerline) of the up point of Polygon **3** is greater than the location of the up point of Polygon **2**; and the location of the down point of Polygon **3** is less than the location of the down point of Polygon **2**.

An additional consideration in ordering the polygons is the location of the most upstream cross section that (if any) intersects the polygon. For each polygon, the next downstream polygon as defined by the up points is unique (after the culling process in the proceeding paragraph has been applied). However, there may two or more polygons that intersect the next downstream cross section. In that situation, the polygon with the most downstream point (the longest one, in some sense) is "chosen." Other polygons intersecting the cross section and their associated data are removed from the four lists.

Each of the remaining polygons, except the most downstream polygon, share one of two possible configurations with a unique (in both up point and next cross section) downstream polygon. Either there is a gap between their projections (i.e., the location of the down point of the upstream polygon is less than that of the up point of the downstream polygon); or their projections overlap. Polygons **4** and **2** have a "gap", Polygons **2** and **1** "overlap."

The algorithm "connects" the polygon centerlines by building a list of the points (vertices) that defines the connected centerline. The overall list begins with the vertices in the most upstream polygon centerline. If there is a gap before the next downstream polygon, the list of vertices of the downstream polygon centerline is added to the overall list.

If there is an overlap with the next downstream polygon, some of the points in the list of vertices of the downstream polygon centerline must are removed. The intersection of the most upstream cross section and the polygon centerline is determined and all points located upstream of that point are remove from the list. The intersection point is inserted at the beginning of the list. The list is then added to the end of the overall list.

The process continues until the list of vertices associated with the centerline of the most downstream polygon is added to the overall list. The resulting overall list of points is converted to a polyline, the center of the polygons.

Cross sections are realigned using the center of the polygons and the conveyance limits. Starting at the upstream end, the points where each cross section intersects the center of the polygons are determined. Because the intersection may be at more than one point, the algorithm eliminates intersections not contained in the conveyance polygons and finds the most upstream intersection that is not upstream of the next upstream cross section. That point is the middle, or second, of three points used to define the cross section.

The remaining two points are determined using the conveyance limits associated with cross section. The conveyance limits are those associated with the conveyance polygon that contains the middle point. The left, or first, point is the closest point on the left conveyance limit. The center of polygons may intersect the left conveyance limit of a polygon (Polygon **1** in Figure 4.43, for example) that "overlaps" the upstream polygon. The algorithm checks for that situation and, if it exists, moves the left point downstream along the left conveyance limit one cell size. The right, or third, point is identified similarly.

The cross section in the feature table is replaced by the polyline defined by the three (left, middle, and right) points. Reference flood elevations are calculated for the new set of cross sections using the algorithm for solving Manning's equation. The cross sections are attributed with those elevations and a new grid of irregularly spaced points (see Figure 4.33) is created.

The distance between each vertex in the bounding polygon and the center of polygons is determined and the maximum of those distances is identified. The center of polygons is buffered that maximum distance and any islands are removed. The resulting polygon is the new bounding polygon.

A polygon is created from the union of the conveyance polygons and the center of polygons buffered one cell size. The islands are removed from that polygon and it is converted to a polyline. That polyline is clipped, using the upstream most and downstream most cross sections as the up- and downstream limits. The process results in two (left and right) continuous conveyance limits. The cross sections are extended to the bounding polygon and the irregularly spaced points are defined and attributed as described in *Section 4.2.3.1 Mapping the Flood Surface*. Those points are used to define the flood surface and, subsequently, the flood depth grids.

4.2.3.3 Non-conveyance Areas

To complete the development of a flood depth grid, areas where flood waters are not conveyed but, rather, pond at the elevation on the main stream need to be identified, attributed with the main stream flood elevation, and added to the flood depth grid. The approach uses the technique, discussed in *Section 4.2.1 Identifying Stream Reaches*, to define the direction grid.

Recall that the value of each cell in a direction grid denotes the neighboring cell which defines the steepest descending path. If, however, the elevation at a cell is lower than that of each of its neighbors, there are no descending paths. Such cells are referred to as sinks. For purposes of defining flow networks on DEMs, sinks are typically removed or, more accurately described, filled-in. Filling-in sinks may create larger sinks composed of several neighboring cells that flow to the original sink. The "filling" process is iterative and continues until all sinks are filled and the DEM is "hydrologically" correct.

A sink could be the result of a DEM including the top of a bridge crossing a stream. The filling routine would continue until all portions of the floodplain upstream of the bridge are "filled" to the elevation of the lowest point on the bridge or surrounding ground. The result can be an artificial large flat area covering the floodplain and making the determination of flow directions difficult. To avoid having to find flow directions within large filled areas, the cells associated with certain segments of streams can be assigned artificially low elevations, or “burned” into the DEM.

By adding that portion of the flood depth grid within the conveyance boundaries to the DEM, we created sinks at places where the flood depths are greater than zero but flows are not conveyed. That is, the non-conveyance areas are treated as sinks.

Consider, for example, the reach shown in Figure 4.44. It is the most downstream reach of the North Fork of the Shenandoah River.

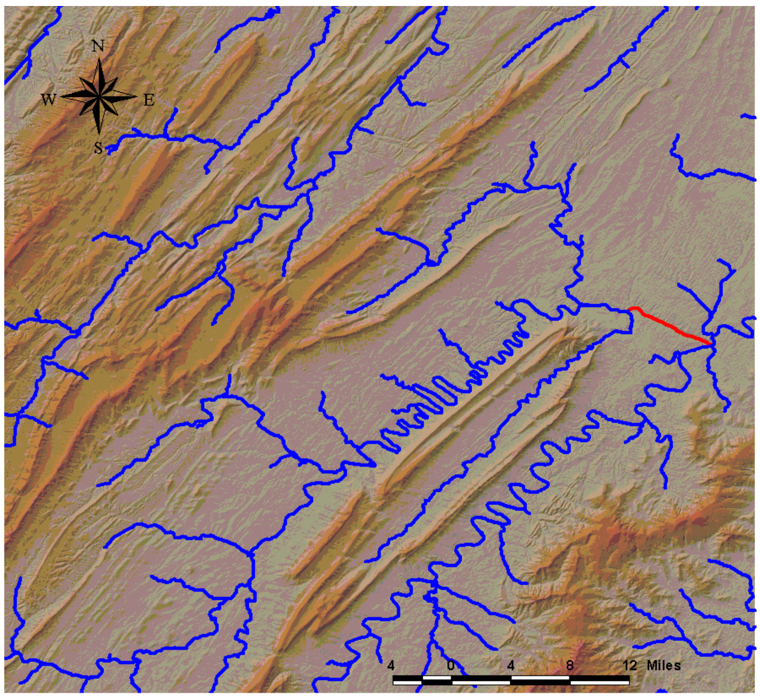


Figure 4.44 Downstream Reach, North Fork of the Shenandoah River

The centerline of the conveyance polygon and the reach through the downstream watershed are burned into the DEM. By burning the reaches, no “filling” will occur within the reach at elevations greater than non-conveyance areas. That is, bridges, for example, will not “overshadow” the floodplain.

Figure 4.45 shows the portion of the flood depth grid contained in the conveyance polygon for the example reach. Depth values at cells from that portion of the flood depth grid are added to the elevation values of the corresponding cells in the portion of the DEM covering the watersheds. The sinks in the resulting grid are filled. Call that filled grid the “wet” grid.

The sinks in the DEM covering the watersheds are filled, forming the “dry” grid. Outside of the conveyance polygon, the nonzero differences between the wet and dry grids are the flood depths in the non-conveyance areas. Those areas are shown in Figure 4.46. Merging those cells with the flood depth grid contained in the conveyance polygon yields the final flood depth grid.

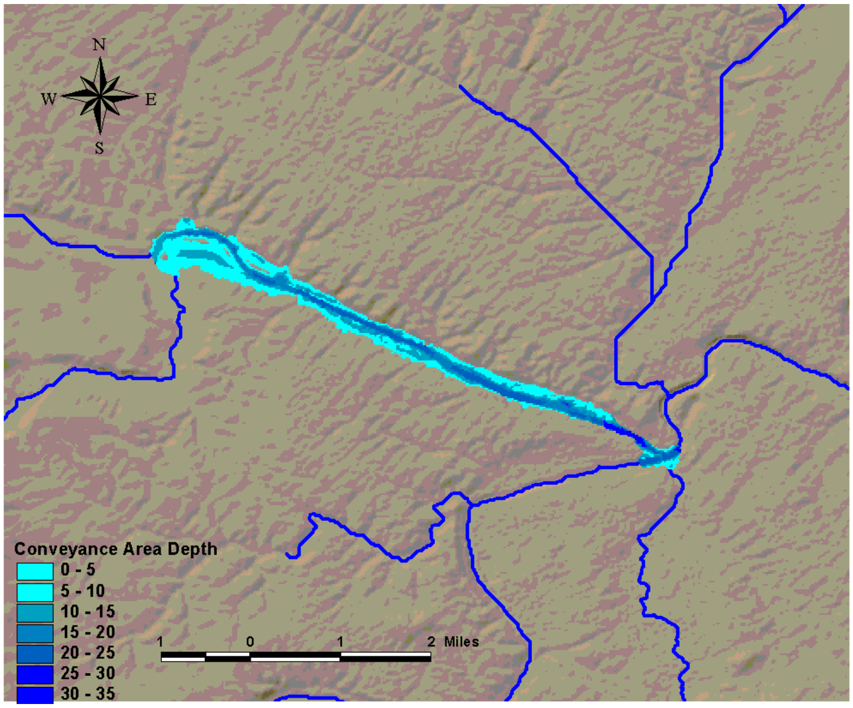


Figure 4.45 Flood Depths within Conveyance Area

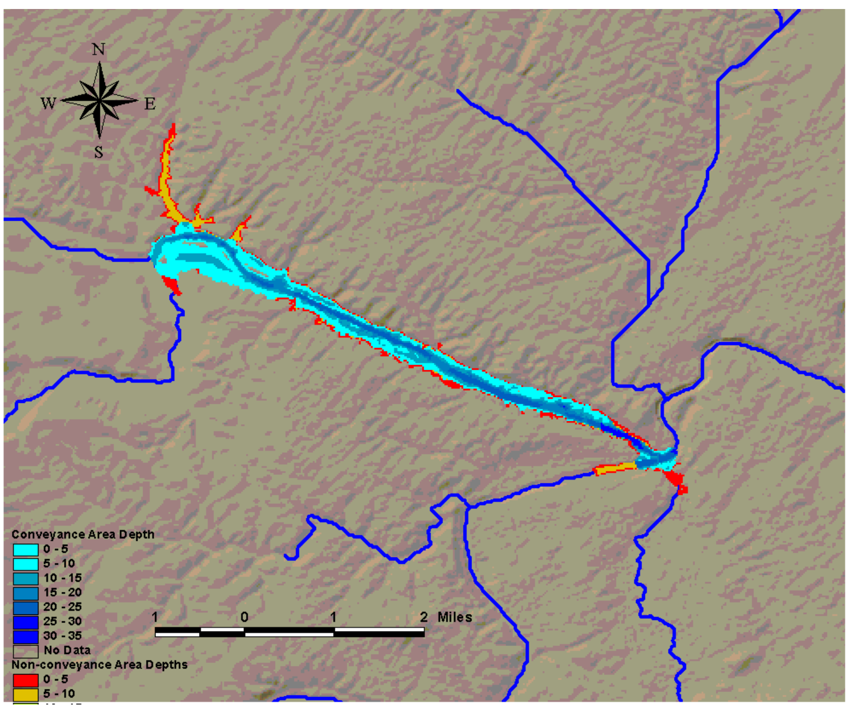


Figure 4.46 Flood Depths in Conveyance Areas

4.2.3.4 Calculating Flood Depths for Other Return Frequencies

A depth frequency relation at a given point provides a means to calculate the probability that the point is subject to flooding at least as deep as a given depth. For example, such a relation can be used to compare the probabilities of a point being flooded by 2 or more feet and being flooded by 5 or more feet. Depth frequency relations are required to estimate expected annual losses. Once the bounding polygon and nonconveyance zones are established, depth grids can be created for other floods by attributing the cross sections (or equivalent) with the appropriate elevations.

Depth grids are created for each frequency analyzed on each reach. For each reach, the cross section feature table is edited to include the discharge values and flood elevations associated with the 2-, 5-, 10-, 25- 50-, 100-, 200-, and 500-year floods. The elevations are subsequently added to the feature table representing the grid of irregularly spaced points. Those points are used to interpolate a flood elevation surface grid. The DEM is subtracted from that grid resulting in a flood depth grid for each frequency.

As described earlier (see *Section 4.2.3.2, Default Hydraulic Analyses*), discharge values are interpolated as power functions of drainage areas. The values are interpolated between the corresponding values at the up- and downstream nodes of the reach. A list of discharge values corresponding to the list of flood frequencies is made at each cross section. If no discharge value was determined for a given frequency, the list is given a value of zero. Recall that the largest value in the list is inserted at the beginning of the list and used as the reference discharge value in the hydraulic analyses. That value is deleted from the list and the calculations for all frequencies begin in order of increasing frequency. As each discharge or elevation value is computed, it becomes the reference value for the next frequency.

The cross section geometry is determined as discussed earlier (see *Section 4.2.3.2.3 Revised Flood Elevation Estimates*). The list of pools (see *Section 4.2.3.2.4, Remove Pools*) contains one polygon. That polygon is defined by removing the conveyance polygon from the bounding polygon. It is “doughnut-shaped” with the conveyance are being the “doughnut hole.” Recall that elevations at points along a cross section and within a pool are set very high. Thus only those portions of the cross sections within the conveyance area are used in the flood elevation computations.

The elevations are computed twice. The first computation uses the conveyance area from the previous frequency (using the reference values) to estimate the flood elevation. The feature table of irregularly spaced points is updated using those elevations and the interpolating values stored in the table (see *Section 4.2.3.1 Mapping the Flood Surface*). Those points are used to develop a flood surface grid from which the DEM is subtracted resulting in a flood depth grid. The flood depth grid is converted to a polygon and the conveyance area within that polygon is determined. That new conveyance area is used to define a new (doughnut-shaped) pool and the process is repeated.

The second flood depth grid is developed using the conveyance area associated with the frequency under investigation. The cells from that grid that are contained in the conveyance polygon are extracted to make the conveyance flood depth grid. One such grid is made for each (non-zero) frequency for each reach.

4.2.3.4.1 Depth Frequency

Creating several flood depth grids and recording the frequencies associated with respective flood events allows an estimate of the depth frequency relation. Similarly, given the depth frequency relation at a point, determining the depth associated with any frequency flood is a relatively easy computation.

Flood frequency is usually defined as a relation between the flood flow or discharge value on a stream reach and the probability that value is exceeded in a given year. Those values are generally taken to be log-Pearson Type III distributed. If Q is a log-Pearson Type III distributed random variable denoting the maximum annual discharge value at some location on a stream and $y_0 = \log_{10}(q_0)$ then the probability that the Q exceeds q_0 in any given year is

$$P[Q > q_0] = \int_{y_0}^{\infty} \frac{\lambda^k (y-m)^{k-1}}{\Gamma(k)} e^{-\lambda(y-m)} dy, \tag{4-10}$$

where m, λ, and k are the so-called location, scale and shape parameters, respectively, and $\Gamma(k)$ is the gamma function of k. In practice, the discharge value associated with a certain frequency flood is found using a table of normalized random variables. Each entry in the table represents the number of standard deviations between the mean of the distribution and the value, y_0, yielding the probability $P[Q>q_0]$. If μ_Q is the mean and σ_Q is the standard deviation of the Pearson Type III distribution the discharge value, q_0, with an annual probability, P, of being exceeded is

$$q_0 = 10^{\mu + K_{P,G_Q}\sigma}, \tag{4-11}$$

where $K_{P,G}$ denotes the normalized random variable which, as indicated, depends on the probability, P, and the coefficient of skew, G_Q. In terms of the distribution parameters,

$$\mu_Q = m + \frac{k}{\lambda}; \qquad \sigma_Q = \frac{\sqrt{k}}{\lambda}; \textit{ and} \qquad G_Q = \frac{2}{\sqrt{k}} \tag{4-12}$$

To assign frequencies to flood depths, the relation between discharge and depth must be known. That relation is referred to as a rating curve. Typically, rating curves are approximated by a series of power functions. That is, rating curves are piecewise described by power functions. For successive ranges, the depth is approximately proportional to the discharge raised to some power:

$$D = \alpha Q^{\beta} \tag{4-13}$$

If $z_0 = \log_{10}(d_0)$ and $y_0 = \log_{10}(q_0)$, then

$$y_0 = \frac{z_0}{\beta} - \frac{\log_{10}(\alpha)}{\beta} \tag{4-14}$$

and

$$P[D > d_0] = \int_{\frac{z_0}{\beta} - \frac{\log_{10}(\alpha)}{\beta}}^{\infty} \frac{\lambda^k (y-m)^{k-1}}{\Gamma(k)} e^{-\lambda(y-m)} dy \,. \tag{4-15}$$

Equivalently,

$$P[D > d_0] = \int_{z_0}^{\infty} \frac{(\lambda/\beta)^k \{z - (\log_{10}(\alpha) + \beta m)\}^{k-1}}{\Gamma(k)} e^{-\left(\frac{\lambda}{\beta}\right)\{z-(\log_{10}(\alpha)+\beta m)\}} dz \,, \tag{4-16}$$

or

$$P[D > d_0] = \int_{z_0}^{\infty} \frac{{\lambda_D}^k (z - m_D)^{k-1}}{\Gamma(k)} e^{-\lambda_D (z - m_D)} dz \,, \tag{4-17}$$

again, Pearson Type III with $\lambda_D = \lambda/\beta$ and $m_D = \log_{10}(\alpha) + \beta m$. The mean, standard deviation and coefficient of skew for the distribution describing depth frequency are

$$\mu_D = \log_{10}(\alpha) + \beta\mu_Q ; \qquad \sigma_D = \beta\sigma_Q ; \textit{ and } \qquad G_D = G_Q \,. \tag{4-18}$$

In summary, the depth frequency relation at any point can be defined given the discharge frequency relation for the reach and the rating curve at the point. The user must supply the discharge frequency information and attribute the cross sections required in the basic algorithm with three or more pairs of elevations and associated frequencies. Note that the algorithm must either restrict “reach” to contain only one discharge frequency relationship or the user must supply “sub-reach” limits where discharge frequency relationships change.

4.2.3.4.2 Discharge Frequency

Almost every floodplain study meeting the requirements for use in the Preview Model has discharge and frequency values associated with the flood elevations. The flood hazard information presented in a Flood Insurance Study, for example, will include a description of the hydrologic analysis performed and a summary of discharges and associated recurrence intervals (i.e., frequencies). The hydraulic models used to develop floodplain studies necessarily contain the discharge values associated with the floods being modeled. The frequencies of those floods are known. Indeed, most modeling efforts begin with a determination of the level of risk to be investigated. That level is usually documented.

Some floodplain studies document the discharge frequency relation in terms of the mean, standard deviation, and coefficient of skew of the (base 10) logarithms of the discharges. Most studies, however, provide pairs of discharge values and associated recurrence intervals. For example, the 100-year flood discharge is 26,680 cubic feet per second (cfs) and the 10-year flood discharge is 14,110 cfs.

Because the Pearson Type III distribution has three parameters, three pairs of discharge values and recurrence intervals are required to define the distribution. The user supplies at least three such pairs and the algorithm finds the mean, standard deviation and coefficient of skew that fits the data best. The fitting procedure is equivalent to plotting the data on sheets of log-Pearson Type III probability paper, each sheet associated with a different coefficient of skew. A least-squares fit of the data is performed on each sheet and the fit yielding the highest correlation coefficient is deemed the best fit.

The algorithm calls on tables of normalized random variables associated with a range of skews (-9 to 9 by steps of 0.1) and finds the values associated with the recurrence intervals. A line is fit through pairs of those values and the corresponding logarithms of the discharge values. The fit is by the method of least-squares regression. The coefficient of skew that results in the fit with the highest correlation coefficient is chosen. The slope of the line is the standard deviation of the distribution and the log(Q) intercept of the line is its mean.

A plot of correlation coefficient from those fits as a function of coefficient of skew has, at most, one local maximum. If it has no local maximum, then the maximum is where the coefficient of skew is either –9 or 9. The algorithm exploits that characteristic to converge to the best fit. The algorithm samples the mean of the maximum and minimum values (starting with +/- 9) and the next highest value. If the correlation coefficient associated with the next highest value is (not) greater than that associated with the mean, the trend is increasing (decreasing) and the mean becomes the minimum (maximum). The process converges to the local maximum.

4.2.3.4.3 Rating Curves

Depth grids are created for each elevation in the attribute table for the cross sections. Because the rating curves are determined using the logarithms of depths, 1.0 foot is added to each depth in each grid. The recurrence interval of the depth grid is used with the discharge frequency relation to determine the discharge associated with the elevation. In increasing order of recurrence interval, the rating curves are computed for each successive pair of flood depths for each cell with both depths greater than zero. The difference in the logarithms of the depths is divided by the difference in the logarithms of the discharge. The resulting ratio is the exponent, β, of the rating curve within the range of discharge values. The proportionality constant, α, is computed by dividing one of the depths by the corresponding discharge value raised to the power β.

The mean, μ_D, and standard deviation, σ_D, are computed as discussed and stored in grids associated with the recurrence intervals. The result is a collection of grids that, piecewise, define the flood depth frequency at each cell. That information can be used to determine expected annual losses at specific sites or over arbitrary regions. The information can also be used to determine depth grids and associated floodplains for frequencies other than those supplied by the user. Algebraic operations on grids are accomplished almost as quickly as the same operations on numbers.

Suppose a user wishes to create the depth grid associated with the 40-year flood for a particular reach with a coefficient of skew of G. The probability of exceeding that event is 1/40 = 0.025. The normalized random variable $K_{0.025,G}$ is found from the table of normalized random variables. The list of user supplied recurrence intervals is searched to identify the μ_D and σ_D grids associated with the 40-year flood. The depth grid is 1.0 subtracted from10 raised to the power $\mu_D + K_{0.025,G}\ \sigma_D$, where, here, μ_D and σ_D represent grids.

4.2.4 Exploring Scenarios

The Flood Model Oversight Committee identified specific items that they believed would enhance the user community's acceptance of the Flood Model. These capabilities provided a level of "What-if" functionality to the user allowing them to utilize the Flood Model as a planning tool. Identified as additional capabilities, the Flood Committee established assessing the impacts of a levee, flow regulations and velocity as additional capabilities necessary for user acceptance.

The following sections continue the discussion of the hazard development as related to the capability of performing this analysis.

4.2.5 Preprocessing Manning's Roughness Coefficient (n-value) using Land Use Land Cover

The Land Use Land Cover (LULC) enhancement now provides a more accurate Manning's roughness coefficient (n-value) to each riverine reach, improving hydraulics computational accuracy. In previous versions of Hazus, a nationwide 0.08 Manning's n-value was hard-coded to all chosen reaches. In Hazus-MH MR4 Patch 1 an n-value of 0.08 was assigned. This was exposed as an editable column, thus allowing users to modify this value if the user knows a specific reach's roughness coefficient. Starting with Hazus-MH 2.1, the Manning's n-value is now preprocessed for each reach by buffering the Hazus stream network by 1 mile, using a 30-meter, 2006 land cover map (ESRI raster format) obtained from the Multi-Resolution Land Characteristics Consortium (MRLC).

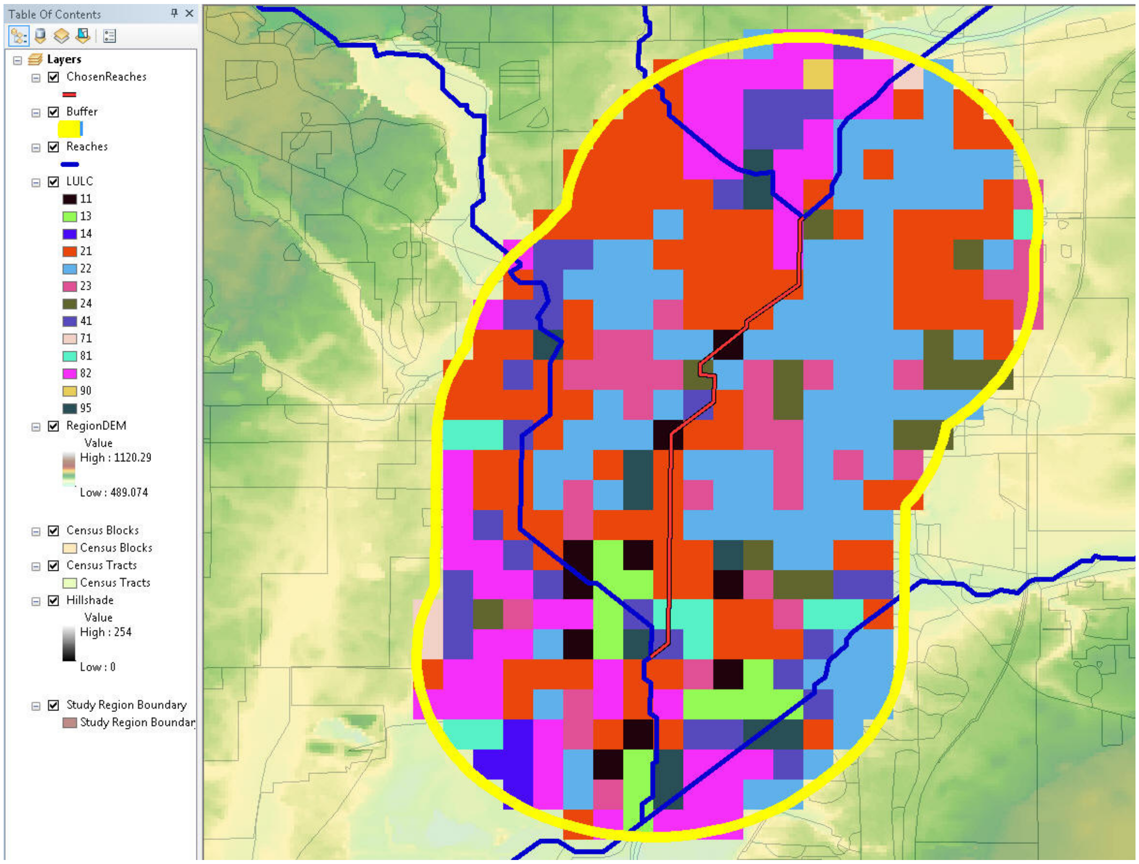


Figure 4.47 A sample chosen reach buffered one mile

The process creates a LULC histogram within the reach's buffer. Then it finds the predominant LULC class within that buffer and assigns its corresponding n-value to that specific reach, as seen in Figure 4.47. In this example, 'Developed, Open Space' (the orange column) is present in 111 pixels of the buffer, as seen in Figure 4.48.

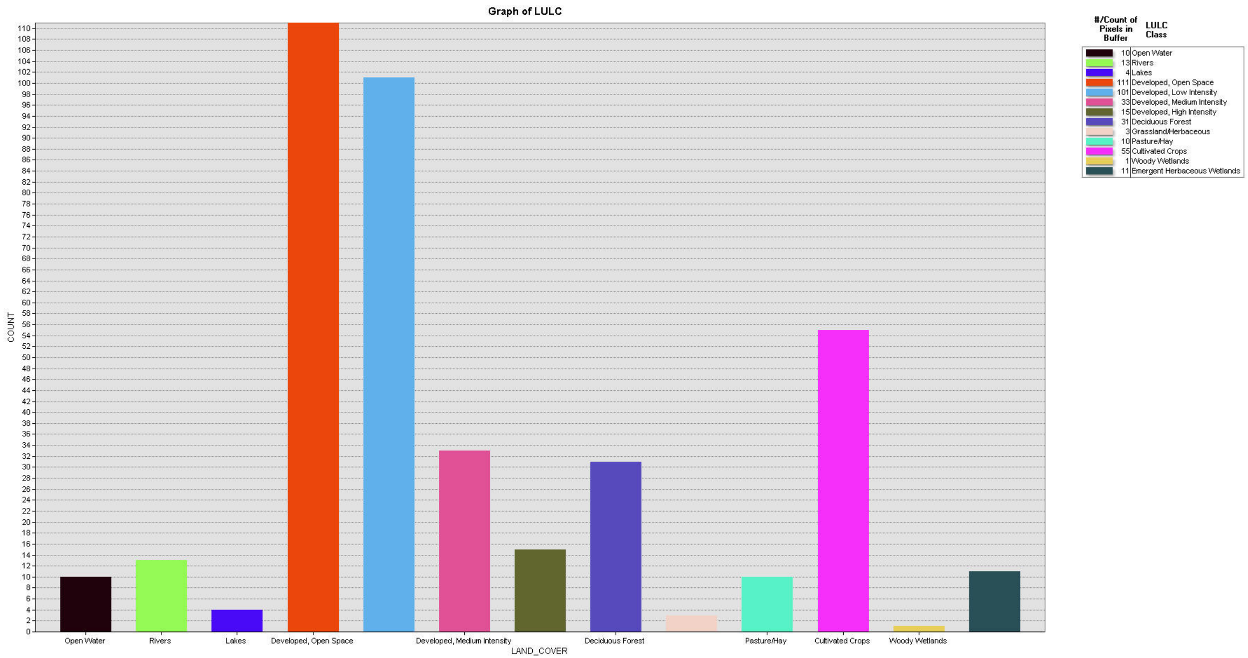


Figure 4.48 A sample reach's LULC histogram

Since this 'Developed, Open Space' LULC class is the most predominant class within the reach's buffer, the entire reach is then assigned a Manning's n-value of 0.12, seen below in Figure 4.49.

Table

LULC

Rowid	VALUE	COUNT	LAND_COVER	MANNINGS_N
0	11	10	Open Water	0.02
1	13	13	Rivers	0.035
2	14	4	Lakes	0.02
3	21	111	Developed, Open Space	0.12
4	22	101	Developed, Low Intensity	0.12
5	23	33	Developed, Medium Intensity	0.05
6	24	15	Developed, High Intensity	0.05
7	41	31	Deciduous Forest	0.16
8	71	3	Grassland/Herbaceous	0.035
9	81	10	Pasture/Hay	0.033
10	82	55	Cultivated Crops	0.04
11	90	1	Woody Wetlands	0.14
12	95	11	Emergent Herbaceous Wetlands	0.035

Figure 4.49 A sample reach's LULC classes, count, and n-value

The 2006 LULC map contains 16 land-cover classes instead of the 21 found in the 1992 classification system. A cross-walk table (Figure 4.50) provided by MRLC (NLCD Classification Schemes, 2007) was used to apply a 1992 based LULC classification system to those land-cover classes used in the 2001 LULC map.

NLCD 1992-2001 Anderson Level I Cross-walk Table.

NLCD 1992 Class Code		NLCD 1992 Description	NLCD 2001 Class Code		NLCD 2001 Description	Modified Anderson Level I
11		Open Water	11		Open Water	1
12		Perennial Ice, Snow	12		Perennial Ice, Snow	8
85		Urban, Recreational Grasses	21		Developed, Open Space	2
21		Low Intensity Residential	22		Developed, Low Intensity	2
22		High Intensity Residential	23		Developed, Medium Intensity	2
23		Commercial, Industrial, Trans.	24		Developed, High Intensity	2
31		Bare Rock, Sand	31		Barren Land, Rock, Sand, Clay	3
			32		Unconsolidated Shore*	3
32		Quarry, Strip Mine, Gravel Pit	31		Barren Land, Rock, Sand, Clay	3
33		Transitional Barren	31		Barren Land, Rock, Sand, Clay	3
33		Transitional Barren	31		Barren Land, Rock, Sand, Clay	3
41		Deciduous Forest	41		Deciduous Forest	4
42		Evergreen Forest	42		Evergreen Forest	4
43		Mixed Forest	43		Mixed Forest	4
			51		Dwarf Scrub**	8
51		Shrubland	52		Shrub, Scrub	5
61		Orchards, Vineyards, Other				6
71		Grasslands, Herbaceous	71		Grassland, Herbaceous	5
			72		Sedge, Herbaceous**	8
			73		Lichens**	8
			74		Moss**	8
81		Pasture, Hay	81		Pasture, Hay	6
82		Row Crops	82		Cultivated Crops	6
83		Small Grains	82		Cultivated Crops	6
84		Fallow	82		Cultivated Crops	6
85		Urban, Recreational Grasses	21		Developed, Open Space	2
91		Woody Wetlands	90		Woody Wetlands	7
92		Emergent, Herbaceous Wetland	95		Emergent Herbaceous Wetlands	7
			91		Palustrine Forested Wetland*	7
			92		Palustrine Scrub/Shrub Wetland*	7
			93		Estuarine Forested Wetland*	7
			94		Estuarine Scrub/Shrub Wetland*	7
			96		Palustrine Emergent Wetland*	7
			97		Estuarine Emergent Wetland*	7
			98		Palustrine Aquatic Bed*	7
			99		Estuarine Aquatic Bed*	7
					* Coastal Areas Only	
					** Alaska Only	

Figure 4.50 NLCD 1992-2001 Anderson Level I Cross-walk Table

The classification system for the 2001 and 2006 LULC maps are identical. Manning's n-values for land-cover classes were obtained from a 2010 issue of The American Meteorological Society (Bunya et al. 2010) and a 2007 FEMA Region 4 report (Ayres Associates, 2007).

Since the size of the 30-meter raster of this LULC map was over 15 GB for the continental USA, it was resampled down to 200-meter resolution using a MAJORITY technique in the ArcMap > ArcToolbox > Data Management Tools > Raster > Resample tool.

The aforementioned cross-walk table was used to transfer all Manning's n-values from the 1992 to the 2001/2006 scheme except for the following urban classes. Based on the 1992 and 2001 class definitions (Definitions, 2007), it is more appropriate to use the 1992 '21. Low Intensity Residential' Manning's n-value for both the 2001 '22. Developed, Low Intensity' and '23. Developed, Medium Intensity'. Also, it is best to use the 1992 '23. Commercial/Industrial/Transportation' Manning's n-value for the 2001 '24. Developed, High Intensity.'

In addition, at the advice of the U.S. Army Core of Engineers (Ackerman, 2011), the Flood Development Team split the 'Open Water' LULC class into 3 classes ('Rivers', 'Lakes', and 'Open Water') to assign more accurate Manning's n-values. The 'Rivers' class was achieved by reassigning all 'Open Water' pixels to the LULC raster that lay within a 1,500-feet buffer of the "basinnet" layer (FL\Hydro folder of Hazus). The 'Lakes' class was defined as the inverse selection of the 'Rivers' class but also excluded the shoreline water pixels. The remaining 'Open Water' pixels refer to the sparse shoreline water pixels that remained in the raster. 'Open Water' has the same Manning's n-value as 'Lakes.' Table 4.1 includes the final Land-Cover and Manning's n-values used in Hazus.

Table 4.1 Land-Cover and Manning's n-values in Hazus

	Land-Cover	Manning's-N	Value (Class)
1	Open Water	0.020	11
2	Perennial Ice / Snow	0.022	12
3	Rivers	0.035	13
4	Lakes	0.020	14
5	Developed, Open Space	0.120	21
6	Developed, Low Intensity	0.120	22
7	Developed, Medium Intensity	0.050	23
8	Developed, High Intensity	0.050	24
9	Barren Land (Rock / Sand / Clay)	0.040	31
10	Deciduous Forest	0.160	41
11	Evergreen Forest	0.180	42
12	Mixed Forest	0.170	43
13	Shrub / Scrub	0.070	52
14	Grassland / Herbaceous	0.035	71
15	Pasture / Hay	0.033	81
16	Cultivated Crops	0.040	82
17	Woody Wetlands	0.140	90
18	Emergent Herbaceous Wetlands	0.035	95

4.3 Coastal Flood Hazard

4.3.1 Introduction

Coastal flood hazards in Hazus are calculated using a general approach and methods that are similar to those presently used by FEMA to produce coastal Flood Insurance Rate Maps (FIRMs):

- Transects are drawn perpendicular to the shoreline
- One FEMA-type model (wave height) is available to calculate water surface elevations (including wave effects), flood depths and flood hazard zones
- Shoreline characteristics and wave conditions at the shoreline determine which models are run along each transect

However, Hazus flood hazard results may differ from those shown on a coastal FIRM for several reasons:

- Hazus can compute coastal flood hazards for flood return periods between 10 years and 500 years (FIRMs show the 100-yr flood hazard, and sometimes the 500-yr flood hazard)
- The topography used by Hazus will most likely be different than that used in the Flood Insurance Study (FIS) to produce a community's FIRMs
- Coastal flood hazard computations made by Hazus contain simplifications to FEMA's erosion, WHAFIS and RUNUP models – this allows users to estimate flood hazards with less input and knowledge than that required by FEMA's models
- Coastal flood hazard computations made by Hazus extend and improve some aspects of FEMA's models, by incorporating more recent scientific developments

4.3.2 User Inputs and Overview of Coastal Flood Hazard Model

The Hazus user is required to supply certain information for the coastal Flood Model to run -- without this information no coastal hazard results can be produced. Needless to say, more accurate user-supplied information will result in more accurate coastal hazard and economic loss results. ***<u>The following user inputs are required:</u>***

- ***<u>Study region,</u>*** over which coastal flood hazards will be computed. The study region boundaries must be specified by the user at the beginning of the analysis. Given the region, the model will determine which coastal counties are part of the study region and will locate default data (in look-up tables) associated with each coastal county.

- ***Shoreline(s).*** The user must identify the start and end of shorelines across which coastal flooding will propagate. Except for small islands, the user may choose to divide each shoreline into two or more segments. Segmentation of shorelines is not required (if a shoreline is not segmented, the entire shoreline will be attributed with the same shore characterization and 100-yr flood conditions).

- ***Coastal flood return period(s)***. The user may specify one or more return periods between 10 years and 500 years. A separate coastal hazard analysis will be performed for each return period specified.

In the Combined Wind and Flood (Coastal Surge) Model, one input required to *characterize each segment of a shoreline* if "No Waves" was selected in the Hurricane Surge analysis is:

- ***Wave exposure***, used to determine whether coastal wave analyses will be run, and if so, to determine the peak wave period Tp at the shoreline from a look-up table (default wave period data are listed for 364 coastal counties in the table):

  - open coast (full exposure), with over-water fetches > 50 miles

  - moderate, with fetches between 10 miles and 50 miles

  - minimal, with fetches between 1 and 10 miles

  - sheltered, with fetches less than 1 mile

  (Note that if a shoreline or segment is classified as sheltered, the model assumes that no damaging waves will affect that shoreline or segment, and no dune/bluff erosion or wave analyses will be computed along transects associated with that shoreline or segment – a stillwater flood surface will be computed by the model.)

Two inputs are required to *characterize 100-yr flood conditions at each shoreline segment*:

- ***100-yr Flood Stillwater Elevation*** (SWEL), obtained from the FIS report or from another source

- ***100-yr wave setup***, obtained from the FIS report or from another source

In addition, the user may edit certain parameters calculated by the model:

- ***10-yr, 50-yr and 500-yr flood stillwater elevations*** (the model calculates values for these based on the 100-yr value and default flood elevation ratios; the user may specify site-specific values from the FIS or another source)

- ***significant wave height Hs at the shoreline*** (the model assumes depth-limited wave heights at all shorelines and exposures – except sheltered; the user may specify a value less than the depth-limited height)

- ***peak wave period Tp at the shoreline*** (the model uses values from look-up tables; the user may specify site-specific values less than the default values)

The coastal Flood Model will take the user inputs and default data, then create a stillwater flood surface throughout the entire study region (i.e., the coastal model will: 1) overlay a stillwater flood surface over the DEM, and 2) identify and remove any isolated pools without a hydraulic connection to the flood source). Subsequent erosion and wave analyses will be used to determine where the flood surface will lie above the stillwater surface. Figure 4.47 illustrates the overall coastal hazard modeling process and Figure 4.52 illustrates the overall coastal FIT hazard modeling process; Table 4.2 compares the coastal Flood Model process with the Flood Information Tool (FIT).

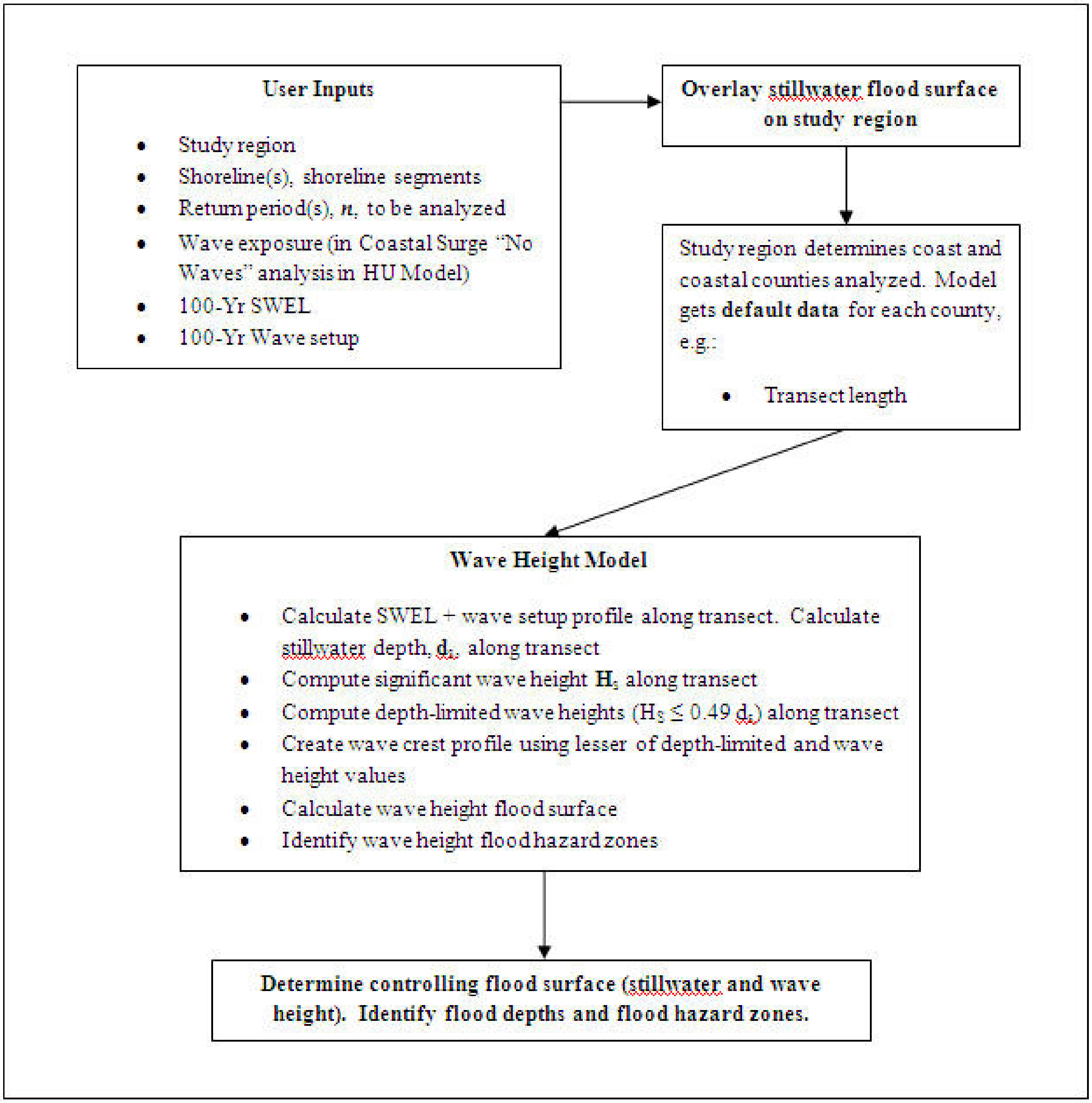


Figure 4.51 Overview of Hazus Coastal Flood Hazard Modeling Process

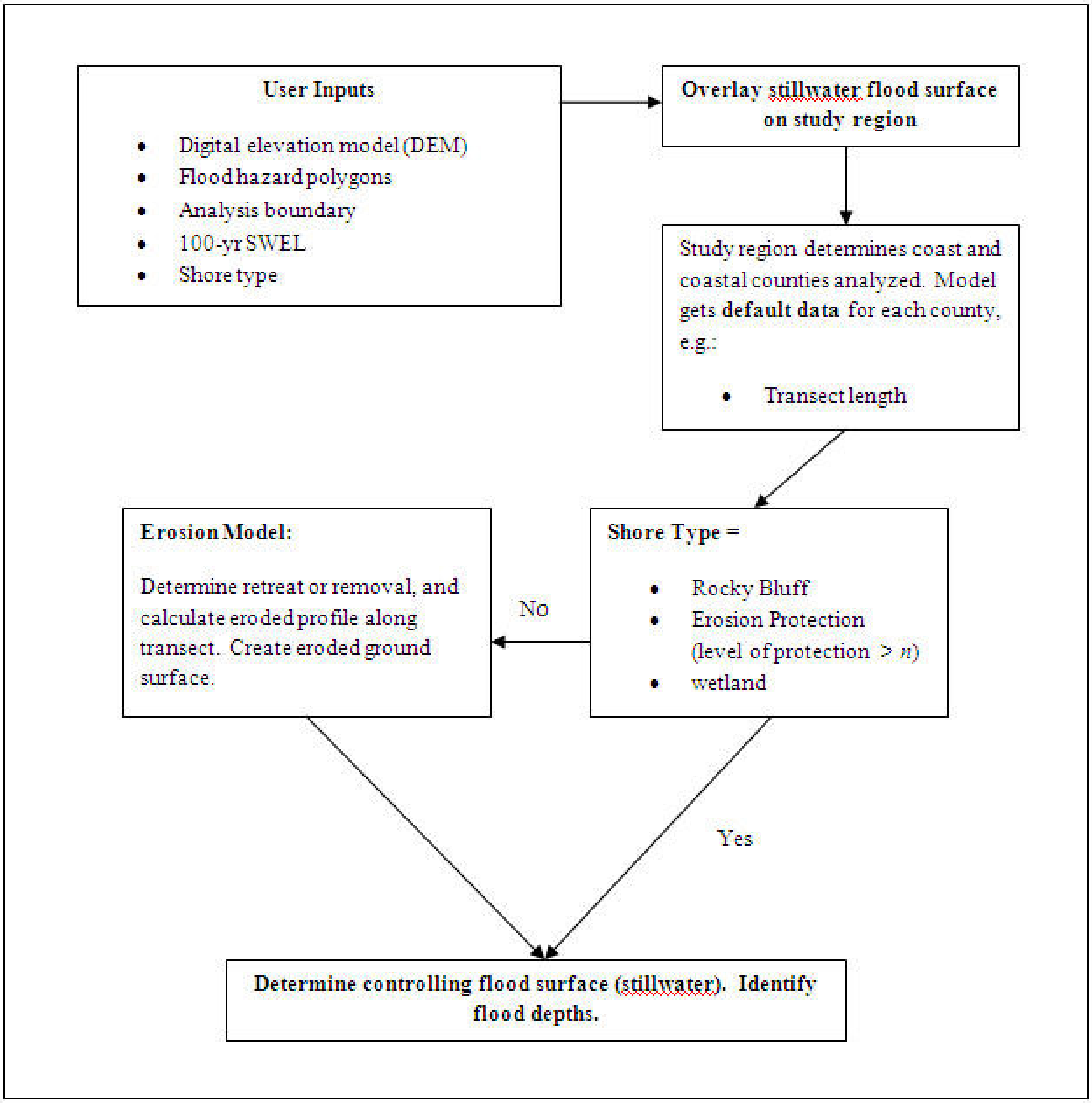


Figure 4.52 Overview of FIT Coastal Flood Hazard Modeling Process

Table 4.2 Coastal Flood Hazard Modeling Process
(U = User action; R = Required; O = Optional; P = Program completes activity; N/A = Activity not supported or undertaken)

	Activity	Flood Model	FIT
Shoreline Characterization	1. Limit Study Area	U-R	U-R[1]
	2(a). Identify Shoreline(s) for analysis	U-R	N/A
	2(b). Draw Shoreline(s) for analysis	N/A	U-R
	3. Segment and characterize shoreline(s): 100-yr SWEL, wave setup, shoreline type, level of protection	U-R[2]	U-R-O[2]
	4. Smooth shoreline for transect construction	P	P
	5. Draw transects	P [3]	P [3]
	6. Edit transects (spacing, location, orientation, length)	N/A	U-O
Eroded Ground	7. Select dune/bluff peak and toe for erosion analysis	N/A	U-O[4]
	8. Calculate eroded ground elevations along transects	N/A	P
	9. Interpolate to determine eroded ground surface between transects	N/A	P
100-Yr Flood Hazard	10. Supply 100-yr flood surface polygons (flood zone and elevations)	N/A	U-R
	11. Select model type (wave height) and constraints	P	N/A
	12. Calculate wave height along transect	P	N/A
	13. Test for flooding from adjacent transects	P	N/A
	14. Interpolate between transects to develop 100-year flood wave surface	P	N/A
	15. Repeat steps 2-14 for analysis of other flood sources	U, P	U, P
	16. Merge 100-year flood surfaces to determine highest 100-year flood elevation and most hazardous zone at every grid cell	P	N/A
	17. Calculate 100-year depth grid	P[5]	P[5]
n-Yr Flood Hazard	18. Flood elevation ratios for other return period analyses	U-O[6]	U-O[6]
	19. Calculate n-year return period flood surfaces	P	P
	20. Calculate n-year return period depth grids and vertical erosion grids	P	P
What-ifs	21. Long-term erosion	N/A	N/A
	22. Shore protection	N/A	N/A

1 *User must select study area by supplying terrain and flood surfaces over a common area.*

2 *Required user inputs for Flood model is 100-yr SWEL; for FIT required are 100-yr SWEL, and shore type with optional wave setup.*

3 *Shore-perpendicular transects are used by model for hazard calculations; transects are used by FIT for eroded ground and what-if calculations.*

4 *User can edit locations in FIT, but not in model.*

5 *Model depth grid includes SWEL and wave height, while FIT includes coastal zone BFE.*

6 *Model will have default values, editable by users in both model and FIT.*

4.3.3 Terms and Definitions

4.3.3.1 Coast

The Coastal Flood Model distinguishes between four coasts: Atlantic, Gulf of Mexico, Pacific, and Great Lakes. Certain attributes for each coast (e.g., *reference elevation*, default *flood elevation ratios*, *wave regeneration* factors, *dune reservoir*, etc.) are contained in look-up tables used by the Coastal Flood Model.

4.3.3.2 Depth-Limited Wave

Wave characteristics (height and period) are limited by water depth. When a wave travels from deep water into shallow water, the wave "feels" the bottom and changes shape, ultimately breaking when the water depth gets too shallow to support the wave. A portion of the wave's energy is dissipated during breaking, and smaller waves reform and continue propagating inland.

The Coastal Flood Model – in keeping with FEMA's flood mapping procedures -- assumes that the limitation on significant *wave height*, H_s, is given by: $H_s \leq 0.49\ d_s$, where d_s = the local stillwater depth (note that this is equivalent to a controlling wave height limit of 0.78 times the local stillwater depth).

The Coastal Flood Model also assumes the peak *wave period*, T_p, will be limited by depth along interior fetches (flooded areas along a transect, inland of the first dune). The limitation on interior fetch wave periods is given by: $T_p \leq 1.7\ (\text{average } d_s)^{0.5}$, where average d_s is the average stillwater depth (in feet) along the fetch.

4.3.3.3 Dune Peak

The top of a dune, or the highest ground elevation close to the shoreline. The Coastal Flood Model takes the highest ground elevation within 500 ft of the shoreline as the first peak along a transect; other peaks may exist farther landward. This feature is not available at the moment.

4.3.3.4 Dune Reservoir

For a single dune case, the cross-section above the stillwater level and seaward of the dune peak. In the case of multiple dune peaks, a different procedure is used to calculate the size of the dune reservoir. This feature is not available at the moment.

4.3.3.5 Dune Toe

The seaward base of the dune, where the dune face ends and the beach begins. The Coastal Flood Model takes the landward-most intersection of the 10-year stillwater elevation and the ground seaward of the dune peak as the dune toe. The dune toe is used by the Coastal Flood Model to generate the eroded dune profile. This feature is not available at the moment.

4.3.3.6 Fetch

The overwater distance across which winds blow and waves develop or grow. The Coastal Flood Model uses the fetch concept in two ways: 1) the fetch at the initial shoreline will determine the transect's *wave exposure;* and 2) the length of interior fetches along a transect will be used in *wave regeneration* calculations.

4.3.3.7 Flood Elevation Ratio

The ratio between the n-year stillwater elevation and the 100-year stillwater elevation at a shoreline. The Coastal Flood Model uses default flood elevation ratios (which the user can override) to calculate n-year stillwater elevations from the 100-year stillwater elevation. The default flood elevation ratios used by the coastal model for tidally influenced coasts represent average values from 46 Atlantic, Gulf of Mexico and Pacific locations. The coastal model uses different default flood elevation ratios for each of the Great Lakes, based on data at 53 locations along the Great Lakes.

4.3.3.8 Freeboard

For wave runup and *overtopping* calculations, the vertical distance between the stillwater elevation and the top of the barrier upon which waves run up. This feature is not available at the moment.

4.3.3.9 Reference Elevation

A water level used in the computation of n-year stillwater elevations. For Atlantic, Gulf of Mexico and Pacific shorelines, the reference elevation is taken to be 0.0 NGVD or NAVD (approximately mean sea level). For the Great Lakes shorelines, the reference elevation is taken as the local chart datum (varies from 244.0 ft NGVD for Lake Ontario to 601.0 ft NGVD for Lake Superior).

4.3.3.10 Roughness

For *wave runup* and *overtopping* calculations, roughness of the *slope* upon which waves run up. Roughness is characterized by a coefficient that equals 1.0 for smooth slopes, and that reduces as roughness increases. The Coastal Flood Model uses default roughness values for each of the five *shore types* subject to *wave runup*. This feature is not available at the moment.

4.3.3.11 Shoreline

The intersection of the land with the sea, bay or lake under normal conditions. The Coastal Flood Model uses two shorelines: 1) a smoothed shoreline, based on TIGER shorelines, and from which *transects* are drawn (this is the shoreline displayed to the user); and 2) a DEM shoreline which is the intersection of the terrain along a *transect* with the *reference elevation*.

4.3.3.12 Slope

For *wave runup* and *overtopping* calculations, an assumed average *slope* upon which waves run up. Slope is measured as an angle from the horizontal. The Coastal Flood Model uses default slope values for each of the five shore types subject to wave runup. This feature is not available at the moment.

4.3.3.13 Stillwater Depth

The vertical distance between the stillwater flood surface and the bottom. For wave height calculation purposes, stillwater depth includes the effects of wave setup. For dune erosion and wave runup calculation purposes, the stillwater depth excludes the effects of wave setup.

4.3.3.14 SWEL

The stillwater elevation at a given location. Different SWELs occur for different return periods at a given location. Flood Insurance Study reports typically list the 10-year, 50-year, 100-year and 500-year SWELs along a shoreline reach.

4.3.3.15 Transect

An imaginary line drawn perpendicular to the shoreline, across which dune erosion and wave effects calculations are made. Transects are drawn automatically by the Coastal Flood Model at approximately 1,000-foot intervals along the shoreline, and the user cannot add, delete or edit transects. Transect lengths vary by coastal county from 2 to 30 miles, based on upland elevations and Storm Surge Inundation Maps (2003) reviewed during model development. Any coastal flooding beyond the transects is assumed to be stillwater flooding (no wave effects). Transects can be divided into two sections: 1) the portion between the transect start and the first dune, bluff or barrier encountered; and 2) flooded areas inland of the first dune/bluff/barrier (interior *fetches*). The terrain along a transect will be used as input for the erosion, wave height and wave runup models.

4.3.3.16 Wave Exposure

The exposure of a shoreline to wave attack. For the purposes of the Coastal Flood Model, shoreline segments will be classified by the user according to one of four exposures, from open coast (full exposure – the most severe wave conditions) to sheltered (waves can be ignored and flooding will be approximated by stillwater flooding). See *Section 4.3.6.1* for wave exposure classification. The Coastal Flood Model scales initial *wave periods* (which are used in *wave runup* calculations) according to wave exposure and coast.

4.3.3.17 Wave Height

The vertical distance between the trough and crest of a wave. Since most waves are irregular (height, length and period are not constant at a given location and point in time), the Coastal

Flood Model adopts the "significant" wave height concept – the significant wave height H_s is approximately the average of the highest one-third of wave heights at a site. The significant wave height is approximately 63% of FEMA's controlling wave height.

4.3.3.18 Wave Overtopping

In some cases, *wave runup* heights will exceed the *freeboard*, and waves or water will pass over the top of a barrier – this is referred to as wave overtopping. Wave overtopping can lead to the mapping of AO zones. This feature is not available at the moment.

4.3.3.19 Wave Period

The time between passage of two successive wave crests past a fixed point. As in the case of wave height, wave periods vary. The "peak" wave period T_p (the period associated with the peak of the wave spectrum) is used by the Coastal Flood Model for *wave runup* calculations, in keeping with FEMA (1995, 2002) methods. This feature is not available at the moment.

4.3.3.20 Wave Regeneration

The Coastal Flood Model accounts for the growth of waves over interior fetches – this process is referred to as wave regeneration. Regeneration is governed by average stillwater depth in the interior fetch, length of fetch, and coast. This feature is not available at the moment.

4.3.3.21 Wave Runup

The height above the stillwater level that waves rush up a slope after breaking. Since incoming waves vary, wave runup also varies at a given site. The Coastal Flood Model uses the average wave runup height R_{ave} to determine flood hazards associated with wave runup. This feature is not available at the moment.

4.3.3.22 Wave Setup

Wave setup is a local increase in the stillwater level due to the presence of breaking waves. The Coastal Flood Model assumes the wave setup component is a maximum near the *shoreline* (at the dune toe), and decays in the inland direction at a rate of 10% per 100 feet. Wave setup is not calculated for interior fetches.

4.3.4 Shorelines and Transects

Shorelines used by the Coastal Flood Model are based on state TIGER shorelines. The Coastal Flood Model pre-processes and divides shoreline features into three categories:

- mainland
- large island (perimeter > 5,000 ft)

- small island (perimeter ≤ 5,000 ft)

State TIGER shorelines have been pre-processed and smoothed for several reasons:

1. a smoothed shoreline follows general shoreline trends and results in better transect layout

2. the smoothing process (which uses a ¼ mile buffer out and buffer in, with interior rings removed) smoothes shoreline irregularities, eliminates many small tributaries and inlets that intersect the shoreline (see Figure 4.53), and clusters groups of islands that are separated by narrow waterways

3. smoothing reduces the number of transect crossings, and improves ground and flood surface interpolation between transects

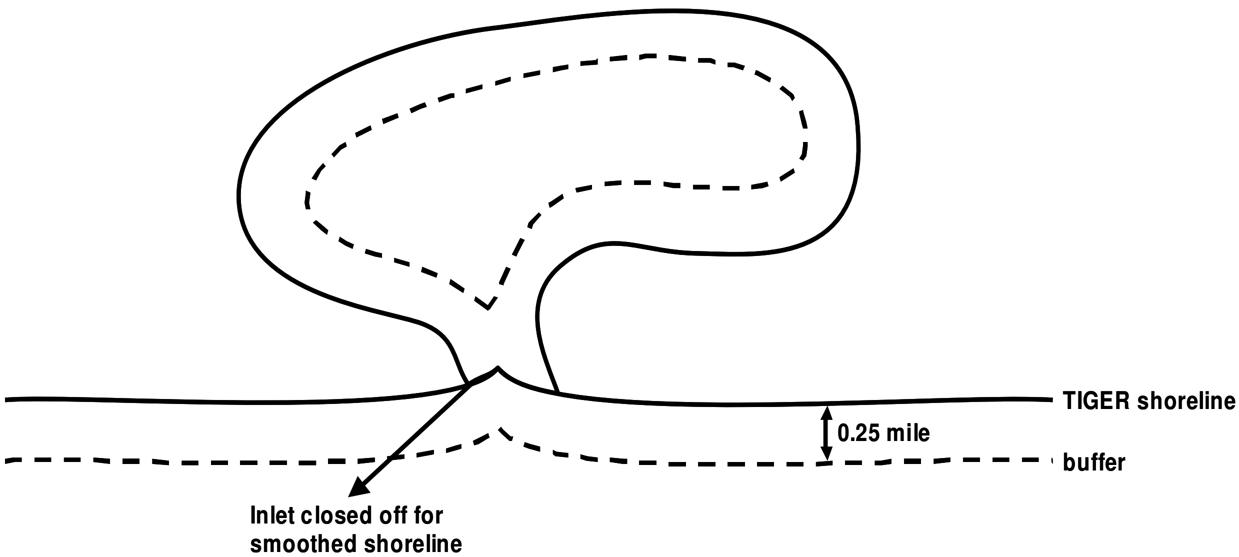


Figure 4.53 Shoreline Smoothing

In general, transects are drawn perpendicular to the smoothed shoreline. Transects along mainland shorelines begin 500 feet seaward of the smoothed shoreline and extend inland to the county default transect length, or to the study region boundary, whichever occurs first. Transects on large islands are drawn within the convex hull of the smoothed shoreline (see Figure 4.54). The number and orientation of transects on the mainland and large islands will vary, depending on the shoreline length and orientation.

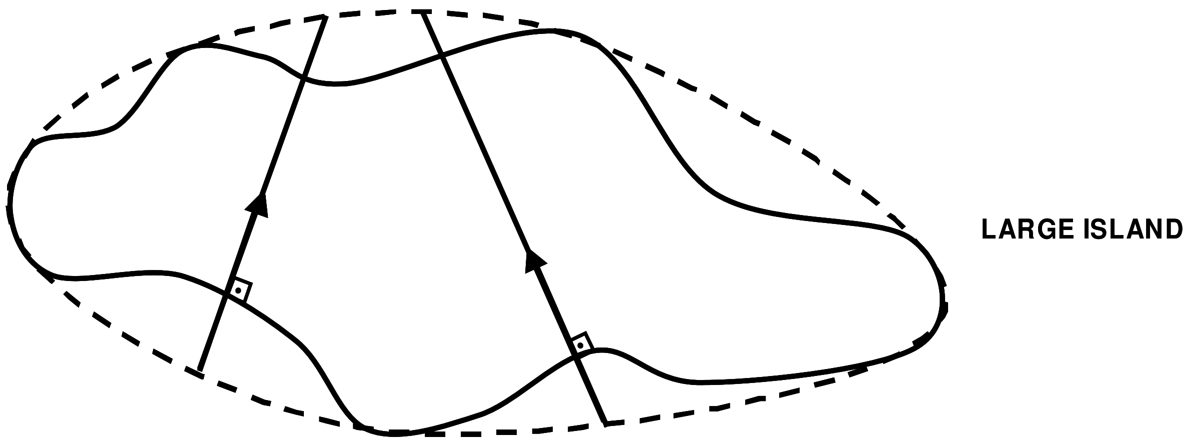


Figure 4.54 Mainland and Large Island Transects

Transects on small islands are drawn differently (see Figure 4.55). Eight transects are drawn for all small islands, four from each corner of the bounding rectangle, and four from the midpoint of each side of the bounding rectangle. Note that four transects are reversals of the other four transects.

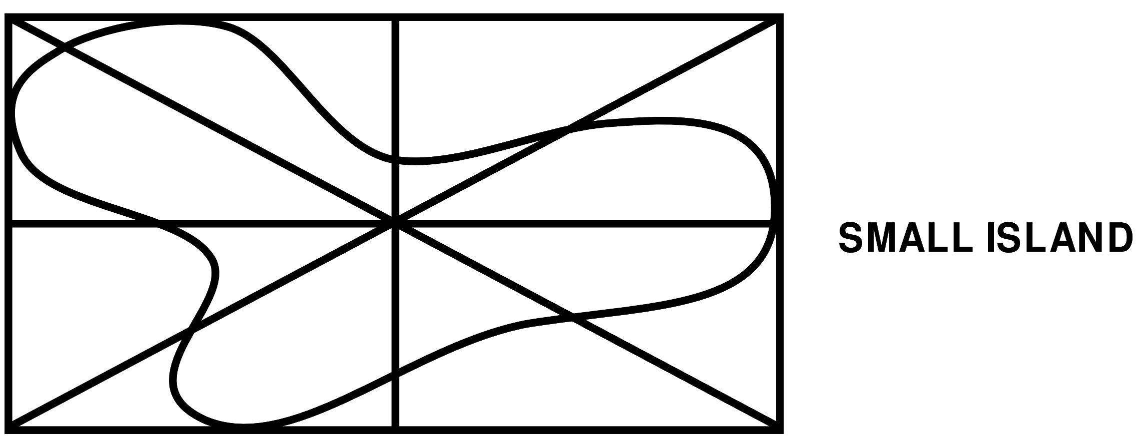


Figure 4.55 Small Island Transects

4.3.5 Shoreline Segmentation

The Coastal Flood Model allows, but does not require, the user to segment mainland and large island shorelines (but does not allow small island shorelines to be segmented). Segmentation permits the user to characterize different portions of a shoreline differently (different wave exposures, different shore types, different 100-year and n-year SWELs, etc.). In the case of large islands, users should segment the shoreline into two or more segments, even if the shore type is uniform along the entire shoreline (one for each flood source affecting the island).

4.3.6 Shoreline Characterization

Each shoreline segment must be characterized by the user. This involves one step:

1. characterizing the 100-year flood and wave conditions for each segment (see Figure 4.56).

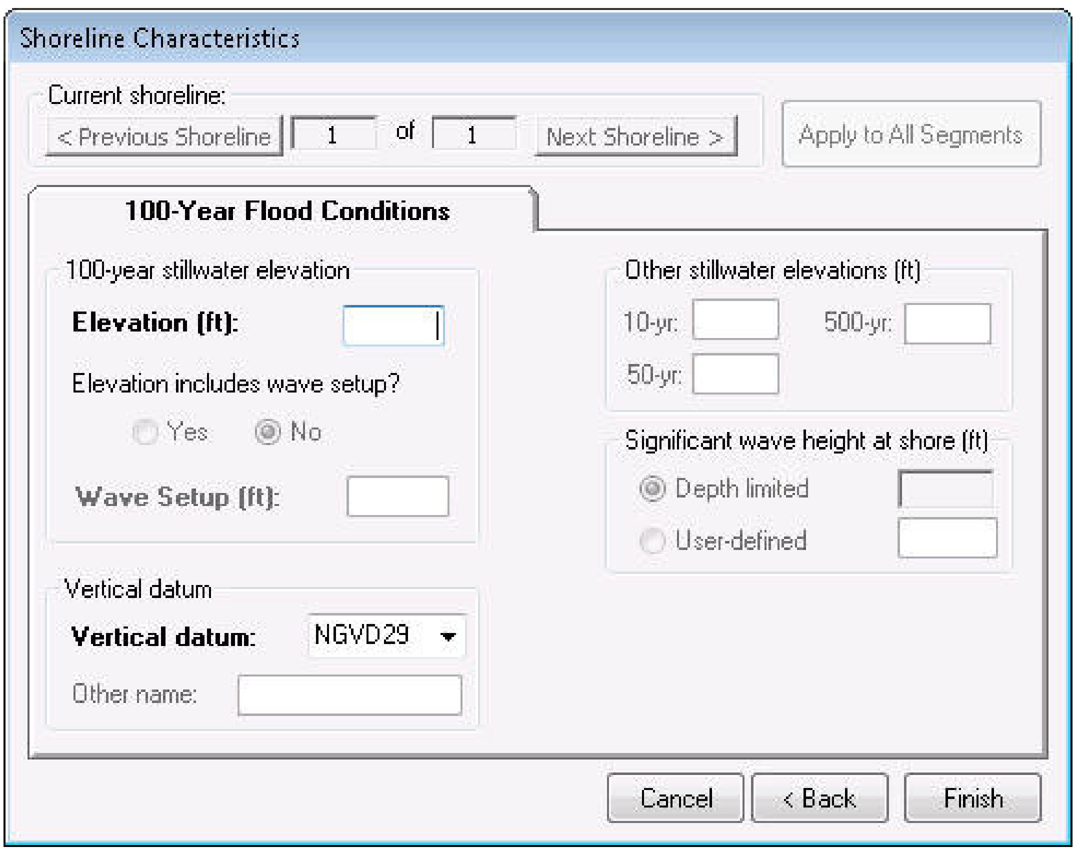


Figure 4.56 100-Year Flood Conditions Tab of Shoreline Characteristics Dialog

4.3.6.1 Wave Exposure

Wave exposure is used to classify the severity of wave conditions that will accompany the 100-year coastal flood event. The Coastal Flood Model divides wave exposure into four categories:

- open coast (full exposure), with over-water fetches > 50 miles
- moderate, with fetches between 10 miles and 50 miles
- minimal, with fetches between 1 and 10 miles
- sheltered, with fetches less than 1 mile

Users should select a wave exposure for each segment corresponding to its fetch under 100-year flood conditions, not under normal conditions. For example, a mainland shoreline segment landward of a low-lying island may have a short fetch under normal conditions, but the island may be flooded and the fetch may increase under more severe conditions.

Shorelines can be classified according their exposure to waves (see Table 4.3). Typical shoreline characteristics associated with wave exposures are summarized in Table 4.3, along with the influence of wave exposure on wave conditions at the shoreline.

Table 4.3 Shoreline Wave Exposure Classification for Coastal Flood Model[1]

Wave Exposure at Shoreline	Typical Location	Wave Height at shoreline (ft)	Typical Peak Wave Period at shoreline (sec)
Exposed, Open Coast, (maximum possible wave conditions -- fully developed waves)	shorelines directly fronting Atlantic, Gulf of Mexico, Pacific, Great Lakes (deepwater with fetches > 50 miles)	H_s = 0.49 times local stillwater depth, d_s	$T_p \approx$ 2-20 sec (varies by coast and flood return period)
Moderate Exposure (wave conditions somewhat reduced from maximum by fetch)	large bays and water bodies, with fetches between 10 miles and 50 miles	$H_s \approx 0.40\ d_s$	$T_p \approx$ 0.45 to 0.70 T_p open coast (varies by coast)
Minimal Exposure (wave conditions significantly reduced from maximum)	small bays and water bodies, with fetches between 1 mile and 10 miles	$H_s \approx 0.20\ d_s$	$T_p \approx$ 0.25 to 0.40 T_p open coast (varies by coast)
Sheltered (no appreciable waves capable of causing erosion or building damage -- essentially stillwater flood conditions)	water bodies, with fetches < 1 mile	$H \approx 0$	$T \approx 0$

1. *Wave heights and periods will vary by region, degree of exposure and flood return period.*

Calculations were made to estimate significant wave height, H_s, versus local stillwater depth, d_s, under a range of wind speed and water depth conditions, and the results are shown in Table 4-2. These H_s values can be used as starting wave heights at the shoreline for overland wave calculations in the Flood Model, absent results of more detailed analyses or wave modeling performed outside the Flood Model.

Note that these H_s versus d_s relationships for Moderate and Minimal Exposure scenarios are approximate, given the number of factors that come into play and the wide range in fetch distances included within the Moderate Exposure and Minimal Exposure categories. The relationships represent expected fetch-limited wave conditions (no depth or duration constraints) near the mid-point of the fetch range for each category.

4.3.6.2 100-Year Stillwater Elevation

The 100-year stillwater elevation is a required user input. The parameter represents the water surface elevation due to tides and/or storm surge, and does not include the effects of wave heights, wave runup or wave setup. The value for this parameter can be obtained from the "*Summary of Stillwater Elevations*" table contained in the FIS report.

Note that some FIS reports do not contain a "*Summary of Stillwater Elevations*" table, but contain a "*Summary of Elevations*" table instead. In this case, the elevations contained in the table are likely to be BFEs (Base Flood Elevations) and not stillwater elevations. The user should review the accompanying text carefully, and if necessary, contact FEMA for stillwater elevations.

4.3.6.3 Wave Setup

Wave setup is a local rise in the stillwater level due to the presence of breaking waves in the nearshore region (see Figure 4.57). The Coastal Flood Model assumes the wave setup reaches a maximum near the dune toe (profile intersection with 10-year SWEL), and decays 10% for each 100 ft inland from that point. If the terrain rises above the stillwater flood level and wave effects diminish to zero, the Coastal Flood Model terminates the wave setup at the same point.

The 100-year flood conditions tab of the *Shoreline Characteri*stics dialog (see Figure 4.56) asks the user whether or not wave setup is included in the 100-year SWEL. A careful reading of the *Summary of Stillwater Elevations* table and accompanying text should answer this question. If the wave setup component is included in the 100-year SWEL listed in the table, the user should select "yes" and input the wave setup height (in feet).

The Coastal Flood Model follows FEMA (1995, 2002) procedures, and adds the wave setup component to the SWEL (without wave setup) for wave height calculation purposes only. Erosion assessment and runup calculations are made with the SWEL (without wave setup) values.

If the FIS is unclear as to whether or not wave setup is included in the 100-year SWEL, the 10-year, 50-year, 100-year and 500-year stillwater values given in the table can be graphed on semi-log paper. If the 100-year SWEL does not contain wave setup, it should fall on a line drawn through the other SWELs. If the 100-year SWEL contains wave setup, it should fall above a line drawn through the other SWELs (and the 100-year wave setup value can be estimated as the vertical difference between the 100-year SWEL and the line).

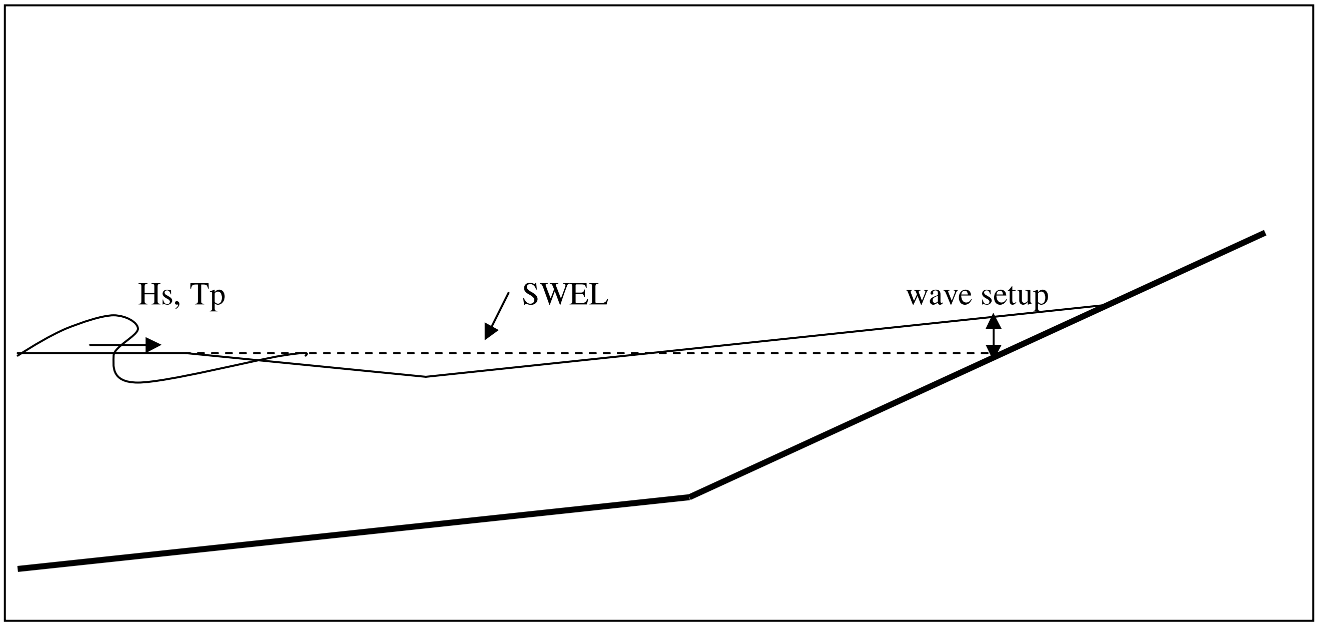


Figure 4.57 Wave Setup Sketch

4.3.6.4 Other Stillwater Elevations

The Coastal Flood Model estimates 10-year, 50-year and 500-year stillwater elevations from the 100-year stillwater elevation input by the user. The model does this using *flood elevation ratios* derived from FIS data (see Tables 4.4 and 4.5). Given the 100-year stillwater elevation, n and the flood elevation ratio corresponding to return period n, Ratio_n, the n-year stillwater elevation is calculated using Eq. 4-19:

n-year stillwater elevation = Ratio_n (100-yr stillwater elevation - RE) + RE (4-19)

Where:

n = coastal flood return period

RE = reference elevation (= 0 for Atlantic, Gulf of Mexico and Pacific coasts; = chart datum elevation for the Great Lakes, as given in Table 4.6)

For the Atlantic, Gulf of Mexico and Pacific coasts, flood elevation ratios are given in Table 4.4. These ratios (for 10-yr, 50-yr and 500-yr flood events) were calculated using data contained in FIS reports for 46 coastal locations in 11 states (MA, DE, NC, SC, GA, FL, AL, TX, CA, OR, WA). The FIS reports were published between 1977 and 2000.

Table 4.4 Coastal Flood Elevation Ratios for Atlantic, Gulf of Mexico and Pacific Coastal Areas (based on 46 locations: 27 Atlantic, 11 Gulf of Mexico, and 8 Pacific)

Return Period	Flood Elevation Ratio			
	Average	Minimum	Maximum	Std. Dev.
Overall Sample (n=46)				
10-yr	**.64**	.44	.89	.12
50-yr	**.88**	.51	.96	.07
500-yr	**1.23**	1.07	1.80	.13
Open Coast (n=31)				
10-yr	.65	.48	.79	.10
50-yr	.89	.76	.94	.04
500-yr	1.21	1.07	1.38	.08
Bay Shoreline (n=15)				
10-yr	.64	.44	.89	.15
50-yr	.87	.51	.96	.11
500-yr	1.29	1.13	1.80	.19
Wave Crest Dominant (n=38)				
10-yr	.61	.44	.89	.13
50-yr	.87	.51	.96	.08
500-yr	1.25	1.07	1.80	.14
Wave Runup Dominant (n=8)				
10-yr	.74	.69	.80	.04
50-yr	.92	.90	.94	.02
500-yr	1.18	1.12	1.24	.04

The average flood elevation ratios are listed in Table 4.4, along with minimum values, maximum values and standard deviations. Ratios are listed for the overall sample (46 locations), for sub-samples broken down by type of flood source (open coast or bay), and for sub-samples broken down by the controlling factor in the establishment of the cross section (wave crest elevation or wave runup elevation). Given the relatively small variation in average ratios across flood sources and dominant wave effects, the Coastal Flood Model uses the overall sample average ratios as the default 10-year, 50-year and 500-year ratios for Atlantic, Gulf of Mexico and Pacific coastal counties. Ratios for other return periods are interpolated by the Coastal Flood Model.

For the Great Lakes, flood elevation ratios are given in Table 4.5. These ratios (for 10-yr, 50-yr and 500-yr flood events) were calculated using USACE data contained in Appendix A of FEMA (1996). Given the relatively small variation in average ratios across the Lakes, the Coastal Flood Model uses the overall sample average ratios as the default 10-year, 50-year and 500-year ratios for all Great Lakes coastal counties. Ratios for other return periods are interpolated by the Coastal Flood Model.

Table 4.5 Flood Elevation Ratios for Great Lakes
(based on 53 locations: 5 Superior, 10 Michigan, 8 Huron, 25 Erie and 5 Ontario)

Return Period	Flood Elevation Ratio			
	Average	Minimum	Maximum	Std. Dev.
Overall Sample (n=53)				
10-yr	**.79**	.84	.73	.03
50-yr	**.95**	.98	.93	.01
500-yr	**1.13**	1.16	1.09	.02
Lake Superior (n=5)				
10-yr	.80	.81	.79	NA
50-yr	.94	.94	.94	NA
500-yr	1.11	1.12	1.11	NA
Lake Michigan (n=10)				
10-yr	.77	.78	.76	NA
50-yr	.94	.94	.94	NA
500-yr	1.14	1.15	1.13	NA
Lake Huron (n=8)				
10-yr	.75	.77	.73	NA
50-yr	.93	.94	.93	NA
500-yr	1.15	1.16	1.13	NA
Lake Erie (n=25)				
10-yr	.83	.84	.80	NA
50-yr	.95	.98	.94	NA
500-yr	1.11	1.14	1.09	NA
Lake Ontario (n=5)				
10-yr	.82	.82	.81	NA
50-yr	.96	.96	.96	NA
500-yr	1.13	1.13	1.12	NA

Calculation of n-year stillwater elevations for the Great Lakes using Eq. 4-19 requires knowledge of reference elevations (chart datums) for the Great Lakes. These are given in Table 4.6.

Table 4.6 Reference Elevation (Chart Datum) for Great Lakes

Great Lake	Chart Datum (ft NGVD)
Superior	601.0
Michigan	578.1
Huron	578.1
St. Clair	573.1
Erie	570.0
Ontario	244.0

The Coastal Flood Model uses the flood elevation ratios and procedures described above to populate the 10-yr, 50-yr and 500-yr stillwater elevations in the 100-year Flood Conditions tab of the Shoreline Characteristics dialog. The user can edit these model-calculated values using site-specific data from the FIS.

4.3.6.5 Significant Wave Height at Shore

The Coastal Flood Model calculates the significant height H_S at the shoreline during 100-year flood conditions as the depth-limited value given by Eq. 4-20.

H_S = 0.49 (100-yr SWEL + 100-year wave setup – reference elevation) (4-20)

The model assumes depth-limited waves (given by Eq. 4-20) are present for all wave exposures (except sheltered) on all coasts, which is a conservative assumption for some situations. The model calculated value is displayed in the *model-estimated significant wave height at shore* window of the *100-year Flood Conditions* tab of the *Shoreline Characteristics* dialog. The user can override the model-calculated value by checking the user-defined radio button and inserting a smaller H_S value (the user cannot input a larger value). H_S units are in feet.

The model-calculated or user-defined H_S will be used by the model for wave height and wave runup calculations.

4.3.6.6 Peak Wave Period

The Coastal Flood Model uses default peak wave period values from a look-up table, where values vary by coast, county and wave exposure. These are displayed in the *model-estimated peak wave period* window of the *100-year Flood Conditions* tab of the *Shoreline Characteristics* dialog. The values in the table were derived from USACE (2002) Wave Information Study wave data and the USACE (2003) Coastal Engineering Manual (for Atlantic, Gulf of Mexico, Pacific and Great Lakes coasts), and from Basco and Shin (1993) (for the Chesapeake Bay). The user can override the model-calculated value by checking the user-defined radio button and inserting a smaller T_p value (the user cannot input a larger value). T_p units are in seconds.

The following assumptions were made in the calculation of the default peak wave periods accompanying the 100-year coastal flood event:

- The peak wave period associated with the 100-year coastal flood event on the Atlantic and Gulf of Mexico coasts is the 100-year peak wave period

- The peak wave period associated with the 100-year coastal flood event on the Pacific coast is the 5-year peak wave period

- The peak wave period associated with the 100-year coastal flood event on the Great Lakes coast is the 3-year peak wave period (Lakes Superior, Michigan, Huron and Erie) and the ½-year peak wave period (Lake Ontario)

The Coastal Flood Model assumes Pacific and Great Lakes wave periods are weakly correlated with the stillwater flood elevation, unlike the Atlantic and Gulf of Mexico coasts where the wave periods and stillwater elevations are strongly correlated. This approach is consistent with that recommended by the National Academy of Sciences (1977) and FEMA (1996).

Peak wave periods (for all coasts) also vary with wave exposure at the shoreline. In general, for a given flood return period, wave periods at the open coast are much greater than those associated with moderate or minimal exposures. The Coastal Flood Model uses ratios of minimal-to-open coast and moderate-to-open coast peak wave periods to estimate wave periods for lesser exposures. These are summarized below.

- T_p *minimal* exposure = 0.25 * open coast T_p for *Atlantic, Gulf of Mexico and Pacific* coasts

- T_p *minimal* exposure = 0.40 * open coast T_p for *Great Lakes* coast

- T_p *moderate* exposure = 0.45 * open coast T_p for *Atlantic and Gulf of Mexico* coasts

- T_p *moderate* exposure = 0.40 * open coast T_p for *Pacific* coast

- T_p *moderate* exposure = 0.70 * open coast T_p for *Great Lakes* coast

The Coastal Flood Model also scales wave periods for flood return periods other than 100-year flood. Holding wave exposure constant, wave periods for n-yr flood events were scaled from 100-yr flood event wave conditions based on average results for WIS data:

- 10-yr flood T_p = 0.84 * 100-yr flood T_p

- 50-yr flood T_p = 0.94 * 100-yr flood T_p

- 500-yr flood T_p = 1.10 * 100-yr flood T_p

Note that the n-year scaling factors used for T_p are approximately equal to the square root of the scaling factors for H_s given in Table 4.4 (overall sample, average values), in keeping with wave height and wave period scaling observed in WIS wave data for the Gulf of Mexico.

4.3.7 Wave Height Model

The wave height model is predicated on the same basic principles as FEMA's WHAFIS model. However, in the case of the wave height model, certain simplifications have been made to reduce required user inputs (the level of user input required by WHAFIS is substantial; the level of user input required by the wave model is minimal).

Both the wave height model and WHAFIS use similar depth-limitations for wave heights (see *Section 4.3.3.2*), and both set wave height = 0 when the stillwater + wave setup depth = 0. Both establish the wave crest elevation using the controlling wave height ($H_c = 1.6\ H_s$). Both assume 70% of the controlling wave height lies above the stillwater + wave setup elevation; therefore, a vertical difference of 2.1 feet or more between the wave crest elevation and the stillwater + wave setup elevation produces a V zone (0.7 * 3.0 ft = 2.1 ft). See Figure 4.53. The limiting equation for significant wave height and the governing equation for wave crest elevation are given by Eqs. 4-22 and 4-23:

$$H_s = 0.63\ H_c \leq 0.49\ d_s \qquad (4\text{-}22)$$

$$\text{Wave crest elevation} = \text{stillwater elevation} + \text{wave setup} + 0.7\ H_c \qquad (4\text{-}23)$$

Differences arise between the wave height model and WHAFIS in the delineation of fetches along a transect, the incorporation of vegetation effects, and in the computation of wave regeneration across flooded fetches.

- WHAFIS requires a user to classify all portions of a transect as a "fetch" or an "obstruction". The latter allows wave heights to grow, the former causes wave heights to diminish. The coastal model wave height procedure does not require the user to differentiate between fetches and obstructions – it treats any flooded section as a fetch where wind energy can be added to waves and wave heights can grow.

- The wave height model does not allow for wave height reductions due to the presence of marsh grass or other vegetation, or due to other obstructions (e.g., buildings) – only water depth limits wave heights and wave crest elevations.

The wave height model uses an improved wave regeneration algorithm. The WHAFIS wave height regeneration algorithm is based on a typical case (fixed water depth and wind speed) analyzed by the National Academy of Sciences (1977), and its fetch factors are a function of fetch length only. The wave height model fetch factors are a function of fetch length, coast and return period (the latter two parameters introduce a dependence on wind speed).

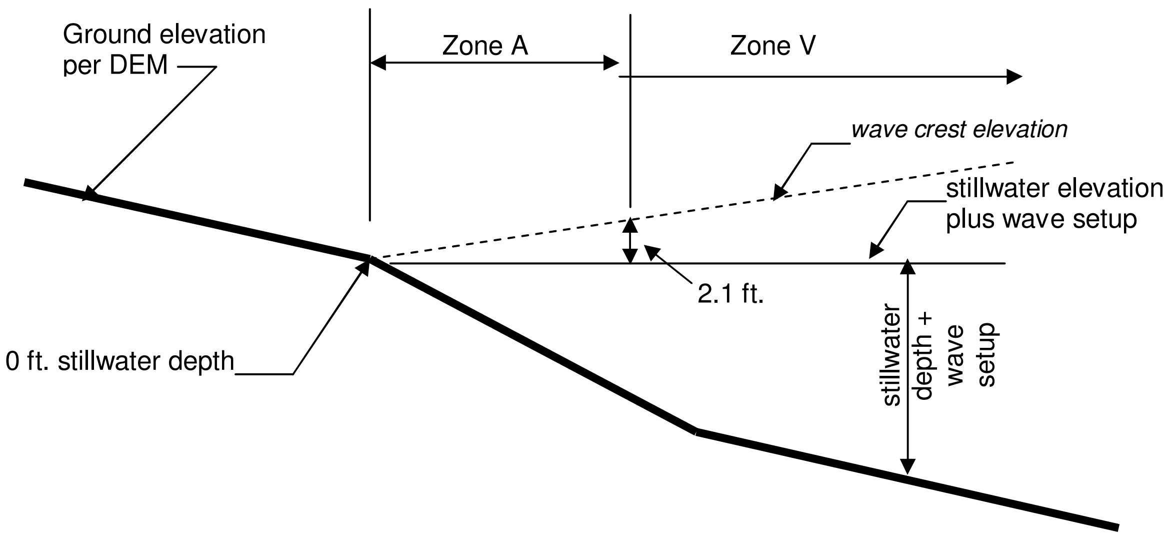


Figure 4.58 Wave Height Model – Relationship between Wave Crest Elevation, Stillwater Flood Depth and Wave Setup

4.4 Combined Hurricane and Flood Hazard

4.4.1 Hurricane-Induced Coastal Surge

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 the wave and surge models are provided below. Combining hurricane and flood losses is addressed in Section 4.4.2.

4.4.1.1 Wave and Surge Model Implementation

Simulating Waves Nearshore (SWAN) is a third-generation spectra wave model capable of generating two-dimensional wave energy spectra under specified conditions of winds, currents and bathymetry. It accounts for nearshore wave behavior such as wave breaking and wave setup and thus is suitable for shallow water computations of wave characteristics.

For computational efficiency, SLOSH uses continuously varying grid cell sizes within each basin. It uses large grid cells near the deep water boundary and progressively smaller grid cells near the coast. In addition SLOSH uses different types of grid formats (polar, elliptical, hyperbolic, etc.) to represent a basin. To eliminate the need for duplicate and potentially conflicting bathymetry data for the storm surge and wave models, we have elected to directly use the SLOSH grids in SWAN by enabling the curvilinear grid option in the SWAN command file. The center of each SLOSH grid cell becomes a grid point in SWAN, with the average depth of the SLOSH cells used as the depth or elevation at that point. This approach is taken for two reasons: (i) to keep an identical computational grid as the input grid so that no additional interpolations are needed by SWAN, and (ii) to compute the wave parameters at the same locations in where surge is calculated in SLOSH.

The hurricane wind field model is implemented in SWAN by using a non-stationary input of wind vectors at the computational grid points. These non-stationary wind vectors are computed for the duration of each SWAN run at fixed time intervals using the hurricane wind field model.

Non-stationary wave conditions at the open ocean boundaries of a SLOSH basin are imposed in terms of wave spectra obtained through a SWAN run on a relatively large coarse grid with cells that are 20 km x 20 km in size. This grid is denoted as the Northwest Atlantic grid. The red outline of this large grid is shown in Figure 4.59 along with the New Orleans SLOSH basin outlined in blue. At first, a SWAN run on this large grid is carried out using the non-stationary wind inputs at the coarse grid points for a given storm duration. The wave spectra obtained at the open boundary of a SLOSH basin from this run are then used as a boundary condition in the SWAN run in the SLOSH basin for the same storm duration.

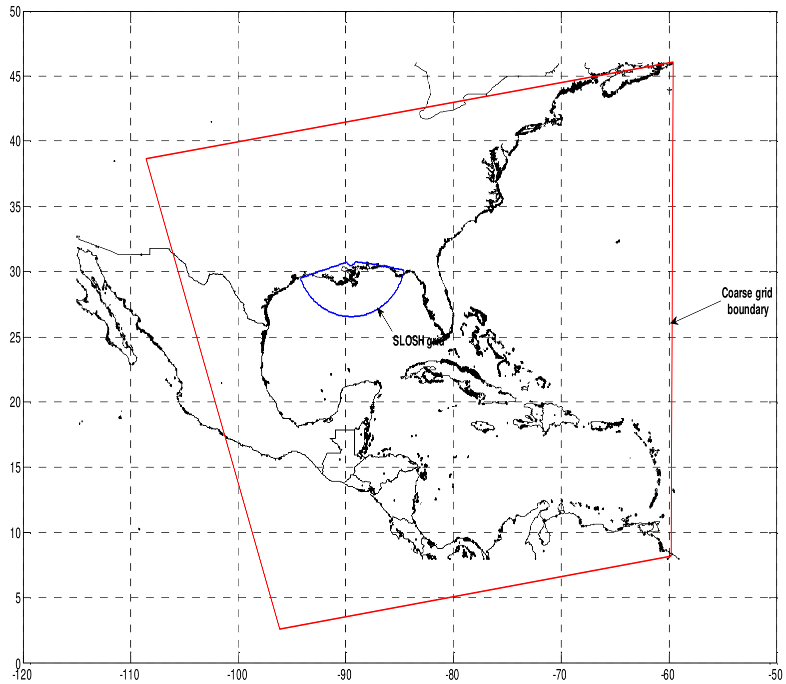


Figure 4.59 Northwest Atlantic Grid Domain

A two-way coupling between the storm tide model and the nearshore wave model has been implemented for the Hazus coastal surge methodology. The process is illustrated in Figure 4.60. For a given hurricane event, the storm surge analysis is run for a fixed period of simulation time (e.g., 15 min) and then suspended. The new water levels from SLOSH are then passed to SWAN, and the wave model is advanced for the same fixed period of simulation time. The nearshore breaking wave stresses from SWAN are then passed back to SLOSH for the next time increment, and the simulation continues until the hurricane passes through and beyond the study region.

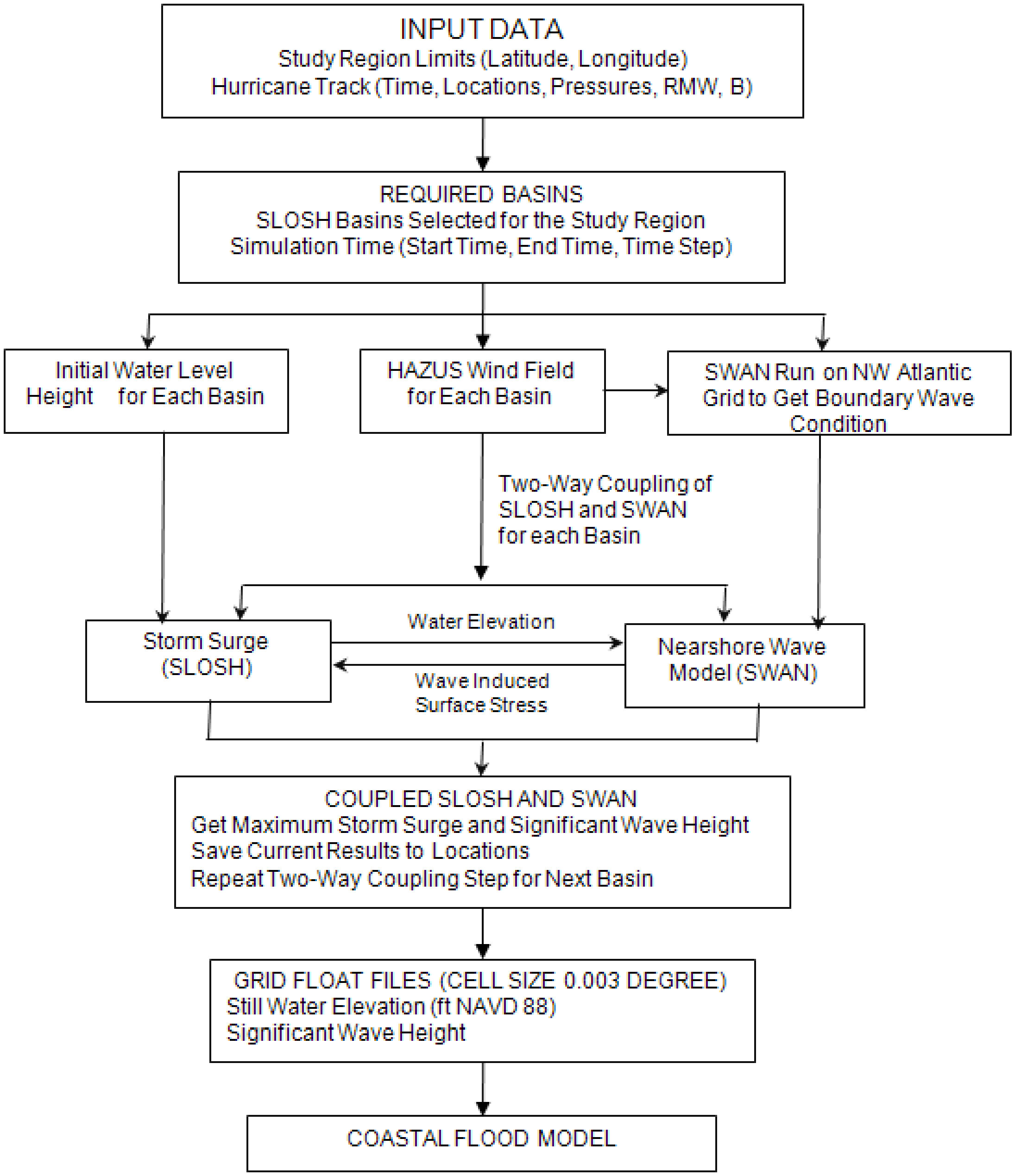


Figure 4.60 Hazus Coastal Storm Surge and Wave Model Flow Chart

4.4.1.2 Coastal Surge Analysis for Study Regions Spanning Multiple SLOSH Basins

At present, there are 32 SLOSH basins along U.S. Atlantic and Gulf of Mexico coastlines, as shown in Figure 4.61 and listed in geographical order in Table 4.7. Eleven basins were updated by NOAA in 2009 to incorporate the latest topography and bathymetric data and to provide higher grid size resolution and better representation of basin features. The updated basins also use the newer NAVD 88 instead of the older NGVD29 for their vertical datum. Given user-provided locations, priority for basin selection is governed by the grid resolution and the computer run time. Model run times depend on simulated storm duration, basin size, and the number of basins. For a given study region one can expect a significant increase in the run time if the number of selected basins increases.

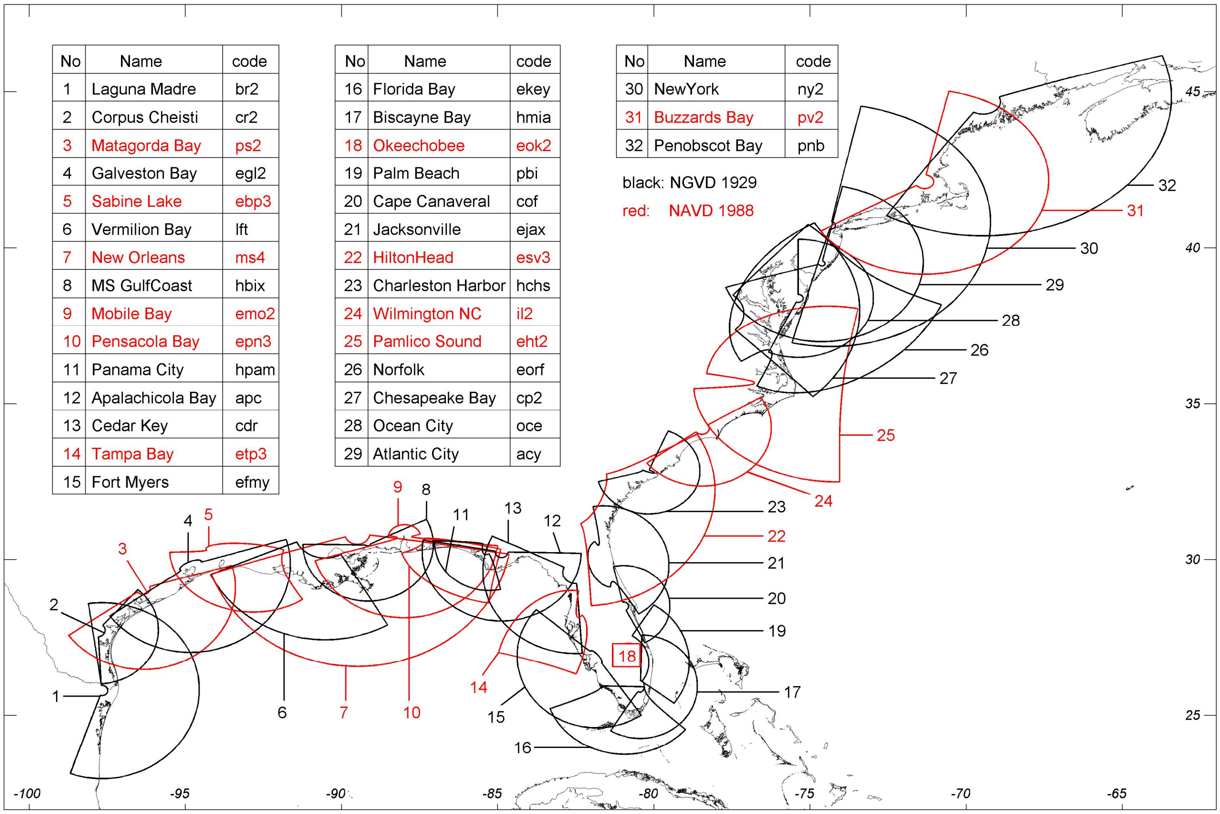


Figure 4.61 SLOSH Basins

Table 4.7 SLOSH Basins Used in Hazus Coastal Surge Methodology

IDBSN	bsnname	bsncode	imxb	jmxb	Datum	Used
1	Laguna-Madre	br2	85	108	NGVD1929	✓
2	Corpus-Cheisti	cr2	67	75	NGVD1929	✓
3	Matagorda-Bay	ps2	192	211	NAVD1988	✓
4	Galveston-Bay	egl2	115	100	NGVD1929	✓
5	Sabine-Lake	ebp3	224	350	NAVD1988	✓
6	Vermilion-Bay	lft	128	156	NGVD1929	
7	New-Orleans	ms4	175	189	NAVD1988	✓
8	MS-GulfCoast	hbix	120	120	NGVD1929	
9	Mobile-Bay	emo2	229	135	NAVD1988	✓
10	Pensacola-Bay	epn3	200	330	NAVD1988	✓
11	Panama-City	hpam	105	118	NGVD1929	✓
12	Apalachicola-Bay	apc	71	93	NGVD1929	✓
13	Cedar-Key	cdr	79	85	NGVD1929	✓
14	Tampa-Bay	etp3	188	215	NAVD1988	✓
15	Fort-Myers	efmy	111	100	NGVD1929	✓
16	Florida-Bay	ekey	170	200	NGVD1929	✓
17	Biscayne-Bay	hmia	125	190	NGVD1929	✓
18	Okeechobee	eok2	129	136	NAVD1988	✓
19	Palm-Beach	pbi	71	153	NGVD1929	✓
20	Cape-Canaveral	cof	69	89	NGVD1929	✓
21	Jacksonville	ejax	84	96	NGVD1929	✓
22	HiltonHead	esv3	152	200	NAVD1988	✓
23	Charleston-Harbor	hchs	95	150	NGVD1929	✓
24	Wilmington-NC	il2	171	236	NAVD1988	✓
25	Pamlico-Sound	eht2	180	130	NAVD1988	✓
26	Norfolk	eorf	100	110	NGVD1929	
27	Chesapeake-Bay	cp2	79	84	NGVD1929	✓
28	Ocean-City	oce	75	99	NGVD1929	
29	Atlantic-City	acy	87	106	NGVD1929	✓
30	NewYork	ny2	90	83	NGVD1929	✓
31	Buzzards-Bay	pv2	183	280	NAVD1988	✓
32	Penobscot-Bay	pnb	108	115	NGVD1929	✓

The following criteria are used to determine which basins will be used for a user-provided study region: (1) where multiple basins overlapped for a given location, the one with the finer grid size resolution, usually the one with minimum distance from the basin origin to the location, will be used; (2) all of the 2009 updated SLOSH basins will be used to take advantage of the better representation of local features; and (3) exclude redundant basins to reduce the model run time. Following these criteria, three basins were removed: Vermilion-Bay Basin, MS-Gulf Coast Basin, and Norfolk Basin. The first two basins are overlapped by the neighboring basin of New Orleans, and the last one is overlapped by its adjacent basins: Chesapeake Bay Basin and Pamlico Sound Basin.

The advantage of this basin selection approach is that it offers good grid resolution in areas of greatest interest while conserving computer resources by minimizing the number of basins required to simulate the storm surge and wave levels in a study region. Figure 4.62 shows an example of the polygons selected to delineate the boundaries between overlapping SLOSH basins. Each dotted polygon boundary is paired with the solid SLOSH basin of the same color. Thus, the number of basins needed to analyze a study region is simply the number of distinct polygons intersected by the study region.

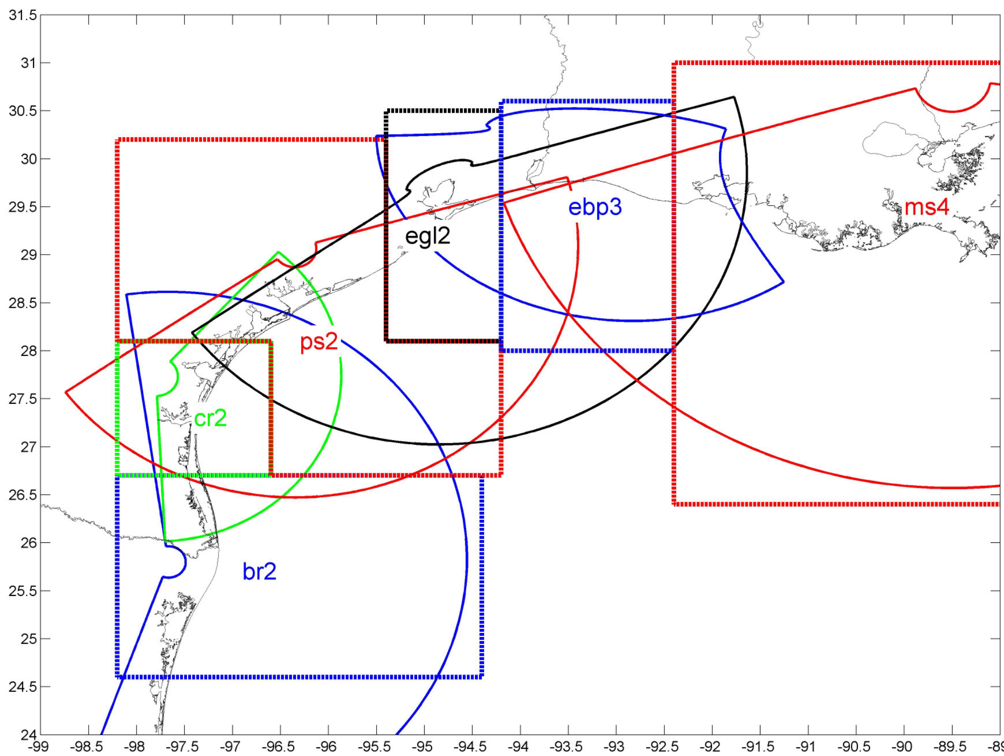


Figure 4.62 Basin Selection Regions for Texas and Louisiana

4.4.1.3 Integration with Coastal Flood Model

Given a known building type (i.e., specific occupancy, foundation type, and building height grouping) at a known location, two inputs are required by the Hazus Coastal Flood Model to estimate the extent of coastal flooding damage as a percentage of building or contents replacement value: (1) the wave height at the location, and (2) the total water depth at the location (i.e., wave crest elevation – ground elevation). The former input is used to determine the flood hazard zone (V-zone or A-zone) and, hence, the depth-damage function, where the latter input (along with the foundation type) is used to determine where to enter into the depth-damage function.

The steps for computing combined hurricane and flood losses are outlined below. All steps are required unless otherwise noted.

Hazus SHELL:

1. Create a coastal study region with both Hurricane and Flood hazards enabled

2. Open the study region in the Hurricane Model

Hazus HURRICANE:

1. Create a user-defined hurricane storm track using one of the following existing user-defined scenario options in the hurricane scenario wizard:

   a. Define storm track manually

   b. Import from exported file

   c. Import HurrEvac storm advisory

2. OPTIONAL: modify the building inventory and/or analysis parameters

   a. General Building Stock (GBS) modifications must be made at the block level to ensure compatibility between the Hurricane Model and the Flood Model.

   b. Set flag if GBS is altered

3. Set the following analysis options:

   a. Enable storm surge model

   b. OPTIONAL: Enable deep water wave model

   c. OPTIONAL: Enable near shore wave model with 2-way coupling

   d. Enable combined wind and flood losses

4. Start the analysis

5. OPTIONAL: Run SWAN on the coarse northwest Atlantic grid (~20 km cell size)

   a. Can be skipped if available time is limited

   b. Provides the wave conditions at boundary of SLOSH basin

   c. SWAN wave model is driven with Hazus wind field model

6. Run SLOSH and SWAN codes

   a. OPTIONS:

      i. Wave model (SWAN) can be turned off if available time is limited

ii. When the wave model is turned on, the coupling options are:

1. One-way coupling (waves computed atop surge)

2. Two-way coupling (waves computed atop surge, and wave setup increases surge)

b. Both models are driven with Hazus wind field model

c. SLOSH provides stillwater elevations throughout basin

i. User can input an initial water level to approximate effect of astronomical tide at the time of hurricane landfall

ii. Save Stillwater elevations (feet) to a grid float file (cell size ~0.003 degrees)

d. SWAN provides significant wave height and dominant wave periods throughout the flooded areas of the basin, but only the wave conditions at the 0 ft shoreline are used in the Coastal Flood Model

i. Save significant wave heights (feet) to a grid float file (cell size ~0.003 degrees)

ii. Save dominant wave periods (sec) to a grid float file (cell size ~0.003 degrees)

7. Repeat step #6 for each required SLOSH basin

a. The number of required basins is determined by the extent of the study region

8. Compute hurricane-only losses using existing methodology

9. Set flags in database to indicate:

a. Wind results are current

b. SLOSH results are current

c. OPTIONAL: SWAN results are current

10. Launch the Coastal Flood Model

Hazus FLOOD:

1. Set flood hazard as Coastal Surge

2. Run the DEM for the study region

3. Create a new scenario

   a. Characterize the shoreline

   b. NOTE: If the wave grid (waveht.flt and waveht.hdr) files were generated in the Hurricane Model, the Shoreline Characterization dialog will not show up. The user can proceed directly to Coastal > Delineate Floodplain.

4. Compute the stillwater depth, $d_{s,}$ in each flooded cell of the DEM:

   a. d_s = SWEL – Ground Elevation

      i. SWEL is from SLOSH (feet, NAVD88 or NGVD29 depending on the basin)

      ii. Ground elevation is from Coastal Flood Model DEM

5. Create transects using existing methodology

6. Where each transect intersects the coastline, compute the following:

   a. Controlling wave height: H_c = min (0.78 d_s, 1.6 H_s) where H_s comes from the wave (SWAN) model

      i. NOTE: The 0.78 factor in the equation above represents an estimate of the maximum depth-limited wave height. A more accurate estimate can be calculated if wave period is also considered. The WHAFIS code wave breaking criteria can be used in conjunction with wave period information from SWAN if sufficient project resources are available to do so, otherwise use 0.78.

   b. Wave crest elevation = SWEL + 0.7 H_c

7. Propagate the wave inland from shoreline along transects using existing methodology (simplified WHAFIS)

   a. For this effort, the Flood Model will ignore wave regeneration and wave dissipation.

   b. The Flood Model will not use shoreline characterization to perform wave runup or dune erosion calculations. These will be ignored.

8. Interpolate between transects to develop the flood depth grid

9. Determine wave zone based on H_c:

   a. If $H_c \geq 1.5$ feet, then use the V-zone damage functions

   b. If $H_c < 1.5$ feet, then use the A-zone damage functions

10. For each unique combination of building type (i.e., specific occupancy, foundation type, and building height grouping) and total depth of flooding, determine the structure and contents losses by entering the appropriate depth-damage curve at the wave crest elevation minus the appropriate first floor reference elevation

11. Area weight the flood-only building contents losses by Census Block, specific occupancy, foundation type, and building height group using the existing Coastal Flood Model methodology.

12. Compute the combined hurricane and flood losses for buildings and contents by Census Block and specific building type using the combined hurricane and flood loss matrices.

4.4.2 Combined Hurricane and Flood Losses for Coastal Storm Surge

This section describes the methodology for combining hurricane and flood losses to buildings in Hazus-MH due to hurricane wind, storm surge and waves. The objective of the combined loss methodology is to estimate the total losses sustained by the general building stock within a region due to the winds, storm surge and waves generated by a single, user-specific hurricane scenario.

The combined hurricane and flood loss methodology builds upon the existing Hazus-MH hurricane loss and coastal flooding loss methodologies without altering either the “hurricane-only” or “flood-only” loss estimates.

The primary motivation for the combined hurricane and flood loss methodology is to avoid “double counting” of damage in cases where the same building is exposed to both hurricane and flood hazards during a hurricane. At a minimum, the combined hurricane and flood loss must be at least the larger of the hurricane-only or the flood-only loss. At a maximum, the combined loss must be no larger than the lesser of the sum of the hurricane-only and flood-only losses or 100% of the building (or contents) replacement value. These constraints can be written as:

$$\max(W, F) \leq C \leq \min(W+F, 1.00) \tag{4-24}$$

where W is the modeled hurricane-only building (or contents) loss ratio expressed as a fraction of the building (or contents) replacement value, F is the modeled flood-only building (or contents) loss ratio, and C is the combined hurricane and flood loss ratio.

As an example, consider a scenario in which the hurricane-only loss estimate for a single family wood frame house is 70% of the building replacement value and the flood-only loss estimate is 50%. In this situation, the lower and upper bounds on the combined hurricane and flood loss would be 70% and 100%, respectively, of the building replacement value.

If, as a special case, we assume that the wind-induced damage and flood-induced damage are spread uniformly and randomly over a building. In this idealized case, the two damage mechanisms can be treated as independent, and the expected combined loss ratio is simply

$$C = W + F - W*F \tag{4-25}$$

An idealized combined hurricane and flood loss matrix based on Equation 4-25 is shown in Table 4.8. Note that the combined wind and flood loss estimate in each cell of the table is always less than or equal to the sum of the wind-only loss and flood-only loss shown in its column and row headings, respectively.

Table 4.8 Combined Hurricane and Flood Loss Matrix for Idealized Case of Hurricane and Flood Losses that are Uniformly and Randomly Distributed throughout the Building

		Wind-Only Building Loss										
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Flood-Only Building Loss	0%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
	10%	10%	19.0%	28.0%	37.0%	46.0%	55.0%	64.0%	73.0%	82.0%	91.0%	100%
	20%	20%	28.0%	36.0%	44.0%	52.0%	60.0%	68.0%	76.0%	84.0%	92.0%	100%
	30%	30%	37.0%	44.0%	51.0%	58.0%	65.0%	72.0%	79.0%	86.0%	93.0%	100%
	40%	40%	46.0%	52.0%	58.0%	64.0%	70.0%	76.0%	82.0%	88.0%	94.0%	100%
	50%	50%	55.0%	60.0%	65.0%	70.0%	75.0%	80.0%	85.0%	90.0%	95.0%	100%
	60%	60%	64.0%	68.0%	72.0%	76.0%	80.0%	84.0%	88.0%	92.0%	96.0%	100%
	70%	70%	73.0%	76.0%	79.0%	82.0%	85.0%	88.0%	91.0%	94.0%	97.0%	100%
	80%	80%	82.0%	84.0%	86.0%	88.0%	90.0%	92.0%	94.0%	96.0%	98.0%	100%
	90%	90%	91.0%	92.0%	93.0%	94.0%	95.0%	96.0%	97.0%	98.0%	99.0%	100%
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

While the idealized combined hurricane and flood loss matrix shown in Table 4.8 satisfies the constraints specified in Equation 4-25, it is nonetheless clear that neither wind nor storm surge damages are uniformly and randomly distributed throughout a structure. Hurricane damage is most frequently initiated at the roof and fenestrations (i.e., windows, doors, or other openings in the building envelope), whereas flood damage is most frequently initiated at the lowest elevations of the structure (e.g., foundation or lowest floor) and progresses upward through the structure as the depth of flooding increases.

In the next subsection, we present an approach for incorporating the non-uniformity of hurricane and flood damage into the combined loss methodology. The approach is based on allocating hurricane and flood losses to building sub-assemblies as a function of the building type and the overall hurricane-only and flood-only loss estimate. The concept of building sub-assemblies is widely used in construction cost estimation and is already used in the Hazus hurricane-only loss methodology. A recent U.S. Army Corps of Engineer New Orleans District study (GEC 2006) also provides guidance for allocating flood losses to building sub-assemblies.

Please note that no attempt was made in the methodology to allocate or apportion the combined loss into wind and flood loss components. While the apportioning of losses may be of great interest in situations where the financial stakeholders and/or indemnification terms for hurricane and flood losses differ, such situations require careful consideration of individual building design and construction details, local hurricane hazards (e.g., the magnitudes, timing, duration, and directionality of wind, surge, and waves), and local site characteristics (e.g., aerodynamic roughness and hydrodynamic roughness) that are clearly beyond the scope of a regional loss estimation and hazard mitigation tool such as Hazus-MH.

4.4.2.1 Building Sub-Assembly Approach

The existing Hazus hurricane loss estimation methodology is a physically-based, damage-to-loss methodology that computes direct economic losses to buildings using a combination of explicit and implicit costing techniques. Detailed simulations of building envelope damage are used to explicitly estimate expected repair and replacement costs for the hurricane-damaged components of the building envelope, such as roof covering, roof sheathing, windows, doors, and wall covering. It also estimates expected losses to the building interior and contents through a combination of the roofing damage fraction and the volume of rain water penetrating through failed fenestrations (windows, doors, garage doors, etc.). The methodology is described in detail in section 7 of the Hazus Hurricane Technical Manual (FEMA 2009a).

A recent study for the New Orleans District of the U.S. Army Corps of Engineers (GEC 2006) provides estimates of overall building and contents losses due to flooding as a function of building type (e.g., one story house on slab foundation), type of flooding (e.g., short or long duration, freshwater or saltwater), and depth of flooding (i.e., flood level relative to first floor). The GEC study is similar to the Hazus hurricane loss methodology in that it builds up the overall flood loss by summing the losses to building components, such as the structural frame, doors/trim, plumbing, cabinets, etc. For single family homes on slab foundations, the building flood loss estimates are built-up by estimating damage to a total of different 20 building components. The component loss estimates are based on interviews with homeowners and business operators and the collective judgment of nine experts in the fields of construction, repair and restoration, and insurance claims adjustment.

By grouping the hurricane loss components and flood loss components into a consistent set of building sub-assemblies, we can more accurately apply Equation 4-25 to each sub-assembly instead of applying it to the entire building. For this purpose, we define seven major building sub-assemblies:

1. Foundation: Includes site work, footings, and walls, slabs, piers or piles.

2. Below First Floor: Items other than the foundation that are located below the first floor of the structure, such as mechanical equipment, stairways, parking pads, break away walls, etc.

3. Structure Framing: Includes all of the main load carrying structural members of the building below the roof framing and above the foundation.

4. Roof Covering: Includes the roof membrane material and flashing

5. Roof Framing: Includes trusses, rafters, and sheathing[1]

[1] For a one-story, wood frame house on a slab foundation, the total framing cost is assumed to be distributed as 39% exterior wall framing, 26% interior wall framing, and 35% roof framing.

6. Exterior Walls: Includes wall coverings, windows, exterior doors, and insulation

7. Interiors: Includes interior wall and floor framing, drywall, paint, interior trim, floor coverings, cabinets, counters, mechanical, and electrical

These groupings allow, for example, roof covering loss to contribute more, on average, to the overall hurricane-only loss than it would to same overall level of flood-only loss.

To illustrate the approach, we consider a one-story, wood frame house on a slab foundation exposed to short duration coastal flooding. The default Hazus Flood Model depth-damage curve for this specific occupancy in the A-zone is plotted in Figure 4.63. Using Table 4.9 from the GEC (2006) report, we can allocate the flood losses to five sub-assemblies. In this preliminary example, we can neglect the Below First Floor sub-assembly (since we have a slab foundation) and merge the Structure Framing sub-assembly into the Exterior Walls sub-assembly for simplicity. The results are shown in Table 4.10.

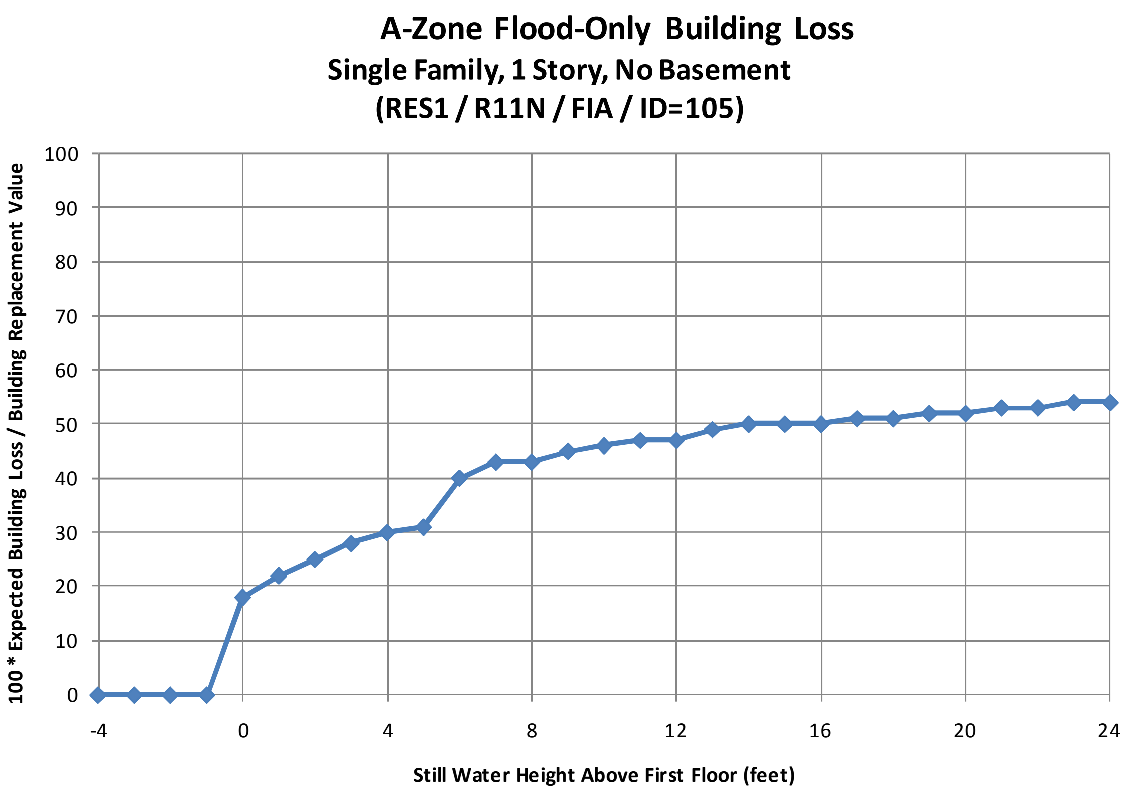


Figure 4.63 Default Depth-Damage Curve in Hazus-MH for One-Story, Single Family Houses on Slab Foundation in the A-Zone

Table 4.9 Hazus-MH Specific Building Types

SBT	Description
WSF1	Wood, Single Family, One Story
WSF2	Wood, Single Family, Two or More Stories
WMUH1	Wood, Multi-Unit Housing, One Story
WMUH2	Wood, Multi-Unit Housing, Two Stories
WMUH3	Wood, Multi-Unit Housing, Three or More Stories
MSF1	Masonry, Single Family, One Story
MSF2	Masonry, Single Family, Two or More Stories
MMUH1	Masonry, Multi-Unit Housing, One Story
MMUH2	Masonry, Multi-Unit Housing, Two Stories
MMUH3	Masonry, Multi-Unit Housing, Three or More Stories
MLRM1	Masonry, Low-Rise Strip Mall, Up to 15 Feet
MLRM2	Masonry, Low-Rise Strip Mall, More than 15 Feet
MLRI	Masonry, Low-Rise Industrial/Warehouse/Factory Buildings
MERBL	Masonry, Engineered Residential Building, Low-Rise (1-2 Stories)
MERBM	Masonry, Engineered Residential Building, Mid-Rise (3-5 Stories)
MERBH	Masonry, Engineered Residential Building, High-Rise (6+ Stories)
MECBL	Masonry, Engineered Commercial Building, Low-Rise (1-2 Stories)
MECBM	Masonry, Engineered Commercial Building, Mid-Rise (3-5 Stories)
MECBH	Masonry, Engineered Commercial Building, High-Rise (6+ Stories)
CERBL	Concrete, Engineered Residential Building, Low-Rise (1-2 Stories)
CERBM	Concrete, Engineered Residential Building, Mid-Rise (3-5 Stories)
CERBH	Concrete, Engineered Residential Building, High-Rise (6+ Stories)
CECBL	Concrete, Engineered Commercial Building, Low-Rise (1-2 Stories)
CECBM	Concrete, Engineered Commercial Building, Mid-Rise (3-5 Stories)
CECBH	Concrete, Engineered Commercial Building, High-Rise (6+ Stories)
SPMBS	Steel, Pre-Engineered Metal Building, Small
SPMBM	Steel, Pre-Engineered Metal Building, Medium
SPMBL	Steel, Pre-Engineered Metal Building, Large
SERBL	Steel, Engineered Residential Building, Low-Rise (1-2 Stories)
SERBM	Steel, Engineered Residential Building, Mid-Rise (3-5 Stories)
SERBH	Steel, Engineered Residential Building, High-Rise (6+ Stories)
SECBL	Steel, Engineered Commercial Building, Low-Rise (1-2 Stories)
SECBM	Steel, Engineered Commercial Building, Mid-Rise (3-5 Stories)
SECBH	Steel, Engineered Commercial Building, High-Rise (6+ Stories)
MHPHUD	Manufactured Home, Pre-HUD
MH76HUD	Manufactured Home, 1976 HUD
MH94HUD-I	Manufactured Home, 1994 HUD - Wind Zone I
MH94HUD-II	Manufactured Home, 1994 HUD - Wind Zone II
MH94HUD-III	Manufactured Home, 1994 HUD - Wind Zone III

Using the depths associated with flood-only losses of 10%, 20%, …, 90% from Figure 4.58 and interpolating from Table 4.10, we can apportion the flood-only building loss to the five retained sub-assemblies. The results for the example house are shown in Table 4.11.

Table 4.10 Distribution of Flood Losses to Building Sub-Assemblies as a Function of Depth of Flooding for a One-Story, Single Family House on Slab Foundation in an A-Zone Exposed to Short Duration Saltwater Flooding (from 2006 GEC Study)

Sub-Assembly	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
Foundation	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Roof Covering	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	1.4%	1.6%	1.6%	2.4%	2.4%	2.4%
Roof Framing	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
Exterior Wall	10.0%	15.2%	18.9%	20.4%	22.5%	23.7%	24.0%	23.8%	23.6%	22.6%	22.6%	22.5%	22.5%	22.4%	22.4%	22.4%
Interiors	90.0%	84.8%	81.1%	79.6%	77.5%	76.3%	76.0%	76.2%	76.4%	76.6%	75.6%	75.5%	75.5%	74.9%	74.9%	74.9%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 4.11 Distribution of Flood Losses to Building Sub-Assemblies as a Function of Flood-Only Building Loss for a Pre-FIRM, One-Story, Single Family House on Slab Foundation in an A-Zone

Building Loss	Foundation	Below First Floor	Structure Frame	Roof Cover	Roof Frame	Exterior Wall	Interiors	Total
10.0%	0.0%	1.5%	0.0%	0.0%	0.0%	0.5%	8.0%	10.0%
20.0%	0.0%	3.0%	0.2%	0.1%	0.1%	3.5%	12.9%	19.7%
30.0%	0.0%	3.0%	1.0%	0.4%	0.4%	5.5%	19.6%	29.9%
40.0%	0.0%	3.0%	1.3%	0.5%	0.5%	7.5%	27.0%	39.8%
50.0%	0.0%	3.0%	1.6%	0.6%	0.6%	10.5%	33.7%	50.1%
60.0%	0.1%	3.0%	2.1%	0.8%	0.8%	12.8%	40.4%	60.0%
70.0%	0.4%	3.0%	2.6%	1.0%	1.0%	15.5%	46.6%	70.0%
80.0%	0.6%	3.0%	3.3%	1.3%	1.3%	17.5%	52.7%	79.5%
90.0%	1.0%	3.0%	3.9%	1.5%	1.5%	19.5%	60.0%	90.4%
100.0%	1.5%	3.0%	5.5%	2.1%	2.1%	25.0%	61.0%	100.3%

The hurricane-only loss simulation results for the example house can likewise be distributed to the same five major sub-assemblies. The hurricane losses from each of the 107,910 building damage simulations are grouped by overall hurricane-only building loss with the average contributions from each of the five major sub-assemblies. The results for the example house are shown in Table 4.12.[2]

By comparing Table 4.11 and Table 4.12, it can be seen that the roof covering and roof framing losses are bigger contributors to the hurricane-only losses than the flood-only losses, whereas the

[2] The results shown in Table 4.12 are for a one-story, wood frame house located in suburban terrain with a gable roof, no garage, roof-to-wall straps, no opening protection, 8d roof deck nails at 6/12 spacing, and no secondary water resistance.

exterior wall and interior losses are bigger contributors to the flood-only losses than the hurricane-only losses. This systematic difference in relative loss contributions suggests that the actual combined hurricane and flood losses should be higher than those based on uniformly and randomly distributed losses to an entire building, as shown previously in Table 4.8.

If we now apply Equation 4-25 to each sub-assembly with the losses expressed as a fraction of their respective sub-assembly replacement values, multiply the combined hurricane and flood loss for each sub-assembly by its total repair and replacement cost expressed as a fraction of the total building repair value, sum the sub-assembly losses, and apply the overall loss constraints of Equation 4-24 we obtain the results shown in Table 4.13.

Table 4.12 Distribution of Hurricane Losses to Building Sub-Assemblies Relative to Building Value as a Function of Hurricane-Only Building Loss for a Pre-FIRM, One-Story, Single Family House Located in Suburban Terrain with a Gable Roof Shape and Medium Wind Resistance

Building Loss	Foundation	Below First Floor	Structure Frame	Roof Cover	Roof Frame	Exterior Wall	Interiors	Total
10%	0.0%	0.0%	0.0%	2.6%	0.0%	0.6%	6.8%	10.0%
20%	0.0%	0.0%	0.0%	5.3%	0.0%	1.2%	13.5%	20.0%
30%	0.0%	0.0%	0.0%	5.7%	0.1%	1.8%	22.4%	30.0%
40%	0.0%	0.0%	0.0%	5.7%	0.1%	2.2%	31.9%	40.0%
50%	0.0%	0.0%	0.1%	5.7%	0.2%	2.7%	41.3%	50.0%
60%	0.0%	0.0%	0.2%	5.7%	0.5%	6.1%	47.5%	60.0%
70%	0.0%	0.0%	0.3%	5.7%	0.9%	9.6%	53.5%	70.0%
80%	1.8%	0.0%	0.4%	5.7%	1.9%	13.6%	56.6%	80.0%
90%	3.2%	0.0%	3.2%	6.3%	2.9%	13.6%	60.9%	90.0%
100%	4.5%	0.0%	5.2%	6.3%	4.1%	18.6%	61.3%	100.0%

Table 4.13 Combined Hurricane and Flood Loss Matrix Assuming Hurricane and Flood Losses are Each Uniformly Distributed within each of the Five Building Sub-Assemblies

		Flood-Only Building Loss										
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Wind-Only Building Loss	0%	0.0%	10.0%	20.0%	30.0%	40.0%	50.0%	60.0%	70.0%	80.0%	90.0%	100.0%
	10%	10.0%	18.8%	27.7%	36.9%	45.9%	55.3%	64.4%	73.6%	82.3%	92.2%	100.0%
	20%	20.0%	27.9%	36.1%	44.4%	52.5%	61.1%	69.3%	77.7%	85.5%	94.5%	100.0%
	30%	30.0%	36.8%	44.2%	51.4%	58.4%	65.9%	73.1%	80.5%	87.4%	95.2%	100.0%
	40%	40.0%	45.5%	52.1%	58.3%	64.1%	70.5%	76.5%	83.0%	88.9%	95.5%	100.0%
	50%	50.0%	54.3%	60.1%	65.2%	69.8%	75.1%	80.1%	85.5%	90.4%	95.9%	100.0%
	60%	60.0%	63.4%	68.3%	72.4%	76.0%	80.3%	84.2%	88.6%	92.7%	97.1%	100.0%
	70%	70.0%	72.6%	76.6%	79.7%	82.3%	85.4%	88.4%	91.8%	95.0%	98.4%	100.0%
	80%	80.0%	82.1%	85.3%	87.8%	89.6%	**91.9%**	**94.2%**	96.7%	99.1%	100.0%	100.0%
	90%	90.0%	91.6%	94.4%	96.1%	97.4%	**99.1%**	**100.0%**	100.0%	100.0%	100.0%	100.0%
	100%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Upon reviewing the results, we see that the combined loss estimates in Table 4.13 are indeed larger than the corresponding loss estimates in Table 4.8, and that the 100% cap is reached in approximately 1/3 of the interior cells. We also note that the combined loss estimates in Table 4.13 are slightly asymmetric. For example, when W=50% and F=20%, C=60.1%. On the other hand, when W=20% and F=50%, C=61.1%.

4.4.2.2 Development of Sub-Assembly Loss Tables

All three models in Hazus-MH (i.e., Earthquake, Flood, and Hurricane) computes aggregate losses to the general building stock according to 33 specific occupancy classes and five general building types. The 33 specific occupancy classes are listed in Table 4.14. The five general building type classes are Wood, Masonry, Steel, Concrete, and Manufactured Housing. To implement the combined loss methodology sub-assembly replacement values and sub-assembly loss tables are needed for each of the 33 specific occupancies and five general building type classes.

Table 4.14 Hazus-MH Specific Occupancy Classes

Class	Description
RES1	Single Family Dwelling
RES2	Manufactured Hosuing
RES3A	Duplex
RES3B	Triplex/Quads
RES3C	Multi-dwellings (5 to 9 units)
RES3D	Multi-dwellings (10 to 19 units)
RES3E	Multi-dwellings (20 to 49 units)
RES3F	Multi-dwellings (50+ units)
RES4	Temporary Lodging
RES5	Institutional Dormitory
RES6	Nursing Home
COM1	Retail Trade
COM2	Wholesale Trade
COM3	Personal and Repair Services
COM4	Professional/ Technical Services
COM5	Banks
COM6	Hospital
COM7	Medical Office/Clinic
COM8	Entertainment & Recreation
COM9	Theaters
COM10	Parking
IND1	Heaving Industry
IND2	Light Industry
IND3	Food/Drug/Chemicals
IND4	Metals/Minerals Processing
IND5	High Technology
IND6	Construction
AGR1	Agriculture
REL1	Churches and Other non-profit Org.
GOV1	Genral Services
GOV2	Emergency Response
EDU1	Grade Schools
EDU2	Colleges Univeristies

The sub-assembly replacement values (as a percentage of total building replacement value) were developed using RS Means (2009) data for typical model buildings representing each specific occupancy. The general building type sub-assembly replacement values were then estimated using a Hazus specific occupancy-general building type mapping scheme for the southeastern United States. Replacement values are summarized in Table 4.15 for two cases: Pre-FIRM construction and Post-FIRM construction. As a rough rule, the foundation sub-assembly costs were typically assumed to increase by 5% when going from Pre-FIRM to Post-FIRM construction. To compensate for the increase in foundation cost, the interiors were typically assumed to decrease by 3% and the structure frame and exterior walls sub-assemblies were each typically assumed to decrease by 1%.

Table 4.15 Sub-Assembly Replacement Values by Specific Occupancy or General Building Type as a Percentage of Total Building Replacement Value

Specific Occupancy or General Building Type		Pre-FIRM Found-ation	Pre-FIRM Below First Floor	Pre-FIRM Structure Frame	Pre-FIRM Roof Covering	Pre-FIRM Roof Framing	Pre-FIRM Exterior Wall	Pre-FIRM Interiors	Pre-FIRM Total	Post-FIRM Found-ation	Post-FIRM Below First Floor	Post-FIRM Structure Frame	Post-FIRM Roof Covering	Post-FIRM Roof Framing	Post-FIRM Exterior Wall	Post-FIRM Interiors	Post-FIRM Total
RES1	Single	6%	2%	13%	5%	5%	20%	49%	100%	11%	3%	10%	5%	5%	19%	47%	100%
RES2	MH	6%	2%	10%	3%	5%	20%	54%	100%	8%	2%	10%	3%	5%	20%	52%	100%
RES3A	Duplex	6%	2%	13%	5%	5%	20%	49%	100%	11%	3%	10%	5%	5%	19%	47%	100%
RES3B	3-4 units	6%	2%	13%	5%	5%	20%	49%	100%	11%	3%	10%	5%	5%	19%	47%	100%
RES3C	5-9 units	5%	1%	10%	2%	3%	10%	69%	100%	10%	1%	9%	2%	3%	9%	66%	100%
RES3D	10-19 units	5%	1%	10%	2%	3%	10%	69%	100%	10%	1%	9%	2%	3%	9%	66%	100%
RES3E	20-49 units	5%	1%	13%	1%	3%	10%	67%	100%	10%	1%	12%	1%	3%	10%	63%	100%
RES3F	50+ units	3%	0%	13%	1%	1%	13%	69%	100%	8%	0%	12%	1%	1%	12%	66%	100%
RES4	Temp. Lodging	3%	1%	9%	1%	2%	10%	74%	100%	8%	1%	8%	1%	2%	9%	71%	100%
RES5	Instutional Dormitory	4%	0%	14%	1%	3%	14%	64%	100%	9%	0%	13%	1%	3%	13%	61%	100%
RES6	Nursing Home	5%	0%	10%	3%	2%	13%	67%	100%	10%	1%	9%	3%	2%	12%	63%	100%
COM1	Retail	6%	1%	10%	5%	5%	10%	63%	100%	11%	1%	9%	5%	5%	9%	60%	100%
COM2	Wholesale	20%	1%	7%	9%	7%	11%	45%	100%	25%	1%	6%	9%	7%	10%	42%	100%
COM3	Personal & repair services	10%	1%	8%	7%	3%	10%	61%	100%	15%	1%	7%	7%	3%	9%	58%	100%
COM4	Professional / Business	4%	1%	11%	1%	3%	17%	63%	100%	9%	1%	10%	1%	3%	16%	60%	100%
COM5	banks	6%	0%	10%	4%	9%	8%	63%	100%	11%	0%	9%	4%	9%	7%	60%	100%
COM6	Hospital	2%	0%	7%	1%	4%	7%	79%	100%	7%	0%	6%	1%	4%	6%	76%	100%
COM7	MedicalOffice	5%	1%	5%	3%	2%	12%	72%	100%	10%	1%	4%	3%	2%	11%	69%	100%
COM8	Entertainment	9%	1%	10%	4%	3%	8%	65%	100%	14%	1%	9%	4%	3%	7%	62%	100%
COM9	Theaters	6%	1%	10%	5%	6%	10%	62%	100%	11%	1%	9%	5%	6%	9%	59%	100%
COM10	Parking	12%	0%	40%	0%	10%	9%	29%	100%	17%	0%	39%	0%	10%	8%	26%	100%
IND1	Heavy	14%	1%	3%	7%	3%	10%	62%	100%	19%	1%	2%	7%	3%	9%	59%	100%
IND2	Light	15%	1%	4%	9%	7%	11%	53%	100%	20%	1%	3%	9%	7%	10%	50%	100%
IND3	Food / Chemical	11%	1%	4%	8%	6%	11%	59%	100%	16%	1%	3%	8%	6%	10%	56%	100%
IND4	Metals/Mineral Processing	7%	0%	25%	2%	6%	8%	52%	100%	12%	0%	24%	2%	6%	7%	49%	100%
IND5	High Technology	11%	0%	5%	4%	4%	4%	72%	100%	16%	0%	4%	4%	4%	3%	69%	100%
IND6	Construction	20%	1%	7%	9%	7%	11%	45%	100%	25%	1%	6%	9%	7%	10%	42%	100%
AGR1	Agriculture	26%	0%	8%	9%	9%	12%	36%	100%	31%	0%	7%	9%	9%	11%	33%	100%
REL1	Church	10%	1%	12%	4%	17%	10%	46%	100%	15%	1%	11%	4%	17%	9%	43%	100%
GOV1	General Services	10%	1%	12%	6%	4%	8%	59%	100%	15%	1%	11%	6%	4%	7%	56%	100%
GOV2	Emergency Response	6%	0%	15%	2%	2%	12%	63%	100%	11%	0%	14%	2%	2%	11%	60%	100%
EDU1	School	4%	1%	12%	3%	6%	10%	64%	100%	9%	1%	11%	3%	6%	9%	61%	100%
EDU2	College	4%	1%	10%	2%	3%	8%	72%	100%	9%	1%	9%	2%	3%	7%	69%	100%
Wood		6%	1%	13%	4%	4%	16%	56%	100%	11%	1%	12%	4%	4%	15%	53%	100%
Steel		4%	0%	12%	1%	2%	15%	66%	100%	9%	0%	11%	1%	2%	14%	63%	100%
Masonry		7%	1%	14%	3%	3%	18%	54%	100%	12%	1%	13%	3%	3%	17%	51%	100%
Concrete		4%	0%	12%	1%	2%	15%	66%	100%	11%	0%	11%	3%	2%	11%	62%	100%
MH		6%	2%	10%	3%	5%	20%	54%	100%	8%	2%	10%	3%	5%	20%	52%	100%

4.4.2.3 Development of Sub-Assembly Loss Tables for Flood Losses

Because flood losses by building component or building sub-assembly are only available for a handful of building types and occupancies from the GEC (2006) study, an entire set of flood sub-assembly loss tables were developed for this project based on engineering judgment. The guidelines given in Table 4.16 were used to facilitate the process and achieve consistency across Specific Occupancies and General Building Types.

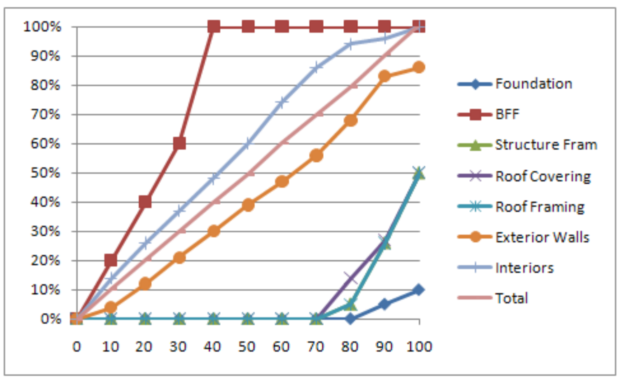
Table 4.16 Guidelines for Development of Flood Sub-Assembly Loss Tables

Sub-Assembly	Pre-FIRM Foundation A Zone Conditions	Pre-FIRM Foundation CA / V Zone Conditions	Post-FIRM Foundation A Zone Conditions	Post FIRM Foundations CA / V Zone Conditions
Foundation	Start damaging foundation at 80% (first non-zero value is at 90%) damage and max damage at 50% Pre-FIRM value (e.g. 3% if foundation represents 6% of the structure value)	Start damaging foundation at 50% damage (first non-zero value is at 60%) and max at 80% Pre-FIRM value (e.g. 5% if foundation represents 6% of the structure value)	Start damaging foundation at 80% (first non-zero value is at 90%) damage and max damage at 50% Post-FIRM value (e.g. 3% if foundation represents 6% of the structure value)	Start damaging foundation at 80% (first non-zero value is at 90%) damage and max damage at 50% Post-FIRM value (e.g. 3% if foundation represents 6% of the structure value)
Below First Floor	Start damaging BFF at 0% damage (first non-zero value is 10%) and achieve 100% Pre-FIRM value by 40% building damage.	Start damaging BFF at 0% damage (first non-zero value is 10%) and achieve 100% Pre-FIRM at 20% building damage.	Start damaging BFF at 0% damage (first non-zero value is 10%) and achieve 100% Post-FIRM value by 40% building damage.	Start damaging BFF at 0% damage (first non-zero value is 10%) and achieve 100% Post-FIRM at 20% building damage.
Structure Frame	Start damaging structure frame at 70% damage (first non-zero value is 80%) and achieve 100% Pre-FIRM value at 100% building damage.	Start damaging structure frame at 10% damage (first non-zero value is 20%) and achieve 100% Pre-FIRM value at 90% building damage.	Start damaging structure frame at 70% damage (first non-zero value is 80%) and achieve 100% Post-FIRM value at 100% building damage.	Start damaging structure frame at 10% damage (first non-zero value is 20%) and achieve 100% Post-FIRM value at 90% building damage.
Roof Cover	Same as Structure	Same as Structure	Same as Structure	Same as Structure
Roof Frame	Same as Structure	Same as Structure	Same as Structure	Same as Structure
Exterior Walls	Start damaging exterior walls at 0% damage (first non-zero value at 10%) and reach maximum (100%) at 100% building damage. Ensure that exterior is always below interior.	Start damaging exterior walls at 10% damage (first non-zero value is 20%) and reach maximum (100%) Pre-FIRM value at 90% building damage.	Start damaging exterior walls at 0% damage (first non-zero value at 10%) and reach maximum (100%) at 100% building damage. Ensure that exterior is always below interior.	Start damaging exterior walls at 10% damage (first non-zero value is 20%) and reach maximum (100%) Post-FIRM value at 90% building damage.
Interiors	Start damaging interior at 0% damage (first non-zero value at 10%) and reach maximum Pre-FIRM value (100%) at 80% building damage.	Start damaging interiors at 0% (first non-zero value at 10%) and reach maximum Pre-FIRM value (100%) at 80% building damage.	Start damaging interiors at 0% damage (first non-zero value at 10%) and reach maximum Post-FIRM value (100%) at 80% building damage.	Start damaging interiors at 0% (first non-zero value at 10%) and reach maximum Post-FIRM value (100%) at 80% building damage.

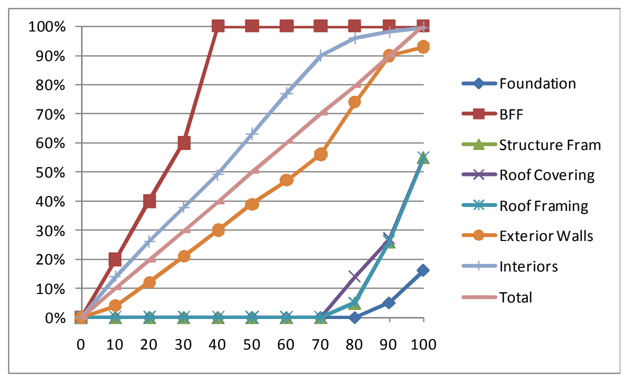
As indicated in Table 4.16, separate sub-assembly loss tables were developed for Pre- and Post-FIRM construction subjected to either A-Zone conditions (i.e., controlling wave heights less than

1.5 feet) or CA- / V- Zone conditions (i.e., controlling wave heights greater than or equal to 1.5 feet). This results in twice as many sub-assembly flood loss tables as sub-assembly hurricane loss tables since the hurricane loss tables are independent of wave conditions.

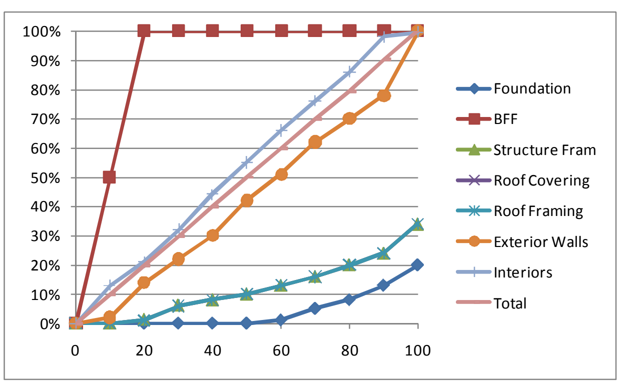
Figure 4.64 illustrates the sub-assembly losses for single-family occupancies. Separate plots are shown for each combination of construction type (Pre- or Post-FIRM) and wave conditions (A- or CA- / V- Zone). In each plot, the horizontal axis is the overall building loss as a percentage of building replacement value and the vertical axis is the sub-assembly loss as a percentage of its own replacement value. Note that losses to the interiors sub-assembly play a relatively larger role under A-Zone wave conditions, whereas losses to the below first floor and foundation sub-assemblies play larger roles under CA- or V-Zone wave conditions. The differences between Pre-FIRM and Post-FIRM sub-assembly loss contributions are generally less pronounced for this occupancy class than the differences between A-Zone and CA- / V-Zone.



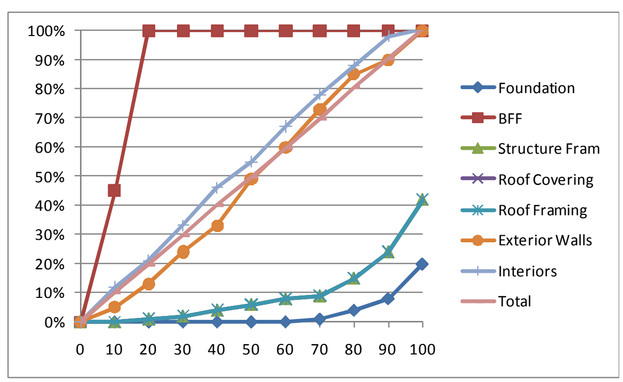
Pre-FIRM, A-Zone



Post-FIRM, A-Zone



Pre-FIRM, CA- or V-Zone



Post-FIRM, CA- or V-Zone

Figure 4.64 RES1 (Single Family) Sub-Assembly Losses for Flood as a Percentage of Sub-Assembly Replacement Value

4.4.2.4 *Final Flood Sub-Assembly Loss Tables*

The final sub-assembly loss tables for flood loss by specific occupancy and general building type are presented for Pre-FIRM and Post-FIRM construction and A-Zone and CA- / V-Zone conditions in Appendix 4A.

4.4.3 Demonstration Cases

To demonstrate the initial, prototype implementation of the coastal storm surge methodology, combined hurricane and flood loss estimates are presented in this section for six recent hurricane events:

1. Andrew (1992) – Miami-Dade County, Florida
2. Isabel (2003) – Dare County, North Carolina
3. Ivan (2004) – Escambia County, Florida
4. Katrina (2005) – Hancock County, Mississippi
5. Gustav (2008) – Terrebonne Parish, Louisiana
6. Ike (2008) – Chambers County, Texas

For each scenario, a study combined hurricane and flood study region was created in Hazus-MH. The hurricane-only losses were computed at the census block level for the default general building stock using the historic hurricane scenario analysis option. Next, the coupled surge and wave model described in Section 4.4.1 was run, resulting in a storm surge stillwater elevation grid and a significant wave height grid. The two grids were then imported into the Hazus Coastal Flood Model and used to produce the flood-only losses at the census block level for each specific occupancy and each general building type in the general building stock. Finally, the combined loss methodology described in Section 4.4.2 was run to produce estimates of the combined hurricane and flood loss in those census blocks that were inundated.

The results are summarized in Table 4.17 through Table 4.21. In the first two tables, only building exposure and building structure losses in census blocks with modeled inundation are included. In Tables 4.19 through 4.21, the modeled hurricane and flood losses for the entire county (or parish) are shown. In the "Combined" columns, the hurricane losses from the non-flooded blocks are added to the combined hurricane and flood losses from the flooded blocks.

Table 4.17 Building Structure Exposure and Losses (Millions of Dollars) in Flooded Census Blocks

Hurricane	Year	County/Parish	State	Exposure ($M)	Flood Loss ($M)	Wind Loss ($M)	Combined Loss ($M)	Lower Bound ($M)	Upper Bound ($M)
Andrew	1992	Miami-Dade	FL	$21,220	$3,490	$3,605	$6,420	$3,605	$7,095
Isabel	2003	Dare	NC	$1,960	$73	$30	$103	$73	$103
Ivan	2004	Escambia	FL	$2,893	$293	$99	$389	$293	$392
Katrina	2005	Hancock	MS	$2,035	$897	$140	$957	$897	$1,037
Gustav	2008	Terrebone	LA	$1,071	$190	$9	$193	$190	$199
Ike	2008	Chambers	TX	$446	$88	$23	$107	$88	$111

Table 4.18 Building Structure Damage (% of Exposure) in Flooded Census Blocks

Hurricane	Year	County/Parish	State	Exposure (%)	Flood Dmg (%)	Wind Dmg (%)	Combined Dmg (%)	Lower Bound (%)	Upper Bound (%)
Andrew	1992	Miami-Dade	FL	100.0%	16.4%	17.0%	30.3%	17.0%	33.4%
Isabel	2003	Dare	NC	100.0%	3.7%	1.5%	5.2%	3.7%	5.2%
Ivan	2004	Escambia	FL	100.0%	10.1%	3.4%	13.4%	10.1%	13.5%
Katrina	2005	Hancock	MS	100.0%	44.1%	6.9%	47.0%	44.1%	51.0%
Gustav	2008	Terrebone	LA	100.0%	17.7%	0.8%	18.1%	17.7%	18.6%
Ike	2008	Chambers	TX	100.0%	19.7%	5.2%	24.1%	19.7%	24.9%

Table 4.19 Building Structure Exposure and Losses (Millions of Dollars) by County

Hurricane	Year	County/Parish	State	Exposure ($M)	Flood Loss ($M)	Wind Loss ($M)	Combined Loss($M)	Lower Bound ($M)	Upper Bound ($M)
Andrew	1992	Miami-Dade	FL	$150,575	$3,490	$22,029	$24,745	$22,029	$25,519
Isabel	2003	Dare	NC	$3,520	$73	$47	$119	$73	$120
Ivan	2004	Escambia	FL	$19,467	$293	$466	$749	$466	$759
Katrina	2005	Hancock	MS	$2,701	$897	$179	$992	$897	$1,076
Gustav	2008	Terrebone	LA	$7,275	$190	$54	$239	$190	$244
Ike	2008	Chambers	TX	$1,951	$88	$89	$172	$89	$177

Table 4.20 Building Structure Damage (% of Exposure) by County

Hurricane	Year	County/Parish	State	Exposure (%)	Flood Dmg (%)	Wind Dmg (%)	Combined Dmg (%)	Lower Bound (%)	Upper Bound (%)
Andrew	1992	Miami-Dade	FL	14.1%	2.3%	14.6%	16.4%	14.6%	16.9%
Isabel	2003	Dare	NC	55.7%	2.1%	1.3%	3.4%	2.1%	3.4%
Ivan	2004	Escambia	FL	14.9%	1.5%	2.4%	3.8%	2.4%	3.9%
Katrina	2005	Hancock	MS	75.3%	33.2%	6.6%	36.7%	33.2%	39.8%
Gustav	2008	Terrebone	LA	14.7%	2.6%	0.7%	3.3%	2.6%	3.4%
Ike	2008	Chambers	TX	22.9%	4.5%	4.6%	8.8%	4.6%	9.1%

Table 4.21 Flooded Census Blocks by County

Flooded CBs	Total CBs	County/Parish	State	Exposure (% FCBs)
2,800	30,417	Miami-Dade	FL	9.2%
913	1,622	Dare	NC	56.3%
503	6,127	Escambia	FL	8.2%
1,688	2,341	Hancock	MS	72.1%
668	2,726	Terrebone	LA	24.5%
352	1,188	Chambers	TX	29.6%

Given the hurricane-only and flood-only estimates produced by the existing Hazus hurricane and flood loss methodologies as a starting point, the combined hurricane and flood losses computed for the six recent hurricanes appear to be reasonable and are within the expected bounds.

4.5 Other Types of Flooding:

4.5.1 Sheet Flooding
Sheet flooding is currently not handled in the Flood Model. This could possibly be an enhancement in the future.

4.5.2 Great Lakes Flooding
The flooding in the Great Lakes is captured in the Coastal part of the Flood Model and follows the same methodology with the coastal flooding on the Pacific, Gulf and Atlantic coasts. However, there are a few differences in the parameters that are used, such as the reference elevations, required dune reservoir to withstand erosion and transect lengths. The reference elevations used by Hazus are as follows:

Lake Erie	570.0 feet
Lake Huron	578.1 feet
Lake Ontario	244.0 feet
Lake Michigan	578.1 feet
Lake St. Clair	573.1 feet
Lake Superior	601.0 feet

4.6 References

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Appendix 4A. Flood Sub-Assembly Loss Tables

Table 4A.1 Flood Sub-Assembly Loss Tables

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES1	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
RES1	Pre	A	10%	0%	20%	0%	0%	0%	4%	14%
RES1	Pre	A	20%	0%	40%	0%	0%	0%	12%	26%
RES1	Pre	A	30%	0%	60%	0%	0%	0%	21%	37%
RES1	Pre	A	40%	0%	100%	0%	0%	0%	30%	48%
RES1	Pre	A	50%	0%	100%	0%	0%	0%	39%	60%
RES1	Pre	A	60%	0%	100%	0%	0%	0%	47%	74%
RES1	Pre	A	70%	0%	100%	0%	0%	0%	56%	86%
RES1	Pre	A	80%	0%	100%	5%	14%	5%	68%	94%
RES1	Pre	A	90%	5%	100%	26%	27%	26%	83%	96%
RES1	Pre	A	100%	10%	100%	50%	50%	50%	86%	100%
RES1	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
RES1	Post	A	10%	0%	20%	0%	0%	0%	4%	14%
RES1	Post	A	20%	0%	40%	0%	0%	0%	12%	26%
RES1	Post	A	30%	0%	60%	0%	0%	0%	21%	38%
RES1	Post	A	40%	0%	100%	0%	0%	0%	30%	49%
RES1	Post	A	50%	0%	100%	0%	0%	0%	39%	63%
RES1	Post	A	60%	0%	100%	0%	0%	0%	47%	77%
RES1	Post	A	70%	0%	100%	0%	0%	0%	56%	90%
RES1	Post	A	80%	0%	100%	5%	14%	5%	74%	96%
RES1	Post	A	90%	5%	100%	26%	27%	26%	90%	98%
RES1	Post	A	100%	16%	100%	55%	55%	55%	93%	100%
RES1	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES1	Pre	CA	10%	0%	50%	0%	0%	0%	2%	13%
RES1	Pre	CA	20%	0%	100%	1%	1%	1%	14%	21%
RES1	Pre	CA	30%	0%	100%	6%	6%	6%	22%	32%
RES1	Pre	CA	40%	0%	100%	8%	8%	8%	30%	44%
RES1	Pre	CA	50%	0%	100%	10%	10%	10%	42%	55%
RES1	Pre	CA	60%	1%	100%	13%	13%	13%	51%	66%
RES1	Pre	CA	70%	5%	100%	16%	16%	16%	62%	76%
RES1	Pre	CA	80%	8%	100%	20%	20%	20%	70%	86%
RES1	Pre	CA	90%	13%	100%	24%	24%	24%	78%	98%
RES1	Pre	CA	100%	20%	100%	34%	34%	34%	100%	100%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES1	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES1	Post	CA	10%	0%	45%	0%	0%	0%	5%	12%
RES1	Post	CA	20%	0%	100%	1%	1%	1%	13%	21%
RES1	Post	CA	30%	0%	100%	2%	2%	2%	24%	33%
RES1	Post	CA	40%	0%	100%	4%	4%	4%	33%	46%
RES1	Post	CA	50%	0%	100%	6%	6%	6%	49%	55%
RES1	Post	CA	60%	0%	100%	8%	8%	8%	60%	67%
RES1	Post	CA	70%	1%	100%	9%	9%	9%	73%	78%
RES1	Post	CA	80%	4%	100%	15%	15%	15%	85%	88%
RES1	Post	CA	90%	8%	100%	24%	24%	24%	90%	98%
RES1	Post	CA	100%	20%	100%	42%	42%	42%	100%	100%
RES2	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
RES2	Pre	A	10%	0%	9%	0%	0%	0%	3%	13%
RES2	Pre	A	20%	0%	35%	0%	0%	0%	4%	27%
RES2	Pre	A	30%	0%	60%	0%	0%	0%	8%	39%
RES2	Pre	A	40%	0%	79%	0%	0%	0%	16%	51%
RES2	Pre	A	50%	0%	100%	0%	0%	0%	23%	62%
RES2	Pre	A	60%	0%	100%	0%	0%	0%	28%	75%
RES2	Pre	A	70%	0%	100%	0%	0%	0%	35%	88%
RES2	Pre	A	80%	2%	100%	2%	2%	2%	53%	95%
RES2	Pre	A	90%	8%	100%	8%	8%	8%	74%	100%
RES2	Pre	A	100%	12%	100%	20%	20%	20%	100%	100%
RES2	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
RES2	Post	A	10%	0%	6%	0%	0%	0%	7%	12%
RES2	Post	A	20%	0%	35%	0%	0%	0%	10%	25%
RES2	Post	A	30%	0%	60%	0%	0%	0%	18%	37%
RES2	Post	A	40%	0%	80%	0%	0%	0%	22%	50%
RES2	Post	A	50%	0%	100%	0%	0%	0%	30%	62%
RES2	Post	A	60%	0%	100%	0%	0%	0%	36%	75%
RES2	Post	A	70%	0%	100%	0%	0%	0%	42%	88%
RES2	Post	A	80%	2%	100%	3%	3%	3%	50%	99%
RES2	Post	A	90%	9%	100%	9%	9%	9%	79%	100%
RES2	Post	A	100%	21%	100%	24%	24%	24%	100%	100%
RES2	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES2	Pre	CA	10%	0%	9%	0%	0%	0%	7%	12%
RES2	Pre	CA	20%	0%	35%	0%	0%	0%	10%	25%
RES2	Pre	CA	30%	0%	60%	0%	0%	0%	21%	35%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES2	Pre	CA	40%	0%	90%	1%	1%	1%	28%	46%
RES2	Pre	CA	50%	0%	100%	2%	2%	2%	34%	57%
RES2	Pre	CA	60%	0%	100%	4%	4%	4%	42%	69%
RES2	Pre	CA	70%	1%	100%	8%	8%	8%	48%	80%
RES2	Pre	CA	80%	3%	100%	10%	10%	10%	57%	91%
RES2	Pre	CA	90%	10%	100%	14%	14%	14%	69%	100%
RES2	Pre	CA	100%	16%	100%	20%	20%	20%	100%	100%
RES2	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES2	Post	CA	10%	0%	3%	0%	0%	0%	7%	12%
RES2	Post	CA	20%	0%	40%	0%	0%	0%	15%	23%
RES2	Post	CA	30%	0%	100%	0%	0%	0%	25%	33%
RES2	Post	CA	40%	0%	100%	1%	1%	1%	31%	46%
RES2	Post	CA	50%	0%	100%	2%	2%	2%	44%	56%
RES2	Post	CA	60%	0%	100%	4%	4%	4%	55%	66%
RES2	Post	CA	70%	1%	100%	8%	8%	8%	60%	78%
RES2	Post	CA	80%	2%	100%	10%	10%	10%	68%	90%
RES2	Post	CA	90%	8%	100%	14%	14%	14%	77%	100%
RES2	Post	CA	100%	19%	100%	25%	25%	25%	100%	100%
RES3A	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
RES3A	Pre	A	10%	0%	20%	0%	0%	0%	4%	14%
RES3A	Pre	A	20%	0%	40%	0%	0%	0%	12%	26%
RES3A	Pre	A	30%	0%	60%	0%	0%	0%	21%	37%
RES3A	Pre	A	40%	0%	100%	0%	0%	0%	30%	48%
RES3A	Pre	A	50%	0%	100%	0%	0%	0%	39%	60%
RES3A	Pre	A	60%	0%	100%	0%	0%	0%	47%	74%
RES3A	Pre	A	70%	0%	100%	0%	0%	0%	56%	87%
RES3A	Pre	A	80%	0%	100%	5%	14%	5%	68%	95%
RES3A	Pre	A	90%	5%	100%	26%	27%	26%	83%	96%
RES3A	Pre	A	100%	10%	100%	50%	50%	50%	86%	100%
RES3A	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
RES3A	Post	A	10%	0%	20%	0%	0%	0%	4%	14%
RES3A	Post	A	20%	0%	40%	0%	0%	0%	12%	26%
RES3A	Post	A	30%	0%	60%	0%	0%	0%	21%	38%
RES3A	Post	A	40%	0%	100%	0%	0%	0%	30%	49%
RES3A	Post	A	50%	0%	100%	0%	0%	0%	39%	62%
RES3A	Post	A	60%	0%	100%	0%	0%	0%	47%	76%
RES3A	Post	A	70%	0%	100%	0%	0%	0%	56%	89%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES3A	Post	A	80%	0%	100%	5%	14%	5%	74%	96%
RES3A	Post	A	90%	5%	100%	26%	27%	26%	90%	97%
RES3A	Post	A	100%	15%	100%	53%	53%	53%	93%	100%
RES3A	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3A	Pre	CA	10%	0%	50%	0%	0%	0%	2%	13%
RES3A	Pre	CA	20%	0%	100%	1%	1%	1%	14%	22%
RES3A	Pre	CA	30%	0%	100%	6%	6%	6%	22%	33%
RES3A	Pre	CA	40%	0%	100%	8%	8%	8%	30%	45%
RES3A	Pre	CA	50%	0%	100%	10%	10%	10%	42%	55%
RES3A	Pre	CA	60%	1%	100%	13%	13%	13%	51%	67%
RES3A	Pre	CA	70%	5%	100%	16%	16%	16%	62%	76%
RES3A	Pre	CA	80%	8%	100%	20%	20%	20%	70%	87%
RES3A	Pre	CA	90%	13%	100%	24%	24%	24%	78%	98%
RES3A	Pre	CA	100%	20%	100%	34%	34%	34%	100%	100%
RES3A	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3A	Post	CA	10%	0%	45%	0%	0%	0%	5%	12%
RES3A	Post	CA	20%	0%	100%	1%	1%	1%	13%	21%
RES3A	Post	CA	30%	0%	100%	2%	2%	2%	24%	34%
RES3A	Post	CA	40%	0%	100%	4%	4%	4%	33%	46%
RES3A	Post	CA	50%	0%	100%	6%	6%	6%	49%	56%
RES3A	Post	CA	60%	0%	100%	8%	8%	8%	60%	68%
RES3A	Post	CA	70%	1%	100%	9%	9%	9%	73%	79%
RES3A	Post	CA	80%	4%	100%	15%	15%	15%	85%	88%
RES3A	Post	CA	90%	8%	100%	24%	24%	24%	90%	98%
RES3A	Post	CA	100%	20%	100%	42%	42%	42%	100%	100%
RES3B	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
RES3B	Pre	A	10%	0%	20%	0%	0%	0%	4%	14%
RES3B	Pre	A	20%	0%	40%	0%	0%	0%	12%	26%
RES3B	Pre	A	30%	0%	60%	0%	0%	0%	21%	38%
RES3B	Pre	A	40%	0%	100%	0%	0%	0%	30%	49%
RES3B	Pre	A	50%	0%	100%	0%	0%	0%	39%	61%
RES3B	Pre	A	60%	0%	100%	0%	0%	0%	47%	74%
RES3B	Pre	A	70%	0%	100%	0%	0%	0%	56%	87%
RES3B	Pre	A	80%	0%	100%	5%	14%	5%	68%	95%
RES3B	Pre	A	90%	5%	100%	26%	27%	26%	83%	96%
RES3B	Pre	A	100%	10%	100%	50%	50%	50%	86%	100%
RES3B	Post	A	0%	0%	0%	0%	0%	0%	0%	0%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES3B	Post	A	10%	0%	20%	0%	0%	0%	4%	14%
RES3B	Post	A	20%	0%	40%	0%	0%	0%	12%	26%
RES3B	Post	A	30%	0%	60%	0%	0%	0%	21%	38%
RES3B	Post	A	40%	0%	100%	0%	0%	0%	30%	49%
RES3B	Post	A	50%	0%	100%	0%	0%	0%	39%	63%
RES3B	Post	A	60%	0%	100%	0%	0%	0%	47%	76%
RES3B	Post	A	70%	0%	100%	0%	0%	0%	56%	90%
RES3B	Post	A	80%	0%	100%	5%	14%	5%	74%	96%
RES3B	Post	A	90%	5%	100%	26%	27%	26%	90%	98%
RES3B	Post	A	100%	15%	100%	53%	53%	53%	93%	100%
RES3B	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3B	Pre	CA	10%	0%	50%	0%	0%	0%	2%	13%
RES3B	Pre	CA	20%	0%	100%	1%	1%	1%	14%	22%
RES3B	Pre	CA	30%	0%	100%	6%	6%	6%	22%	33%
RES3B	Pre	CA	40%	0%	100%	8%	8%	8%	30%	45%
RES3B	Pre	CA	50%	0%	100%	10%	10%	10%	42%	55%
RES3B	Pre	CA	60%	1%	100%	13%	13%	13%	51%	67%
RES3B	Pre	CA	70%	5%	100%	16%	16%	16%	62%	76%
RES3B	Pre	CA	80%	8%	100%	20%	20%	20%	70%	87%
RES3B	Pre	CA	90%	13%	100%	24%	24%	24%	78%	98%
RES3B	Pre	CA	100%	20%	100%	34%	34%	34%	100%	100%
RES3B	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3B	Post	CA	10%	0%	45%	0%	0%	0%	5%	12%
RES3B	Post	CA	20%	0%	100%	1%	1%	1%	13%	22%
RES3B	Post	CA	30%	0%	100%	2%	2%	2%	24%	34%
RES3B	Post	CA	40%	0%	100%	4%	4%	4%	33%	46%
RES3B	Post	CA	50%	0%	100%	6%	6%	6%	49%	56%
RES3B	Post	CA	60%	0%	100%	8%	8%	8%	60%	68%
RES3B	Post	CA	70%	1%	100%	9%	9%	9%	73%	79%
RES3B	Post	CA	80%	4%	100%	15%	15%	15%	85%	88%
RES3B	Post	CA	90%	8%	100%	24%	24%	24%	90%	98%
RES3B	Post	CA	100%	20%	100%	42%	42%	42%	100%	100%
RES3C	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
RES3C	Pre	A	10%	0%	20%	0%	0%	0%	4%	11%
RES3C	Pre	A	20%	0%	40%	0%	0%	0%	11%	21%
RES3C	Pre	A	30%	0%	58%	0%	0%	0%	16%	32%
RES3C	Pre	A	40%	0%	100%	0%	0%	0%	26%	41%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES3C	Pre	A	50%	0%	100%	0%	0%	0%	30%	53%
RES3C	Pre	A	60%	0%	100%	0%	0%	0%	43%	62%
RES3C	Pre	A	70%	0%	100%	0%	0%	0%	49%	73%
RES3C	Pre	A	80%	0%	100%	2%	4%	2%	53%	83%
RES3C	Pre	A	90%	2%	100%	10%	10%	10%	56%	93%
RES3C	Pre	A	100%	8%	100%	20%	20%	20%	68%	100%
RES3C	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
RES3C	Post	A	10%	0%	16%	0%	0%	0%	2%	11%
RES3C	Post	A	20%	0%	40%	0%	0%	0%	9%	23%
RES3C	Post	A	30%	0%	60%	0%	0%	0%	17%	33%
RES3C	Post	A	40%	0%	100%	0%	0%	0%	22%	44%
RES3C	Post	A	50%	0%	100%	0%	0%	0%	26%	56%
RES3C	Post	A	60%	0%	100%	0%	0%	0%	42%	65%
RES3C	Post	A	70%	0%	100%	0%	0%	0%	53%	76%
RES3C	Post	A	80%	0%	100%	1%	5%	1%	62%	87%
RES3C	Post	A	90%	2%	100%	14%	15%	14%	76%	94%
RES3C	Post	A	100%	12%	100%	26%	26%	26%	90%	100%
RES3C	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3C	Pre	CA	10%	0%	45%	0%	0%	0%	2%	11%
RES3C	Pre	CA	20%	0%	100%	1%	1%	1%	8%	20%
RES3C	Pre	CA	30%	0%	100%	2%	2%	2%	18%	30%
RES3C	Pre	CA	40%	0%	100%	4%	4%	4%	24%	41%
RES3C	Pre	CA	50%	0%	100%	7%	7%	7%	32%	50%
RES3C	Pre	CA	60%	1%	100%	10%	10%	10%	41%	60%
RES3C	Pre	CA	70%	2%	100%	12%	12%	12%	51%	69%
RES3C	Pre	CA	80%	3%	100%	20%	20%	20%	60%	78%
RES3C	Pre	CA	90%	8%	100%	20%	20%	20%	70%	88%
RES3C	Pre	CA	100%	9%	100%	21%	21%	21%	71%	99%
RES3C	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3C	Post	CA	10%	0%	45%	0%	0%	0%	4%	11%
RES3C	Post	CA	20%	0%	100%	1%	1%	1%	11%	21%
RES3C	Post	CA	30%	0%	100%	2%	2%	2%	19%	32%
RES3C	Post	CA	40%	0%	100%	3%	3%	3%	26%	43%
RES3C	Post	CA	50%	0%	100%	5%	5%	5%	30%	54%
RES3C	Post	CA	60%	0%	100%	7%	7%	7%	41%	64%
RES3C	Post	CA	70%	1%	100%	8%	8%	8%	52%	74%
RES3C	Post	CA	80%	3%	100%	10%	10%	10%	58%	85%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES3C	Post	CA	90%	7%	100%	14%	14%	14%	61%	95%
RES3C	Post	CA	100%	12%	100%	35%	35%	35%	75%	100%
RES3D	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
RES3D	Pre	A	10%	0%	20%	0%	0%	0%	4%	11%
RES3D	Pre	A	20%	0%	40%	0%	0%	0%	11%	21%
RES3D	Pre	A	30%	0%	58%	0%	0%	0%	16%	32%
RES3D	Pre	A	40%	0%	100%	0%	0%	0%	26%	41%
RES3D	Pre	A	50%	0%	100%	0%	0%	0%	30%	53%
RES3D	Pre	A	60%	0%	100%	0%	0%	0%	43%	62%
RES3D	Pre	A	70%	0%	100%	0%	0%	0%	49%	73%
RES3D	Pre	A	80%	0%	100%	2%	4%	2%	53%	83%
RES3D	Pre	A	90%	2%	100%	10%	10%	10%	56%	93%
RES3D	Pre	A	100%	8%	100%	20%	20%	20%	68%	100%
RES3D	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
RES3D	Post	A	10%	0%	16%	0%	0%	0%	2%	11%
RES3D	Post	A	20%	0%	40%	0%	0%	0%	9%	23%
RES3D	Post	A	30%	0%	60%	0%	0%	0%	17%	33%
RES3D	Post	A	40%	0%	100%	0%	0%	0%	22%	44%
RES3D	Post	A	50%	0%	100%	0%	0%	0%	26%	56%
RES3D	Post	A	60%	0%	100%	0%	0%	0%	42%	65%
RES3D	Post	A	70%	0%	100%	0%	0%	0%	53%	76%
RES3D	Post	A	80%	0%	100%	1%	5%	1%	62%	87%
RES3D	Post	A	90%	2%	100%	14%	15%	14%	76%	94%
RES3D	Post	A	100%	12%	100%	26%	26%	26%	90%	100%
RES3D	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3D	Pre	CA	10%	0%	45%	0%	0%	0%	2%	11%
RES3D	Pre	CA	20%	0%	100%	1%	1%	1%	9%	21%
RES3D	Pre	CA	30%	0%	100%	2%	2%	2%	10%	32%
RES3D	Pre	CA	40%	0%	100%	3%	3%	3%	15%	43%
RES3D	Pre	CA	50%	0%	100%	6%	6%	6%	24%	53%
RES3D	Pre	CA	60%	1%	100%	9%	9%	9%	32%	62%
RES3D	Pre	CA	70%	2%	100%	12%	12%	12%	43%	72%
RES3D	Pre	CA	80%	3%	100%	14%	14%	14%	57%	81%
RES3D	Pre	CA	90%	7%	100%	17%	17%	17%	61%	91%
RES3D	Pre	CA	100%	15%	100%	20%	20%	20%	73%	100%
RES3D	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3D	Post	CA	10%	0%	45%	0%	0%	0%	4%	11%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES3D	Post	CA	20%	0%	100%	1%	1%	1%	11%	21%
RES3D	Post	CA	30%	0%	100%	2%	2%	2%	19%	32%
RES3D	Post	CA	40%	0%	100%	3%	3%	3%	26%	43%
RES3D	Post	CA	50%	0%	100%	5%	5%	5%	30%	54%
RES3D	Post	CA	60%	0%	100%	7%	7%	7%	41%	64%
RES3D	Post	CA	70%	1%	100%	8%	8%	8%	52%	74%
RES3D	Post	CA	80%	3%	100%	10%	10%	10%	58%	85%
RES3D	Post	CA	90%	7%	100%	14%	14%	14%	61%	95%
RES3D	Post	CA	100%	20%	100%	25%	25%	25%	76%	100%
RES3E	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
RES3E	Pre	A	10%	0%	20%	0%	0%	0%	4%	11%
RES3E	Pre	A	20%	0%	40%	0%	0%	0%	11%	22%
RES3E	Pre	A	30%	0%	58%	0%	0%	0%	16%	32%
RES3E	Pre	A	40%	0%	100%	0%	0%	0%	26%	42%
RES3E	Pre	A	50%	0%	100%	0%	0%	0%	30%	54%
RES3E	Pre	A	60%	0%	100%	0%	0%	0%	43%	64%
RES3E	Pre	A	70%	0%	100%	0%	0%	0%	49%	75%
RES3E	Pre	A	80%	0%	100%	2%	4%	2%	53%	86%
RES3E	Pre	A	90%	2%	100%	10%	10%	10%	56%	95%
RES3E	Pre	A	100%	8%	100%	22%	22%	22%	75%	100%
RES3E	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
RES3E	Post	A	10%	0%	16%	0%	0%	0%	2%	12%
RES3E	Post	A	20%	0%	40%	0%	0%	0%	9%	23%
RES3E	Post	A	30%	0%	60%	0%	0%	0%	17%	34%
RES3E	Post	A	40%	0%	100%	0%	0%	0%	22%	46%
RES3E	Post	A	50%	0%	100%	0%	0%	0%	27%	57%
RES3E	Post	A	60%	0%	100%	0%	0%	0%	44%	67%
RES3E	Post	A	70%	0%	100%	0%	0%	0%	55%	78%
RES3E	Post	A	80%	0%	100%	2%	5%	2%	63%	89%
RES3E	Post	A	90%	2%	100%	15%	15%	15%	77%	96%
RES3E	Post	A	100%	14%	100%	30%	30%	30%	100%	100%
RES3E	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3E	Pre	CA	10%	0%	45%	0%	0%	0%	2%	11%
RES3E	Pre	CA	20%	0%	100%	1%	1%	1%	9%	21%
RES3E	Pre	CA	30%	0%	100%	2%	2%	2%	10%	32%
RES3E	Pre	CA	40%	0%	100%	3%	3%	3%	15%	43%
RES3E	Pre	CA	50%	0%	100%	6%	6%	6%	24%	53%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES3E	Pre	CA	60%	1%	100%	9%	9%	9%	32%	63%
RES3E	Pre	CA	70%	2%	100%	12%	12%	12%	43%	72%
RES3E	Pre	CA	80%	3%	100%	14%	14%	14%	57%	82%
RES3E	Pre	CA	90%	7%	100%	17%	17%	17%	61%	92%
RES3E	Pre	CA	100%	15%	100%	20%	20%	20%	75%	100%
RES3E	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3E	Post	CA	10%	0%	45%	0%	0%	0%	4%	11%
RES3E	Post	CA	20%	0%	100%	1%	1%	1%	11%	22%
RES3E	Post	CA	30%	0%	100%	2%	2%	2%	19%	33%
RES3E	Post	CA	40%	0%	100%	3%	3%	3%	26%	44%
RES3E	Post	CA	50%	0%	100%	5%	5%	5%	31%	56%
RES3E	Post	CA	60%	0%	100%	7%	7%	7%	41%	66%
RES3E	Post	CA	70%	1%	100%	9%	9%	9%	54%	76%
RES3E	Post	CA	80%	3%	100%	10%	10%	10%	61%	87%
RES3E	Post	CA	90%	7%	100%	14%	14%	14%	66%	97%
RES3E	Post	CA	100%	20%	100%	25%	25%	25%	94%	100%
RES3F	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
RES3F	Pre	A	10%	0%	0%	0%	0%	0%	3%	11%
RES3F	Pre	A	20%	0%	0%	0%	0%	0%	6%	22%
RES3F	Pre	A	30%	0%	0%	0%	0%	0%	7%	33%
RES3F	Pre	A	40%	0%	0%	0%	0%	0%	10%	44%
RES3F	Pre	A	50%	0%	0%	0%	0%	0%	22%	54%
RES3F	Pre	A	60%	0%	0%	0%	0%	0%	34%	63%
RES3F	Pre	A	70%	0%	0%	0%	0%	0%	46%	72%
RES3F	Pre	A	80%	0%	0%	3%	3%	3%	50%	83%
RES3F	Pre	A	90%	12%	0%	12%	12%	12%	63%	89%
RES3F	Pre	A	100%	25%	0%	15%	15%	15%	66%	100%
RES3F	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
RES3F	Post	A	10%	0%	0%	0%	0%	0%	1%	12%
RES3F	Post	A	20%	0%	0%	0%	0%	0%	3%	24%
RES3F	Post	A	30%	0%	0%	0%	0%	0%	4%	35%
RES3F	Post	A	40%	0%	0%	0%	0%	0%	5%	47%
RES3F	Post	A	50%	0%	0%	0%	0%	0%	7%	59%
RES3F	Post	A	60%	0%	0%	0%	0%	0%	13%	70%
RES3F	Post	A	70%	0%	0%	0%	0%	0%	16%	82%
RES3F	Post	A	80%	0%	0%	3%	3%	3%	27%	91%
RES3F	Post	A	90%	5%	0%	15%	15%	15%	33%	99%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES3F	Post	A	100%	25%	0%	20%	20%	20%	73%	100%
RES3F	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3F	Pre	CA	10%	0%	0%	0%	0%	0%	1%	11%
RES3F	Pre	CA	20%	0%	0%	1%	1%	1%	7%	21%
RES3F	Pre	CA	30%	0%	0%	1%	1%	1%	13%	32%
RES3F	Pre	CA	40%	0%	0%	2%	2%	2%	35%	39%
RES3F	Pre	CA	50%	0%	0%	2%	2%	2%	44%	49%
RES3F	Pre	CA	60%	1%	0%	3%	3%	3%	52%	59%
RES3F	Pre	CA	70%	3%	0%	5%	5%	5%	60%	68%
RES3F	Pre	CA	80%	5%	0%	7%	7%	7%	66%	78%
RES3F	Pre	CA	90%	6%	0%	9%	9%	9%	70%	88%
RES3F	Pre	CA	100%	7%	0%	10%	10%	10%	71%	100%
RES3F	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES3F	Post	CA	10%	0%	0%	1%	1%	1%	1%	12%
RES3F	Post	CA	20%	0%	0%	1%	1%	1%	6%	22%
RES3F	Post	CA	30%	0%	0%	6%	6%	6%	11%	33%
RES3F	Post	CA	40%	0%	0%	7%	7%	7%	18%	43%
RES3F	Post	CA	50%	0%	0%	9%	9%	9%	30%	53%
RES3F	Post	CA	60%	1%	0%	13%	13%	13%	40%	62%
RES3F	Post	CA	70%	8%	0%	18%	18%	18%	50%	71%
RES3F	Post	CA	80%	10%	0%	21%	21%	21%	58%	80%
RES3F	Post	CA	90%	12%	0%	23%	23%	23%	60%	91%
RES3F	Post	CA	100%	14%	0%	25%	25%	25%	74%	100%
RES4	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
RES4	Pre	A	10%	0%	10%	0%	0%	0%	4%	10%
RES4	Pre	A	20%	0%	30%	0%	0%	0%	7%	20%
RES4	Pre	A	30%	0%	70%	0%	0%	0%	9%	31%
RES4	Pre	A	40%	0%	100%	0%	0%	0%	13%	41%
RES4	Pre	A	50%	0%	100%	0%	0%	0%	27%	49%
RES4	Pre	A	60%	0%	100%	0%	0%	0%	42%	58%
RES4	Pre	A	70%	0%	100%	0%	0%	0%	58%	67%
RES4	Pre	A	80%	0%	100%	2%	2%	2%	64%	77%
RES4	Pre	A	90%	1%	100%	8%	8%	8%	70%	85%
RES4	Pre	A	100%	3%	100%	12%	12%	12%	78%	95%
RES4	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
RES4	Post	A	10%	0%	10%	0%	0%	0%	1%	11%
RES4	Post	A	20%	0%	40%	0%	0%	0%	4%	22%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES4	Post	A	30%	0%	80%	0%	0%	0%	5%	32%
RES4	Post	A	40%	0%	100%	0%	0%	0%	6%	43%
RES4	Post	A	50%	0%	100%	0%	0%	0%	9%	54%
RES4	Post	A	60%	0%	100%	0%	0%	0%	14%	65%
RES4	Post	A	70%	0%	100%	0%	0%	0%	22%	75%
RES4	Post	A	80%	0%	100%	7%	7%	7%	31%	84%
RES4	Post	A	90%	4%	100%	13%	13%	13%	40%	93%
RES4	Post	A	100%	12%	100%	17%	17%	17%	55%	100%
RES4	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES4	Pre	CA	10%	0%	20%	0%	0%	0%	2%	10%
RES4	Pre	CA	20%	0%	100%	1%	1%	1%	8%	19%
RES4	Pre	CA	30%	0%	100%	3%	3%	3%	15%	29%
RES4	Pre	CA	40%	0%	100%	5%	5%	5%	25%	38%
RES4	Pre	CA	50%	0%	100%	7%	7%	7%	30%	48%
RES4	Pre	CA	60%	1%	100%	9%	9%	9%	35%	58%
RES4	Pre	CA	70%	2%	100%	13%	13%	13%	40%	67%
RES4	Pre	CA	80%	4%	100%	16%	16%	16%	45%	77%
RES4	Pre	CA	90%	6%	100%	20%	20%	20%	50%	86%
RES4	Pre	CA	100%	10%	100%	25%	25%	25%	55%	95%
RES4	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES4	Post	CA	10%	0%	30%	1%	1%	1%	1%	10%
RES4	Post	CA	20%	0%	100%	4%	4%	4%	8%	20%
RES4	Post	CA	30%	0%	100%	8%	8%	8%	15%	29%
RES4	Post	CA	40%	0%	100%	13%	13%	13%	28%	38%
RES4	Post	CA	50%	0%	100%	16%	16%	16%	38%	48%
RES4	Post	CA	60%	1%	100%	21%	21%	21%	47%	57%
RES4	Post	CA	70%	3%	100%	24%	24%	24%	57%	66%
RES4	Post	CA	80%	5%	100%	27%	27%	27%	64%	76%
RES4	Post	CA	90%	7%	100%	30%	30%	30%	73%	86%
RES4	Post	CA	100%	11%	100%	31%	31%	31%	80%	95%
RES5	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
RES5	Pre	A	10%	0%	0%	0%	0%	0%	3%	12%
RES5	Pre	A	20%	0%	0%	0%	0%	0%	5%	24%
RES5	Pre	A	30%	0%	0%	0%	0%	0%	7%	36%
RES5	Pre	A	40%	0%	0%	0%	0%	0%	9%	48%
RES5	Pre	A	50%	0%	0%	0%	0%	0%	19%	58%
RES5	Pre	A	60%	0%	0%	0%	0%	0%	31%	68%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES5	Pre	A	70%	0%	0%	0%	0%	0%	42%	78%
RES5	Pre	A	80%	0%	0%	3%	3%	3%	50%	88%
RES5	Pre	A	90%	5%	0%	8%	8%	8%	60%	97%
RES5	Pre	A	100%	15%	0%	15%	15%	15%	89%	100%
RES5	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
RES5	Post	A	10%	0%	0%	0%	0%	0%	1%	13%
RES5	Post	A	20%	0%	0%	0%	0%	0%	3%	25%
RES5	Post	A	30%	0%	0%	0%	0%	0%	4%	38%
RES5	Post	A	40%	0%	0%	0%	0%	0%	7%	50%
RES5	Post	A	50%	0%	0%	0%	0%	0%	12%	63%
RES5	Post	A	60%	0%	0%	0%	0%	0%	17%	75%
RES5	Post	A	70%	0%	0%	0%	0%	0%	21%	87%
RES5	Post	A	80%	0%	0%	6%	8%	8%	37%	95%
RES5	Post	A	90%	8%	0%	15%	15%	15%	59%	100%
RES5	Post	A	100%	20%	0%	27%	27%	27%	94%	100%
RES5	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES5	Pre	CA	10%	0%	0%	0%	0%	0%	4%	12%
RES5	Pre	CA	20%	0%	0%	3%	3%	3%	8%	23%
RES5	Pre	CA	30%	0%	0%	5%	5%	5%	10%	34%
RES5	Pre	CA	40%	0%	0%	8%	8%	8%	14%	45%
RES5	Pre	CA	50%	0%	0%	13%	13%	13%	20%	55%
RES5	Pre	CA	60%	4%	0%	17%	17%	17%	26%	65%
RES5	Pre	CA	70%	9%	0%	21%	21%	21%	32%	74%
RES5	Pre	CA	80%	10%	0%	25%	25%	25%	40%	84%
RES5	Pre	CA	90%	20%	0%	28%	28%	28%	46%	94%
RES5	Pre	CA	100%	30%	0%	30%	30%	30%	69%	100%
RES5	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES5	Post	CA	10%	0%	0%	3%	3%	3%	1%	13%
RES5	Post	CA	20%	0%	0%	5%	5%	5%	6%	24%
RES5	Post	CA	30%	0%	0%	10%	10%	10%	11%	34%
RES5	Post	CA	40%	0%	0%	12%	12%	12%	20%	45%
RES5	Post	CA	50%	0%	0%	17%	17%	17%	34%	53%
RES5	Post	CA	60%	1%	0%	19%	19%	19%	46%	63%
RES5	Post	CA	70%	4%	0%	21%	21%	21%	53%	74%
RES5	Post	CA	80%	8%	0%	25%	25%	25%	62%	83%
RES5	Post	CA	90%	13%	0%	28%	28%	28%	69%	93%
RES5	Post	CA	100%	20%	0%	30%	30%	30%	93%	100%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES6	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
RES6	Pre	A	10%	0%	0%	0%	0%	0%	3%	11%
RES6	Pre	A	20%	0%	0%	0%	0%	0%	6%	23%
RES6	Pre	A	30%	0%	0%	0%	0%	0%	8%	35%
RES6	Pre	A	40%	0%	0%	0%	0%	0%	11%	46%
RES6	Pre	A	50%	0%	0%	0%	0%	0%	22%	56%
RES6	Pre	A	60%	0%	0%	0%	0%	0%	34%	66%
RES6	Pre	A	70%	0%	0%	0%	0%	0%	47%	75%
RES6	Pre	A	80%	0%	0%	5%	5%	5%	56%	84%
RES6	Pre	A	90%	5%	0%	11%	11%	11%	64%	93%
RES6	Pre	A	100%	10%	0%	21%	21%	21%	75%	100%
RES6	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
RES6	Post	A	10%	0%	0%	0%	0%	0%	1%	13%
RES6	Post	A	20%	0%	0%	0%	0%	0%	3%	25%
RES6	Post	A	30%	0%	0%	0%	0%	0%	4%	37%
RES6	Post	A	40%	0%	0%	0%	0%	0%	5%	50%
RES6	Post	A	50%	0%	0%	0%	0%	0%	15%	60%
RES6	Post	A	60%	0%	0%	0%	0%	0%	28%	70%
RES6	Post	A	70%	0%	0%	0%	0%	0%	39%	81%
RES6	Post	A	80%	0%	0%	4%	4%	4%	43%	92%
RES6	Post	A	90%	4%	0%	11%	11%	11%	54%	100%
RES6	Post	A	100%	14%	0%	25%	25%	25%	100%	100%
RES6	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES6	Pre	CA	10%	0%	0%	0%	0%	0%	1%	12%
RES6	Pre	CA	20%	0%	0%	3%	3%	3%	7%	22%
RES6	Pre	CA	30%	0%	0%	4%	4%	4%	13%	33%
RES6	Pre	CA	40%	0%	0%	6%	6%	6%	17%	44%
RES6	Pre	CA	50%	0%	0%	9%	9%	9%	21%	54%
RES6	Pre	CA	60%	1%	0%	12%	12%	12%	30%	64%
RES6	Pre	CA	70%	3%	0%	14%	14%	14%	40%	73%
RES6	Pre	CA	80%	7%	0%	17%	17%	17%	51%	82%
RES6	Pre	CA	90%	10%	0%	20%	20%	20%	57%	92%
RES6	Pre	CA	100%	13%	0%	22%	22%	22%	76%	100%
RES6	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
RES6	Post	CA	10%	0%	0%	1%	1%	1%	1%	12%
RES6	Post	CA	20%	0%	0%	4%	4%	4%	6%	23%
RES6	Post	CA	30%	0%	0%	7%	7%	7%	11%	34%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
RES6	Post	CA	40%	0%	0%	10%	10%	10%	21%	44%
RES6	Post	CA	50%	0%	0%	12%	12%	12%	31%	55%
RES6	Post	CA	60%	1%	0%	15%	15%	15%	41%	64%
RES6	Post	CA	70%	2%	0%	18%	18%	18%	51%	74%
RES6	Post	CA	80%	5%	0%	21%	21%	21%	61%	83%
RES6	Post	CA	90%	11%	0%	22%	22%	22%	71%	93%
RES6	Post	CA	100%	15%	0%	27%	27%	27%	97%	100%
COM1	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
COM1	Pre	A	10%	0%	10%	0%	0%	0%	8%	11%
COM1	Pre	A	20%	0%	30%	0%	0%	0%	17%	22%
COM1	Pre	A	30%	0%	80%	0%	0%	0%	22%	34%
COM1	Pre	A	40%	0%	100%	0%	0%	0%	29%	45%
COM1	Pre	A	50%	0%	100%	0%	0%	0%	38%	57%
COM1	Pre	A	60%	0%	100%	0%	0%	0%	47%	68%
COM1	Pre	A	70%	0%	100%	0%	0%	0%	60%	78%
COM1	Pre	A	80%	0%	100%	9%	9%	9%	70%	87%
COM1	Pre	A	90%	8%	100%	14%	14%	14%	76%	96%
COM1	Pre	A	100%	23%	100%	25%	25%	25%	100%	100%
COM1	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
COM1	Post	A	10%	0%	10%	0%	0%	0%	9%	12%
COM1	Post	A	20%	0%	30%	0%	0%	0%	17%	23%
COM1	Post	A	30%	0%	80%	0%	0%	0%	25%	35%
COM1	Post	A	40%	0%	100%	0%	0%	0%	31%	47%
COM1	Post	A	50%	0%	100%	0%	0%	0%	41%	59%
COM1	Post	A	60%	0%	100%	0%	0%	0%	54%	70%
COM1	Post	A	70%	0%	100%	0%	0%	0%	67%	81%
COM1	Post	A	80%	0%	100%	5%	5%	5%	78%	91%
COM1	Post	A	90%	9%	100%	22%	22%	22%	86%	96%
COM1	Post	A	100%	20%	100%	40%	40%	40%	100%	100%
COM1	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM1	Pre	CA	10%	0%	20%	0%	0%	0%	2%	12%
COM1	Pre	CA	20%	0%	100%	2%	2%	2%	7%	23%
COM1	Pre	CA	30%	0%	100%	5%	5%	5%	12%	33%
COM1	Pre	CA	40%	0%	100%	8%	8%	8%	29%	43%
COM1	Pre	CA	50%	0%	100%	11%	11%	11%	41%	53%
COM1	Pre	CA	60%	1%	100%	17%	17%	17%	48%	62%
COM1	Pre	CA	70%	3%	100%	22%	22%	22%	53%	72%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM1	Pre	CA	80%	8%	100%	25%	25%	25%	65%	82%
COM1	Pre	CA	90%	12%	100%	28%	28%	28%	74%	92%
COM1	Pre	CA	100%	16%	100%	31%	31%	31%	89%	100%
COM1	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM1	Post	CA	10%	0%	20%	0%	0%	0%	2%	13%
COM1	Post	CA	20%	0%	100%	1%	1%	1%	5%	24%
COM1	Post	CA	30%	0%	100%	5%	5%	5%	14%	35%
COM1	Post	CA	40%	0%	100%	8%	8%	8%	24%	46%
COM1	Post	CA	50%	0%	100%	12%	12%	12%	34%	56%
COM1	Post	CA	60%	0%	100%	16%	16%	16%	44%	66%
COM1	Post	CA	70%	0%	100%	19%	19%	19%	54%	77%
COM1	Post	CA	80%	0%	100%	22%	22%	22%	64%	88%
COM1	Post	CA	90%	6%	100%	24%	24%	24%	69%	99%
COM1	Post	CA	100%	27%	100%	34%	34%	34%	100%	100%
COM2	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
COM2	Pre	A	10%	0%	10%	0%	0%	0%	7%	16%
COM2	Pre	A	20%	0%	30%	0%	0%	0%	14%	32%
COM2	Pre	A	30%	0%	80%	0%	0%	0%	21%	47%
COM2	Pre	A	40%	0%	100%	0%	0%	0%	27%	63%
COM2	Pre	A	50%	0%	100%	0%	0%	0%	35%	79%
COM2	Pre	A	60%	0%	100%	0%	0%	0%	44%	94%
COM2	Pre	A	70%	0%	100%	6%	6%	6%	84%	100%
COM2	Pre	A	80%	2%	100%	17%	17%	17%	93%	100%
COM2	Pre	A	90%	16%	100%	50%	50%	50%	100%	100%
COM2	Pre	A	100%	40%	100%	65%	65%	65%	100%	100%
COM2	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
COM2	Post	A	10%	0%	10%	0%	0%	0%	8%	17%
COM2	Post	A	20%	0%	30%	0%	0%	0%	15%	34%
COM2	Post	A	30%	0%	80%	0%	0%	0%	22%	51%
COM2	Post	A	40%	0%	100%	0%	0%	0%	26%	69%
COM2	Post	A	50%	2%	100%	2%	2%	2%	45%	80%
COM2	Post	A	60%	7%	100%	8%	8%	8%	70%	88%
COM2	Post	A	70%	13%	100%	13%	13%	13%	87%	97%
COM2	Post	A	80%	25%	100%	25%	25%	25%	97%	100%
COM2	Post	A	90%	40%	100%	40%	40%	40%	100%	100%
COM2	Post	A	100%	60%	100%	56%	56%	56%	100%	100%
COM2	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM2	Pre	CA	10%	0%	20%	0%	0%	0%	5%	16%
COM2	Pre	CA	20%	0%	100%	1%	1%	1%	15%	30%
COM2	Pre	CA	30%	0%	100%	2%	2%	2%	30%	44%
COM2	Pre	CA	40%	0%	100%	4%	4%	4%	40%	58%
COM2	Pre	CA	50%	0%	100%	6%	6%	6%	58%	70%
COM2	Pre	CA	60%	1%	100%	9%	9%	9%	67%	84%
COM2	Pre	CA	70%	5%	100%	13%	13%	13%	80%	94%
COM2	Pre	CA	80%	10%	100%	26%	26%	26%	95%	100%
COM2	Pre	CA	90%	32%	100%	37%	37%	37%	100%	100%
COM2	Pre	CA	100%	59%	100%	50%	50%	50%	100%	100%
COM2	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM2	Post	CA	10%	0%	20%	0%	0%	0%	9%	16%
COM2	Post	CA	20%	0%	100%	1%	1%	1%	17%	32%
COM2	Post	CA	30%	0%	100%	3%	3%	3%	32%	46%
COM2	Post	CA	40%	0%	100%	5%	5%	5%	40%	61%
COM2	Post	CA	50%	0%	100%	8%	8%	8%	59%	73%
COM2	Post	CA	60%	1%	100%	11%	11%	11%	67%	88%
COM2	Post	CA	70%	6%	100%	17%	17%	17%	85%	96%
COM2	Post	CA	80%	14%	100%	32%	32%	32%	98%	100%
COM2	Post	CA	90%	37%	100%	40%	40%	40%	100%	100%
COM2	Post	CA	100%	60%	100%	50%	50%	50%	100%	100%
COM3	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
COM3	Pre	A	10%	0%	10%	0%	0%	0%	8%	12%
COM3	Pre	A	20%	0%	30%	0%	0%	0%	17%	23%
COM3	Pre	A	30%	0%	80%	0%	0%	0%	22%	35%
COM3	Pre	A	40%	0%	100%	0%	0%	0%	29%	47%
COM3	Pre	A	50%	0%	100%	0%	0%	0%	38%	59%
COM3	Pre	A	60%	0%	100%	0%	0%	0%	47%	71%
COM3	Pre	A	70%	0%	100%	0%	0%	0%	60%	82%
COM3	Pre	A	80%	0%	100%	9%	9%	9%	72%	90%
COM3	Pre	A	90%	9%	100%	19%	19%	19%	77%	98%
COM3	Pre	A	100%	30%	100%	35%	35%	35%	90%	100%
COM3	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
COM3	Post	A	10%	0%	10%	0%	0%	0%	9%	12%
COM3	Post	A	20%	0%	30%	0%	0%	0%	17%	25%
COM3	Post	A	30%	0%	80%	0%	0%	0%	25%	37%
COM3	Post	A	40%	0%	100%	0%	0%	0%	31%	49%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM3	Post	A	50%	0%	100%	0%	0%	0%	41%	62%
COM3	Post	A	60%	0%	100%	0%	0%	0%	54%	74%
COM3	Post	A	70%	0%	100%	0%	0%	0%	67%	86%
COM3	Post	A	80%	0%	100%	9%	9%	9%	88%	94%
COM3	Post	A	90%	10%	100%	21%	21%	21%	91%	100%
COM3	Post	A	100%	40%	100%	36%	36%	36%	100%	100%
COM3	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM3	Pre	CA	10%	0%	20%	0%	0%	0%	2%	13%
COM3	Pre	CA	20%	0%	100%	1%	1%	1%	7%	24%
COM3	Pre	CA	30%	0%	100%	4%	4%	4%	12%	35%
COM3	Pre	CA	40%	0%	100%	10%	10%	10%	35%	42%
COM3	Pre	CA	50%	0%	100%	13%	13%	13%	44%	54%
COM3	Pre	CA	60%	2%	100%	24%	24%	24%	54%	62%
COM3	Pre	CA	70%	5%	100%	30%	30%	30%	60%	72%
COM3	Pre	CA	80%	11%	100%	34%	34%	34%	71%	81%
COM3	Pre	CA	90%	20%	100%	35%	35%	35%	75%	92%
COM3	Pre	CA	100%	25%	100%	38%	38%	38%	96%	100%
COM3	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM3	Post	CA	10%	0%	20%	0%	0%	0%	8%	13%
COM3	Post	CA	20%	0%	100%	2%	2%	2%	20%	23%
COM3	Post	CA	30%	0%	100%	4%	4%	4%	32%	34%
COM3	Post	CA	40%	0%	100%	8%	8%	8%	38%	46%
COM3	Post	CA	50%	0%	100%	12%	12%	12%	55%	56%
COM3	Post	CA	60%	0%	100%	18%	18%	18%	65%	66%
COM3	Post	CA	70%	1%	100%	26%	26%	26%	75%	76%
COM3	Post	CA	80%	3%	100%	35%	35%	35%	83%	86%
COM3	Post	CA	90%	5%	100%	40%	40%	40%	90%	97%
COM3	Post	CA	100%	20%	100%	54%	54%	54%	100%	100%
COM4	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
COM4	Pre	A	10%	0%	10%	0%	0%	0%	5%	11%
COM4	Pre	A	20%	0%	30%	0%	0%	0%	10%	22%
COM4	Pre	A	30%	0%	80%	0%	0%	0%	14%	33%
COM4	Pre	A	40%	0%	100%	0%	0%	0%	18%	45%
COM4	Pre	A	50%	0%	100%	0%	0%	0%	23%	56%
COM4	Pre	A	60%	0%	100%	0%	0%	0%	29%	67%
COM4	Pre	A	70%	0%	100%	0%	0%	0%	37%	77%
COM4	Pre	A	80%	0%	100%	10%	10%	10%	45%	86%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM4	Pre	A	90%	10%	100%	26%	26%	26%	53%	92%
COM4	Pre	A	100%	19%	100%	35%	35%	35%	59%	100%
COM4	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
COM4	Post	A	10%	0%	10%	0%	0%	0%	5%	12%
COM4	Post	A	20%	0%	30%	0%	0%	0%	10%	24%
COM4	Post	A	30%	0%	80%	0%	0%	0%	14%	35%
COM4	Post	A	40%	0%	100%	0%	0%	0%	17%	47%
COM4	Post	A	50%	0%	100%	0%	0%	0%	23%	59%
COM4	Post	A	60%	0%	100%	0%	0%	0%	34%	69%
COM4	Post	A	70%	0%	100%	0%	0%	0%	44%	80%
COM4	Post	A	80%	0%	100%	4%	4%	4%	54%	90%
COM4	Post	A	90%	9%	100%	19%	19%	19%	56%	98%
COM4	Post	A	100%	20%	100%	35%	35%	35%	78%	100%
COM4	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM4	Pre	CA	10%	0%	20%	0%	0%	0%	6%	11%
COM4	Pre	CA	20%	0%	100%	2%	2%	2%	11%	21%
COM4	Pre	CA	30%	0%	100%	3%	3%	3%	23%	30%
COM4	Pre	CA	40%	0%	100%	5%	5%	5%	30%	40%
COM4	Pre	CA	50%	0%	100%	9%	9%	9%	39%	50%
COM4	Pre	CA	60%	4%	100%	13%	13%	13%	41%	60%
COM4	Pre	CA	70%	8%	100%	18%	18%	18%	48%	70%
COM4	Pre	CA	80%	12%	100%	22%	22%	22%	55%	79%
COM4	Pre	CA	90%	15%	100%	25%	25%	25%	58%	90%
COM4	Pre	CA	100%	22%	100%	27%	27%	27%	66%	100%
COM4	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM4	Post	CA	10%	0%	16%	0%	0%	0%	1%	13%
COM4	Post	CA	20%	0%	100%	2%	2%	2%	5%	23%
COM4	Post	CA	30%	0%	100%	5%	5%	5%	11%	34%
COM4	Post	CA	40%	0%	100%	7%	7%	7%	18%	45%
COM4	Post	CA	50%	0%	100%	13%	13%	13%	23%	56%
COM4	Post	CA	60%	0%	100%	17%	17%	17%	32%	66%
COM4	Post	CA	70%	2%	100%	23%	23%	23%	43%	75%
COM4	Post	CA	80%	6%	100%	28%	28%	28%	51%	84%
COM4	Post	CA	90%	11%	100%	33%	33%	33%	62%	93%
COM4	Post	CA	100%	23%	100%	38%	38%	38%	72%	100%
COM5	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
COM5	Pre	A	10%	0%	0%	0%	0%	0%	2%	12%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM5	Pre	A	20%	0%	0%	0%	0%	0%	5%	25%
COM5	Pre	A	30%	0%	0%	0%	0%	0%	7%	37%
COM5	Pre	A	40%	0%	0%	0%	0%	0%	14%	49%
COM5	Pre	A	50%	0%	0%	0%	0%	0%	19%	62%
COM5	Pre	A	60%	0%	0%	0%	0%	0%	25%	74%
COM5	Pre	A	70%	0%	0%	0%	0%	0%	31%	86%
COM5	Pre	A	80%	0%	0%	4%	4%	4%	41%	96%
COM5	Pre	A	90%	5%	0%	17%	17%	17%	62%	100%
COM5	Pre	A	100%	21%	0%	41%	41%	41%	80%	100%
COM5	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
COM5	Post	A	10%	0%	0%	0%	0%	0%	2%	13%
COM5	Post	A	20%	0%	0%	0%	0%	0%	6%	26%
COM5	Post	A	30%	0%	0%	0%	0%	0%	9%	39%
COM5	Post	A	40%	0%	0%	0%	0%	0%	11%	52%
COM5	Post	A	50%	0%	0%	0%	0%	0%	18%	65%
COM5	Post	A	60%	0%	0%	0%	0%	0%	23%	77%
COM5	Post	A	70%	0%	0%	0%	0%	0%	64%	85%
COM5	Post	A	80%	0%	0%	9%	9%	9%	76%	94%
COM5	Post	A	90%	8%	0%	24%	24%	24%	87%	100%
COM5	Post	A	100%	25%	0%	45%	45%	45%	99%	100%
COM5	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM5	Pre	CA	10%	0%	0%	0%	0%	0%	2%	13%
COM5	Pre	CA	20%	0%	0%	1%	1%	1%	3%	25%
COM5	Pre	CA	30%	0%	0%	4%	4%	4%	7%	36%
COM5	Pre	CA	40%	0%	0%	6%	6%	6%	12%	47%
COM5	Pre	CA	50%	0%	0%	9%	9%	9%	18%	58%
COM5	Pre	CA	60%	1%	0%	10%	10%	10%	23%	70%
COM5	Pre	CA	70%	3%	0%	14%	14%	14%	30%	80%
COM5	Pre	CA	80%	5%	0%	17%	17%	17%	37%	91%
COM5	Pre	CA	90%	8%	0%	21%	21%	21%	48%	100%
COM5	Pre	CA	100%	20%	0%	36%	36%	36%	100%	100%
COM5	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM5	Post	CA	10%	0%	0%	0%	0%	0%	2%	13%
COM5	Post	CA	20%	0%	0%	1%	1%	1%	3%	26%
COM5	Post	CA	30%	0%	0%	4%	4%	4%	8%	37%
COM5	Post	CA	40%	0%	0%	6%	6%	6%	14%	50%
COM5	Post	CA	50%	0%	0%	10%	10%	10%	21%	60%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM5	Post	CA	60%	1%	0%	12%	12%	12%	25%	72%
COM5	Post	CA	70%	2%	0%	15%	15%	15%	33%	84%
COM5	Post	CA	80%	4%	0%	18%	18%	18%	39%	95%
COM5	Post	CA	90%	10%	0%	24%	24%	24%	75%	100%
COM5	Post	CA	100%	23%	0%	48%	48%	48%	100%	100%
COM6	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
COM6	Pre	A	10%	0%	0%	0%	0%	0%	1%	10%
COM6	Pre	A	20%	0%	0%	0%	0%	0%	2%	20%
COM6	Pre	A	30%	0%	0%	0%	0%	0%	3%	30%
COM6	Pre	A	40%	0%	0%	0%	0%	0%	4%	40%
COM6	Pre	A	50%	0%	0%	0%	0%	0%	6%	51%
COM6	Pre	A	60%	0%	0%	0%	0%	0%	8%	60%
COM6	Pre	A	70%	0%	0%	0%	0%	0%	10%	70%
COM6	Pre	A	80%	0%	0%	4%	4%	4%	16%	80%
COM6	Pre	A	90%	5%	0%	9%	9%	9%	19%	89%
COM6	Pre	A	100%	6%	0%	10%	10%	10%	21%	98%
COM6	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
COM6	Post	A	10%	0%	0%	0%	0%	0%	1%	10%
COM6	Post	A	20%	0%	0%	0%	0%	0%	3%	21%
COM6	Post	A	30%	0%	0%	0%	0%	0%	5%	31%
COM6	Post	A	40%	0%	0%	0%	0%	0%	7%	42%
COM6	Post	A	50%	0%	0%	0%	0%	0%	8%	52%
COM6	Post	A	60%	0%	0%	0%	0%	0%	9%	62%
COM6	Post	A	70%	0%	0%	0%	0%	0%	13%	73%
COM6	Post	A	80%	1%	0%	6%	6%	6%	24%	82%
COM6	Post	A	90%	5%	0%	11%	11%	11%	34%	90%
COM6	Post	A	100%	7%	0%	15%	15%	15%	36%	100%
COM6	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM6	Pre	CA	10%	0%	0%	0%	0%	0%	2%	10%
COM6	Pre	CA	20%	0%	0%	3%	3%	3%	6%	20%
COM6	Pre	CA	30%	0%	0%	6%	6%	6%	10%	29%
COM6	Pre	CA	40%	0%	0%	10%	10%	10%	19%	37%
COM6	Pre	CA	50%	0%	0%	14%	14%	14%	23%	46%
COM6	Pre	CA	60%	2%	0%	18%	18%	18%	33%	55%
COM6	Pre	CA	70%	4%	0%	22%	22%	22%	40%	64%
COM6	Pre	CA	80%	8%	0%	28%	28%	28%	49%	72%
COM6	Pre	CA	90%	11%	0%	33%	33%	33%	56%	81%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM6	Pre	CA	100%	18%	0%	39%	39%	39%	60%	90%
COM6	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM6	Post	CA	10%	0%	0%	0%	0%	0%	1%	10%
COM6	Post	CA	20%	0%	0%	1%	1%	1%	5%	20%
COM6	Post	CA	30%	0%	0%	4%	4%	4%	12%	30%
COM6	Post	CA	40%	0%	0%	9%	9%	9%	23%	39%
COM6	Post	CA	50%	0%	0%	13%	13%	13%	31%	48%
COM6	Post	CA	60%	0%	0%	19%	19%	19%	40%	57%
COM6	Post	CA	70%	0%	0%	23%	23%	23%	49%	67%
COM6	Post	CA	80%	0%	0%	28%	28%	28%	54%	76%
COM6	Post	CA	90%	2%	0%	32%	32%	32%	63%	85%
COM6	Post	CA	100%	8%	0%	34%	34%	34%	68%	94%
COM7	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
COM7	Pre	A	10%	0%	8%	0%	0%	0%	7%	10%
COM7	Pre	A	20%	0%	24%	0%	0%	0%	15%	19%
COM7	Pre	A	30%	0%	64%	0%	0%	0%	19%	29%
COM7	Pre	A	40%	0%	100%	0%	0%	0%	25%	39%
COM7	Pre	A	50%	0%	100%	0%	0%	0%	33%	49%
COM7	Pre	A	60%	0%	100%	0%	0%	0%	41%	59%
COM7	Pre	A	70%	0%	100%	0%	0%	0%	52%	68%
COM7	Pre	A	80%	0%	100%	3%	3%	3%	63%	77%
COM7	Pre	A	90%	4%	100%	9%	9%	9%	68%	86%
COM7	Pre	A	100%	10%	100%	13%	13%	13%	71%	95%
COM7	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
COM7	Post	A	10%	0%	10%	0%	0%	0%	1%	12%
COM7	Post	A	20%	0%	30%	0%	0%	0%	3%	23%
COM7	Post	A	30%	0%	80%	0%	0%	0%	6%	33%
COM7	Post	A	40%	0%	100%	0%	0%	0%	7%	45%
COM7	Post	A	50%	0%	100%	0%	0%	0%	15%	55%
COM7	Post	A	60%	0%	100%	0%	0%	0%	23%	66%
COM7	Post	A	70%	0%	100%	0%	0%	0%	46%	74%
COM7	Post	A	80%	0%	100%	3%	3%	3%	53%	84%
COM7	Post	A	90%	5%	100%	9%	9%	9%	59%	93%
COM7	Post	A	100%	14%	100%	15%	15%	15%	73%	100%
COM7	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM7	Pre	CA	10%	0%	20%	0%	0%	0%	1%	11%
COM7	Pre	CA	20%	0%	100%	2%	2%	2%	6%	20%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM7	Pre	CA	30%	0%	100%	3%	3%	3%	11%	30%
COM7	Pre	CA	40%	0%	100%	5%	5%	5%	30%	38%
COM7	Pre	CA	50%	0%	100%	13%	13%	13%	35%	47%
COM7	Pre	CA	60%	1%	100%	19%	19%	19%	41%	56%
COM7	Pre	CA	70%	4%	100%	25%	25%	25%	50%	64%
COM7	Pre	CA	80%	8%	100%	29%	29%	29%	55%	74%
COM7	Pre	CA	90%	12%	100%	33%	33%	33%	63%	83%
COM7	Pre	CA	100%	17%	100%	38%	38%	38%	69%	92%
COM7	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM7	Post	CA	10%	0%	20%	0%	0%	0%	2%	11%
COM7	Post	CA	20%	0%	100%	2%	2%	2%	5%	21%
COM7	Post	CA	30%	0%	100%	5%	5%	5%	9%	32%
COM7	Post	CA	40%	0%	100%	7%	7%	7%	16%	42%
COM7	Post	CA	50%	0%	100%	11%	11%	11%	21%	53%
COM7	Post	CA	60%	0%	100%	14%	14%	14%	29%	63%
COM7	Post	CA	70%	0%	100%	18%	18%	18%	33%	73%
COM7	Post	CA	80%	1%	100%	22%	22%	22%	40%	83%
COM7	Post	CA	90%	4%	100%	26%	26%	26%	46%	93%
COM7	Post	CA	100%	15%	100%	29%	29%	29%	58%	100%
COM8	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
COM8	Pre	A	10%	0%	10%	0%	0%	0%	1%	12%
COM8	Pre	A	20%	0%	30%	0%	0%	0%	6%	24%
COM8	Pre	A	30%	0%	80%	0%	0%	0%	9%	35%
COM8	Pre	A	40%	0%	100%	0%	0%	0%	10%	47%
COM8	Pre	A	50%	0%	100%	0%	0%	0%	16%	59%
COM8	Pre	A	60%	0%	100%	0%	0%	0%	21%	70%
COM8	Pre	A	70%	0%	100%	0%	0%	0%	30%	81%
COM8	Pre	A	80%	0%	100%	3%	3%	3%	39%	92%
COM8	Pre	A	90%	4%	100%	10%	10%	10%	56%	100%
COM8	Pre	A	100%	15%	100%	30%	30%	30%	100%	100%
COM8	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
COM8	Post	A	10%	0%	10%	0%	0%	0%	1%	13%
COM8	Post	A	20%	0%	30%	0%	0%	0%	4%	25%
COM8	Post	A	30%	0%	80%	0%	0%	0%	10%	37%
COM8	Post	A	40%	0%	100%	0%	0%	0%	11%	49%
COM8	Post	A	50%	0%	100%	0%	0%	0%	23%	61%
COM8	Post	A	60%	0%	100%	0%	0%	0%	36%	72%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM8	Post	A	70%	0%	100%	0%	0%	0%	62%	82%
COM8	Post	A	80%	0%	100%	3%	3%	3%	79%	93%
COM8	Post	A	90%	5%	100%	11%	11%	11%	94%	100%
COM8	Post	A	100%	25%	100%	40%	40%	40%	100%	100%
COM8	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM8	Pre	CA	10%	0%	20%	0%	0%	0%	2%	12%
COM8	Pre	CA	20%	0%	100%	1%	1%	1%	9%	22%
COM8	Pre	CA	30%	0%	100%	3%	3%	3%	16%	33%
COM8	Pre	CA	40%	0%	100%	6%	6%	6%	30%	43%
COM8	Pre	CA	50%	0%	100%	9%	9%	9%	40%	53%
COM8	Pre	CA	60%	1%	100%	11%	11%	11%	50%	64%
COM8	Pre	CA	70%	5%	100%	14%	14%	14%	60%	73%
COM8	Pre	CA	80%	9%	100%	17%	17%	17%	70%	83%
COM8	Pre	CA	90%	11%	100%	21%	21%	21%	80%	93%
COM8	Pre	CA	100%	26%	100%	25%	25%	25%	95%	100%
COM8	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM8	Post	CA	10%	0%	20%	0%	0%	0%	2%	12%
COM8	Post	CA	20%	0%	100%	1%	2%	3%	6%	24%
COM8	Post	CA	30%	0%	100%	3%	3%	3%	12%	35%
COM8	Post	CA	40%	0%	100%	6%	6%	6%	29%	46%
COM8	Post	CA	50%	0%	100%	9%	9%	9%	39%	57%
COM8	Post	CA	60%	1%	100%	11%	11%	11%	49%	68%
COM8	Post	CA	70%	3%	100%	14%	14%	14%	59%	79%
COM8	Post	CA	80%	6%	100%	17%	17%	17%	69%	89%
COM8	Post	CA	90%	11%	100%	21%	21%	21%	79%	98%
COM8	Post	CA	100%	26%	100%	42%	42%	42%	100%	100%
COM9	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
COM9	Pre	A	10%	0%	10%	0%	0%	0%	1%	13%
COM9	Pre	A	20%	0%	30%	0%	0%	0%	5%	25%
COM9	Pre	A	30%	0%	80%	0%	0%	0%	7%	37%
COM9	Pre	A	40%	0%	100%	0%	0%	0%	8%	50%
COM9	Pre	A	50%	0%	100%	0%	0%	0%	12%	62%
COM9	Pre	A	60%	0%	100%	0%	0%	0%	16%	75%
COM9	Pre	A	70%	0%	100%	0%	0%	0%	23%	87%
COM9	Pre	A	80%	0%	100%	3%	3%	3%	30%	97%
COM9	Pre	A	90%	5%	100%	9%	9%	9%	77%	100%
COM9	Pre	A	100%	25%	100%	28%	28%	28%	100%	100%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM9	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
COM9	Post	A	10%	0%	10%	0%	0%	0%	1%	13%
COM9	Post	A	20%	0%	30%	0%	0%	0%	4%	26%
COM9	Post	A	30%	0%	80%	0%	0%	0%	8%	38%
COM9	Post	A	40%	0%	100%	0%	0%	0%	9%	51%
COM9	Post	A	50%	0%	100%	0%	0%	0%	19%	63%
COM9	Post	A	60%	0%	100%	0%	0%	0%	29%	75%
COM9	Post	A	70%	0%	100%	0%	0%	0%	51%	86%
COM9	Post	A	80%	0%	100%	3%	3%	3%	71%	95%
COM9	Post	A	90%	11%	100%	15%	15%	15%	90%	100%
COM9	Post	A	100%	27%	100%	42%	42%	42%	100%	100%
COM9	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM9	Pre	CA	10%	0%	20%	0%	0%	0%	2%	13%
COM9	Pre	CA	20%	0%	100%	1%	1%	1%	7%	23%
COM9	Pre	CA	30%	0%	100%	2%	2%	2%	12%	35%
COM9	Pre	CA	40%	0%	100%	4%	4%	4%	23%	45%
COM9	Pre	CA	50%	0%	100%	8%	8%	8%	33%	56%
COM9	Pre	CA	60%	1%	100%	11%	11%	11%	43%	66%
COM9	Pre	CA	70%	5%	100%	15%	15%	15%	53%	76%
COM9	Pre	CA	80%	11%	100%	18%	18%	18%	63%	85%
COM9	Pre	CA	90%	15%	100%	21%	21%	21%	73%	95%
COM9	Pre	CA	100%	26%	100%	30%	30%	30%	100%	100%
COM9	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM9	Post	CA	10%	0%	20%	0%	0%	0%	2%	13%
COM9	Post	CA	20%	0%	100%	1%	1%	1%	5%	25%
COM9	Post	CA	30%	0%	100%	2%	2%	2%	10%	37%
COM9	Post	CA	40%	0%	100%	8%	8%	8%	25%	46%
COM9	Post	CA	50%	0%	100%	10%	10%	10%	35%	57%
COM9	Post	CA	60%	1%	100%	13%	13%	13%	45%	68%
COM9	Post	CA	70%	5%	100%	17%	17%	17%	55%	78%
COM9	Post	CA	80%	11%	100%	20%	20%	20%	65%	88%
COM9	Post	CA	90%	15%	100%	23%	23%	23%	75%	99%
COM9	Post	CA	100%	26%	100%	42%	42%	42%	100%	100%
COM10	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
COM10	Pre	A	10%	0%	0%	0%	0%	0%	15%	24%
COM10	Pre	A	20%	0%	0%	0%	0%	0%	20%	49%
COM10	Pre	A	30%	0%	0%	0%	0%	0%	25%	75%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM10	Pre	A	40%	0%	0%	0%	0%	0%	35%	100%
COM10	Pre	A	50%	6%	0%	6%	0%	6%	86%	100%
COM10	Pre	A	60%	14%	0%	18%	0%	14%	100%	100%
COM10	Pre	A	70%	18%	0%	35%	0%	18%	100%	100%
COM10	Pre	A	80%	25%	0%	52%	0%	25%	100%	100%
COM10	Pre	A	90%	30%	0%	70%	0%	30%	100%	100%
COM10	Pre	A	100%	40%	0%	83%	0%	40%	100%	100%
COM10	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
COM10	Post	A	10%	0%	0%	0%	0%	0%	15%	25%
COM10	Post	A	20%	0%	0%	0%	0%	0%	25%	52%
COM10	Post	A	30%	1%	0%	1%	0%	1%	35%	77%
COM10	Post	A	40%	2%	0%	2%	0%	2%	49%	100%
COM10	Post	A	50%	8%	0%	8%	0%	8%	100%	100%
COM10	Post	A	60%	21%	0%	21%	0%	21%	100%	100%
COM10	Post	A	70%	33%	0%	33%	0%	33%	100%	100%
COM10	Post	A	80%	45%	0%	45%	0%	45%	100%	100%
COM10	Post	A	90%	57%	0%	57%	0%	57%	100%	100%
COM10	Post	A	100%	69%	0%	69%	0%	69%	100%	100%
COM10	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM10	Pre	CA	10%	0%	0%	0%	0%	0%	15%	24%
COM10	Pre	CA	20%	0%	0%	0%	0%	0%	20%	49%
COM10	Pre	CA	30%	0%	0%	0%	0%	0%	25%	75%
COM10	Pre	CA	40%	0%	0%	0%	0%	0%	35%	100%
COM10	Pre	CA	50%	6%	0%	6%	0%	6%	86%	100%
COM10	Pre	CA	60%	14%	0%	18%	0%	14%	100%	100%
COM10	Pre	CA	70%	18%	0%	35%	0%	18%	100%	100%
COM10	Pre	CA	80%	25%	0%	52%	0%	25%	100%	100%
COM10	Pre	CA	90%	30%	0%	70%	0%	30%	100%	100%
COM10	Pre	CA	100%	40%	0%	83%	0%	40%	100%	100%
COM10	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
COM10	Post	CA	10%	0%	0%	0%	0%	0%	2%	31%
COM10	Post	CA	20%	0%	0%	0%	0%	1%	5%	60%
COM10	Post	CA	30%	0%	0%	1%	0%	2%	11%	89%
COM10	Post	CA	40%	0%	0%	3%	0%	3%	72%	97%
COM10	Post	CA	50%	0%	0%	13%	0%	13%	100%	100%
COM10	Post	CA	60%	0%	0%	29%	0%	29%	100%	100%
COM10	Post	CA	70%	3%	0%	44%	0%	44%	100%	100%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
COM10	Post	CA	80%	9%	0%	59%	0%	59%	100%	100%
COM10	Post	CA	90%	12%	0%	74%	0%	74%	100%	100%
COM10	Post	CA	100%	15%	0%	88%	0%	88%	100%	100%
IND1	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
IND1	Pre	A	10%	0%	10%	0%	0%	0%	1%	13%
IND1	Pre	A	20%	0%	30%	0%	0%	0%	5%	25%
IND1	Pre	A	30%	0%	80%	0%	0%	0%	7%	37%
IND1	Pre	A	40%	0%	100%	0%	0%	0%	8%	50%
IND1	Pre	A	50%	0%	100%	0%	0%	0%	12%	62%
IND1	Pre	A	60%	0%	100%	0%	0%	0%	16%	75%
IND1	Pre	A	70%	0%	100%	0%	0%	0%	23%	87%
IND1	Pre	A	80%	0%	100%	2%	2%	2%	40%	97%
IND1	Pre	A	90%	5%	100%	11%	11%	11%	82%	100%
IND1	Pre	A	100%	22%	100%	38%	38%	38%	100%	100%
IND1	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
IND1	Post	A	10%	0%	10%	0%	0%	0%	1%	13%
IND1	Post	A	20%	0%	30%	0%	0%	0%	4%	26%
IND1	Post	A	30%	0%	80%	0%	0%	0%	8%	39%
IND1	Post	A	40%	0%	100%	0%	0%	0%	9%	52%
IND1	Post	A	50%	0%	100%	0%	0%	0%	19%	64%
IND1	Post	A	60%	0%	100%	0%	0%	0%	29%	76%
IND1	Post	A	70%	0%	100%	0%	0%	0%	51%	87%
IND1	Post	A	80%	0%	100%	2%	2%	2%	74%	97%
IND1	Post	A	90%	11%	100%	15%	15%	15%	100%	100%
IND1	Post	A	100%	28%	100%	50%	50%	50%	100%	100%
IND1	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
IND1	Pre	CA	10%	0%	20%	0%	0%	0%	2%	13%
IND1	Pre	CA	20%	0%	100%	1%	1%	1%	7%	23%
IND1	Pre	CA	30%	0%	100%	2%	2%	2%	12%	35%
IND1	Pre	CA	40%	0%	100%	4%	4%	4%	23%	46%
IND1	Pre	CA	50%	0%	100%	8%	8%	8%	33%	57%
IND1	Pre	CA	60%	1%	100%	11%	11%	11%	44%	67%
IND1	Pre	CA	70%	4%	100%	13%	13%	13%	55%	77%
IND1	Pre	CA	80%	9%	100%	16%	16%	16%	66%	87%
IND1	Pre	CA	90%	12%	100%	18%	18%	18%	77%	97%
IND1	Pre	CA	100%	20%	100%	42%	42%	42%	100%	100%
IND1	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
IND1	Post	CA	10%	0%	20%	0%	0%	0%	2%	13%
IND1	Post	CA	20%	0%	100%	1%	1%	1%	5%	25%
IND1	Post	CA	30%	0%	100%	2%	2%	2%	10%	37%
IND1	Post	CA	40%	0%	100%	5%	5%	5%	25%	48%
IND1	Post	CA	50%	0%	100%	9%	9%	9%	36%	60%
IND1	Post	CA	60%	1%	100%	13%	13%	13%	47%	70%
IND1	Post	CA	70%	3%	100%	18%	18%	18%	55%	81%
IND1	Post	CA	80%	9%	100%	20%	20%	20%	66%	91%
IND1	Post	CA	90%	12%	100%	24%	24%	24%	80%	100%
IND1	Post	CA	100%	27%	100%	55%	55%	55%	100%	100%
IND2	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
IND2	Pre	A	10%	0%	10%	0%	0%	0%	1%	15%
IND2	Pre	A	20%	0%	30%	0%	0%	0%	4%	29%
IND2	Pre	A	30%	0%	80%	0%	0%	0%	6%	43%
IND2	Pre	A	40%	0%	100%	0%	0%	0%	7%	58%
IND2	Pre	A	50%	0%	100%	0%	0%	0%	11%	72%
IND2	Pre	A	60%	0%	100%	0%	0%	0%	25%	84%
IND2	Pre	A	70%	0%	100%	0%	0%	0%	42%	95%
IND2	Pre	A	80%	0%	100%	17%	17%	17%	60%	100%
IND2	Pre	A	90%	16%	100%	40%	40%	40%	71%	100%
IND2	Pre	A	100%	20%	100%	60%	60%	60%	100%	100%
IND2	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
IND2	Post	A	10%	0%	10%	0%	0%	0%	1%	16%
IND2	Post	A	20%	0%	30%	0%	0%	0%	3%	31%
IND2	Post	A	30%	0%	80%	0%	0%	0%	7%	46%
IND2	Post	A	40%	0%	100%	0%	0%	0%	8%	61%
IND2	Post	A	50%	0%	100%	0%	0%	0%	16%	76%
IND2	Post	A	60%	0%	100%	0%	0%	0%	25%	90%
IND2	Post	A	70%	0%	100%	0%	0%	0%	54%	99%
IND2	Post	A	80%	0%	100%	10%	10%	10%	90%	100%
IND2	Post	A	90%	10%	100%	49%	49%	49%	100%	100%
IND2	Post	A	100%	32%	100%	65%	65%	65%	100%	100%
IND2	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
IND2	Pre	CA	10%	0%	20%	0%	0%	0%	1%	15%
IND2	Pre	CA	20%	0%	100%	1%	1%	1%	6%	27%
IND2	Pre	CA	30%	0%	100%	3%	3%	3%	11%	41%
IND2	Pre	CA	40%	0%	100%	6%	6%	6%	21%	52%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
IND2	Pre	CA	50%	0%	100%	11%	11%	11%	35%	63%
IND2	Pre	CA	60%	1%	100%	17%	17%	17%	45%	73%
IND2	Pre	CA	70%	4%	100%	24%	24%	24%	55%	82%
IND2	Pre	CA	80%	9%	100%	28%	28%	28%	65%	92%
IND2	Pre	CA	90%	18%	100%	31%	31%	31%	87%	100%
IND2	Pre	CA	100%	25%	100%	55%	55%	55%	100%	100%
IND2	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
IND2	Post	CA	10%	0%	20%	0%	0%	0%	8%	14%
IND2	Post	CA	20%	0%	100%	3%	3%	3%	12%	27%
IND2	Post	CA	30%	0%	100%	8%	8%	8%	21%	39%
IND2	Post	CA	40%	0%	100%	11%	11%	11%	31%	52%
IND2	Post	CA	50%	0%	100%	15%	15%	15%	43%	65%
IND2	Post	CA	60%	0%	100%	19%	19%	19%	53%	77%
IND2	Post	CA	70%	0%	100%	23%	23%	23%	64%	89%
IND2	Post	CA	80%	0%	100%	28%	28%	28%	77%	100%
IND2	Post	CA	90%	13%	100%	44%	44%	44%	100%	100%
IND2	Post	CA	100%	50%	100%	49%	49%	49%	100%	100%
IND3	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
IND3	Pre	A	10%	0%	10%	0%	0%	0%	1%	13%
IND3	Pre	A	20%	0%	30%	0%	0%	0%	4%	26%
IND3	Pre	A	30%	0%	80%	0%	0%	0%	6%	39%
IND3	Pre	A	40%	0%	100%	0%	0%	0%	7%	52%
IND3	Pre	A	50%	0%	100%	0%	0%	0%	11%	65%
IND3	Pre	A	60%	0%	100%	0%	0%	0%	15%	78%
IND3	Pre	A	70%	0%	100%	0%	0%	0%	21%	90%
IND3	Pre	A	80%	0%	100%	8%	8%	8%	28%	100%
IND3	Pre	A	90%	12%	100%	22%	22%	22%	64%	100%
IND3	Pre	A	100%	20%	100%	42%	42%	42%	100%	100%
IND3	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
IND3	Post	A	10%	0%	10%	0%	0%	0%	1%	14%
IND3	Post	A	20%	0%	30%	0%	0%	0%	3%	28%
IND3	Post	A	30%	0%	80%	0%	0%	0%	7%	41%
IND3	Post	A	40%	0%	100%	0%	0%	0%	8%	55%
IND3	Post	A	50%	0%	100%	0%	0%	0%	16%	68%
IND3	Post	A	60%	0%	100%	0%	0%	0%	25%	81%
IND3	Post	A	70%	0%	100%	0%	0%	0%	43%	92%
IND3	Post	A	80%	0%	100%	11%	11%	11%	63%	99%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
IND3	Post	A	90%	13%	100%	31%	31%	31%	80%	100%
IND3	Post	A	100%	24%	100%	60%	60%	60%	100%	100%
IND3	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
IND3	Pre	CA	10%	0%	20%	0%	0%	0%	1%	13%
IND3	Pre	CA	20%	0%	100%	2%	2%	2%	6%	24%
IND3	Pre	CA	30%	0%	100%	4%	4%	4%	11%	37%
IND3	Pre	CA	40%	0%	100%	6%	6%	6%	21%	48%
IND3	Pre	CA	50%	0%	100%	11%	11%	11%	31%	58%
IND3	Pre	CA	60%	1%	100%	18%	18%	18%	41%	67%
IND3	Pre	CA	70%	6%	100%	23%	23%	23%	51%	77%
IND3	Pre	CA	80%	11%	100%	32%	32%	32%	58%	85%
IND3	Pre	CA	90%	17%	100%	42%	42%	42%	68%	93%
IND3	Pre	CA	100%	24%	100%	50%	50%	50%	80%	100%
IND3	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
IND3	Post	CA	10%	0%	20%	0%	0%	0%	2%	14%
IND3	Post	CA	20%	0%	100%	2%	2%	2%	4%	26%
IND3	Post	CA	30%	0%	100%	4%	4%	4%	8%	39%
IND3	Post	CA	40%	0%	100%	6%	6%	6%	30%	49%
IND3	Post	CA	50%	0%	100%	11%	11%	11%	39%	60%
IND3	Post	CA	60%	1%	100%	18%	18%	18%	52%	69%
IND3	Post	CA	70%	6%	100%	23%	23%	23%	63%	79%
IND3	Post	CA	80%	11%	100%	32%	32%	32%	70%	88%
IND3	Post	CA	90%	17%	100%	42%	42%	42%	74%	97%
IND3	Post	CA	100%	30%	100%	50%	50%	50%	100%	100%
IND4	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
IND4	Pre	A	10%	0%	0%	0%	0%	0%	1%	15%
IND4	Pre	A	20%	0%	0%	0%	0%	0%	6%	30%
IND4	Pre	A	30%	0%	0%	0%	0%	0%	9%	45%
IND4	Pre	A	40%	0%	0%	0%	0%	0%	10%	61%
IND4	Pre	A	50%	0%	0%	0%	0%	0%	16%	76%
IND4	Pre	A	60%	0%	0%	0%	0%	0%	21%	90%
IND4	Pre	A	70%	0%	0%	0%	0%	0%	55%	100%
IND4	Pre	A	80%	0%	0%	17%	17%	17%	90%	100%
IND4	Pre	A	90%	8%	0%	37%	37%	37%	100%	100%
IND4	Pre	A	100%	25%	0%	57%	57%	57%	100%	100%
IND4	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
IND4	Post	A	10%	0%	0%	0%	0%	0%	1%	17%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
IND4	Post	A	20%	0%	0%	0%	0%	0%	4%	33%
IND4	Post	A	30%	0%	0%	0%	0%	0%	10%	49%
IND4	Post	A	40%	0%	0%	0%	0%	0%	11%	65%
IND4	Post	A	50%	0%	0%	0%	0%	0%	23%	80%
IND4	Post	A	60%	0%	0%	0%	0%	0%	36%	95%
IND4	Post	A	70%	0%	0%	2%	2%	2%	97%	100%
IND4	Post	A	80%	0%	0%	26%	26%	26%	100%	100%
IND4	Post	A	90%	9%	0%	47%	47%	47%	100%	100%
IND4	Post	A	100%	26%	0%	65%	65%	65%	100%	100%
IND4	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
IND4	Pre	CA	10%	0%	0%	0%	0%	0%	2%	15%
IND4	Pre	CA	20%	0%	0%	1%	1%	1%	9%	29%
IND4	Pre	CA	30%	0%	0%	4%	4%	4%	16%	42%
IND4	Pre	CA	40%	0%	0%	8%	8%	8%	25%	54%
IND4	Pre	CA	50%	0%	0%	11%	11%	11%	35%	65%
IND4	Pre	CA	60%	2%	0%	15%	15%	15%	45%	76%
IND4	Pre	CA	70%	9%	0%	18%	18%	18%	55%	88%
IND4	Pre	CA	80%	11%	0%	23%	23%	23%	65%	98%
IND4	Pre	CA	90%	25%	0%	35%	35%	35%	95%	100%
IND4	Pre	CA	100%	35%	0%	55%	55%	55%	100%	100%
IND4	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
IND4	Post	CA	10%	0%	0%	0%	0%	0%	8%	15%
IND4	Post	CA	20%	0%	0%	2%	2%	2%	10%	31%
IND4	Post	CA	30%	0%	0%	6%	6%	6%	14%	44%
IND4	Post	CA	40%	0%	0%	9%	9%	9%	32%	55%
IND4	Post	CA	50%	0%	0%	14%	14%	14%	33%	69%
IND4	Post	CA	60%	2%	0%	19%	19%	19%	44%	80%
IND4	Post	CA	70%	5%	0%	27%	27%	27%	52%	89%
IND4	Post	CA	80%	8%	0%	33%	33%	33%	61%	100%
IND4	Post	CA	90%	18%	0%	48%	48%	48%	80%	100%
IND4	Post	CA	100%	25%	0%	67%	67%	67%	100%	100%
IND5	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
IND5	Pre	A	10%	0%	0%	0%	0%	0%	2%	11%
IND5	Pre	A	20%	0%	0%	0%	0%	0%	12%	22%
IND5	Pre	A	30%	0%	0%	0%	0%	0%	18%	32%
IND5	Pre	A	40%	0%	0%	0%	0%	0%	20%	43%
IND5	Pre	A	50%	0%	0%	0%	0%	0%	32%	54%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
IND5	Pre	A	60%	0%	0%	0%	0%	0%	42%	64%
IND5	Pre	A	70%	0%	0%	0%	0%	0%	60%	74%
IND5	Pre	A	80%	0%	0%	6%	6%	6%	80%	83%
IND5	Pre	A	90%	9%	0%	18%	18%	18%	89%	90%
IND5	Pre	A	100%	15%	0%	20%	20%	20%	100%	100%
IND5	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
IND5	Post	A	10%	0%	0%	0%	0%	0%	3%	12%
IND5	Post	A	20%	0%	0%	0%	0%	0%	10%	23%
IND5	Post	A	30%	0%	0%	0%	0%	0%	23%	34%
IND5	Post	A	40%	0%	0%	0%	0%	0%	25%	45%
IND5	Post	A	50%	0%	0%	0%	0%	0%	35%	57%
IND5	Post	A	60%	0%	0%	0%	0%	0%	48%	68%
IND5	Post	A	70%	0%	0%	0%	0%	0%	63%	78%
IND5	Post	A	80%	0%	0%	6%	6%	6%	75%	88%
IND5	Post	A	90%	5%	0%	10%	10%	10%	92%	98%
IND5	Post	A	100%	25%	0%	30%	30%	30%	100%	100%
IND5	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
IND5	Pre	CA	10%	0%	0%	0%	0%	0%	6%	11%
IND5	Pre	CA	20%	0%	0%	2%	2%	2%	18%	21%
IND5	Pre	CA	30%	0%	0%	5%	5%	5%	20%	31%
IND5	Pre	CA	40%	0%	0%	7%	7%	7%	30%	42%
IND5	Pre	CA	50%	0%	0%	11%	11%	11%	40%	51%
IND5	Pre	CA	60%	1%	0%	14%	14%	14%	50%	61%
IND5	Pre	CA	70%	4%	0%	18%	18%	18%	60%	71%
IND5	Pre	CA	80%	8%	0%	21%	21%	21%	70%	80%
IND5	Pre	CA	90%	10%	0%	26%	26%	26%	75%	90%
IND5	Pre	CA	100%	13%	0%	28%	28%	28%	80%	100%
IND5	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
IND5	Post	CA	10%	0%	0%	0%	0%	0%	5%	11%
IND5	Post	CA	20%	0%	0%	2%	2%	2%	13%	22%
IND5	Post	CA	30%	0%	0%	5%	5%	5%	28%	33%
IND5	Post	CA	40%	0%	0%	7%	7%	7%	38%	43%
IND5	Post	CA	50%	0%	0%	11%	11%	11%	46%	54%
IND5	Post	CA	60%	1%	0%	14%	14%	14%	56%	64%
IND5	Post	CA	70%	4%	0%	18%	18%	18%	66%	74%
IND5	Post	CA	80%	8%	0%	21%	21%	21%	76%	84%
IND5	Post	CA	90%	11%	0%	26%	26%	26%	86%	94%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
IND5	Post	CA	100%	18%	0%	42%	42%	42%	100%	100%
IND6	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
IND6	Pre	A	10%	0%	10%	0%	0%	0%	5%	16%
IND6	Pre	A	20%	0%	30%	0%	0%	0%	10%	32%
IND6	Pre	A	30%	0%	80%	0%	0%	0%	16%	48%
IND6	Pre	A	40%	0%	100%	0%	0%	0%	21%	64%
IND6	Pre	A	50%	0%	100%	0%	0%	0%	28%	80%
IND6	Pre	A	60%	0%	100%	0%	0%	0%	35%	96%
IND6	Pre	A	70%	0%	100%	13%	13%	13%	65%	100%
IND6	Pre	A	80%	2%	100%	30%	30%	30%	100%	100%
IND6	Pre	A	90%	18%	100%	50%	50%	50%	100%	100%
IND6	Pre	A	100%	30%	100%	75%	75%	75%	100%	100%
IND6	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
IND6	Post	A	10%	0%	10%	0%	0%	0%	1%	19%
IND6	Post	A	20%	0%	30%	0%	0%	0%	3%	37%
IND6	Post	A	30%	0%	80%	0%	0%	0%	7%	54%
IND6	Post	A	40%	0%	100%	0%	0%	0%	8%	73%
IND6	Post	A	50%	0%	100%	0%	0%	0%	16%	90%
IND6	Post	A	60%	0%	100%	0%	0%	0%	62%	98%
IND6	Post	A	70%	0%	100%	14%	14%	14%	100%	100%
IND6	Post	A	80%	7%	100%	41%	41%	41%	100%	100%
IND6	Post	A	90%	15%	100%	70%	70%	70%	100%	100%
IND6	Post	A	100%	41%	100%	75%	75%	75%	100%	100%
IND6	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
IND6	Pre	CA	10%	0%	20%	0%	0%	0%	5%	16%
IND6	Pre	CA	20%	0%	100%	2%	2%	2%	9%	30%
IND6	Pre	CA	30%	0%	100%	6%	6%	6%	14%	45%
IND6	Pre	CA	40%	0%	100%	9%	9%	9%	21%	59%
IND6	Pre	CA	50%	0%	100%	14%	14%	14%	31%	72%
IND6	Pre	CA	60%	1%	100%	18%	18%	18%	41%	85%
IND6	Pre	CA	70%	4%	100%	24%	24%	24%	51%	96%
IND6	Pre	CA	80%	8%	100%	34%	34%	34%	76%	100%
IND6	Pre	CA	90%	20%	100%	47%	47%	47%	100%	100%
IND6	Pre	CA	100%	25%	100%	80%	80%	80%	100%	100%
IND6	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
IND6	Post	CA	10%	0%	20%	0%	0%	0%	5%	16%
IND6	Post	CA	20%	0%	100%	2%	2%	2%	11%	33%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
IND6	Post	CA	30%	0%	100%	6%	6%	6%	18%	48%
IND6	Post	CA	40%	0%	100%	9%	9%	9%	25%	63%
IND6	Post	CA	50%	0%	100%	14%	14%	14%	36%	77%
IND6	Post	CA	60%	1%	100%	18%	18%	18%	50%	90%
IND6	Post	CA	70%	4%	100%	25%	25%	25%	65%	100%
IND6	Post	CA	80%	10%	100%	39%	39%	39%	100%	100%
IND6	Post	CA	90%	25%	100%	57%	57%	57%	100%	100%
IND6	Post	CA	100%	35%	100%	82%	82%	82%	100%	100%
AGR1	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
AGR1	Pre	A	10%	0%	0%	0%	0%	0%	2%	22%
AGR1	Pre	A	20%	0%	0%	0%	0%	0%	18%	38%
AGR1	Pre	A	30%	0%	0%	0%	0%	0%	28%	58%
AGR1	Pre	A	40%	0%	0%	0%	0%	0%	38%	76%
AGR1	Pre	A	50%	0%	0%	0%	0%	0%	60%	90%
AGR1	Pre	A	60%	0%	0%	0%	0%	0%	100%	100%
AGR1	Pre	A	70%	2%	0%	30%	30%	30%	100%	100%
AGR1	Pre	A	80%	8%	0%	55%	55%	55%	100%	100%
AGR1	Pre	A	90%	19%	0%	75%	75%	75%	100%	100%
AGR1	Pre	A	100%	24%	0%	100%	100%	100%	100%	100%
AGR1	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
AGR1	Post	A	10%	0%	0%	0%	0%	0%	12%	21%
AGR1	Post	A	20%	0%	0%	0%	0%	0%	21%	42%
AGR1	Post	A	30%	0%	0%	0%	0%	0%	35%	61%
AGR1	Post	A	40%	0%	0%	0%	0%	0%	49%	80%
AGR1	Post	A	50%	0%	0%	0%	0%	0%	65%	100%
AGR1	Post	A	60%	2%	0%	14%	14%	14%	100%	100%
AGR1	Post	A	70%	12%	0%	35%	35%	35%	100%	100%
AGR1	Post	A	80%	16%	0%	60%	60%	60%	100%	100%
AGR1	Post	A	90%	23%	0%	85%	85%	85%	100%	100%
AGR1	Post	A	100%	35%	0%	100%	100%	100%	100%	100%
AGR1	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
AGR1	Pre	CA	10%	0%	0%	0%	0%	0%	10%	19%
AGR1	Pre	CA	20%	0%	0%	1%	1%	1%	18%	38%
AGR1	Pre	CA	30%	0%	0%	4%	4%	4%	27%	53%
AGR1	Pre	CA	40%	0%	0%	8%	8%	8%	40%	69%
AGR1	Pre	CA	50%	0%	0%	14%	14%	14%	55%	82%
AGR1	Pre	CA	60%	1%	0%	19%	19%	19%	65%	97%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
AGR1	Pre	CA	70%	6%	0%	30%	30%	30%	88%	100%
AGR1	Pre	CA	80%	10%	0%	52%	52%	52%	100%	100%
AGR1	Pre	CA	90%	21%	0%	73%	73%	73%	100%	100%
AGR1	Pre	CA	100%	33%	0%	90%	90%	90%	100%	100%
AGR1	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
AGR1	Post	CA	10%	0%	0%	0%	0%	0%	10%	20%
AGR1	Post	CA	20%	0%	0%	1%	1%	1%	20%	41%
AGR1	Post	CA	30%	0%	0%	9%	9%	9%	30%	56%
AGR1	Post	CA	40%	0%	0%	12%	12%	12%	42%	75%
AGR1	Post	CA	50%	0%	0%	18%	18%	18%	60%	88%
AGR1	Post	CA	60%	1%	0%	27%	27%	27%	74%	100%
AGR1	Post	CA	70%	6%	0%	40%	40%	40%	100%	100%
AGR1	Post	CA	80%	16%	0%	60%	60%	60%	100%	100%
AGR1	Post	CA	90%	25%	0%	80%	80%	80%	100%	100%
AGR1	Post	CA	100%	39%	0%	95%	95%	95%	100%	100%
REL1	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
REL1	Pre	A	10%	0%	10%	0%	0%	0%	9%	16%
REL1	Pre	A	20%	0%	30%	0%	0%	0%	17%	30%
REL1	Pre	A	30%	0%	80%	0%	0%	0%	28%	45%
REL1	Pre	A	40%	0%	100%	0%	0%	0%	38%	59%
REL1	Pre	A	50%	0%	100%	0%	0%	0%	50%	75%
REL1	Pre	A	60%	0%	100%	0%	0%	0%	66%	89%
REL1	Pre	A	70%	0%	100%	4%	4%	4%	80%	100%
REL1	Pre	A	80%	5%	100%	21%	21%	21%	100%	100%
REL1	Pre	A	90%	23%	100%	38%	38%	38%	100%	100%
REL1	Pre	A	100%	45%	100%	56%	56%	56%	100%	100%
REL1	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
REL1	Post	A	10%	0%	10%	0%	0%	0%	11%	17%
REL1	Post	A	20%	0%	30%	0%	0%	0%	18%	33%
REL1	Post	A	30%	0%	80%	0%	0%	0%	30%	48%
REL1	Post	A	40%	0%	100%	0%	0%	0%	49%	62%
REL1	Post	A	50%	0%	100%	0%	0%	0%	55%	80%
REL1	Post	A	60%	0%	100%	0%	0%	0%	66%	95%
REL1	Post	A	70%	0%	100%	11%	11%	11%	93%	100%
REL1	Post	A	80%	6%	100%	32%	32%	32%	100%	100%
REL1	Post	A	90%	13%	100%	55%	55%	55%	100%	100%
REL1	Post	A	100%	27%	100%	72%	72%	72%	100%	100%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
REL1	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
REL1	Pre	CA	10%	0%	20%	0%	0%	0%	10%	15%
REL1	Pre	CA	20%	0%	100%	1%	1%	1%	20%	28%
REL1	Pre	CA	30%	0%	100%	5%	5%	5%	30%	40%
REL1	Pre	CA	40%	0%	100%	11%	11%	11%	40%	51%
REL1	Pre	CA	50%	0%	100%	17%	17%	17%	50%	63%
REL1	Pre	CA	60%	5%	100%	21%	21%	21%	66%	73%
REL1	Pre	CA	70%	11%	100%	27%	27%	27%	77%	82%
REL1	Pre	CA	80%	18%	100%	31%	31%	31%	88%	92%
REL1	Pre	CA	90%	27%	100%	37%	37%	37%	99%	100%
REL1	Pre	CA	100%	50%	100%	56%	56%	56%	100%	100%
REL1	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
REL1	Post	CA	10%	0%	20%	0%	0%	0%	10%	16%
REL1	Post	CA	20%	0%	100%	1%	1%	1%	21%	30%
REL1	Post	CA	30%	0%	100%	5%	5%	5%	35%	42%
REL1	Post	CA	40%	0%	100%	11%	11%	11%	40%	55%
REL1	Post	CA	50%	0%	100%	17%	17%	17%	55%	67%
REL1	Post	CA	60%	5%	100%	21%	21%	21%	66%	79%
REL1	Post	CA	70%	13%	100%	27%	27%	27%	80%	86%
REL1	Post	CA	80%	18%	100%	31%	31%	31%	86%	100%
REL1	Post	CA	90%	30%	100%	46%	46%	46%	97%	100%
REL1	Post	CA	100%	43%	100%	65%	65%	65%	100%	100%
GOV1	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
GOV1	Pre	A	10%	0%	10%	0%	0%	0%	1%	13%
GOV1	Pre	A	20%	0%	30%	0%	0%	0%	6%	26%
GOV1	Pre	A	30%	0%	80%	0%	0%	0%	9%	39%
GOV1	Pre	A	40%	0%	100%	0%	0%	0%	10%	52%
GOV1	Pre	A	50%	0%	100%	0%	0%	0%	16%	65%
GOV1	Pre	A	60%	0%	100%	0%	0%	0%	21%	78%
GOV1	Pre	A	70%	0%	100%	0%	0%	0%	50%	88%
GOV1	Pre	A	80%	1%	100%	18%	18%	18%	89%	88%
GOV1	Pre	A	90%	6%	100%	22%	22%	22%	95%	100%
GOV1	Pre	A	100%	26%	100%	40%	40%	40%	100%	100%
GOV1	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
GOV1	Post	A	10%	0%	10%	0%	0%	0%	1%	14%
GOV1	Post	A	20%	0%	30%	0%	0%	0%	4%	28%
GOV1	Post	A	30%	0%	80%	0%	0%	0%	10%	41%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
GOV1	Post	A	40%	0%	100%	0%	0%	0%	11%	55%
GOV1	Post	A	50%	0%	100%	0%	0%	0%	23%	68%
GOV1	Post	A	60%	0%	100%	0%	0%	0%	61%	78%
GOV1	Post	A	70%	0%	100%	0%	0%	0%	83%	89%
GOV1	Post	A	80%	0%	100%	9%	9%	9%	89%	100%
GOV1	Post	A	90%	6%	100%	35%	35%	35%	100%	100%
GOV1	Post	A	100%	13%	100%	67%	67%	67%	100%	100%
GOV1	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
GOV1	Pre	CA	10%	0%	20%	0%	0%	0%	9%	12%
GOV1	Pre	CA	20%	0%	100%	2%	2%	2%	17%	23%
GOV1	Pre	CA	30%	0%	100%	4%	4%	4%	24%	35%
GOV1	Pre	CA	40%	0%	100%	6%	6%	6%	38%	46%
GOV1	Pre	CA	50%	0%	100%	14%	14%	14%	46%	55%
GOV1	Pre	CA	60%	2%	100%	23%	23%	23%	53%	65%
GOV1	Pre	CA	70%	6%	100%	33%	33%	33%	66%	72%
GOV1	Pre	CA	80%	10%	100%	40%	40%	40%	70%	82%
GOV1	Pre	CA	90%	15%	100%	44%	44%	44%	72%	93%
GOV1	Pre	CA	100%	25%	100%	51%	51%	51%	80%	100%
GOV1	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
GOV1	Post	CA	10%	0%	20%	0%	0%	0%	9%	13%
GOV1	Post	CA	20%	0%	100%	2%	2%	2%	21%	24%
GOV1	Post	CA	30%	0%	100%	4%	4%	4%	30%	37%
GOV1	Post	CA	40%	0%	100%	6%	6%	6%	40%	49%
GOV1	Post	CA	50%	0%	100%	14%	14%	14%	50%	59%
GOV1	Post	CA	60%	2%	100%	23%	23%	23%	61%	68%
GOV1	Post	CA	70%	5%	100%	32%	32%	32%	67%	78%
GOV1	Post	CA	80%	10%	100%	40%	40%	40%	74%	86%
GOV1	Post	CA	90%	12%	100%	41%	41%	41%	79%	100%
GOV1	Post	CA	100%	30%	100%	55%	55%	55%	100%	100%
GOV2	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
GOV2	Pre	A	10%	0%	0%	0%	0%	0%	10%	11%
GOV2	Pre	A	20%	0%	0%	0%	0%	0%	18%	23%
GOV2	Pre	A	30%	0%	0%	0%	0%	0%	29%	33%
GOV2	Pre	A	40%	0%	0%	0%	0%	0%	38%	44%
GOV2	Pre	A	50%	0%	0%	0%	0%	0%	46%	56%
GOV2	Pre	A	60%	0%	0%	0%	0%	0%	52%	68%
GOV2	Pre	A	70%	0%	0%	0%	0%	0%	66%	78%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
GOV2	Pre	A	80%	0%	0%	16%	16%	16%	74%	84%
GOV2	Pre	A	90%	5%	0%	18%	18%	18%	77%	96%
GOV2	Pre	A	100%	25%	0%	35%	35%	35%	80%	100%
GOV2	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
GOV2	Post	A	10%	0%	0%	0%	0%	0%	10%	12%
GOV2	Post	A	20%	0%	0%	0%	0%	0%	20%	23%
GOV2	Post	A	30%	0%	0%	0%	0%	0%	29%	35%
GOV2	Post	A	40%	0%	0%	0%	0%	0%	37%	48%
GOV2	Post	A	50%	0%	0%	0%	0%	0%	47%	60%
GOV2	Post	A	60%	0%	0%	0%	0%	0%	52%	72%
GOV2	Post	A	70%	0%	0%	0%	0%	0%	62%	84%
GOV2	Post	A	80%	0%	0%	8%	8%	8%	73%	93%
GOV2	Post	A	90%	7%	0%	16%	16%	16%	84%	100%
GOV2	Post	A	100%	26%	0%	40%	40%	40%	100%	100%
GOV2	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
GOV2	Pre	CA	10%	0%	0%	0%	0%	0%	10%	11%
GOV2	Pre	CA	20%	0%	0%	3%	3%	3%	20%	21%
GOV2	Pre	CA	30%	0%	0%	7%	7%	7%	27%	31%
GOV2	Pre	CA	40%	0%	0%	10%	10%	10%	36%	42%
GOV2	Pre	CA	50%	0%	0%	16%	16%	16%	40%	52%
GOV2	Pre	CA	60%	3%	0%	22%	22%	22%	55%	60%
GOV2	Pre	CA	70%	8%	0%	25%	25%	25%	60%	70%
GOV2	Pre	CA	80%	11%	0%	32%	32%	32%	66%	80%
GOV2	Pre	CA	90%	14%	0%	35%	35%	35%	75%	90%
GOV2	Pre	CA	100%	17%	0%	40%	40%	40%	80%	100%
GOV2	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
GOV2	Post	CA	10%	0%	0%	0%	0%	0%	10%	12%
GOV2	Post	CA	20%	0%	0%	3%	3%	3%	20%	23%
GOV2	Post	CA	30%	0%	0%	7%	7%	7%	30%	33%
GOV2	Post	CA	40%	0%	0%	10%	10%	10%	35%	45%
GOV2	Post	CA	50%	0%	0%	13%	13%	13%	46%	56%
GOV2	Post	CA	60%	3%	0%	21%	21%	21%	52%	65%
GOV2	Post	CA	70%	8%	0%	26%	26%	26%	60%	74%
GOV2	Post	CA	80%	11%	0%	31%	31%	31%	65%	85%
GOV2	Post	CA	90%	14%	0%	37%	37%	37%	70%	95%
GOV2	Post	CA	100%	19%	0%	42%	42%	42%	99%	100%
EDU1	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
EDU1	Pre	A	10%	0%	10%	0%	0%	0%	4%	12%
EDU1	Pre	A	20%	0%	30%	0%	0%	0%	8%	23%
EDU1	Pre	A	30%	0%	80%	0%	0%	0%	15%	34%
EDU1	Pre	A	40%	0%	100%	0%	0%	0%	20%	46%
EDU1	Pre	A	50%	0%	100%	0%	0%	0%	24%	58%
EDU1	Pre	A	60%	0%	100%	0%	0%	0%	28%	70%
EDU1	Pre	A	70%	0%	100%	0%	0%	0%	34%	82%
EDU1	Pre	A	80%	0%	100%	3%	3%	3%	41%	92%
EDU1	Pre	A	90%	5%	100%	12%	12%	12%	50%	100%
EDU1	Pre	A	100%	20%	100%	35%	35%	35%	77%	100%
EDU1	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
EDU1	Post	A	10%	0%	10%	0%	0%	0%	4%	11%
EDU1	Post	A	20%	0%	30%	0%	0%	0%	8%	22%
EDU1	Post	A	30%	0%	80%	0%	0%	0%	15%	32%
EDU1	Post	A	40%	0%	100%	0%	0%	0%	20%	43%
EDU1	Post	A	50%	0%	100%	0%	0%	0%	24%	55%
EDU1	Post	A	60%	0%	100%	0%	0%	0%	28%	66%
EDU1	Post	A	70%	0%	100%	0%	0%	0%	34%	77%
EDU1	Post	A	80%	0%	100%	7%	7%	7%	41%	86%
EDU1	Post	A	90%	7%	100%	14%	14%	14%	50%	94%
EDU1	Post	A	100%	22%	100%	32%	32%	32%	55%	100%
EDU1	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
EDU1	Pre	CA	10%	0%	20%	0%	0%	0%	5%	12%
EDU1	Pre	CA	20%	0%	100%	1%	1%	1%	8%	23%
EDU1	Pre	CA	30%	0%	100%	4%	4%	4%	12%	34%
EDU1	Pre	CA	40%	0%	100%	6%	6%	6%	22%	44%
EDU1	Pre	CA	50%	0%	100%	12%	12%	12%	30%	53%
EDU1	Pre	CA	60%	4%	100%	18%	18%	18%	41%	61%
EDU1	Pre	CA	70%	8%	100%	24%	24%	24%	50%	70%
EDU1	Pre	CA	80%	13%	100%	29%	29%	29%	62%	79%
EDU1	Pre	CA	90%	19%	100%	33%	33%	33%	70%	88%
EDU1	Pre	CA	100%	20%	100%	34%	34%	34%	75%	100%
EDU1	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
EDU1	Post	CA	10%	0%	20%	0%	0%	0%	5%	11%
EDU1	Post	CA	20%	0%	100%	1%	1%	1%	8%	21%
EDU1	Post	CA	30%	0%	100%	4%	4%	4%	12%	32%
EDU1	Post	CA	40%	0%	100%	6%	6%	6%	23%	42%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
EDU1	Post	CA	50%	0%	100%	12%	12%	12%	28%	51%
EDU1	Post	CA	60%	4%	100%	18%	18%	18%	38%	60%
EDU1	Post	CA	70%	8%	100%	24%	24%	24%	44%	69%
EDU1	Post	CA	80%	13%	100%	29%	29%	29%	50%	79%
EDU1	Post	CA	90%	19%	100%	33%	33%	33%	56%	88%
EDU1	Post	CA	100%	20%	100%	34%	34%	34%	62%	99%
EDU2	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
EDU2	Pre	A	10%	0%	10%	0%	0%	0%	1%	11%
EDU2	Pre	A	20%	0%	30%	0%	0%	0%	6%	21%
EDU2	Pre	A	30%	0%	80%	0%	0%	0%	9%	32%
EDU2	Pre	A	40%	0%	100%	0%	0%	0%	10%	43%
EDU2	Pre	A	50%	0%	100%	0%	0%	0%	16%	53%
EDU2	Pre	A	60%	0%	100%	0%	0%	0%	21%	64%
EDU2	Pre	A	70%	0%	100%	0%	0%	0%	35%	72%
EDU2	Pre	A	80%	0%	100%	3%	3%	3%	46%	83%
EDU2	Pre	A	90%	3%	100%	6%	6%	6%	57%	90%
EDU2	Pre	A	100%	10%	100%	10%	10%	10%	70%	100%
EDU2	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
EDU2	Post	A	10%	0%	10%	0%	0%	0%	1%	11%
EDU2	Post	A	20%	0%	30%	0%	0%	0%	4%	22%
EDU2	Post	A	30%	0%	80%	0%	0%	0%	10%	33%
EDU2	Post	A	40%	0%	100%	0%	0%	0%	11%	44%
EDU2	Post	A	50%	0%	100%	0%	0%	0%	23%	55%
EDU2	Post	A	60%	0%	100%	0%	0%	0%	34%	65%
EDU2	Post	A	70%	0%	100%	0%	0%	0%	45%	75%
EDU2	Post	A	80%	0%	100%	4%	4%	4%	56%	85%
EDU2	Post	A	90%	5%	100%	10%	10%	10%	68%	94%
EDU2	Post	A	100%	15%	100%	25%	25%	25%	80%	100%
EDU2	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
EDU2	Pre	CA	10%	0%	20%	0%	0%	0%	2%	11%
EDU2	Pre	CA	20%	0%	100%	1%	1%	1%	9%	20%
EDU2	Pre	CA	30%	0%	100%	3%	3%	3%	16%	30%
EDU2	Pre	CA	40%	0%	100%	5%	5%	5%	23%	40%
EDU2	Pre	CA	50%	0%	100%	8%	8%	8%	31%	50%
EDU2	Pre	CA	60%	4%	100%	12%	12%	12%	40%	59%
EDU2	Pre	CA	70%	9%	100%	16%	16%	16%	51%	68%
EDU2	Pre	CA	80%	14%	100%	19%	19%	19%	60%	77%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
EDU2	Pre	CA	90%	19%	100%	21%	21%	21%	69%	86%
EDU2	Pre	CA	100%	20%	100%	24%	24%	24%	75%	96%
EDU2	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
EDU2	Post	CA	10%	0%	20%	0%	0%	0%	4%	11%
EDU2	Post	CA	20%	0%	100%	1%	1%	1%	11%	21%
EDU2	Post	CA	30%	0%	100%	3%	3%	3%	18%	31%
EDU2	Post	CA	40%	0%	100%	5%	5%	5%	23%	42%
EDU2	Post	CA	50%	0%	100%	8%	8%	8%	34%	52%
EDU2	Post	CA	60%	4%	100%	12%	12%	12%	44%	61%
EDU2	Post	CA	70%	9%	100%	16%	16%	16%	53%	70%
EDU2	Post	CA	80%	14%	100%	19%	19%	19%	63%	80%
EDU2	Post	CA	90%	19%	100%	21%	21%	21%	69%	90%
EDU2	Post	CA	100%	21%	100%	24%	24%	24%	75%	100%
Wood	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
Wood	Pre	A	10%	0%	10%	0%	0%	0%	1%	14%
Wood	Pre	A	20%	0%	30%	0%	0%	0%	3%	27%
Wood	Pre	A	30%	0%	80%	0%	0%	0%	5%	40%
Wood	Pre	A	40%	0%	100%	0%	0%	0%	5%	54%
Wood	Pre	A	50%	0%	100%	0%	0%	0%	8%	68%
Wood	Pre	A	60%	0%	100%	0%	0%	0%	11%	81%
Wood	Pre	A	70%	0%	100%	0%	0%	0%	25%	91%
Wood	Pre	A	80%	0%	100%	6%	6%	6%	48%	97%
Wood	Pre	A	90%	6%	100%	13%	13%	13%	74%	100%
Wood	Pre	A	100%	15%	100%	29%	29%	29%	100%	100%
Wood	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
Wood	Post	A	10%	0%	10%	0%	0%	0%	1%	15%
Wood	Post	A	20%	0%	30%	0%	0%	0%	3%	29%
Wood	Post	A	30%	0%	80%	0%	0%	0%	6%	43%
Wood	Post	A	40%	0%	100%	0%	0%	0%	9%	57%
Wood	Post	A	50%	0%	100%	0%	0%	0%	14%	70%
Wood	Post	A	60%	0%	100%	0%	0%	0%	24%	82%
Wood	Post	A	70%	0%	100%	0%	0%	0%	31%	95%
Wood	Post	A	80%	0%	100%	11%	11%	11%	55%	100%
Wood	Post	A	90%	6%	100%	20%	20%	20%	88%	100%
Wood	Post	A	100%	25%	100%	40%	40%	40%	100%	100%
Wood	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
Wood	Pre	CA	10%	0%	20%	0%	0%	0%	10%	12%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
Wood	Pre	CA	20%	0%	100%	1%	1%	1%	18%	22%
Wood	Pre	CA	30%	0%	100%	6%	6%	6%	25%	32%
Wood	Pre	CA	40%	0%	100%	9%	9%	9%	31%	44%
Wood	Pre	CA	50%	0%	100%	13%	13%	13%	41%	54%
Wood	Pre	CA	60%	3%	100%	21%	21%	21%	49%	62%
Wood	Pre	CA	70%	9%	100%	29%	29%	29%	56%	71%
Wood	Pre	CA	80%	16%	100%	36%	36%	36%	60%	81%
Wood	Pre	CA	90%	22%	100%	42%	42%	42%	69%	90%
Wood	Pre	CA	100%	27%	100%	51%	51%	51%	70%	100%
Wood	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
Wood	Post	CA	10%	0%	20%	0%	0%	0%	10%	12%
Wood	Post	CA	20%	0%	100%	1%	1%	1%	20%	22%
Wood	Post	CA	30%	0%	100%	6%	6%	6%	27%	34%
Wood	Post	CA	40%	0%	100%	9%	9%	9%	33%	46%
Wood	Post	CA	50%	0%	100%	13%	13%	13%	44%	56%
Wood	Post	CA	60%	3%	100%	21%	21%	21%	57%	64%
Wood	Post	CA	70%	9%	100%	29%	29%	29%	62%	74%
Wood	Post	CA	80%	16%	100%	36%	36%	36%	69%	83%
Wood	Post	CA	90%	22%	100%	42%	42%	42%	75%	92%
Wood	Post	CA	100%	27%	100%	51%	51%	51%	85%	100%
Steel	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
Steel	Pre	A	10%	0%	0%	0%	0%	0%	1%	12%
Steel	Pre	A	20%	0%	0%	0%	0%	0%	3%	24%
Steel	Pre	A	30%	0%	0%	0%	0%	0%	5%	35%
Steel	Pre	A	40%	0%	0%	0%	0%	0%	5%	48%
Steel	Pre	A	50%	0%	0%	0%	0%	0%	8%	59%
Steel	Pre	A	60%	0%	0%	0%	0%	0%	11%	71%
Steel	Pre	A	70%	0%	0%	0%	0%	0%	26%	79%
Steel	Pre	A	80%	0%	0%	6%	6%	6%	51%	84%
Steel	Pre	A	90%	8%	0%	14%	14%	14%	66%	91%
Steel	Pre	A	100%	16%	0%	21%	21%	21%	70%	100%
Steel	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
Steel	Post	A	10%	0%	0%	0%	0%	0%	1%	13%
Steel	Post	A	20%	0%	0%	0%	0%	0%	2%	25%
Steel	Post	A	30%	0%	0%	0%	0%	0%	5%	37%
Steel	Post	A	40%	0%	0%	0%	0%	0%	6%	49%
Steel	Post	A	50%	0%	0%	0%	0%	0%	12%	61%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
Steel	Post	A	60%	0%	0%	0%	0%	0%	31%	69%
Steel	Post	A	70%	0%	0%	0%	0%	0%	42%	79%
Steel	Post	A	80%	0%	0%	10%	10%	10%	68%	83%
Steel	Post	A	90%	7%	0%	17%	17%	17%	86%	90%
Steel	Post	A	100%	15%	0%	20%	20%	20%	88%	100%
Steel	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
Steel	Pre	CA	10%	0%	0%	0%	0%	0%	9%	10%
Steel	Pre	CA	20%	0%	0%	1%	1%	1%	15%	21%
Steel	Pre	CA	30%	0%	0%	3%	3%	3%	24%	30%
Steel	Pre	CA	40%	0%	0%	7%	7%	7%	33%	40%
Steel	Pre	CA	50%	0%	0%	11%	11%	11%	42%	49%
Steel	Pre	CA	60%	4%	0%	16%	16%	16%	51%	58%
Steel	Pre	CA	70%	7%	0%	21%	21%	21%	60%	66%
Steel	Pre	CA	80%	11%	0%	27%	27%	27%	69%	75%
Steel	Pre	CA	90%	16%	0%	31%	31%	31%	78%	84%
Steel	Pre	CA	100%	21%	0%	38%	38%	38%	86%	92%
Steel	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
Steel	Post	CA	10%	0%	0%	0%	0%	0%	9%	11%
Steel	Post	CA	20%	0%	0%	1%	1%	1%	15%	22%
Steel	Post	CA	30%	0%	0%	3%	3%	3%	24%	32%
Steel	Post	CA	40%	0%	0%	7%	7%	7%	33%	42%
Steel	Post	CA	50%	0%	0%	11%	11%	11%	42%	52%
Steel	Post	CA	60%	4%	0%	16%	16%	16%	51%	61%
Steel	Post	CA	70%	7%	0%	21%	21%	21%	60%	70%
Steel	Post	CA	80%	11%	0%	27%	27%	27%	69%	79%
Steel	Post	CA	90%	16%	0%	31%	31%	31%	78%	88%
Steel	Post	CA	100%	21%	0%	38%	38%	38%	86%	96%
Concrete	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
Concrete	Pre	A	10%	0%	0%	0%	0%	0%	1%	12%
Concrete	Pre	A	20%	0%	0%	0%	0%	0%	3%	24%
Concrete	Pre	A	30%	0%	0%	0%	0%	0%	5%	35%
Concrete	Pre	A	40%	0%	0%	0%	0%	0%	5%	48%
Concrete	Pre	A	50%	0%	0%	0%	0%	0%	8%	59%
Concrete	Pre	A	60%	0%	0%	0%	0%	0%	11%	71%
Concrete	Pre	A	70%	0%	0%	0%	0%	0%	26%	79%
Concrete	Pre	A	80%	0%	0%	2%	2%	2%	51%	85%
Concrete	Pre	A	90%	3%	0%	8%	8%	8%	66%	92%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
Concrete	Pre	A	100%	8%	0%	13%	13%	13%	79%	100%
Concrete	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
Concrete	Post	A	10%	0%	0%	0%	0%	0%	1%	13%
Concrete	Post	A	20%	0%	0%	0%	0%	0%	3%	26%
Concrete	Post	A	30%	0%	0%	0%	0%	0%	6%	38%
Concrete	Post	A	40%	0%	0%	0%	0%	0%	7%	51%
Concrete	Post	A	50%	0%	0%	0%	0%	0%	15%	63%
Concrete	Post	A	60%	0%	0%	0%	0%	0%	39%	72%
Concrete	Post	A	70%	0%	0%	0%	0%	0%	54%	82%
Concrete	Post	A	80%	0%	0%	3%	3%	3%	79%	90%
Concrete	Post	A	90%	2%	0%	8%	8%	8%	87%	100%
Concrete	Post	A	100%	25%	0%	30%	30%	30%	100%	100%
Concrete	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
Concrete	Pre	CA	10%	0%	0%	0%	0%	0%	8%	10%
Concrete	Pre	CA	20%	0%	0%	1%	1%	1%	17%	20%
Concrete	Pre	CA	30%	0%	0%	3%	3%	3%	26%	30%
Concrete	Pre	CA	40%	0%	0%	6%	6%	6%	33%	40%
Concrete	Pre	CA	50%	0%	0%	11%	11%	11%	41%	49%
Concrete	Pre	CA	60%	1%	0%	15%	15%	15%	50%	58%
Concrete	Pre	CA	70%	3%	0%	19%	19%	19%	59%	67%
Concrete	Pre	CA	80%	7%	0%	23%	23%	23%	65%	77%
Concrete	Pre	CA	90%	11%	0%	26%	26%	26%	73%	86%
Concrete	Pre	CA	100%	15%	0%	29%	29%	29%	74%	97%
Concrete	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
Concrete	Post	CA	10%	0%	0%	0%	0%	0%	8%	11%
Concrete	Post	CA	20%	0%	0%	1%	1%	1%	17%	23%
Concrete	Post	CA	30%	0%	0%	3%	3%	3%	26%	34%
Concrete	Post	CA	40%	0%	0%	6%	6%	6%	33%	45%
Concrete	Post	CA	50%	0%	0%	11%	11%	11%	41%	55%
Concrete	Post	CA	60%	1%	0%	15%	15%	15%	50%	65%
Concrete	Post	CA	70%	3%	0%	19%	19%	19%	59%	75%
Concrete	Post	CA	80%	7%	0%	23%	23%	23%	65%	86%
Concrete	Post	CA	90%	11%	0%	26%	26%	26%	73%	96%
Concrete	Post	CA	100%	25%	0%	35%	35%	35%	94%	100%
Masonry	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
Masonry	Pre	A	10%	0%	10%	0%	0%	0%	0%	15%
Masonry	Pre	A	20%	0%	30%	0%	0%	0%	3%	29%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
Masonry	Pre	A	30%	0%	80%	0%	0%	0%	4%	43%
Masonry	Pre	A	40%	0%	100%	0%	0%	0%	4%	58%
Masonry	Pre	A	50%	0%	100%	0%	0%	0%	7%	72%
Masonry	Pre	A	60%	0%	100%	0%	0%	0%	9%	86%
Masonry	Pre	A	70%	0%	100%	0%	0%	0%	22%	97%
Masonry	Pre	A	80%	0%	100%	15%	15%	15%	38%	100%
Masonry	Pre	A	90%	6%	100%	26%	26%	26%	68%	100%
Masonry	Pre	A	100%	16%	100%	34%	34%	34%	100%	100%
Masonry	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
Masonry	Post	A	10%	0%	10%	0%	0%	0%	0%	15%
Masonry	Post	A	20%	0%	30%	0%	0%	0%	2%	30%
Masonry	Post	A	30%	0%	80%	0%	0%	0%	4%	44%
Masonry	Post	A	40%	0%	100%	0%	0%	0%	5%	59%
Masonry	Post	A	50%	0%	100%	0%	0%	0%	10%	73%
Masonry	Post	A	60%	0%	100%	0%	0%	0%	26%	84%
Masonry	Post	A	70%	0%	100%	0%	0%	0%	36%	96%
Masonry	Post	A	80%	0%	100%	15%	15%	15%	55%	100%
Masonry	Post	A	90%	5%	100%	34%	34%	34%	74%	100%
Masonry	Post	A	100%	25%	100%	44%	44%	44%	100%	100%
Masonry	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
Masonry	Pre	CA	10%	0%	20%	0%	0%	0%	1%	15%
Masonry	Pre	CA	20%	0%	100%	1%	1%	1%	4%	27%
Masonry	Pre	CA	30%	0%	100%	3%	3%	3%	7%	41%
Masonry	Pre	CA	40%	0%	100%	5%	5%	5%	13%	53%
Masonry	Pre	CA	50%	0%	100%	8%	8%	8%	33%	59%
Masonry	Pre	CA	60%	1%	100%	13%	13%	13%	47%	68%
Masonry	Pre	CA	70%	2%	100%	17%	17%	17%	58%	78%
Masonry	Pre	CA	80%	4%	100%	21%	21%	21%	67%	88%
Masonry	Pre	CA	90%	6%	100%	25%	25%	25%	75%	98%
Masonry	Pre	CA	100%	17%	100%	31%	31%	31%	100%	100%
Masonry	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
Masonry	Post	CA	10%	0%	20%	0%	0%	0%	8%	13%
Masonry	Post	CA	20%	0%	100%	1%	1%	1%	12%	26%
Masonry	Post	CA	30%	0%	100%	3%	3%	3%	20%	37%
Masonry	Post	CA	40%	0%	100%	5%	5%	5%	29%	49%
Masonry	Post	CA	50%	0%	100%	8%	8%	8%	37%	61%
Masonry	Post	CA	60%	1%	100%	13%	13%	13%	44%	73%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
Masonry	Post	CA	70%	3%	100%	17%	17%	17%	53%	84%
Masonry	Post	CA	80%	5%	100%	21%	21%	21%	61%	95%
Masonry	Post	CA	90%	10%	100%	30%	30%	30%	79%	100%
Masonry	Post	CA	100%	24%	100%	45%	45%	45%	100%	100%
MH	Pre	A	0%	0%	0%	0%	0%	0%	0%	0%
MH	Pre	A	10%	0%	9%	0%	0%	0%	3%	13%
MH	Pre	A	20%	0%	35%	0%	0%	0%	4%	27%
MH	Pre	A	30%	0%	60%	0%	0%	0%	8%	39%
MH	Pre	A	40%	0%	79%	0%	0%	0%	16%	51%
MH	Pre	A	50%	0%	100%	0%	0%	0%	23%	62%
MH	Pre	A	60%	0%	100%	0%	0%	0%	28%	75%
MH	Pre	A	70%	0%	100%	0%	0%	0%	35%	88%
MH	Pre	A	80%	2%	100%	2%	2%	2%	53%	95%
MH	Pre	A	90%	8%	100%	8%	8%	8%	74%	100%
MH	Pre	A	100%	12%	100%	20%	20%	20%	100%	100%
MH	Post	A	0%	0%	0%	0%	0%	0%	0%	0%
MH	Post	A	10%	0%	6%	0%	0%	0%	7%	12%
MH	Post	A	20%	0%	35%	0%	0%	0%	10%	25%
MH	Post	A	30%	0%	60%	0%	0%	0%	18%	37%
MH	Post	A	40%	0%	80%	0%	0%	0%	22%	50%
MH	Post	A	50%	0%	100%	0%	0%	0%	30%	62%
MH	Post	A	60%	0%	100%	0%	0%	0%	36%	75%
MH	Post	A	70%	0%	100%	0%	0%	0%	42%	88%
MH	Post	A	80%	2%	100%	3%	3%	3%	50%	99%
MH	Post	A	90%	9%	100%	9%	9%	9%	79%	100%
MH	Post	A	100%	21%	100%	24%	24%	24%	100%	100%
MH	Pre	CA	0%	0%	0%	0%	0%	0%	0%	0%
MH	Pre	CA	10%	0%	9%	0%	0%	0%	7%	12%
MH	Pre	CA	20%	0%	35%	0%	0%	0%	10%	25%
MH	Pre	CA	30%	0%	60%	0%	0%	0%	21%	35%
MH	Pre	CA	40%	0%	90%	1%	1%	1%	28%	46%
MH	Pre	CA	50%	0%	100%	2%	2%	2%	34%	57%
MH	Pre	CA	60%	0%	100%	4%	4%	4%	42%	69%
MH	Pre	CA	70%	1%	100%	8%	8%	8%	48%	80%
MH	Pre	CA	80%	3%	100%	10%	10%	10%	57%	91%
MH	Pre	CA	90%	10%	100%	14%	14%	14%	69%	100%
MH	Pre	CA	100%	16%	100%	20%	20%	20%	100%	100%

SOCC or GBT	Pre- or Post-FIRM	Zone	Building Loss	Foundation	Below First Floor	Structure Frame	Roof Covering	Roof Framing	Exterior Walls	Interiors
MH	Post	CA	0%	0%	0%	0%	0%	0%	0%	0%
MH	Post	CA	10%	0%	3%	0%	0%	0%	7%	12%
MH	Post	CA	20%	0%	40%	0%	0%	0%	15%	23%
MH	Post	CA	30%	0%	100%	0%	0%	0%	25%	33%
MH	Post	CA	40%	0%	100%	1%	1%	1%	31%	46%
MH	Post	CA	50%	0%	100%	2%	2%	2%	44%	56%
MH	Post	CA	60%	0%	100%	4%	4%	4%	55%	66%
MH	Post	CA	70%	1%	100%	8%	8%	8%	60%	78%
MH	Post	CA	80%	2%	100%	10%	10%	10%	68%	90%
MH	Post	CA	90%	8%	100%	14%	14%	14%	77%	100%
MH	Post	CA	100%	19%	100%	25%	25%	25%	100%	100%

Chapter 5. Direct Physical Damage - General Building Stock

5.1 Introduction

This chapter describes methods for determining building damage to the general building stock associated with riverine and coastal flooding, as well as methods for estimating damage related to floodwater velocity. The flowchart of the overall methodology, highlighting the building damage component and showing its relationship to other components, is shown in Figure 5.1.

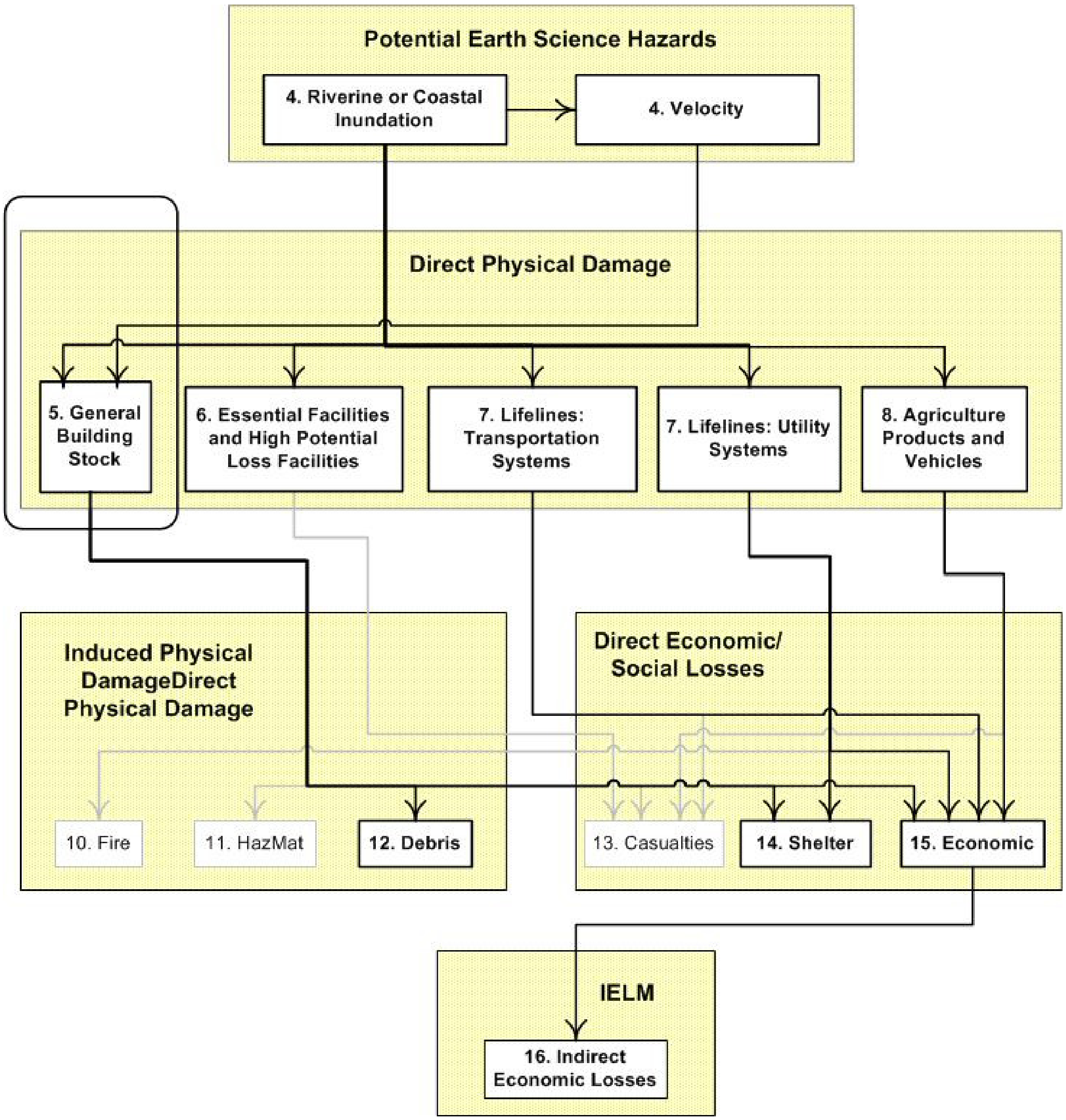

Figure 5.1 Building Damage Relationship to Other Components of the Methodology

5.1.1 Scope

This chapter focuses on the loss estimation process as defined by Hazus for the Flood Model. The scope of this chapter includes development of methods for estimation of flood damage to buildings and contents given knowledge of the occupancy and its typical configuration (e.g., foundation type and assumed first floor elevation), and an estimate of the depth of flooding throughout the study area. The extent of damage to the building and its contents is estimated directly from the depth of flooding by the application of a depth-damage curve associated with each occupancy class. Building parameters related most directly to flood damage are discussed in Section 5.2

Section 5.3 discusses the various sources of residential and non-residential depth-damage curves from which the Hazus damage function library was developed. This section also identifies the default damage curve associated with each occupancy class. Section 5.4 provides flood damage models for velocity, Section 5.5 describes models for damage reduction resulting from warning, and Section 5.6 addresses the Flood Models treatment of uncertainty. Finally, Section 5.7 provides guidance for expert users, including a discussion of estimation of benefits associated with flooding and natural floodplains.

5.1.2 Input Requirements and Output Information

Input required to estimate building damage using depth damage curves includes the following two items:

- Occupancy class, foundation type, and assumed first floor elevation, typically related to the development era (e.g., pre-FIRM or post-FIRM)
- Depth of flooding throughout the census block

The “output” from a depth-damage curve is an estimate of the damage to the building(s) at a given depth, expressed as a percentage of the replacement cost of the structure(s), and later translated into dollars using the Valuation module (described in Chapter 14).

For the analysis of the general building stock in a given census block, the Flood Model assumes that the inventory is evenly distributed throughout the census block, and area-weighted estimates of damage (rather than depth) are utilized to reflect the variation in flood depth throughout the block. (Area weighted depths are not used, as many of the depth-damage curves are non-linear). While the depth damage curves may be applied to a single building as well as to all buildings of given type, they are more reliable as predictors of damage for large, rather than small, population groups. The user is advised to use and report the results with the appropriate amount of caution.

5.1.3 Form of Damage Functions

As noted, flood damage functions are in the form of depth-damage curves, relating depth of flooding (in feet), as measured from the top of the first finished floor, to damage expressed as a percent of replacement cost.

Depth-damage functions are provided separately for buildings and for contents. For flood loss analyses, buildings are defined to include both the structural (load-bearing) system, as well as architectural, mechanical and electrical components, and building finishes. (This varies from the earthquake loss analysis definition wherein the structural components are limited to the load-bearing system, and the non-load-bearing systems, such as architectural, mechanical, electrical, and finishes are defined as “non-structural”.)

5.2 Building Parameters Related to Flood Damage

Unlike the earthquake model where the model building type, design level and quality of construction all play a critical role in the structure’s ability to resist earthquake damage, these features do not play a major role in damage resistance to flooding. 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, it is unlikely that a building will suffer structural failure in a flood. (Structural failure should be distinguished, however, from suffering substantial damage, wherein the damage due to inundation exceeds 50% of the structure’s total replacement cost and the building is considered a total loss.) 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.

5.2.1 Building Age

Building age is a key parameter for estimating expected flood damage. Age is an issue because building codes (and expected building performance) change over time, and because development regulations change when a community enters the National Flood Insurance Program (NFIP). For example, if half of the total building floor area of a census block was developed prior to entrance in the NFIP, then it can be assumed that this half of the exposure will be more susceptible to damage resulting from a 100-year flood event.

To address the issue of age, both sources of the Hazus Flood Model’s inventory data (U.S. Census and D&B, see Chapter 3) were reviewed for content of this data. The Census data does provide a range of year of construction at the Block Group level. The ranges are in decades starting with pre-1939 structures and including every decade up to 1990, as seen in Table 3.8. It can be assumed that typical development practices will result in the homogenous development of all blocks within a single block group. In other words, the commercial/industrial development and the residential development throughout the block group are assumed to occur concurrently. It is therefore possible to distribute the census block group age distribution throughout the constituent census blocks, as well as to assume that this distribution is applicable to non-residential development.

5.2.2 Foundation Type and First Floor Elevation

Because first floor elevation (as determined from foundation type) is another key parameter for the estimation of flood damage, information on foundation types for the general building stock is required. Within the Hazus Flood Model, all census blocks have been assigned a code identifying the primary local flood hazard type as well as a foundation mapping scheme. The rules for the census block mapping schemes are as follows:

- The default value for all census blocks is "R" (riverine).
- Those census blocks that are immediately adjacent to the Great Lakes have been coded as "L" for Great Lakes.
- Those census blocks that are within the FEMA Q3's for coastal regions will be coded as "C" (coastal).
- For those blocks with both riverine and coastal hazards, it is assumed that the coastal foundation practices will dominate, since the building codes for coastal are more stringent.

5.2.3 Model Building Types

Although most flood depth-damage functions are independent of structural system or construction material, the Hazus inventory database includes Model Building Type as a basic parameter because of the importance of structure type to the estimation of earthquake and hurricane damage. Within the Flood Model, the Model Building Types are a simplified version of the ones used by the Hazus Earthquake Model, and are listed in Table 5.1.

Table 5.1 Model Building Types

No.	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
1	Wood	Wood (light frame and commercial and industrial)		All	1 to 2	14 to 24
2	Steel	Steel frame structures including those with infill walls or concrete shear walls	Low-rise Mid-rise High-rise	1-3 4-7 8+	2 5 13	24 60 156
3	Concrete	Concrete frame or shear wall structures including tilt-up, precast, and infill walls	Low-rise Mid-rise High-rise	1-3 4-7 8+	2 5 12	20 50 120
4	Masonry	All structures with masonry bearing walls	Low-rise Mid-rise High-rise	1-3 4-7 8+	2 5 12	20 50 120
5	MH	Mobile Homes		All	1	10

A general discussion of the five (5) structural systems is provided in the following sections.

Wood (W)

Within the Hazus model, there are two general types of wood structures: 1) small, multi-family or single family dwellings of not more than 5,000 square feet of floor area; and 2) large multi-family, commercial, or industrial buildings of more than 5,000 square feet of floor area. The essential structural feature of the smaller (5,000 square feet or less) buildings is repetitive framing by wood rafters or joists on wood stud walls. These buildings may have masonry chimneys and may be partially or fully covered with masonry veneer. Most of these buildings, especially the single-family residences, are not engineered but are constructed in accordance with "conventional construction" provisions of building codes. The floors and roofs may be sheathed with sawn lumber, plywood or fiberboard sheathing. Walls are covered with boards, stucco, plaster, plywood, gypsum board, particleboard, or fiberboard, or a combination of several materials. Interior partition walls are usually covered with plaster or gypsum board.

The larger buildings (floor areas greater than 5,000 square feet) have framing systems consisting of beams or major horizontal members spanning between columns supporting lighter floor joists or rafters. These horizontal members may be glue-laminated wood, solid-sawn wood beams, wood or steel trusses, or steel beams. The exterior walls are covered with plywood, stucco, plaster, other types of paneling, or a combination of materials. The interior surfaces of the walls and interior partitions usually are covered with gypsum board or plaster.

Steel (S)

Steel buildings are usually framed with a series of steel girders spanning between steel columns supporting beams and various forms of wood or concrete floors and roof. Exterior walls are constructed of steel siding, window walls, or cladding panels, but may include cast-in-place concrete shear walls or unreinforced masonry infill walls. If ceilings are used in these buildings they are usually suspended acoustical tiles. These buildings most commonly house offices, warehouses, commercial, or industrial occupancies.

Concrete (C)

Concrete buildings are those where the structural frames and/or exterior walls are made of reinforced concrete, either cast-in-place, pre-cast tilt-up, or pre-cast elements. Interior framing can be steel, wood, concrete, pre-cast, or any combination. These buildings are most commonly used for office, warehouse, commercial, or industrial occupancies. Interior finishes are usually concrete, gypsum board, or plaster.

Masonry (M)

Masonry buildings are those where the exterior walls are masonry, either reinforced or unreinforced. These buildings are most commonly used for office, warehouse, commercial, industrial, or multi-family occupancies. Interior finishes are usually, concrete, gypsum board, or plaster.

Mobile Homes (MH)

These are prefabricated housing units that are trucked to the site and then placed on isolated piers, jack stands, or masonry block foundations (usually without any positive anchorage). Floors and roofs of mobile homes usually are constructed with plywood and outside surfaces are covered with sheet metal.

5.3 Building and Contents Damage Due to Flooding

The Hazus Flood Model methodology for estimating direct physical damage (e.g., repair costs) to the general building stock is fairly simple and straightforward. For a given census block, each occupancy class (and foundation type) has an appropriate damage function assigned to it (i.e., 1-story, no basement), and computed water depths are used to determine the associated percent damage. This percent damage is multiplied by the full (and depreciated) replacement value of the occupancy class in question to produce an estimate of total full (and depreciated) dollar loss. The “damage states” are derived from the percent damage (e.g., 1-10% damage is considered slight, 11-50% damage is considered moderate, and 51-100% is considered substantial damage. In addition to the library of damage functions (including FIA “credibility-weighted” damage functions, as well as various USACE District functions), inventory data on foundation type and first floor elevation, the presence of basements and estimates of the number of stories are required (see Chapter 3 for more discussion of inventory parameters).

5.3.1 Compilation of Depth-Damage Functions

Estimation of direct damage to the general building stock (percent damage to structures and their contents) is accomplished through the use of readily-available depth-damage curves, compiled from a variety of sources including the Federal Insurance and Mitigation Administration (FIMA) FIA[1] “credibility weighted” depth-damage curves, and selected curves developed by the U.S. Army Corps of Engineers (USACE), and the USACE Institute for Water Resources (USACE IWR). Functions have been compiled for the USACE Chicago, Galveston, New Orleans, New York, Philadelphia, St. Paul, and Wilmington Districts. While default damage functions have been selected for each occupancy class, all referenced damage functions have been incorporated into the damage function library housed within the software and are available for user review and selection.

5.3.1.1 FIMA (FIA) Residential Depth-Damage Curves - Riverine

FIMA (formerly known as the FIA) is responsible for administering the National Flood Insurance Program (NFIP). FIA has created national depth-damage curves that are used in the actuarial rate setting process. The original depth-damage functions, developed in 1970 and 1973,

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[1] During recent re-organizations at the FEMA, the Federal Insurance Administration (FIA) and the Mitigation Directorate were combined into a single entity called the Federal Insurance and Mitigation Administration (FIMA). However, because the damage functions were published as the FIA credibility-weighted functions, they will continue to be referred as FIA depth damage functions.

are referred to as "theoretical base tables." Some of the information used to develop the initial curves came from post-flood surveys conducted by the Corps of Engineers.

With time, a wealth of damage and loss data has been collected as part of the flood insurance claims process. Losses include both structure and contents losses, and are determined relative to actual cash value (depreciated replacement cost). The majority of claims are for residential structures. The FIA damage functions are updated annually based on this damage data, as part of the flood insurance rate review process. A statistical "credibility" analysis is used to combine the "theoretical base tables" with the "rate review" results. When sufficient claims exist to provide statistical confidence in the results, the depth-damage relationship is based exclusively on the claims data. When claims data are insufficient, the claims data and base tables are combined using a weighting process. The result is two sets of curves: pure summaries of claims data, and credibility analyses combining available claims data into weighted curves.

The "Depth Damage" report prepared by the NFIP Actuarial Information System (1998)[2] indicates that actual depth-damage claims data are available for 10 categories of structures. Each category, along with the historic number of claims for the period of 1978 – 1998 are given below.

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

According to the NFIP Actuarial Information System "Credibility and Weighting" report (1998), credibility analyses and the resulting weighted curves are available for six structure categories. These categories represent aggregations of the original ten categories:

1. One floor, no basement
2. Two or more floors, no basement
3. Two or more floors, with basement
4. Split-level, no basement
5. Split-level, with basement
6. Mobile home

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

Categories with fewer documented claims will rely more heavily on the theoretical base tables. Figure 5.2 presents the six FIA credibility-weighted damage functions. It should be noted that several of the curves are not continuous. That is, because claims data are often sparse, damage values are not provided for all depths. For use in the Hazus software, 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 function application.

5.3.1.1.1 Modification of FIA Single Family Residential Depth-Damage Curve to Reflect Basement Exclusions

As noted, the FIA claims data and "credibility-weighted" depth-damage curves reflect the limitations of FIA insurance coverage. That is, damage to items not covered by FIA policies (e.g., basement flooring and other finishes) will not be represented in the FIA damage functions. Because the intent of Hazus is to estimate total flood damages regardless of insurance

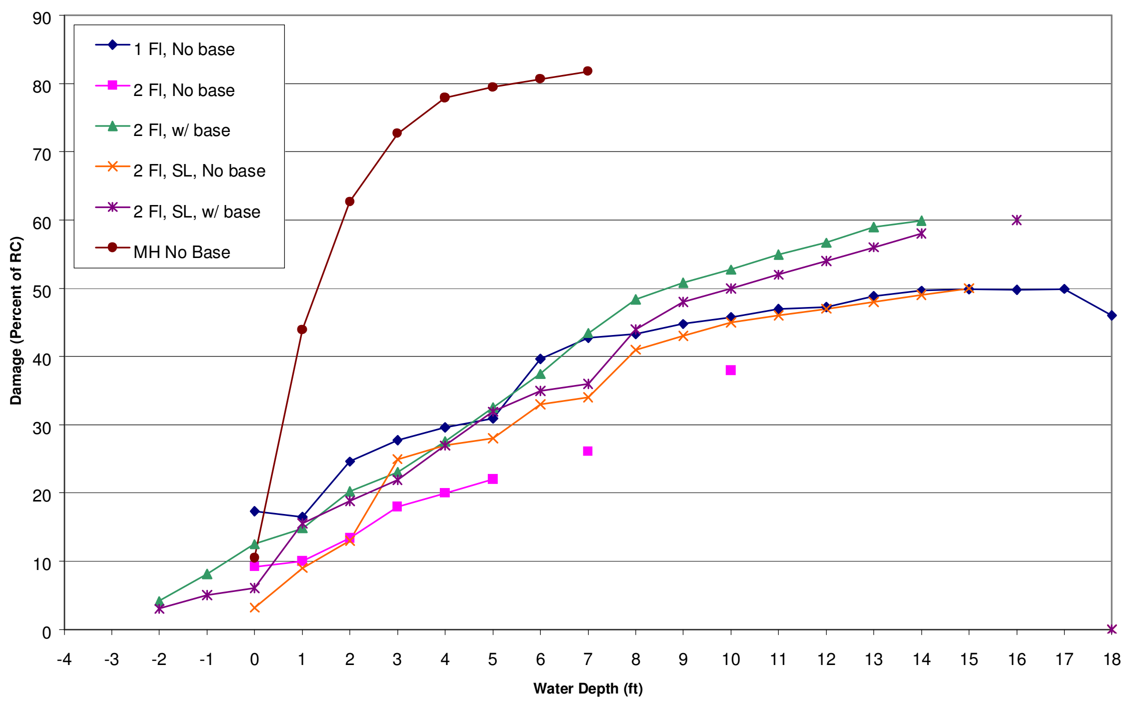

Figure 5.2 FIA Credibility-Weighted Building Depth-Damage Curves as of 12/31/1998

coverage, the damage functions for structures with basements (two-floor, with basement, and split-level with basement) were modified to estimate likely basement losses for use as a default damage function.

As outlined in the NFIP "Dwelling Policy," a number of coverage exclusions apply to basements, as well as to enclosures under elevated structures[3]. Basement exclusions include:

- Personal property (contents)

- Building equipment, machinery, fixtures and components, including finished walls, floors, ceilings and other improvements, except for required utility connections, fiberglass insulation, drywalls and sheetrock walls and ceilings but only to the extent of replacing drywalls and sheetrock walls in an unfinished manner (i.e., nailed to framing but not taped, painted or covered).

- Enclosure exclusions for elevated Post-FIRM buildings include:

- Personal property (contents)

- Building enclosures, equipment, machinery fixtures and components (except for required utility connections and the footings, foundation, posts, pilings, piers or other foundation walls and anchorage system as required for support of the buildings).

To estimate likely basement damage relative to FIA policy exclusions in basements, a distribution of basement component replacement cost, relative to the total structure replacement cost was required. Residential replacement cost models taken from "Means Square Foot Costs" (Means, 2006) were used to develop the component cost distribution given in Table 5.2. Table 5.2 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 and also assumed to be excluded from coverage.

[3] It should be noted that the FIA V-Zone depth-damage functions reflect full coverage in any enclosures, and therefore do not require adjustment.

Table 5.2 Basement Component Cost Expressed as a Percent of Total Structure Replacement Cost– (two floors total, including the basement, assuming 1600 SF main structure)

	Econ.	Avg.	Custom	Luxury		
Total finished basement cost/SF of main	$14.25	$18.10	$26.10	$32.30		
Total Structure Cost/ SF, including basement	$69.00	$96.88	$125.63	$152.55		
Basement as a % of Total	21%	19%	21%	21%		
	Econ.	**Avg.**	**Custom**	**Luxury**	**Used for Final**	**Excluded**
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%
Total	21%	19%	21%	21%	20%	

Likely flood damage thresholds for basement components were estimated by the project team for two basic conditions: 1) flood water at –4 feet (four feet below the top of the finished ground floor, approximately 4-5 feet of water in the basement, the lowest depth reported by FIA); and 2) flood water at -1 foot (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 feet (four feet below the finished ground floor, approximately 4 feet 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 foot:
  - 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 curve 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 curve. A total of 7% damage was added in at –4 feet, with an additional 4% added in at –1 foot, 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 2/3 of the cost of wall finishes, and in some cases, part of ceiling costs.) The resulting structure damage curve for "two or more floors, with basement" is given in Figure 5.3. Figure 5.4 shows the curves for "split level, with basement."

The resulting curves 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 percent of the 86,236 claims were for structures with water depths less than 0 feet), indicates average damages (FPAVG – average damage amount divided by property value) on the order of 7-15 percent for water depths between –10 and -1 feet, roughly consistent with the proposed curve.

Similarly, contents claims data for a variety of basement structures ranged from about 15 - 40 percent for water depths between –10 and -1 feet. The "contents-residential, first floor only" CWDD curve reaches its maximum of about 60 percent damage at 10 feet of water, as does the "contents-residential, first floor and above" CWDD curve. The difference between these two curves is small, and both are based on a limited number of claims; approximately 57,000 claims contribute to the credibility weighting for the first curve, while only 17,400 claims are available for the second. The majority of claims are for depths of five feet and less, and full credibility (i.e., resulting curve based entirely on claims history) is available only for a depth of 1 foot for the first curve.

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 2-story structures. The resulting contents damage function for 1-story residence reaches its maximum damage of about 91 percent damage at 5 feet of water. At 5 feet, damage to the 2-story structure is 55 percent, and it reaches its maximum of 92.5 percent 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 2-story structure.

This information was used to adjust the FIA "credibility-weighted" depth damage functions 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 2-story structures, the 60/40 first/second-story split was used, resulting in a contents distribution of 33 percent in the basement, 40 percent on the first floor, and 27 percent on the second.

The adjusted contents curve for "two-floor with basement" (resulting from the modification of the "first floor only" FIA curve) is given in Figure 5.5. At –4 feet (the lowest point on the FIA curve), it is assumed that basement contents (33 percent of total contents) are a total loss. The remainder of the curve simply reflects the addition of the basement losses. As shown, the curve reaches its maximum of about 93 percent at 10 feet. To adjust the multi-story curve, the slope of the original curve was applied, using the 33 percent basement damage as the y-intercept. The resulting curve, also shown on Figure 5.5, reaches about 75 percent at 8 feet (total loss of basement and first floor contents), and 100 percent at 13 feet (total loss of all contents when water is about 4 feet above the second floor.

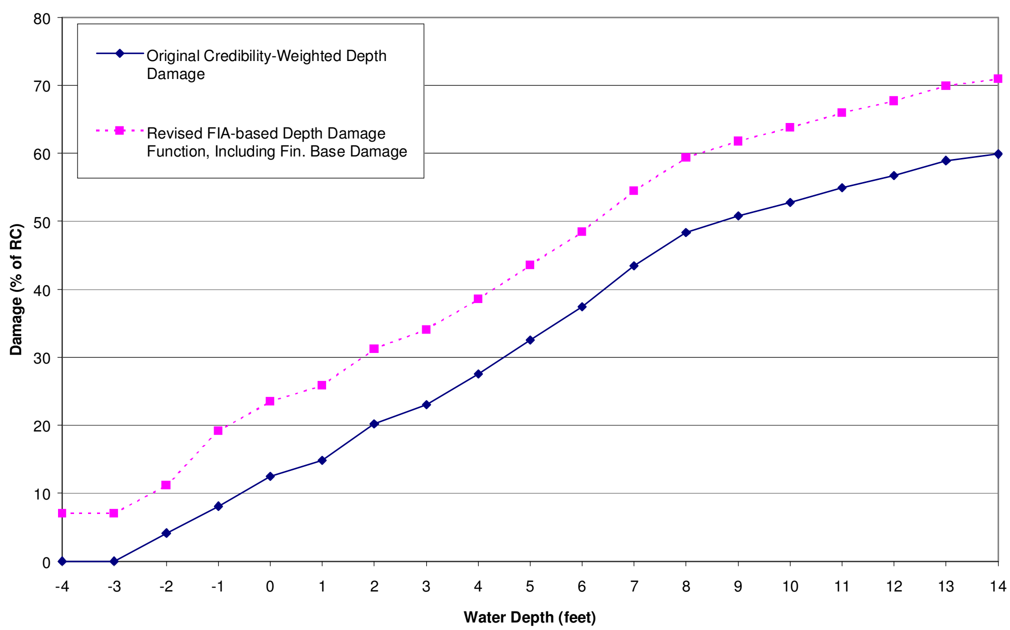

Figure 5.3 FIA-Based Structure Depth-Damage Curve 2 or More Stories, Basement-Modified

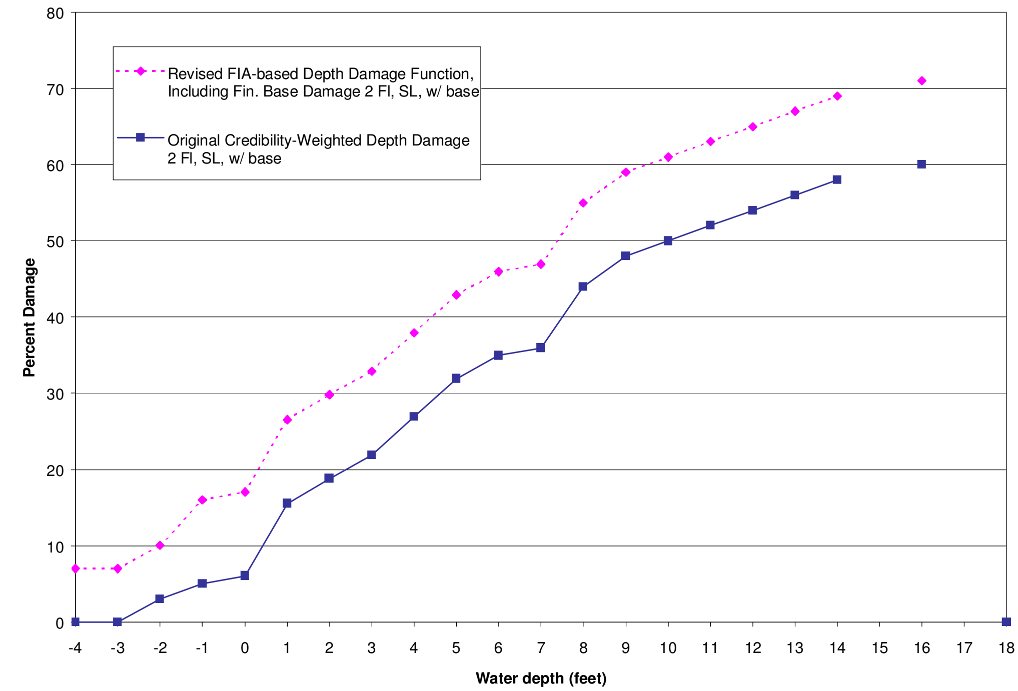

Figure 5.4 FIA-Based Structure Depth-Damage Curve Split Level, Basement-Modified

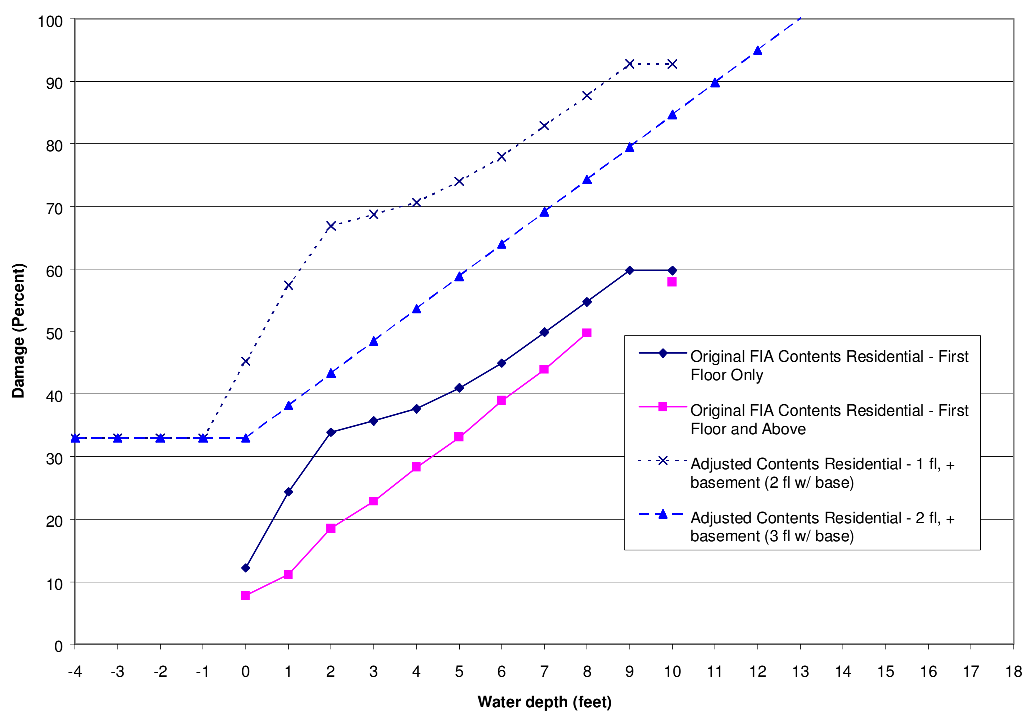

Figure 5.5 FIA-based Residential Contents Damage Curves

5.3.1.2 FIMA (FIA) Residential Depth-Damage Curves – Coastal

In addition to the riverine (non-velocity zone) depth-damage functions, the FIA has developed depth-damage curves appropriate to velocity zones, designated as V-zone curves by the FIA. These curves are applicable to areas subject to three-foot wave action associated with 100-year flood events. Three curves each 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" (H. Leikin, 1987).

5.3.1.3 USACE Depth-Damage Curves (Residential and Non-Residential)

5.3.1.3.1 Chicago District

The 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, resulting in seven curves representing the various ranking combinations. In addition, seven residential damage functions (1-story, 2-story, split-level with and without basement, and mobile home) were also provided.

5.3.1.3.2 Galveston District

The Galveston District has numerous damage functions, including residential, and more than 145 different non-residential flood damage functions (IWR 85-R-5). These non-residential damage functions include damage to the structure, as well as to its inventory and equipment. The damage functions are based on flood damage records, as well as post-event surveys, including surveys following Hurricane Claudette in 1979. The damage curves are currently used by Galveston and other Districts, including Tulsa and Fort Worth, and are applicable to fresh-water 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.

5.3.1.3.3 New Orleans District

The New Orleans District has 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). Depth-damage functions include residential and non-residential structure and contents damage for four types of flooding:

- Hurricane flooding, long duration (one week), salt water
- Hurricane flooding, short duration (one day), salt water

- Riverine or rainfall flooding, long duration (two or three days), freshwater

- Riverine or rainfall flooding, short duration (one day or less), freshwater

Residential structures are classified by number of stories (one, two, or mobile 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, condos, 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 curves typically begin at –1 foot 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.

5.3.1.3.4 New York District

As part of the Passaic River Basin studies, the New York District developed a variety of residential and non-residential structure and contents damage functions, for structures 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.

Residential damage functions include bi-level, cape, colonial, mobile home, split, two-family and other types. Commercial structures are handled with one 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.

5.3.1.3.5 Philadelphia District

The U.S. Army Corps of Engineers Philadelphia District published coastal depth-damage curves as part of a 1991 study entitled "Delaware Coast From Cape Henlopen to Fenwick Island, Delaware; Reconnaissance Study Report." The depth-damage curves consider various structural characteristics, including location (A-zone vs. V-zone), height (1-, 1.5-, and 2-story), foundation (structures on piles and not on piles), and construction material for structure not on piles (wood frame, concrete block, or masonry). The curves were based on "previous studies of similar areas and FIA curves" and predict damage to both structures and contents. However, these studies are not documented and the Corps no longer uses the approach laid out in the Delaware Coast report. As such, the Delaware curves are included herein solely as an example data set, and are not relied upon for the development of Hazus damage evaluation methodology.

5.3.1.3.6 St. Paul District

The St. Paul District has estimated damage to the Grand Forks area as part of a flood control project, as documented in "General Reevaluation Report and Environmental Impact Statement" (1998). The depth-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.

It should be noted that these damage functions are identified as "no basement." For the Corps' Grand Forks application, it appears that the Corps essentially shifted the damage curve to the left for structures with basements, allowing damage to occur at lower water depths.

5.3.1.3.7 Wilmington District

The Wilmington District provided 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 a number of damage functions reflecting erosion. The residential damage functions consider structure size (1-, 1.5-, and 2-story, split-level, and mobile home), and configuration (basement, no basement, high-raised, high-raised with ½ 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, wash-a-teria, and warehouse.

5.3.1.3.8 USACE Institute for Water Resources (IWR)

The USACE Institute for Water Resources (IWR) is working on a compilation project of "past flood damage surveys" with the identified objective of compiling residential and business damage functions and content valuation functions. The outcome of this study will be a set of recommended depth-damage functions for use throughout the Corps (e.g., a national standard). To date, 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.). The IWR recommended structure and contents model for single family residential structures (no basement) is included in the Hazus damage function library.

5.3.1.4 Other Coastal Depth-Damage Functions

The Tampa Bay Regional Planning Council as part of a 1988 contingency planning study developed additional coastal depth-damage functions. Depth-damage curves (or "loss coefficients") based on historic property damage were presented. These relationships consider structure location (A-zone vs. V-zone) and use (single family, multi-family, mobile home, commercial, industrial, and non-residential). No contents damage functions were presented.

5.3.2 Default Structure and Contents Damage Curves

Default curves to estimate structure and contents damage for Level 1 analyses have been selected for each Hazus occupancy class, for conditions of riverine and coastal flooding. These curves are identified in Tables 5.3 and 5.4. It should be noted that the default riverine damage functions for residential structures with basements have been modified from the original FIA relationship (which reflects FIMA (formerly FIA) policy exclusions) to reflect total damage. The modification is documented in Section 5.3.1.1.1.

Table 5.3 Default Damage Functions for Estimation of Structure Damage

Hazus Occ. Class	Flooding Type/Zone	Curve Source	Curve Description
RES1	Riverine/ A- Zone	FIA "credibility-weighted" depth-damage curves (CWDD)	1 floor, no basement 2 floor no basement 2 floor, split level, no basement
	Riverine/ A- Zone	Modified FIA CWDD:	EQE-modified versions of FIA CWDD: 2 floor, w/ basement 2 floor, split level, w/ basement
	Coastal/ V- Zone	FIA V-Zone Damage function	Combined curve (average of with and without obstruction)
	Coastal/ A- Zone	FIA V-Zone Damage function	Combined curve (average of with and without obstruction)
RES2	All Zones	FIA CWDD	Mobile home
RES3	All Zones	USACE – Galveston*	Apartment

Notes:

* *All depth-damage curves developed by the USACE Galveston District are assumed to represent structures with no basement.*

Table 5.3 Default Damage Functions for Estimation of Structure Damage (Continued)

Hazus Occ. Class	Flooding Type/Zone	Curve Source	Curve Description
RES4	All Zones	USACE – Galveston	Average of “Hotel” and “Motel Unit”
RES5	All Zones		No RES5 curves available – use RES6
RES6	All Zones	USACE – Galveston	Nursing Home
COM1	All Zones	USACE – Galveston	Average of 47 retail classes
COM2	All Zones	USACE – Galveston	Average of 22 wholesale/warehouse classes
COM3	All Zones	USACE – Galveston	Average of 16 personal and repair services classes
COM4	All Zones	USACE – Galveston	Average of “Business” and “Office”
COM5	All Zones	USACE – Galveston	Bank
COM6	All Zones	USACE – Galveston	Hospital
COM7	All Zones	USACE – Galveston	Average of 4 medical office/clinic classes
COM8	All Zones	USACE – Galveston	Average of 15 entertainment & recreation classes
COM9	All Zones	USACE – Galveston	Average of 3 theatre classes
COM10	All Zones	USACE – Galveston	Garage
IND1	All Zones	USACE – Galveston	Average of 16 heavy industrial classes
IND2	All Zones	USACE – Galveston	Average of 14 light industrial classes
IND3	All Zones	USACE – Galveston	Average of 10 food/drug/chemical classes
IND4	All Zones	USACE – Galveston	Average of 4 metals/mineral processing classes
IND5	All Zones		No IND5 curves available – use IND3
IND6	All Zones	USACE – Galveston	Average of 8 construction classes
AGR1	All Zones	USACE – Galveston	Average of 3 agricultural classes
REL1	All Zones	USACE – Galveston	Church
GOV1	All Zones	USACE – Galveston	Average of “City Hall” and “Post Office”
GOV2	All Zones	USACE – Galveston	Average of “Police Station” and “Fire Station”
EDU1	All Zones	USACE – Galveston	Average of “School” and “Library”
EDU2	All Zones	USACE – Galveston	Average of “School” and “Library”

Notes:

* *All depth-damage curves developed by the USACE Galveston District are assumed to represent structures with no basement.*

Table 5.4 Default Damage Functions for Estimation of Contents Damage

Hazus Occ. Class	Flooding Type/Zone	Curve Source	Curve Description
RES1	Riverine/ A- Zone & Coastal/ A- Zone	FIA "credibility-weighted" depth-damage curves (CWDD)	Residential contents – 1st floor only (for 1 floor, no basement) Residential contents – 1st floor and above(for 2 floor no basement, and 2 floor, split level, no basement)
	Riverine/ A- Zone	Modified FIA CWDD:	EQE-modified versions of FIA CWDD: Residential contents – 1st floor and above (for 2 floor, w/ basement, and 2 floor, split level, w/ basement)
	Coastal/ V- Zone	FIA V-Zone Damage function	Combined curve (average of with and without obstruction)
RES2	All Zones	FIA CWDD	Contents – Residential – Mobile Home
RES3	All Zones	USACE – Galveston *	Apartment contents
RES4	All Zones	USACE – Galveston	Average of "Hotel – Equipment" and "Motel Unit - Inventory"
RES5	All Zones		No RES5 curves available – use RES6
RES6	All Zones	USACE – Galveston	Nursing Home –Equipment
COM1	All Zones	USACE – Galveston	Average of 47 retail classes – equipment and inventory, when available
COM2	All Zones	USACE – Galveston	Average of 22 wholesale/warehouse classes – equipment and inventory, when available
COM3	All Zones	USACE – Galveston	Average of 16 personal and repair services classes – equipment and inventory, when available
COM4	All Zones	USACE – Galveston	Average of "Business – inventory" and "Office, equipment"
COM5	All Zones	USACE – Galveston	Average of Bank inventory and equipment
COM6	All Zones	USACE – Galveston	Average of Hospital inventory and equipment
COM7	All Zones	USACE – Galveston	Average of 4 medical office/clinic classes, inventory and equipment, when available
COM8	All Zones	USACE – Galveston	Average of 13 entertainment & recreation classes, inventory and equipment, when available
COM9	All Zones	USACE – Galveston	Average of 3 theatre classes, equipment
COM10	All Zones	USACE – Galveston	Garage, inventory
IND1	All Zones	USACE – Galveston	Average of 16 heavy industrial classes, inventory & equipment, when available

Notes:

* *All depth-damage curves developed by the USACE Galveston District are assumed to represent structures with no basement.*

Table 5.4 Default Damage Functions for Estimation of Contents Damage (Continued)

Hazus Occ. Class	Flooding Type/Zone	Curve Source	Curve Description
IND2	All Zones	USACE – Galveston	Average of 14 light industrial classes, inventory & equipment, when available
IND3	All Zones	USACE – Galveston	Average of 10 food/drug/chemical classes, inventory & equipment, when available
IND4	All Zones	USACE – Galveston	Average of 4 metals/mineral processing classes, inventory & equipment, when available
IND5	All Zones		No IND5 curves available – use IND3
IND6	All Zones	USACE – Galveston	Average of 8 construction classes, inventory & equipment, when available
AGR1	All Zones	USACE – Galveston	Average of 3 agricultural classes, inventory & equipment, when available
REL1	All Zones	USACE – Galveston	Average of “Church” inventory and equipment
GOV1	All Zones	USACE – Galveston	Average of “City Hall” and “Post Office” equipment
GOV2	All Zones	USACE – Galveston	Average of “Police Station” equipment and “Fire Station” inventory
EDU1	All Zones	USACE – Galveston	Average of “School,” Equipment and “Library,” Inventory
EDU2	All Zones	USACE – Galveston	Average of “School,” Equipment and “Library,” Inventory

Notes:

- *All depth-damage curves developed by the USACE Galveston District are assumed to represent structures with no basement.*

5.3.2.1 Commentary on the Assignment and Implementation of Coastal Damage Functions

Several recent studies point to the need for distinguishing between coastal A-zones and riverine A-zones. While the dominant form of damage to buildings in the latter is inundation, buildings in coastal A-zones are often subject to more severe flood forces. Recent post-disaster building damage assessments in coastal areas have shown buildings in coastal A-zones are often damaged by waves, high velocity flows, scour and erosion, and floating debris. Conditions in coastal A-zones are probably closer to those in V-zones than non-coastal A-zones. This observation is supported by FEMA-sponsored laboratory tests of breakaway wall failures. The tests found typical wood frame wall panels fail under wave conditions much less severe than the 3-foot wave that presently divides V-zones and coastal A-zones. Finally, FEMA's newly revised Coastal Construction Manual introduces the coastal A-zone as a flood hazard zone distinct from the non-coastal A-zone. Design and construction recommendations for coastal A-zones are similar to those required for V-zones. Accordingly, FIA V-Zone damage functions have been selected as the default damage function for single-family residential structures in coastal A- zones as well as coastal V-zones.

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 category (single family homes). However, since single-family dwellings make up the majority of the coastal exposure in the default database, this assumption is deemed adequate. The USACE Galveston non-residential damage functions have been selected as defaults in both riverine and coastal areas, until more detailed non-residential coastal damage functions become available.

In general, A-zone and V-zone depth-damage curves define water depth differently.

- In A-zones (non-velocity zones), the water depth is relative to the top of the finished flooring of the lowest floor, excluding the basement.

- In V-zones, the water depth is relative to the bottom of the floor beam of the lowest floor.

This variation in reference depth requires that particular attention be paid to both default distributions of foundations and their associated height above grade in Level 1, and individual building elevations being analyzed in Level 2 analyses.

The Hazus Flood Model addresses direct damage to buildings and their contents. Readers are referred to the recent Heinz Center (2000) report – ***The Hidden Costs of Coastal Hazards: Implications for Risk Assessment and Mitigation*** – for an expanded discussion of direct costs and other costs associated with coastal flood disasters.

5.4 Building Damage Due to Velocity

Flooding with significant velocity can result in structure and content damage in addition to the damage caused by simple inundation. The USACE notes that velocity is a "… major factor aggravating structure and content damage…" and that the "… additional force creates greater danger of foundation collapse and forceful destruction on contents" (USACE, 1996a).

The relationship between velocity and damage has been addressed in a number of models and methods. For example, the Ontario Ministry of Natural Resources provides the following guidelines (OMNR, 1997) for structures:

> "Structural Integrity (structures above ground) **-** A depth of 0.8m is the safe upper limit for the above ground/super structure of conventional brick veneer, and certain types of concrete block buildings. The structural integrity of elevated structures is more a function of flood velocities (e.g., erosion of foundations, footings or fill) than depth. The maximum permissible velocity depends on soil type, vegetation cover and slope but ranges between 0.8-1.5m/s *(2.62 ft/sec – 4.92 ft/sec)*".

Within the Hazus Flood Model, velocity-based building collapse curves developed by the Portland District of the U.S. Army Corps of Engineers have been utilized (except for manufactured housing). These curves (as provided in IWR 85-R-5, 1985) relate collapse potential (e.g., collapse or no collapse) to overbank velocity (in feet per second) and water depth (in feet) for three building material classes (wood frame, steel frame, and masonry or concrete bearing wall structures). The Portland collapse curves for wood frame, masonry and steel frame are given in Figures 5.6, 5.7 and 5.8, respectively.

For application within the Flood Model, it has been assumed that below velocities of 2 feet per second, collapse potential is extremely low and damage is due to inundation only. Further, the "masonry and concrete bearing wall" model is applied to both the concrete and masonry Hazus building types.

For manufactured housing (MH), velocity damage curves are based on information developed by FEMA (FEMA, 1985), relating velocity and depth to drag forces. Based on information provided within that document, it is assumed that drag forces exceed MH design capacity at around 13 pounds per linear foot of home length, and it is possible to determine the relationship between depth and velocity for this threshold level of drag force. This results in a simpler velocity damage function for MH than for the other material types; for a given depth, if the velocity equals or exceeds the collapse velocity, the structure is assumed to collapse.

Velocity-depth damage functions as implemented within Hazus are provided in Tables 5.5 through 5.8 for building types wood, masonry and concrete, steel, and manufactured homes, respectively. These functions relate velocity and depth to collapse potential. If it is determined that a given building or building type collapses, the building is assumed to be a total loss, and the percent damage is reset to 100. If the model indicates that the velocity does not lead to collapse, damage is estimated based on inundation levels only.

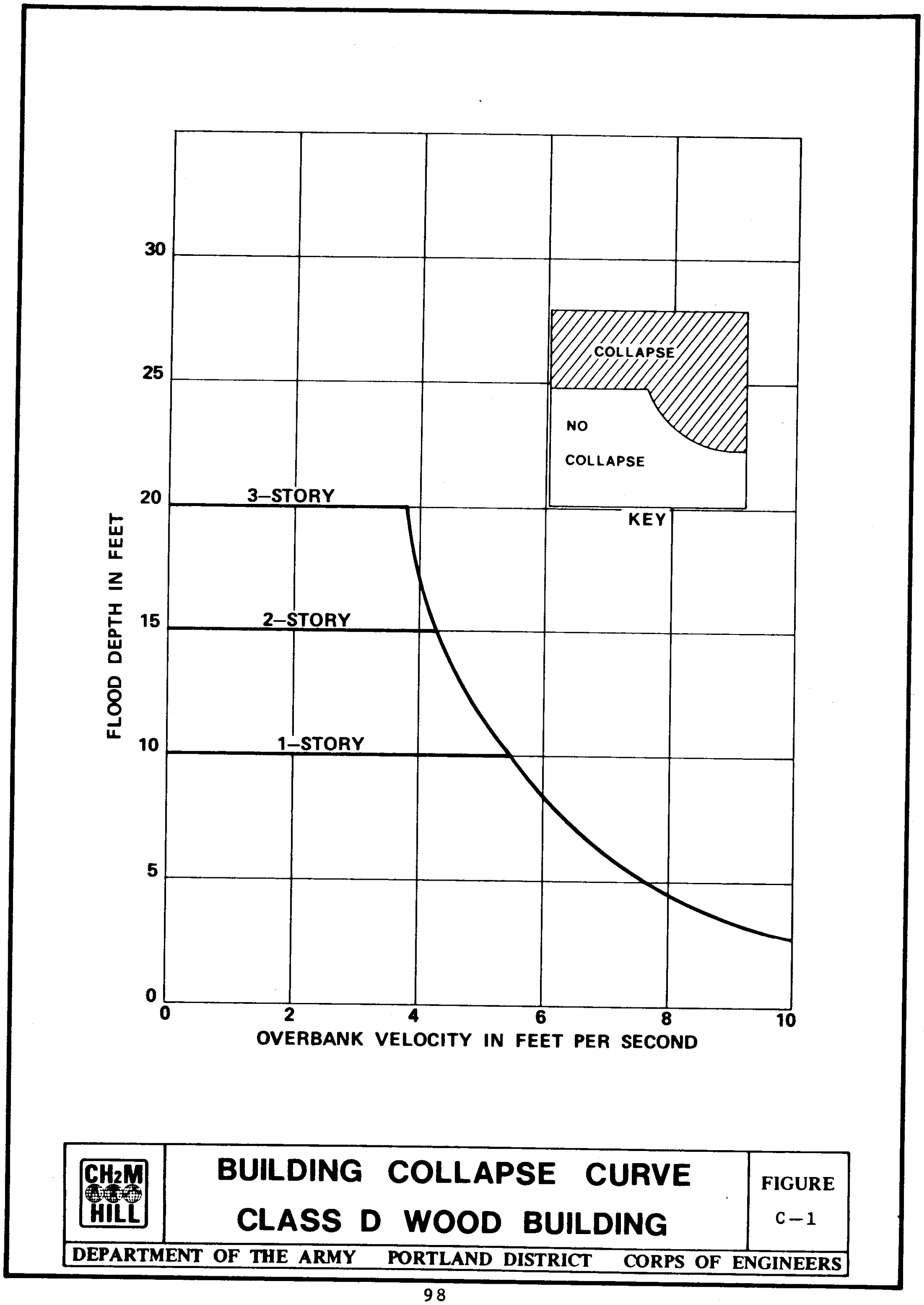

Figure 5.6 Building Collapse Curve for Wood Frame Buildings developed by the USACE Portland District (USACE, 1985)

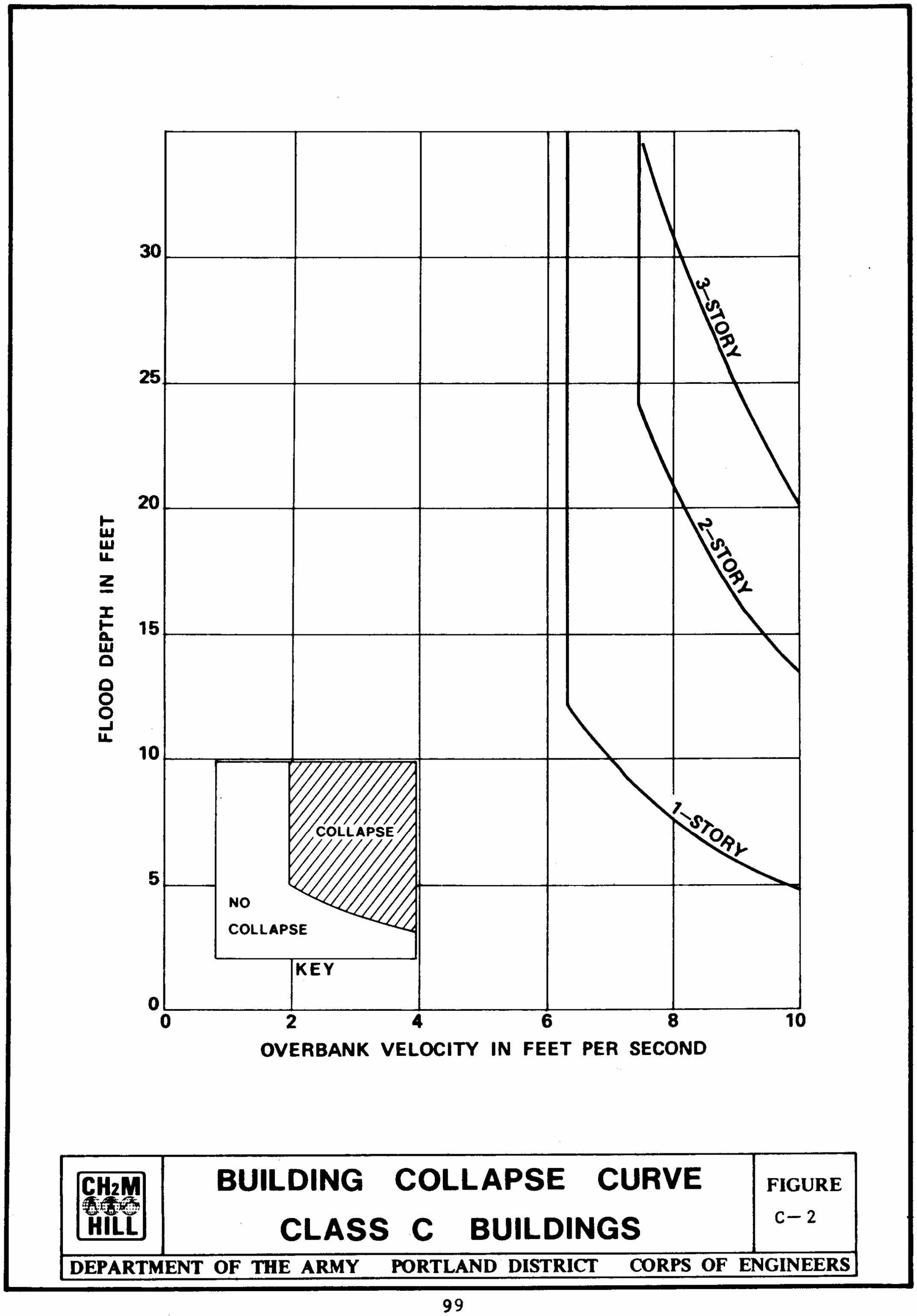

Figure 5.7 Building Collapse Curve for Masonry and Concrete Bearing Wall Buildings developed by the USACE Portland District (USACE, 1985)

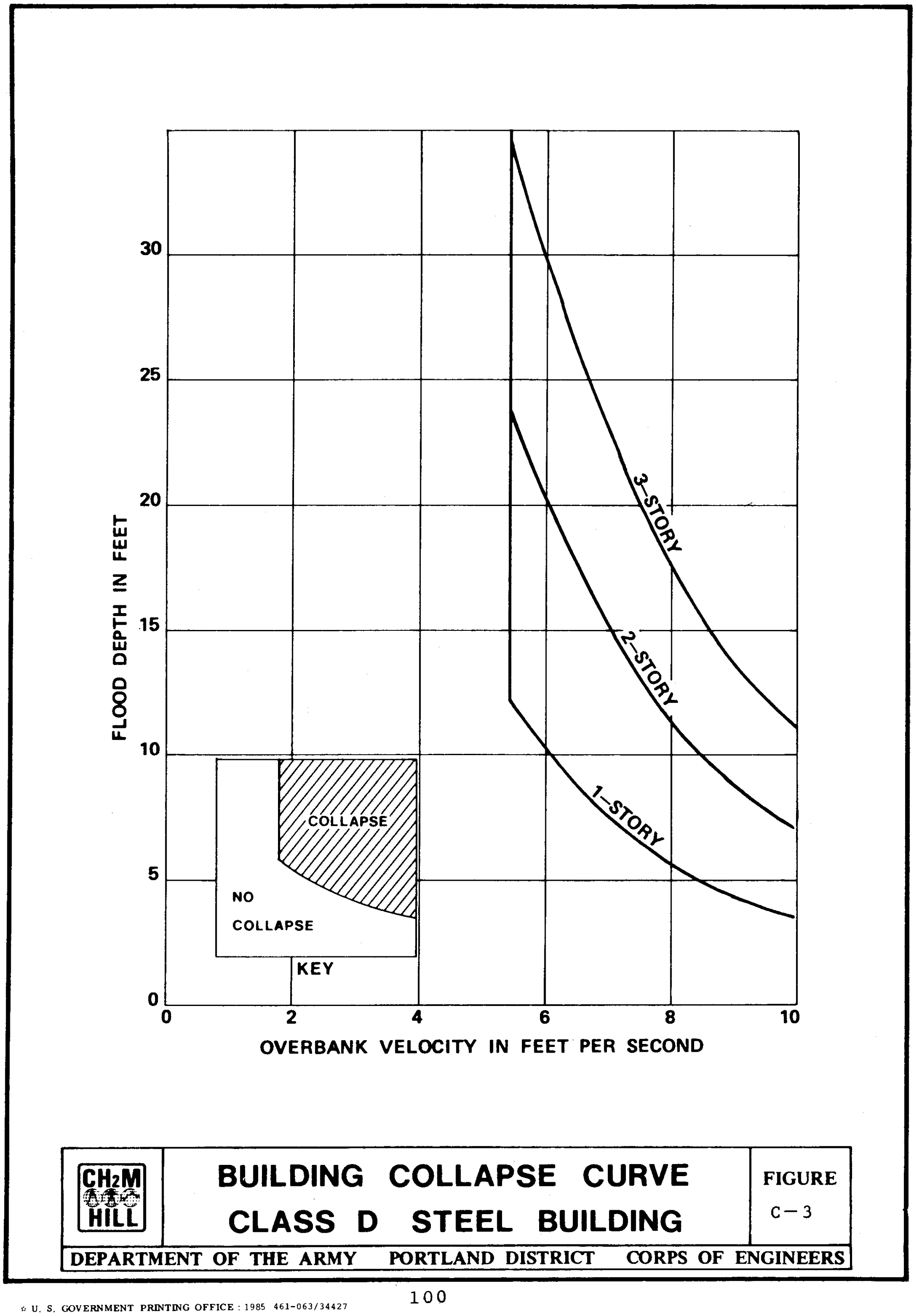

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Figure 5.8 Building Collapse Curve for Steel Frame Buildings developed by the USACE Portland District (USACE, 1985)

Table 5.5 Velocity-Depth Damage Relationship for Wood Buildings

Material	# Stories (hgt)	Depth Threshold in feet DT(hgt)	Velocity Threshold in feet/sec VT(hgt)	Collapse Potential			
				V < 2 fps any Depth	V < VT(hgt) D < DT(hgt)	V < VT(hgt) D >= DT(hgt)	V >= VT(hgt) any Depth
Wood	1 story	10	5.34	no collapse	no collapse	collapse	collapse if D > $268.38V^{-1.9642}$
Wood	2 story	15	4.34	no collapse	no collapse	collapse	collapse if D > $268.38V^{-1.9642}$
Wood	3 story	20	3.75	no collapse	no collapse	collapse	collapse if D > $268.38V^{-1.9642}$
Wood	4+ stories			no collapse	no collapse	no collapse	no collapse

Table 5.6 Velocity-Depth Damage Relationship for Masonry and Concrete Buildings

Material	# Stories (hgt)	Velocity Threshold in feet/sec VT(hgt)	Collapse Potential		
			V < 2 fps	V < VT(hgt)	V >= VT(hgt)
Masonry & Concrete	1 story	6.31	no collapse	no collapse	collapse if D > $525.09V^{-2.0406}$
Masonry & Concrete	2 story	7.47	no collapse	no collapse	collapse if D > $1210.6V^{-1.9511}$
Masonry & Concrete	3 story	9.02	no collapse	no collapse	collapse if D > -4.8864V+69.086
Masonry & Concrete	4+ stories		no collapse	no collapse	no collapse

Table 5.7 Velocity-Depth Damage Relationship for Steel Buildings

Material	# Stories (hgt)	Velocity Threshold in feet/sec VT(hgt)	Collapse Potential		
			V < 2 fps	V < VT(hgt)	V >= VT(hgt)
Steel	1 story	5.40	no collapse	no collapse	collapse if $D > 0.3125V^2 - 6.6875V + 39.125$
Steel	2 story	5.40	no collapse	no collapse	collapse if $D > 0.5808V^2 - 12.595V + 74.859$
Steel	3 story	5.40	no collapse	no collapse	collapse if $D > 0.7737V^2 - 17.112V + 104.89$
Steel	4+ stories		no collapse	no collapse	no collapse

Table 5.8 Velocity-Depth Damage Relationship for Manufactured Housing

Flood Depth (ft) relative to top of finished floor	Collapse velocity (fps)
-0.9	11.08
-0.5	4.52
0.0	3.20
0.5	2.61
1.0	2.26
1.5	2.02
2.0	1.85
3.0	1.60
4.0	1.43
5.0	1.31
6.0	1.21
7.0	1.13
8.0	1.07
9.0	1.01
10.0	0.96
11.0	0.92
12.0	0.89

5.5 Consideration of Warning and Associated Damage Reduction

Information detailing the implementation of damage reduction was obtained from the IWR and the USACE New York District. The following publications were received and reviewed to identify applications within Hazus for damage reduction based on flood warning:

- URS Consultants, Inc. (1992a), "Updated Flood Damage Evaluation Guidelines for the Passaic River Basin Project," prepared by URS Consultants for the USACE New York District.

- URS Consultants, Inc. (1992b), "Passaic River Basin Economic Updates – Sample Selection Requirements," prepared by URS Consultants for the USACE New York District.

- USACE (1994), "Framework for Estimating National Economic Development Benefits and Other Beneficial Effects of Flood Warning and Preparedness Systems," IWR Report 94-R-3, March 1994.

- USACE (1984), "Flood Emergency Preparedness System: Passaic River Basin, New Jersey and New York, Detailed Project Report and Environmental Assessment," USACE New York District.

This material was reviewed to identify applications within Hazus for damage reduction related to flood warning. The work done by the New York District models the effectiveness of a flood warning system through the modification of the Day curve, for conditions specific to the Passaic River basin. Harold Day, in a series of publications in the late 1960's, developed a method that introduced the consideration of warning time to the depth-damage relationship. Application of the methodology resulted in several curves that relate damage reduction to forecast lead time, defined as the time required for warning dissemination and effective public response. The Day curve based on a scenario of riverine flooding in residential areas is presented as Figure 5.9.

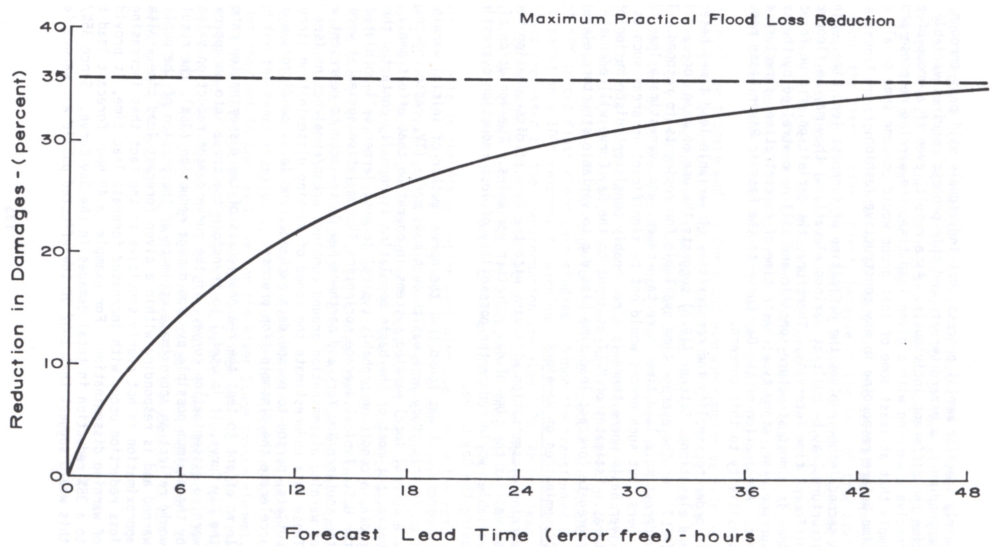

Figure 5.9 Day Curve for Residential Areas (Source: USACE, New York District, 1984)

The original Day curve indicates a maximum loss reduction of 35% of total damage (e.g., structure and contents), and assumes a public response rate of 100%. A response rate of 100% is not likely in all circumstances, and as such, the New York district modified this and some other of the major lead time assumptions inherent in the Day curve:

1. Building location – Forecast lead-time will vary at each building, based on water velocity, storm type (riverine or flash), basin time of concentration, and structure elevation. These variables were considered to develop a mean forecast lead-time for the Passaic River basin, defined as the average time available for public response.

2. Warning dissemination – The speed of warning dissemination is affected by several factors, including the dissemination medium (TV, radio, siren, etc.), time of day, source, and content. As such, the public will receive the flood warning at varying times. The New York District used this understanding to develop distributions of warning dissemination.

3. Public response – Once the warning is disseminated, all residents will not respond with damage reduction activity at the same rate. Research has shown that the public response rate is conditioned upon demographic factors, such as age, income, ethnicity, and past experience with floods. The District used the results of a literature review to develop a public response time distribution, which was capped at a rate of 85%.

The work performed by the New York District improved upon the original Day curve producing a modified curve that was tailored to conditions in the Passaic River basin. While a few select sophisticated users could modify the Day curves in a fashion similar to the New York District, most will not have the expertise. Accordingly, the implementation of damage reduction from warning within Hazus will be based on the generalized Day curve shown in Figure 5.9, and will allow the user to make a few simple modifications, as follows:

- The user must enter warning time in hours (default is no warning, and accordingly, no damage reduction).

- The default assumption for the maximum reduction in damage to contents (and inventory) will be set at 35 percent, varying as shown on the Day Curve. The user will have the option to adjust the maximum damage reduction, and the software will automatically scale the damage reduction function accordingly.

- The user may opt to apply the damage reduction factor to structure damage (in addition to contents damage), if flood-fighting efforts (e.g., sandbagging, etc.) are considered significant. As with contents and inventory, the user will have the option to adjust the maximum damage reduction up to a maximum of 35%.

- The user will have the option of applying a damage reduction factor to vehicles. The user must specify the percent of vehicles (0 – 100%) removed from the floodplain as a result of the warning.

It should be noted that the use of the original Day curve as the basis for modeling the effect of warning time on the depth-damage relationship, is not the most accurate method available. IWR Report 94-R-3 expands upon this point:

> The Day curve methodology is perfectly applicable today. The actual Day curves, however, should not be used. The Day curve methodology was surely a pathfinding work at the time, but continued use of curves based on the contents of a typical house in the early 1960s likely do not apply to current floodplain situations.

Even given this deficiency, the Day curves appear to be the best currently available source for use as a nationally applicable default data set.

5.6 Consideration of Uncertainty

The Hazus Flood Model, like the earthquake model, does not address uncertainty. While the importance of the consideration of uncertainty is widely acknowledged, it has not been addressed in the current version of Hazus. Therefore, model results should not be considered exact figures, and should be used accordingly. Nevertheless, it is the belief of the Flood Committee that planning decisions made with the benefit of model results will be better than decisions made without any consideration of science.

5.7 Guidance for Expert Users

5.7.1 Selection of Alternate Depth-Damage Functions

The Flood Model provides the user with the opportunity to compare and select alternative depth damage functions from the extensive library of functions within the model. 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.

5.7.2 Sources of Additional Depth-Damage Functions

Additional depth-damage functions may be available from local USACE Districts or floodplain managers and may include depth-damage relationships developed from post-flood surveys. Users can also develop custom depth-damage functions reflecting the unique characteristics of their community.

5.7.3 Development of Custom Depth-Damage Functions

The user can develop a new damage function using features within the model. The user would create the damage function in the Building Damage Function menu and save the function under a name provided by the user. The user would then assign the newly-developed damage function to the occupancy class of interest.

5.8 References

1. FEMA (1985), Manufactured Home Installation in Flood Hazard Areas", Federal Emergency management Agency Publication FEMA-85.

2. GEC (1996), "Depth –Damage Relationships for Structures, Contents, and Vehicles and Content-to-Structure Value Ratios (CSVRs) in Support of the Jefferson and Orleans Flood Control Feasibility Studies", Final Report, prepared by Gulf Engineers & Consultants for the USACE New Orleans District.

3. GEC (1997), "Depth –Damage Relationships for Structures, Contents, and Vehicles and Content-to-Structure Value Ratios (CSVR) in Support of the Lower Atchafalaya Reevaluation and Mroganza to the Gulf, Louisiana Feasibility Studies" Final Report, Volume I, prepared by Gulf Engineers & Consultants for the USACE New Orleans District.

4. The H. John Heinz III Center for Science, Economics and the Environment (2000). "The Hidden Costs of Coastal Hazards – Implications for Risk Assessment and Mitigation.

5. OMNR (1997), "Natural Hazards Training Manual", Ontario Ministry of Natural Resources.

6. URS Consultants, Inc. (1992a), "Updated Flood Damage Evaluation Guidelines for the Passaic River Basin Project," prepared by URS Consultants for the USACE New York District.

7. URS Consultants, Inc. (1992b), "Passaic River Basin Economic Updates – Sample Selection Requirements," prepared by URS Consultants for the USACE New York District.

8. USACE (1984), "Flood Emergency Preparedness System: Passaic River Basin, New Jersey and New York, Detailed Project Report and Environmental Assessment," USACE New York District.

9. USACE (1985), "Business Depth-Damage Analysis Procedures", U.S. Army Corps of Engineers, Institute for Water Resources.

10. USACE (1994), "Framework for Estimating National Economic Development Benefits and Other Beneficial Effects of Flood Warning and Preparedness Systems," IWR Report 94-R-3, March 1994.

11. USACE (1996a), "Risk-Based Analysis for Flood Damage Reduction Studies", Engineering Manual EM 1110-2-1619, U.S. Army Corps of Engineers, CECW-EH-Y, Washington D.C.

Chapter 6. Direct Physical Damage - Essential and High Potential Loss Facilities

6.1 Introduction

This chapter describes the methods for determining direct physical damage to essential facilities. In general, these methods are identical to those presented in Chapter 5 for determination of damage to the general building stock (the Hazus Flood Model applies pre-selected default damage functions to estimate damage to essential facility structures), except that essential facilities are handled as point facilities in the determination of their hazard exposure. The flowchart of the methodology highlighting the essential and high potential loss facility damage components and showing its relationship to other components is shown in Figure 6.1.

6.1.1 Scope

The scope of this chapter includes: (1) classification of essential facilities, (2) building damage functions for essential facilities, (3) methods for estimation of flood damage to essential facilities, given knowledge of the model building type and occupancy classification, and an estimate of first floor elevation and basement, and (3) guidance for expert users, including estimation of damage to high potential loss (HPL) facilities.

Essential facility buildings and their damage functions are described in Sections 6.2 and evaluation of damage to essential facilities is given in Section 6.3. Section 6.4 provides guidance for expert users. Typically, sections of Chapter 6 reference (rather than repeat) material of the corresponding section of Chapter 5.

6.1.2 Essential Facilities Classification

Facilities that provide services to the community and those that should be functional following a flood are considered to be essential facilities. Examples of essential facilities include hospitals, police stations, fire stations, emergency operations centers (EOC's) and schools.

Essential facilities are classified on the basis of facility function and, in the case of hospitals, size. Table 6.1 lists the classes of essential facilities used in the methodology. Hospitals are classified on the basis of number of beds (assumed to reflect hospital size) to ensure consistency with the previously developed earthquake model.

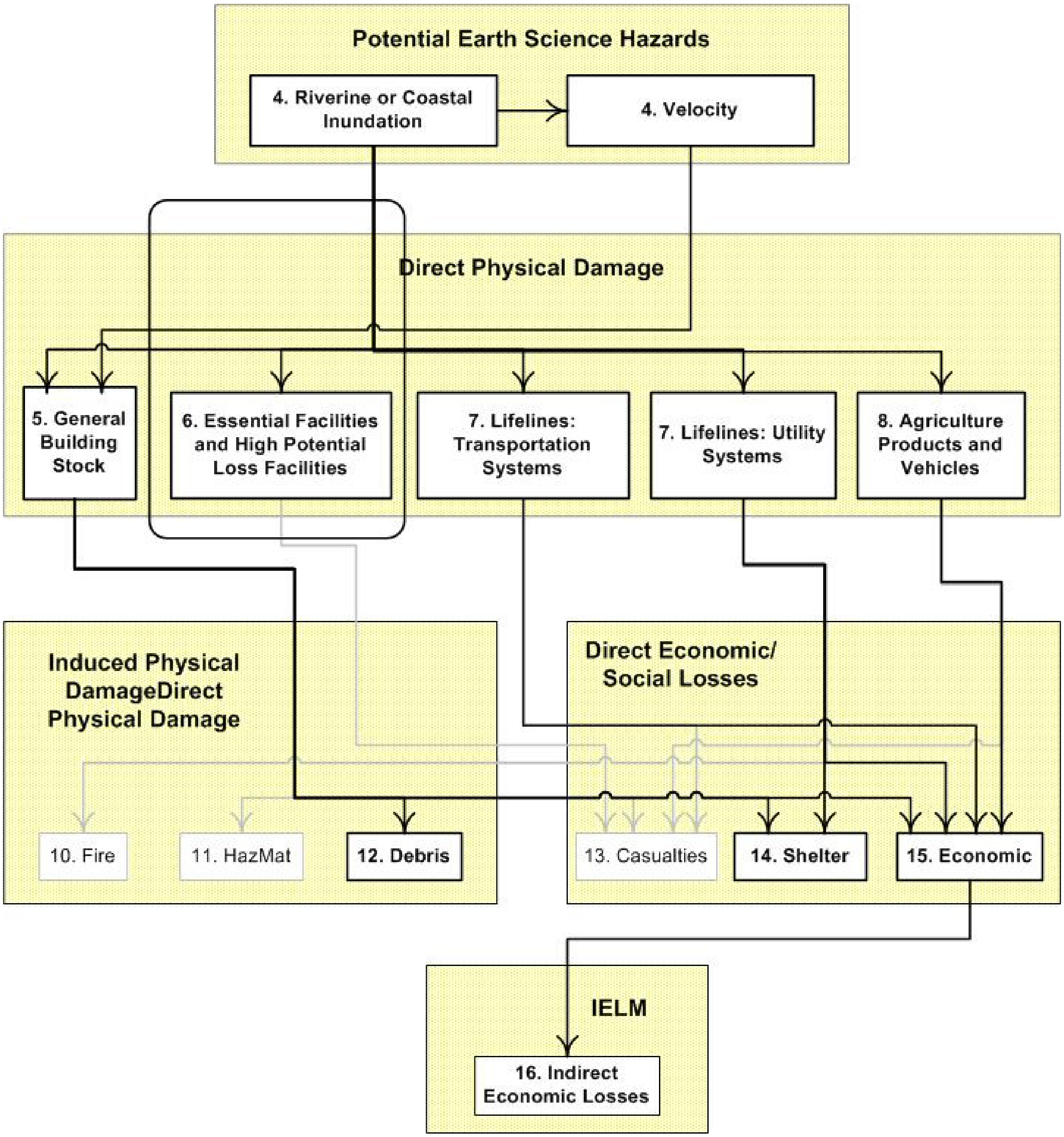

Figure 6.1 Essential and High Potential Loss Facility Component Relationship to Other Components of the Hazus Flood Methodology

Table 6.1 Essential Facilities Occupancy Classes

No.	Label	Occupancy Class	Description
Medical Care Facilities			
1	EFHS	Small Hospital	Hospital with less than 50 Beds
2	EFHM	Medium Hospital	Hospital with beds between 50 & 150
3	EFHL	Large Hospital	Hospital with greater than 150 Beds
4	EFMC	Medical Clinics	Clinics, Labs, Blood Banks
Emergency Response			
5	EFFS	Fire Station	
6	EFPS	Police Station	
7	EFEO	Emergency Operation Centers	
Schools			
8	EFS1	Schools	Primary/ Secondary Schools (K-12)
9	EFS2	Colleges/Universities	Community and State Colleges, State and Private Universities

6.1.3 Input Requirements and Output Information

Input required to estimate essential facility damage using depth-damage curves includes the following:

- Model building type including height, basement and first floor elevation for the essential facility (or type of essential facilities) of interest,
- Damage curve assignment or creation and assignment of the user's own damage function, and
- Site-specific water depth determined by the hazard module

The "output" of the depth-damage curves is an estimate of the expected damage as a percentage of replacement cost of the structure and/or contents. Depth damage curves, their sources and applicability are discussed in detail in Chapter 5.

Typically, the model building type (including height, basement, and first floor elevation) is not known for each essential facility and must be inferred from information available in the inventory of essential facilities using the occupancy relationships described in Chapter 3.

6.1.4 Form of Damage Functions

The form of the damage functions used for essential facilities is the same as those for the general building stock, described in detail in Chapter 5 of this report. Since vulnerability to flooding damage is less dependent on building type than earthquake damage, application of depth damage functions developed for the general building stock to other structures is not unreasonable. Flood proofing of essential facilities can be accounted for by modifying the depth damage function to reflect the level of expected protection from the flood proofing.

6.2 Description of Occupancies and Model Building Types

The model building types and associated building parameters (foundation, first floor elevation, etc.) used for essential facilities are identical to those used for general building stock. Building parameters related to flood damage are described in Section 5.2. For each class of essential facility, a default building type, configuration, and first floor elevation have been assumed. These default assumptions are documented in Table 6.2. It should be noted that facility age will be based on the median age of structures within the essential facility's census block.

Essential facilities also include certain special equipment, such as emergency generators, and certain special contents, such as those used to operate a hospital. Special equipment and contents of essential facilities are considered to be sensitive to flooding and can potentially impact the functionality of the hospital. Table 6.2 also provides depth thresholds beyond which the essential facilities are considered non-operational. That is, the depth of flooding at which point the facility may close.

Table 6.2 Essential Facilities Classification and Model Building Types

Occupancy Class	Description	Age	Model Building Type	Basement	First Floor Elev. (ft)	Building Height	Damage Function	Depth Threshold for Functionality (feet)
EFHS	Small Hospital	Median	Concrete	Yes	3	Low	COM6	0.5
EFHM	Medium Hospital	Median	Concrete	Yes	3	Mid	COM6	0.5
EFHL	Large Hospital	Median	Concrete	Yes	3	Mid	COM6	0.5
EFMC	Medical Center	Median	Concrete	Yes	3	Low	COM7	0.5
EFFS	Fire Station	Median	Concrete	No	0	Low	GOV2	2
EFPS	Police Station	Median	Concrete	Yes	0	Low	GOV2	1
EFEO	Emergency Operations	Median	Concrete	Yes	0	Low	GOV2	1
EFS1	School	Median	Brick	No	0	Low	EDU1	0.5
EFS2	University	Median	Concrete	No	0	Low	EDU2	0.5

6.3 Building Damage Due to Flooding

Damage to essential facilities is estimated in a manner similar to damage to the general building stock, except that essential facility hazard exposure is based on site-specific data. That is, depth is determined at the latitude and longitude location of the essential facility.

For each class of essential facility, a default damage function has been identified. These defaults, noted in Table 6.2, are identified as the default for a selected occupancy class. For example, the default damage function for small, medium and large hospitals classified as essential facilities is the same as the default used for hospitals in the general building stock (COM6). For a detailed discussion of building damage functions, see Chapter 5 of this Technical Manual.

6.4 Guidance for Expert Users

6.4.1 Selection of Alternate Depth-Damage Functions

The Flood Model provides the user the opportunity to compare and select alternative depth damage functions from the extensive library of functions within the model. The user can identify the damage function they would prefer to use in the estimation of damage to essential facilities and add the identification into the inventory field labeled Damage function. Within any scenario that impacts that facility, the selected damage function will be accessed.

6.4.2 Development of New Depth-Damage functions

The user can develop a new damage function using features within the model. The user would create the damage function in the Building Damage Function menu and save the function under a name provided by the user. The user would then use the process discussed above to assign the function to the selected facility classification.

6.4.3 Velocity-Damage Functions

While velocity-damage functions have been included in the methodology for the general building stock (see Section 5.4), the current versions of Hazus Flood does not allow the application of these damage functions to essential facilities. It is expected that this functionality will be added to subsequent versions of the model.

6.4.4 High Potential Loss Facilities

6.4.4.1 Introduction

This section describes damage evaluation of high potential loss (HPL) facilities. HPL facilities could result in heavy flood losses, if significantly damaged. Examples of such facilities include nuclear power plants, certain military and industrial facilities, dams, etc.

6.4.4.2 Input Requirements and Output Information

The importance of these facilities (in terms of potential flood losses) suggests that damage assessment be done in a special way as compared to ordinary buildings. Each HPL facility should be treated on an individual basis by users who have sufficient expertise to evaluate damage to such facilities. Required input for damage evaluation includes depth-damage functions developed specifically for each individual HPL facility, reflecting the facilities configuration and specific vulnerabilities.

The direct output (damage estimate) from implementation of the depth-damage curves is an estimate of percent damage (relative to replacement cost). This output is used directly as an input to other damage or loss estimation methods or combined with inventory information to predict the distribution of damage as a function of facility type, and geographical location. In the latter case, the number and geographical location of facilities of interest would be a required input to the damage estimation method.

6.4.4.3 Form of Damage Functions and Damage Evaluation

The form of user-supplied HPL facility damage functions should be the same as that of buildings (Chapter 5) and their use in the methodology would be similar to that of essential facilities.

6.5 Essential Facility and HPL Damage References

Refer to Section 5.8 for building damage references.

Chapter 7. Lifelines: Transportation and Utilities

7.1 Introduction

The treatment of lifelines is discussed in this section of the report. Lifelines are defined as the transportation and utility infrastructure that provides the United States with communications, water, power, mobility and other necessities for both continuity of governance and economic health. Hazus provides some default data, but due to the sensitive nature of these facilities, national datasets are typically unavailable. Therefore, it is usually necessary for local communities to provide the data for analysis. The Flood Model has developed damage and loss functions for the infrastructure that is most vulnerable to the impact of inundation.

The Flood Model approaches the damage to lifeline facilities by identifying those components are either particularly expensive to replace, or when damaged by floodwaters force an extended closure, thereby removing critical infrastructure from the community and the emergency responders attempting to restore the community. Table 7.1 provided the basis for this effort and the determination of those facilities and components that would require damage functions. Within each of these facilities, there are components that could be identified that drove the overall facilities vulnerability to flooding.

Table 7.1 further identifies sub-hazards that may affect the various lifeline components and the expected maximum level of vulnerability. The flood sub-hazards that are being considered include:

- Inundation – a function of water elevation
- Scour/erosion – a function of floodwater velocity and duration.
- Debris Impact/Hydraulic Loading – a function of water elevation and velocity

Most of the components are vulnerable to inundation except bridges/foundations and buried pipeline crossings that are vulnerable to scour, and bridge decks that are vulnerable to hydraulic pressure.

The overall maximum vulnerability (the highest of any of the three sub-hazards) is listed in Table 7.1. Therefore, the lifeline components selected for fragility modeling are identified in Table 7.1, including:

- Bridges
- Water system components with medium or high exposure,
- Wastewater system components with medium or high exposure.

- Electrical power, communications, natural gas, and petroleum lifeline system components with fragilities similar to water and wastewater facilities.

Evaluation of “special” components such as dams and power plants is beyond the scope of this project.

Along with the determination of vulnerability, the impact of damage on the systems functionality, whether or not damage to the component is a high dollar loss item, and the overall recovery time for the component are identified on Table 7.1.

Table 7.1 Lifeline System Components, Vulnerability to Flood Sub-hazards, Criticality and Potential Dollar Loss and Outage Time

Lifeline	Selected for Evaluation (X) "Special" (S)	Overall Vulnerability	Flood Sub-hazard Vulnerability			Criticality	Dollar Loss and Outage Time
			Inundation	Scour/ Erosion	Debris Impact/ Hydraulic Pressure		
Bridges	X	High	Low	Medium	High	Medium	High
Water Systems							
Water Treatment Plants	X	High	High	Low	Low	High	High
Tanks		Low	Low	None	None	Medium	Medium
Reservoirs (Impoundment Controlled Channels/Pipelines)		Low	None	None	None	Low	Medium
Dams/Impoundments (free flow)	S	High	None	High	Low	High	High
Pump Stations	X	Medium	High	None	None	Medium	Medium
Pipelines – Bridge Crossings	X	High	Low	None	Medium	Medium	Low
Pipelines – Buried River Crossings	X	High	None	High	Low	Medium	Medium
Pipelines – Distribution/Transmission		Low	None	Low	None	Low	Low
Control Vaults (Air release valves, meter pits, control valves)	X	High	High	Low	Low	Medium	Low
Wastewater Systems							
Treatment Plants	X	High	High	Low	Low	High	High
Pump/Lift Stations	X	High	High	None	None	Medium	Medium
Pipelines – Bridge Crossings	X	High	Low	None	Medium	Medium	Low
Pipelines – Buried River Crossings	X	High	None	High	Low	Medium	Medium
Collection Systems	X	Medium	High	None	None	Low	Low
Control Vaults (meter pits, control valves)	X	High	High	Low	Low	Low	Low

Table 7.1 Lifeline System Components, Vulnerability to Flood Sub-hazards, Criticality and Potential Dollar Loss and Outage Time (Continued)

Lifeline	Selected for Evaluation (X) "Special" (S)	Overall Vulnerability	Flood Sub-hazard Vulnerability			Criticality	Dollar Loss and Outage Time
			Inundation	Scour/ Erosion	Debris Impact/ Hydraulic Pressure		
Power							
Generation Plants	S	High	High	None	None	Low	High
Substations	X	High	High	None	None	Low	Medium
Transmission/Distribution (above)		Low	None	Medium	Low	Low	Low
Distribution (below)		Low	Low	None	None	Low	Medium
Access Vaults		Low	High	Low	Low	Low	Low
Telecommunications							
Switching Station	X	High	High	Low	Low	High	High
Transmission/Distribution Bridge Crossing	X	High	Low	None	Medium	Medium	Low
Transmission/Distribution Buried River Crossing	X	High	Low	High	Low	Medium	Medium
Transmission/Distribution Buried		Low	Low	Low	None	Medium	Low
Access Vaults		Low	High	Low	Low	Low	Low
Natural Gas							
Compressor Station		Low	Medium	None	None	Medium	Medium
Pipelines – Bridge Crossings	X	High	None	None	Medium	Medium	Medium
Pipelines – Buried River Crossings	X	High	None	High	Low	Medium	Medium
Pipelines – Distribution/Transmission		Low	None	Low	None	Low	Low
Control Stations (regulator stations, meter pits, control valves)		Low	Medium	None	None	Low	Low

Table 7.1 Lifeline System Components, Vulnerability to Flood Sub-hazards, Criticality and Potential Dollar Loss and Outage Time (Continued)

Lifeline	Selected for Evaluation (X) "Special" (S)	Overall Vulnerability	Flood Sub-hazard Vulnerability			Criticality	Dollar Loss and Outage Time
			Inundation	Scour/ Erosion	Debris Impact/ Hydraulic Pressure		
Petroleum							
Refineries	S	Medium	High	None	None	Low	High
Pumping Plants	X	Medium	High	None	None	Low	Medium
Tank Farms	S	High	Medium	None	None	Low	Medium
Pipelines – Bridge Crossings	X	High	None	None	Medium	Medium	Medium
Pipelines – Buried River Crossings	X	High	None	High	Low	Medium	Medium
Pipelines -- Transmission		Low	None	Low	None	Low	Low

7.2 Scope

The scope of this chapter includes development of methods for estimation of flood damage to the selected lifeline infrastructure given knowledge of facility and an estimate of the depth of flooding throughout the study area. Model facility types are defined at the end of this section. The extent and severity of damage to structural contents of these facilities are estimated directly from the depth of flooding and the application of the assigned depth damage curve. This chapter focuses on the loss estimation process as defined by Hazus for the Flood Model.

The interaction between the estimation of direct damage to the other components of the flood loss estimation model can be seen in Figure 7.1 below. While this should appear familiar to the reader of the earthquake model technical manual, the figure has been modified to accurately reflect those features unique to the Flood Model and remove those features unique to the earthquake model.

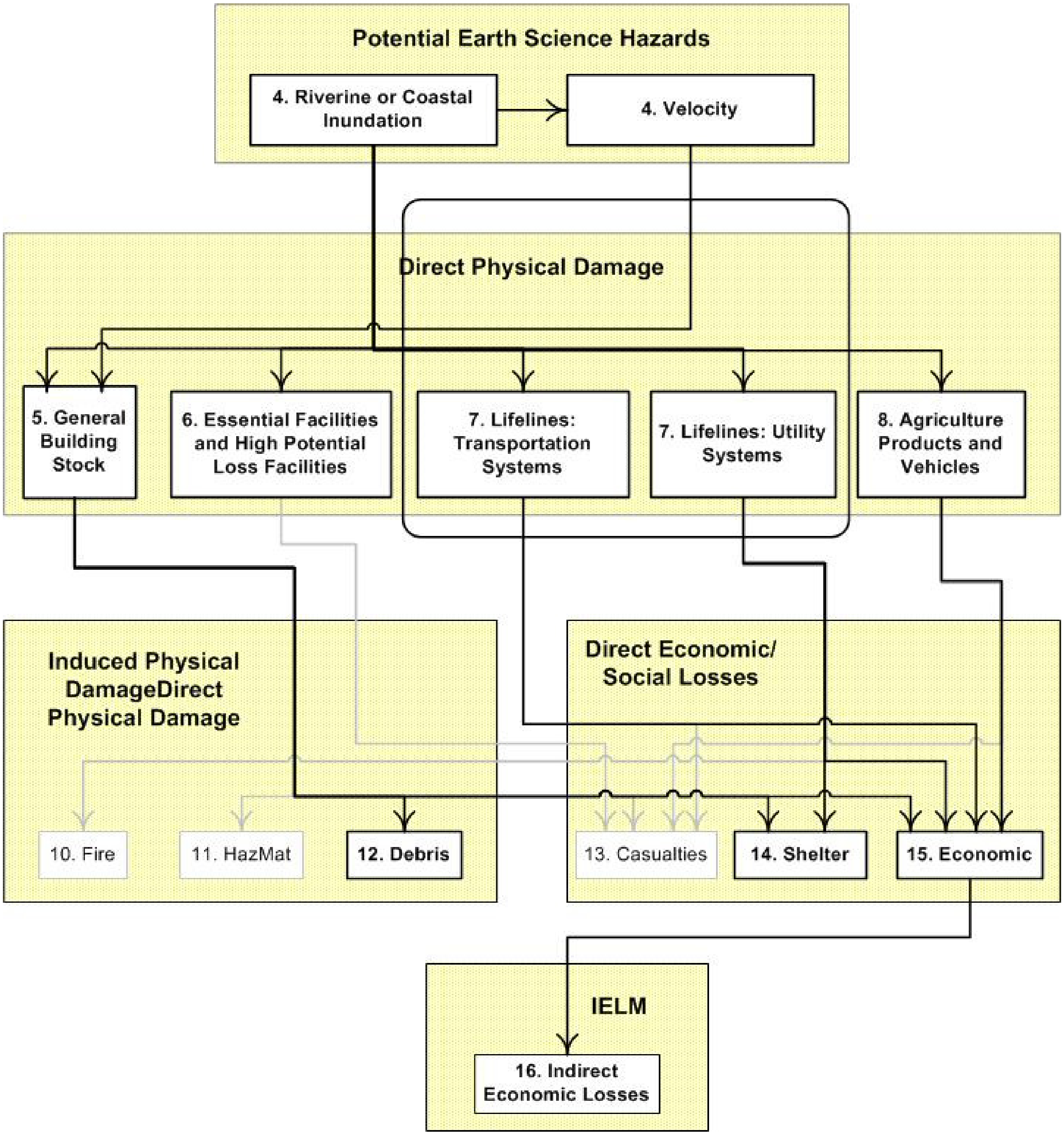

Figure 7.1 Transportation and Utility Systems Relationship to the Components

Analyzing losses for lifeline facilities is for the most part similar to that discussed in the general building stock chapter, but the damage functions for lifelines really define the potential damage to components of the lifeline system that are either uniquely vulnerable to inundation (such as electrical components) or are expensive or difficult to repair/replace (such as motors, controllers, etc.).

7.2.1 Input Requirements and Output Format

7.2.2 Form of the Damage Functions

With the obvious exception of bridges (discussed below) the damage functions for lifelines are very similar to the depth to damage curves used to the general building stock. The depth of flooding within the facility is compared to the height of critical components and the amount of damage can be estimated. In most cases, the elevation of the equipment also provides for a depth of flooding at which point the functionality of the facility starts to become questionable.

7.2.3 Transportation Bridges

In discussions with the FHWA, no comprehensive database of bridge damage could be identified. As a result, the proposed damage relationships are estimates that should be calibrated once the overall flood module is operable.

Hazus comes with the national bridge inventory database as part of the default data and the objective is to use as much of the information in that database as possible. This database includes all bridges in the U.S. with a span of 20-feet or greater. In discussions with an FHWA representative it was suggested that possible fields within the bridge inventory database include: scour potential, waterway adequacy, and span type (simple versus continuous). The FHWA also provided other references for further information.

The database field discussed, the scour potential rating, has values that range from 0 to 9, where 0 indicates the bridge is closed as a result of scour damage, and 9 indicates that the bridge is not over water. Scour ratings 4-9 are not used in Hazus. Ratings of significance to the Flood Model are:

- 1 – closed
- 2 – existing problem
- 3 – 100-year flood could damage.

There appears to be a very low probability of failure due to flooding for bridges with a scour potential greater than 3. As bridges are designed for 500-year floods, for single span bridges over water (i.e. – scour potential < 9), the Hazus Flood Model assumes a 1% probability of failure for floods with a return period of 100 years, and 1.5% probability for floods with a return period of

1000 years. For continuous bridges, the Hazus Flood Model uses 25% of the values for single span bridges.

The waterway adequacy gives some indication how much the bridge is restricting the channel, but there is no known correlation to bridge damage due to flooding.
Most bridge failures are simple spans. Scour of bridge piers on continuous spans does not usually result in collapse. Expected damage for continuous span bridges is taken to be 25% of that for single span bridges. Similarly, bridges with multiple piers provide redundancy that reduces their vulnerability. The span type is included in the National Bridge Database, but the number of piers is not.

The relationships for single-span and continuous-span bridge damage due to flooding is shown below.

Table 7.2 Highway Single-span Bridge Damage Relationship

Flood Return Period	Scour Potential(1)/Probability of Failure (percent)				
	1	2	3	4-8	9
100-year	5	2	1	0	N/A
500-year (2x 100-year probability)	10	4	2	0	N/A
1000-year (1.5x 500-year probability)	15	6	3	0	N/A

The Scour Potential is a field in the Hazus Bridge database and is from the FHWA inventory of bridges

Table 7.3 Highway Continuous-Span Bridge Damage Relationship

Flood Return Period	Scour Potential(1)/Probability of Failure (percent)				
	1	2	3	4-8	9
100-year	1.25	0.5	0.25	0	N/A
500-year (2x 100-year probability)	2.5	1	0.5	0	N/A
1000-year (1.5x 500-year probability)	3.75	1.5	0.75	0	N/A

(1) *The Scour Potential is a field in the Hazus Bridge database and is from the FHWA inventory of bridges*

In the future, it may be possible to develop damage relationships for different bridge span materials (concrete, steel, wood), but no data exists, and the focus is on the bridge foundation vulnerability rather than the span.

"Failure" is defined to be loss of function due to flood/scour damage. As there is very limited data, the preliminary recommendation is that "failure" represents a damage value of 25% of replacement cost. This is a mean value taking into account damage that could be scour/undercutting of a single pier, to collapse of a span. This same relationship is applied to rail and light rail bridges. The damage relationships are applicable to pipelines supported on highway bridges.

7.2.4 Treatment of Plants, Pump Stations, Vaults, Substations, and Telecommunication Facilities - Inundation

Fragility relationships based on inundation have been developed for treatment plants, pump stations, vaults, substations, and telecommunications facilities. The Flood Model currently provides damage and loss estimates for select potable water, wastewater, oil, and natural gas facilities only. Electric power and telecommunications was deferred to a later date. The operational vulnerabilities, damage, and restoration times are primarily a function of the fragility of:

1. Electrical equipment,

2. Mechanical equipment, and

3. Building damage (minor impact on operation).

However, in many situations, the operation of these facilities will be terminated based on a management decision to shut down the facility at some threshold floodwater elevation.

There are two general scenarios for inundation damage, diked/protected and unprotected/ undiked. For unprotected facilities, the damage and recovery time will increase to a maximum as the water depth increases to a defined level (assumed to be one-half a story height (i.e. damage is 100% when flood level is 4 feet above the floor level).

For protected facilities, there will be no damage until the protection elevation is exceeded (dike overtops). At this point the entire facility would be expected to flood. This same approach may also be used for facilities with below-grade components. For example, for a wet-well/dry-well sewage pump station, there would be no damage until the water elevation rose above the ground floor slab elevation. Once that elevation was exceeded, the dry well and the electrical components located in the dry well would be submerged. The user will be required to input this information as part of the site data. It should be noted that flood protection can be automatically or manually implemented. "Automatic" implementation could be inherent in the design (i.e. dikes are always in place), or may require intervention (closing floodgates, etc.).

For some facilities such as treatment plants, there may be multiple structures with different floor slab elevations. In this situation, the user is required to select the elevation that best represents the vulnerability of the overall facility. One approach might be to select the floor elevation of the facility with key process electrical equipment. When addressing treatment plants (and sewer treatment facilities), the Flood Model includes the value of the control buildings and support buildings in the total value of the treatment plant, but generally, the damage associated with the structure is minimal when compared to the damages associated with the electrical components and systems within the structure. In other words, damage to buildings at a water treatment plant do not play a role in the functionality of the plant. Damage to the electrical controls and components within the plant are the critical path for functionality.

7.2.5 Utility Systems

The Flood Model performs loss estimation analysis on

- potable water system facilities including: treatment plants, control vaults and control stations, tanks, wells,

- wastewater system facilities including treatments plants, control vaults and control stations, lift stations,

- oil facilities including refineries, control vaults and control stations, and tanks,

- natural gas facilities including: compressor stations and control vaults and control stations,

- electric power plants and substations.

7.2.6 Lifeline Classifications, Functionality Thresholds and Damage Functions

Tables 7.4 through 7.9 provide the user with the classifications for the various facility types available within Hazus. For the convenience of Hazus-MH Earthquake Model users, the new classifications are aligned with older classifications. The Flood Model project team developed several damage functions for various classifications of lifelines and these functions are available for the user to access in the model. The user can assign a different damage function to each facility class within their study region. Therefore a user whose study region has a closed pressure system can use functions related to that system.

ter 7. Lifelines:

Table 7.4 Potable Water Classifications, Functionality Thresholds and Damage Function

Label	HAZUS-99 Earthquake Classification	Specific Occupancy	Functionality Threshold Depth	Percent Damage by depth of flooding in feet[2]											Comments
				0	1	2	3	4	5	6	7	8	9	10	
PWP1 PWP2	PWP1, PWP2	Exposed Transmission Pipeline Crossing	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage expected from submergence
PWP1 PWP2.	PWP1, PWP2	Buried Transmission Pipeline Crossing	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage expected from submergence
PWP1 PWP2	PWP1, PWP2	Pipelines (non-crossing)	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage expected from submergence
PWTS	PWT1, PWT2	Small Water Treatment Plants Open/Gravity	0	0	5	8	10	17	24	30	30	30	30	40	Cleanup, repair of small motors, buried conduits, and transformers required when flood level exceeds ground level. Clean and repair of major electrical equipment initiated when flood level exceeds 3 feet.
PWTM	PWT3, PWT4	Medium Water Treatment Plants Open/Gravity	0	0	5	8	10	17	24	30	30	30	30	40	
PWTL	PWT5, PWT6	Large Water Treatment Plants Open/Gravity	0	0	5	8	10	17	24	30	30	30	30	40	
PWT_			0	0	3	4	5	9	12	15	15	15	15	15	PW_O Less than average damage
PWT_			0	0	8	12	15	26	36	45	45	45	45	45	PW_O More than average damage
PWTS	PWT1, PWT2	Small Water Treatment Plants Closed/Pressure	4	0	1	2	5	15	30	40	40	40	40	40	Assumes all equipment raised 3 feet above ground level. Mechanical/electrical equipment represents a greater percentage of the plant value that for "open" design
PWTM	PWT3, PWT4	Medium Water Treatment Plants Closed/Pressure	4	0	1	2	5	15	30	40	40	40	40	40	
PWTL	PWT5, PWT6	Large Water Treatment Plants Closed/Pressure	4	0	1	2	5	15	30	40	40	40	40	40	
PWT_			4	0	1	1	3	8	15	20	20	20	20	20	PW_C Less than average damage

Table 7.4 Potable Water Classifications, Functionality Thresholds and Damage Functions (Continued)

Label	Earthquake Classification	Specific Occupancy	Functionality Threshold Depth	Percent Damage by depth of flooding in feet[2]											Comments
				0	1	2	3	4	5	6	7	8	9	10	
PWT_			4	0	2	3	8	23	45	60	60	60	60	60	PW_C More than average damage
PPPS	PPP1, PPP2	Pumping Plants (Small) Below Grade	4	0	0	0	0	40	40	40	40	40	40	40	Assumes entrance is 3 feet above ground level and is not sealed. Assumes all electrical equipment is below grade. Once entrance level exceeded, entire pump station floods.
PPPM / PPPL	PPP3, PPP4	Pumping Plants (Med/Large) Below Grade	4	0	0	0	0	40	40	40	40	40	40	40	
PPPS	PPP1, PPP2	Pumping Plants (Small) Above Grade	4	0	1	2	5	15	30	40	40	40	40	40	Assumes all equipment raised 3 feet above ground level.
PPPM / PPPL	PPP3, PPP4	Pumping Plants (Med/Large) Above Grade	4	0	1	2	5	15	30	40	40	40	40	40	
PCVS	N/A	Control Vaults and Stations	1	0	40	40	40	40	40	40	40	40	40	40	Assumes entrance is at grade, and is not sealed.
PSTGC	PST1, PST2	Water Storage Tanks At Grade Concrete	24	0	0	0	0	0	0	0	0	0	0	0	Assumes that the tank bottom is at grade, and that the water level in the tank exceeds the flood depth (so the tank will not float).

ter 7. Lifelines:

Table 7.4 Potable Water Classifications, Functionality Thresholds and Damage Functions (Continued)

Label	Earthquake Classification	Specific Occupancy	Functionality Threshold Depth	Percent Damage by depth of flooding in feet[2]											Comments
				0	1	2	3	4	5	6	7	8	9	10	
PSTGS	PST3, PST4	Water Storage Tanks At Grade Steel	24	0	0	0	0	0	0	0	0	0	0	0	
PSTGW	PST6	Water Storage Tanks At Grade Wood	24	0	0	0	0	0	0	0	0	0	0	0	
PSTAS	PST5	Water Storage Tanks Elevated	80	0	0	0	0	0	0	0	0	0	0	0	Assumes that the tank foundations are not damaged.
PSTBC	N/A	Water Storage Tanks Below Grade (all)	4	0	0	0	0	5	5	5	5	5	5	5	Assumes that the tank vent is 3 feet above grade, and that cleanup will be required.
PWE	PWE1	Wells	4	0	1	2	5	20	25	30	30	30	30	30	Assumes that the electrical equipment and well vent/openings are s 3 feet above grade. Assumes that the well is not permanently contaminated.

[2] *Assumes electrical switch gear located 3 feet above grade*

Table 7.5 Wastewater classifications, Functionality Thresholds and Damage Functions

Label	Earthquake Classification	Specific Occupancy	Functionality Threshold Depth	Percent Damage by depth of flooding in feet[2]											Comments
				0	1	2	3	4	5	6	7	8	9	10	
WWP1 WWP2	WWP1, WWP2	Exposed Collector River Crossings	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage expected from submergence
WWP1 WWP2	WWP1, WWP2	Buried Collector River Crossings	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage expected from submergence
WWP1 WWP2	WWP1, WWP2	Pipes (non-crossings)	N/A	0	5	5	5	5	5	5	5	5	5	5	No damage expected from submergence
WWTS	WWT1, WWT2	Small Wastewater Treatment Plants	0	0	5	8	10	17	24	30	30	30	30	40	Cleanup, repair of small motors, buried conduits, and transformers required when flood level exceeds ground level. Clean and repair of major electrical equipment initiated when flood level exceeds 3 feet
WWTM	WWT3, WWT4	Medium Wastewater Treatment Plants	0	0	5	8	10	17	24	30	30	30	30	40	
WWTL	WWT5, WWT6	Large Wastewater Treatment Plants	0	0	5	8	10	17	24	30	30	30	30	40	
WWT_				0	3	4	5	9	12	15	15	15	15	20	WWT_ Less than average damage
WWT_				0	8	12	15	26	36	45	45	45	45	60	WWT_ More than average damage
WWCV	N/A	Control Vaults and Control Stations	1	0	40	40	40	40	40	40	40	40	40	40	Assumes entrance is at grade, and is not sealed.

Table 7.5 Wastewater classifications, Functionality Thresholds and Damage Functions (Continued)

Label	Earthquake Classification	Specific Occupancy	Functionality Threshold Depth	Percent Damage by depth of flooding in feet[2]											Comments
				0	1	2	3	4	5	6	7	8	9	10	
WLSS	WLS1, WLS2	Lift Station (Small) Wet Well/Dry Well	4	0	0	0	0	40	40	40	40	40	40	40	Assumes entrance is 3 feet above ground level and is not sealed. Assumes all electrical equipment is below grade. Once entrance level exceeded, entire pump station floods
WLSM / WLSL	WLS3, WLS4	Lift Station (Med/Large) Wet Well/Dry Well	4	0	0	0	0	40	40	40	40	40	40	40	
WLSS	WLS1, WLS2	Lift Station (Small) Submersible	N/A	0	0	0	0	10	10	10	10	10	10	10	Same as WLSW and WLMW except flood water does not harm submersible pumps, only electrical equipment.
WLSM / WLSL	WLS3, WLS4	Lift Station (Med/Large) Submersible	N/A	0	0	0	0	10	10	10	10	10	10	10	

[2] *Assumes electrical switch gear is located 3-feet above grade.*

Table 7.6 Crude and Refined Oil Classifications, Functionality Thresholds and Damage Functions

Label	Earthquake Classification	Specific Occupancy	Functionality Threshold Depth	Percent Damage by depth of flooding in feet(2)											Comments
				0	1	2	3	4	5	6	7	8	9	10	
OIP1 OIP2	OIP1, OIP2	Exposed Transmission Pipelines River Crossings	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage expected from submergence
OIP1 OIP2	OIP1, OIP2	Buried Transmission Pipelines River Crossings	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage expected from submergence
OIP1 OIP2	OIP1, OIP2	Pipelines (non-crossing)	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage expected from submergence
OPP	OPP1, OPP2	Pumping Plant	0	0	1	2	5	15	30	40	40	40	40	40	Assumes all equipment raised 3 feet above ground level.
OTF	OTF1, OTF2	Tank Farm	0	0	0	0	0	0	0	0	0	0	0	0	Assumes that the tank bottom is at grade, and that the water level in the tank exceeds the flood depth (so the tank will not float). Assumes pump stations and control stations are considered separately.
OCV	N/A	Oil Control Vault & Control Station	1	0	40	40	40	40	40	40	40	40	40	40	Assumes entrance is at grade, and is not sealed.

Table 7.7 Crude and Refined Oil Classifications, Functionality Thresholds and Damage Functions

Label	Earthquake Classification	Specific Occupancy	Functionality Threshold Depth	Percent Damage by depth of flooding in feet(2)											Comments
				0	1	2	3	4	5	6	7	8	9	10	
ORFS	ORF1, ORF2	Small Oil Refinery	4	0	1	2	5	15	30	40	40	40	40	40	Assumes all equipment raised 3 feet above ground level. Mechanical/electrical equipment represents a greater percentage of the plant value that for "open" design
ORFM	ORF3, ORF4	Medium Oil Refinery	4	0	1	2	5	15	30	40	40	40	40	40	
ORFL	ORF3, ORF4	Large Oil Refinery	4	0	1	2	5	15	30	40	40	40	40	40	

[2] *Assumes electrical switch gear is located 3-feet above grade.*

Table 7.8 Natural Gas Classifications, Functionality Thresholds and Damage Functions

Label	Earthquake Classification	Specific Occupancy	Functionality Threshold Depth	Percent Damage by depth of flooding in feet[2]											Comments
				0	1	2	3	4	5	6	7	8	9	10	
NGP1 NGP2	NGP1, NGP2	Exposed Transmission Pipelines River Crossings	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage expected from submergence
NGP1 NGP2	NGP1, NGP2	Buried Transmission Pipelines River Crossings	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage expected from submergence
NGP1 NGP2	NGP1, NGP2	Pipelines (Non-crossing)	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage expected from submergence
NGCV	N/A	Control Valves and Control Stations	1	0	40	40	40	40	40	40	40	40	40	40	Assumes entrance is at grade, and is not sealed.
NGC	NGC1, NGC2	Compressor Stations	4	0	1	2	5	15	30	40	40	40	40	40	Assumes all equipment raised 3 feet above ground level.

[2] *Assumes electrical switch gear is located 3-feet above grade.*

Table 7.9 Electric Power Classifications, Functionality Thresholds and Damage Functions

Label	Earthquake Classification	Specific Occupancy	Functionality Threshold Depth	Percent Damage by depth of flooding in feet[2]											Comments
				0	1	2	3	4	5	6	7	8	9	10	
ESSL	ESS1, ESS2	Low Voltage Substation	4	0	2	4	6	7	8	9	10	12	14	15	Control room damaged starting at 0 feet, and maximized at 7' depth. Additional damage to cabling and incidental damage to transformers and switchgear.
ESSM	ESS3, ESS4	Medium Voltage Substation	4	0	2	4	6	7	8	9	10	12	14	15	
ESSH	ESS5, ESS6	High Voltage Substation	4	0	2	4	6	7	8	9	10	12	14	15	
EDC	EDC1, EDC2	Distribution Circuits Elevated Crossings	N/A	0	0	0	1	1	1	1	2	2	2	2	Low vulnerability due to flooding of ends of buried cables and possible barge traffic impacting transmission towers
EDC	EDC1, EDC2	Distribution Circuits Buried Crossings	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage due to submergence.
EDC	EDC1, EDC2	Distribution Circuits (non-crossing)	N/A	0	0	0	0	0	0	0	0	0	0	0	No damage due to submergence.
EPPS	EPP1, EPP2	Small Power Plants	4	0	2.5	5	7.5	10	12.5	15	17.5	20	25	30	Support facilities damaged on ground level. Control and generation facilities damaged when water elevation reaches 2nd level.
EPPM	EPP3, EPP4	Medium Power Plants	4	0	2.5	5	7.5	10	12.5	15	17.5	20	25	30	
EPPL	EPP3, EPP4	Large Power Plants	4	0	2.5	5	7.5	10	12.5	15	17.5	20	25	30	

[2] *Assumes electrical switch gear is located 3-feet above grade.*

7.2.7 References

US Department of Transportation, Federal Highway Administration, “Recording and Coding Guide for the Structure Inventory and Appraisal of the Nations Bridges”, Federal Highway Administration Report No. FHWA-96-001, December 1995.

Rhodes, J., Trent R, “Economics of Floods Scour and Bridge Failures,” Hydraulic Engineering Conference Proceedings (1993), Rhodes, J., Trent R, “An Evaluation of Highway Flood Damage Statistics,” Hydraulic Engineering Conference Proceedings (1993), Pan American Health Organization, *Natural Disaster Mitigation in Drinking Water and Sewerage Systems - Guidelines for Vulnerability Analysis*, 1998.

Chapter 8. Direct Damage to Vehicles

8.1 Introduction

Motor vehicles of all types and sizes are damaged during flood events. It is known that these damages can be significant, particularly for events with limited warning. The Hazus Flood Model is capable of estimating the dollar cost of flood related damages to motor vehicles for flood events of various size. The user has the option of estimating these damages in default mode or of applying local information on the vehicle fleet, location, dealerships, and other information available to planners.

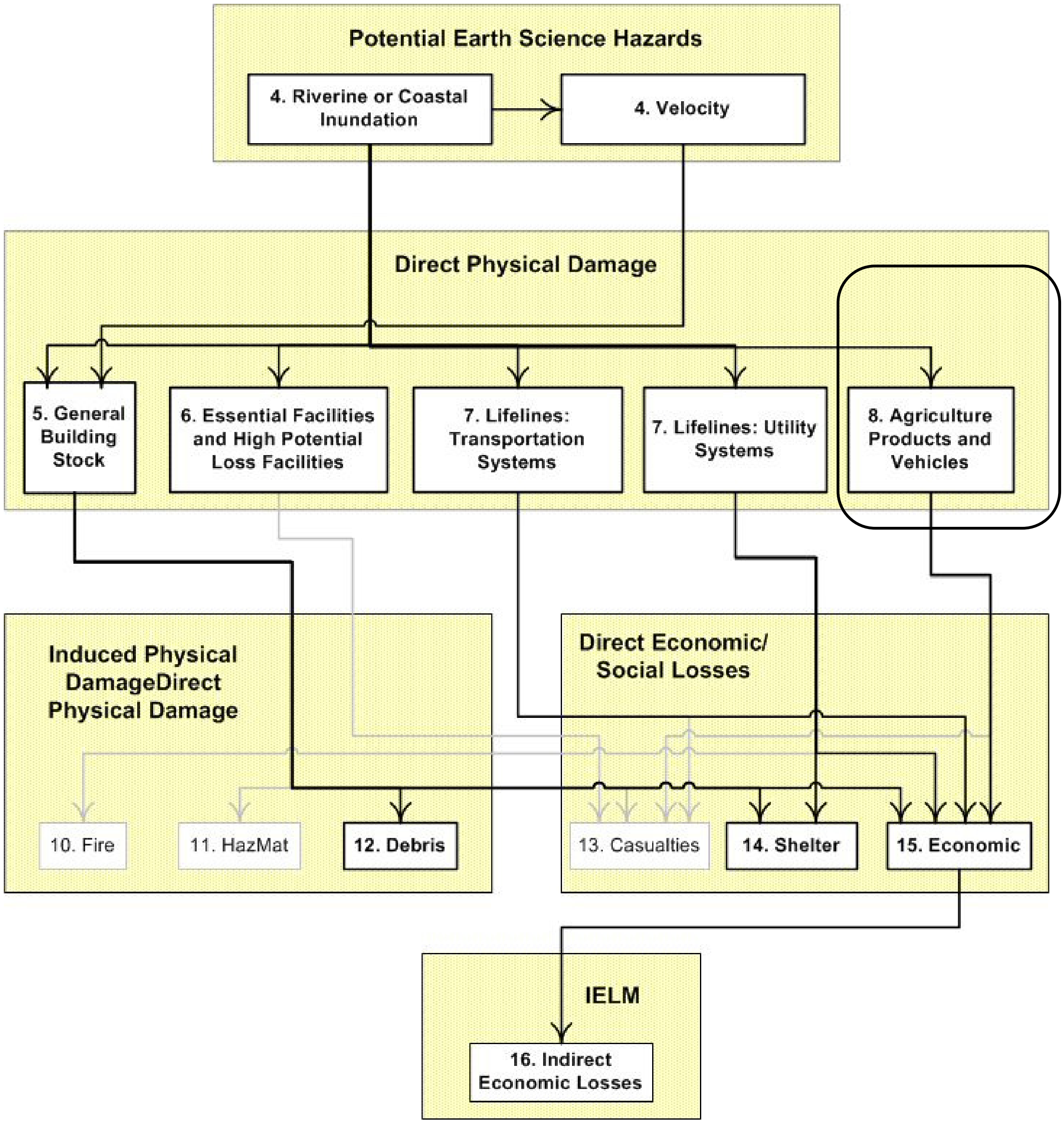

Figure 8.1 Vehicles Relationship to the Components of the Hazus Flood Methodology

8.1.1 Motor Vehicle Damage Estimation

Unlike many other assets, motor vehicles can be moved out of harms way provided that ample time is available before the event and there is a place to deposit the vehicles out of the expected inundation area. The available time for relocating vehicles is important, in part, due to safety issues for drivers who may be operating vehicles in flooded or partially flooded areas. Vehicles are found in flood areas for several reasons including:

- They may be parked at residences, in structures, or on the street;
- They may be in parking facilities at transportation facilities;
- They may be in parking facilities at business locations;
- They may be in use at a business facility or site; or
- They may be parked at motor vehicle sales and repair facilities.

For each location and vehicle profile there is a different likelihood that the vehicle will be damaged and/or that it can be relocated. For example, vehicles at residences can be differentiated by the availability of someone to move the vehicle. This may also be a function of the time available between the warning and the event. If an operator is in the residence and there is an appropriate alternative location for the vehicle, out of the flood risk area, the vehicle can be protected. However, no one may be available at the location and/or they may not be able to reach the location in a suitable time.

Transportation facilities are a collection point for vehicles. Travelers to airports, train stations, and mass transit facilities often park a car at the facility. Depending on their travel plans, they may or may not be available to relocate the vehicle. Multi-story parking facilities may place only those vehicles at or below ground at risk. Vehicles parked at a work location may be moveable provided that the employee works at the vehicle site. Many workers leave their vehicles at a central work location and actually perform their work at a different location. Here again, the distance from the vehicle and the available warning time will determine if the vehicle can be moved.

Other categories of vehicles potentially at risk include those parked at retail facilities and those located in dealer inventories or at vehicle repair facilities. Often employees are concerned about their own family and belongings and are not available to the employer. Note that vehicles may need to be stored for several days after the initial event.

These risks extend to all types of vehicles including cars, small trucks, heavy-duty trucks, and construction equipment. Automobiles are more susceptible to water damage then larger vehicles, but even heavy duty construction equipment can be damaged or destroyed if the water is high enough, debris laden, or sediment filled. Damage to privately owned vehicles and business owned vehicles could have economic and social impacts beyond the direct cost of the damage.

Employment may be reduced as a result of the loss of capital equipment and social structures may be impacted by reduced mobility.

8.1.2 Classification

Vehicles were classified into three major classifications including passenger cars, light trucks, and heavy trucks. These classifications were chosen to identify the general height of the vehicle above the ground and therefore the depth of flooding necessary to start causing damage to the vehicle.

8.1.3 Input Requirements and Output Information

There are no special input or output information necessary for the Flood Model to assess damage to vehicles.

8.1.4 Form of Damage Functions

The vehicle flood damage functions take into consideration the "step-wise" nature of flood damage to vehicles. That is, depths of less than a foot or two are likely to cause no damage, but when the engine compartment is submerged, the vehicle is likely to be considered a total loss as the electronic/computer components and electrical systems are destroyed. In addition, warning is a significant component of vehicle loss modeling, as 100 percent of the loss can easily be avoided by moving the vehicle out of the inundation area. It is anticipate that damage functions will be developed using an expert opinion-based approach for each class of vehicle included in the vehicle inventory.

8.2 Damage Due to Inundation

8.2.1 Overview

For each vehicle type (car, light truck, heavy truck), percentage of damage with regard to the flood level is assigned depending on whether the flood is below carpet, between carpet and dashboard, or above dashboard, as given in Table 8.1.

Table 8.1 Vehicle Depth Damage Relationships

Flood Level (feet)	Car	Light Trk	Heavy Trk	% of Damage
Below Carpet	<1.5	<2.7	<5	15%
Between Carpet & Dashboard	1.5-2.4	2.7-3.7	5-7.5	60%
Above Dashboard	>2.4	>3.7	>7.5	100%

After flood information is provided, these tables of figures will allow one to use Hazus to estimate the value of vehicle damage in an area. All the numbers presented here are suggested default values and users should be able to modify them according to local characteristics.

Generally, one will expect the number of vehicles parked in an area to more or less match the number of registered vehicles in that area, especially during nighttime.

8.2.2 Depth-Damage Functions

The vehicular depth damage functions are step functions since flood damage occurs when critical components are immersed. The depth damage functions can be seen in Figure 8.2 below.

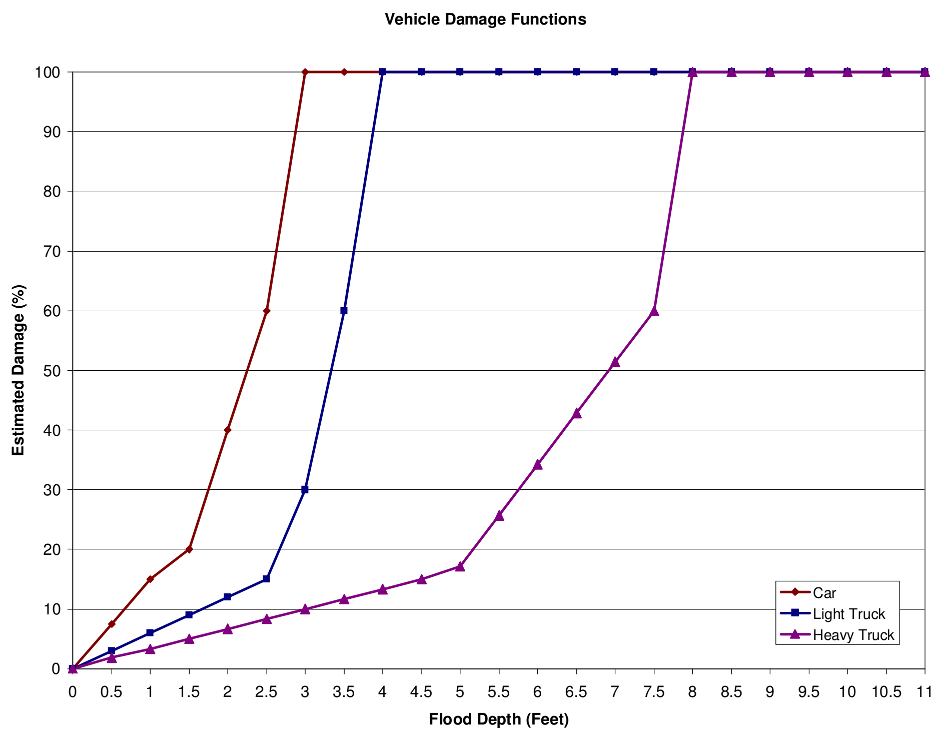

Figure 8.2 Vehicle Depth Damage Functions

8.2.3 Consideration of Warning and Associated Damage Reduction

The Flood Model provides an input parameter to allow the user to account for the potential reduction of vehicle losses due to warning. The approach is a simple reduction of the net damage and loss based on the users input. As there is very little research information regarding the impact of flood warning on vehicle damage it was determined that the best approach would be to allow the user to anticipate the complete removal of all vehicles from the flooded area with sufficient warning. The default value currently assumes that all vehicles are in the census block at the time of the flood.

8.3 Guidance for Expert Users

There is little additional analysis an expert user can perform over the default provisions, the advanced user can modify the default data, or use their local transportation planning square footage formula to develop a revised inventory that can be imported into the Flood Model. The advanced user can develop new depth damage functions for various vehicle types based on the existing functions.

Chapter 9. Direct Damage to Agriculture (Crops)

9.1 Introduction

This chapter describes the methods for determining the direct physical damage to agriculture products, specifically crops. Unique to the Flood Model within Hazus, the treatment of agriculture products is based in part on the methodology developed by the USACE in their Agriculture Damage Assessment Model (AGDAM). The methodology required the project team to gather information from multiple sources and compile the data into a format usable within the model. The Flood Model collected and provides default data as a starting point for the user.

The user should use care as the agriculture industry is in a continual state of flux with farmers continually changing their planting efforts to anticipate or meet the needs of the marketplace. The value of agriculture products varies widely as the condition of the farming community varies due to weather, insects, and market trends. Every effort has been made to allow the user to modify the inventory and valuation of the agriculture product default data.

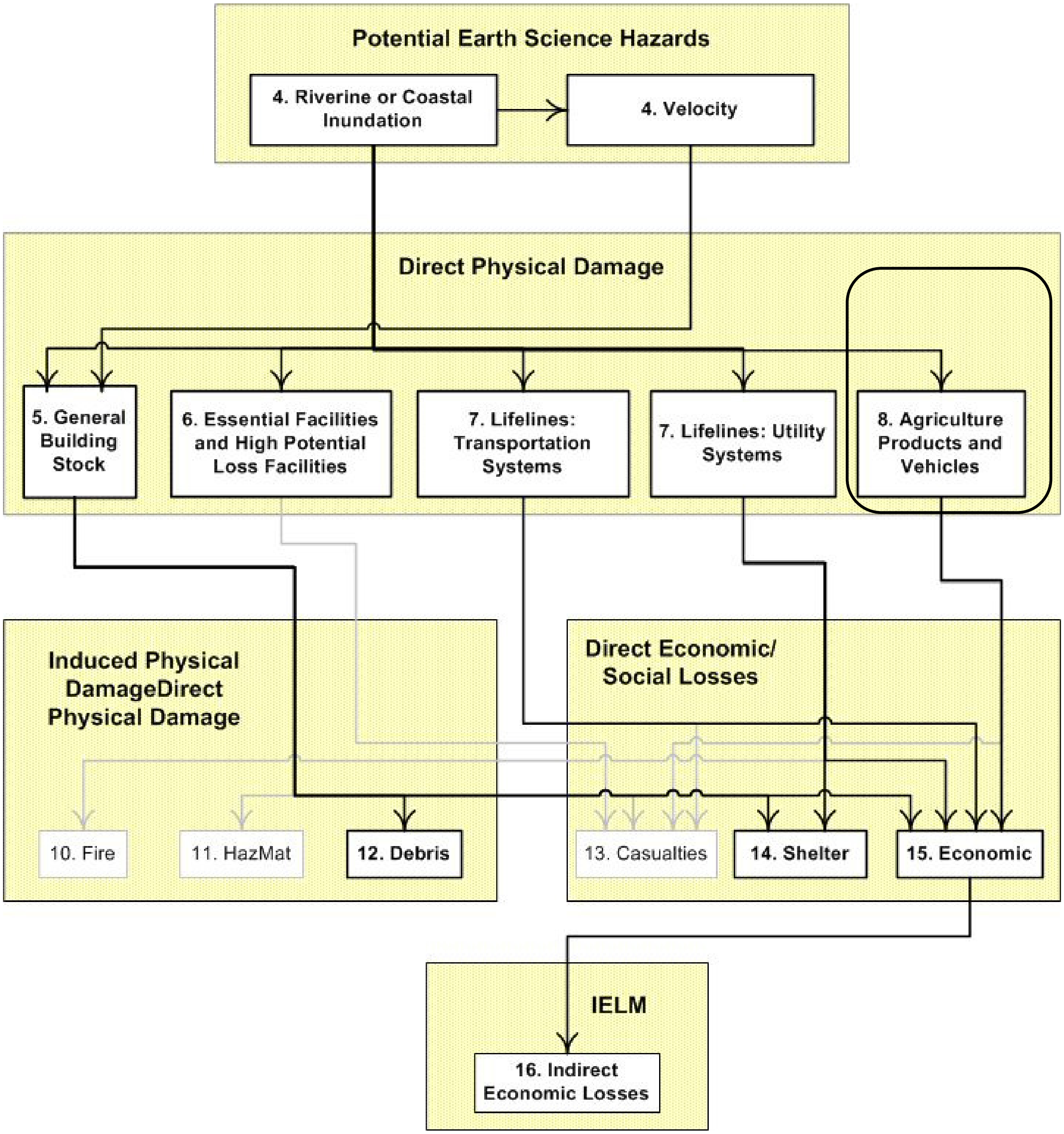

Figure 9.1 Agricultural Products Relationship to the Components of the Hazus Flood Methodology

9.1.1 Scope

The scope of this chapter includes (1) classification of the agriculture products, (2) crop damage functions based on the Julian calendar, function modifiers for duration, (3) methods for estimation of flood damage to agriculture products, given knowledge of the crop type and relative location in the floodplain, and (4) guidance for expert users.

9.1.2 Classification of Agriculture Products

There are a wide variety of agriculture products in production at any given moment within the United States. This, combined with a relative limited number of damage functions related to agriculture products, forced the Flood Model team to limit the quantity of crops defined within each state. The project team collected the top 20 agriculture products within each state and captured the current valuation (sale price) of the products to give the user a strong basis for moving forward. The resulting list of 40 crops included within the Hazus Flood Model (subject to the limit of 20 per state) is given in Table 9.1.

Table 9.1 Crop Types Currently Available Within the Hazus Flood Model

Crop Type	Crop Type	Crop Type
Alfalfa Hay	Apples	Bahiagrass
Barley	Bromegrass-Alfalfa Hay	Common Bermudagrass
Corn	Corn Silage	Corn, Sweet
Cotton Lint	Crested Wheatgrass-Alfalfa Hay	Flax
Grain Sorghum	Grapes, Wine	Grass Hay
Grass-Clover	Grass-Legume Hay	Improved Bermudagrass
Kentucky Bluegrass	Oats	Oranges
Orchard Grass	Orchardgrass-Alfalfa Hay	Peanuts
Pears	Potatoes, Irish	Reed Canarygrass
Rice	Smooth Bromegrass	Soybeans
Sugar Beets	Tall Fescue	Tall Fescue-Ladino
Timothy-Red Clover Hay	Tobacco	Tomatoes
Trefoil-Grass Hay	Watermelons	Wheat
Wheat, Winter		

The crop data was gathered using the National Resources Inventory (NRI) dataset. The NRI consists of sample points throughout the county. These data points are associated with soils data and given expansion factors that identify what the data point represents in terms of a sampling in terms of acres. For example, on point could represent 25,000 acres of crop types and soils. The NRI data is also associated with polygons that have been developed by intersecting the 8-digit hydraulic unit codes (HUC) developed by the USGS with the county boundary. The data provides the crop type and units. The NRI is captured approximately every 5-years. To smooth the data out, the project team averaged five years of data to develop the default crop inventory.

To identify the crop yield, the sample points within a given polygon are multiplied by the expansion factor and then summed over the polygon. The total yields are then averaged over the collection intervals of the NRI data to produce the average yield seen by the user when viewing the inventory data.

To capture the annual fluctuations in pricing for each crop type, the National Agriculture Statistical Survey (NASS) was obtained. The NASS covers nearly every aspect of the agriculture industry and provides the link between the crop types and the price per unit. Since the NASS data represents a snapshot of the current agriculture crop market price, the most recent survey is used.

To provide the user with some concept of the costs invested by the farmer in the preparation of their crops, the National Resources Inventory and Analysis Institute (NRIAI) compiles data related to the crop care budgets and from that the harvest cost, or the amount of money invested by the farmer to bring the crop to market.

9.1.3 Input Requirements and Output Information

The Flood Model provides a default agriculture product base, which includes the key input requirements for the analysis. These inputs include the crop type, its association with a geographic dataset that locates the crop within non-developed areas within the study region, the current market value of the product, and the planting season of the crop as it relates to the time of flooding.

9.1.4 Form of Damage Functions

The damage functions for crops do not depend on the depth of flooding. Damage to crops depends on when the flood occurs and the duration of flooding. The user is provided with damage functions based on calendar date and the duration modifiers based on Julian date. The Flood Model automatically converts calendar date to the Julian calendar system. The user is able to modify the damage functions to reflect local crop planting cycles and the user has the capability of modifying the functions.

The user is required to provide a date of flooding (calendar) and the Flood Model estimates the losses based on standard durations provided by the USACE of 3-days, 7-days and 14-days. Losses are estimated based on the area of inundation versus total area of crop land and the subsequent reduction in output, investment, and income.

The loss model used is based on the USACE's AGDAM methodology and program.[1] Only two viable methodologies for agricultural flood loss estimation were identified in the literature search: AGDAM and the USACE Vicksburg District's CACFDAS (Computerized Agricultural Crop Flood Damage Assessment System) model.[2] The principal difference between them is that AGDAM considers probabilistic flood hazard, while CACFDAS is deterministic and uses

[1] The Hydrologic Engineering Center, U.S. Army Corps of Engineers. 1985. *AGDAM Users Manual* (provisional). Davis, California.

[2] The USDA's Risk Management Agency does not have any model specifically for flood.

historic flood records as inputs; otherwise, for any specific event, the core methodologies are very similar. The core of the AGDAM model can be represented as follows for each crop and elevation range that is flooded:

$$L = A\left(pY_0 - H\right) \cdot D(t) \cdot R(t) \tag{9-1}$$

where:

L	=	loss ($),
A	=	cultivated area (acres),
P	=	price ($/bushel),
Y_0	=	normal annual yield (bushels/acre),
H I	=	harvest cost ($/acre),
D(t)	=	crop loss at day t of the year (% of maximum net revenue), and
R(t)	=	the crop loss modifier for flood duration (percent of maximum potential loss).

During the proof of concept analysis, the vulnerability of crops to standing water became evident as comparisons to the 1993 floods in Story County showed that much of the crop loss was due to standing water that pooled in "potholes" (local term) from accumulated rainfall. The County is very flat with poorly defined drainage. While the "potholes" generally drain within 36 to 72 hours, in 1993, frequent and continuous rainfall caused the potholes to stay filled, leading to crop loss. "Potholes" are a regional topographic feature defined by the extent of recent glaciation. They tend to pose a flooding problem in central and northern Iowa, southern Minnesota, Wisconsin, and northern Illinois. In southern Iowa, southern Illinois, and Indiana, they are generally not a problem and crop loss would primarily be from river flooding.[3] Other reasons for the underestimation of losses include the neglect of weather-related factors such as a wet, cool growing season, delayed planting, and early frost that were all important in reducing yields in 1993.

It is critical to note, therefore, that the losses modeled with the AGDAM approach are limited to crops lost due to riverine flooding and different in scope than the estimates of "actual" 1993 flood loss. Since modeling the behavior of standing water would be exceedingly difficult, the Flood Model will estimate crop losses using an AGDAM-type approach and the user must modify the results as appropriate based on local knowledge of factors such as "potholes," assumed weather impacts, etc. This modification would allow a more reasonable estimate of direct loss in the agriculture sector that could be input into the model for indirect economic losses.

9.2 Damage Due to Inundation

The Flood Model directly addresses the damage associated with inundation, and as discussed in the previous section, the damage functions developed by the USACE include modifiers to account for the duration of inundation. In most cases, crops will not suffer significant losses for

[3] Communication with Dr. A. Austin, Iowa State University Center for Disaster Related Research, 2/19/99.

a very short-term flood. As the duration of the flood approaches 14-days, the likelihood of significant damage greatly increases.

9.3 Damage due to Collateral Hazards (duration)

The Flood Model is not developing a specific duration factor. However, the Flood Model will estimate agriculture damage for a range of durations. The USACE has a set of duration functions with factors for 0, 3, 7, and 14 days of duration. The Flood Model will provide a single table that lists the losses by crop type for each duration period.

9.4 Benefits of Flooding

In recent years, there has been growing interest in more detailed and accurate assessment of the beneficial functions of floodplains to support floodplain management decision-making (Kusler, 1997). Undeveloped and evacuated floodplains provide a number of valuable functions to society, which have historically been overlooked. The major functions include attenuation of flood flows, maintenance of high soil and water quality, water supply, wildlife habitat, and recreational opportunities.

9.4.1 Flood Attenuation

Undeveloped floodplains help attenuate flooding through the absorption and storage of floodwaters. Floodplains also help reduce flood velocity because friction factors are much higher in the floodplain than in the main channel. The velocity reduction reduces erosion and allows for the deposition of sediment. The construction of flood control projects such as levees, floodwalls, and channel modifications result in decreased floodway width and increased hydraulic conveyance. Such structural remedies are designed to protect areas previously located in the historic floodway and quickly pass floods downstream. However, they also serve to separate the river from its floodplain, eliminating the flow management services provided by floodplain wetlands. The resulting increases in flow rates, flood depths, and sediment loads often increase the costs of flood damages for downstream communities and property owners. In coastal areas, wetlands can form a buffer between development infrastructure and hurricanes and other storm surges. Coastal wetlands absorb enormous amounts of water and dissipate wave energy that would otherwise allow storms to do severe damage inland (LCWCRTF, 1997). The flood attenuation value that natural floodplains provide to society is manifested in the following ways:

- Loss reductions in structure, contents, infrastructure, and income
- Cost reductions in emergency response, administration, and health care
- Retarded rate of sediment deposition into lakes, reservoirs, and estuaries

9.4.2 Soil Quality

As flood flows spread out over a floodplain, nutrient rich sediments are deposited. This deposition can improve soil quality for agricultural and environmental purposes.

9.4.3 Water Quality

Undeveloped floodplains provide water treatment value by improving water quality. Floodplain plants and soils provide natural water filtering, nutrient uptake, and detoxification of pollutants that would otherwise flow into watercourses (USACE, 1996). Trees growing along the riverbank and in within wetlands provide shade that reduces water temperatures. Studies of polluted waters flowing through wetlands have shown significant reductions in biochemical oxygen demand (BOD), phosphorous, and nitrogen.

9.4.4 Water Supply

Floodplains are an important setting for groundwater recharge. Riverine floodplains reduce the frequency and duration of low surface flows (maintain base flows) by slowly releasing water stored during flooding (Cowdin, 1999). Water stored through floodplains can be used for agricultural, municipal, industrial purposes.

9.4.5 Wildlife Habitat

It has been estimated that nearly 70% of all vertebrate species rely on the floodplain during their life cycle (American Rivers, 2000) for food, shelter, migration, and reproduction. Natural floodplains have a high degree of biological diversity and productivity. River corridors are frequently used as migration avenues for birds; aquatic and wetland areas provide habitats for fish; floodplain trees serve as important nesting habitats.

9.4.6 Recreational Setting

Floodplains provide the setting for a host of recreational activities, such as swimming, boating, fishing, hunting, hiking, camping, and viewing wildlife.

9.4.7 Others

There are several other important functions provided by natural floodplains that are not considered further in this paper. Floodplains improve air quality through removal of atmospheric carbon, can moderate temperatures in urban areas, and provide a setting for educational and scientific research activity.

9.5 Ecological Assessment of Natural Floodplain Functions

The term floodplain is defined by FEMA as any land area susceptible to being inundated by floodwater from any source (FEMA, 2000). Within this broad definition are aquatic, riparian, and wetland sections (Figure 9.2). Aquatic areas are characterized by having standing or moving water at some time during the year, such as streams and lakes, whereas riparian areas border rivers, streams and creeks and typically include the channel banks and the greater floodplains. Wetlands are special aquatic areas that often develop in transitional zones between aquatic and upland habitats, and can occur in riverine, lacustrine, and coastal settings. Wetlands are either permanently or seasonally wet and support specially adapted vegetation and wildlife (Cowdin, 1999).

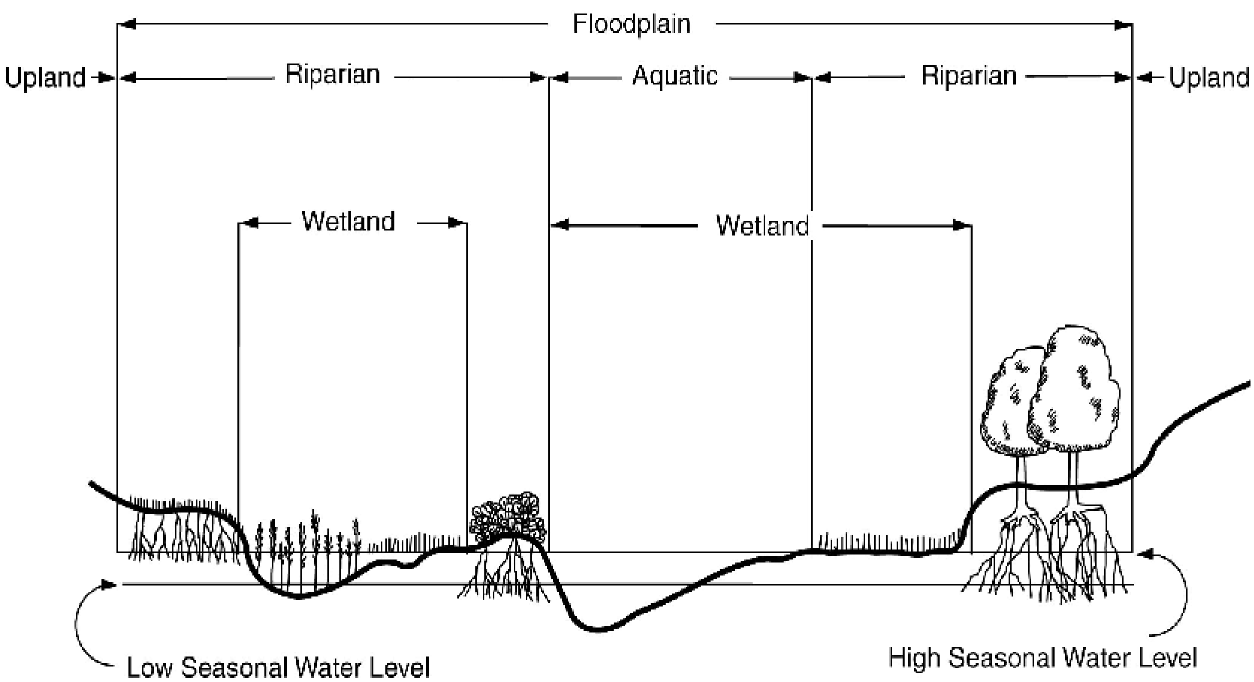

Figure 9.2 Riverine floodplain sections (Source: Cowdin, 1999)

The majority of methods used for the functional assessment of natural floodplains are focused on the evaluation of wetlands. Not all wetlands perform all functions, nor do they perform all functions equally well. Numerous factors, such as the size of a wetland and its location within a watershed, may determine what functions it will perform (Novitski, et al., 1996). Several wetland assessment methods have been developed that are used by wetland managers and planners to assign floodplain functions to specific wetlands. Three of these methods are summarized in the following paragraphs.

9.5.1 Wetland Evaluation Technique

First developed in 1983, the wetland evaluation technique (WET) is designed to evaluate individual wetlands based on their functions. Characteristics such as vegetation, topography, and watershed characteristics are used to estimate whether a wetland has a high, medium, or low probability of performing various functions (Novitski, et al., 1996):

- groundwater recharge
- groundwater discharge
- flood flow alteration
- sediment stabilization
- sediment/toxicant retention
- nutrient removal/transformation
- production export
- wildlife diversity/abundance
- aquatic diversity/abundance
- recreation
- uniqueness/heritage

The evaluation is based on the capability and potential of a wetland to perform each function, as well as its societal significance (ecologic and economic). The resulting probability ratings estimate the likelihood of a wetland to perform each function.

9.5.2 Environmental Monitoring Assessment Program

The environmental monitoring assessment program (EMAP) was created by the U.S. EPA in 1988, with the goal of measuring the condition and trends of many types of ecological resources, such as forests, wetlands, deserts, agricultural systems, and surface waters (EPA, 1997). The wetlands component of the EMAP is designed to identify indicators of wetland condition, standardize measurement protocols, develop indices of condition, and establish a national network for monitoring wetland condition (Novitski, et al., 1996). The categories used to assess wetland condition are biological integrity, harvestable productivity, flood reduction and shoreline protection, groundwater conservation, and water quality improvement. Indices of wetland condition relate to one or more of these categories, and are compared to those of the least impacted wetlands in the region, so called reference wetlands.

9.5.3 Hydrogeomorphic Approach

Hydrogeomorphic (HGM) classification was originally developed in the early 1990s, and is somewhat of a hybrid of the WET and EMAP methodologies. The US Army Corps of Engineers has adopted the approach in order to satisfy requirements of Section 404 of the Clean Water Act. The approach is intended to be regionally-applicable, with the ability both to assess a variety of wetland types and functions, and to assess functions accurately and efficiently within time and resource constraints (Smith, et al., 1995). To apply HGM classification to a given region, the functions performed by wetlands in a specific hydrogeomorphic setting are first identified. The characteristics of a specific wetland are then compared to the characteristics of reference wetlands (Novitski, et al., 1996). This comparison is used to assign a value to each beneficial function. The particular characteristics evaluated are limited to those important to the region and hydrogeomorphic setting.

The WET, EMAP, and HGM methodologies are the primary approaches used for wetland assessment, but are by no means the only ones. Unfortunately, many existing techniques have been plagued by a variety of problems and limitations including high costs, technical expertise needs, and margins of error. Moreover, the methods may provide only a portion of the assessment information needed for specific floodplain management purposes. Overall, these techniques can be used to help assess the natural functions of wetland and broader floodplain areas, but should be approached with care (Kusler, 1997).

9.6 Economic Valuation of Natural Floodplain Functions

Floodplains perform a multitude of complex and interrelated functions that provide valuable goods and services to society (Cowdin, 1999). But because of the non-market nature of most floodplain benefits, they are often difficult to quantify. However, several techniques have been developed to measure the economic value of non-market goods and services; they can be grouped into four primary categories: market approaches, indirect market methods, expressed preference models, and benefit transfer.

9.6.1 Market Approaches

These methods rely on market-determined prices to determine the value of ecosystem goods that are sold in organized markets.

- *Direct Market Price Method* – current or past market prices are used to assign value to goods or services. Some examples of floodplain goods sold in the open market include water supply, commercially harvested fish, and wood products.

- *Factor Income/Productivity Method* – the value of a marketed good is measured relative to the change in value of a non-market ecosystem service that serves as a factor of production for the marketed good. The factor income/productivity method relies on estimating and using this production relationship to estimate how changes in an ecosystem will affect the production costs or profits of the marketed good. For example, an increase in soil quality could lead to lower crop production expenses. The resulting increase in agricultural profits could be used as a measure of the soil quality function of an undeveloped floodplain. Weakness: applicable only if the production unit in question is small relative to the overall production of the marketed good, or if the improvement in the ecosystem service represents only a small marginal change (USACE, 1996).

9.6.2 Indirect Market Methods

These methods infer values for goods and services based on prices observed for other related goods and services (Cowdin, 1999):

- *Avoided Costs* – Avoided costs can be estimated in two ways. In the least cost alternative method, the value of a good or service is measured by assuming that its benefit cannot have a value higher than the alternative costs avoided. For example, the water quality benefit of a floodplain could be measured as the cost of building and operating a water treatment facility.

In the property damages avoided method, the benefit of the ecosystem service is estimated based on the dollar value of property damages expected to result from not having the service (assumes no alternative). As an example, consider the justification of a floodplain development regulation. The benefits of flow and velocity reduction could be estimated by the value of avoided property damages.

- *Replacement Costs* – measures the value of a good or service assuming that its benefit cannot have a value higher than the cost of producing the same good or service in another way. For example, the value of preserving habitat in one particular location can be measured by the cost of replacing that habitat (with similar structural and functional characteristics) in another (Cowdin, 1999).

- *Hedonic* Pricing – measures the contributions of various characteristics to the price of a good. For example, the hedonic property value model asserts that the price paid for a property directly reflects environmental attributes such as clean air, beauty, and proximity to wetlands, fishing, and hiking (Farnam, 1999). As such, this method is useful for the value estimation of ecosystem amenities and aesthetics. Strength: actual market prices are used. Weakness: the environmental characteristics must be shown to affect price.

- *Travel Cost* – measures the value for a good or service based upon the costs (time and money) incurred by consumers to obtain that good. This method is typically applied to the measurement of recreational benefits. Strength: allows the use of observed values. Weakness: region-wide modeling is required to estimate impacts of changes in site quality.

9.6.3 Expressed Preference Models

In this approach, values are determined for ecosystem services directly through expressed preferences in money bids, hypothetical markets, policy referenda, and surveys (USACE 1996).

- *Contingent Valuation Method* – sophisticated surveys are used to estimate willingness to pay for environmental improvement. Strength: can be applied to estimate values for a multitude of ecosystem benefits. Weakness: questions can be misinterpreted and responses can be biased. In short, the results may not be reliable.

9.6.4 Benefit Transfer

The benefit transfer approach is not really an evaluation model, but rather a way to apply results between studies. Existing non-market values are transferred to a new study which is different from the study for which the values were originally estimated (Farnam, 1999). Strength: estimates can be quickly and cheaply developed. Weakness: the quality of the results depends heavily on the quality of the original study.

Table 9.2 indicates which economic methods are applicable to various functions of natural floodplains. Table 9.3 summarizes the results of previous studies in which monetary values were derived for certain floodplain functions through the application of economic valuation methods.

ter 9. Direct Damage to

Table 9.2 Economic Methods for Valuing Natural Floodplain Functions

Natural Floodplain Functions	Valuation Method						
	Market Price Analysis	Factor Income/ Productivity	Avoided Costs	Replacement Costs	Travel Costs*	Hedonic Property Pricing*	Contingent Valuation*
Attenuate Flood Flows		X	X	X		X	X
Maintain Soil Quality	X	X	X	X			X
Maintain Water Quality	X	X	X	X			X
Maintain Water Supply	X	X	X	X			X
Maintain Wildlife Habitats	X	X	X	X	X	X	X
Maintain Air Quality	X	X	X	X		X	X

* *Original studies or transfers from other studies.*

(Adapted from Cowdin, 1999)

Table 9.3 Summary of Non-market Values ($ 1998)

Activity	Number of Studies	Methodologies	Range	Mean	Units
Camping	24	Travel cost; Contingent valuation	9.10 - 32.5	23.50	$/Day
Picnicking	12	Travel cost; Contingent valuation	6.5 - 52	20.80	$/Day
Biking	2	Travel cost; Contingent valuation	60.20 - 61.38	60.81	$/Day
Boating *	21	Travel cost; Contingent valuation	7.70 - 216.55	51.35	$/Day
Recreational Fishing	4	Travel cost; Contingent valuation	15 - 95.30	55.00	$/Day
Waterfowl Hunting	21	Travel cost; Contingent valuation	27.60 - 113.16	51.51	$/Day
Flood Prevention	3	Hedonic Pricing	5 - 10	7	% of property value
Value of Wetlands	2	Contingent valuation	19.57-251	---	$/respondent

** Motorized and non-motorized boating.*

(Adapted from Farnam, 1999)

9.7 Guidance for Expert Users

Agriculture products is a simplified analysis intended to provide the user with a broad range of potential losses to account for the variation of duration that may occur. The Flood Model provides the expert user with the capability to add or set existing crops to zero. The crop inventory must be placed in an existing sub-county polygon. The user should not modify the GIS layer as the browser viewer is joined to the flAG.mdb file in order to display those polygon areas where the NASS shows with no crops within the sub-county regions.

The advanced user can adjust the duration factors and the damage curves to meet their needs. There is currently no damage function library for agriculture crops at this time.

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Chapter 10. Induced Damage Models - Hazardous Materials Release

10.1 Introduction

Hazardous materials are those chemicals, reagents or substances that exhibit physical or health hazards, whether the materials are in a usable or waste state. The scale, and hence the consequences, of hazardous materials releases can vary from very small, such as a gallon of paint falling off of shelves, to regional, such as release of toxic chemicals from a processing plant. Most hazardous materials incidents have immediately led to human casualties only in cases where explosions have occurred. Non-explosive hazardous materials incidents, which comprise the vast majority, typically have led to contamination of the environment and temporary health consequences to human beings. Hazardous materials releases can also lead to fires. With specific reference to flood caused hazardous materials incidents, the data thus far indicate that there have been no human identified casualties. The consequences of these incidents have been fires and contamination of the environment, and have led to economic impacts because of the response and clean-up requirements. The methodology highlighting the Hazardous Materials Release component is shown in Figure 10.1.

While the Flood Model does not directly estimate damage caused by the release of hazardous materials, nor does the model estimate the probabilities of such a release occurring. The user can, however, place the locations of the hazardous materials inventory onto the hazard data (the depth grid) and identify those areas where the hazardous materials sites had been exposed to significant flooding.

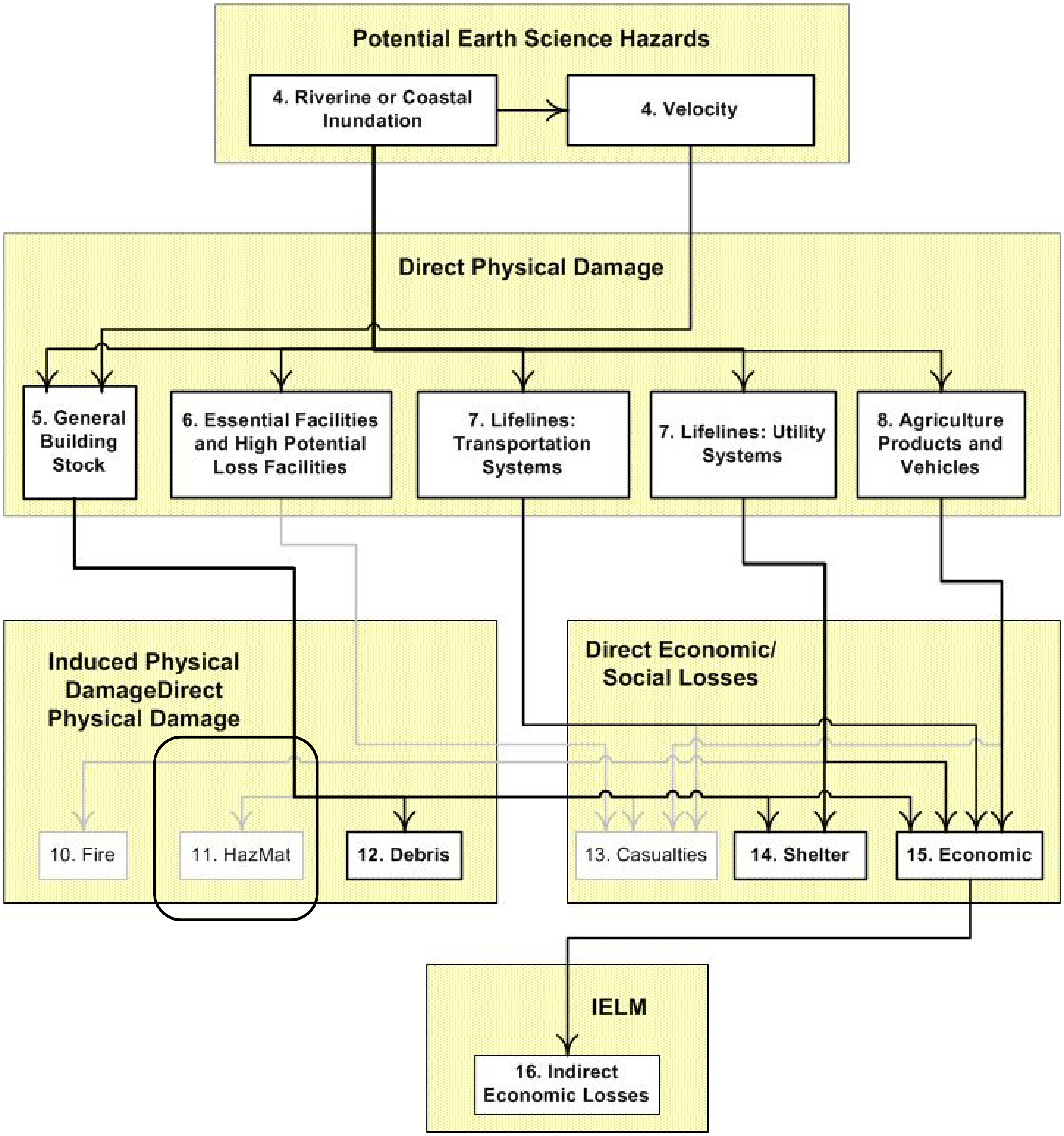

Figure 10.1 Hazard Materials Relationship to Other Components of the Hazus Flood Methodology

10.1.1 Scope

This loss estimation methodology has been restricted to identifying the location of facilities that contain hazardous material which could lead to a significant immediate demand on health care and emergency response facilities. These types of incidents would include large toxic releases, fires or explosions. Thus, the default database of hazardous material facilities is limited to facilities where large quantities of chemicals that are considered highly toxic, flammable or highly explosive are stored. Estimates of releases that could cause pollution of the environment and the need for long-term clean-up effects are beyond the scope of this methodology.

An exhaustive search of the existing literature for models that can be utilized to predict the likelihood of occurrence of hazardous materials releases during flooding was conducted at the beginning of this study. Unfortunately, no directly usable models were found.

Due to the limitations of state-of-the-art hazardous materials release models, this module is restricted to establishing a standardized approach for classifying materials and developing a good database that can be used by local planners to identify those facilities that may be most likely to have significant releases in the event of flooding. A default database of potential sites is provided from an EPA database of hazardous materials sites. This database can be supplemented by the user with local information. A more detailed vulnerability assessment would involve going to individual facilities to determine how chemicals are stored, the vulnerability of buildings and storage tanks and other relevant information.

10.1.2 Classification of Hazardous Materials

The most widely used detailed classification scheme is the one that has been developed by the National Fire Protection Association, and is presented in the 1991 Uniform Fire Code, among other documents. This classification scheme is shown in Table 10.1. The hazards posed by the various materials are divided into two major categories: Physical Hazards and Health Hazards. Depending upon the exact nature of the hazard, these two major categories are divided into subcategories. These subcategories of hazards, with their definitions, and examples of materials that fall within each category, are contained in Appendix 10A and 10B. A more detailed description of these categories, with more extensive examples can be found in Appendix VI-A of the 1991 Uniform Fire Code. Table 10.1 also contains minimum quantities of the materials that must be on site to require permitting according to the Uniform Fire Code. It should be noted that the minimum permit quantities might vary depending upon whether the chemical is stored inside or outside of a building.

10.1.3 Input Requirements and Output Information

The input to this module is essentially a listing of the locations of facilities storing hazardous materials and the types/amounts of the materials stored at the facility. Facilities need only be identified if they use, store or handle quantities of hazardous materials in excess of the quantities listed in Table 10.1. Other facilities that may have hazardous materials, but in quantities less than those listed in Table 10.1 should not be included in the database because it is anticipated that releases of these small quantities will not put significant immediate demands on health and emergency services. However, the user may choose to modify threshold amounts in building the database.

Table 10.1 Classification of Hazardous Materials and Permit Amounts

Label	Material Type	Permit Amount		Hazard Type & Remarks
		Inside Building	Outside Building	
HM01	Carcinogens	10 lbs	10 lbs	Health
HM02	Cellulose nitrate	25 lbs	25 lbs	Physical
HM03	Combustible fibers	100 cubic ft	100 cubic ft	Physical
	Combustible liquids			Physical
HM04	Class I	5 gallons	10 gallons	
HM05	Class II	25 gallons	60 gallons	
HM06	Class III-A	25 gallons	60 gallons	
HM07	Corrosive gases	Any amount	Any amount	Health [1]
HM08	Corrosive liquids	55 gallons	55 gallons	Physical; Health
	Cryogens			
HM09	Corrosive	1 gallon	1 gallon	Health
HM10	Flammable	1 gallon	60 gallons	Physical
HM11	Highly toxic	1 gallon	1 gallon	Health
HM12	Nonflammable	60 gallons	500 gallons	Physical
HM13	Oxidizer (including oxygen)	50 gallons	50 gallons	Physical
HM14	Highly toxic gases	Any amount	Any amount	Health; [1]
HM15	Highly toxic liquids & solids	Any amount	Any amount	Health
HM16	Inert	6,000 cubic ft	6,000 cubic ft	Physical; [1]
HM17	Irritant liquids	55 gallons	55 gallons	Health
HM18	Irritant solids	500 lbs	500 lbs	Health
HM19	Liquefied petroleum gases	> 125 gallons	> 125 gallons	Physical
HM20	Magnesium	10 lbs	10 lbs	Physical
HM21	Nitrate film	(Unclear)	(Unclear)	Health
HM22	Oxidizing gases (including oxygen)	500 cubic feet	500 cubic feet	Physical [1]
	Oxidizing liquids			Physical
HM23	Class 4	Any amount	Any amount	
HM24	Class 3	1 gallon	1 gallon	
HM25	Class 2	10 gallons	10 gallons	
HM26	Class 1	55 gallons	55 gallons	
	Oxidizing solids			Physical
HM27	Class 4	Any amount	Any amount	
HM28	Class 3	10 lbs	10 lbs	
HM29	Class 2	100 lbs	100 lbs	
HM30	Class 1	500 lbs	500 lbs	

Table 10.1 Classification of Hazardous Materials and Permit Amounts (Continued)

Label	Material Type	Permit Amount		Hazard Type & Remarks
		Inside Building	Outside Building	
	Organic peroxide liquids and solids			Physical
HM31	Class I	Any amount	Any amount	
HM32	Class II	Any amount	Any amount	
HM33	Class III	10 lbs	10 lbs	
HM34	Class IV	20 lbs	20 lbs	
	Other health hazards			Health
HM35	Liquids	55 gallons	55 gallons	
HM36	Solids	500 lbs	500 lbs	
HM37	Pyrophoric gases	Any amount	Any amount	Physical [1]
HM38	Pyrophoric liquids	Any amount	Any amount	Physical
HM39	Pyrophoric solids	Any amount	Any amount	Physical
HM40	Radioactive materials	1 m Curie in unsealed source	1 m Curie in sealed source	Health [1]
HM41	Sensitizer, liquids	55 gallons	55 gallons	Health
HM42	Sensitizer, solids	500 lbs	500 lbs	Health
HM43	Toxic gases	Any amount	Any amount	Health [1]
HM44	Toxic liquids	50 gallons	50 gallons	Health
HM45	Toxic solids	500 lbs	500 lbs	Health
HM46	Unstable gases (reactive)	Any amount	Any amount	Physical [1]
	Unstable liquids (reactive)			Physical
HM47	Class 4	Any amount	Any amount	
HM48	Class 3	Any amount	Any amount	
HM49	Class 2	5 gallons	5 gallons	
HM50	Class 1	10 gallons	10 gallons	
	Unstable solids (reactive)			Physical
HM51	Class 4	Any amount	Any amount	
HM52	Class 3	Any amount	Any amount	
HM53	Class 2	50 lbs	50 lbs	
HM54	Class 1	100 lbs	100 lbs	
	Water -reactive liquids			Physical
HM55	Class 3	Any amount	Any amount	
HM56	Class 2	5 gallons	5 gallons	
HM57	Class 1	10 gallons	10 gallons	
	Water-reactive solids			Physical
HM58	Class 3	Any amount	Any amount	
HM59	Class 2	50 pounds	50 pounds	
HM60	Class 1	100 pounds	100 pounds	

[1] Includes compressed gases

To build the hazardous materials database for a selected region, the user should attempt to gather the following information:

- Name of Facility or Name of Company
- Street Address
- City
- County
- State
- Zip Code
- Name of Contact in Company
- Phone Number of Contact in Company
- Standard Industrial Classification (SIC) Code
- Chemical Abstracts Service (CAS) Registry Number
- Chemical Name
- Chemical Quantity
- Hazus Hazardous Material Class (From Table 10.1)
- Latitude and Longitude of Facility

The Chemical Abstracts Service (CAS) registry number is a numeric designation assigned by the American Chemical Society's Chemical Abstracts Service and uniquely identifies a specific chemical compound. This entry allows one to conclusively identify a material regardless of the name or naming system used. To obtain this data the user must identify the local agency with which users of hazardous materials must file for permits. Based upon current understanding of the process, this local agency would be the Fire Department for incorporated areas, and the County Health Department for unincorporated areas. The user may opt to use only the information contained in a modified version of the EPA-TRI Database that is provided in the methodology. This database, however, is limited and the user is urged to collect additional inventory.

The output of this module is essentially a database that can be sorted according to any of the fields listed above. It can be displayed on a map and overlaid with other maps.

10.2 Description of Methodology

The analysis here is divided into three levels, as described below:

- Default Analysis: Listing of all facilities housing hazardous materials that are contained in the default hazardous materials database.

- User-Supplied Data Analysis: Listing of all facilities housing hazardous materials that are contained in the default hazardous materials database and refined by the user with locally available information.

- Advanced Data and Models Analysis: Detailed risk assessment for individual facilities, including expert-generated estimates.

10.3 Guidance for Expert-Generated Estimates

The Flood Model is not configured to perform an expert generated estimate for hazardous materials. This is because flood related release of hazardous materials creates the added requirement of identifying the amount of dilution of the material in the flood waters (depending on the material), reactivity with water and other issues that are beyond the current scope of the Hazus Flood Model.

Should the user want to pursue further analysis and estimate of material release, it is recommended that the user identify the site of the hazardous materials using GPS units and determine the depth of flooding at that location. The user can then determine if the materials are in fact released. The user will also be able to determine the general velocity (low, medium, high) and the flood water discharge at the release site. Using this information, the user may be able to use existing plume models to determine the spread and dilution of the materials.

The most elementary form of detailed analysis would consist of a hazardous materials expert doing a walk through to identify target hazard areas. In most jurisdictions, the fire department personnel are the best trained in issues pertaining to hazardous materials. Many fire departments are also willing to meet with major users of hazardous materials to do what is termed "pre-planning". In this effort, fire departments visit the facilities of users, identify areas that they think are particularly vulnerable, and suggest improvements. If there were code violations, the fire department personnel would point this out. In highly industrialized areas, there are consulting firms that are capable of conducting this assessment. The smaller consulting firms tend to be comprised only of individuals with expertise in hazardous materials issues.

It must be borne in mind that when assessing the potential for hazardous materials releases during floods, the depth of flooding, the performance of the storage facility/container with respect to inundation are important. Another very important factor is the level of preparedness, especially where it pertains to the ability to contain an incident and prevent it from spreading or enlarging.

The structural vulnerability of a hazardous materials facility is assessed by a qualified structural engineer. For example, the integrity of a storage tank, containing 100,000 gallons of petroleum, should be evaluated by a structural engineer.

In conducting a detailed analysis, it is important not only to assess the potential for occurrence of incidents, but it is also important to assess the capability of containing incidents and preventing them from spreading or becoming enlarged. The level of preparedness of the individual facilities generally determines this. There have been a number of cases where the incidents would have been smaller than they actually were, had the organization/facility had the capability to respond in a timely manner. The type of expert needed here is an “Emergency Planner”. Unfortunately, it is not easy to find an emergency planner who specializes in assessing individual facilities. Here again, perhaps the most qualified and educated personnel are fire department personnel. In most cases, hazardous materials consultants also address issues pertaining to response. In the case when an expert is not available, the document by the U.S. Environmental Protection Agency (EPA, 1987), which provides technical guidance for hazards analysis and emergency planning for extremely hazardous substances is an excellent guide. Another useful guide is the “Hazardous Materials Emergency Response Guide” published by the National Response Team (1987). The user should keep in mind that both of these documents are quite general in nature, and do not address flood concerns specifically. Nevertheless, in the absence of more specific information, these guides are definitely useful in getting the user started towards assessing the risks.

10.4 References

International Conference of Building Officials, *Uniform Fire Code*, 1991.

U.S. Environmental Protection Agency 1987, FEMA, U.S. Department of Transportation, *Technical Guidance for Hazards Analysis – Emergency Planning for Extremely Hazardous Substances*, U.S. Environmental Protection Agency December.

National Response Team 1987, *Hazardous Materials Emergency Planning Guide*, March.

Appendix 10A. Listing of Chemicals contained in SARA Title III, including their CAS Numbers, Hazards and Threshold Planning Quantities

CAS Number	Chemical Name	Hazard	Threshold Planning Quantity (pounds)
00075-86-5	Acetone cyanohydrin	Poison	1,000
01752-30-3	Acetone thiosemicarbazide	Poison	1,000 +
00107-02-8	Acrolein	Flammable liquid & poison	500
00079-06-1	Acrylamide	Poison	1,000 +
00107-13-1	Acrylonitrile	Flammable liquid & poison	10,000
00814-68-6	Acrylyl chloride	Poison	100
00111-69-3	Adiponitrile	Poison	1,000
00116-06-3	Aldicarb	Deadly poison	100 +
00309-00-2	Aldrin	Poison	500 +
00107-18-6	Allyl alcohol1	Flammable liquid & poison	1,000
00107-11-9	Allylamine	Flammable liquid & poison	500
20859-73-8	Aluminum phosphide	Flammable solid & poison	500
00054-62-6	Aminopterin	Poison	500 +
00078-53-5	Amiton	Deadly poison	500
03734-97-2	Amiton oxalate	Deadly poison	100 +
07664-41-7	Ammonia, anhydrous	Poison	500
00300-62-9	Amphetamine	Deadly poison	1,000
00062-53-3	Aniline	Poison	1,000
00088-05-1	Aniline, 2,4,6-trimethyl	Poison	500
07783-70-2	Antimony pentafluoride	Corrosive to skin, eyes, mucuous membranes	500
01397-94-0	Antimycin A	Poison	1,000 +
00086-88-4	Antu	Poison	500 +
01303-28-2	Arsenic pentoxide	Poison	100 +
01327-53-3	Arsenous oxide	Poison	100
07784-34-1	Arsenous trichloride	Poison	500
07784-42-1	Arsine	Poison gas & flammable gas	100
02642-71-9	Azinphos-ethyl	Poison	100 +
00086-50-0	Azinphos-methyl	Poison	10 +
00098-87-3	Benzal chloride	Moderately toxic	500
00098-16-8	Benzehamine,3-(trifluoromethyl)-	Poison	500
00100-14-1	Benzene, 1-(chloromethyl)-4-nitro-	Poison	500 +
00098-05-5	Benzenearsonic acid	Deadly poison	10 +
03615-21-2	Benzimidazole, 4,5-dichloro-2-(trifluoromethyl)	Poison	500 +
00098-07-7	Benzotrichloride (benzoic trichloride)	Corrosive & poison	100
00100-44-7	Benzyl chloride	Corrosive & poison	500
00140-29-4	Benzyl cynaide	Poison	500
15271-41-7	Bicyclo [2,2,1]heptane-2-carbonitrile,5-chloro-6((((methylamino)carbonyl)oxy)imino)-(1S-(1-alpha,2-beta,4-alpha,5-alpha,6E))-	Poison	500 +
00111-44-4	Bis(2chloroethyl)ether	Poison	10,000
00542-88-1	Bis(chloromethyl)ether	Poison & carcinogen	100
00534-07-6	Bis(chloromethyl)ketone	Poison	10 +
04044-65-9	Bitoscanate	Poison	500 +
10294-34-5	Boron trichloride	Corrosive, poison, irritant & reactive with water	500
07637-07-2	Boron trifluoride	Poison & strong irritant	500
00353-42-4	Borontrifluoride compound with methyl ether (1:1)	Flammable, corrosive & poison	1,000
28772-56-7	Bromadiolone	Deadly poison	100 +
07726-95-6	Bromine	Corrosive & poison	500
01306-19-0	Cadmium oxide	Poison	100 +
02223-93-0	Cadmium stearate	Poison	1,000 +
07778-44-1	Calcium arsenate	Poison & carcinogen	500 +
00056-25-7	Cantharidin	Deadly poison	100 +
00051-83-2	Carbachol chloride	Deadly poison	500 +

CAS Number	Chemical Name	Hazard	Threshold Planning Quantity (pounds)
26419-73-8	Carbamic acid, methyl-O-(((2,4-dimethyl-1,3-dithiolan-2-yl)methylene)amino)-	Poison	100 +
01563-66-2	Carbofuran	Poison	10 +
00075-15-0	Carbon disulfide	Flammable liquid & poison	10,000
000786-19-6	Carbophenothion	Poison	500
00057-74-9	Chlordane	Flammable liquid & poison	1,000
00470-90-6	Chlorfenvinfos	Poison	500
07782-50-5	Chlorine (not muratic acid or bleach)	Poison gas	100
24934-91-6	Chlormephos	Poison	500
00999-81-5	Chlormequat chloride		100 +
00079-11-8	Chloroacetic acid	Corrosive & poison	100 +
00107-07-3	Chloroethanol	Flammable liquid & poison	500
00627-11-2	Chloroethyl chloroformate	Poison	1,000
00555-77-1	Tris(2-chloroethyl)amine	Moderately toxic	100
00067-66-3	Chloroform	Poison	10,000
00107-30-2	Chloromethyl methyl ether	Flammable liquid & poison	100
03691-35-8	Chlorophacinone	Poison	100 +
01982-47-4	Chloroxuron	Poison	500 +
21923-23-9	Chlorthiophos	Poison	500
10025-73-7	Chromic chloride	Poison	1 +
10210-68-1	Cobalt carbonyl	Poison	10 +
62207-76-5	Cobalt,((2,2'-(1,2-ethanediylbis(nitrilomethylidyne))bis(6-fluorophenolato))(2-)-N,N',O,O')-	Poison	100+
00064-86-6	Colchicine	Poison	10 +
00056-72-4	Coumaphos	Poison	100 +
05836-29-3	Coumatetralyl	Poison	500 +
00095-48-7	Othro-cresol	Poison	1,000 +
00535-89-7	Crimidine	Deadly poison	100 +
00123-73-9	Crotonaldehyde	Poison	1,000
04170-30-3	E-crotonaldehyde	Flammable liquid & poison	1,000
00506-68-3	Cyanogen bromide	Poison	500 +
00506-78-5	Cyanogen iodide	Poison	1,000 +
02636-26-2	Cyanophos	Poison	1,000
00675-14-9	Cyanuric fluoride	Poison	1000
00066-81-9	Cycloheximide	Poison	100 +
000108-91-8	Cyclohexylamine	Flammable liquid & poison	10,000
17702-41-9	Decaborane (14)		500 +
08065-48-3	Demeton	Deadly poison	500
00919-86-8	Demeton-s-methyl	Poison	500
10311-84-9	Dialifor	Poison	100 +
19287-45-7	Diborane	Flammable gas & poison	100
00110-57-6	Trans-1,4-dichlorobutene	Poison	500
00149-74-6	Dichloromethylphenylsilane	Flammable liquid & poison	1,000
00062-73-7	Dichlorvos	Poison	1,000
00141-66-2	Dicrotophos	Poison	100
01464-53-5	Diepoxybutane	Poison	500
00814-49-3	Diethyl chlorophosphate	Deadly poison	500
01642-54-2	Diethylcarbamazine citrate	Poison	100+
00071-63-6	Digitoxin	Deadly poison	100+
02238-07-5	Diglycidyl ether	Poison	1,000
20830-75-5	Digoxin	Deadly poison	10+
00115-26-4	Dimefox	Poison	500
00060-51-5	Dimethiate	Poison	500+
06923-22-4	3-(Dimethoxy phosphinyloxy)-N-methyl-cis croton-amide(monocrotophos)	Poison	10
00075-78-5	Dimethyldichlorosilane	Poison & irritant	500
00057-14-7	Dimethylhydrazine	Flammable liquid & poison	1,000
00099-98-9	Dimethyl-p-phenylenediamine	Poison	10+
02524-03-0	Dimethyl phosphochloridothioate	Corrosive & poison	500
00077-78-1	Dimethyl sulfate	Corrosive & poison	500
00644-64-4	Dimetilan	Poison	500+
00534-52-1	4,6-Dinitro-o-cresol	Poison	10+

CAS Number	Chemical Name	Hazard	Threshold Planning Quantity (pounds)
26419-73-8	Carbamic acid, methyl-O-(((2,4-dimethyl-1,3-dithiolan-2-yl)methylene)amino)-	Poison	100 +
01563-66-2	Carbofuran	Poison	10 +
00075-15-0	Carbon disulfide	Flammable liquid & poison	10,000
000786-19-6	Carbophenothion	Poison	500
00057-74-9	Chlordane	Flammable liquid & poison	1,000
00470-90-6	Chlorfenvinfos	Poison	500
07782-50-5	Chlorine (not muratic acid or bleach)	Poison gas	100
24934-91-6	Chlormephos	Poison	500
00999-81-5	Chlormequat chloride		100 +
00079-11-8	Chloroacetic acid	Corrosive & poison	100 +
00107-07-3	Chloroethanol	Flammable liquid & poison	500
00627-11-2	Chloroethyl chloroformate	Poison	1,000
00555-77-1	Tris(2-chloroethyl)amine	Moderately toxic	100
00067-66-3	Chloroform	Poison	10,000
00107-30-2	Chloromethyl methyl ether	Flammable liquid & poison	100
03691-35-8	Chlorophacinone	Poison	100 +
01982-47-4	Chloroxuron	Poison	500 +
21923-23-9	Chlorthiophos	Poison	500
10025-73-7	Chromic chloride	Poison	1 +
10210-68-1	Cobalt carbonyl	Poison	10 +
62207-76-5	Cobalt,((2,2'-(1,2-ethanediylbis(nitrilomethylidyne))bis(6-fluorophenolato))(2-)-N,N',O,O')-	Poison	100+
00064-86-6	Colchicine	Poison	10 +
00056-72-4	Coumaphos	Poison	100 +
05836-29-3	Coumatetralyl	Poison	500 +
00095-48-7	Othro-cresol	Poison	1,000 +
00535-89-7	Crimidine	Deadly poison	100 +
00123-73-9	Crotonaldehyde	Poison	1,000
04170-30-3	E-crotonaldehyde	Flammable liquid & poison	1,000
00506-68-3	Cyanogen bromide	Poison	500 +
00506-78-5	Cyanogen iodide	Poison	1,000 +
02636-26-2	Cyanophos	Poison	1,000
00675-14-9	Cyanuric fluoride	Poison	1000
00066-81-9	Cycloheximide	Poison	100 +
000108-91-8	Cyclohexylamine	Flammable liquid & poison	10,000
17702-41-9	Decaborane (14)		500 +
08065-48-3	Demeton	Deadly poison	500
00919-86-8	Demeton-s-methyl	Poison	500
10311-84-9	Dialifor	Poison	100 +
19287-45-7	Diborane	Flammable gas & poison	100
00110-57-6	Trans-1,4-dichlorobutene	Poison	500
00149-74-6	Dichloromethylphenylsilane	Flammable liquid & poison	1,000
00062-73-7	Dichlorvos	Poison	1,000
00141-66-2	Dicrotophos	Poison	100
01464-53-5	Diepoxybutane	Poison	500
00814-49-3	Diethyl chlorophosphate	Deadly poison	500
01642-54-2	Diethylcarbamazine citrate	Poison	100+
00071-63-6	Digitoxin	Deadly poison	100+
02238-07-5	Diglycidyl ether	Poison	1,000
20830-75-5	Digoxin	Deadly poison	10+
00115-26-4	Dimefox	Poison	500
00060-51-5	Dimethiate	Poison	500+
06923-22-4	3-(Dimethoxy phosphinyloxy)-N-methyl-cis croton-amide(monocrotophos)	Poison	10
00075-78-5	Dimethyldichlorosilane	Poison & irritant	500
00057-14-7	Dimethylhydrazine	Flammable liquid & poison	1,000
00099-98-9	Dimethyl-p-phenylenediamine	Poison	10+
02524-03-0	Dimethyl phosphochloridothioate	Corrosive & poison	500
00077-78-1	Dimethyl sulfate	Corrosive & poison	500
00644-64-4	Dimetilan	Poison	500+
00534-52-1	4,6-Dinitro-o-cresol	Poison	10+

CAS Number	Chemical Name	Hazard	Threshold Planning Quantity (pounds)
00088-85-7	Dinoseb	Poison	100+
01420-07-1	Dinoterb	Poison	500+
00078-34-2	Dioxathion	Poison	500
00082-66-6	Diphacinone	Poison	10+
00152-16-9	Diphosphoramide, octamethyl	Poison	100
00298-04-4	Disulfoton	Poison	500
00514-73-8	Dithiazamine iodide	Poison	500+
00541-53-7	Dithiobiuret	Poison	100+
00316-42-7	Emetine, dihydrochloride	Poison	1+
00115-29-7	Endosulfan	Poison	10+
02778-04-3	Endothion	Poison	500+
00072-20-8	Endrin	Poison	500+
00106-89-8	Epichlorohydrin	Flammable liquid & poison	1,000
02104-64-5	EPN	Poison	100+
00050-14-6	Ergocalciferol	Poison	1,000+
00379-79-3	Ergotamine tartate	Poison	500+
01622-32-8	Ethanesulfonyl chloride,2-chloro	Poison	500
10140-87-1	Ethanol,1,2-dichloroacetate	Combustible & poison	1,000
00563-12-2	Ethion	Poison	1,000
13194-48-4	Ethoprophos	Poison	1,000
00538-07-8	Ethylbis(2-chloroethyl)amine	Deadly poison	500
00107-15-3	Ethylenediamine	Corrosive, flammable liquid, irritant	10,000
00371-62-0	Ethylene fluorohydrin	Poison	10
00151-56-4	Ethyleneimine	Flammable liquid & poison	500
00075-21-8	Ethylene oxide	Flammable gas & poison	1,000
00542-90-5	Ethylthiocyanate	Poison	10,000
22224-92-6	Fenamiphos	Poison	10+
00122-14-5	Fenitrothion	Poison	500
00115-90-2	Fensulfothion	Poison	500
04301-50-2	Fluenetil	Poison	100+
07782-41-4	Fluorine	Oxidizer & poison	500
00640-19-7	Fluoroacetamide (1061)	Poison	100+
00144-49-0	Fluoroacetic acid	Poison	10+
00359-06-8	Fluoroacetyl chloride	Poison	10
00051-21-8	Fluorouracil	Poison	500+
00944-22-9	Fonofos	Poison	500
00050-00-0	Formaldehyde	Combustible liquid & poison	500
00107-16-4	Formaldehyde cyanohydrin	Poison	1,000
23422-53-9	Formetanate hydrochloride	Poison	500+
02540-82-1	Formothion	Poison	100
17702-57-7	Formparanate	Poison	100+
21548-32-3	Fosthientan	Poison	500
03878-19-1	Fuberidazole	Poison	100+
00110-00-9	Furan	Flammable liquid & poison	500
13450-90-3	Gallium trichloride	Poison	500+
00077-47-4	Hexachlorocyclopentadiene	Corrosive & deadly poison	100
04835-11-4	Hexamethylenediamine,N,N-dibutyl	Poison	500
00302-01-2	Hydrazine	Flammable liquid, corrosive & poison	1,000
00074-90-8	Hydrocyanic acid	Deadly poison	100
07647-01-0	Hydrogen chloride (gas only)	Highly corrosive irritant	500
07664-39-3	Hydrogen fluoride	Corrosive & poison	100
07722-84-1	Hydrogen peroxide (conc. >52%)	Oxidizer, moderately toxic	1,000
07783-07-5	Hydrogen selenide	Flammable gas & deadly poison	10
07783-06-4	Hydrogen sulfide	Flammable gas & poison	500
00123-31-9	Hydroquinone	Poison	500+
13463-40-6	Iron pentacarbonyl	Poison	100
00297-78-9	Isobenzan	Poison	100+
00078-82-0	Isobutyronitrile	Flammable liquid & poison	1,000
00102-36-3	Isocyanic aicd,3,4-dichlorophenyl ester	Poison	500+
00465-73-6	Isodrin	Poison	100+

CAS Number	Chemical Name	Hazard	Threshold Planning Quantity (pounds)
00055-91-4	Isofluorphate	Poison	100
04098-71-9	Isophorone diisocyanate	Poison	100
00108-23-6	Isopropyl chloroformate	Flammable liquid & poison	1,000
00119-38-0	Isopropylmethylpyrazolyl dimethylcarbamate	Poison	500
00078-97-7	Lactonitrile	Poison	1,000
21609-90-5	Leptophos	Poison	500+
00541-25-3	Lewisite	Poison	10
00058-89-9	Lindane	Poison	1,000+
07580-67-8	Lithium hydride	Flammable solid & poison	100
00109-77-3	Malononitrile	Poison	500+
12108-13-3	Mangenese tricarbonyl methylcyclopentadienyl	Poison	100
00950-10-7	Mephosfolan	Poison	500
01600-27-7	Mercuric acetate	Poison	500+
07487-94-7	Mercuric chloride	Poison	500+
21908-53-2	Mercuric oxide	Powerful oxidant	500+
10476-95-6	Methacrolein diacetate	Poison	1,000
00760-93-0	Methacrylic anhydride	Poison	500
00126-98-7	Methylacrylonitrile	Poison	500
00920-46-7	Methacryloyl chloride	Poison	100
30674-80-7	Methacryloyloxyethylisocyanate	Poison	100
10265-92-6	Methamidophos	Poison	100+
00558-25-8	Methanesulfonyl fluoride	Poison	1,000
00950-37-8	Methidathion	Poison	500+
02032-65-7	Methiocarb	Poison	500+
16752-77-5	Methomyl	Poison	500+
00151-38-2	Methoxyethylmercuric acetate	Poison	500+
00074-83-9	Methyl bromide	Poison gas	1,000
00080-63-7	Methyl 2-chloroacrylate	Moderately toxic	500
00079-22-1	Methyl chloroformate	Flammable liquid, corrosive & poison	500
00060-34-4	Methyl hydrazine	Flammable liquid, corrosive, poison	500
00624-83-9	Methyl isocyanate	Flammable liquid & poison	500
00556-61-6	Methyl isothiocyanate	Flammable liquid & poison	500
00074-93-1	Methyl mercaptan	Flammable gas & poison	500
00502-39-6	Methylmercuric dicyanamide	Poison	500+
03735-23-7	Methyl phenkapton	Poison	500
00676-97-1	Methyl phosphonic dichloride	Corrosive & poison	100
00556-64-9	Methyl thiocyanate	Poison	10,000
00075-79-6	Methyl trichlorosilane	Flammable liquid, corrosive & poison	500
00079-84-4	Methyl vinyl ketone		10
01129-41-5	Metolcarb	Poison	100+
07786-34-7	Mevinphos	Poison	500
00315-18-4	Mexacarbate	Poison	500+
00050-07-7	Mitomycin C	Poison	500+
06923-22-4	Monocrotophos	Poison	10+
02763-96-4	Muscinol	Poison	10,000
00505-60-2	Mustard gas	Poison	500
13463-39-3	Nickel carbonyl	Flammable liquid & poison	1
00054-11-5	Nicotine	Poison	100
00065-30-5	Nicotine sulfate	Poison	100+
07697-37-2	Nitric acid (.40% pure)	Corrosive, oxidizer & poison	1,000
10102-43-9	Nitric oxide	Poison gas	100
00098-95-3	Nitrobenzene	Poison	10,000
01122-60-7	Nitrocyclohexane	Poison	500
10102-44-0	Nitrogen dioxide	Oxidizer & moderately toxic	100
00051-75-2	Nitrogen mostard	Deadly poison	10
00062-75-9	N-Nitrosodimethylamine	Poison	1,000
00991-42-4	Norbormide	Poison	100+
PMN-82-147	Organorhodium complex	Flammable & toxic	10+
00630-60-4	Ouabain	Poison	100+
23135-22-0	Oxamyl	Poison	100+

CAS Number	Chemical Name	Hazard	Threshold Planning Quantity (pounds)
00078-71-7	Oxetane,3,3,-bis(chloromethyl)-	Poison	500
02497-07-6	Oxydisulfoton	Poison	500
10028-15-6	Ozone	Poison	100
01910-42-5	Paraquat	Poison	10+
02074-50-2	Paraquat methosulfate	Poison	10+
00056-38-2	Parathion	Poison	100
00298-00-0	Parathion-methyl	Poison	100+
13002-03-8	Paris green	Poison	500+
19624-22-7	Pentaborane	Flammable liquid & poison	500
02570-26-5	Pentadecylamine	Poison	100+
00079-21-0	Peracetic acid	Corrosive & poison	500
00594-42-3	Perchloromethylmercaptan	Poison	500
00108-95-2	Phenol	Poison	500+
04418-66-0	Phenol,2,2-thiobis(4-chloro-6-methyl)	Poison	100+
00064-00-6	Phenol,3-(1-methylethyl)-methylcarbamate	Poison	500+
00058-36-6	Phenoarsazine 10,10-oxydi-	Poison	500+
00696-28-6	Phenyl dichloroarsine	Poison	500
00059-88-1	Phenylhydrazine hydrochloride	Poison	1,000+
00062-38-4	Phenylmercury acetate	Poison	500+
02097-19-0	Phenylsilatrane	Poison	100+
00103-85-5	Phenylthiourea	Poison	100+
00298-02-2	Phorate	Poison	10
04104-14-7	Phosacetim	Poison	100+
00947-02-4	Phosfolan	Poison	100+
00075-44-5	Phosgene	Poison gas	10
00732-11-6	Phosmet	Poison	10+
13171-21-6	Phosphamidon	Poison	100
07803-51-2	Phosphine	Flammable & poison gas	500
02665-30-7	Phosphonothioic acid, methyl-o-(4-nitrophenol)o-phenyl ester	Poison	500
50782-69-9	Phosphonothioic acid, methyl-s-(2-(bis(1-methylethyl)amino)o-ethyl ester`	Poison	100
02703-13-1	Phosphonothioic acid methyl,-o-ethyl-o-4-(methylthio)phenyl ester	Deadly poison	500
03254-63-5	Phosphoric acid, dimethyl,4-(mehtylthio)phenyl ester	Poison	500
02587-90-8	Phosphorothioic aicd,o,o-dimethyl-s-(2-methyl-thio-ethyl ester	Poison	500
07723-14-0	Phosphorus	Flammable solid & poison	100
10025-87-3	Phosphorus oxychloride	Corrosive, irritant & poison	500
10026-13-8	Phosphorus pentachloride	Corrosive & poison	500
01314-56-3	Phosphorus pentoxide	Corrosive & poison	10
07719-12-2	Phosphorus trichloride	Corrosive & poison	1,000
00057-47-6	Physostigmine	Poison	100+
00057-64-7	Physostigmine, salicylate (1:1)	Poison	100+
00124-87-8	Picrotoxin	Poison	500+
00110-89-4	Piperidine	Poison	1,000
23505-41-1	Pirimifos-ethyl	Poison	1,000
10124-50-2	Potassium arsenite	Poison	500+
00151-50-8	Potassium cyanide	Deadly poison	100
00506-61-6	Potassium silver cyanide	Poison & irritant	500
02631-37-0	Promecarb	Poison	500+
00106-96-7	Propagyl bromide	Flammable liquid & deadly poison	10
00057-57-8	beta-Propiolactone	Poison	500
00107-12-0	Propionitrile	Flammable liquid & poison	500
00542-76-7	Propionitrile, 3-chloro	Poison	1,000
00070-69-9	Propiophenone,4-amino	Poison	100+
00109-61-5	Propyl chloroformate	Flammable liquid, corrosive & poison	500
00075-56-9	Propylene oxide	Flammable liquid & poison	10,000
00075-55-8	Propyleneimene	Flammable liquid & poison	10,000
02275-18-5	Prothoate	Poison	100+
00129-00-0	Pyrene	Poison	1,000+

CAS Number	Chemical Name	Hazard	Threshold Planning Quantity (pounds)
00140-76-1	Pyridine,2-methyl-5-vinyl	Poison	500
00504-24-5	Pyridine,4-amino	Poison	500+
01124-33-0	Pyridine,4-nitro-,1-oxide	Poison	500+
53558-25-1	Pyriminil	Poison	100+
14167-18-1	Salcomine	Poison	500+
00107-44-8	Sarin	Deadly poison	10
07783-00-8	Selenous acid	Poison	1,000+
07791-23-3	Selenium oxychloride	Poison	500
00563-41-7	Semicarbazide hydrochloride	Poison	1,000+
03037-72-7	Silane, (4-aminobutyl)diethoxymethyl	Poison	1,000
07631-89-2	Sodium arsenate	Poison	1,000+
07784-46-5	Sodium arsenite	Deadly poison	500+
26628-22-8	Sodium azide	Poison	500
00124-65-2	Sodium cacodylate	Poison	100+
00143-33-9	Sodium cyanide	Deadly poison	100
00062-74-8	Sodium fluoroacetate	Deadly poison	10+
13410-01-0	Sodium selenate	Poison	100+
10102-18-8	Sodium selenite	Poison	100+
10102-20-2	Sodium tellurite	Poison	500+
00900-95-8	Stannane, acetoxytriphenyl	Poison	500+
00057-24-9	Strychnine	Poison	100+
00060-41-3	Strychnine, sulfate	Poison	100+
03689-24-5	Sulfotep	Poison	500
03569-57-1	Sulfoxide,3-chloropropyloctyl	Poison	500
07446-09-5	Sulfur dioxide	Poison gas	500
07783-60-0	Sulfur tetrafluoride	Poison gas	100
07446-11-9	Sulfur trioxide	Corrosive & poison	100
07664-93-9	Sulfuric acid (>93%)	Corrosive & poison	1,000
00077-81-6	Tabun	Poison	10
13494-80-9	Tellurium	Poison	500+
07783-80-4	Tellarium hexafluoride	Poison gas	100
00107-49-3	TEPP	Poison	100
13071-79-9	Terbufos	Deadly poison	100
00078-00-2	Teraethyllead	Flammable liquid & poison	100
00597-64-8	Tetraethyltin	Poison	100
00075-74-1	Tetramethyllead	Poison	100
00509-14-8	Tetranitromethane	Oxidizer & poison	500
10031-59-1	Thallium sulfate	Poison	100+
06533-73-9	Thallous carbonate	Poison	100+
07791-12-0	Thallous chloride	Poison	100+
02757-18-8	Thallous malonate	Poison	100+
07446-18-6	Thallous sulfate	Poison	100+
02231-57-4	Thiocarbazide	Poison	1,000+
39196-18-4	Thiofanox	Poison	100+
00297-97-2	Thioazin	Poison	500
00108-98-5	Thiophenol	Flammable liquid & poison	500
00079-19-6	Thiosemicarbazide	Poison	100+
05344-82-1	Thiourea, (2-chlorophenyl)	Poison	100+
00614-78-8	Thiourea (2-methylphenyl)	Poison	500+
07550-45-0	Titanium tetrachloride	Corrosive & poison	100
00584-84-9	Toluene 2,4-diisocyanate	Poison	500
00091-08-7	Toluene 2,6-diisocyanate	Poison	100
08001-35-2	Toxaphene	Poison	500+
01031-47-6	Triamiphos	Poison	500+
24017-47-8	Triazofos	Poison	500
00076-02-8	Trichloroacetyl chloride	Corrosive & moderately toxic	500
01558-25-4	Trichloro(chloromethyl)silane	Poison	100
27137-85-5	Trichloro(chlorophenyl)silane	Corrosive & poison	500
00115-21-9	Trichloroethylsilane	Flammable liquid & poison	500
00327-98-0	Trichloronate	Poison	500
00098-13-5	Trichlorophenylsilane	Corrosive & poison	500
00998-30-1	Triethoxysilane	Poison	500

CAS Number	Chemical Name	Hazard	Threshold Planning Quantity (pounds)
00075-77-4	Trimethylchlorosilane	Flammable liquid, corrosive & moderately toxic	1,000
00824-11-3	Trimethylolpropane phosphate	Poison	100+
01066-45-1	Trimethyltin chloride	Deadly poison	500+
00639-58-7	Triphenyltin chloride	Poison	500+
02001-95-8	Valinomycin	Poison	1,000+
01314-62-1	Vanadium pentoxide	Poison	100+
00108-05-4	Vinyl acetate monomer	Flammable liquid & moderately toxic	1,000
00081-81-2	Warfarin	Poison	500+
00129-06-6	Warfarin sodium	Poison	100+
28347-13-9	Xylene dichloride	Poison	100+
58270-08-9	Zinc, dichloro(4,4-dimethyl-5((((methylamino)carbonyl)oxino)pentanenitrile)-,(T-4)	Poison	100+
01314-84-7	Zinc phosphide	Flammable solid & poison	500

Note: For the Treshold Planning Quantities marked with a "+", the quantity listed applies only if in powdered form and with a particle size of less than 100 microns, or is handled in solution or molten form, or has a NFPA rating for reactivity of 2, 3 or 4. Otherwise the Treshold Planning Quantity is 10,000 lbs. The material is still required to be reported on an annual inventory at the Treshold Planning Quantity or 500 lbs, whichever is less.

Source of hazard information: N. Irving San and Richard J. Lews, Sr., Dangerous Properties of Industrial Materials, Seventh Edition, Volumes I - III, Van Nostrand Reinhold, New York, (1989).

Appendix 10B. Listing of Chemicals contained in the TRI Database, including their CAS Numbers and Hazards

CAS NUMBER	CHEMICAL NAME	HAZARDS
75-07-0	Acetaldehyde	Poison
60-35-5	Acetamide	Experimental carcinogen
67-64-1	Acetone	Moderately toxic
75-05-8	Acetonitrile	Poison
53-96-3	2-Acetylaminofluorene	Moderately toxic
107-02-8	Acrolein	Poison
79-06-1	Acrylamide	Poison
79-10-7	Acrylic acid	Poison
107-13-1	Acrylonitrile	Poison
309-00-2	Aldrin	Poison
107-05-1	Allyl chloride	Poison
7429-90-5	Aluminum (fume or dust)	Not considered a industrial poison
1344-28-1	Aluminum oxide	Experimental tumorigen
117-79-3	2-Aminoanthraquinone	Experimental carcinogen
60-09-3	4-Aminoazobenzene	Poison
92-67-1	4-Aminobiphenyl	Poison
82-28-0	1-Amino-2-methylanthraquinone	Experimental neoplastigen
7664-41-7	Ammonia	Poison
6484-52-2	Ammonium nitrate (solution)	Powerful oxidizer & an allergen
7783-20-2	Ammonium sulfate (solution)	Moderately toxic
62-53-3	Aniline	Poison
90-04-0	o-Anisidine	Moderately toxic
109-94-9	p-Anisidine	Moderately toxic
134-29-2	o-Anisidine hydrochloride	Experimental carcinogen
120-12-7	Anthracene	Experimental tumorigen
7440-36-0	Antimony	Poison
7440-38-2	Arsenic	Carcinogen
1332-21-4	Asbestos (friable)	Carcinogen
7440-39-3	Barium	Poison
98-87-3	Benzal chloride	Poison
55-21-0	Benzamide	Moderately toxic
71-43-2	Benzene	Poison
92-87-5	Benzidine	Poison
98-07-7	Benzoic trichloride (Benzotrichloride)	Poison
98-88-4	Benzoyl chloride	Carcinogen
94-36-0	Benzoyl peroxide	Poison
100-44-7	Benzyl chloride	Poison
7440-41-7	Beryllium	Deadly poison
92-52-4	Biphenyl	Poison
111-44-4	Bis(2-chloroethyl) ether	Poison
542-88-1	Bis(chloromethyl) ether	Poison
108-60-1	Bis(2-chloro-1-methyulethyl) ether	Poison
103-23-1	Bis(2-ethylhexyl) adipate	Experimental carcinogen
75-25-2	Bromoform (Tribromomethane)	Poison
74-83-9	Bromomethane (methyl bromide)	Poison
106-99-0	1,3-Butadiene	Experimental carcinogen
141-32-2	Butyl acrylate	Moderately toxic
71-36-3	n-Butyl alcohol	Poison
78-92-2	sec-Butyl alcohol	Poison
75-65-0	tert-Butyl alcohol	Moderately toxic
85-68-7	Butyl benzyl phthalate	Moderately toxic
106-88-7	1,2-Butylene oxide	Moderately toxic
123-72-8	Butyraldehyde	Moderately toxic
2650-18-2	C.I. Acid Blue 9, diammonium salt	Poison
3844-45-9	C.I. Acid Blue, disodium salt	Experimental neoplastigen
4680-78-8	C.I. Acid Green 3	Experimental tumorigen
569-64-2	C.I. Basic Green 4	Poison
989-38-8	C.I. Basic Red 1	Poison
1937-37-7	C.I. Direct black 38	Experimental tumorigen
2602-46-2	C.I. Direct Blue 6	Experimental carcinogen

CAS NUMBER	CHEMICAL NAME	HAZARDS
16071-86-6	C.I. Direct Brown 95	Experimental carcinogen
2832-40-8	C.I. Disperse Yellow 3	Experimental tumorigen
3761-53-3	C.I. Food Red 5	
81-88-9	C.I. Food Red 15	Poison
3118-97-6	C.I. Solvent Orange 7	Experimental carcinogen
97-56-3	C.I. Solvent Yellow 3	Experimental carcinogen
842-07-9	C.I. Solvent Yellow 14	Experimental carcinogen
492-80-8	C.I. Solvent Yellow 34 (Auramine)	Poison
128-66-5	C.I. Vat Yellow 4	Experimental carcinogen
7440-43-9	Cadmiun	Poison
156-62-7	Calcium cyanamide	Poison
133-06-2	Captan	Moderately toxic
63-25-2	Carbaryl	Poison
75-15-0	Carbon disulfide	Poison
56-23-5	Carbon tetrachloride	Poison
463-58-1	Carbonyl sulfide	Poison
120-80-9	Catechol	Moderately toxic
133-90-4	Chloramben	Experimental carcinogen
57-74-9	Chlordane	Poison
7782-50-5	Chlorine	Moderately toxic
10049-04-4	Chlorine dioxide	Moderately toxic
79-11-8	Chloroacetic acid	Poison
532-27-4	2-Chloroacetophenone	Poison
108-90-7	Chlorobenzene	Poison
510-15-6	Chlorobenzilate	Experimental carcinogen
75-00-3	Chloroethane	Mildly toxic
67-66-3	Chloroform	Poison
74-87-3	Chloromethane (Methyl chloride)	Mildly toxic
107-30-2	Chloromethyl methyl ether	Poison
126-99-8	Chloroprene	Poison
1897-45-6	Chlorothalonil	Moderately toxic
7740-47-3	Chromium	Poison
7440-48-4	Cobalt	Poison
7440-50-8	Copper	Experimental tumorigen
120-71-8	p-Cresidine	Moderately toxic
1319-77-3	Cresol (mixed isomers)	Moderately toxic
108-39-4	m-Cresol	Poison
95-48-7	o-Cresol	Poison
106-44-5	p-Cresol	Poison
98-82-8	Cumene	Moderately toxic
80-15-9	Cumene hydroperoxide	Moderately toxic
135-20-6	Cupferron	Poison
110-82-7	Cyclohexane	Poison
94-75-7	2,4-D (Acetic acid,(2,4-dichlore-phenoxy))	Poison
1163-19-5	Decabromodiphenyl oxide	Experimental neoplastigen
2303-16-4	Diallate	Poison
615-05-4	2,4-Diaminoanisole	Poison
39156-41-7	2,4-Diaminoanisole sulfate	Poison
101-80-4	4,4-Diaminophenyl ether	Poison
25376-45-8	Diaminotoluane (mixed isomers)	Poison
95-80-7	2,4-Diaminotoluene	Poison
334-80-3	Diazomethane	Experimental tumorigen
132-64-9	Dibenzofuran	
96-12-8	1,2-Dibromo-3-chloropropane (DBCP)	Poison
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	Poison
84-74-2	Dibutyl phthalate	Moderately toxic
25321-22-6	Dichlorobenzene (mixed isomers)	Poison
95-50-1	1,2-Dichlorobenzene	Poison
541-73-1	1,3-Dichlorobenzene	Poison
106-46-7	1,4-Dichlorobenzene	Poison
91-94-1	3,3-Dichlorobenzidine	Experimental carcinogen
75-27-4	Dichlorobromomethane	Moderately toxic
107-06-2	1,2-Dichloroethane	Poison

CAS NUMBER	CHEMICAL NAME	HAZARDS
540-59-0	1,2-Dichloroethylene	Poison
75-09-2	Dichloromethane (Methylene chloride)	Poison
120-83-2	2,4-Dichlorophenol	Poison
78-87-5	1,2-Dichloropropane	Moderately toxic
542-75-6	1,3-Dichloropropylene	Poison
62-73-7	Dichlorvos	Poison
115-32-2	Dicofol	Poison
1464-53-5	Diepoxybutane	Poison
111-42-2	Diethanolamine	Moderately toxic
117-81-7	di-(2-ethylhexyl) phthalate (DEHP)	Poison
84-66-2	Diethyl phthalate	Poison
64-67-5	Diethyl sulfate	Poison
119-90-4	3,3-Dimethoxybenzidine	Moderately toxic
60-11-7	4-Dimethylaminoazobenzene	Poison
119-93-7	3,3-Dimethylbenzidine (o-Tolidine)	Poison
79-44-7	Dimethylcarbamyl chloride	Poison
57-14-7	1,1-Dimethyl hydrazine	Poison
105-67-9	2,4-Dimethylphenol	Poison
131-11-3	Dimethyl phthalate	Moderately toxic
77-78-1	Dimethyl sulfate	Poison
534-52-1	4,6-Dinitro-o-cresol	Poison
51-28-5	2,4-Dinitrophenol	Deadly poison
121-14-2	2,4-Dinitrotoluene	Poison
606-20-2	2,5-Dinitrotoluene	Moderately toxic
117-84-0	n-Dioctyl phthalate	Mildly toxic
123-91-1	1,4-Dioxane	Poison
122-66-7	1,2-Diphenylhydrazine (Hydrazobenzene)	Poison
106-89-8	Epichlorohydrin	Poison
110-80-5	2-Ethoxyethanol	Moderately toxic
140-88-5	Ethyl acrylate	Poison
100-41-4	Ethylbenzene	Moderately toxic
541-41-3	Ethyl chloroformate	Poison
74-85-1	Ethylene	Simple asphyxiant
107-21-1	Ethylene glycol	Poison
151-56-4	Ethyleneimine (Aziridine)	Poison
75-21-8	Ethylene oxide	Poison
96-45-7	Ethylene thiourea	Poison
2164-17-2	Fluometuron	Poison
50-00-0	Formaldehyde	Poison
76-13-1	Freon 113	Mildly toxic
76-44-8	Heptachlor (1,4,5,6,7,8,8,-Heptachloro-3a,4,7,7a-tetrahydro-4,7-methano-1H-indene)	Poison
118-74-1	Hexachlorobenzene	Poison
87-68-3	Hexachloro-1,3-butadiene	Poison
77-47-4	Hexachlorocyclopentadiene	Deadly poison
67-72-1	Hexachloroethane	Poison
13355-87-1	Hexachloronaphthalene	Poison
680-31-9	Hexamethylphosphoramide	Experimental carcinogen
302-01-2	Hydrazine	Poison
10034-93-2	Hydrazine sulfate	Poison
7647-01-0	Hydrochloric acid	Poison
74-90-8	Hydrogen cyanide	Deadly poison
7664-39-3	Hydrogen fluoride	Poison
123-31-9	Hydroquinone	Poison
78-84-2	Isobutyraldehyde	Moderately toxic
67-63-0	Isopropyl alcohol	Poison
80-05-7	4,4-Isopropylidenediphenol	Poison
7439-92-1	Lead	Poison
58-89-9	Lindene	Poison
108-31-6	Maleic acid	Poison
12427-38-2	Maneb	Experimental carcinogen
7439-96-5	Manganese	Experimental tumorigen
108-78-1	Melamine	Experimental carcinogen

CAS NUMBER	CHEMICAL NAME	HAZARDS
7439-97-6	Mercury	Poison
67-56-1	Methanol	Poison
72-43-5	Methoxychlor (Benzene-1,1-(2,2,2,-trichloroethylidene)bis(4-methoxy)	Moderately toxic
109-86-4	2-Methoxyethanol	Moderately toxic
96-33-3	Methyl acrylate	Poison
1634-04-4	Methyl tert-butyl ether	Flammable
101-14-4	4,4-Methylenebis(2-chloro aniline)	Poison
101-61-1	4,4-Methylenebis (N,N-dimethyl)benzenamine	Moderately toxic
101-68-8	Methylenebis(phenylisocyanate)	Poison
74-95-3	Methylene bromide	Poison
101-77-9	4,4-Methylenedianiline	Poison
78-93-3	Methyl ethyl ketone	Moderately toxic
60-34-4	Methyl hydrazine	Poison
74-88-4	Methyl iodide	Poison
108-10-1	Methyl isobutyl ketone	Poison
624-83-9	Methyl isocyanate	Poison
80-62-6	Mehtyl methacrylate	Moderately toxic
90-94-8	Michler's ketone	Poison
1313-27-5	Molybdenum trioxide	Poison
505-60-2	Mustard gas	Poison
91-20-3	Naphthalene	Poison
134-32-7	alpha-Naphthylamine	Poison
91-59-8	beta-Naphthylamine	Poison
7440-02-0	Nickel	Poison
7697-37-2	Nitric acid	Poison
139-13-9	Nitrilotriacetic acid	Poison
99-59-2	5-Nitro-o-anisidine	Moderately toxic
98-95-3	Nitrobenzene	Poison
92-93-3	4-Nitrobephenyl	Poison
1836-75-5	Nitrofen	Poison
51-75-2	Nitrogen mustard	Deadly poison
55-63-0	Nitroglycerin	Poison
88-75-5	2-Nitrophenol	Poison
100-02-7	4-Nitrophenol	Poison
79-46-9	2-Nitropropane	Poison
156-10-5	p-Nitrosodiphenylamine	Poison
121-69-7	N,N,-Dimethylaniline	Poison
924-16-3	N-Nitrosodi-n-butylamine	Moderately toxic
55-18-5	N-Nitrosodiethylamine	Poison
62-75-9	N-Nitrosodimethylamine	Poison
86-30-6	N-Nitrosodiohenylamine	Moderately toxic
621-64-7	N-Nitrosodi-n-propylamine	Moderately toxic
4549-40-0	N-Nitrosomethylvinylamine	Poison
59-89-2	N-Nitrosomorpholine	Poison
759-73-9	N-Nitroso-N-ethylurea	Poison
684-93-5	N-Nitroso-N-methylurea	Poison
16543-55-8	N-Nitrosonorrnicotine	Experimental carcinogen
100-75-4	N-Nitrosopiperidine	Poison
2234-13-1	Octachloronaphthlene	Poison
20816-12-0	Osmiun tetroxide	Poison
56-38-2	Parathion	Deadly poison
87-86-5	Pentachlorophenol	Poison
79-21-0	Peracetic acid	Poison
108-95-2	Phenol	Poison
106-50-3	p-Phenylenediamine	Poison
90-43-7	2-Phenylphenol	Poison
75-44-5	Phosgene	Poison
7664-38-2	Phosphoric acid	Poison
7723-14-0	Phosphorus	Poison
85-44-9	Phthalic anhydride	Poison
88-89-1	Picric acid	Poison

CAS NUMBER	CHEMICAL NAME	HAZARDS
1336-36-3	Polychlorinated biphenyls (PCBs)	Moderately toxic
1120-71-4	Propane sultone	Poison
57-57-8	beta-Propiolactone	Poison
123-38-6	Propionaldehyde	Moderately toxic
114-26-1	Propoxur	Poison
115-07-1	Propylene (propene)	Simple asphyxiant
75-55-8	Propyleneimine	Poison
75-56-9	Propylene oxide	Poison
110-86-1	Pyridine	Poison
91-22-5	Quinoline	Poison
106-51-4	Quinone	Poison
82-68-8	Quintozene (Pentachloronitrobenzene)	Experimental carcinogen
81-07-2	Saccharin	Moderately toxic
94-59-7	Safrole	Poison
7782-49-2	Selenium	Poison
7440-22-4	Silver	Experimental tumorigen
1310-73-2	Sodium hydroxide (solution)	Poison
7757-82-6	Sodium sulfate (solution)	Moderately toxic
100-42-5	Styrene	Experimental poison
96-09-3	Styrene oxide	Moderately toxic
7664-93-9	Sulfuric acid	Poison
100-21-0	Terephthalic acid	Moderately toxic
79-34-5	1,1,2,2,-Tetrachloroethane	Poison
127-18-4	Tetrachloroethylene	Experimental poison
961-11-5	Tetrachlorovinphos	Poison
7440-28-0	Thallium	Poison
62-55-5	Thioacetamide	Poison
139-65-1	4,4-Thiodianiline	Poison
62-56-6	Thiourea	Poison
1314-20-1	Thorium dioxide	Carcinogen
7550-45-0	Titanium tetrachloride	Poison
108-88-3	Toluene	Poison
584-84-9	Toulene-2,4-diisocyanate	Poison
91-08-7	Toluene-2,6-diisocyanate	Poison
95-53-4	o-Toluidine	Poison
636-21-5	o-Toluidine hydrochloride	Poison
8001-35-2	Toxaphene	Poison
68-76-8	Triaziquone	Poison
52-68-6	Trichlorfon (Phosphoric acid (2,2,2-trichloro-1-hydroxyethyl)-dimethyl ester	Poison
120-82-1	1,2,4-Trichlorobenzene	Poison
71-55-6	1,1,1-Trichloroethane (methyl chloroform)	Poison
79-00-5	1,1,2-Trichloroethane	Poison
79-01-6	Trichloroethylene	Experimental poison
95-95-4	2,4,5-Trichlorophenol	Poison
88-06-2	2,4,6-Trichlorophenol	Poison
1582-09-8	Trifluralin	Moderately toxic
95-63-6	1,2,4-Trimethylbenzene	Moderately toxic
126-72-7	Tris(2,3-dibromopropyl) phosphate	Poison
51-79-6	Urethane (Ethyl carbamate)	Moderately toxic
7440-62-2	Vanadium (fume or dust)	Poison
108-05-4	Vinyl acetate	Moderately toxic
593-60-2	Vinyl bromide	Moderately toxic
75-01-4	Vinyl chloride	Poison
75-35-4	Vinylidene chloride	Poison
1330-20-7	Xylene (mixed isomers)	Moderately toxic
108-38-3	m-Xylene	Moderately toxic
95-47-6	o-Xylene	Moderately toxic
106-42-3	p-Xylene	Moderately toxic
87-62-7	2,6-Xylidine	Moderately toxic
7440-66-6	Zinc (fume or dust)	Skin & systemic irritant
12122-67-7	Zineb	Moderately toxic

Chapter 11. Induced Damage Methods – Debris

11.1 Introduction

Debris disposal can be a significant issue following most natural disasters, including floods. Flood debris can include flood-damaged building finishes (e.g., carpeting, drywall, etc.) and contents (e.g., furniture, appliances, etc.), 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 model focuses on building-related debris, and does not address contents removal or additional debris loads such as vegetation and sediment. For additional information on debris management, the reader is referred to material published by the EPA (EPA, 1995) and FEMA (FEMA, 1999).

The Hazus Flood Model debris estimation methodology is similar to that developed for the Hazus earthquake model, in that it evaluates building-related debris by major component (finishes, structural components, and foundation materials), yet it recognizes a fundamental difference in the type of debris generated by the two types of events. For earthquakes, the debris from damaged buildings includes both structural and nonstructural components, while most flood-related debris is contents and finishes. The methodology highlighting the debris component is shown in the flowchart in Figure 11.1.

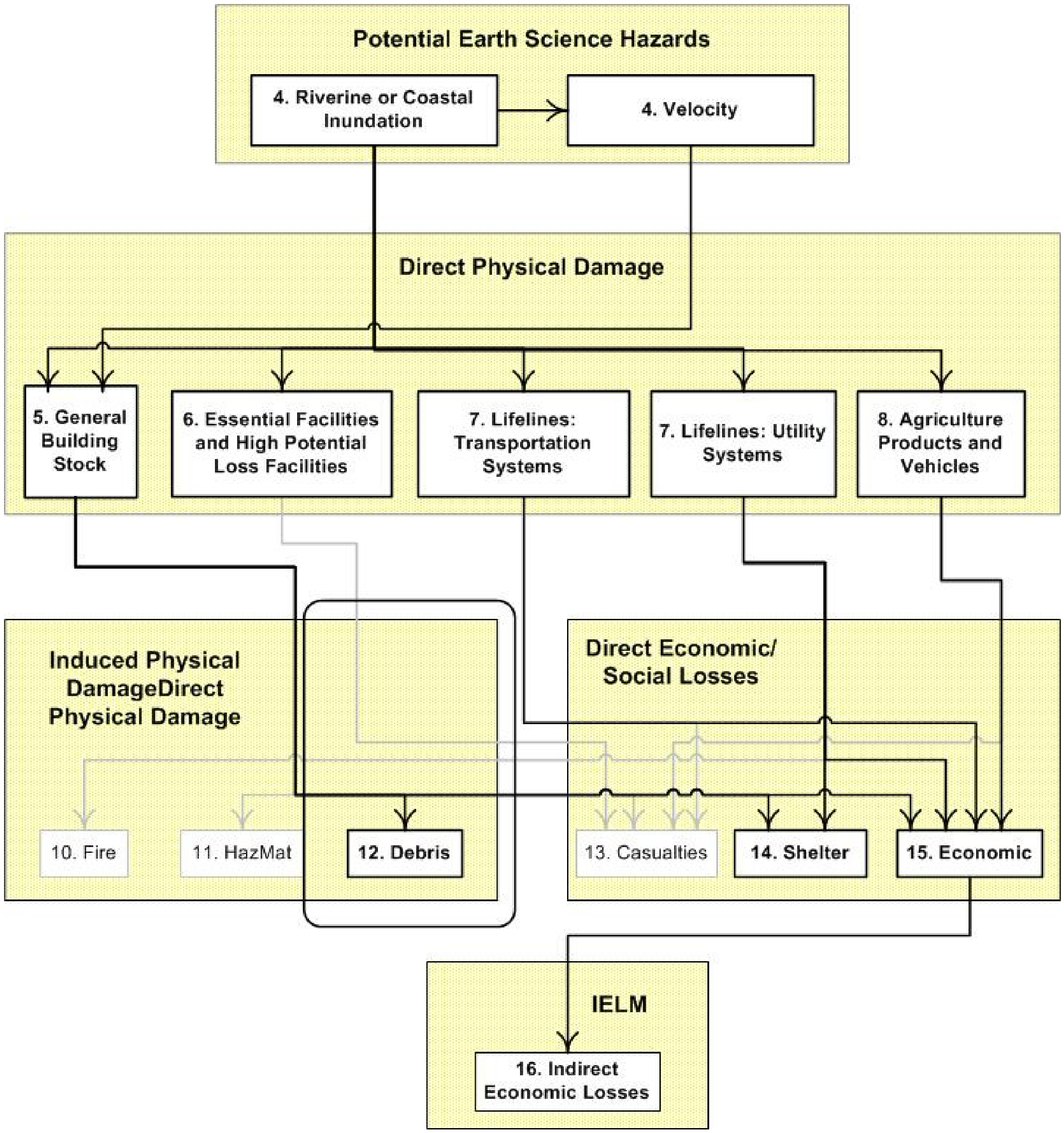

Figure 11.1 Debris Estimation Relationship to Other Components of the Hazus Flood Methodology

11.1.1 Scope

The Hazus Flood Model will estimate debris from building damage during floods, including building finishes, and structural components. No debris estimates are made for building contents, or for bridges or other lifelines.

11.1.2 Form of Damage Estimate

The debris module will determine the expected amounts of debris generated within each census block. Output from this module is the debris weight (in tons). The classes of debris are defined as follows:

- Building finishes
- Structural components
- Foundation materials

11.1.3 Input Requirements and Output Information

Input to this module includes the following items:

- Depth of flooding throughout the census block
- Building square footage by occupancy class for each census block from the inventory
- Foundation distribution information, classified into "Footings" and "Slab on grade", and RES1 foundation information regarding the presence of basements

11.2 Description of Methodology

The Hazus Flood Model debris estimation methodology was developed using a simplified engineering-based component analysis to identify building components requiring replacement (i.e., wood sub-floor, carpet, wall finishes, etc) at various depths of water, and to estimate their weight. For each occupancy class, structural component weights have been assumed as an average over typical model building types, based on the original the Hazus Earthquake debris model ("Unit Weight (tons per 1000 ft2) for Structural and Nonstructural Elements for the Model Building Types", Table 11.1, Hazus Earthquake Loss Estimation Methodology Technical Manual, FEMA/NIBS, 2002).

For each occupancy type, a determination has been made as to the typical depth associated with substantial damage (i.e., more than 50% damage), assuming a typical building configuration. For buildings suffering substantial damage, the debris model assumes that the building will be demolished with no salvage, including the foundation.

11.2.1 Debris Generated From Damaged Structures

Debris generated from damaged buildings (in tons) is based on the following factors:

1. Water depth in ranges relevant to debris generation; typically 0 to 4 feet, 4 to 8 feet, 8 to 12 feet, etc.

2. Occupancy type

3. Foundation type ("Footing" vs. "Slab on grade"), and presence of basement (RES1 only)

The recommended debris model of debris weights by occupancy class is given in Table 11.1.

Table 11.1 Debris Weight by Occupancy Class

Occupancy	Depth of Flooding	Debris Weight (Tons/1000 sq. ft.)			
		Finishes	Structure	Foundations	
				Footing	Slab on Grade
RES1 (without basement)	0'-4'	4.1			
	4' to 8'	6.8			
	8'+	6.8	6.5	12.0	25.0
RES1 (with basement)	-8' to -4'	1.9			
	-4' to 0'	4.7			
	0' to 6'	8.8			
	6'+	10.2	32.0	12.0	25.0
RES2	0' to 1'	4.1			
	1'+	6.5	10.0	12.0	25.0
RES3 (small 1 to 4 units)	0' to 4'	4.1			
	4' to 8'	6.8			
	8'+	10.9	6.5	12.0	25.0

Table 11.1 Debris Weight by Occupancy Category (Continued)

Occupancy	Depth of Flooding	Debris Weight (Tons/1000 sq. ft.)			
		Finishes	Structure	Foundations	
				Footing	Slab on Grade
RES3 (medium 5 to 19 units)	0' to 4'	4.1			
	4' to 8'	6.8			
	8' to 12'	10.9			
	12'+	13.6	6.5	13.8	25.0
RES3 (large 20+ units)	0' to 4'	4.1			
	4' to 8'	6.8			
	8' to 12'	10.9			
	12'+	13.6	47.8	19.0	25.0
RES4	0' to 4'	4.1			
	4' to 8'	6.8			
	8' to 12'	10.9			
	12'+	13.6	58.6	9.9	25.0
RES5	0' to 4'	4.1			
	4' to 8'	6.8			
	8' to 12'	10.9			
	12'+	13.6	68.7	18.3	25.0
RES6	0' to 4'	4.1			
	4' to 8'	6.8			
	8' to 12'	10.9			
	12'+	13.6	6.5	12.0	25.0
EDU1	0' to 4'	1.3			
	4' to 8'	2.0			
	8' to 12'	3.3			
	12'+	5.3	30.4	21.3	25.0
EDU2	0' to 4'	1.3			
	4' to 8'	2.0			
	8' to 12'	3.3			
	12'+	5.3	30.4	21.3	25.0
COM1	0' to 4'	1.8			
	4' to 8'	2.5			
	8' to 12'	4.3			
	12'+	5.0	47.1	2.1	25.0
COM2	0' to 4'	0.5			
	4' to 8'	1.0			
	8' to 12'	1.5			
	12'+	2.0	50.4	5.2	37.5

Table 11.1 Debris Weight by Occupancy Category (Continued)

Occupancy	Depth of Flooding	Debris Weight (Tons/1000 sq. ft.)			
		Finishes	Structure	Foundations	
				Footing	Slab on Grade
COM3	0' to 4'	0.5			
	4' to 8'	1.0			
	8' to 12'	1.5			
	12'+	2.0	43.7	8.7	25.0
COM4	0' to 4'	1.8			
	4' to 8'	2.5			
	8' to 12'	4.3			
	12'+	5.0	30.3	7.5	25.0
COM5	0' to 4'	1.8			
	4' to 8'	2.5			
	8' to 12'	4.3			
	12'+	5.0	23.5	8.7	25.0
COM6 (with basement	-8' to -4'	1.6			
	-4' to 0'	2.5			
	0' to 4'	5.9			
	4' to 8'	8.3			
COM7	0' to 4'	1.8			
	4' to 8'	2.5			
	8' to 12'	4.3			
	12'+	5.0	31.3	8.7	25.0
COM8	0' to 4'	1.0			
	4' to 8'	1.3			
	8' to 12'	2.8			
	12'+	3.1	26.9	8.7	25.0
COM9	0' to 4'	1.0			
	4' to 8'	1.3			
	8' to 12'	2.8			
	12'+	3.1	44.9	8.7	25.0
COM10	Any > 0'	0.0	69.3	5.2	37.5
GOV1	0' to 4'	1.8			
	4' to 8'	2.5			
	8' to 12'	4.3			
	12'+	5.0	31.3	8.7	25.0
GOV2	0' to 4'	0.5			
	4' to 8'	0.7			
	8' to 12'	1.5			
	12'+	1.7	18.0	8.7	25.0

Table 11.1 Debris Weight by Occupancy Category (Continued)

Occupancy	Depth of Flooding	Debris Weight (Tons/1000 sq. ft.)			
		Finishes	Structure	Foundations	
				Footing	Slab on Grade
IND1	0’ to 4’	0.5			
	4’ to 8’	0.7			
	8’ to 12’	1.5			
	12’+	1.7	50.4	5.2	37.5
IND2	0’ to 4’	0.5			
	4’ to 8’	0.7			
	8’ to 12’	1.5			
	12’+	1.7	40.2	5.2	37.5
IND3	0’ to 4’	0.5			
	4’ to 8’	0.7			
	8’ to 12’	1.5			
	12’+	1.7	49.8	5.2	37.5
IND4	0’ to 4’	0.5			
	4’ to 8’	0.7			
	8’ to 12’	1.5			
	12’+	1.7	34.8	5.2	25.0
IND5	0’ to 4’	0.5			
	4’ to 8’	0.7			
	8’ to 12’	1.5			
	12’+	1.7	58.3	5.2	25.0
IND6	0’ to 4’	1.8			
	4’ to 8’	2.5			
	8’ to 12’	4.3			
	12’+	5.0	34.0	5.2	37.5
REL1	0’ to 4’	1.0			
	4’ to 8’	1.3			
	8’ to 12’	2.8			
	12’+	3.1	32.5	8.7	25
AGR1	Any > 0’	0.0	12.3	5.2	25.0

To implement the debris estimation model, the default foundation distribution must be reclassified into two foundation types; “slab-on-grade” and “footings”. Table 11-2 provides the association of the detailed foundation types into the more general foundation types for debris estimation. As shown in the table, structures with basements are treated as slab foundations to reflect the typical presence of a concrete floor slab.

Table 11.2 Mapping Of Detailed Hazus Foundation Types Into General Foundation Types For Debris Estimation

Foundation types considered "Slab-on-grade"	Foundation types considered "Footings"
Basement/Garden Level	Pile
Slab-on-Grade	Solid wall
	Pier/Post
	Crawlspace
	Fill

The input provided from hazard module is the depth distribution throughout the census block, which may be applied to the square footage exposure for each occupancy type to determine square footage exposure by depth.

The expected debris amount (in tons) for occupancy type i in the current census block is given by:

$$EDW(i,j) = Depth\%_j \times Fa_i \times \left(DWF_{i,j} + DWS_{i,j} + \left(DWFoF_{i,j} \times FoF\%\right) + \left(DWFoS_{i,j} \times FoS\%\right)\right) \tag{11-1}$$

where:

EDW(i,j)	=	Expected debris weight of occupancy i, for depth j
$Depth\%_j$	=	the percent of the current census block subjected to the given depth, j
Fa_i	=	floor area of occupancy i (in 1000 square feet)
$DWF_{i,j}$	=	debris weight (in tons per 1000 square foot) of building finishes for occupancy i, and depth j, taken from Table 11-1.
$DWS_{i,j}$	=	debris weight (in tons per 1000 square foot) of building structural components for occupancy i, and depth j, taken from Table 11-1.
$DWFoF_{i,j}$	=	debris weight (in tons per 1000 square foot) of foundation materials for buildings with footing foundations for occupancy i, and depth j, taken from Table 11-1.
FoF%	=	percent of building area with footing foundations, aggregated from default foundation type distribution according to Table 11-2. (Note: FoF% and FoS% must sum to 100%)
$DWFoS_{i,j}$	=	debris weight (in tons per 1000 square foot) of foundation materials for buildings with slab-on-grade foundations for occupancy i, and depth j, taken from Table 11-1.
FoS%	=	percent of building area with slab-on-grade foundations, aggregated from default foundation type distribution according to Table 11-2. (Note: FoF% and FoS% must sum to 100%)

For RES1 structures, a factor is added to incorporate the basement/no-basement distribution, in conjunction with the basement and no basement models presented in Table 11-1.

11.2.2 Natural Debris Carried by Floodwaters

The Hazus Flood module currently does not estimate debris loads associated with vegetation, sediment and other natural debris carried by floodwaters.

11.3 Guidance for Expert-Generated Estimates

There is no difference in the debris estimation methodology for Advanced Data and Models Analysis. Users seeking more accurate debris estimates are encouraged to input more detailed inventory data, or to use alternative methods to estimate debris loads associated with building contents, and natural debris.

11.4 References

1. EPA (1995), *Planning for Disaster Debris*, U.S. Environmental Protection Agency, Solid Waste and Emergency Response, EPA530-K-95-010.

2. FEMA (1999), *Debris Management Guide*, Federal Emergency Management Agency, Publication FEMA-325.

3. FEMA/NIBS (2002), *HAZUS-99 Service Release 2 (SR-2) Technical Manual*, developed by the Federal Emergency Management Agency, through agreements with the National Institute of Building Sciences, Washington, D.C.

Chapter 12. Direct Social Losses – Casualties

12.1 Introduction

During the Flood Model methodology development, casualty data was collected and analyzed to assess the feasibility of incorporating a flood casualty model. The data collection and review are discussed in Section 12.2. Available casualty data for flood events was essentially limited to fatalities. That is, data on flood-related injuries was not widely available. Further, review of the fatality data indicated that drowning dominated the data for cause of death. Accordingly, a fatality model for drowning deaths in floods was proposed, but its implementation was deferred by the Flood Model Oversight Committee. The model development work done to date and documented here will be used as a basis for future methodology development for eventual inclusion in the Hazus Flood Model.

The Oversight Committee deferred the implementation of a flood casualty model because the committee felt that the methodology, while valid, was based on only a few storm events and was therefore not validated with the same level of scientific vigor as the rest of the Flood Model. Furthermore, the Oversight Committee believed that casualties related to flooding do not create the same significant impact on the medical infrastructure as those associated with earthquakes. Additional data collection following future flood events would facilitate development of more rigorous models, and is strongly recommended. In anticipation of future casualty model implementation, Section 12.3 provides suggestions for the potential form of casualty models for the Flood Model. Finally, the Flood Model Oversight Committee recommended that the Flood Model software include a PDF reference file that contains a discussion of flood-related casualties (provided here as Section 12.4) for the Flood Model users.

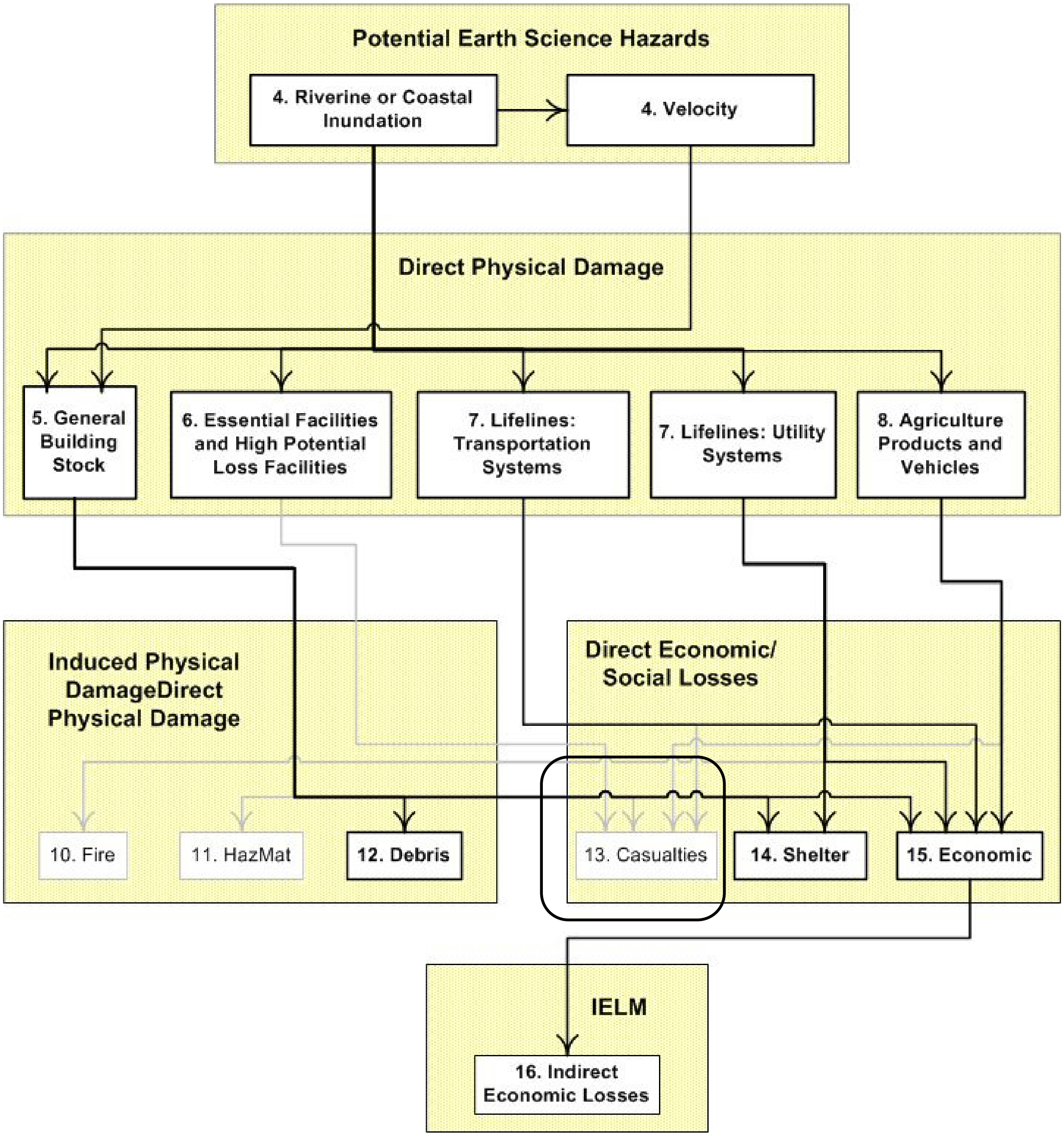

Figure 12.1 Social Losses Casualties Relationship to Other Components of the Hazus Flood Methodology

12.2 Summary of Collected Casualty Data

Available casualty data from U.S. floods, including the well-documented casualties in Houston, Texas associated with Tropical Storm Allison (June 2001), were reviewed to assess the types and causes of casualties in flooding. Primary data sources include the Morbidity and Mortality Weekly Report (MMWR), published by the Center for Disease Control (CDC), and various publications of the Texas Department of Health, Bureau of Epidemiology.

Data reviewed include both pure flood events (e.g., 1993 Mississippi floods) and hurricane events, which may be accompanied by heavy rainfall and significant inland flooding. For hurricane events, wind-related casualties are distinguished from flood-related casualties by cause. For example, deaths caused by fallen trees are considered wind-related, while drowning is generally flood-related. The eighteen events for which casualty data were reviewed are listed in Table 12.1. For each of these events, the total number of fatalities is provided in Table 12.2, and Table 12.3 provides a breakdown of all deaths by their cause. As shown, heavy death tolls occurred both in hurricane events (Floyd, Hugo, and Andrew) and flood events (Midwestern floods, Central Texas storms and Tropical Storm Alberto). Drowning was the cause of more than half of the deaths in all events (54%).

Table 12.1 Flood Events with Available Data Casualty

Event Name/Type	Date	Area Impacted	Notes
Tropical Storm Allison	June, 2001	Harris County, TX	Rapid rise flooding
Hurricane Floyd	September 16, 1999	North Carolina	Hurricane with significant inland flooding
Storm-related flooding	October 17, 1998	Central Texas	Rapid rise flooding
Hurricane Georges	September 21, 1998	Puerto Rico	
Hurricane Marilyn	September 15, 1996	US Virgin Islands & Puerto Rico	
Hurricane Opal	October 4, 1996	Florida, Alabama, Georgia, North Carolina	
Storm	May 5, 1995	Dallas Co., TX	Rapid rise flooding
Flood	October, 1994	Texas	Rapid rise flooding
Tropical Storm Alberto	July 4, 1994	Georgia	Tropical storm with significant inland flooding
Midwestern Floods	Summer/Fall, 1993	Missouri	
Midwestern Floods	Spring/ Summer 1993	Iowa	
Hurricane Andrew	August 24-26, 1992	Florida, Louisiana	
Nor'easter	December, 1992	CT, DE, MD, MA, NJ, RI, NY (Suffolk, Westchester and Nassau Counties, and 5 cos. In NY City), and Philadelphia Co PA.	
Hurricane Hugo	September 21, 1989	South Carolina	
Hurricane Hugo	September 18, 1989	Puerto Rico	
Hurricane Gloria	September 27, 1986	Rhode Island, Connecticut	
Hurricane Elena	September 2,1986	Mississippi	

Table 12.2 Fatalities, By Event

Event Type	Total Number of Deaths
Hurricane Floyd	52
Midwestern Flood - Missouri	43
Hurricane Hugo – South Carolina	35
Hurricane Andrew- Florida	33
Storm – Central Texas, 1998	31
Tropical Storm Alberto	30
Hurricane Opal	27
Tropical Storm Allison	24
Storm – Dallas, Texas	20
Flood – Texas, 1994	19
Hurricane – Louisiana	17
Hurricane Marilyn	10
Hurricane Hugo – Puerto Rico	9
Hurricane Georges	8
Hurricane Gloria	5
Nor'easter	4
Hurricane Elena	3
Midwestern Flood - Iowa	1
Total Number of Deaths	371

Table 12.3 Deaths, By Cause – All Events

Cause category	Total Number of Deaths
Drowning (in MV)	119
Drowning (other)	38
Drowning (on boat)	20
Drowning (as pedestrian)	15
Drowning (in home)	9
Sub-total: All drownings	***201 (54%)***
Trauma (inc. crush)	55
Cardiac	26
Electrocution	25
MVA	15
Fire/Burns/Smoke Inhalation	20
Asphyxiation	9
Carbon Monoxide poisoning	4
Other	12
Unknown	4
Sub-total: Non-Drowning	***170 (46%)***
TOTAL: All Causes	***371***

Of the eighteen events, only six events were "flooding" events for which both exposed population estimates and fatality data were available. These events, which may all be categorized as "rapid rise" or "very rapid rise" flooding, account for 173 of the fatalities within the overall database (47%). Only these events were included in subsequent analysis:

- Tropical Storm Allison (24 deaths)
- Hurricane Floyd (52 deaths)
- Storm-related flooding in Central Texas in 1998 (31 deaths)
- Storm-related flooding in Dallas County, Texas in 1995 (20 deaths)
- Flooding in Texas in 1994 (19 deaths)
- Midwestern Floods (27 deaths)

Table 12.4 provides a breakdown of deaths by their cause for the final six flooding events included in the analysis. As shown, drowning was the cause of more than 77% of deaths in these events. Because drowning is the primary cause of death in floods, it was proposed that the Hazus Flood Casualty Model focus on drowning deaths in "rapid rise" or "very rapid rise" flooding.

Table 12.4 Deaths, By Cause – Flood Events Only

Cause Category	Total Number of Deaths
Drowning (in MV)	86
Drowning	21
Drowning (as pedestrian)	15
Drowning (on boat)*	7
Drowning (in home)	5
Sub-total: All drownings	***134 (77.5%)***
MVA	9
Cardiac	9
Trauma	7
Electrocution	7
Hypothermia	2
Fire	2
Fall	1
Carbon Monoxide poisoning	1
Asphyxiation	1
Sub-total: Non-Drowning	***39 (22.5%)***
TOTAL: All Causes	***173***

** These drownings occurred during Hurricane Floyd and are wind/rain-related drownings, rather than flood-related drownings*

It should be noted that data on non-fatal injuries was available for just six events total, and included data for just one flood event. Accordingly, the available data are insufficient to develop a non-fatal injury model for flood.

12.3 Proposed Form of Casualty Models for Eventual Inclusion into Hazus Flood

It is suggested that the NIBS Flood Module consider three types of flood casualties, as follows:

- Casualties that occur in the floodwaters -- these casualties would be evaluated in aggregate at the community level. That is, injury and death rates per 100,000 population would be applied to the "exposed community." These casualty rates would depend on the rate of inundation (tentatively characterized into 3 classes: rapid/very rapid rise, moderate speed rise, slow rise), as well as selected demographic characteristics (Male/female, age, etc). The rates would include a reduction factor if the community has a swift-water rescue capability.

- Casualties that occur within buildings -- these casualties would be evaluated for two time frames: during the flooding, and during flood clean up. Building casualties during flooding depend on the amount of warning, flood depth or damage, and occupancy type. Building casualties during clean up depend on flood depth or damage, occupancy type, and electric power service interruption.

- Rain-related motor vehicle casualties -- in addition to the casualties that occur in the floodwaters, rain-related motor vehicle accident injuries and deaths are quantifiable. Previous research conducted by the UCLA School of Public Health, Center for Public Health and Disasters focused on the El Nino phenomenon provided source data for the development of casualty rates (per 100,000 population) based on low, medium and high rainfall rates. These casualty estimates would be optional, and the user would be expected to select the appropriate rainfall category.

12.4 Documentation Displayed in the Hazus Flood Model

Flooding of all types (riverine, flash flooding, coastal, fluctuating lake levels and other sources) is a major hazard in the U.S., accounting for the single largest total property losses, and major life loss, of any one hazard. Flooding has a long history in the U.S., including the infamous Johnstown flood of 1889[1], and the Mississippi floods of 1927. Recent floods have included the Mississippi Flood of 1993, the Northwest floods of 1996, and the North Dakota Red River flood of 1997. Figure 12.2 and Figure 12.3 show U.S. fatalities due to flooding, with an increasing trend that, if normalized for population growth, appears to be relatively steady (FEMA, 1997).

An effort has been made to develop methodology to estimate casualties due to flooding. Because there is limited data related to casualties beyond fatalities (i.e., injuries requiring hospitalization, minor injuries), the Flood Model Oversight Committee and FEMA decided to defer the estimation of casualties while further data collection and methodology development could continue. Below are two charts that can help the user asses the likelihood of incurring casualties during a given flood event. It should be noted that the United States averages approximately 100 deaths per year due to flooding, although this has been increasing over the last few years.

1 Johnstown PA, the victim of a disastrous flood in 1889, is one of the greatest natural disasters in U.S. history. At 3:10 PM on May 31, the South Fork Dam, a poorly maintained earthfill dam holding a major upstream reservoir, collapsed after heavy rains, sending a great wall of water rushing down the Conemaugh Valley at speeds of 20 to 40 miles per hour (32 to 64 km/h). At 4:07 PM, the 30-foot high wall of water smashed into Johnstown, which lay on the floodplain of the Conemaugh River. The flood swept away most of the northern half of the city, killing 2,209 people and destroying 1,600 homes. After another disastrous flood in 1936, a flood-control program was completed (1943), but this did not prevent heavy flooding in July 1977 in which 68 people were killed.

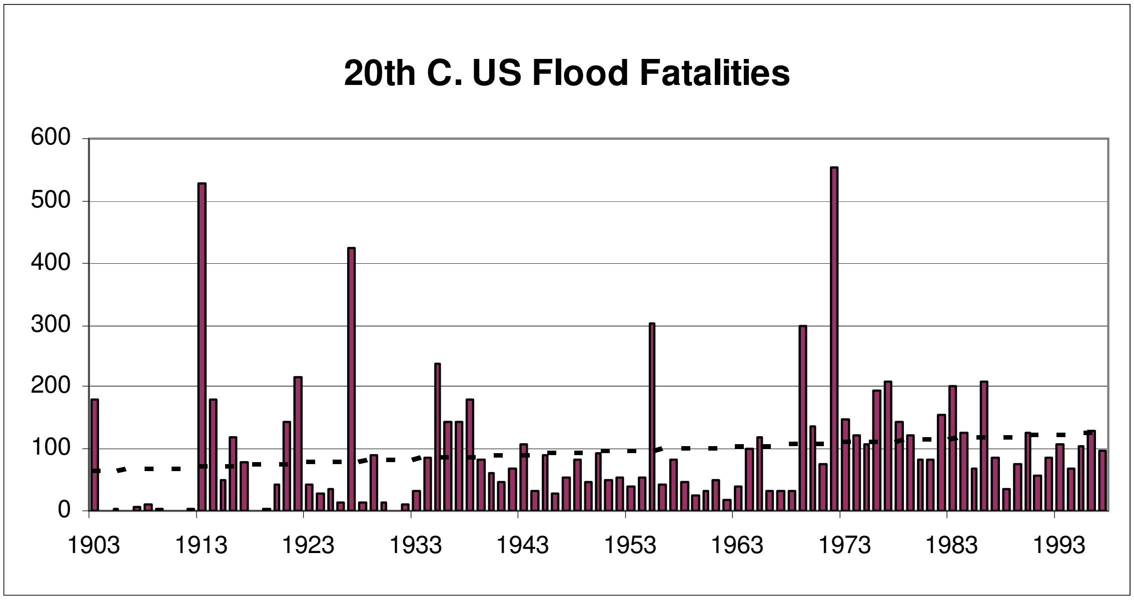

Figure 12.2 20th Century U.S. Flood Fatalities

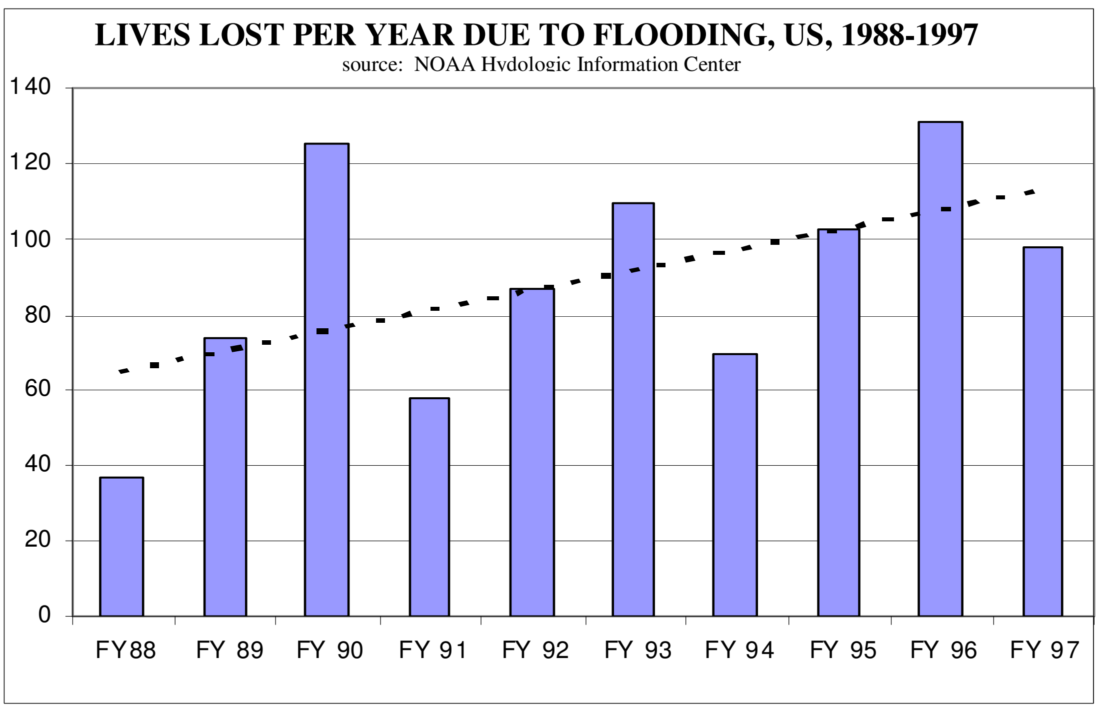

Figure 12.3 U.S. Flood Fatalities, 1988-1997

12.5 References

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2. CDC (1989a), "Deaths Associated with Hurricane Hugo - Puerto Rico", MMWR 1989; 38(39); 680-682.

3. CDC (1989b), "Update: Work-Related Electrocutions Associated with Hurricane Hugo - Puerto Rico", MMWR 1989; 38(42); 718-725.

4. CDC (1989c), "Medical Examiner/Coroner Reports of Deaths Associated with Hurricane Hugo - South Carolina", MMWR 1989; 38(44); 754,759-762.

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Chapter 13. Direct Social Losses - Displaced Households Due to Loss of Housing Habitability and Short-term Shelter Needs

13.1 Introduction

A significant part of any planning scenario is to estimate the number of individuals who will need to be sheltered in the short-term. Modifications have been made to the algorithm developed for Hazus Earthquake to reflect the difference in sheltering needs between earthquakes and floods. Flood sheltering needs are based on the displaced population, not the Damage State of the structure. The Hazus Flood Model determines the number of individuals likely to use government-provided short-term shelters through determining the number of displaced households as a result of the flooding. To determine how many of those households and the corresponding number of individuals will seek shelter in government-provided shelters the number is modified by factors accounting for income and again by factors accounting for age. The flowchart highlighting the Shelters component is shown in Figure 13.1.

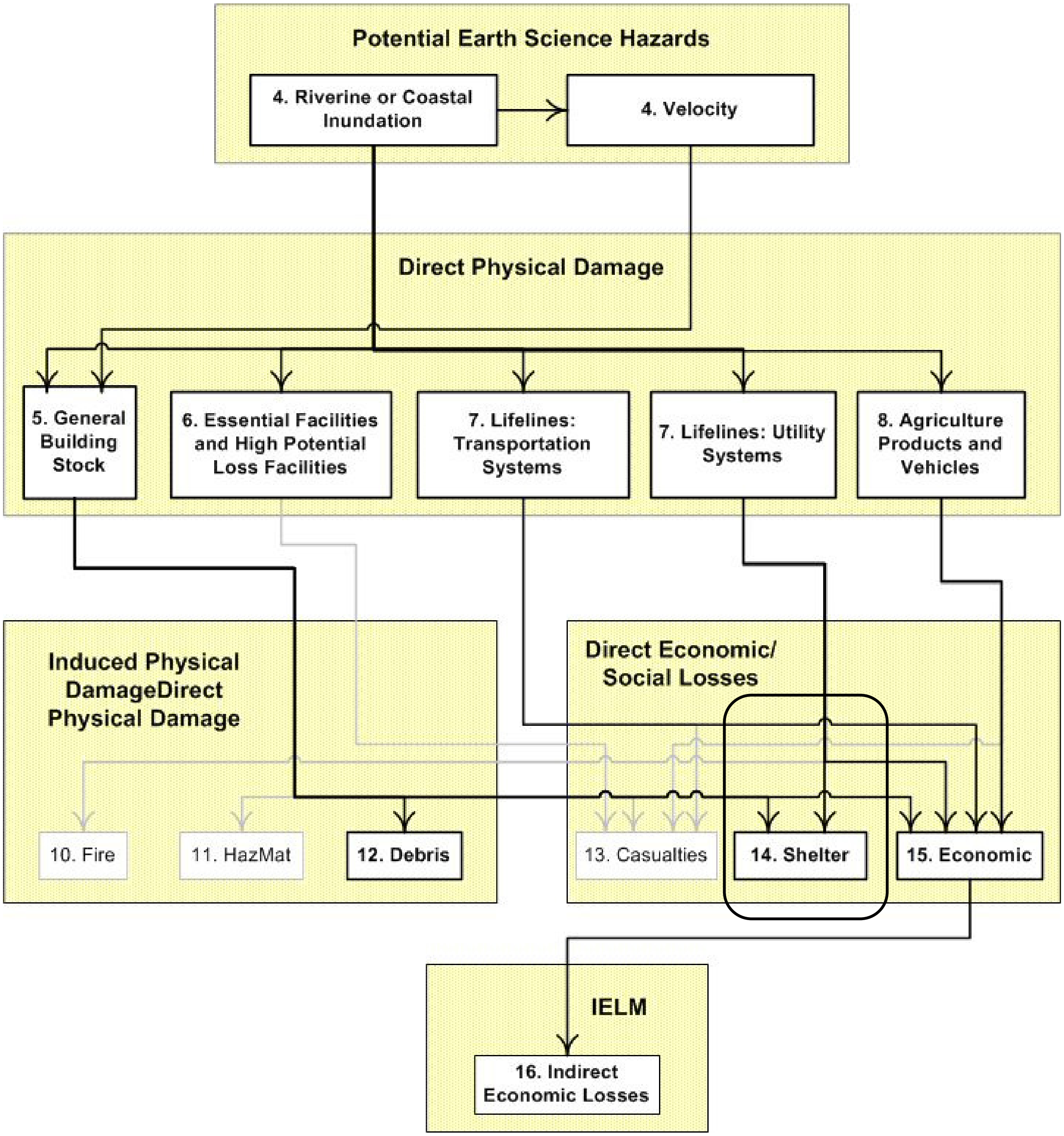


Figure 13.1 Shelter Relationship to Other Components in the Hazus Flood Methodology

13.2 Displaced Households - Form of Loss Estimate

The displaced population is based on the inundation area. Individuals and households will be displaced from their homes when the home has suffered little or no damage either because they were evacuated (i.e., a warning was issued) or there is no physical access to the property because of flooded roadways. Those displaced persons using shelters will most likely be individuals with lower incomes and those who do not have family and friends within the immediate area. Consequently, modification factors for flood are based primarily on income. Age plays a secondary role in that there are some individuals who will seek shelter even though they have the financial means of finding their own shelter. These will usually be younger, less established families and elderly families.

13.2.1 Input Requirements

The algorithm uses information from the census database in the following areas:

- Total number of households in the community;
- Total number of individuals in the community;
- Distribution of households by income; and
- Distribution of individuals by age.

The user can use either the census information or any local database that contains the same information. Should local information be used, the income data needs to be formatted into the following categories:

- Household income up to $10,000 per year;
- Household income greater than $10,000 but less than $15,000 per year;
- Household income from $15,000 to less than $25,000 per year;
- Household income from $25,000 to less than $35,000 per year; and
- Household income of $35,000 or greater per year.

The age distribution data needs to be formatted into the following categories:

- Individuals less than 16 years of age;
- Individuals from 16 to 65 years of age; and
- Individuals greater than 65 years of age.

13.2.2 Description of Methodology

The controlling factor is physical access into the area where the property is located. This is a function of the depth of water and the ability to travel into the area either on foot or by vehicle. For short-term sheltering estimations the user will need to determine at what depth of flooding will access to the area be obstructed. This depth typically would vary somewhere between 6” (typical curb height) and 12” (where vehicles will begin to float). Any residential unit located in the area where flood depth, defined as d_i, equals or exceeds that depth will be displaced from their home.

The determination of the number of displaced individuals is represented by:

$$\#DI_{IN} = \sum_{j=1}^{n} POP_{IN} \tag{13-1}$$

where:

$\#DI_{IN}$	=	The number of displaced individuals as a result of inundation where $d \geq i$
POP_{IN}	=	The population of a census block located within the area of inundation defined by $d \geq i$
J	=	the number of census blocks within the flooded area defined by $d \geq i$
D	=	depth of flooding
I	=	the depth of flooding at which travel into the area is restricted.

Under some planning scenarios it might be important to know how many households have been displaced. Using the census data this calculation is as follows:

$$\#DH_{IN} = \sum_{j=1}^{n} H_{IN} \tag{13-2}$$

where:

$\#DH_{IN}$	=	The number of displaced households as a result of inundation where $d \geq i$
H_{IN}	=	The number of households in a census block located within the area of inundation defined by $d \geq i$

J = the number of census blocks within the flooded area defined by $d \geq i$

D = depth of flooding

I = the depth of flooding at which travel into the area is restricted.

13.2.2.1 Displaced Persons As A Result Of Utility Damage

The utilities required for a structure to be occupied are water and sewer. During colder weather loss of utilities that provide heat such as gas or electricity may result in increased population within the shelters, certainly it would increase the number of displaced persons.

It is recommended that the number of displaced persons as a result of utility losses be calculated in a similar manner to that of the Earthquake Model.

The equation would be:

$$\#DI_{UTIL} = \%WAG\ [POP - \#DI_{IN}] \tag{13-3}$$

where:

#DIUTIL = Number of displaced persons as a result of lost utility services

%WAG = Probability of a dwelling unit being without utilities and vacated (user supplied)

default value = 0

Similarly, when considering displaced households due to utility loss, the equation would be:

$$\#DH_{UTIL} = \%WAG\ [H - \#DH_{IN}] \tag{13-4}$$

where:

$\#DH_{UTIL}$ = Number of displaced households as a result of lost utility services

%WAG = Probability of a dwelling unit being without utilities and vacated (user supplied)

default value = 0

H = Total number of households

When determining the probability that a dwelling unit will be without utilities, the user is encouraged to review past flooding events within the jurisdiction to see if utilities have been adversely affected. This would give an indication as to the probability of loss of utilities. Additionally, looking at the utility distribution within the study area would also provide some guidance.

The number of displaced persons needs to be modified by factors that reflect the likelihood that an individual would use publicly provided shelters. The key factors in this determination will be income and age as follows:

- Low income families as they lack the means to find other shelter on their own; and
- Young and elderly families who may have the means of finding temporary shelter on their own, but prefer to use publicly provided shelters.

Factors provided are "Shelter Category Weights" and "Shelter Relative Modification Factors" similar to that of the Earthquake model. These factors are used in the calculation of a constant defined as:

$$\alpha_{km} = (IW \text{ x } IM_k) + (AW \text{ x } AM_m) \qquad (13\text{-}5)$$

where:

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 persons using publicly provided shelters is then represented by:

$$\#STP = \sum_{k=1}^{5} \sum_{m=1}^{3} \{\alpha_{km} \text{ x } DP \text{ x } HI_k \text{ x } HA_m\} \qquad (13\text{-}6)$$

Where:

#STP	=	Number of people using established shelters
α_{km}	=	a constant
DP	=	Displaced population = $\#DI_{IN} + DI_{UTIL}$
HI_k	=	Percentage of population in the k^{th} income class

HA_m = Percentage of population in m^{th} age class

13.2.2.2 Shelter Category Weight

These factors (see Table 13.1) represent the importance of the particular category in the determination of how many will seek publicly provided shelters. During flood events most displaced individuals will obtain their own sheltering in hotels or with friends and family. The ability to find shelter on their 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 community provided shelters. In many respects, this is also a function of income since many young families tend to fall in the lower income brackets and the older (65 years or older) are living on fixed incomes potentially in the lower brackets.

Table 13.1 The Shelter Category Weights

CLASS	DESCRIPTION	DEFAULT
IW	Income Weighting Factor	0.80
AW	Age Weighting Factor	0.20

Recognizing the importance of income in the equation, the default-weighing factor was set at 0.80. This automatically establishes age weighting factor as 0.20 as the sum of these factors must total 1. Shelter statistics from previous flood disasters usually do not include information on household income and age. Typically, the Red Cross does not record this information citing privacy as the reason. Therefore, there is little guidance available to the user in modifying the default values. In sample calculations that were performed using a displaced population in excess of 49,000 and using the default Relative Modification Factors, changing the weight factors from .8 to .75 and from 0.2 to 0.25 decreased the shelter estimation by approximately 3.5 percent. It is therefore recommended that the default Shelter Category Weights be used unless the user has good statistical data on the individuals whom have used shelters in the past.

13.2.2.3 Shelter Relative Modification Factors

These factors (see Table 13.2) estimate the percentage of each category that will seek publicly provided shelters. As described in the Earthquake Model Technical Manual, these factors were originally developed by George Washington University[1] and modified for the Flood Model.

The factors for income are the estimated percentage of that particular group that will most likely seek public shelter. As the household annual income increases, the likelihood of the household using public shelter decreases. Since income is the most significant component, the factors have been set to total 1 or 100%. If the user wishes to modify the default values, care should be taken to make sure the revised factors total 1. It should be noted that this is a departure from the George Washington University study and is based on the proof of concept evaluation.

Table 13.2 Relative Modification Factors

Class	Description	Default	Default for Communities with 60% or More of Households with Income >$35,000
Income			
IM_1	Household Income < $10,000	0.40	0.46
IM_2	$10,000 < Household Income < $15,000	0.30	0.36
IM_3	$15,000 < Household Income < $25,000	0.15	0.12
IM_4	$25,000 < Household Income < $35,000	0.10	0.05
IM_5	$35,000 < Household Income	0.05	0.01
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	

13.2.3 User-defined Changes to Weight and Modification Factors

Sensitivity calculations where performed on the income factors to ascertain the impacts of changing default values. Eight random communities were selected of varying sizes. When the default values for IM_1 through IM_3 were increased by 10 percent and the factors IM_4 and IM_5 were reduced to maintain the same ratio as the default, the resulting change in the shelter estimation decreased in 5 of the communities by between 1 percent and 3.7 percent. This indicates that small modifications in the factors have relatively little effect on the estimated shelter population.

In three of the communities, the population change was much more significant in that population decreased between 10.5 percent and 12 percent. Review of the census data for these communities showed that more than 60% of the households in these communities had incomes greater than $35,000. In the other five communities, the percentages ranged from a low of 23.45 percent to a high of 40.23 percent. To compensate for the large segment of the population within the higher income bracket, default values for IM_1 through IM_3 were increased, and values for IM_4 and IM_5 were decreased. Therefore, a second set of default values has been developed for use in communities where 60 percent or more of the households have an income greater than $35,000.

As with the Shelter Category Weights it is recommended that default values be used unless the user has good statistical data available on who uses shelters.

The factors for age are intended to estimate those individuals who will use public shelter without regard to their income. These tend to be primarily younger families and those over the age of 65.

In the first grouping of age, those under 16 years, we can establish the default value as nearly 0 because the income categories are households, while the age category is individuals. If a household uses a shelter, this will usually include the children. It would be very rare that this age group would use the shelters while the family went elsewhere. The second category, those between 16 and 65 is also established as a relatively small percentage since it is in this age bracket that most working people fall. If their income is low, they will be accounted for with the income factor. Few of these individuals will use publicly provided shelter if their income allows them to find other means. Additionally, those in this category are most likely to have friends and/or family near the area that could provide them shelter.

The largest of the factor is the final category and those are the individuals over 65. These individuals will tend to be on fixed incomes and will be estimated with the income factor. However, these individuals are less likely to have family and friends to help them or, because of their age are less likely to try and find shelter elsewhere.

13.3 References

1. Hazus Earthquake Loss Estimation Methodology – Technical Manual Volume III, pages 14-7 and 14-8. "These constants where originally developed by George Washington University under contract with the Red Cross and are based on "expert" opinion (Harrald, Fouladi, and Al-Hajj, 1992)… The modification factors provided [default for earthquake model] are the mean of the George Washington University modification factors…"

Chapter 14. Direct Economic Losses

14.1 Introduction

This chapter describes the conversion of percent damage, developed in previous modules, into estimates of dollar loss. In the past, loss estimation studies have generally limited the consideration of loss to estimates of the repair and replacement costs of the building stock.

The methodology provides estimates of the building repair 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. To account for this, business interruption and rental income losses are estimated. These losses are calculated from the building damage estimates by use of methods described later. The methodology highlighting the Direct Economic Loss component is shown in Figure 14.1.

This expression of losses provides an estimate of the costs of building repair and replacement that is a frequently required output of a loss estimation study. The additional estimates of consequential losses give an indication of the immediate impact of such building damage on the community: the financial consequences to the community's businesses due to businesses interruption, the financial resources that will be needed to make good the damage, and an indication of job and housing losses. In strict economic terms, buildings, inventories, and public facilities represent capital investments that produce income, and the value of the building and inventory will be the capitalized value of the income produced by the investment that created the building or inventory. Hence, if we estimate the dollar value of the buildings damaged or destroyed, and add the income lost from the absence of the functioning facilities we may be overestimating the indirect economic loss (see Chapter 15). However, for the assessment of direct economic loss, the losses can be estimated and evaluated independently.

Since a significant use for loss estimation studies is expected to be that of providing input into future benefit-cost studies used to evaluate mitigation strategies and budgets, the list of these consequential losses is similar to that developed for the FEMA benefit-cost procedure described in FEMA publications 227 and 228, and 255 and 256. This procedure is, however, limited to conventional real-estate parameters similar to those used in evaluating the feasibility of a development project and does not attempt to evaluate the full range of socio/economic impacts that might follow specific mitigation strategies.

Thus, for this loss estimation methodology, even though the derivation of these consequential losses represents a considerable expansion of the normal consideration of building damage/loss, this module is still limited in its consideration of economic loss to those losses that can be directly derived from building and infrastructure damage, and that lend themselves to ready conversion from damage to dollars. The real socio/economic picture is much more complex: economic impacts may have major societal effects on individuals or discrete population groups, and there may be social impacts that ultimately manifest themselves in economic consequences. In many cases the linkages are hard to trace with accuracy and the effects, while easy to discern, are difficult to quantify because definite systematic data is lacking.

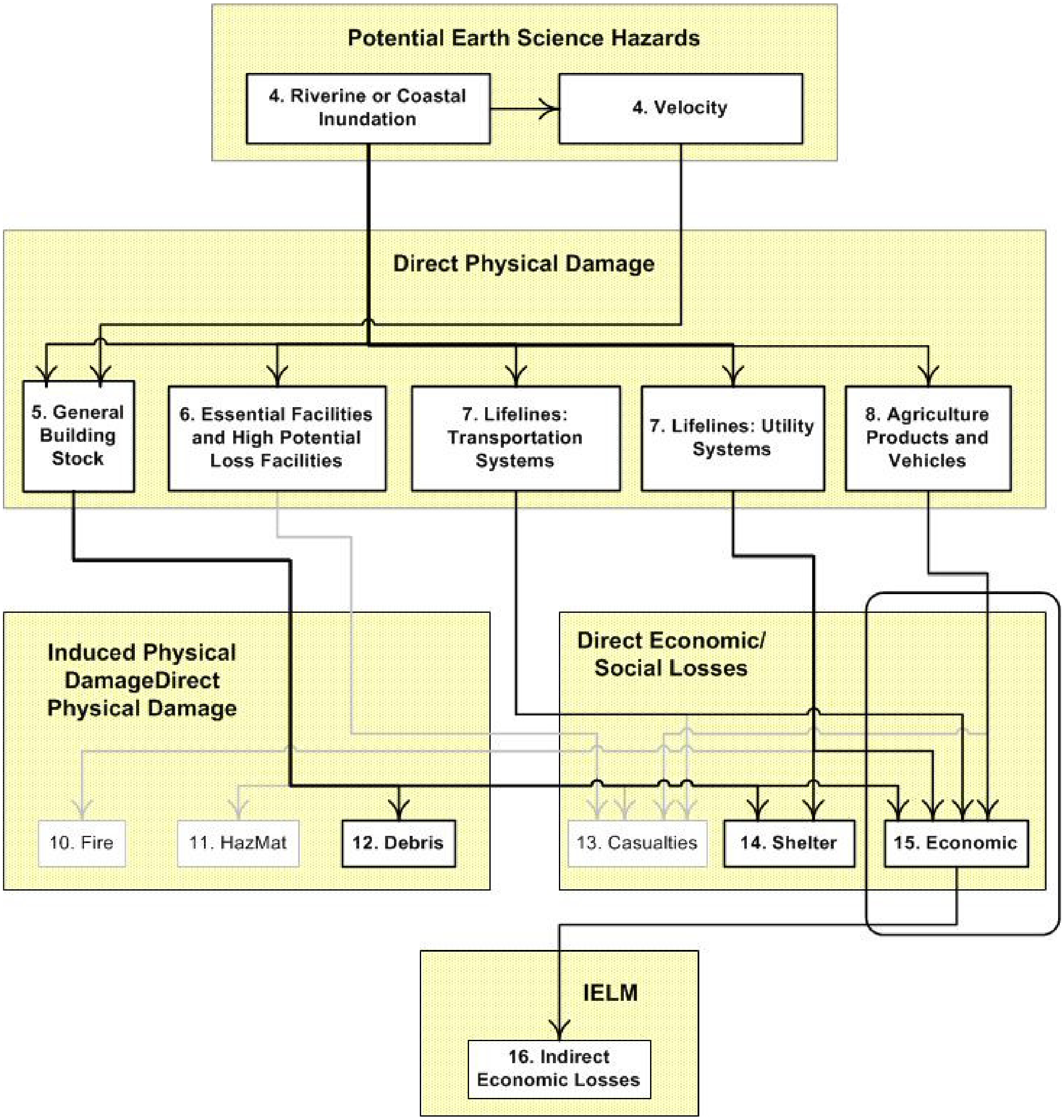


Figure 14.1 Direct Economic Loss Module Relationship to Other Components of the Methodology

Given the complexity of the problem and the present paucity of data, the methodology focuses on a few key issues that are of critical importance to government and the community, that can be quantified with reasonable assurance, and that provide a picture of the cost consequences of building and infrastructure damage that are understandable and would be of major concern to a municipality or region. In addition, application of the methodology will provide information that would be useful in a more detailed study of a particular economic or social sector, such as impact on housing stock or on a significant local industry. Finally, the structure of the methodology should be of assistance in future data gathering efforts.

While the links between this module and the previous modules dealing with damage are very direct and the derivations are very transparent, the links between this module and that of Chapter 15, Indirect Economic Losses, are less so. While some of the estimates derived in this module, such as income loss by sector, building repair costs, and the loss of contents and inventories, may be imported directly into the Indirect Loss Module, some interpretation of the direct economic loss estimates would be necessary for a more detailed indirect economic loss study. It would be necessary, for example, to translate the repair and replacement times and costs derived in this module to monthly reconstruction investment estimates for use in a longer-term indirect loss estimate.

14.1.1 Scope

This chapter provides descriptions of the methodologies, the derivation of default data, and explanatory tables for a number of direct economic loss items, derived from estimates of building (Section 14.2), lifeline (Section 14.3), vehicle (Section 14.4) and agriculture (Section 14.5) damage.

Within the HAZUS methodology, direct economic losses to buildings include:

- Building repair and replacement costs (structural and non-structural damage)
- Building contents losses
- Building inventory losses
- Relocation expenses
- Capital related income losses (previously loss of proprietor's income)
- Wage losses
- Rental income losses

The first three categories are building-related losses, termed "Capital Stock Losses," while the last four are time-dependent income losses, requiring an estimation of building restoration or outage time.

Direct economic losses for the Hazus Flood Module are similar to those currently implemented in the HAZUS99 Earthquake Module as listed above, except that earthquake losses depend on damage state probability, while flood losses depend on depth-related percent damage. It should be noted that the earthquake module estimates damage and losses to structure and non-structural components separately, while the flood module estimates one aggregate "building" loss.

In addition to the existing income losses, the Flood Module incorporates output losses, and employment losses (in terms of the number of jobs).

Direct economic losses for utility and transportation systems (Section 14.3) are limited to the cost of repairing damage to selected lifeline systems, as follows:

- Transportation - bridges
- Water - water treatment plants, pump stations, control vaults, and pipeline river crossings.
- Wastewater - wastewater treatment plants, lift stations, control vaults, pipeline river crossings, and collection systems.
- Petroleum – pump stations and pipeline river crossings.
- Natural gas – control vaults/metering stations and pipeline river crossings.
- Telecommunications – switching stations, control vaults/stations and cable river crossings.
- Electrical power – substations.

Default full replacement values for transportation and utility lifeline facilities, developed originally for the Hazus Earthquake Model, are provided as a guide. It is recommended that the user input more accurate replacement values based on knowledge of lifeline facility values in the region.

Direct economic losses to vehicles (discussed in Section 14.4) include dollar losses associated with damage to cars, light trucks and heavy trucks. And finally, direct economic losses to agriculture (Section 14.5) include estimates of losses associated with flood durations of 1 day, 3 days, 7 days and 14 days.

14.1.2 Form of Direct Economic Loss Estimates

Direct economic loss estimates are provided in 2006 dollars except for employment losses, which are presented in terms of number of jobs.

14.1.3 Input Requirements

The input data for calculation of the direct economic losses consists primarily of building and transportation and utility system damage estimates from the direct physical damage module. These damage estimates are in the form of percent damage relative to full replacement cost, and associated dollar estimates of damage for each occupancy class. The dollar estimates of damage are based on default building and lifeline replacement cost (valuation) models available for each occupancy or facility class.

The types of economic data that the user can supply or modify from default include; contents value (percent of building replacement cost) for different occupancies, annual gross sales by occupancy, typical rental costs, relocation expenses and income by occupancy, as well as replacement values for the various transportation and utility facilities. While default values are provided for these data, the user may wish to provide more accurate local values or update default values to current dollars.

14.2 Description of Methodology: Buildings

The Flood Loss Estimation Module of Hazus includes two basic building valuation models; a full replacement cost model, and a depreciated cost model. Both models are based on industry standard cost models published by R.S. Means Company ("Means Square Foot Costs", 2006). The Means-based approach is consistent with previous cost modeling within the earthquake module of Hazus, although the incorporation of depreciation is a new feature added for the Flood Model.

14.2.1 Full Building Replacement Costs

14.2.1.1 Default Values for Building Replacement Cost

Building replacement cost models within Hazus are based on industry-standard cost-estimation models published in *Means Square Foot Costs* (R.S. Means, 2006). Replacement cost data are stored within HAZUS at the census block level for each occupancy class. For each Hazus occupancy class, a basic default structure full replacement cost model (cost per square foot) has been determined, and is provided in Table 14.1. Commercial and industrial occupancies have a typical building replacement cost model associated with each occupancy class (e.g., COM4, Professional/Technical/Business Services, is represented by a typical, 80,000 square foot, 5 to 10 story office building). In most cases, the typical building chosen to represent the occupancy class is the same as was used in the original Hazus earthquake model (based on Means, 1994), except for single family residential, multi-family residential, and industrial uses. Square foot costs presented in the table have been averaged over the various alternatives for exterior wall construction (e.g., wood siding over wood frame, brick veneer over wood frame, stucco on wood frame or precast concrete, concrete block over wood joists or precast concrete, etc.). For non-residential structures, the default configuration assumes structures without basements.

The RES1 (single family residential) replacement cost model is the most complex, utilizing socio-economic data from the census to determine an appropriate mix of construction classes

(Economy, Average, Custom and Luxury) and associated replacement cost models. The algorithm is described in Section 14.2.1.1.1. Within Means, basements are not considered in the base cost of the structure and are handled as an additive adjustment (additional cost per square foot of main structure). Table 14.2 provides Means (2006) replacement costs for the various single family dwelling configurations available in the default building inventory (1, 2, and 3 story and split-level), assuming a typical size of 1,800 square feet. Costs have been averaged for the various alternatives for exterior wall construction.

Because the default single family residential (SFR) damage model is based on the FIA credibility-weighted depth damage functions, whose coverage extends to garages, the replacement cost of garages will also be included in the basic replacement cost. Relevant Means models for SFR garages include costs by construction class (economy, average, custom, and luxury), for detached and attached 1-car, 2-car and 3-car garages, constructed of wood or masonry. For incorporation into Hazus, costs by size and construction class have been averaged for attached/detached and various materials. Average costs associated with garage types included in the default inventory for single family residential structures (1-car, 2-car and 3-car) are provided in Table 14.3.

14.2.1.1.1 Single-Family Residential Valuation Algorithm

The algorithm defined below will be used to develop the valuation for single-family residential buildings at the census block level. This algorithm utilizes socio-economic data from the census to derive an appropriate Means-based cost for each census block. The earthquake and wind models shall use a "roll-up" of the results from the Flood Model calculations. Some round-off error will occur, but this cannot be avoided.

The valuation algorithm can be summarized mathematically in equation (1) below:

$$V_{RES1,\,k} = (A_{RES1,\,k})*[\sum_{i=1}^{4}\sum_{j=1}^{4} w_{i,k}*w_{j,k}*C_{i,j}] + (A_{RES1,\,k})*w_{l,k}*[\sum_{i=1}^{4}\sum_{j=1}^{4} w_{i,k}*w_{j,k}*C_{i,j,l}]$$

$$+(RES1Cnt_{k})*[\sum_{i=1}^{4}\sum_{j=1}^{4} w_{i,k}*w_{m,k}*C_{i,\,m}] \qquad (14\text{-}1)$$

Where:

$V_{RES1,\,k}$ is the total estimated valuation for single-family residences (RES1) for a given census block (k). $V_{RES1,\,k}$ is editable when viewing the dollar exposure by specific occupancy table.

$A_{RES1,k}$ is the total single-family residential (RES1) floor area (square feet) for a given census block (k) found in the square foot by specific occupancy table. $A_{RES1,k}$ is editable when viewing the square foot by specific occupancy table.

i	the Means construction class (1 = Economy, 2 = Average, 3 = Custom, 4 = Luxury).
$w_{i,k}$	is the weighting factor for the Means construction class (i) for the given census block (k) and is determined from the income ratio range as shown in Table 14.4 below. Values are displayed in percent to the user and are editable when viewing the dollar exposure parameters tables.
j	the number of stories class for single-family (RES1) structures (1 = 1-story, 2 = 2-story, 3 = 3-story, and 4 = split level)
$w_{j,k}$	is the weighting factor for the Number of Stories class (j) for the given census block (k) depending on the census region of that block (by state FIPS). Weighting factors were developed from regional construction type distributions as discussed in Section 3. Values are displayed in percent to the user and are editable when viewing the dollar exposure parameters tables.
$C_{i,j}$	is the single-family (RES1) cost per square foot for the given Means construction class (i) and number of stories class (j). RES1 replacement costs are seen in the third column of Table 14.2. Values are editable when viewing the dollar exposure parameters tables.
l	the basement status available for single-family residences (1 = yes, 2 = no).
$w_{l,k}$	is the weighting factor for basements for the given census block (k) depending on the census region of that block (by state FIPS). Weighting factors were developed from regional foundation type distributions as discussed in Section 3. Values are displayed in percent to the user and are editable when viewing the dollar exposure parameters tables. Default will be established based on whether the block is a coastal or non-coastal block.
$C_{i,j,l}$	the additional cost, per square foot of the main structure, for a finished basement for the given Means construction class (i) and number of stories class (j), as shown in Table 14.2, Column 4. Note: $C_{i,j,l} = 0$ when $l = 2$. Values are editable when viewing the dollar exposure parameters tables.
m	the garage combinations available for single-family residences (1 = 1-car, 2 = 2-car, 3 = 3-car, 4 = carport, and 5 = none).
$w_{m,k}$	is the weighting factor for the garage type (m) for the given census block (k) depending on the census region of that block (by state

FIPS). Weighting factors were developed from regional construction type distributions as discussed in Section 3. Values are displayed in percent to the user and are editable when viewing the dollar exposure parameters tables.

$C_{i,m}$ the additional replacement cost for a given garage type (m), for the given Means construction class (i) as shown in Table 14.3. Note: $C_{i,m} = 0$ when m = 4 (covered carport) or m = 5 (none). Values are editable when viewing the dollar exposure parameters table.

R_{ES1Cnt} the count of RES1 structures within the given census block (k) taken directly from the Building Count by occupancy table.

As the algorithm shows, the basic replacement cost per square foot is a function of the Means construction class, the number of stories and an additional cost per square foot of the main structure for the existence of a finished or unfinished basement. Finally, there is an additional cost per housing unit based on the garage associated with the structure. The valuation parameters are presented in a series of tables in Section 14.2.1.1.4 of this document.

14.2.1.1.2 Manufactured Housing Valuation Algorithm

It is necessary to clarify that RES2 within HAZUS99 and Hazus-MH, while designated Manufactured Housing, represents Mobile Homes and not single-family pre-manufactured housing. The US Census provides a detailed count of the mobile homes within each census block and this quantity is used to develop the total floor area (square foot) of the RES2 occupancy classification. The total floor area was developed assuming a typical floor area and average distribution of singlewide to doublewide mobile homes. Unlike other occupancy classifications, there are no allowances for variation of floor heights (number of stories) or other valuation parameters. The valuation of manufactured housing is the straight multiplication of the total floor area by the baseline replacement cost per square foot. The cost per square foot (C_{RES2}) is defined in Table 14.1.

The algorithm for manufactured housing is defined in equation (2) below:

$$V_{RES2,k} = A_{RES2,k} * C_{RES2} \qquad (14\text{-}2)$$

Where:

$V_{RES2,k}$ is the total estimated valuation for Manufactured Housing (RES2) for a given census block (k). $V_{RES2,\,k}$ is editable when viewing the dollar exposure by specific occupancy table.

$A_{RES2,k}$ is the total Manufactured Housing (RES2) floor area (square feet) for a given census block (k) found in the square foot by specific occupancy table. $A_{RES2,k}$ is editable when viewing the square foot by specific occupancy table.

C_{RES2} is the Manufactured Housing (RES2) cost per square foot. RES2 replacement costs are given in Table 14.1 ($30.90/SqFt). The value is editable when viewing the dollar exposure parameters tables.

The Flood Model has accounted for differential areas between singlewide and doublewide manufactured housing in the total floor area, it is assumed that the cost per square foot does not vary greatly between the two structure types.

14.2.1.1.3 Other Residential and Non-Residential Occupancies

The algorithm for the remaining residential occupancies (RES3-RES6) and all non-residential (COM, IND, EDU, REL, GOV, and AGR) occupancies is not as complex as the single family model but allows for the potential incorporation of a distribution for number of stories. It should be noted that the replacement costs seen in Table 14.1 are an average replacement cost by occupancy. In other words, the replacement cost is averaged across structure types, stories and construction classes to produce the values in Table 14.1.

The algorithm for the remaining residential occupancies and non-residential occupancies can be seen in equation (3) below:

$$V_{x,k} = A_{x,k} * C_x \qquad (14\text{-}3)$$

Where:

x defines the remaining occupancy classifications (x ranges from 3 to 33 for the remaining occupancies, i.e., RES5, COM1, REL1, etc.) for which the cost is being calculated.

$V_{x,k}$ is the total estimated valuation for the specific occupancy (x) (such as RES4, COM3, or IND6) for a given census block (k). $V_{x,\,k}$ is editable when viewing the dollar exposure by specific occupancy table.

$A_{x,k}$ is the total floor area (square feet) for a specific occupancy (x) (such as RES3, COM8, IND4, GOV1, etc.) for a given census block (k) found in the square foot by specific occupancy table. $A_{x,k}$ is editable when viewing the square foot by specific occupancy table.

C_x is the cost per square foot for the specific occupancy (x). The replacement costs are seen in Table 14.1 below by specific occupancy. Values are editable when viewing the dollar exposure parameters tables.

At this time, the Flood Model depreciation models for non-single-family residential structures will not depend on features such as the number of stories. A distribution of number of stories will still be developed in the dollar exposure parameters table since the creation of such depreciation models are seen as a potential enhancement in future versions of the Hazus Flood Model.

14.2.1.1.4 Valuation Tables

The following tables present the baseline valuation parameters for the variables discussed in Section 14.2 of this document. Each of these parameters is editable by the user.

Table 14.1 Default Full Replacement Cost Models (Means, 2006)

HAZUS Occupancy Class Description		Sub-category	Means Model Description (Means Model Number)	Means Typ Size	Means Cost/SF (2006)
OCC Code	**OCC Description**	**OCC sub-class**			
RES1	Single Family Dwelling	See Table 14-2			
RES2	Manufactured Housing	Manufactured Housing	Manufactured Housing Institute, 2004 average sales price and size data for new manufactured home (latest data available)	1,625	$35.75
RES3A	Multi Family Dwelling – small	Duplex	SFR Avg 2 St., MF adj, 3000 SF	3,000	$79.48
RES3B		Triplex/Quads	SFR Avg 2 St., MF adj, 3000 SF	3,000	$86.60
RES3C	Multi Family Dwelling – medium	5-9 units	Apt, 1-3 st, 8,000 SF (M.010)	8,000	$154.31
RES3D		10-19 units	Apt., 1-3 st., 12,000 SF (M.010)	12,000	$137.67
RES3E	Multi Family Dwelling – large	20-49 units	Apt., 4-7 st., 40,000 SF (M.020)	40,000	$135.39
RES3F		50+ units	Apt., 4-7 st., 60,000 SF (M.020)	60,000	$131.93
RES4	Temp. Lodging	Hotel, medium	Hotel, 4-7 st., 135,000 SF (M.350)	135,000	$132.52
RES5	Institutional Dormitory	Dorm, medium	College Dorm, 2-3 st, 25,000 SF (M.130)	25,000	$150.96
RES6	Nursing Home	Nursing home	Nursing Home, 2 st., 25,000 SF (M.450)	25,000	$126.95
COM1	Retail Trade	Dept Store, 1 st	Store, Dept., 1 st., 110,000 SF (M.610)	110,000	$82.63
COM2	Wholesale Trade	Warehouse, medium	Warehouse, 30,000 SF (M.690)	30,000	$75.95
COM3	Personal and Repair Services	Garage, Repair	Garage, Repair, 10,000 SF (M.290)	10,000	$102.34
COM4	Prof./ Tech./Business Services	Office, medium	Office, 5-10 st., 80,000 SF (M.470)	80,000	$133.43
COM5	Banks	Bank	Bank, 1 st., 4100 SF (M.050)	4,100	$191.53
COM6	Hospital	Hospital, medium	Hospital, 2-3 st., 55,000 SF (M.330)	55,000	$224.29

Table 14.2 Default Full Replacement Cost Models (Means, 2006) (Continued)

HAZUS Occupancy Class Description		Sub-category	Means Model Description (Means Model Number)	Means Typ Size	Means Cost/SF (2006)
OCC Code	OCC Description	OCC sub-class			
COM7	Medical Office/Clinic	Med. Office, medium	Medical office, 2 st., 7,000 SF (M.410)	7,000	$164.18
COM8	Entertainment & Recreation	Restaurant	Restaurant, 1 st., 5,000 SF (M.530)	5,000	$170.51
COM9	Theaters	Movie Theatre	Movie Theatre, 12,000 SF (M.440)	12,000	$122.05
COM10	Parking	Parking garage	Garage, Pkg, 5 st., 145,000 SF (M.270)	145,000	$43.72
IND1	Heavy	Factory, small	Factory, 1 st., 30,000 SF (M.200)	30,000	$88.28
IND2	Light	Warehouse, medium	Warehouse, 30,000 SF (M.690)	30,000	$75.95
IND3	Food/Drugs/Chemicals	College Laboratory	College Lab, 1 st., 45,000 SF (M.150)	45,000	$145.07
IND4	Metals/Minerals Processing	College Laboratory	College Lab, 1 st., 45,000 SF (M.150)	45,000	$145.07
IND5	High Technology	College Laboratory	College Lab, 1 st., 45,000 SF (M.150)	45,000	$145.07
IND6	Construction	Warehouse, medium	Warehouse, 30,000 SF (M.690)	30,000	$75.95
AGR1	Agriculture	Warehouse, medium	Warehouse, 30,000 SF (M.690)	30,000	$75.95
REL1	Church	Church	Church, 1 st., 17,000 SF (M.090)	17,000	$138.57
GOV1	General Services	Town Hall, small	Town Hall, 1 st., 11,000 SF (M.670)	11,000	$107.28
GOV2	Emergency Response	Police Station	Police Station, 2 st., 11,000 SF (M.490)	11,000	$166.59
EDU1	Schools/Libraries	High School	School, High, 130,000 SF (M.570)	130,000	$115.31
EDU2	Colleges/Universities	College Classroom	College Class. 2-3 st, 50,000 SF (M.120)	50,000	$144.73

Table 14.3 Replacement Costs (and Basement Adjustment) for RES1 Structures by Means Constructions Class (Means, 2006)

Means Construction Class	Height Class	Average Base cost per square foot	Adjustment for Finished Basement (cost per SF of main str.)	Adjustment for Unfinished Basement (cost per SF of main str.)
Economy	1 story	$ 65.91	$ 19.30	$ 7.10
	2 story	$ 70.13	$ 11.10	$ 4.65
	3-story	N/A – use 2 st	N/A – use 2 st	N/A – use 2 st
	Split level	$ 64.46	$ 13.90	$ 5.50
Average	1 story	$ 92.84	$ 24.05	$ 8.45
	2 story	$ 90.15	$ 15.55	$ 5.45
	3-story	$ 94.49	$ 12.35	$ 4.25
	Split level	$ 84.96	$ 18.45	$ 6.50
Custom	1 story	$ 114.91	$ 39.55	$ 5.45
	2 story	$ 112.91	$ 22.90	$ 9.20
	3-story	$ 116.99	$ 16.80	$ 6.85
	Split level	$ 105.25	$ 28.55	$ 11.35
Luxury	1 story	$ 139.76	$ 43.75	$ 16.75
	2 story	$ 133.09	$ 25.75	$ 10.10
	3-story	$ 137.08	$ 19.00	$ 7.60
	Split level	$ 124.81	$ 31.90	$ 12.45

Note: Assumes main living area is 1800 square feet.

Table 14.4 Single Family Residential Garage Adjustment (Means, 2006)

Means Construction Class	Garage Type	Average Additional Garage Cost per Residence
Economy	1 car	$12,600
	2 car	$19,780
	3 car	$26,750
Average	1 car	$13,120
	2 car	$20,460
	3 car	$27,580
Custom	1 car	$15,030
	2 car	$23,850
	3 car	$32,380
Luxury	1 car	$17,320
	2 car	$27,700
	3 car	$37,630

Table 14.5 Weights (percent) for Means Construction/Condition Models

Income	Weights (w) for:			
	c_{Lg}	c_{Cg}	c_{Aa}	c_{Ep}
$I_k < 0.5$	-	-	-	100
$0.5 \le I_k < 0.85$	-	-	25	75
$0.85 \le I_k < 1.25$	-	25	75	-
$1.25 \le I_k < 2.0$	-	100	-	-
$I_k \ge 2.0$	100	-	-	-

14.2.2 Contents Replacement Cost

Contents replacement value is estimated as a percent of structure replacement value. The NIBS Flood Module will utilize the same contents to structure value ratios as are employed in the HAZUS99 and Hazus-MH Earthquake Module (Table 15.5 in the HAZUS99 Technical Manual), provided in Table 14.5.

Table 14.6 Default Hazus Contents Value Percent of Structure Value

No.	Label	Occupancy Class	Contents Value (%)
		Residential	
1	RES1	Single Family Dwelling	50
2	RES2	Mobile Home	50
3	RES3	Multi Family Dwelling	50
4	RES4	Temporary Lodging	50
5	RES5	Institutional Dormitory	50
6	RES6	Nursing Home	50
		Commercial	
7	COM1	Retail Trade	100
8	COM2	Wholesale Trade	100
9	COM3	Personal and Repair Services	100
10	COM4	Professional/Technical/ Business Services	100
11	COM5	Banks	100
12	COM6	Hospital	150
13	COM7	Medical Office/Clinic	150
14	COM8	Entertainment & Recreation	100
15	COM9	Theaters	100
16	COM10	Parking	50
		Industrial	
17	IND1	Heavy	150
18	IND2	Light	150
19	IND3	Food/Drugs/Chemicals	150
20	IND4	Metals/Minerals Processing	150
21	IND5	High Technology	150
22	IND6	Construction	100

Table 14.6 Default Hazus Contents Value Percent of Structure Value (Continued)

No.	Label	Occupancy Class	Contents Value (%)
		Agriculture	
23	AGR1	Agriculture	100
		Religion/Non/Profit	
24	REL1	Church/Membership Organization	100
		Government	
25	GOV1	General Services	100
26	GOV2	Emergency Response	150
		Education	
27	EDU1	Schools/Libraries	100
28	EDU2	Colleges/Universities	150

14.2.3 Default Values for Regional Cost Variation

All costs provided in the tables are average national costs. Within the Hazus Flood Module, the national costs will be localized by application of a residential and non-residential Means location factor, provided with Hazus-MH by state and county throughout the U.S.

14.2.4 Procedure for Updating Building Cost Estimates

All calculations associated with estimating building replacement values by occupancy for each census block have been performed, and complete data for any county within the U.S. are provided as default data within Hazus. Users have the ability to modify replacement cost values for individual occupancy classes at the census block level. These costs may be edited directly within the table browsers of the Hazus Flood Model.

14.2.5 Depreciated Building Replacement Cost

The depreciation models utilized in the Hazus Flood Model are based on industry-standard depreciation methods presented in Means Square Foot Costs (R.S. Means, 2006). Within Means, two depreciation cost models are available; one for single family residential structures, and one for commercial/industrial/institutional structures.

14.2.5.1 Single Family Residential

Means (2006) includes three tabular depreciation models for residential structures, based on actual structure age and general condition (Good, Average, and Poor). These models are shown graphically in Figure 14.2.

The underlying assumption in the methodology used in the Hazus Flood Model is that for any community, some combination of the full replacement cost models (economy, average, custom or luxury) and depreciation models (good, average, or poor) will best represent the true depreciated value. This basic premise was tested on more than 8000 homes in Grand Forks, North Dakota, more than 160,000 homes in Mecklenburg County, North Carolina, and more than 60,000 homes in Fort Collins in Colorado. Results indicated that good agreement with assessed (depreciated) value could be attained from the models. A socio-economic analysis was performed to determine the optimal means for selecting combinations of models, based on available census data. The result of that analysis is a selection algorithm, documented in Section 3.7.5.

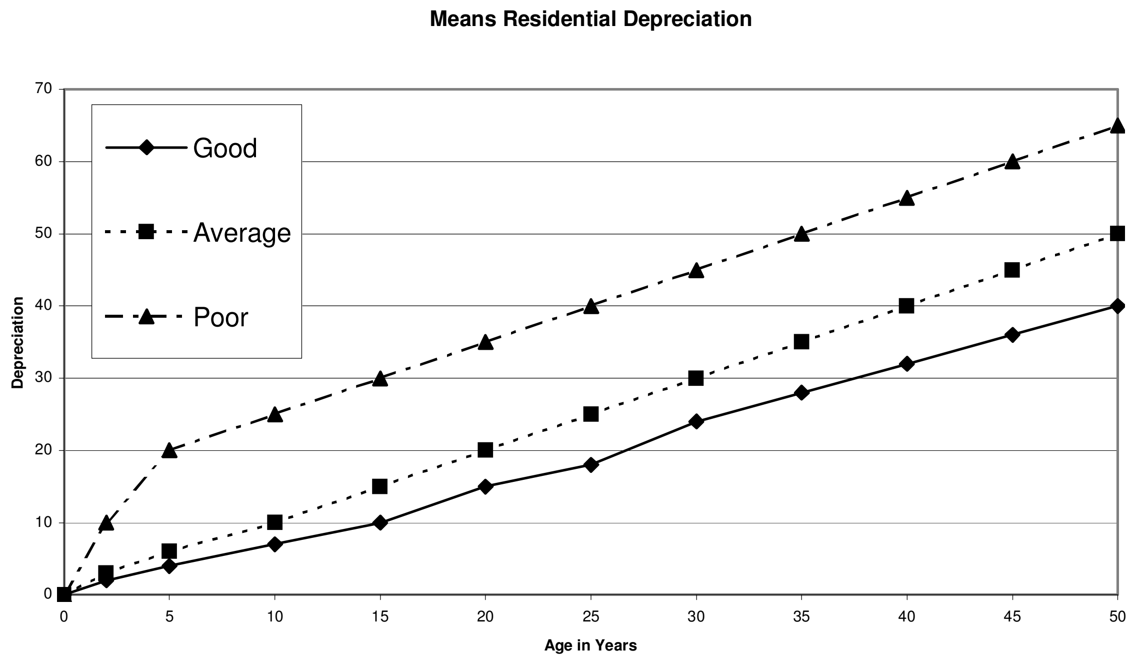


Figure 14.2 Single Family Residential Depreciation Models (Means, 2002)

14.2.5.2 Other Residential and Non-Residential

Unlike the residential depreciation model, the Means commercial/industrial/institutional depreciation is determined from "observed age" and building framing material (frame, masonry on wood, and masonry on masonry or steel), although there is little variation between the models for the different framing types. Accordingly, an average depreciation model has been developed and tested, and selected for implementation with the default inventory. A non-residential structure's "observed age" is assumed to reflect the structure's condition (e.g., the observed age should reflect any remodeling or renovation that would reduce deterioration, and therefore decrease the observed age).

During testing, it was assumed that chronological age is approximately equivalent to observed age for the non-residential structures, primarily because these structures are less likely to be used far beyond their typical life expectancy. (For example, in Grand Forks many homes are significantly older than the typical life expectancy of about 50 - 60 years, whereas commercial and industrial structures did not demonstrate the same widespread longevity.) Based on the results of the testing, it appears that the methodology will produce reasonable approximations of current (depreciated) value employing this assumption. Accordingly, for the default inventory, age of non-residential structures will be assumed to be distributed in a manner similar to the residential structures in the same Census Block Group. It should be noted, however, that when the user inputs more detailed building inventory data at Level 2, entry of actual or "observed" age data for these structures is expected to supersede the default age data, and to enhance their results.

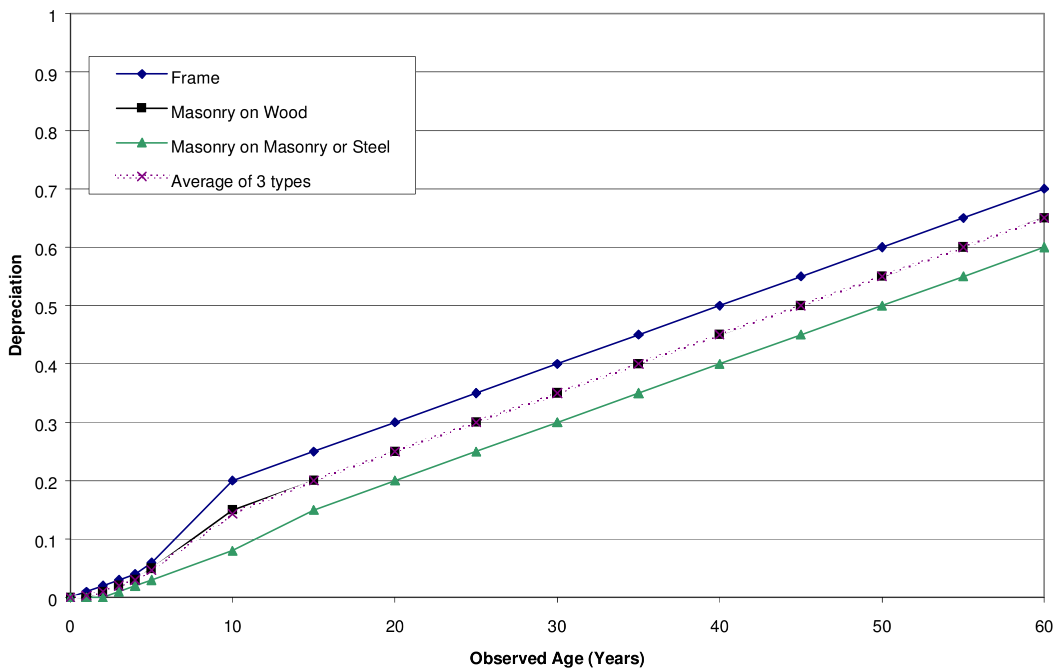


Figure 14.3 Means Commercial/Industrial/Institutional Depreciation Model (Means, 2006)

14.2.6 Building Contents Losses

Building contents are defined as furniture, equipment that is not integral with the structure, computers and other supplies. Contents do not include inventory or nonstructural components such as lighting, ceilings, mechanical and electrical equipment and other fixtures. Contents damage functions are applied in the same manner as building damage functions and are discussed in Section 5.

14.2.7 Business Inventory Losses

Inventory losses in the flood module are determined in a manner consistent with the other building losses, as well as the methodology currently utilized in the Hazus earthquake module. For occupancies with inventory considerations (COM1, COM2, IND1 - IND6 and AGR1, as defined in the HAZUS99 Earthquake Technical Manual), inventory losses are estimated using USACE-based depth-damage functions, in conjunction with Hazus default inventory values determined as a percentage of annual sales per square foot (see ***Earthquake Loss Estimation Methodology Hazus Technical Manual***, Section 15.2.3).

The damage function library assembled includes 144 Inventory depth-damage curves provided by the U.S. Army Corps of Engineers, Galveston District. These functions include:

- 44 depth-damage functions for facilities classified according to their SIC code and description as COM1 Retail Trade (e.g., grocery store, furniture store)
- 23 functions for COM2 Wholesale Trade (e.g., food warehouse, paper products warehouse)
- 10 functions for IND1 Heavy Industrial (e.g., fabrication shop, machine shop-heavy)
- 11 functions for IND2 Light Industrial (e.g., furniture manufacturing, commercial printing)
- 12 functions for IND3 Foods/Drugs/Chemicals (e.g., chemical plant, feed mill)
- 4 functions for IND4 Metals/Mineral Processing (e.g., foundry)
- 3 functions for IND6 Construction (e.g., roofing contractor, plumbing company)

For each occupancy class, applicable functions will be averaged to develop a default depth-damage function.

To estimate inventory losses, percent damage (determined from the depth-damage function) will be multiplied by the total inventory value (determined according to Hazus Earthquake Methodology - floor area times the percent of gross sales or production per square foot), as follows:

$$INV_i = \sum_j \%DAM\text{-}INV_{i,j} * Fa_{i,j} * SALES_i * B_{i_i} \quad (10) \qquad (14\text{-}4)$$

$$INV = INV_7 + INV_8 + \sum_{i=17}^{23} INV_i \quad (11) \qquad (14\text{-}5)$$

Where:

INV_i	=	value of inventory losses for occupancy I
INV	=	total value of inventory losses
$\%DAM\text{-}INV_{i,j}$	=	percent inventory damage for occupancy i and depth j (from depth-damage function)
$Fa_{i,j}$	=	floor area of occupancy group i and depth j (in square feet)
$SALES_i$	=	annual gross sales or production (per square foot) for occupancy i (see Table 14.7)

Bi_i = business inventory as a percentage of annual gross sales for occupancy i (i = 7, 8, 17-23, see Table 14.8)

Tabulated monetary direct economic parameter values from the original Hazus Earthquake Technical Manual have been updated to current (2006) costs for use in Hazus using a ratio of the annual Consumer Price Index (CPI). That is, the original dollar value was multiplied by the ratio of the CPI value for the current year to the CPI value for the year the data was developed. Annual CPIs for the years 1990 through 2006 are given in Table 14.6. For example, to scale 1990 annual sales data to current year (2006), the 1990 value ($30/sf) was multiplied by 1.4836 (the ratio of 193.9 to 130.7).

Table 14.7 Consumer Price Index 1990 - 2006
(Source: http://www.bls.gov/cpi/home.htm)

Year	Annual CPI
1990	130.70
1991	136.20
1992	140.30
1993	144.50
1994	148.20
1995	152.40
1996	156.90
1997	160.50
1998	163.00
1999	166.60
2000	172.20
2001	177.10
2002	179.90
2003	184.00
2004	188.90
2005	195.30
2006	201.39*

Note: Based on data for January – August, 2006

Table 14.8 Annual Gross Sales or Production (Dollars per Square Foot)

No.	Label	Occupancy Class	Output/ Employment	Sq. ft. floor Space/Employee[3]	Annual Sales (2006 $/sf)
Commercial					
7	COM1	Retail Trade[1]	$43,171	825	46
8	COM2	Wholesale Trade[1]	$64,414	900	66
Industrial					
17	IND1	Heavy[2]	$333,501	550	616
18	IND2	Light[2]	$98,333	590	196
19	IND3	Food/Drugs/Chemicals[2]	$247,695	540	602
20	IND4	Metals/Minerals Processing[2]	$495,655	730	567
21	IND5	High Technology[2]	$135,772	300	378
22	IND6	Construction[3]	$167,259	250	664
Agriculture					
23	AGR1	Agriculture[3]	$98,286	250	128

[1] *2005 values (latest available) of output/employment estimated using ratios from BLS "Industry Productivity & Cost Survey" data on Output per Person by Industry*

[2] *2006 values (based on 1st 2 quarters) of output/employment estimated using ratios from BLS "Industry Productivity & Cost Survey" data on Output per Person by Industry*

[3] *2004 values (latest available) estimated from BEA commodity output data and BLS employment data, because Industry Productivity data not available*

[4] *ATC-13, Table 4.7, pages 94-97 (ATC, 1985)*

Table 14.9 Business Inventory (% of Gross Annual Sales) (ref: NIBS/FEMA Hazus Technical Manual, Table 15.8)

No.	Label	Occupancy Class	Business Inventory (%)
Commercial			
7	COM1	Retail Trade	13
8	COM2	Wholesale Trade	10
Industrial			
17	IND1	Heavy	5
18	IND2	Light	4
19	IND3	Food/Drugs/Chemicals	5
20	IND4	Metals/Minerals Processing	3
21	IND5	High Technology	4
22	IND6	Construction	2
Agriculture			
23	AGR1	Agriculture	8

14.2.8 Relocation Expenses

Relocation expenses in the Hazus Flood Model are estimated in a manner consistent with the current earthquake model. In the HAZUS99 & Hazus-MH earthquake model, relocation expenses represent disruption costs to building owners for selected occupancies. These include all occupancies except entertainment (COM8), theatres (COM9), parking facilities (COM10) and heavy industry (IND1). Expenses include "… disruption costs that include the cost of shifting and transferring, and the rental of temporary space". These costs are assumed to be incurred once the building reaches a damage threshold of 10% (beyond damage state "slight" in the earthquake model). Below that threshold, it is assumed unlikely that the occupants will not need to relocate. Relocation losses will be estimated as follows:

$$\mathrm{REL}_i = \sum_j \text{ If } \%\mathrm{DAM\text{-}BL}_{i,j} > 10\%\text{: } \mathrm{Fa}_{i,j} * \begin{bmatrix} (1-\%OO_i)*(DC_i)+ \\ \%OO_i*(DC_i + RENT_i * RT_{i,j}) \end{bmatrix} \tag{14-6}$$

where:

REL_i	=	relocation costs for occupancy class i (i = 1-13 and 18-28)
$\mathrm{Fa}_{i,j}$	=	floor area of occupancy group i and depth j (in square feet)
$\%\mathrm{DAM\text{-}BL}_{i,j}$	=	percent building damage for occupancy i and water depth j (from depth-damage function), ***if greater than 10%.***
Dc_i	=	disruption costs for occupancy i (\$/ft^2, column 6 in Table 14.9)
$\mathrm{RT}_{i,j}$	=	recovery time (in days) for occupancy i and water depth j (See Table 14.11 for preliminary flood restoration time estimates)
$\%\mathrm{OO}_i$	=	percent owner occupied for occupancy i (HAZUS99 Technical Manual Table 15.14, reprinted here as Table 14.10)
RENT_i	=	rental cost (\$/ft^2/day) for occupancy i (column 5 in Table 14.9)

It should be noted that the default values for rental costs and disruption costs provided in Table 14.9, have been updated from the original development year of 1994 to the year 2006 baseline using CPI scaling, as discussed in Section 14.3.7.

Table 14.10 Rental Costs and Disruption Costs

No.	Label	Occupancy Class	Rental Cost (2006)		Disruption Costs (2006)
			($/ft^2/month)	($/ft^2/day)	($/ft^2)
Residential					
1	RES1	Single-family Dwelling	0.68	0.02	0.82
2	RES2	Mobile Home	0.48	0.02	0.82
3	RES3A	Multi-family Dwelling; Duplex	0.61	0.02	0.82
4	RES3B	Multi-family Dwelling;	0.61	0.02	0.82
5	RES3C	Multi-family Dwelling; 5 - 9 units	0.61	0.02	0.82
6	RES3D	Multi-family Dwelling; 10 - 19 units	0.61	0.02	0.82
7	RES3E	Multi-family Dwelling; 20 - 49 units	0.61	0.02	0.82
8	RES3F	Multi-family Dwelling; 50+ units	0.61	0.02	0.82
9	RES4	Temporary Lodging	2.04	0.07	0.82
10	RES5	Institutional Dormitory	0.41	0.01	0.82
11	RES6	Nursing Home	0.75	0.03	0.82
Commercial					
12	COM1	Retail Trade	1.16	0.04	1.09
13	COM2	Wholesale Trade	0.48	0.02	0.95
14	COM3	Personal and Repair Services	1.36	0.05	0.95
15	COM4	Professional/Technical/ Business	1.36	0.05	0.95
16	COM5	Banks	1.70	0.06	0.95
17	COM6	Hospital	1.36	0.05	1.36
18	COM7	Medial Office/Clinic	1.36	0.05	1.36
19	COM8	Entertainment & Recreation	1.70	0.06	0.00
20	COM9	Theaters	1.70	0.06	0.00
21	COM10	Parking	0.34	0.01	0.00
Industrial					
22	IND1	Heavy	0.20	0.01	0.00
23	IND2	Light	0.27	0.01	0.95
24	IND3	Food/Drugs/Chemicals	0.27	0.01	0.95
25	IND4	Metals/Minerals Processing	0.20	0.01	0.95
26	IND5	High Technology	0.34	0.01	0.95
27	IND6	Construction	0.14	0.00	0.95
Agriculture					
28	AGR1	Agriculture	0.68	0.02	0.68
Religion/Non-Profit					
29	REL1	Church/Membership Organization	1.02	0.03	0.95
Government					
30	GOV1	General Services	1.36	0.05	0.95
31	GOV2	Emergency Response	1.36	0.05	0.95
Education					
32	EDU1	Schools/Libraries	1.02	0.03	0.95
33	EDU2	Colleges/Universities	1.36	0.05	0.95

Table 14.11 Percent Owned Occupied
(ref: NIBS/FEMA Hazus Technical Manual, Table 15.14)

No.	Label	Occupancy Class	Percent Owner Occupied
Residential			
1	RES1	Single-family Dwelling	75
2	RES2	Mobile Home	85
3	RES3	Multi-family Dwelling	35
4	RES4	Temporary Lodging	0
5	RES5	Institutional Dormitory	0
6	RES6	Nursing Home	0
Commercial			
7	COM1	Retail Trade	55
8	COM2	Wholesale Trade	55
9	COM3	Personal and Repair Services	55
10	COM4	Professional/Technical/ Business Services	55
11	COM5	Banks	75
12	COM6	Hospital	95
13	COM7	Medial Office/Clinic	65
14	COM8	Entertainment & Recreation	55
15	COM9	Theaters	45
16	COM10	Parking	25
Industrial			
17	IND1	Heavy	75
18	IND2	Light	75
19	IND3	Food/Drugs/Chemicals	75
20	IND4	Metals/Minerals Processing	75
21	IND5	High Technology	55
22	IND6	Construction	85
Agriculture			
23	AGR1	Agriculture	95
Religion/Non-Profit			
24	REL1	Church/Membership Organization	90
Government			
25	GOV1	General Services	70
26	GOV2	Emergency Response	95
Education			
27	EDU1	Schools/Libraries	95
28	EDU2	Colleges/Universities	90

14.2.9 Loss of Income

Income-related losses are time-dependent; the losses will depend on the amount of time required to restore business operations. Restoration times include time for physical restoration of the damage to the building, as well as time for clean-up, time required for inspections, permits and the approval process, as well as delays due to contractor availability.

Earthquake damage restoration and flood damage restoration differ in a variety of ways, including:

- Damage due to flooding is likely to be widespread throughout the inundated area; earthquakes will cause differing degrees of damage to structures located within the same area.

- In an earthquake, inventory that does not break can be picked up and sold. Flooded-damaged inventory is usually a total loss.

- An earthquake-damaged business may be able to re-open quickly with undamaged inventory in a new location (e.g., alternate space, parking lot) in parallel with clean up. A flood-damaged business is less likely to re-open during clean up, in particular, re-opening may depend on resupply of inventory.

Because flood damage is fundamentally different than earthquake damage, a flood-specific restoration time model has been developed. The project team has developed draft estimates of required restoration time by occupancy, assumed to vary with flood depth. Here, flood depths are generally examined in increments of four feet, 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 4x8 dry wall will be laid horizontally to replace the damaged wallboard. The proposed restoration model is provided in Table 14.11 on the following page, and includes restoration time required for physical building restoration, as well as additional time required for clean-up, permitting, contractor availability, and potential hazardous materials issues. (This table corresponds to the existing Hazus earthquake Table 15.11, Building Recovery Time).

It should be noted that restoration times increase with depth, until the building has reached the 50% damage threshold, beyond which the building is considered a total loss. Once a building reaches 50% damage, it is assumed that the building will be demolished and re-built. For structures, outside the 100-year floodplain, reconstruction can be accomplished at the same site, and will require 18 months; 12 months for physical construction, plus 6 months for damage determination, permits, approvals, etc. If the structure is located within the 100-year floodplain, reconstruction to the original configuration at the same location will not be allowed, and the building is a potential buy-out candidate. Associated political considerations are assumed to add an additional 6-month delay to the reconstruction process, bringing the total time estimate to 24 months.

Future model development will include an assessment as to whether Interruption time multipliers (reduction factors), similar to those used in the earthquake model (Table 15.12 – Building and Service Interruption Time Modifiers), are applicable to flood. For consideration in this process, the project team has reviewed the list of occupancies to determine the dominant restoration element, provided in Table 14.12.

Table 14.12 Flood Restoration Time by Occupancy

Occupancy	Depth	Location	Physical Restoration Time (Months)	Add-ons				Max Total Time	Notes
				Dry-out & Clean up	Insp., permits, Ord., approval	Contr. Avail.	Hazmat Delay		
RES1 (No Base)	0' – 4'		3 to 6	1	2	3		12	
	4' – 8'		6 to 9	1	2	3		15	
	8'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	8'+	Inside 100-yr	18	1	2	3		24	Total loss, subject to buy-out review/political process
RES1 (W/Base)	(-8') – (-4')		3 to 6	1	2	3		9	No sub-floor repair required
	(-4') – 0'		6 to 9	1	2	3		15	
	0' – 6'		9 to 12	1	2	3		18	
	6'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	6'+	Inside 100-yr	18	1	2	3		24	Total loss, subject to buy-out review/political process
RES2	0' TO 1'		3 to 6	1	2	3		12	
	1'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	1'+	Inside 100-yr	18	1	2	3		24	Total loss, subject to buy-out review/political process
RES3 (SM)	0' – 4'		3 to 6	1	2	3		12	Same as RES1
	4' – 8'		6 to 9	1	2	3		15	
	8'+	Outside 100-yr	12	1	2	3		18	
	8'+	Inside 100-yr	18	1	2	3		24	

Table 14.12 Flood Restoration Time by Occupancy (Continued)

Occupancy	Depth	Location	Physical Restoration Time (Months)	Add-ons				Max Total Time	Notes
				Dry-out & Clean up	Insp., permits, Ord., approval	Contr. Avail.	Hazmat Delay		
RES3 (MED) 5-9 & 10-19 units	0' – 4'		5 to 8	1	2	3		14	(RES1*1.2) + 1 Month based on 3-5 units per floor
	4' – 8'		8 to 12	1	2	3		18	
	8' – 12'		12	1	2	3		18	Note: available apt models reach 5-% damage ~ 12'
	12'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	12'+	Inside 100-yr	18	1	2	3		24	Total loss, subject to buy-out review/political process
RES3 (LRG) 20-49 & 50+ units	0' – 4'		5 to 8	1	2	3		14	(RES1*1.2) + 1 Month based on 3-5 units per floor
	4' – 8'		8 to 12	1	2	3		18	(RES1*1.2) + 1 Month based on 3-5 units per floor
	8'+		12	1	2	3		18	Note: available apt models reach 5-% damage ~ 12'
	12'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	12'+	Inside 100 yr	18	1	2	3		24	Total loss, subject to buy-out review/political process
RES4	0' – 4'		5 to 8	1	2	3		14	Use RES3 (LRG)
	4' – 8'		8 to 12	1	2	3		18	
	8'+		12	1	2	3		18	
	12'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	12'+	Inside 100 yr	18	1	2	3		24	Total loss, subject to buy-out review/political process

Table 14.12 Flood Restoration Time by Occupancy (Continued)

Occupancy	Depth	Location	Physical Restoration Time (Months)	Add-ons				Max Total Time	Notes
				Dry-out & Clean up	Insp., permits, Ord., approval	Contr. Avail.	Hazmat Delay		
RES5 RES6 EDU1 EDU2	0' – 4'		6 to 10	1	2	3		16	Repairs may require less work (fewer partitions & finishes), but have more politics or funding issues. Use RES3 (LRG) but increase 1.2 factor to 1.5
	4' – 8'		10 to 15	1	2	3		21	
	8' – 12'		19	1	2	3		25	
	12'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	12'+	Inside 100-yr	18	1	2	3		24	Total loss, subject to buy-out review/political process
COM1 COM2 COM8 COM9 REL1	0' – 4'		7 to 13	1	2	3		19	Use RES3*2.0 – Longer clean up, but no wood sub-floor, perimeter wall, linoleum. Inventory damaged/destroyed, restoration depends on resupply, damage widespread in inundation area, insurance is a factor.
	4' – 8'		13 to 19	1	2	3		25	
	8'+		25	1	2	3		31	
	12'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	12'+	Inside 100 yr	18	1	2	3		24	Total loss, subject to buy-out review/political process
COM3	0' – 4'		3 to 6	1	2	3		12	On average, same as RES1 without a basement.
	4' – 8'		6 to 9	1	2	3		15	
	8'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	8'+	Inside 100 yr	18	1	2	3		24	Total loss, subject to buy-out review/political process

Table 14.12 Flood Restoration Time by Occupancy (Continued)

Occupancy	Depth	Location	Physical Restoration Time (Months)	Add-ons: Dry-out & Clean up	Add-ons: Insp., permits, Ord., approval	Add-ons: Contr. Avail.	Add-ons: Hazmat Delay	Max Total Time	Notes
COM4 COM5 COM7 GOV1 GOV2	0' – 4'		6 to 10	1	2	3		16	Use RES3 (LRG)*1.5 (same as RES5 & RES6)
	4' – 8'		10 to 15	1	2	3		21	
	8' – 12'		19	1	2	3		25	
	12'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	12'+	Inside 100-yr	18	1	2	3		24	Total loss, subject to buy-out review/political process
COM6 (assume w/base)	(-8') - (-4')		6	1	2	3		16	Hospitals are highly regulated, have equipment issues. This model represents full repair/restoration, but certain repairs will be prioritized to allow selected operations to begin sooner.
	(-4') – 0'		12	1	2	3		21	
	0' – 4'		18	1	2	3		18	
	4' – 8'		24	1	2	3		24	
COM10	Any > 0'			1				1	Parking lot restoration is not dependent on flood depth, only clean up.
IND1	Any > 0'		1 to 3	1	2		1	7	For heavy industrial, clean up is the primary issue, especially for equipment. Relocation is unlikely. Hazmat is a potential for this occupancy class.
IND2 IND6	Any > 0'		1 to 2	1	2			5	Like heavy industrial except no equipment issues. Totally content issues.
IND3	0' – 4'		6 to 10	1	2	3	1	17	Like laboratories, perimeter walls. Hazmat a potential issue. Use RES3*1.5 + Hazmat delay. Similar to RES5, RES6, COM4, COM5, COM7.
	4' – 8'		10 to 15	1	2	3	1	22	
	8' – 12'		19	1	2	3	1	26	
	12'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	12'+	Inside 100-yr	18	1	2	3		24	Total loss, subject to buy-out review/political process

Table 14.12 Flood Restoration Time by Occupancy (Continued)

Occupancy	Depth	Location	Physical Restoration Time (Months)	Add-ons				Max Total Time	Notes
				Dry-out & Clean up	Insp., permits, Ord., approval	Contr. Avail.	Hazmat Delay		
IND4	0' – 4'		6 to 10	1	2	3	2	18	Like IND3, but use a 2-month delay for hazmat.
	4' – 8'		10 to 15	1	2	3	2	27	
	8' – 12'		19	1	2	3	2	26	
	12'+	Outside 100-yr	12	1	2	3		18	Total loss, requires replacement
	12'+	Inside 100-yr	18	1	2	3		24	Total loss, subject to buy-out review/political process
IND5	0' – 4'		7 to 13	1	2	3	2	21	Use RES3*2 + 2-month Hazmat delay. (Similar to COM1, COM2, COM8, COM9.
	4' – 8'		13 to 19	1	2	3	2	27	
	8' – 12'		25	1	2	3	2	33	
	12'+	Outside 100-yr	12	1	2	3	2	20	Total loss, requires replacement
	12'+	Inside 100-yr	18	1	2	3	2	26	Total loss, subject to buy-out review/political process
AGR1	Any > 0'		1 to 2	1	2		2	7	Like IND2 with 2-month hazmat delay,

Table 14.13 Elements Dominating Building and Service Interruption for Floods

Label	Occupancy Class	Element Dominating Restoration
Residential		
RES1	Single Family Dwelling	Building (+ Utilities)
RES2	Mobile Home	Building (+ Utilities)
RES3	Multi Family Dwelling	Building (+ Utilities)
RES4	Temporary Lodging	Building (+ Utilities)
RES5	Institutional Dormitory	Building (+ Utilities)
RES6	Nursing Home	Building (+ Utilities)
Commercial		
COM1	Retail Trade	Inventory
COM2	Wholesale Trade	Inventory
COM3	Personal and Repair Services	Inventory/Equipment
COM4	Professional/Technical/ Business Services	Building (+ Utilities)
COM5	Banks/Financial Institutions	Building (+ Utilities)
COM6	Hospital	Building (+ Utilities)/Equipment
COM7	Medical Office/Clinic	Building (+ Utilities)
COM8	Entertainment & Recreation	Building (+ Utilities)/Contents
COM9	Theaters	Building (+ Utilities)/Contents
COM10	Parking	-----
Industrial		
IND1	Heavy	Equipment
IND2	Light	Inventory
IND3	Food/Drugs/Chemicals	Inventory/Equipment
IND4	Metals/Minerals Processing	Equipment
IND5	High Technology	Inventory/Equipment
IND6	Construction	Building (+ Utilities)
Agriculture		
AGR1	Agriculture	Inventory/Equipment
Religion/Non-Profit		
REL1	Church/Membership Organization	Building (+ Utilities)
Government		
GOV1	General Services	Building (+ Utilities)
GOV2	Emergency Response	Building (+ Utilities)
Education		
EDU1	Schools/Libraries	Building (+ Utilities)
EDU2	Colleges/Universities	Building (+ Utilities)

14.2.9.1 Capital Related, Wage, Output and Employment Losses

Capital related loss (previously referred to as proprietor's income loss and described in more detail in the HAZUS99 & Hazus-MH Technical Manual) is estimated as follows in the Hazus Flood Model:

$$YLOS_i = \sum_j (1\text{-}IRF_i)*FA_{I,j}*INC_i* LOF_{i,j} \quad (14\text{-}7)$$

where:

$YLOS_i$ = capital related losses for occupancy class I

$FA_{i,j}$ = floor area of occupancy class i (in square feet) at depth j

INC_i = income per day (per square foot) for occupancy class i (column 5 in Table 14.13)

$LOF_{i,j}$ = business loss of function time (in days) for occupancy i and water depth j. (See Table 14.11 for preliminary restoration time estimates)

IRF_i = Income recapture factor for occupancy class i (see Table 14.14)

It should be noted that capital related loss uses "loss of function" rather than "recovery time" as the time-dependent variable, and therefore is evaluated over the entire damage range, rather than just above the 10% damage threshold.

In addition to capital related losses, several other income-related losses may be calculated in the same manner, as follows:

- Wage losses, currently calculated within Hazus, are estimated by substituting Wages (per square foot per day, column 6 from Table 14.13) for Income, and replacing the income recapture factor with the wage recapture factor (Table 14.14).

- Sales or output losses can be estimated by substituting Output (per square foot per day, column 8 from Table 14.13) for Income, and replacing the income recapture factor with the output recapture factor (Table 14.14). The resulting output losses may then be used to derive employment losses ("equivalent jobs" lost), by multiplying the output losses by employment/output ratios for each industry. The employment/output ratios can be obtained from published sources and IMPLAN tables, and default values will be provided with the flood methodology.

Table 14.14 Proprietor's Income

No.	Label	Occupancy Class	Income (2006)		Wages (2006) per Sq. Ft. per Day	Employees per Sq. Ft.	Output (2006) per Sq. Ft. per Day
Residential							
1	RES1	Single-family Dwelling	0.00	0.00	0.00	0.00	0.00
2	RES2	Mobile Home	0.00	0.00	0.00	0.00	0.00
3	RES3A	Multi-family Dwelling; Duplex	0.00	0.00	0.00	0.00	0.00
4	RES3B	Multi-family Dwelling;	0.00	0.00	0.00	0.00	0.00
5	RES3C	Multi-family Dwelling; 5 - 9 units	0.00	0.00	0.00	0.00	0.00
6	RES3D	Multi-family Dwelling; 10 - 19 units	0.00	0.00	0.00	0.00	0.00
7	RES3E	Multi-family Dwelling; 20 - 49 units	0.00	0.00	0.00	0.00	0.00
8	RES3F	Multi-family Dwelling; 50+ units	0.00	0.00	0.00	0.00	0.00
9	RES4	Temporary Lodging	35.90	0.10	0.23	0.00	0.52
10	RES5	Institutional Dormitory	0.00	0.00	0.00	0.00	0.00
11	RES6	Nursing Home	59.83	0.16	0.39	0.01	0.86
Commercial							
12	COM1	Retail Trade	22.15	0.06	0.21	0.00	0.45
13	COM2	Wholesale Trade	36.32	0.10	0.26	0.00	0.58
14	COM3	Personal and Repair Services	47.86	0.13	0.31	0.00	0.69
15	COM4	Professional/Technical/ Business	377.12	1.03	0.37	0.00	1.00
16	COM5	Banks	430.34	1.18	0.60	0.01	3.26
17	COM6	Hospital	59.83	0.16	0.39	0.01	0.86
18	COM7	Medial Office/Clinic	119.65	0.33	0.77	0.01	1.72
19	COM8	Entertainment & Recreation	219.43	0.60	0.48	0.01	1.08
20	COM9	Theaters	71.79	0.20	0.46	0.01	1.03
21	COM10	Parking	0.00	0.00	0.00	0.00	0.00
Industrial							
22	IND1	Heavy	90.79	0.25	0.41	0.00	1.74
23	IND2	Light	90.79	0.25	0.41	0.00	1.74
24	IND3	Food/Drugs/Chemicals	121.05	0.33	0.55	0.00	2.32
25	IND4	Metals/Minerals Processing	275.03	0.75	0.43	0.00	1.84
26	IND5	High Technology	181.57	0.50	0.83	0.01	3.48
27	IND6	Construction	88.51	0.24	0.45	0.01	1.72
Agriculture							
28	AGR1	Agriculture	83.99	0.23	0.09	0.00	0.86
Religion/Non-Profit							
29	REL1	Church/Membership Organization	47.86	0.13	0.31	0.00	1.72
Government							
30	GOV1	General Services	39.31	0.11	2.96	0.03	0.69
31	GOV2	Emergency Response	0.00	0.00	4.50	0.04	0.79

Table 14.15 Proprietor's Income (Continued)

No.	Label	Occupancy Class	Income (2006)		Wages (2006) per Sq. Ft. per Day	Employees per Sq. Ft.	Output (2006) per Sq. Ft. per Day
Education							
32	EDU1	Schools/Libraries	59.83	0.16	0.39	0.01	3.33
33	EDU2	Colleges/Universities	119.65	0.33	0.77	0.01	5.06

Table 14.16 HAZUS99 Earthquake Table of Recapture Factors

Occ.	Wage Recapture (%)	Employment Recapture (%)	Income Recapture (%)	Output Recapture (%)
RES1	0	0	0	0
RES2	0	0	0	0
RES3	0	0	0	0
RES4	0.60	0.60	0.60	0.60
RES5	0.60	0.60	0.60	0.60
RES6	0.60	0.60	0.60	0.60
COM1	0.87	0.87	0.87	0.87
COM2	0.87	0.87	0.87	0.87
COM3	0.51	0.51	0.51	0.51
COM4	0.90	0.90	0.90	0.90
COM5	0.90	0.90	0.90	0.90
COM6	0.60	0.60	0.60	0.60
COM7	0.60	0.60	0.60	0.60
COM8	0.60	0.60	0.60	0.60
COM9	0.60	0.60	0.60	0.60
COM10	0.60	0.60	0.60	0.60
IND1	0.98	0.98	0.98	0.98
IND2	0.98	0.98	0.98	0.98
IND3	0.98	0.98	0.98	0.98
IND4	0.98	0.98	0.98	0.98
IND5	0.98	0.98	0.98	0.98
IND6	0.95	0.95	0.95	0.95
AGR1	0.75	0.75	0.75	0.75
REL1	0.60	0.60	0.60	0.60
GOV1	0.80	0.80	0.80	0.80
GOV2	0	0	0	0
EDU1	0.60	0.60	0.60	0.60
EDU2	0.60	0.60	0.60	0.60

14.2.10 Rental Income Losses

Rental income losses will be estimated as follows:

$$RY_i = \sum_j \text{ If } \%DAM\text{-}BL_{i,j} > 10\%: (1-\%OO_i) * FA_{i,j} * RENT_i * RT_{i,j} \tag{14-8}$$

where:

Ry_i	=	rental income losses for occupancy I
$\%DAM\text{-}BL_{i,j}$	=	percent building damage for occupancy i and water depth j (from depth-damage function), ***if greater than 10%.***
$\%Oo_i$	=	percent owner occupied for occupancy i (HAZUS99 Technical Manual Table 15.14, reprinted here as Table 14.10)
$FA_{i,j}$	=	floor area of occupancy group i (in square feet) at depth j
$RENT_i$	=	rental cost ($\$/ft^2/day$) for occupancy i (column 5 in Table 14.9)
$RT_{i,j}$	=	recovery time (in days) for occupancy i and water depth j (See Table 14.11 for preliminary flood restoration time estimates)

14.2.11 Guidance for Estimates Using Advanced Data and Models Analysis

The default data provided with the Hazus 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) that might result in costs considerably different than the typical aggregated costs provided as part of the default database provided with this methodology.

14.2.12 Average Annualized Loss Estimates for Buildings

The Flood Model requires the following flood losses from the suite of return periods (10-year, 25-year, 50-year, 100-year, and 500-year return periods) in order to determine the average annualized loss (AAL) calculation. The Flood Model computes the GBS losses by census block (and by occupancy) for the suite of return periods. The loss units are in thousands of dollars. Given the five required "Return Period (RP_{xx}) – Loss (L_{xx})" pairs – e.g.,:

Return Period		Economic Loss	Source of Loss Estimate
RP_{10}	10	L_{10}	Calculated directly within HAZUS Flood
RP_{25}	25	L_{25}	
RP_{50}	50	L_{50}	
RP_{100}	100	L_{100}	
RP_{500}	500	L_{500}	

we can estimate the approximate AAL by examining losses in each return period range:

$$
\begin{aligned}
AAL = \quad & (f_{10} - f_{25}) * \frac{L_{10} + L_{25}}{2} + \\
& (f_{25} - f_{50}) * \frac{L_{25} + L_{50}}{2} + \\
& (f_{50} - f_{100}) * \frac{L_{50} + L_{100}}{2} + \qquad (14\text{-}9) \\
& (f_{100} - f_{500}) * \frac{L_{100} + L_{500}}{2} + \\
& f_{500} * L_{500}
\end{aligned}
$$

where

$$f_{10} = \frac{1}{10} \quad \text{(frequency / probability of occurrence of a 10 year flood)}$$

$$\Leftrightarrow \quad (L_{10}+L_{25})(\ ½\ f_{10} – ½\ f_{25}) +$$

$$(L_{25}+L_{50})(\ ½\ f_{25} – ½\ f_{50}) +$$

$$(L_{50}+L_{100})(\ ½\ f_{50} – ½\ f_{100}) + \qquad (14\text{-}10)$$

$$(L_{100}+L_{500})(\ ½\ f_{100}\text{-}\ ½\ f_{500}) +$$

$$L_{500} * f_{500}$$

$$\Leftrightarrow \quad L_{10}(½\ f_{10}\text{-}\ ½\ f_{25}) +$$

$$L_{25}(½\ f_{10} – ½\ f_{25}) + L_{25}(\ ½\ f_{25} – ½\ f_{50}) +$$

$$L_{50}(½\ f_{25} – ½\ f_{50}) + L_{50}(\ ½\ f_{50} – ½\ f_{100}) + \qquad (14\text{-}11)$$

$$L_{100}(½\ f_{50} – ½\ f_{100}) + L_{100}(\ ½\ f_{100} – ½\ f_{500}) +$$

$$L_{500}(\ ½\ f_{100} – ½\ f_{500}) +$$

$$L_{500} *f_{500}$$

$$\Leftrightarrow \quad L_{10}(\ ½\ f_{10} – ½\ f_{25}) +$$

$$L_{25}(\ ½\ f_{10} – ½\ f_{50}) +$$

$$L_{50}(\ ½\ f_{25} – ½\ f_{100}) + \qquad (14\text{-}12)$$

$$L_{100}(\ ½\ f_{50} – ½\ f_{500}) +$$

$$L_{500}(\ ½\ f_{100} + ½\ f_{500})$$

$$\Leftrightarrow \quad L_{10}C_{10} + L_{25}C_{25} + L_{50}C_{50} + L_{100}C_{100} + L_{500}C_{500} \tag{14-13}$$

Where

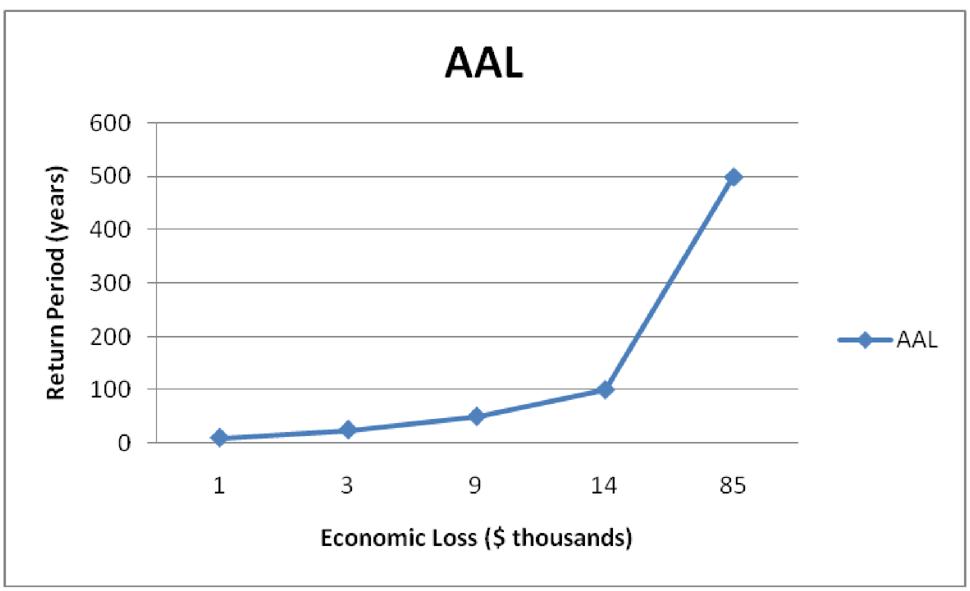
$$C_{10} = \frac{f_{10} - f_{25}}{2} = \frac{\frac{1}{10} - \frac{1}{25}}{2} = 0.03$$

$$C_{25} = \frac{f_{10} - f_{50}}{2} = \frac{\frac{1}{10} - \frac{1}{50}}{2} = 0.04$$

$$C_{50} = \frac{f_{25} - f_{100}}{2} = \frac{\frac{1}{25} - \frac{1}{100}}{2} = 0.015 \tag{14-14}$$

$$C_{100} = \frac{f_{50} - f_{500}}{2} = \frac{\frac{1}{50} - \frac{1}{500}}{2} = 0.009$$

$$C_{500} = \frac{f_{100} + f_{500}}{2} = \frac{\frac{1}{100} + \frac{1}{500}}{2} = 0.006$$



$$AAL = 0.030L_{10} + 0.040L_{25} + 0.015L_{50} + 0.009L_{100} + 0.006L_{500} \quad (14\text{-}15)$$

Here is sample data calculated using 14-15:

Return Period		Sample Economic Loss		Frequency Constant by RP (See Equation 14-14)		AAL contribution by RP
RP_{10}	10	L_{10}	1	C_{10}	0.030	0.030
RP_{25}	25	L_{25}	3	C_{25}	0.040	0.120
RP_{50}	50	L_{50}	9	C_{50}	0.015	0.135
RP_{100}	100	L_{100}	14	C_{100}	0.009	0.126
RP_{500}	500	L_{500}	85	C_{500}	0.006	0.510
					AAL Total	**0.921**

14.3 Description of Methodology: Lifelines

14.3.1 Bridges

The Flood Model uses the following methodology to develop losses for highway bridges, railway bridges, and light rail bridges. The Flood Model uses data provided with the default bridge inventory within Hazus, including the following fields:

- BridgeId: (this is the unique identifier for each bridge). Remember that bridges are point facilities and are independent of each other.

- BridgeClass: This field is the first part of the bridge specific occupancy defined in the bridge damage function tables

- ScourIndex: This field is key to the analysis and is the second part of the bridge specific occupancy in the bridge damage function tables.

- Cost: This field is necessary for the estimation of loss

The Flood Model will examine all bridges within the inundated area by performing a point in grid analysis. Those bridges that are not in the inundated area are assumed to be undamaged and are skipped. For bridges within the flood depth grid, but where the flood depth is <= 0 feet, the bridge is close to the floodplain but not inundated and the bridge is skipped. Therefore, only those bridges where the flood depth is greater than 0-feet are analyzed. If the bridge is considered inundated then, the scour index is checked. If the scour index is in (4, 5, 6, 7, 8, 9, T, N) then no analysis is performed as the engineering study has determined that the bridge will not be subjected to scour. If the scour index is in (U, 1, 2, 3) then an analysis must be performed. As with other models, the user can define their own damage function and the model will check to see if the user is using the default functions or one of their own.

- Damage ($) is calculated as follows:

(%)	=	Prob of failure * 0.25
($)	=	Prob of failure * 0.25 * Cost
Function	=	(1-Prob of Failure)
Note	=	Prob of Failure is interpolated above
		0.25 is a hard value based on expert opinion (failure represents 25% damage, see Section 7.2.3)
		Cost is from the Cost field in the hzBridge tables (provided in the Technical Manual in the classification tables in Chapter 3, see for example, Table 3.19)

14.3.2 Utility Systems

14.3.2.1 Potable Water Facilities

The Flood Model uses the depth of flooding and its impact on critical components of the water system to determine the percentage of damage expected for those facilities. The damage functions were discussed and presented in Section 7.0 of this document. Once the expected amount of damage is know in percent (%), it is necessary to multiply this with the replacement value (see Table 3.26) to determine the amount of loss. The equations for this analysis are shown below.

(% damage) = damage at (depth of water – equipment height) and is read directly from the table of depth damage values

($ Loss) = (% Damage) * (Inventory $ value)

The Flood Model performs this analysis for control vaults and control stations, wells, tanks, pumps and potable water treatment plants. In the case of the potable water treatment plants, the Flood Model is essentially examining the components most critical to functionality and loss and ignoring other features such as buildings that are likely to be included in the General Building Stock. If the user needs to have the analysis include damages to the buildings within the treatment plant, it is recommended that they create User Defined facilities to analyze the structures.

14.3.2.2 Wastewater Systems

The Flood Model uses the depth of flooding and its impact on critical components of the wastewater system to determine the percentage of damage expected for those facilities. The damage functions were discussed and presented in Section 7.0 of this document. Once the expected amount of damage is know in percent (%), it is necessary to multiply this with the replacement value (see Table 3.27) to determine the amount of loss. The equations for this analysis are shown below.

(% damage) = damage at (depth of water – equipment height) and is read directly from the table of depth damage values

($ Loss) = (% Damage) * (Inventory $ value)

The Flood Model performs this analysis for control vaults and control stations, lift stations, and wastewater treatment plants. In the case of the wastewater treatment plants, the Flood Model is essentially examining the components most critical to functionality and loss and ignoring other features such as buildings that are likely to be included in the General Building Stock. If the user needs to have the analysis include damages to the buildings within the treatment plant, it is recommended that they create User Defined facilities to analyze the structures.

14.3.2.3 Petroleum Systems

The Flood Model uses the depth of flooding and its impact on critical components of the petroleum (oil) transmission system to determine the percentage of damage expected for those facilities. The damage functions were discussed and presented in Section 7.0 of this document. Once the expected amount of damage is know in percent (%), it is necessary to multiply this with the replacement value (see Table 3.28) to determine the amount of loss. The equations for this analysis are shown below.

(% damage) = damage at (depth of water – equipment height) and is read directly from the table of depth damage values

($ Loss) = (% Damage) * (Inventory $ value)

The Flood Model performs this analysis for control vaults and control stations, tanks, and refineries. In the case of the refineries, the Flood Model is essentially examining the components most critical to functionality and loss and ignoring other features such as buildings that are likely to be included in the General Building Stock. If the user needs to have the analysis include damages to the buildings within the refinery, it is recommended that they create User Defined facilities to analyze the structures.

14.3.2.4 Natural Gas Systems

The Flood Model uses the depth of flooding and its impact on critical components of the natural gas transmission system to determine the percentage of damage expected for those facilities. The damage functions were discussed and presented in Section 7.0 of this document. Once the expected amount of damage is know in percent (%), it is necessary to multiply this with the replacement value (see Table 3.29) to determine the amount of loss. The equations for this analysis are shown below.

(% damage) = damage at (depth of water – equipment height) and is read directly from the table of depth damage values

($ Loss) = (% Damage) * (Inventory $ value)

The Flood Model performs this analysis for control vaults and control stations, compressor plants, and tanks.

14.3.2.5 Electric Power Systems

The Flood Model uses the depth of flooding and its impact on critical components of the electric power generation and transmission system to determine the percentage of damage expected for those facilities. The damage functions were discussed and presented in Section 7.0 of this document. Once the expected amount of damage is know in percent (%), it is necessary to multiply this with the replacement value (see Table 3.30) to determine the amount of loss. The equations for this analysis are shown below.

(% damage) = damage at (depth of water – equipment height) and is read directly from the table of depth damage values

($ Loss) = (% Damage) * (Inventory $ value)

The Flood Model performs this analysis for control vaults and control stations, substations, and power plants. In the case of the power plants, the Flood Model is essentially examining the components most critical to functionality and loss and ignoring other features such as buildings that are likely to be included in the General Building Stock. If the user needs to have the analysis include damages to the buildings within the power plant, it is recommended that they create User Defined facilities and analyze the structures.

14.3.2.6 Communication Systems

The determination of losses for communications facilities has been deferred to future versions of the Flood Model. It is anticipated that the methodology would be very similar to that described above, although the facilities have not been completely defined.

14.4 Description of Methodology: Vehicles

The vehicle loss methodology is very similar to that developed for General Building Stock, in that the area weighted depth damage will be utilized to estimate the total damage and total loss by vehicle type.

The methodology takes the inventory data and manipulates the data in order to perform the analysis. The vehicle count is identified as Car (Car), Light Truck (LtTrk), and Heavy Truck (HvyTrk). These are the key occupancies and the occupancies by which results will be reported. Vehicles are distributed evenly over each census block. As noted, the inventory is split between used vehicles and new vehicles. Results do not make this distinction and are a summation over the two classes. There are no parameters for elevation of the vehicle. These are implicit in the damage functions.

The percentage of the census block at a given flood depth is determined in the same fashion as the GBS analysis. The damage function for each of the three occupancies can either be the default functions, or those created and selected by the User. The Flood Model uses piece-wise linear interpolation to identify the actual percentage of damage at the given flood depth. The damage will be the Percentage Damage (%) multiplied by the Percentage of Census Block at the flood depth multiplied by the day and night vehicle count. The estimated dollar loss will be the above percentages multiplied by the dollar exposures, as follows:

$$\text{DmgByOccup(Count)} = \text{FP*DP*OccupCount} \qquad (14\text{-}9)$$

and

$$\text{LossByOccup(\$)} = \text{FP*DP*OccupExp(\$)} \qquad (14\text{-}10)$$

Where

FP	=	the percentage of the census block at the given flood depth
DP	=	the damage percent at the given flood depth for the given occupancy
OccupCount	=	the total count of Cars, LtTrk, or HvyTrk for the given census block
OccupExp	=	the total exposure of NewCars, UsedCars, NewLtTrk, UsedLttrk, NewHvyTrk, UsedHvyTrk.

14.5 Description of Methodology: Agriculture (Crops)

The Flood Model performs an assessment of the amount of flooding that has occurred within the given sub-county polygons generated from the intersection of the 8-digit HUCS, the US Census County boundary, and the USGS Land Use, Land Cover dataset where the land use is an agricultural classification. The depth of flooding is irrelevant in the current methodology, but the user is required to define a date of flooding in order to determine where in the crop cycle the user is interested in assessing losses. The "date" of the flood is input by the user in the format of day and month (01-Jan or 11 July), by selecting values in a combo box, and the model converts this into the Julian Calendar day (day 1 or day 192 respectively in this example).

Since the Flood Model hazard does not directly handle duration, the duration will be handled through the production of results for four duration intervals 0-day, 3-day, 7-day and 14-day. The methodology can be described as follows:

- Determine affected area as the intersection of the floodplain polygon with the agriculture polygon (acres)
- Identify the quantity of crops in the polygon and the affected area (Yield/acre * area)
- Identify damage (read from the damage function for Julian day)
- Initial Loss = Yield in flooded area * $ * % damaged crop
- Duration Loss = Initial Loss * duration modifier

This methodology will produce a value for a single day flood (0-day), a 3-day flood, 7-day flood and 14-day flood. Review of the damage functions indicates that most crops will be receiving the maximum impact at 14-days, which therefore defines an upper bound for the user.

14.6 References

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5. R.S. Means (2006), *Means Square Foot Costs*

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11. US Department of Transportation, Federal Highway Administration, "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nations Bridges", Federal Highway Administration Report No. FHWA-96-001, December 1995.

Chapter 15. Indirect Economic Losses

15.1 Introduction

The Hazus Indirect Economic Loss Module evaluates the economic disruption or ripple effects that follow from direct losses. The relationship between the Indirect Economic Loss Module and other Hazus modules is shown in Figure 15.1, the flowchart of the overall methodology.

This chapter provides background, explanation, and discussion of the Indirect Economic Loss Module. Section 15.2 provides background on the concept of indirect losses. Section 15.3 briefly presents the traditional modeling approach for tracing indirect losses, known as input-output modeling.

Following this background, Section 15.4 describes how indirect losses are modeled within Hazus. Because traditional approaches do not account for many of the important features of natural disaster impacts, the Indirect Economic Loss Module utilizes an innovative approach for addressing the supply and demand shocks that occur in such events. The core of the module is a computational algorithm that rebalances a region's interindustry trade flows based on discrepancies between sector supplies and demands.

Section 15.5 provides guidance on running the Hazus Indirect Economic Loss Module. It discusses data requirements, module operation, and the types of results produced. In running the module, the user can choose between two levels of analysis: a Default Data Analysis ("Level 1") that runs on data included with Hazus, or a User-Supplied Data Analysis ("Level 2") that requires the user to obtain and input certain economic data on the study region.

Section 15.6 offers discussion and presents examples to assist the user in interpreting the Indirect Economic Loss Module's results. It outlines the types of situations and questions for which the module is intended to be used. It also discusses how the module is *not* intended to be used. Numerical examples are provided to educate users about the principles of indirect loss, to caution against common misunderstandings, and to demonstrate how to properly account for losses. Guidance is provided on how to compare module results with observed economic consequences in actual disasters.

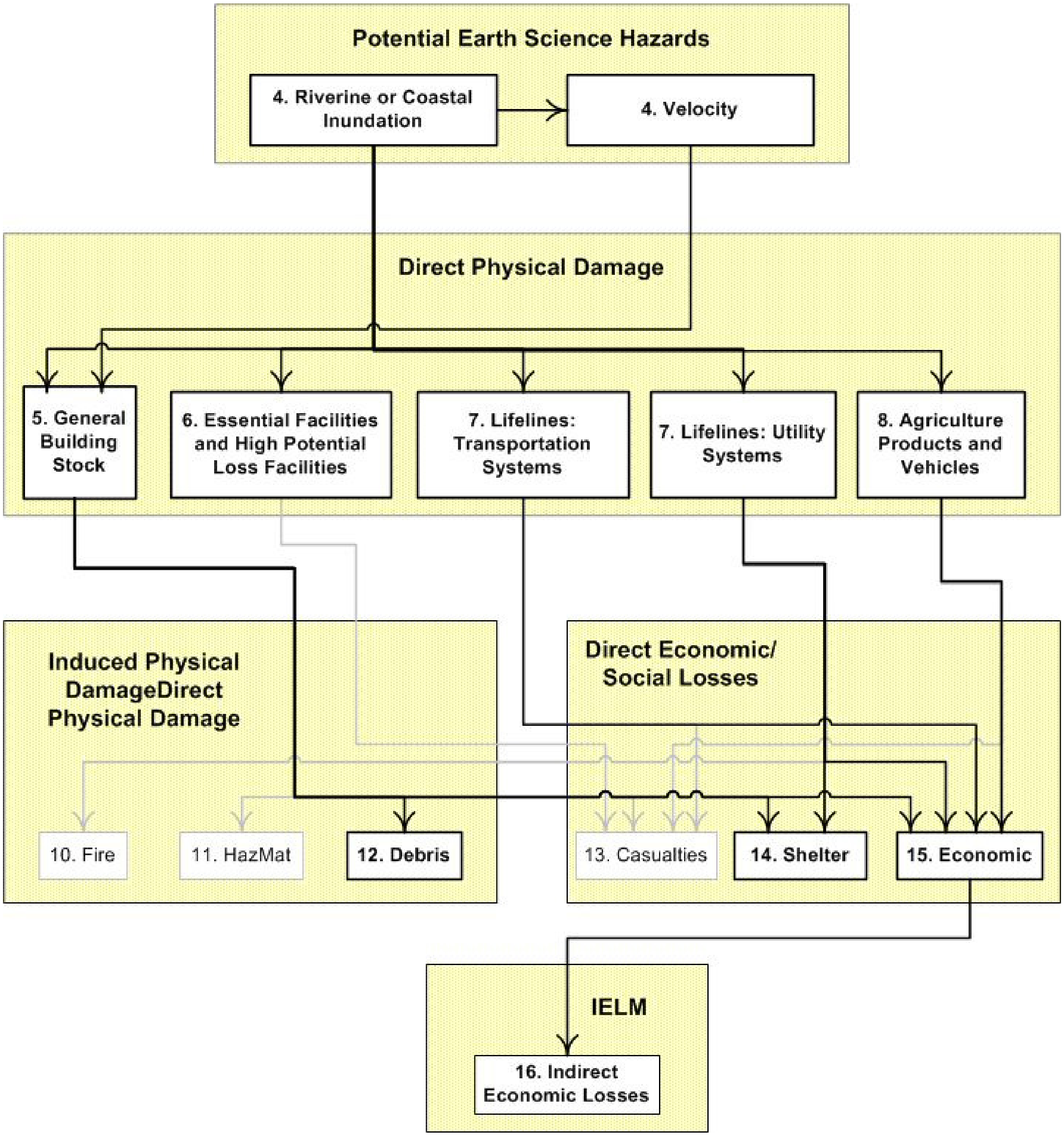

Figure 15.1 Relationship of Indirect Economic Loss to Other Components in the Hazus Flood Methodology

15.2 Background: What are Indirect Losses?

This section provides a conceptual overview of indirect economic losses in natural disasters. Section 15.2.1 briefly defines and discusses some key terms and principles in natural hazard loss measurement. Section 15.2.2 describes the concept of indirect losses more fully, while section 15.2.3 discusses the significance of whether a regional or national accounting stance is adopted in the measurement of this loss.

15.2.1 Principles of Natural Hazard Loss Estimation

This section briefly sets forth some basic economic principles of loss estimation, including clarifying the confusion between direct and indirect losses, property damage and business interruption losses, and real resource costs and tradeoffs. (For a detailed discussion, see Rose and Lim (2002) and Rose (2002).)

Welfare economics, the scientific basis for economic policy-making (see, e.g., Boadway and Bruce, 1984), provides a starting point for an analysis of economic loss from natural hazards. A major theme is that cost should be measured in terms of the value of resources used (or destroyed) and at prices that represent their efficient allocation. This provides a guide for avoiding double-counting and being inclusive of all resources, including non-market ones. Business interruption losses represent a proxy for the ideal resource valuation because of measurement problems and because businesses, insurers, and governments typically make decisions on the basis of associated metrics such as lost sales or profits.

Lost sales, however, represent a "gross" measure of production. A more appropriate measure is "value-added," which is a "net" measure that includes only the contributions of primary factors of production (labor, capital, natural resources), and omits the cost of "intermediate" goods (goods used by businesses to produce other goods and that hence do not yield direct utility to final consumers). These intermediate goods thus represent a form of double-counting if included in impact estimates. Sales (revenues) losses are often the most important consideration to businesses, so they are prevalent in the literature. An alternative that is sometimes used is loss of profits, but this represents only one component of value-added (returns to capital) because it ignores returns to labor (wages and salaries) and natural resources (rents and royalties).

One of the fundamental distinctions in economics is between stocks and flows. Stocks refer to a quantity at a single point in time, while flows refer to the services or outputs of stocks over time. Property damage represents a decline in stock value and usually leads to a decrease in service flows. Business interruption losses are a flow measure, but emanate only in part from a company's own property damage.

One reason flow measures are superior to stock measures is that the former include a time dimension. Stock measures pertain simply to the value of an asset at a single point in time. The typical measure of damage (purchase or replacement cost) is thus invariant to how long the asset is out of service. For example, if a factory is damaged in a flood, there is a tendency to specify the loss in fixed terms, irrespective of whether production is shut down for a week or a year awaiting repairs. Attention to flow losses represents a major shift in the focus of hazard loss estimation—that losses are not a definite or set amount but are highly variable depending on the length of the "economic disruption," typically synonymous with the recovery plus reconstruction periods. This also brings home the point that disaster losses are not simply determined by the strength of the stimulus (coupled with initial vulnerability), but also highly dependent on human ingenuity, will, and resources.

Care should be exercised to avoid double-counting of hazard losses. Many goods and services have quite diverse attributes, and all of those damaged/interrupted should be counted (e.g., a hydroelectric dam provides electricity, recreational opportunities in the reservoir behind it, and flood control). It is important, however, to remember that some goods and services cannot yield all of these attributes to their maximum simultaneously, and that only one or the other, or some balance of the two, should only be counted (e.g., a river can provide services to swimmers or it can be a repository for waste but not both at the same time). Another way to avoid double-counting is to avoid attributing losses to more than one entity in the case of private goods, as in the case of avoiding counting retail store sales as a loss to both the storeowner and its customers. Just as important, however, is the inclusion of all relevant losing entities or stakeholders. Caution must be exercised here because of the regional character of most hazards and the inclination just to consider those living within its boundaries. Tourism associated with natural environments is an excellent case in point. Loss of environmental value should not just be gauged by local residents but by all potential users.

A closely related consideration pertains to the distinction between costs and transfers. Tax expenditures, in particular, do not reflect the use of resources and are not real costs to society. In general, they simply represent a shifting of dollars from one entity to another. The complication that arises here, however, pertains to the spatial delineation of the affected group. Local property or sales taxes within a region are transfers, but payments of federal income tax do represent an outflow and can be legitimately included in the regional cost estimates.

While total business interruption losses are the bottom line, distinguishing between its direct and indirect components helps ensure that everything is counted and provides more precise information for decision-making. Unfortunately, this has been the subject of great confusion from the outset. Clarification is best made in terms of flow measures. Some analysts have characterized direct loss as pertaining to property damage and indirect loss as pertaining to business interruption (see, e.g., ATC, 1991; Heinz Center, 2000); however, this is not helpful because both have direct and indirect counterparts.

Direct flow losses pertain to production in businesses damaged by the hazard itself. A business that shuts down because its office building has been flooded would suffer such direct flow losses. The term also includes lost production stemming from direct loss of public utility and infrastructure services. For example, a factory may have to shut down because the bridge that its suppliers and employers use to reach it is damaged.

The extent of business interruption does not stop here, but sets off a chain reaction of indirect flow losses (also sometimes referred to as "second-order" or "higher-order" effects). A factory shutdown will reduce supplies to its customers, who may be forced to curtail their production for lack of critical inputs. In turn, their customers may be forced to do the same, as will the customers of these customers, and so on. The factory shutdown will also reduce orders for its inputs. Its suppliers will then have to reduce their production and hence cancel orders for their inputs. The suppliers of the suppliers will follow suit, and so forth. The sum total of all of these indirect effects is a multiple of the direct effects; hence, the concept of a "multiplier" is often applied to their estimation.

Many analysts are hesitant to measure indirect losses for various reasons. First, they cannot be as readily verified as direct losses. Second, modeling them requires utilizing simple economic models carefully, or, more recently, utilizing quite sophisticated economic models. Third, the size of indirect effects can be quite variable depending on the resiliency of the economy and the pace of recovery. Fourth is the danger of manipulating indirect effects for political purposes (e.g., it is not unusual in the context of economic development for promoters to inflate multipliers). However, none of these reasons undercut the importance of indirect effects, especially if one considers their likely size (see, e.g., Cochrane, 1997).

In the Indirect Loss Module, the term "indirect effects" will be used to cover all flow losses beyond those associated with the direct curtailment of output as a result of hazard-induced property damage or loss of utility and infrastructure services in the producing facility itself. This term covers all of the higher-order Input-Output effects associated with quantity interdependence effects, as well as general equilibrium price interdependence effects.

15.2.2 How Indirect Losses Occur

As noted earlier, floods and other natural disasters may produce dislocations in economic sectors not sustaining direct damage. All businesses are forward-linked (rely on regional customers to purchase their output) or backward-linked (rely on regional suppliers to provide their inputs) and are thus potentially vulnerable to interruptions in their operation. Such interruptions are called indirect economic losses. Note that these losses are not confined to immediate customers or suppliers of damaged enterprises. All of the successive rounds of customers of customers and suppliers of suppliers are impacted. In this way, even limited physical damage causes a chain reaction, or ripple effect, that is transmitted throughout the regional economy.

The extent of indirect losses depends upon such factors as the availability of alternative sources of supply and markets for products, the length of the production disturbance, and deferability of production. Figure 15.2 provides a highly-simplified depiction of how direct damages induce indirect losses. In this economy firm A ships its output to one of the factories that produce B, and that factory ships to C. Firm C supplies households with a final product (an example of a final demand, FD) and could also be a supplier of intermediate input demand to A and B. There are two factories producing output B, one of which is destroyed in the flood. The first round of indirect losses occurs because: 1) direct damage to production facilities and to inventories cause shortages of inputs for firms needing these supplies (forward-linked indirect loss); 2) damaged production facilities reduce their demand for inputs from other producers (backward-linked indirect loss); or 3) reduced availability of goods and services stunt household, government, investment, and export demands (all part of final demand).

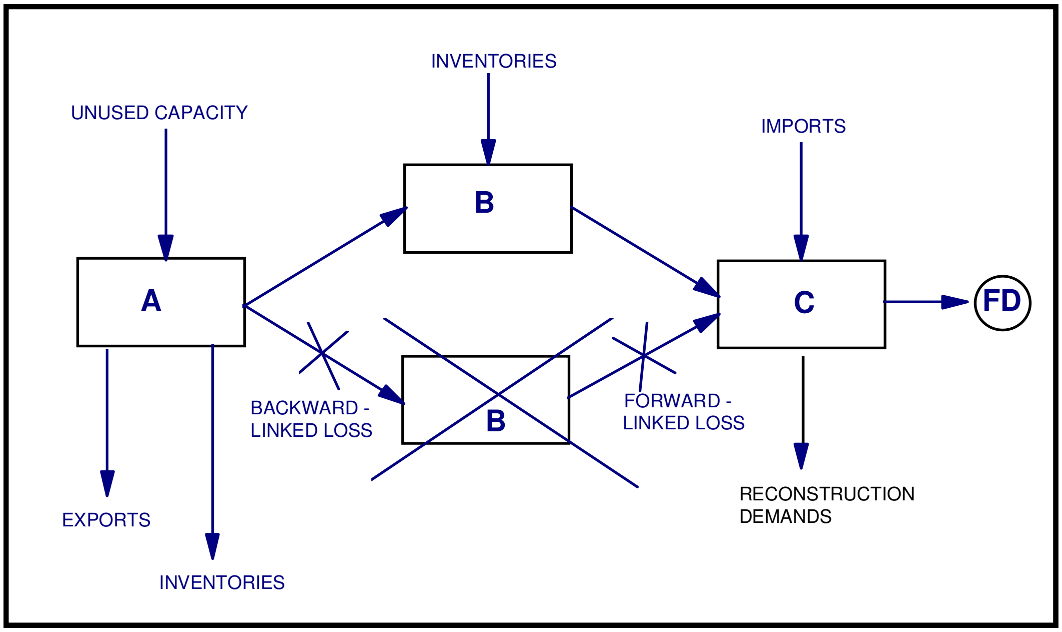

Figure 15.2 Indirect Losses and Adjustments to Lessen Them

The supply shortages caused as a result of reduced availability of input B could cripple factory C, if C is unable to locate alternative sources. Three options are possible: 1) secure additional supplies from outside the region (imports); 2) obtain additional supplies from the undamaged factory (excess capacity); and 3) draw from B's unsold stock of output (inventories). The net effect of diminished supplies are referred to as forward-linked losses, the term forward (often referred to as downstream) implying that the impact of direct damages is shifted to the next stage or stages of the production process.

Disasters can also produce indirect losses if producer and consumer demands for goods and services are reduced. If, in the example provided in Figure 15.2, firm B has a reduced demand for inputs from A, then A may be forced to scale back operations. As in the case of forward-linked losses, the affected firms may be able to circumvent a weakened market, in this case by either finding alternative outlets such as exports or building up inventory. (Building up inventory is not a permanent solution, since eventually the inventories have to be sold. Firms may be willing to do so on a temporary basis, hoping that market conditions will improve at a later date.)

The higher rate of unemployment caused by direct damages and subsequent indirect factory slowdowns or closures would reduce personal income payments and could cause normal household demands to erode. However, it is more likely that the receipt of disaster assistance, unemployment compensation, or borrowing, would buoy household spending throughout the reconstruction period. Evidence from recent events (Hurricanes Andrew and Hugo, the Loma Prieta Earthquake and the Northridge Earthquake) confirms that normal household demands are only slightly altered by disaster in the short-run. As a result of this observation, the Indirect Loss Module discussed below delinks household incomes and demands.

15.2.3 Regional vs. National Losses

It has sometimes appeared that natural disasters tend to stimulate employment and revitalize a region. Clearly, the generous federal disaster relief policies in place after the 1964 Alaskan earthquake, the 1971 San Fernando earthquake, and Hurricane Agnes in 1972, served to buoy the affected economies, thereby preventing the measurement of significant indirect losses. From a regional accounting stance, it appeared that the net losses were inconsequential. However, this viewpoint fails to take into account the cost of disasters on both household and federal budgets.

Some, if not most, public and private post-disaster spending is unfunded; that is, it is not paid for out of current tax revenues and incomes. In the case of households this amounts to additional indebtedness which shifts the burden or repayment to some future time period. Federal expenditures are not budget neutral either. As in the case of households, governments cannot escape the financial implications of increased spending for disaster relief. Either lower priority programs must be cut, taxes raised, or the federal debt increased. The first two options simply shift the reduction in demand and associated indirect damages to other regions. Projects elsewhere may be canceled, services curtailed, and/or household spending diminished as after-tax incomes shrink. The debt option provides no escape either, since it, too, places the burden on others, e.g., a future generation of taxpayers.

From a national accounting stance, indirect losses can be measured by deriving regional indirect impacts, adjusted for the liability the Federal government incurs in providing disaster relief, and for offsetting increases in outputs elsewhere. The positive effects outside aid produces for the region are to some degree offset by negative effects produced by the three federal budget options. Since it is impossible to know *a priori* which option the federal government will utilize, it is safest to assume that the two effects cancel; i.e., that the positive outcomes from federal aid are offset by the negative national consequences caused by the budget shortfall.

Since the primary user of the Hazus®*MH* Loss Estimation Methodology is likely to be the local entity involved in disaster planning and response decisions, the Indirect Loss Module is designed accordingly. That is, it adopts a local accounting stance. One simplistic approach to obtaining a national measure of net loss would be to exercise the Loss Module excluding outside federal assistance.

15.3 Background: How are Indirect Losses Modeled?

The most widely used tool of regional economic impact analysis is known as Input-Output analysis (Miller and Blair, 1985; Rose and Miernyk, 1989). Input-output techniques are commonly utilized to assess the total (direct plus indirect) economic gains and losses caused by sudden changes in the demand for a region's products. Higher demand for rebuilding and a lower demand for tourism, for example, lend themselves to traditional input-output I-O methods. This technique is relatively simple to apply and is already in widespread use in state and local agencies, though not necessarily those associated with emergency management.

The Hazus Indirect Loss Module is based on the Input-Output framework but incorporates important methodological innovations that adapt it to natural hazard analysis. Section 15.3.1

therefore provides a brief introduction to the principles of Input-Output analysis, which is accompanied in Section 15.3.2 by a simple numerical example of how it can be applied to evaluate indirect losses. Disaster losses are to some extent offset by the gains associated with reconstruction activities; modeling this stimulus in the Input-Output context is discussed in Section 15.3.3. Finally, Section 15.3.4 identifies some limitations of Input-Output analysis and notes alternative modeling methodologies that have been developed in the disaster context. These discussions provide background for the Hazus Indirect Loss Module methodology.

15.3.1 A Primer on Input-Output Loss Modeling Techniques

Input-output analysis was first formulated by Nobel laureate Wassily Leontief and has gone through several decades of refinement by Leontief and many other economists. At its core is a static, linear model of all purchases and sales between sectors of an economy, based on the technological relationships of production. Input-output (I-O) modeling traces the flows of goods and services among industries and from industries to household, governments, investment, and exports. These trade flows indicate how much of each industry's output is comprised of its regional suppliers' products, as well as inputs of labor, capital, imported goods, and the services of government. The resultant matrix can be manipulated in several ways to reveal the economy's interconnectedness, not only in the obvious manner of direct transactions but also in terms of dependencies several steps removed (e.g., the construction of a bridge generates not only a direct demand for steel but also indirect demands via steel used in machines for its fabrication and in railroad cars for its transportation).

Input-Output techniques have been applied to estimate natural hazard impacts since the seminal work of Cochrane (1974). More recently, a number of researchers have refined and applied Input-Output methods in the disaster context, addressing such issues as flexible treatment of imports, business resiliency, transportation and utility lifeline impacts, and optimal recovery strategies. For reviews of this literature, see Jones and Chang (1995) and Rose (2002).

A very brief technical review of the basic Input-Output methodology is provided here for those users who may be unfamiliar with interindustry modeling.[1] The presentation is restricted to a simple three industry economy. The shipments depicted as arrows in Figure 15.2 are represented as annual flows in Table 15.1. The *X*'s represent the dollar value of the good or service shipped from the industry listed in the left-hand heading to the industry listed in the top heading. The *Y*'s are shipments to consumers (goods and services), businesses (investment in plant and equipment and retained inventories), government (goods, services and equipment), to other regions (exported goods and services). The *V*'s are the values-added in each sector, representing

[1] Input-output and "interindustry" are often used synonymously because of the emphasis in I-O on the sectoral unit of analysis, mainly comprised of producing industries. Strictly speaking, however, interindustry refers to a broad set of modeling approaches that focus on industry interactions, including activity analysis, linear programming, social accounting matrices, and even computable general equilibrium models. Most of these have an input-output table at their core. The reader interested in a more complete understanding of I-O analysis is referred to Rose and Miernyk (1989) for a brief survey; Miller and Blair (1985) for an extensive textbook treatment; and Boisvert (1992) for a discussion of its application to earthquake impacts. For other types of interindustry models applied to natural disaster impact analysis, the reader is referred to the work of Rose and Benavides (1998) for a discussion of mathematical programming and to Brookshire and McKee (1992) for a discussion of computable general equilibrium analysis.

payments to labor (wages and salaries), capital (dividends, rents, and interest), natural resources (royalties and farm rents), and government (indirect business taxes). The *M*'s represent imports to each producing sector from other regions.

Table 15.1 Intersectoral Flows of a Hypothetical Regional Economy (dollars)

To: From:	A	B	C	Final Demand	Gross Output
A	X_{aA}	X_{aB}	X_{aC}	Y_a	X_a
B	X_{BA}	X_{BB}	X_{BC}	Y_B	X_B
C	X_{CA}	X_{CB}	X_{CC}	Y_C	X_C
V	V_a	V_B	V_C		
M	M_a	M_B	M_C		
Gross Outlay	X_a	X_B	X_C	Y	X

A basic accounting balance holds: total output of any good is equal to that sold as an intermediate input to all sectors and that sold as final goods and services:

$$X_A = X_{AA} + X_{AB} + X_{AC} + Y_A \qquad (15\text{-}1)$$

Rearranging terms, the amount of output available from any industry for final demand is simply the amount produced less the amount shipped to other industries.

To transform the I-O accounts into an analytical model, it is then assumed that the purchases by each of the industries have some regularity and thus represent technological requirements. Technical coefficients that comprise the structural I-O matrix are derived by dividing each input value by its corresponding total output. That is:

$$a_{AA} = \frac{X_{AA}}{X_A};\; a_{AB} = \frac{X_{AB}}{X_B};\; a_{AC} = \frac{X_{AC}}{X_C}; \qquad (15\text{-}2)$$

The a's are simply the ratios of inputs to outputs. An a_{AB} of 0.2 means that 20 percent of industry B's total output is comprised of product A.

Equation (15-1) can then be written as:

$$X_A = a_{AA} X_A + a_{AB} X_B + a_{AC} X_C + Y_A \qquad (15\text{-}3)$$

In matrix form Equation (15-3) is:

$$X = AX + Y \qquad (15\text{-}4)$$

To solve for the gross output of each sector, given a set of final demand requirements, we proceed through the following steps:

$$(I - A)X = Y \tag{15-5}$$
$$(I - A)^{-1}Y = X \tag{15-6}$$

The term $(I - A)^{-1}$ is known as the Leontief Inverse. It indicates how much each sector's output must increase as a result of (direct and indirect) demands to deliver an additional unit of final goods and services of each type. It might seem that a $1 increase in the final demand for product A would result in the production of just an additional $1 worth of A. However, this ignores the interdependent nature of the industries. The production of A requires ingredients from a combination of industries, A, B, and/or C. Production of B, requires output from A, B, and/or C, and so on. Thus, the one dollar increase in demand for A will stimulate A's production to change by more than one dollar. The result is a multiple of the original stimulus, hence, the term "multiplier effect" (a technical synonym for ripple effect).

Given the assumed regularity in each industry's production requirements, the Leontief Inverse need only be computed once for any region (at a given point in time) and can then be used for various policy simulations reflected in changes in final demand (e.g., the impact of public sector investment) as follows:

$$(\mathrm{I} - \mathrm{A})^{-1}\Delta\mathrm{Y} = \Delta\mathrm{X} \tag{15-7}$$

More simply, the column sums of the Leontief Inverse are sectoral multipliers, *M*, specifying the total gross output of the economy directly and indirectly stimulated by a one unit change in final demand for each sector. This allows for a simplification of Equation (15-7) for cases where only one sector is affected (or where one wishes to isolate the impacts due to changes in one sector) as follows:[2]

$$\mathrm{M_A}\Delta\mathrm{Y_A} = \Delta\mathrm{X} \tag{15-8}$$

Under normal circumstances final demand changes will alter household incomes and subsequently consumer spending. Thus, under some uses of input-output techniques, households

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[2] Note that the previous discussion pertains to demand-side (backward-linked) multipliers. A different set of calculations is required to compute supply-side (forward-linked) multipliers. (Computationally, the structural coefficients of the supply-side model are computed by dividing each element in a given <u>row</u> by the <u>row</u> sum.) Though mathematically symmetric, the two versions of the model are not held in equal regard. There is near universal consensus that demand-side multipliers have merit because there is no question that material input requirements are needed directly and indirectly in the production. However, the supply-side multipliers have a different connotation—that the availability of an input stimulates its very use. To many, this implies the fallacy of "supply creates its own demand." Thus, supply-side multipliers must be used with great caution, if at all, and are not explored at length here. For further discussion of the conceptual and computational weaknesses of the supply-side model, see Oosterhaven (1988) and Rose and Allison (1988).

Note also that the multipliers discussed thus far pertain to output relationships. Multipliers can also be calculated for employment, income, and income distribution effects in analogous ways. Also note that sectoral output multipliers usually have values of between 2.0 and 4.0 at the national level and are lower for regions, progressively shrinking as these entities become less self-sufficient and hence the endogenous cycle of spending is short-circuited by import leakages. For example, sectoral output multipliers for Suffolk County, the core of the Boston Metropolitan Statistical Area, are for the most part in the range of 1.5 to 2.0.

(broadly defined as the recipients of all income payments) are "endogenized" (included within the *A* matrix) by treating it as any other sector, i.e., a user (consumer) of outputs and as a supplier of services. An augmented Leontief inverse is computed and yields a set of coefficients, or multipliers, that capture both “indirect” (interindustry) and subsequent “induced” (household income) effects. Multipliers are computed from a matrix with respect to households. These are referred to as Type II multipliers in contrast to the Type I multipliers derived from the “open” I-O table, which excludes households. Of course, since they incorporate an additional set of spending linkages, Type II multipliers are larger than Type I, typically by around 25%.

15.3.2 An Illustration of Input-Output Techniques

Conventional input-output models provide a starting point for measuring indirect losses that are backward-linked, providing that the disaster does not significantly alter the region’s input patterns and trade flows. (Section 15.4 discusses how the Hazus Indirect Loss Module modifies the methodology in cases where such changes are significant.) The calculation of indirect losses for a simple case is illustrated in the following example beginning with the input-output transactions matrix presented in Table 15.2.

Table 15.2 Interindustry Transactions

To: From:	A	B	Households	Other Final Demand	Gross Output
A	20	45	30	5	100
B	40	15	30	65	150
Households	20	60	10	10	100
Imports	20	30	30	0	80
Gross Outlay	100	150	100	80	430

This simplified transactions table is read as follows: $20 of industry A’s output is used by itself (e.g., a refinery uses fuel to transform crude oil into gasoline and heating oil). $45 of output A is shipped to industry B. $30 is marketed to the household sector and $5 is sold to government, used in investment, or exported to another region. $20 worth of household services is required to produce $100 of output A, and $60 is needed for $150 of B. According to the table, 30 percent of the consumer’s gross outlay is allocated to the purchase of A, 30 percent to B, 10 percent to household services, and 30 percent to imports.

Assume that the input-output table shown above represents a tourist-based economy. Industry A represents construction while B represents tourism. What would happen to this economy if a flood destroyed half the region’s hotels? Direct economic losses are comprised of manmade

assets destroyed in the disaster plus the reductions in economic activity[3] in the tourist sector. Assume that the damage to hotels influences some tourists to vacation elsewhere the year of the disaster, reducing the annual $95 million demand for hotel accommodations by $45 million.
For the purposes of this illustration, household spending and demands are linked. Therefore, a Type II multiplier would be utilized to assess the income and output changes anticipated. The effect of declining tourism on the region's economy is easily derived from the initial change in demand and the Type II multipliers presented in Figure 15.3. Each tourist dollar not spent results in a loss of $1.20 and $2.03 worth of production from A and B, respectively.

The resultant total (direct plus indirect) decline in regional household income is $1.17 per tourist dollar lost (row 3 column 2 of the closed Leontief Inverse). If nothing else changed (including no pick up in construction activity), the regional income lost for the year is $52.65 million ($45 million times 1.17). Of this total, $18 million (40 cents of lost income for each tourist dollar lost, or .4 times $45 million) is directly traceable to the disaster, while the other $34.65 million in regional income loss represents indirect income losses cause by reduced demands for intermediate goods and consumer items via backward interindustry linkages and normal household spending.

	Total Coefficients (Type II Multiplier)		
	Construction	Tourism	Household
	2.12	1.2	1.11
$(I-A)^{1-}$ =	1.29	2.03	1.11
	1.04	1.17	1.85
		x $45 Million	
		= $52.65 Million	

	Direct Coefficients		
	Construction	Tourism	Household
	0.2	0.3	0.3
A =	0.4	0.1	0.3
	0.2	0.4	0.1
		x $45 Million	
		= $18 Million	

	Direct, Indirect, Induced Income Losses
Secondary Income	= $52.65 Million
Loss	= $34.65 Million

	Direct Income Losses
Minus	$18 Million

Figure 15.3 Illustrative Computation

15.3.3 The Stimulative Impact of Reconstruction Aid

The preceding example was an illustration of how Input-Output techniques can be used to simply estimate the negative impacts, or losses, caused by a disaster. These negative effects would be countered by the stimulative impact of state and federal disaster aid and insurance settlements. Whether these positive forces completely offset the negatives produced by the reduction in tourist trade in the preceding example hinges on the magnitude of the direct effects and the

[3] Economic activity can be gauged by several indicators. One is Gross Output (sales volume). Another is Value-Added, or Gross National Product (GNP), which measures the contribution to the economy over and above the value of intermediate inputs already produced, thereby avoiding double-counting (note the "Gross" in GNP simply refers to the inclusion of depreciation and differs from double-counting meaning of the term in Gross Output.) Specifically, Value-Added refers to returns to primary factors of production: labor, capital, and natural resources. The concept is identical to the oft used term National Income, which is numerically equal to GNP.

associated multipliers for these two activities. Assume, for example, that $50 million of outside reconstruction funds pour into the community in the first year. The Type II income multiplier for the construction industry is 1.04. The net regional income loss the year of the disaster is, therefore: ($50 million x 1.04) - ($45 million x 1.17), or a net loss of $0.65 million.

Indirect income changes in this case are very significant and can be computed as the difference of total income impacts and direct income impacts. We know from the direct coefficients matrix that household income changes directly by 20 and 40 cents, respectively, for each dollar change in construction and tourist expenditures. The net indirect regional impact from the reduction in tourism, and the aid program are therefore: ($50 x 1.04 - $50 x .2) - ($45 x 1.17 - $45 x .4), or a net gain of $7.35 million.

This is what the region loses or gains; however, national impacts are quite different. The $50 million of federal assistance injected into the region must be paid for either by cutting federal programs elsewhere, raising taxes, or borrowing. Each option impacts demand and outputs negatively. Although it is unlikely that they will precisely offset the gains the region enjoys, it is safe to assume that they will be similar in magnitude. If so, indirect losses from a national perspective is the net regional loss with the positive effects from federal aid omitted. The national net income loss will then remain $52.65 million.

The foregoing analysis was limited to the year of the disaster and presupposed that unemployed households did not dip into savings or receive outside assistance in the form of unemployment compensation, both of which are often the case. In terms of the summation of impacts over an extended time horizon, results do not significantly change if alternative possibilities are introduced. For example, if households choose to borrow or utilize savings while unemployed or to self-finance rebuilding, future spending is sacrificed. Therefore, even though an unemployed household may be able to continue to meet expenses throughout the reconstruction period, long-term levels of expenditure and hence product demand, must decline.

In the preceding analysis, indirect losses were derived from demand changes only. This approach lends itself to events in which supply disruptions are minimal, or where sufficient excess capacity exists. A different method is required when direct damage causes supply shortages, as is often the case in floods and other disasters. The Hazus Indirect Loss Module, Section 15.4 below, modifies the basic I-O methodology to accommodate both supply and demand disruptions.

15.3.4 Alternative Modeling Techniques

This section briefly discusses the strengths and limitations of Input-Output methods and makes comparisons with two other major modeling approaches, computable general equilibrium (CGE) and econometric models. For a more detailed discussion, including issues of validation and modeling uncertainty, see Rose (2002).

Input-Output techniques provide a valuable guide for the estimation of indirect losses, but they are also subject to a number of limitations. Among their advantages is the focus on production interdependencies, which makes the method especially well suited to examining how damage in some sectors can ripple through the economy. Input-Output analysis also provides an excellent organizational framework for data collection and display, a transparent view of the structure of an economy, and a ready capacity to accommodate engineering data. It is well-suited to performing distributional analysis and providing insight into the inherent unevenness of direct and indirect impacts across industries and between industries, households, government, and other institutions. However, care must be exercised in applying these models to a given context, depending on resource availabilities, the timing of recovery, etc.

Disadvantages of the basic Input-Output model include its linearity, lack of behavioral context, lack of interdependence between price and output, lack of explicit resource constraints, and lack of input and import substitution possibilities. The linearity assumption permeates every facet of the workings of the model and implies no economies or diseconomies of scale and no input substitution. The lack of input substitution will lead to upper-bound results, e.g., a twenty percent decrease in electricity available in any sector would lead to a twenty percent reduction in that sector's output. The inflexibility of anything other than constant returns to scale, however, might lead to understating losses (as scale decreases due to capital stock damage or input curtailment, unit cost increases would not be reflected). Infinite supply elasticities overlook real world capacity limitations. Thus, several refinements are needed to apply the basic Input-Output model to properly estimate higher-order losses from natural hazards.

As an alternative, the use of computable general equilibrium (CGE) modeling for impact analysis in general is rapidly increasing, especially at the regional level (see Partridge and Rickman, 1998). CGE is a multi-market simulation model based on the simultaneous optimizing behavior of individual consumers and firms in response to price signals, subject to economic account balances and resource constraints (see, e.g., Shoven and Whalley, 1992).

This approach is not so much a replacement for I-O as a more mature cousin or extension, and it retains many of the latter's advantages and overcomes most of its disadvantages (Rose, 1995). For example, CGE retains the multi-sector characteristics and emphasis on interdependence, but also incorporates input/import substitution, increasing or decreasing-returns-to-scale, behavioral content (in response to prices and changes in taste or preferences), workings of markets (both factor and product) and non-infinite supply elasticities (including explicit resource constraints). Moreover, the empirical core of most CGE models is an I-O table extended to include disaggregated institutional accounts, thus becoming a social accounting matrix (SAM).

At the same time, CGE models do have shortcomings, the major ones being the assumption that all decision-makers optimize and that the economy is always in equilibrium. The latter is not a problem when the period of analysis is more than one year and the external shock is small, but natural hazards have the opposite characteristics. As with Input-Output techniques, CGE models are typically developed from non-survey or data-reduction techniques due to cost considerations, and their accuracy is difficult to assess. Moreover, while Input-Output models are overly rigid and exaggerate hazard impacts, the typical CGE model is overly flexible and understates them.

Until recently, all applications of CGE models to natural hazards have been experiments with synthetic models (see Boisvert, 1992; Brookshire and McKee, 1992). More realistic applications have been undertaken by Rose and Guha (1999), and Rose and Liao (2002) to impacts of utility lifeline disruptions in the aftermath of earthquakes. Potential application to other aspects of hazard loss estimation, however, is unlimited given the capabilities of this approach. Currently, several refinements are needed of the standard CGE model for estimating economic losses from natural hazards, most notably to incorporate elasticities with low numerical values, reflecting the short-run or very short-run nature of hazard recovery.

Again care must be exercised in applying CGE models properly. I-O models, with an adjustment for inventories, are probably better suited to recovery periods of less than one week, but CGE models are better suited to all other cases, except possibility where martial law is declared and resource reallocation is undertaken by centralized administration and not through market signals. CGE models can be adjusted for a greater range of resiliency options than I-O, though the adjustment process is more complex.

A third alternative is econometric models. These models have only rarely been used in indirect loss estimation because of their expense, lack of sectoral detail, and difficulty in distinguishing direct and indirect effects (the major exception being the work of Guimaraes et al., 1993; Ellson et al., 1984). Second, econometric models have their own, well-established set of criteria for model validation. Still, the potential application of these models to indirect loss estimation is great, since neither I-O nor CGE models have forecasting capabilities, which are especially useful in examining potential impacts of a future disaster or in distinguishing the actual activity of an economy from what it would have been like in the absence of the shock (i.e., establishing a baseline). Furthermore, for longer timeframes of impact (e.g., two or more years) where the timepath of the economy is important, econometric models may be superior to either Input-Output or CGE techniques.

15.4 Methodology of the Indirect Loss Module

This section discusses the functionality of the Indirect Loss Module. It begins with an overview of the purpose and structure of the module (Section 15.4.1), including a summary of differences between the module in the Hazus Flood and Earthquake methodologies. This is followed by detailed discussion of how the underlying model works: the data inputs (Sections 15.4.2~4) and the core model algorithms (15.4.5). Special attention is paid to the treatment of changes over time, the effects of rebuilding and borrowing, estimating tax revenue impacts, and modeling distributional impacts. Section 15.4.6 focuses on two special sectors, which are treated uniquely in the analysis: agriculture and tourism. Results are discussed in Section 15.4.7, and a cautionary note is provided in Section 15.4.8 regarding the appropriate application of the module in the context of small study regions.

15.4.1 Overview

This module estimates the indirect economic impacts that result from damage caused by flood disasters. In the first instance, physical damage disrupts economic activity and thus causes *direct* economic losses to various sectors in the regional economy. These direct economic losses are estimated in the Direct Economic Loss Module (see earlier chapter). Subsequently, because businesses are interdependent, the direct economic losses cause “upstream” and “downstream” ripple effects to other businesses and business sectors (e.g., losses to customers or suppliers of flood-damaged businesses). *Indirect* economic losses are defined as this additional disruption to economic activity. It is important to recognize, however, that damage-induced losses are to some extent balanced by economic gains from repair and reconstruction activity. The Indirect Loss Module first estimates total economic disruption, including the effects of both losses and gains. Disruptions to the economy can be measured in terms of impacts on regional income, employment, or production. The module then subtracts the direct loss component to arrive at an estimate of indirect economic impacts.

Currently, there exists no standard methodology for evaluating the economic disruption effects of flood disasters. The Indirect Loss Module of the Hazus Flood methodology therefore builds on the approach developed in the Hazus Earthquake methodology and makes several modifications to address differences between the two types of hazards. In particular, it recognizes that the types of economies at risk from floods typically differ from those exposed to earthquake. The Flood Indirect Loss Module therefore includes new capabilities for handling agricultural losses and tourism impacts. In addition, in comparison with the Earthquake Indirect Loss Module, new capabilities have been added to estimate impacts on local tax revenues and to look at how total impacts are distributed among social groups. The latter provides a sense of who are the “winners” and “losers” from disasters.

The structure of the Indirect Loss Module can be described as consisting of the following major elements, which are discussed more fully below:

- *Data describing the economy of the study region* – This consists of two main types of information: (1) data on regional economic size and structure; (2) data on factors influencing regional economic response to external shocks, such as the unemployment rate.

- *Inputs representing direct economic losses (damage-related)* – This represents the linkage with flood damages and the Direct Economic Loss module.

- *Inputs representing direct economic gains (reconstruction-related)* – This drives the indirect gains related to reconstruction stimulus effects.

- *Algorithms for estimating how the economy responds to these inputs* – This is the core of the Indirect Loss Module. The algorithms handle both demand shocks (along the tradition of Input-Output methods) and supply shocks.

- *Results* – The module generates a series of results that provide a multi-faceted view of flood impacts on the regional economy.

The Indirect Loss Module can be run at two levels of analysis. The Default Data Analysis (“Level 1”) utilizes primarily default data and requires minimal user input. In User-Supplied Data Analysis (“Level 2”), the user provides information specific to the economy of the study region and the disaster being modeled. The model algorithms and types of required data are the same in each case; the two levels differ only in the degree to which they use region-specific data.

15.4.2 Required Economic Data

The Indirect Loss Module requires data on the size and structure of the regional economy. Size is indicated by the current regional employment and income levels. Note that employment refers to the number of persons who work within the study region, rather than the number of employed persons who reside there. Employment by place of work is appropriate in this type of analysis because the model will estimate job loss within the study region due to physical damage there from the disaster.

Regional economic structure is represented by a regional Input-Output transactions table that shows inter-industry purchases for a base year. A 10-industry disaggregation scheme is used. The user may obtain Input-Output data for the region from IMPLAN, a standard source (this represents a Level 2 analysis; see section 15.5.2 below). If the user does not provide this data, the module will select and apply synthetic data for a default economy (i.e., a Level 1 analysis). Synthetic Input-Output data for 21 default economies are provided, defined by their economic type (e.g., primarily manufacturing), size (e.g., large), and, for agricultural economies, the region of the U.S. in which they are located. The Input-Output data for each synthetic economy was developed by averaging data for a series of actual county economies of that description. For details on the synthetic data for agricultural economies, see section 15.4.6.1 below. For details on other economic types, see Appendix 15A.

Data are also required on how the regional economy may respond to external shocks. The unemployment rate provides a general indicator of the available slack or unused capacity in the economy. Estimates are also needed of the degree to which excess supply can be absorbed by new export markets or inventory accumulation and the degree to which excess demand can be satisfied by new imports or drawing from inventories. Default values are provided.

15.4.3 Damage-Related Inputs

The Indirect Loss Module is linked to preceding modules through several channels that indicate either damage or rebuilding. In terms of damage, first, flooded buildings lead to various degrees of loss of function in the 10 industries or sectors of the economy, forcing them to cut output. A vector of loss of function by industry in the first year of the disaster provides a set of constraints to the Indirect Loss module that is related to the general building stock damage levels. Loss of function is based upon the time needed to clean up and repair a facility or to rent an alternative facility to resume business functions (see preceding chapter). Loss of function is calculated for each occupancy class. Table 15.3 links the occupancy classes in the Direct Loss Module to the economic sectors in the Indirect Loss Module. Loss of function associated with lifeline disruption is not evaluated.

Table 15.3 Correspondence between Building Occupancy Classes and Economic Sectors

Building Occupancy Class (Direct Loss Module)	Economic Sector (Indirect Loss Module)
IND3	Agriculture (Ag)
NONE	Mining (Mine)
IND6	Construction (Cnst)
IND 1,2,3,4,5 (AVG.)	Manufacturing (Mfg)
COM3	Transportation (Trans)
COM 1,2 (AVG.)	Trade (Trde)
COM 5,4 (AVG.)	Finance, Insurance and Real Estate (FIRE)
(COM 2,4,6,7,8,9; RES 4,6; REL; ED 1,2) (AVG.)	Service (Serv)
GOV1	Government (Govt)
NONE	Miscellaneous (Misc)

In addition to buildings, the Indirect Loss module also requires input on flood damage to agricultural production. As described in an earlier chapter, the Hazus methodology for estimating direct flood damage to agriculture considers only crop losses; livestock losses are not included in this analysis. It does, however, consider the time-of-year that flooding takes place. The user will be required to provide a date of flooding, and the model will estimate the losses based on 3-day, 7-day, and 14-day flood durations. If flooding occurs before planting, no losses are assumed. Outputs of the direct loss module for agriculture will include the dollar value of lost crops for the inundated area, by crop type. The Indirect Loss Module uses the direct loss estimates for 7-day flooding, but the user may override this default and select one of the other durations. The module estimates regional economic impacts due to agricultural damage in a similar manner to how economic impacts due to building-related damage are evaluated. Specifically, the link between agricultural damage and the Indirect Loss Module consists of a direct, percent reduction in production in the agriculture sector. This percent reduction accounts for the relative shares of crop versus livestock production in the study area.

15.4.4 Reconstruction-Related Inputs

The stimulus effect of reconstruction activities will partially offset the loss effect deriving from physical damage. The module requires two main types of reconstruction-related inputs: post-disaster spending on reconstruction, repair and replacement of damaged buildings and their contents, and of transportation and utility lifelines. This spending stimulus is based on the total dollar damage caused by the flood in these categories and modified by the percent of damage that is replaced or rebuilt.

Several modifications to the dollar damage estimates are needed before they can be used in the analysis of reconstruction stimulus. The first adjustment accounts for the fact that not all damage may be repaired or replaced. A percentage rebuilding factor is applied to the dollar damage estimates. The second modification is the timing of the reconstruction in terms of weeks, months, or years after the disaster. The distribution of reconstruction expenditures over time is discussed further below.

The third modification is the itemization of expenditures by type (plant, equipment, etc.) so that this spending injection is compatible with the economic model used to determine indirect effects. The input-output (I-O) model at the core of the module disaggregates the economy into 10 sectors according to one-digit Standard Industrial Classification (SIC) codes. The brunt of the reconstruction expenditures will be assigned to Manufacturing and Construction sectors.

One idiosyncrasy of the I-O model is the role of Wholesale and Retail Trade and of Transportation. These sectors are based on the concept of a "margin," i.e., the cost of doing business (labor, insurance, electricity, gasoline, office supplies) plus profits, but does not include the items sold or shipped (which are merely a pass-through in any case).[4] Those expenditures assigned to Construction require no adjustment, but when spending on manufactured goods is inserted into the model, portions of the total should be assigned to the Wholesale/Retail Trade sector and to the Transportation sector. For very large items bought directly from the factory, there is no Trade sector activity, but for smaller items (e.g., office equipment, trucks), the adjustment is necessary. Generally, the Wholesale margin is 80%. Whether purchased from the factory or from the Trade sector, the Transportation margin is always applicable and is typically equal to 20%.

A similar adjustment is necessary in nearly all cases for consumer spending for replacement of contents. In this case, it is more appropriate to use the Retail Trade margin of 80%. Again, the Transportation margin of 20% would be applicable to purchases of larger items.

In cases where the margin adjustment is required, the module simply applies the following formulas:

$$\frac{\Delta L}{1+tm} = \Delta Y_M \qquad (15\text{-}9)$$

$$\Delta L - \Delta Y_M = \Delta T \qquad (15\text{-}10)$$

where:

$\Delta L =$ Portion of loss estimate (reconstruction/replacement) to which margin adjustment applies.

$\Delta Y_M =$ Manufacturing expenditures after margin adjustment.

$\Delta T =$ Retail/wholesale, trade or transportation expenditures.

$tm =$ Retail/wholesale, trade or transportation margin.

[4] The reason for this device is that many items are sold through wholesale and retail outlets and transported commercially, and, if included as "inputs" to these sectors, the linkage between buyers and sellers would be lost, i.e., it would appear that most purchases were from Wholesale/Retail Trade or Transportation, as if these sectors produced most items in the economy.

15.4.5 Model Algorithms for Rebalancing the Economy

15.4.5.1 Core Algorithms

Traditional Input-Output analysis, as illustrated above, models how demand shocks filter through the economy to produce indirect losses. In contrast, the supply shocks that would be caused by a natural disaster require a different treatment. The Indirect Loss Module begins with the same inter-industry trading patterns that are represented by the *A* matrix in Input-Output analysis. However, once damage to buildings and lifelines constrain the capacity of each economic sector to ship its output to other sectors, or receive shipments, the trading patterns have to be readjusted.

To do this, the Indirect Loss Module estimates how much each sector's output will decline as a result of direct damage and then addresses how the resultant excess demands and/or supplies will be filled and/or disposed of. In the event that the sum of all interindustry demands and final demands exceed the post-disaster constraint on production, then available imports and inventory changes could temporarily help to rebalance the economy. In some sectors excess supplies might exist. If so, inventories may be allowed to accumulate or new markets might be found outside the affected region. Surviving production is reallocated according to the interindustry direct coefficients matrix until all sector excess supplies and demands are eliminated. At this point, a new level of regional output, value added and employment is computed and contrasted with the levels observed prior to the disaster. The difference between these levels approximates indirect loss.[5]

Thus, the Indirect Loss Module is a computational algorithm that utilizes input-output coefficients to reallocate surviving production. The algorithm computes post-event excess demands and supplies. It rebalances the economy by drawing from imports, inventories, and idle capacity when supplies are constrained. It allows for inventory accumulation, production for export (to other regions) and sales to meet reconstruction needs in the event that normal demands are insufficient to absorb excess supplies The process of reallocation is governed by the amount of imbalance detected in each of the economy's sectors. Rebalancing is accomplished iteratively by adjusting production proportionately until the discrepancy between supplies and demands is within a tolerable limit.[6] A simple schematic of the process is provided in Figure 15.4.

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[5] This approach relies on both the existence of regional input-output tables and several assumptions regarding: inventory management, importability of shortages, exportability of surpluses and the amount of excess capacity existing in each sector. It does not accommodate the effects of relative price changes on final demands, nor does it entertain the degree to which labor and capital are substitutable in the underlying production functions. Treatment of these issues require a more sophisticated approach, one which is discussed in the literature under the topic heading Computable General Equilibrium (CGE) Systems.

[6] The tolerable limit is the degree to which the solution values vary from one iteration to the next.

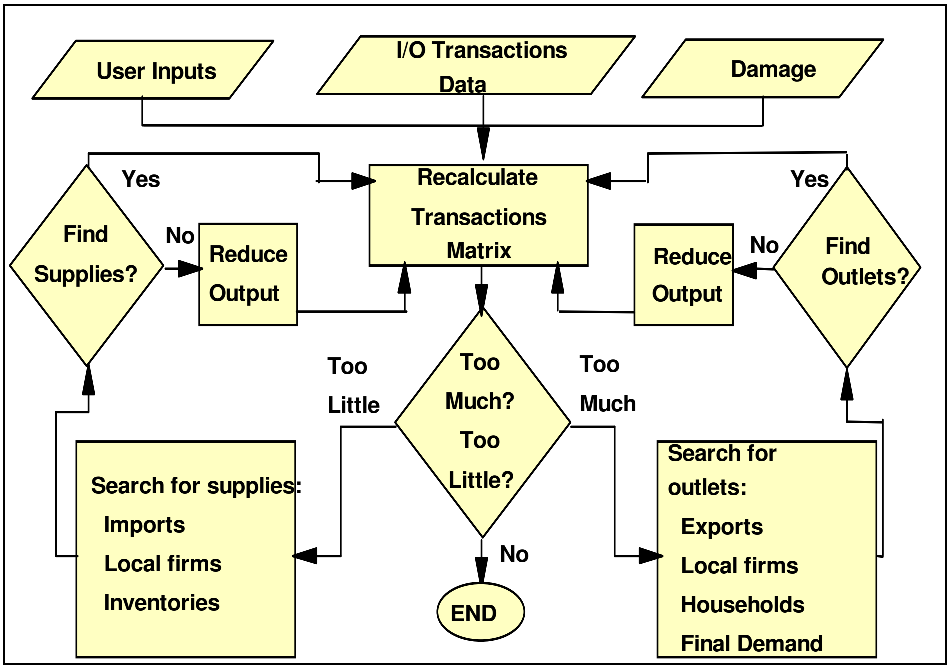

Figure 15.4 Indirect Loss Module Schematic

As an illustration of the core algorithms, consider a simple economy with three industries: construction, manufacturing, and trade. Table 15.4 shows the inter-industry transactions matrix for this economy before the disaster. There are also two rows for payments to households (HH) from those industries and imports which those industries require, plus two columns that represent household demands and exports. Households make no purchases from other households. All amounts in the table are in dollars. In the economy's initial state, the row and column sums are equal.

Table 15.4 Initial Transactions

From/To	Constr	Mfg	Trade	HH	Export	Sum
Constr	10	30	20	20	35	115
Mfg	20	20	10	30	80	160
Trade	15	20	5	40	5	85
HH	30	40	20			90
Import	40	50	30			120
Sum	115	160	85	90	120	

Table 15.5 shows how the economy changes due to the direct impact from a disaster. In this case, there is a 10% loss of manufacturing output as the result of damage to manufacturing facilities. Corresponding to this loss, both the purchases and sales of the manufacturing sector fall by 10%, as reflected in the row and column sums. The transactions directly affected are highlighted in bold type in the table. A new column, named "Lost HH," has been added to this table to reflect manufacturing output that is unavailable to households because of the disaster.

Table 15.5 10% Direct Loss in Manufacturing

From/To	Constr	Mfg	Trade	HH	Export	Sum	Lost HH
Constr	10	**27**	20	20	35	112	
Mfg	**18**	**18**	**9**	**27**	**72**	**144**	**3**
Trade	15	**18**	5	40	5	83	
HH	30	**36**	20			86	
Import	40	**45**	30			115	
Sum	113	**144**	84	87	112		

Table 15.6 illustrates the first example of the indirect response to this situation. This is a "fully-constrained" economy, characterized by no more than 2% unemployment, 0% import replacement, 0% inventory availability or replacement, and 0% additional exports. This means that there are no ways for manufacturers to replace inputs that were disrupted by the disaster.

Under these circumstances, construction and trade firms must cut their previous manufacturing by 10%. There is full employment in the local economy, meaning that other firms in manufacturing cannot increase output to meet the desired purchases by construction and trade. Further imports are not allowed, and there are no inventories of manufacturing output to use. Construction and trade firms, faced with an irreplaceable 10% loss in manufactured goods have no choice but to reduce their production by 10%. The net result is that the 10% direct loss in manufacturing translates into a 10% loss throughout the entire economy. Portions of the table affected by indirect loss are highlighted in italics. The row and column sums are once again in balance. Household consumption is decreased for all three sectors, and there is no way to make up for it.

Table 15.6 Response to Loss with Fully Constrained Economy

From/To	Constr	Mfg	Trade	HH	Export	Sum	Lost HH
Constr	9	**27**	18	18	31.5	103.5	2
Mfg	**18**	**18**	**9**	**27**	**72**	**144**	**3**
Trade	13.5	**18**	4.5	36	4.5	76.5	4
HH	27	**36**	18			81	
Import	36	**45**	27			108	
Sum	103.5	**144**	76.5	81	108		

The fully constrained economy is an extreme case, and most economies are characterized by some flexibility, or slack, so that inputs can be replaced and outputs can be sold. We illustrate this by raising the potential level of additional imports by 10%, and the potential level of additional exports by 40%. This is insufficient to ensure that construction and trade can acquire the supplies they need to meet local demands and sell products that are no longer being bought by manufacturing.[7] Sectors not suffering direct losses return to their pre-event levels of production.[8] Manufacturing might import additional manufactured inputs where needed to replace its own direct losses, but labor is not available due to the low unemployment rate and the assumption that the temporarily unemployed labor in manufacturing will not be available to other firms in the sector. Manufacturing losses will only be replaced as damaged manufacturing facilities return to production.

In Table 15.7, the underlined values show where the important changes have occurred. Both construction and trade were allowed to import the manufactured inputs they lost as a result of the disaster. Also, construction and trade exported that portion of their output that manufacturing no longer purchased. Because of these two factors, there is no indirect loss in the case illustrated in Table 15.7.

The same results may be obtained in other ways. Instead of increasing imports, there might be some unemployment in the local economy. In this case, other firms in the manufacturing sector could hire some of the unemployed resources to make up the shortfall. Alternatively, there might be inventories of manufactured goods, either at the manufacturers or in storage at the construction and trade firms that require those goods. On the output side, firms faced with a reduction in purchases from the manufacturing sector may decide to continue production and store the resulting product in inventory until the disrupted facilities are back in production or until they can find new export markets.

Table 15.7 Response to Loss with Relaxed Import and Export Constraints

From/To	Constr	Mfg	Trade	HH	Export	Sum	Lost HH
Constr	10	**27**	20	20	38	115	
Mfg	**18**	**18**	**9**	**27**	**72**	144	**3**
Trade	15	**18**	5	40	7	85	
HH	30	**36**	20			86	
Import	42	**45**	31			118	
Sum	115	144	85	87	117		

In Table 15.7, manufacturing remains at its immediate post-disaster level because the situation being illustrated is immediately after the event, before reconstruction can take place. If the slack in the system came from unemployment instead of imports, the results would be different. That portion of the manufacturing sector undamaged by the disaster could hire additional resources and make up the direct losses. Overall production would regain its pre-disaster levels. Therefore, unlike the example illustrated which shows no net indirect change, there would be a

[7] Construction only needs to increase its level of imports by 2, 5% of its initial imports of 40, and trade only requires an increase in imports of 1, or 3.3% of 30. Construction requires additional exports of 3, or 8.6% of original exports. The limiting sector is trade, required to find export markets for 2 units, 40% of the 5 units it originally exported.

[8] Even if the slack assumptions are set higher, the algorithm limits sectoral production to be no higher than prior to the earthquake (unless there is a positive counter-stimulus from, say, reconstruction activity).

net indirect increase in sales that would be equal to the direct loss, making for a net economic change of zero.

Tables 15.6 and 15.7 show an important way in which this algorithm departs from traditional Input-Output (I-O) analysis. The technical coefficients for both tables are different from those of the original economy. This is because imports and exports have been allowed to replace lost supplies and sales in the system. The usual technical coefficients in an I-O table assume that the relationships between imports and intermediate inputs are fixed, as well as assuming that the relationships between exports and intermediate outputs are fixed. Though these assumptions are convenient for the purposes of I-O analysis, they are a departure from reality in general, and especially so in emergency situations. Also note, from Table 15.7, that the household and import/export sectors are no longer balanced in terms of row and column sums. This is due to the short-run nature of the problems being solved in the model. In the longer run, households must repay their borrowing, and exports must rise to repay the short-run imports, unless government disaster aid or some other form of external financing is used to pay for the short-run consumption and imports.

Tables 15.6 and 15.7 illustrate the two extremes that the model can reflect in responding to pure supply-side disruptions. In its fully functional implementation, the model adjusts simultaneously for multiple shocks of varying amplitude in any number of sectors, while also accounting for demand-side (final demand) increases that typically accompany disasters.

15.4.5.2 The Time Dimension

The model is evaluated at various levels of temporal resolution for the 15-year period following the disaster. For the first 2 months after the disaster, weekly time intervals are used. Between 2 months and 24 months, the economy is evaluated on a monthly basis. From 2 years to 15 years, the economy is evaluated annually. It is made dynamic by considering how industry loss of function is restored and reconstruction expenditures are made over the time windows. Thus while the inputs to the Indirect Economic Loss module differ with each time interval, the rebalancing algorithm for the economy and adjustment factors (e.g., availability of supplemental imports to make up for lost production) do not change. The time patterns of functional restoration and reconstruction are user inputs and are discussed in Section 15.5.

15.4.5.3 The Effect of Borrowing for Rebuilding

Borrowing impacts the model in that future demands are reduced in proportion to the temporal payments for rebuilding. In the case of the Northridge earthquake, for example, this amounted to less than 50 percent. Federal assistance and insurance settlements provided the bulk of the financial resources for reconstruction. The importance of refinancing lies in longer-term effects of repayment. If the affected region receives no assistance, then the stimulative effects of rebuilding are only temporary. The region will eventually have to repay loans and future spending will suffer. This is accounted for in the model as follows.

1. It is assumed that all loans mature 15 years *from the time of the disaster*. Therefore, the first year's loans are for 15 years. The second year's loans are for 14 years, and so on.

2. Tax implications are ignored. Interest is not tax deductible.

3. Borrowing costs are assumed to be 6 percent. This is a real interest rate (inflation free). The discount rate is assumed to be 3 percent. It too is inflation free.

The loan payments are computed as follows (Table 15.8).

Table 15.8 Annual Borrowing Costs

Year	1	2 through 15
Annual Payment	$\left[\dfrac{r}{(1-(1+r)^{(-15+1)})}\right] loan1$	$\left[\dfrac{r}{(1-(1+r)^{(-16+t+1)})}\right] loan_t + Pay_{t-1}$
Explanation	loan 1 times the annual payment factor (r is real interest)	payment from t-1 plus loan t times the annual payment factor

Future demands are reduced by the annual payments times the percentage households spend on each sector's output. For example, if households are paying back $50 million in year 1 then spending from all categories declines as shown in the following table. The second column in Table 15.9 is the pre-disaster spending pattern. For example, 0.2 percent of household income was spent on agricultural products; 24.6 percent was spent on services. This percentage times the $50 million loan repayment cost yields the reduction in household spending by sector in year 1.

Table 15.9 The Effect of Loan Repayment on Household Demands

Sector	Household Spending (% spent on each sector)	Reduced Demand in $ millions (% times loan payment)
Ag	0.2%	0.08
Mine	0.0%	0
Cnst	11.2%	5.59
Mfg	7.5%	3.75
Trns	6.2%	3.08
Trde	21.6%	10.82
FIRE	23.2%	11.59
Serv	24.6%	12.3
Govt	5.3%	2.63
Misc	0.3%	0.15

Exercising the module sequentially using average values over the reconstruction period derives time dependent indirect losses.

15.4.5.4 Tax Revenue Impacts

In addition to estimates of losses in terms of regional output, income, and employment, the Indirect Loss Module evaluates the potential impacts of the disaster on local government tax revenues. The application and relative importance of different types of taxes varies across levels of government. For example, sales and income taxes are the major revenue sources at the state level but are rarely imposed by either cities or counties. On the other hand, property taxes are rarely imposed at the state level and are the major source of funding for local government entities, including towns, cities, and some special purpose districts such as schools.

Taxes also differ according to whether they are imposed periodically or on an on-going basis, a feature that makes a significant difference for the timing of hazard impacts. For example, property taxes are typically collected annually, and revenues will not be affected by destruction of assets until the next tax period. Additionally, those property owners who suffer sizeable damage may be granted a waiver for all or part of their property tax for a temporary period.

The Indirect Loss Module estimates tax revenue losses only for local government. Note that most floods affect only sub-state areas, and state-level tax impacts are not directly applicable. However, state-level tax collections (and federal collections as well—mainly in the form of personal and corporation income taxes) are returned to local jurisdictions or spent by higher-government entities in or elsewhere on behalf of local areas. Of course, expenditures hardly ever match revenues because of national level purchases (e.g., aircraft carriers) or because of redistribution objectives, but calculation of tax revenue reductions to all levels of government in the aftermath of disaster is justified. However, these calculations should be done separately for each level. Note that state level tax impacts (e.g., corporate and personal income) are not likely to have much affect on spending in the region impacted by flood. The region is likely to be a small portion of the state and considerations of need for recovery and reconstruction are likely to stave off any reduction in government spending. Thus, there is little need to calculate lost state personal or corporate income tax payment decreases except for the largest events.

To evaluate local tax impacts, the module makes use of the Indirect Business Tax (IBT) feature of IMPLAN Input-Output data. The IBT component is composed of sales taxes, property taxes, licenses, and fees (although not disaggregated into these components). These components accrue variously to local, state, and federal governments. The tax impact methodology depends upon whether the analysis is using default, synthetic Input-Output data (Level 1 analysis) or the user has provided region-specific Input-Output data (Level 2 analysis) (see section 15.4.2 Required Economic Data, above).

If the analysis is using default data, the module applies default IBT coefficients. To derive the default IBT coefficients, IMPLAN data were used to compute ratios of indirect business tax to sector output for one percent of the nation's counties and states. The resultant averages and associated standard deviations are provided in Table 15.10. It appears that, except for mining, the averages vary within a narrow range. Furthermore, taxes collected in the aggregated sectors of transportation/utilities (433), trade (447), and finance, insurance and real estate (456) make up the predominance of the IBT revenue. These findings suggest that IBT will change in proportion to output loss. The average IBT ratios shown in Table 15.10 are applied to the estimates of total output loss, or the difference between pre- and post-flood sectoral outputs, caused by the disaster. The resulting estimate is reported as a percent reduction in IBT tax collection. The percent reduction in IBT tax is reported, rather than the dollar amount, since this is an approximation. The user could then apply the percent reduction to an accurate measure of IBT for their particular county. This would give them the reduction in IBT tax revenue.

Table 15.10 Ratio of IBT to Sector Output for 1 Percent of the Nation's Counties and States

Sector	Average	Standard deviation
Agriculture	1.38%	0.88%
Mining	11.63%	8.87%
Construction	0.43%	0.16%
Manufacturing	1.11%	0.55%
TCPU	4.34%	1.04%
Trade	14.11%	2.61%
FIRE	12.91%	2.06%
Services	1.43%	0.83%
Government	0.00%	0.00%
Other	0.00%	0.00%

If the user has provided IMPLAN Input-Output data for the study region (Level 2), a more refined treatment of tax revenue loss is possible, emphasizing impacts on local government. Here, IBT coefficients are extracted from the IMPLAN dataset. The user supplies information on the local property tax rate and local sales tax rate, if any (i.e., excluding any state sales tax), and the categories of sales that are taxed. Since few jurisdictions impose local income tax, this category is not evaluated. Loss of property tax, a major source of local government revenue, is calculated from Hazus direct damage estimates to buildings. The value of structural damage, excluding tax-exempt categories of buildings, is multiplied by the local property tax rate. As for local sales tax, this loss is evaluated by first identifying the sub-sectors whose sales are taxable (e.g., hotels) and their shares of the major sectors (e.g., services). The model's results on sectoral loss of output are then multiplied by taxable sub-sector shares to derive an implicit output loss to these sub-sectors. This is in turn multiplied by the tax rate to derive the loss of local sales tax revenue. To avoid double-counting of various IBTs, sales tax and property tax revenue decreases are subtracted from the estimated IBT total revenue decrease. This will yield an IBT residual loss category comprised of licenses, fees, severance taxes, etc., that can be considered separately or added back to sales and property tax revenue losses to obtain an appropriate total.

The loss of local property and sales tax revenues, in addition to simply being reported, will have an impact in the model on local government sector spending. Government consumption in each year will be reduced by the amount of tax revenue loss in the previous year.

15.4.5.5 Distributional Impacts

Income distribution impacts of natural hazards are especially important for both normative and positive reasons. Several analysts have found that the poor are especially vulnerable to hazards in particular, and that hazards exacerbate inequalities in income distribution in general. Thus, the evaluation of such impacts is important from the perspective of equity, including new approaches to the topic, such as "Environmental Justice."[9]

Distributional impacts are also important from the vantage point of predicting and improving public policy through increased public participation. Impact analyses often focus on how the community as a whole is affected. However, this imparts an inordinate amount of altruism on the part of the citizenry, since individuals primarily want to know how they themselves will be affected. Only when citizens are well-informed will public participation be worthwhile. Thus, income distribution impacts provide stakeholders with useful information that can help promote the best interests of society as a whole.

Data on the size distribution of personal income are tedious to compile at the small area level. Moreover, some types of data compatible with an input-output model are non-existent at any level. This pertains primarily to capital-related income payments such as dividends, interest, rents, and royalties. The reason is that most individuals receive these payments from more than one sector and often from sources outside the given region. Thus, care must be taken to link sectors and individuals (or households) and to adjust for "transboundary flows" of income, pertaining to leakages of capital-related income and the wages and salaries of commuting workers. Tracing sectoral specific linkages is important because hazards have differential effects across the economy. Adjusting for transboundary flows is desirable to avoid inflating the impact, e.g., dividends not distinguished by geographic origin will mistakenly show up as a reduction in the impacted area, despite the fact that a majority of income flows to areas that are unscathed by the hazard.[10]

The type of income distribution data best suited to the Input-Output framework of the IELM of Hazus is a multi-sector income distribution matrix (see Rose et al., 1988; Rose and Beaumont, 1988). This matrix contains the income payments from each economic sector to each separate income bracket. Dividing each of the income payment flows for a given sector by the gross output or total direct income of that sector yields a coefficient, or structural, matrix of income distribution that can be adapted to economies of various scales or sectoral mixes. To calculate the distribution of impacts across income brackets, the module multiplies the structural matrix of income distribution by the estimated changes in sectoral gross output due to the disaster.

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[9] The focus here is on income, but the unevenness of hazard impacts also relates to socio-economic groups such as minorities and the elderly.

[10] Dividends represent business profits paid out to share-holders (in contrast to retained earnings). Of course, non-residents of the region impacted by the hazard are affected because ownership is spread throughout the U.S., thus broadening the geographic coverage of impacts. Ideally, these impacts on other regions would be calculated separately, but this is probably impractical given cost and data limitations.

At present, the most up-to-date multi-sector income distribution matrix (IDM) for the U.S. is benchmarked to 1987 and is contained in Li et al. (1999). A matrix for 1992 has been developed by the U.S Department of Agriculture Economic Research Service and is available for public use. These two matrices are deemed adequate for a Level 1 analysis.[11] Although not region specific per se, a good portion of the difference in such matrices between regions is captured by the differences in the relevant prominence of economic sectors, a feature that is picked up by the various synthetic economies at a Level 1.

A more accurate approach is adopted in a Level 2 analysis where the user has supplied IMPLAN Input-Output data for the region. From the IMPLAN database, the Indirect Loss Module accesses data on sectoral factor payments (i.e., payments by economic sectors to labor and other factors of production) and on income distribution to households.

The income distribution features of IMPLAN are contained in the Social Accounting Matrix (SAM) component, which is now well integrated into that system (this was not the case a few years ago).[12] This disaggregation is both on the income and consumption sides[13] for nine household income brackets (the upper bracket is $70,000 and above). The soundness of data for the income distribution component are solid for wages and salaries (usually about 80% of the total), but somewhat weaker for capital-type income (usually about 10-15% of the total). For the latter, IMPLAN typically uses national averages for each region, which aren't even sectorally specific, though the SAM implicitly makes a reasonable net transboundary flow adjustment.[14]

To calculate distribution impacts across income groups, the module first computes sectoral output changes due to the disaster. It next computes sectoral factor[15]-output ratios (total direct income payments per dollar of gross output) based on the IMPLAN data. The sectoral output changes are multiplied by the corresponding factor-output ratios to derive a vector of sectoral total income payment changes. This vector of income changes is then multiplied by the IMPLAN SAM data on income distribution across the 9 income brackets.

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[11] Both of these matrices can be updated to the current year by a methodology developed by Hanson and Rose (1997) and adapted by Oladosu (2000).

[12] Many of the income component definitions and impact analysis procedures in the current version of IMPLAN are consistent with the elaborated discussion in Rose et al. (1988).

[13] Income groups differ significantly in terms of the mix of goods and services they purchase, which has a significant effect not only on sectoral impacts, but also overall impacts. Differentials in savings rates also greatly affect the latter, and are important in assessing the ability to withstand a disaster and the pattern of replenishing the savings in the years following it. The disaggregation of consumption by income bracket, however, is still too complicated for even a Level 2 analysis at this point.

[14] Ideally, the adjustment would be at the gross level, counting both all inflows and all outflows. Inflows would not meet the endogeneity requirement to be included in a Type II multiplier. The gross flow and adjustment implicitly assumes that any region that has a positive net outflow of dividends does not have *any* inflow of dividends. This "no cross-payments" assumption is analogous to be "no cross-hauling" assumption for goods and services, and with the same implications—overstating impacts (see Rose and Stevens, 1991). Again data and cost limitations preclude any major adjustments.

[15] Factor payments refers to the fact that the entries are: "employee compensation" (wages and salaries) and "proprietary and other property income" (capital-related income).

15.4.6 Special Sectors

The modeling of impacts in two sectors, agriculture and tourism, requires separate discussion. Losses in these sectors can be particularly significant in flood disasters, and the modeling of the loss mechanisms also differs from that of the general algorithm described above. Indirect loss modeling in the Hazus Earthquake methodology did not specifically consider these two sectors.

15.4.6.1 Agriculture

As indicated above, the treatment of agricultural losses in the Indirect Loss Module differs somewhat from that of other sectors. The direct loss input includes not only building-related loss but also damage to agricultural production. In addition, for default data analyses (Level 1), Hazus provides synthetic Input-Output tables for agriculture-based economies. Both of these elements of the methodology are discussed in this section.

Estimates of direct agricultural damage include crop loss; however, Hazus does not evaluate livestock loss, which is assumed to be zero. To account for this, the total dollar value of crop loss for the inundated area is divided by the dollar value of expected crop production for the study region to yield a percentage crop loss figure. This figure is then adjusted for the ratio of crop versus livestock production to derive a percent output loss estimate for the agriculture sector. This then serves as one of the inputs driving the core rebalancing algorithm of the Indirect Loss Module.

If the user has supplied IMPLAN Input-Output data for the region (Level 2 analysis), the ratio of crop versus livestock production is obtained from the actual data on the composition of the agriculture sector in the study region. Direct loss estimates for various crop types (aggregated to match the IMPLAN sub-sectoring scheme for agriculture) are divided by their respective expected production levels for the study region to yield crop-specific loss percentages. These estimates are then aggregated to develop an overall agriculture sector loss percentage by weighting them with their actual shares of regional agricultural production.

If a default data analysis is being run (Level 1 analysis), the user will have selected the synthetic economic type that best represents the study area. Default data have been developed for the crop share of total agriculture based on the USDA-NASS, 1997 Census of Agriculture. Table 15.11 shows census data on livestock sales as a percent of total agricultural sales by state. The default crop share of total agricultural production is the difference between total and livestock sales for the applicable state.

Table 15.11 Livestock Sales as a Percent of Total Agricultural Sales, by State

State	Sheep, Lambs, & Wool	Cattle & Calves	Dairy Products	Hogs & Pigs	Other Livestock & Livestock Products	Poultry & Poultry Products	Total
Alabama	(Z)	9.2	1.7	1.1	2.1	65.5	79.6
Alaska	0.4	6.6	11.3	1.3	15.5	0.1	35.2
Arizona	0.3	18.7	14.8	1.1	0.6	0.2	35.7
Arkansas	(Z)	6.9	1.4	4	1.7	46.1	60.1
California	0.2	6.1	13.8	0.2	0.6	5.1	26
Colorado	3	56	4.2	3.8	0.6	3.1	70.7
Connecticut	0.1	1.5	15.7	0.2	2.8	17.1	37.4
Delaware	(Z)	1.4	2.8	0.9	0.2	69.3	74.6
Florida	(Z)	5	6.4	0.1	2.4	5.8	19.7
Georgia	(Z)	4.5	4.3	2.1	0.5	50.2	61.6
Hawaii	(Z)	5.6	5.8	1.3	2.8	3.6	19.1
Idaho	0.9	27.2	16.7	0.1	1.6	0.4	46.9
Illinois	0.1	6.4	3	12.4	0.3	1.1	23.3
Indiana	0.1	6.3	4.9	16.1	0.7	9.9	38
Iowa	0.3	15.5	3.4	25.4	0.2	3.5	48.3
Kansas	0.1	59.3	1.7	3.3	0.1	0.5	65
Kentucky	(Z)	18.1	7.8	3.7	11	7.9	48.5
Louisiana	(Z)	7	5.1	0.2	4.1	14.1	30.5
Maine	0.1	2.3	21.8	0.3	10.4	16.7	51.6
Maryland	0.1	4.4	13.3	1.1	2.8	43.4	65.1
Massachusetts	0.1	1.4	13.2	0.5	2.7	3.5	21.4
Michigan	0.2	7.8	18.1	6.4	1.2	4.7	38.4
Minnesota	0.2	9	13.2	17.5	0.5	9	49.4

Table 15.11 Livestock Sales as a Percent of Total Agricultural Sales, by State (Continued)

State	Sheep, Lambs, & Wool	Cattle & Calves	Dairy Products	Hogs & Pigs	Other Livestock & Livestock Products	Poultry & Poultry Products	Total
Mississippi	(Z)	6.9	2.7	2.6	8.6	38	58.8
Missouri	0.1	21.1	5.5	15.7	0.6	14	57
Montana	1.7	44.6	1.9	1.7	1.5	0.3	51.7
Nebraska	0.1	50.4	1.2	8	0.2	1.5	61.4
Nevada	2.8	38	15.5	0.2	0.8	(Z)	57.3
New Hampshire	0.3	3.2	31.4	0.8	2.1	12.9	50.7
New Jersey	0.1	1.3	5.4	0.6	2.5	5.1	15
New Mexico	1.1	40	28.6	0.1	0.6	1	71.4
New York	0.1	7	51.5	0.5	2.5	3	64.6
North Carolina	(Z)	2.2	2.3	33.5	0.6	27.6	66.2
North Dakota	0.3	17.4	2.8	1.2	0.9	1	23.6
Ohio	0.2	7.4	10.9	7.8	1.1	12.2	39.6
Oklahoma	0.1	55.7	3.6	8.2	0.7	9.7	78
Oregon	0.9	16.2	7	0.2	1.2	3.3	28.8
Pennsylvania	0.1	8.9	33	5.9	1.9	18	67.8
Rhode Island	0.1	1.4	9.8	1	1.8	4.2	18.3
South Carolina	(Z)	4.8	3.4	4.1	0.9	37	50.2
South Dakota	1	37.3	4.7	7.9	0.7	2.1	53.7
Tennessee	0.1	19.6	9.6	3.3	1.5	13.5	47.6
Texas	0.7	52.7	5.4	0.8	0.9	8.3	68.8
Utah	3.4	29.6	22.3	4.6	4.1	7.8	71.8
Vermont	0.2	7.5	74	0.1	4.4	1.2	87.4
Virginia	0.2	16.6	11.6	3.3	2.5	32.4	66.6
Washington	0.1	13.6	13.1	0.2	1.4	3.6	32
West Virginia	0.5	25.6	8	0.5	1	49.9	85.5
Wisconsin	0.1	12	49.2	2.7	2.2	4.3	70.5
Wyoming	7.9	67.6	1.1	2.7	1.5	(Z)	80.8

The selection of the synthetic economic type in default data analysis (Level 1) also differs for agricultural versus other types of economies such as manufacturing-based economies. For the latter, the module considers the size of the study area economy when selecting the most appropriate synthetic economy to use as a proxy. For agricultural economies, on the other hand, size is less important a distinguishing factor than the type of region in which the study area is located.

A variety of experiments were conducted to establish a set of agricultural regions that lay users could easily apply. One such experiment derived a set of tables from counties dependent on agriculture, where dependence was defined as the county's prominence in terms of government payments and agricultural products sold normalized by county income. The counties were then grouped as: low dependence, moderate dependence, and high dependence. A subsequent evaluation of the procedure concluded that unique counties could dominate the results, rendering the resulting synthetic tables too specific. As a result the approach was abandoned in favor of a more accepted means of categorizing agricultural regions, one developed by the Department of Agriculture's Economic Research Service (ERS).

The task of the developing a set of homogeneous agricultural regions had been undertaken by the ERS; using a form of cluster analysis, the ERS observed that few commodities tended to dominate farm production in geographic areas that transcend State boundaries (and watersheds). Cropping and livestock patterns in such areas clustered according to a region's climate, soil, water, and topography. The ERS identified those counties with similar agricultural practices and environmental characteristics (as reflected in USDA's Land Resource Regions) and produced a crude map of farm resource regions. See Figure 15.5. These nine Farm Resource Regions served as the basis for deriving the Level 1 default agriculture-based economies.

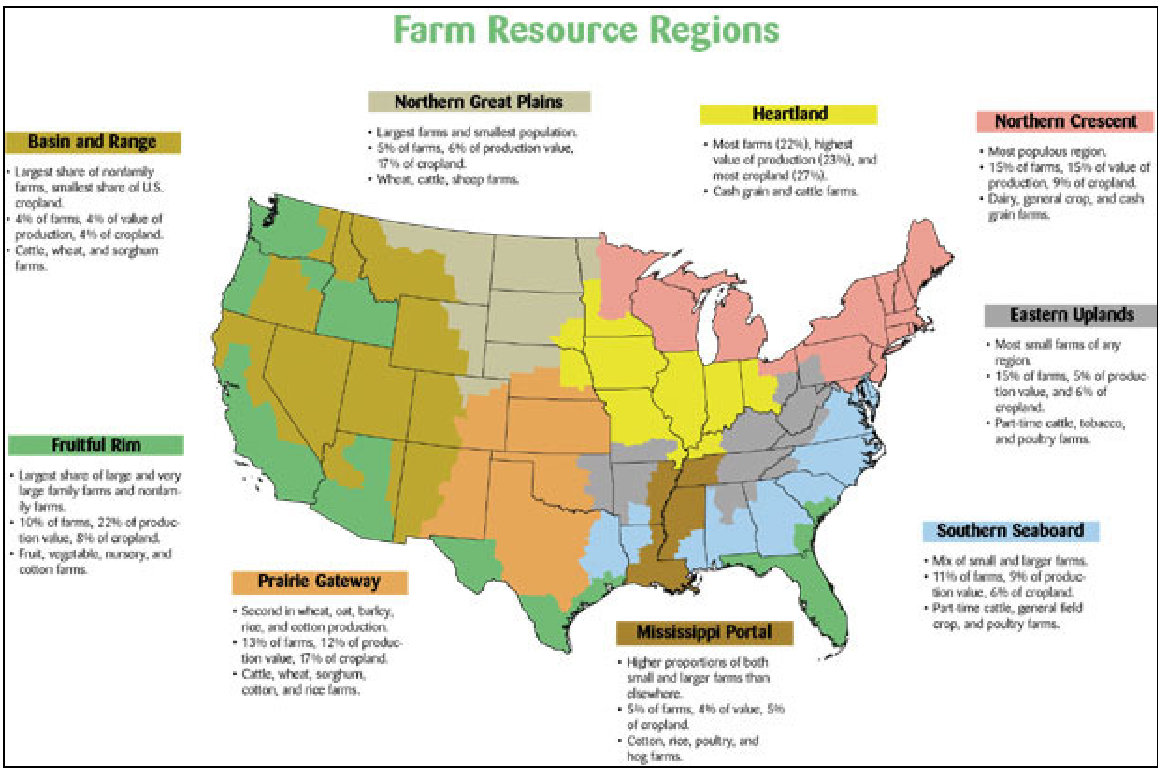

Figure 15.5 Farm Resource Regions Defined by ERS

Inter-industry or Input-Output tables were derived for each of the nine regions as follows. Budget limitations dictated that tables be derived from a random sample of counties. 45 counties (five from each of the nine ERS regions) were drawn from the population (3,111 U.S. counties). The sample was then slightly[16] altered to reflect a wider geographic area, and to include counties nearer to rivers or streams. The final set of counties used to establish the nine synthetic agricultural economies is provided in Appendix 15A. IMPLAN tables were obtained for all 45 counties and aggregated by region. The resulting regional IMPLAN files are shown in Table 15.12.

Table 15.12 Level 1 Synthetic IMPLAN Tables

ERS Region	Region Name	IMPLAN File Name	ERS Description
1	Heartland	Region1.iap	Most farms (22%), highest value of production (23%), and most people (27%). Cash grain and cattle farms
2	Northern Crescent	Region2.iap	Most populous region. 15% of farms, 15% of value of production, 9% of cropland. Dairy, general crops, and cash grain farms.
3	Northern Great Plains	Region3.iap	Largest farms and smallest population. 5% of farms, 6% of production value, 17% of cropland. Wheat, cattle and sheep farms.
4	Prairie Gateway	Region4.iap	Second in wheat, oat, barley and cotton production. 13% of farms, 12% of production value, and 17% of cropland. Cattle, wheat, sorghum, cotton, and rice farms.
5	Eastern Uplands	Region5.iap	Most small farms of any region. 15% of farms, 5% of production, and 6% of cropland. Part-time cattle, tobacco, and poultry farms.
6	Southern Seaboard	Region6.iap	Mix of small and larger farms. 11% of farms, 9% of production value, and 6% of cropland. Part-time cattle, general field crop, and poultry farms.
7	Fruitful Rim	Region7.iap	Largest share of large and very large family farms and non-family farms. 10% of farms, 22% of production value, 8% of cropland. Fruit, vegetables, nursery, and cotton farms.
8	Basin and Range	Region8.iap	Largest share of non-family farms, smallest share of U.S. cropland. 4% of farms, 4% of value of production, 4% of cropland. Cattle, wheat, and sorghum farms.
9	Mississippi Portal	Region9.iap	Higher proportion of both small and large farms than elsewhere. 5% of farms, 4% of value, 5% of cropland. Cotton, rice, poultry, and hog farms.

[16] Five counties out of randomly drawn 45 were replaced.

15.4.6.2 Tourism

Some economic sectors are more prone to flood damage than others. A good example is tourism, which is especially prevalent in coastal areas that are relatively more vulnerable to wave surges from hurricanes and severe storms. This section discusses two issues related to tourism in the Indirect Loss Module: the representation of tourism-dominated economies in the Level 1 synthetic economic tables, and the modeling of tourism-related impacts.

In Level 1, with regard to synthetic economic tables, analysis suggested that tourism-based economies can be adequately represented by the category of service-dominated economies. This treatment was governed by several considerations. First, “tourism” does not have a universally accepted definition. Moreover, IMPLAN, as well as every other major packaged regional economic model, lacks a specific tourist industry. Underlying this is the absence of a single Standard Industrial Classification (SIC) code on which government data collection can be based. This situation is further complicated by the fact that not all of the expenditures in these sectors are for what is typically considered tourism (e.g., use of hotels by business travelers).

Furthermore, the direct losses sustained by a region’s tourism sector is likely to produce demand driven (and not supply constrained) dislocations. In this case, the choice of a synthetic economic table as well as the degree of sectoral disaggregation adopted in the Indirect Loss Module hinges on the accuracy of the model’s multipliers (output, income, value added and employment).

Multiplier analysis was performed to assess the sensitivity of IMPLAN multipliers to the makeup of the sectors used to reflect the tourism industry. A number of aggregation schemes were developed, the most elaborate of which grouped all recreation and tourism related sectors. This single aggregate was comprised of IMPLAN sectors 454 (eating and drinking), 463 (hotels and lodging places), 483 (motion pictures), 484 (theatrical productions), 485 (bowling), 486 (commercial sports), 487 (racing and track), 488 (amusement and recreation…) and 489 (membership sports). Type I multipliers were estimated for five counties whose economies are dominated by tourism or services. The results suggest that that the multipliers for this level of aggregation were comparable (varying from 1.24 to 1.33). An alternative simpler aggregation scheme was also tested. The output multipliers for the IMPLAN service sector (a 1-digit level of aggregation) resulted in a comparably narrow range of results (Type I multipliers of 1.28 to 1.34). The value added, employment and personal income multipliers exhibited a slightly greater variance. The multiplier analysis thus showed that the service sector serves as a reasonably accurate proxy for recreation and tourism.

Tourism-related losses are treated somewhat differently from impacts deriving from damage to other sectors. The methodology here estimates losses in regional economic output, employment, and income due to a reduction of tourism activity in flood disasters. It accounts for both the loss of direct tourist expenditures and its indirect or ripple effect throughout the regional economy. The decrease in tourism, which largely arises from perceptions of the disaster, may not correlate well with the actual amount of damage suffered. Indeed, tourist activity may essentially cease for a time after the disaster. Loss of tourism is therefore treated as a demand shock to the economy. Note that the Indirect Loss Module core algorithm is able to handle both supply and demand losses simultaneously without double-counting.

The methodology does not distinguish between purchases by tourists and other types of visitors such as businessmen. Rather, it simply refers to them all as "non-resident" expenditures, all of which are likely to be decreased by a major flood. The methodology does not consider the stimulus effect of expenditures by relief workers coming into the disaster region. It also does not consider the stimulus effect to hotel and other tourism sectors from the expenditures of local residents who are displaced from their homes.

To evaluate the initial, direct loss of tourism activity, the user must provide estimates of the number of visitor-days lost and the timeframe over which activity returns to normal. Default data are provided to translate this into the dollar and percent direct demand loss that is suffered by the service sector. The percent direct loss is then input to the IELM along with direct losses from other sources. The user can elect not to evaluate tourism-related losses. If tourism impacts are evaluated, the model will automatically constrain import and export parameters for the service sector. This is to ensure that the model does not try to import or export tourism services (e.g., hotels) as it tries to rebalance the economy. Further detail on these steps is provided below.

To translate visitor-days into percent demand loss for the tourist-related sectors, default data were developed. First, visitor-days must be converted to dollars. Data on dollars per visitor-day were developed based on data from a variety of sources (see Tyrrell, 2001; Strauss and Lord, 1997). The U.S. Input-Output table is the basis for the sectoral components of tourists expenditures (Table 15.13). The standard trade and transport margins (see Table 15.14) were then applied to account for expenditures from these sectors. Although most of the expenditures are for goods produced in the region in which the flood takes place (e.g., hotels) some goods are produced elsewhere, and regional distinctions are based on their importation. Thus, default regional purchase coefficients (RPCs) (see final column of Table 15.15) were applied to the trade/transportation-adjusted expenditure vector. The RPC values were developed from analysis of IMPLAN data for several tourism-based economies.[17] To model impacts, the RPC-adjusted data are entered as they change, primarily in the service sector but also in trade and transportation sectors of the synthetic economy chosen for analysis.

[17] To develop these default values, regional purchase coefficients (RPCs) were calculated for several counties from IMPLAN data. The analysis revealed that the RPCs embedded in IMPLAN are identical across counties for sectors 484, 486, 487, 488, and 489. Table 15.15 also suggests that RPCs vary for the other sectors, but not by much. The final column of Table 15.15 consists of educated guesses for RPCs that would be appropriate as default values in the Indirect Economic Loss Module. Note that the RPC for sector 463 could arguably be set to 1.

Table 15.13 National Personal Consumption for Tourism Sectors, 1997 (millions of dollars)

IMPLAN Sector	Industry Descriptor	Personal Consumption
397	Travel Trailers and Camper	$1,396
421	Sporting and Athletic Goods- N.E.C.	$5,379
451	Automotive Dealers & Service Stations	$142,794
454	Eating & Drinking	$253,683
463	Hotels and Lodging Places	$37,536
477	Automobile Rental and Leasing	$8,374
484	Theatrical Producers- Bands Etc.	$7,707
486	Commercial Sports Except Racing	$2,420
487	Racing and Track Operation	$5,058
488	Amusement and Recreation Services- N.E.C.	$52,466
489	Membership Sports and Recreation Clubs	$14,606
	Total	$531,417

Source: U. S. Input-Output Table.

Table 15.14 Margins for Tourism Commodities

Margined Sector	Tourism Sector		
	Petroleum Products	Travel Trailers and Campers	Sporting & Athletic Goods
Transportation	0.023	0.004	0.004
Wholesale Trade	0.147	0.006	0.129
Retail Trade	0.200	0.241	0.450
Total	0.370	0.251	0.583

Source: MIG (2001).

Table 15.15 RPCs for a Sample of Counties that Rely on Tourism

IMPLAN Sector	Industry Descriptor	RPC Larimer, CO	RPC NY, NY	RPC Atlantic, NJ	RPC Center, PA	RPC Dare, NC	Default Values
397	Travel Trailers & Campers	0.0008	1.0000	1.0000	1.0000	1.0000	1.00
421	Sporting & Athletic Equipment	0.0956	0.0000	0.0060	0.3995	0.0000	0.10
451	Automotive Dealers & Service Stations	0.9500	0.9500	0.9473	0.9498	0.9481	0.95
454	Eating & Drinking Establishments	0.9000	0.8145	0.8084	0.8759	0.9000	0.85
463	Hotels and Lodging Places	0.8001	0.5230	0.5205	0.5855	0.7641	0.60
477	Automobile Rental and Leasing	0.9000	0.7277	0.8263	0.8918	0.9000	0.85
484	Theatrical Productions	0.8355	0.85	0.85	0.8283	0.8501	0.85
486	Commercial Sports Except Racing	0.8355	0.85	0.85	0.8283	0.8501	0.85
487	Racing & Track Operation	0.8355	0.85	0.85	0.8283	0.8501	0.85
488	Membership Sports & Recreation Clubs	0.8355	0.85	0.85	0.8283	0.8501	0.85
489	Amusement & Recreation Services	0.8355	0.85	0.85	0.8283	0.8501	0.85

Secondly, dollars lost in tourism are converted to a percentage figure for Services, Trade, and Transportation. This involves dividing the loss into base levels of these sectors' production. For example, the base level is obtained by scaling the Service sector in the synthetic economy to the employment level that the user has specified for the study region. The initial percent loss in Services is linearly interpolated over the recovery duration specified.

The tourist-related demand loss is then input to the Indirect Loss Module along with other direct losses from agricultural damage, building damage, consumption demand loss due to loan repayment, etc. The core algorithm rebalances the economy and derives the associated indirect impacts.

If the user elects to evaluate tourism impacts, the module will automatically constrain import and export parameters for the services sector. The rationale is as follows: A flood will either reduce demand for tourism or reduce the supply of hotel/motel units. As noted above, the model should be able to accommodate either or both, without double counting. The model normally adjusts for excesses supply or demand by 1) cutting demand to supplying sectors (if alternative supplies cannot be secured); or 2) cutting shipments to demanding sectors (if alternative markets cannot be found). In the case of tourism, the availability of hotels and eating establishments will shape the supply. Tourism can be thought of as being produced from a fixed coefficient production function. It is doubtful that people will visit amusement parks if lodging is unavailable. It therefore seems reasonable to constrain tourism so that hotels are not imported (in the case where the flood damages units) or exported (in the case where tourists cancel trips to the flood prone area). One way to constrain the Service sector is to assume that services are not exportable or importable. This assumption seems reasonable since a bulk of this sector is likely to be tied to the region. By clamping down on exports, the model will be able to handle a reduction in tourist spending the same way that a conventional, demand-driven Input-Output model would. In the case of supply shortages, a buffer could be built in to reflect normal excess capacity such as normal hotel vacancy rates. This can be reflected in the “inventory” or “excess capacity” parameter of the algorithm.

The Level 2 analysis is similar to that in Level 1, except that instead of using default values, IMPLAN data for the specific study region will be used to calculate the direct loss of tourism activity. As in Level 1, Hazus will ask the user to specify (or accept default values for) the reduction in visitor-days and the recovery timeframe for tourism activity.

15.4.7 Results

Results of the analysis are reported in terms of changes in regional income, employment, and output. Direct, indirect, and total impacts are reported over a timeframe of 15 years following the disaster. Results are reported for two scenarios: with and without reconstruction aid from outside the region. The comparison of the two scenarios may be of interest from a policy analysis standpoint. The case with outside aid represents the scenario specified by the user (default values are provided), in which some impacts may be positive due to economic gains deriving from an inflow of reconstruction funds to the region. Results for the case without outside aid are obtained by automatically re-running the module without any external assistance, in which case reconstruction is assumed to be financed completely from regional resources. Detailed results are disaggregated by industry and, in the case of distributional impacts, by household income group. Results on government tax revenue impacts are provided separately.

15.4.8 A Note Regarding Small Study Areas

Study regions may consist of single counties, higher levels of aggregation such as several counties comprising a metropolitan area, or lower levels of aggregation such as a group of contiguous census tracts. In principal, the methodology underlying the Indirect Economic Loss module is applicable regardless of the level of aggregation. However, its accuracy is likely to be greater for study regions that represent cohesive economic regions, often called “trading areas” (e.g., cities or metropolitan areas) than for those at lower levels of aggregation because of the ability of the core Input-Output model to meaningfully represent the region’s economic structure. Furthermore, in evaluating regional employment impacts, the module requires input data on the number of jobs located within the study region -- that is, data on employment by place of work rather than by place of residence. While this information can be obtained at the county level, its availability and reliability at lower levels of aggregation are much more problematic. Similar problems are associated with other input data such as unemployment rates. More generally, the user should also be aware that some of the input assumptions to the model (such as the availability of alternate markets) are related to the study region’s level of aggregation. By adjusting the nature of the economy and the linkage to surrounding regions, the analyst can get a “ball park” estimate of what the real indirect losses and gains might be. Section 15.5 below provides some discussion of appropriate input data and assumptions to the module.

The Indirect Loss Module was developed on the assumption that the study area for analysis would consist of a single county or possibly multiple counties. The Input-Output tables that form the core of the methodology are based on county-level data. As a study area is decreased in size, it becomes more "open" and an increasing share of inter-industry transactions are conducted with entities outside the region. Thus, indirect effects are much less significant for small regions than for large ones. For flood analysis, a user could define a study region consisting of, for example, a single river reach that made up a small fraction of a county. The evaluation of indirect economic impacts for such a small study area could very well be meaningless.

If the user has defined a study area that is smaller than a single county, the Indirect Loss Module will be run at the county level. Damage and related inputs that pertain to the sub-county study area will be scaled to the county level. This approach assumes that areas of the county outside the study area have not suffered any flood damage.

15.5 Running the Indirect Loss Module

This section provides guidance to the user on steps for running the Indirect Loss Module. As noted earlier, the module can be run with default data (Level 1) or with user-provided, region-specific data (Level 2).

15.5.1 Default Data Analysis (Level 1)

15.5.1.1 User Inputs and Default Data

Running the Indirect Economic Loss module requires a number of user inputs. While default values are provided for all of these inputs, as discussed below, it is advisable even in a Default Data Analysis to override certain of them with data for the study region where available. Table 15.16 describes the inputs required and their default values.

Hazus provides default values for the current employment based on Dun & Bradstreet data and income levels for the region based on County Business Pattern data. It is recommended that the Default Data Analysis (Level 1) user review the default values provided and replace them if more accurate or recent data is available. Note that in User-Supplied Data Analysis (Level 2), where a user-provided IMPLAN Input-Output table is used instead of a synthetic table, the current employment and income levels are read in from the IMPLAN files and override the default values.

The type or composition of the economy, together with the employment level, is used by the module to automatically select a synthetic Input-Output transactions table to represent the study region economy. Default Data Analysis utilizes a synthetic transactions table aggregated from four basic classes of economies: 1) primarily manufacturing, 2) primarily service, secondarily manufacturing, 3) primarily service, secondarily trade, and 4) primarily agricultural. Each of the first three types is broken into four size classifications: super (greater than 2 million in employment), large (greater than 0.6 million but less than 2 million), mid range (greater than 30 thousand but less than .6 million) and low (less than 30 thousand). Appendix 15A provides examples of regions in each type and size class. While type 1 (manufacturing) is the default, the user should revise this as appropriate. Appendix Tables 15A.2, 15A.3, and 15A.4 can be used as a guide. Agricultural economies are broken into nine regional classifications (see Section

15.4.6.1 above). The Indirect Loss Module automatically selects the appropriate region based on the county FIPS code of the study area.

Supplemental imports, inventories (demands), inventories (supplies), and new export markets represent available channels for excess supply or demand that can help reduce the bottleneck effects in the post-disaster economy. As mentioned above, appropriate values depend in part on the level of aggregation of the study region. Default values are set at 0 for inventories supply and demand for all industries. Default values for imports and exports are set at values considered appropriate for a “distinct” or self-contained study region such as a metropolitan area. The default values are presented, together with discussion of how they can be modified in a User-Supplied Data Analysis (Level 2), in Section 16.5.2.2.

The supplemental imports variable, due to limitations on available data, needs further explanation. Data on the amount of imports per sector are available only in the aggregate. For any one sector in the economy, the total amount of intermediate products imported is known, but the amount of these imports that comes from any individual sector is not known. The amount of new imports that may be allowed must be set to a very small level. Otherwise, the amount of products that may be imported will almost always replace any intermediate goods lost from local suppliers, and no indirect output losses will be observed. The level of supplemental imports also needs to be kept low because of factor homogeneity problems. There will be cases when there are no substitutes for locally obtained intermediate goods. In such cases, allowing imports would unreasonably eliminate indirect losses. Being conservative in the amount of imports allowed helps avoid both of these problems. The default values for imports have been tested in the model, and are felt to yield realistic results.

Table 15.16 User Supplied Inputs for Indirect Economic Loss Module

Variable	Definition	Units[(a)]	Default Value
Current Level of Employment	The number of people gainfully employed, by place of work (not residence).	Employed persons	Region-specific
Current Level of Income	Total personal income for the study region.	Million dollars	Region-specific
Composition of the Economy (Default Data Analysis only)	• Primarily manufacturing • Primarily service, secondarily manufacturing. • Primarily service, secondarily trade. • Primarily agricultural.	1, 2, 3, or 4	1
Supplemental Imports	In the event of a shortage, the amount of an immediate product unavailable from local suppliers which may be obtained from new imports.	Percent of current total current annual imports (by industry)	Defaults for “distinct region”
Inventories (Supplies)	In the event of a shortage, the amount of a good that was supplied from within a region that can be drawn from inventories within the region.	Percent of annual sales (by industry)	0 (for all industries)
Inventories (Demand)	In the event of a surplus, the amount of a good placed in inventory for future sale.	Percent of current annual sales (by industry)	0 (for all industries)
New Export Markets	In the event of a surplus, the amount of a good which was once sold within the region that is now exported elsewhere.	Percent of current annual exports (by industry)	Defaults for “distinct region”

Table 15.16 User Supplied Inputs for Indirect Economic Loss Module (Continued)

Variable	Definition	Units[a]	Default Value
Percent Rebuilding	The percent of damaged structures that are repaired or replaced	Percent	95%
Unemployment Rate	The pre-event unemployment rate as reported by the U.S. Bureau of Labor Statistics	Percent	6%
Outside Aid/Insurance	The percentage of reconstruction expenditures that will be financed by Federal/State aid (grants) and insurance payouts.	Percent	50%
Interest Rate	Current market interest rate for commercial loans.	Percent	5%
Restoration of function	The percent of total annual production capacity that is lost due to direct physical damage, taking into account reconstruction progress.	Percent (by industry, by time interval for 5 years)	Defaults for moderate-major event
Rebuilding (buildings)	The percent of total building repair and reconstruction that takes place in a specific year.	Percent (by time interval for 5 years)	70% (yr.1), 30% (yr.2)
Rebuilding (lifelines)	The percent of total transportation and utility lifeline repair and reconstruction that takes place in a specific year.	Percent (by time interval for 5 years)	90% (yr.1), 10% (yr.2)
Stimulus	The amount of reconstruction stimulus anticipated in addition to buildings and lifelines repair and reconstruction.	Percent (by industry, by Time interval for 5 years)	0% (for all)
Property tax rate	The local property tax rate.	Percent	0%
Property tax exemptions	Categories of building use types that are exempt from property tax.	Checklist	None checked
Sales tax rate	The local sales tax rate.	Percent	0%
Sales tax exemptions	Categories of sales that are exempt from sales tax.	Checklist	None checked
Tourism loss	Loss of tourism activity due to disaster, in terms of number of visitor-days lost.	Number	0
Tourism restoration	Timeframe over which loss of tourism activity returns to normal.	Number of years	Same as years of rebuilding to reach 100%

Note: (a) Percent data should be entered as percentage points, e.g. 60 for 60%.

The variables for percent rebuilding, unemployment rate, percent outside aid, and interest rate all influence how the economy is expected to react to the disaster, in particular the reconstruction stimulus, the available slack or unused capacity in the economy, and the associated indebtedness that would be incurred from reconstruction financing. The user is recommended to revise the unemployment and interest rates as appropriate. However, all of these variables can be adjusted for purposes of "what-if" scenario modeling. For example, how would regional indirect economic losses change if only 20 percent of reconstruction was financed by sources outside the region such as insurance or federal disaster aid?

Parameters for functional restoration, as well as rebuilding for both buildings and lifelines, are associated with the anticipated speed of reconstruction and recovery. To specify functional restoration, user inputs are required for the percent of each industry's production capacity that is lost as a result of physical damage in each year for the first 5 years after the disaster. Default parameters are provided that are designed to be consistent with a "moderate-to-major" scale of disaster. These parameter values and suggestions for modifying them in a User-Supplied Data Analysis are provided in the next section.

In terms of rebuilding, the module requires user inputs as to the percent of total rebuilding expenditures for buildings and lifelines respectively that are expected to be made in each of the first 5 years following the disaster. Table 15.17 provides an example. Note that the total dollar amount required to fully rebuild damaged and destroyed public and private capital is provided by the Direct Economic Loss module. The percent of this total that is actually rebuilt is specified by the user input on "percent rebuilding" and may be less than 100 percent if not all of the damage is repaired or replaced. The annual percents for rebuilding buildings and lifelines as shown in Table 15.17 provide the timeline over which the reconstruction expenditures are made and should therefore sum to 100 percent over the 5-year period.

Table 15.17 Rebuilding Expenditures Example

Year	1	2	3	4	5	Total
% of Total Rebuilding Expenditures (Buildings)	70	30	0	0	0	100
% of Total Rebuilding Expenditures (Lifelines)	90	10	0	0	0	100

Reconstruction speed is also to a large extent related to the scale of the disaster. In general, lifeline reconstruction is expected to proceed much more quickly than building reconstruction, as has been the experience in previous disasters. For a Default Data Analysis, default parameters are provided that are designed to be consistent with a "moderate-to-major" scale of disaster. Modifying these parameters would be appropriate in a User-Supplied Data Analysis, and guidelines are provided below. These parameters can also be adjusted in Default Data Analysis for purposes of "what-if" scenario modeling for faster or slower paces of reconstruction.

No default data are provided for evaluating tax impacts, and this analysis is not conducted in a Default Data Analysis (Level 1). Similarly, no default data is provided for visitor-days lost due to the disaster, and tourism losses are not estimated in Level 1. The default value for the timeframe of loss will be the same as the default value (or user-override value) for recovery in the overall economy, as indicated by completion of rebuilding of buildings.

15.5.1.2 Calculation of Indirect Impacts

A direct shock is introduced into the Indirect Loss Module by adjusting the outputs and purchases in proportion to a sector's loss of function. Restrictions on shipments (forward linkages) and purchases (backward linkages) are computed and the resultant excess demands or supplies are derived. See Figure 15.6. A sample transactions table is used to illustrate. The first two rows above the table indicate the total direct shock and associated indirect losses, which are initially zero. The first round effects are simply the direct loss of function times the inputs to that sector (backward links) and shipments from that sector (forward links). In the event of a 30 percent loss of function in the transportation sector, for example, demand for manufactured goods would fall by 15.6 (0.3 times 51.9). The remainder of the column effects is computed similarly.

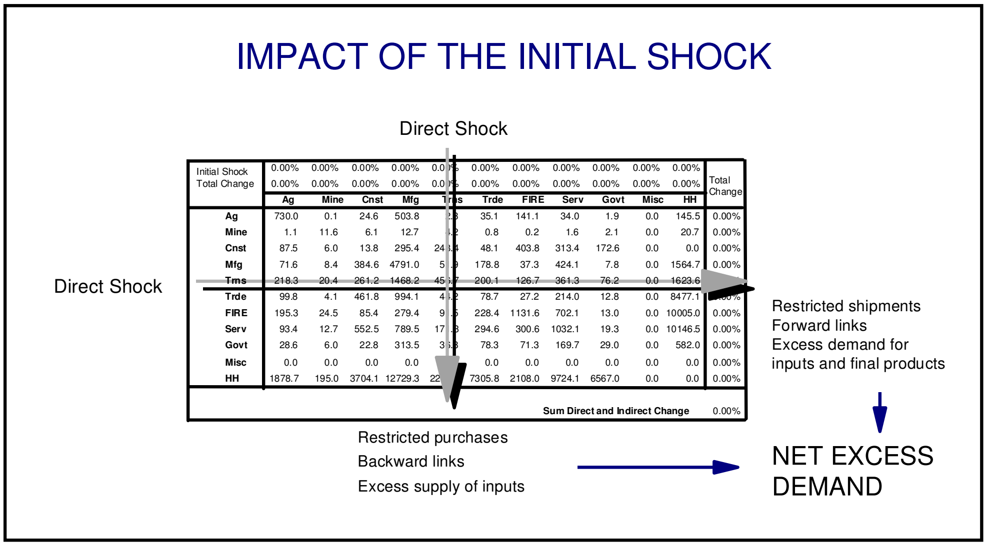

Figure 15.6 Initial Effects of the Shock

The same 30 percent shock would limit shipments to other sectors; finance, insurance, and real estate, for example, will initially receive 38.0 less (0.3 times 126.7) in services from transportation.

These first round effects produce excess demands and supplies that trigger a search for markets and alternative supply sources.

In building the model, several critical choices had to be made regarding post-event household spending patterns, labor mobility, elasticity of supplies from the construction industry, and the potential for product substitutions due to relative price changes. Evidence from previous disasters suggests that: 1) normal spending patterns are not significantly altered; 2) the workforce is highly mobile, particularly in the construction sector; and 3) relative prices do not change appreciably. Therefore, labor and construction sales are not constrained, and normal household spending is fixed and independent of current income. Given these conditions, the model assesses the net excess supplies (output less the sum of intermediate and final demands). A positive net value implies an excess supply; a negative indicates excess demand. It then attempts to resolve sectoral imbalances through a series of adjustments. If excess demand is detected, the algorithm checks to see if sufficient capacity exists in a sector. Excess capacities are a function of user defined level of unemployment and is calculated within the model using the following equation.

$$AC = 2.36 \times (UR - .02) \tag{15-11}$$

Where:

AC is available production capacity and expressed as a percentage (measured as a decimal) of the pre-event capacity

UR is the unemployment rate (e.g., .05).

If idle capacity is insufficient to meet excess demand then the model explores the potential of importing and/or drawing down inventories. These options are also provided by the user and are expressed as a percent of pre-event capacities.

Disposal of excess supplies is logically similar. Two options, inventory accumulation and exports, are explored. As in the case of the previous options, both are expressed as a percentage and are determined by the user. In most cases excess supplies are not critical to the model's, operation, particularly when reconstruction spending looms large. Much of the excesses are drawn into the rebuilding process.

After completing the first iteration of output adjustments, the algorithm recalculates the intermediate supplies and demands and then reinvestigates the adjustment options previously explored. Outputs are revised in proportion to the amount each sector is out of balance. A moving average of previously attempted outputs is used to initialize each iteration's search. The search is terminated once the sum of the absolute sectoral output differences diminishes to a specified level; the default is set at .00001.

Indirect income loss is calculated as using the following formula.

$$\sum_{t=1}^{T} \sum_{i=1}^{j} \frac{(td_{i,t} - dd_{i,t})Y_i}{(1+r)^t} \tag{15-12}$$

where:

tdi,t	is the total percent reduction in sector i income during period t.
Y_t	is income of sector i.
$dd_{i,t}$	is the direct percent reduction in sector i income during period t.
r	is the real interest rate to discount the indirect losses
j	is the number of sectors

dd is computed in the model by multiplying the initial sectoral income by the respective loss of function. The variable td is the total percentage reduction in income caused by the combination of direct loss and forward and backward linked losses. The difference between the two is then the percentage reduction in income attributable to indirect effects. The difference is pure indirect loss. This percentage when multiplied by sectoral incomes yields indirect income lost. A similar formula to Equation 15-12, without discounting, is used to evaluate indirect employment loss.

15.5.1.3 The Formats of the Outputs

The module produces three summary reports on the results: (1) Total economic impact, (2) Indirect economic impact with aid, (3) Indirect economic impact without aid.

The summary report on Total Economic Impact provides a picture of direct, indirect, and total economic impacts. Its format is shown in Table 15.18 below. Estimates are provided for the study region by year following the disaster. Results pertain to scenarios with and without outside aid. The former represents net effects including both losses and reconstruction gains, while the latter refers to the case of losses alone. Note that impacts may be either losses (negative numbers) or gains (positive numbers). Results are given by time interval for the first 5 years. Average figures are also provided for years 6 to 15.

Impacts are presented in terms of income, employment, and production or output effects. All incomes are discounted at the rate of 3 percent. In the case of income, Year 6 to Year 15 losses or gains are discounted to the present. Employment loss or gains are shown as numbers of workers.

Table 15.18 Format of "Total Economic Impact" Summary Report

	First Year	**Second Year**	**Third Year**	**Fourth Year**	**Fifth Year**	**Years 6-15**
With outside aid Income – Direct	($ mil.)					
Indirect	…					
Total	…					
Employment – Direct	(jobs)					
Indirect	…					
Total	…					
Production – Direct	($ mil.)					
Indirect	…					
Total						
Without outside aid **Income** – Direct	($ mil.)					
Indirect						
Total						

Table 15.18 Format of "Total Economic Impact" Summary Report (Continued)

	First Year	Second Year	Third Year	Fourth Year	Fifth Year	Years 6-15
Employment – Direct	(jobs)					
Indirect						
Total						
Production – Direct	($ mil.)					
Indirect						
Total						

Several additional reports are provided. Two summary reports that break down the results by the 10 major industries. Differences in impacts and recovery trends typically are very significant between industries, in part because much of the gains from the reconstruction stimulus accrues to the construction industry (and to some extent the manufacturing and trade industries). A report on distributional impacts breaks down income impacts according to 9 major household income groups. A report on tax revenue impacts is also provided. In addition, the Hazus Quick Assessment Report includes indirect income impacts for Year 1, along with direct income impacts.

15.5.2 User-Supplied Data Analysis (Level 2)

This level of Analysis differs from the Default Data (Level 1) level of analysis in three main respects: (1) interindustry trade flows, as represented in the Input-Output model of the economy, (2) specification of restoration and rebuilding parameters, and (3) specification of tax and tourism parameters. Rather than selecting from built-in synthetic Input-Output transactions tables, the user should obtain specific tables for the study region from a standard source, the Minnesota IMPLAN Group. In terms of specifying restoration and rebuilding parameters, the user can replace the built-in data with suggested parameter "packages" appropriate to the disaster being modeled. In addition, other parameters such as the availability of supplementary imports can also be modified.

15.5.2.1 IMPLAN Input-Output Data

Hazus requires three files from the IMPLAN input-output data set (the asterisk in each of the following file names refers to the IMPLAN model name. Therefore, a model for Jackson County would produce a file named JACKSON.402):

-- *.402 This is the transactions matrix.

-- *.403 This is a file of final demands information.

-- *.404 This is a file of final payments information.

Details regarding the operation of the IMPLAN program and the construction of these files can be obtained from the technical documentation for the system. IMPLAN is currently sold and supported by the Minnesota IMPLAN Group; the Group can be reached at:

Minnesota IMPLAN Group, Inc. (MIG)
1940 S. Greeley, Suite 201
Stillwater, MN 55082
Voice 612-439-4421 FAX 612-439-4813
e-mail linda003@maroon.tc.umn.edu

Software and data for any county in the United States can be obtained from the IMPLAN group. When requesting data, regions can also be defined by specifying a zip code aggregation.

The user can either request the three data files for the study region from MIG or obtain the software and database to construct the files. In the former case, the user should specify that the required industry aggregation scheme is essentially a one-digit Standard Industrial Classification (SIC) grouping that maps detailed IMPLAN industries into the ten industry groups used in the methodology. Table 15.19 describes the correspondence between IMPLAN and **Hazus** industry classes.

Table 15.19 Industry Classification Bridge Table

IMPLAN	Hazus
1-27	AG (Agriculture)
28-47	MINE (Mining)
48-57	CNST (Construction)
58-432	MFG (Manufacturing)
433-446	TRNS (Transportation)
447-455	TRDE (Trade)
456-462	FIRE (Finance, Insurance and Real Estate)
463-509	SERV (Service)
510-523	GOVT (Government)
524	MISC (Miscellaneous)

If the user obtains the IMPLAN software, the three data files can be constructed by following the instructions and constructing an aggregated Input-Output account using an existing or built-in template for 1-digit SIC classification.

15.5.2.2 Specifying Indirect Loss Factors

In addition to applying IMPLAN Input-Output data for the study region, a User-Supplied Data Analysis can involve adjusting module parameters to more closely fit the study region and disaster being modeled. Parameter sets and selection algorithms are suggested below for both the four indirect loss "factors" -- supplemental imports, new export markets, inventories supply, and inventories demand -- and industry restoration and rebuilding.

As previously noted in the Default Data Analysis discussion, availability of supplemental imports and new export markets is related in part to the size or level of aggregation of the study region and its geographic situation. A single county making up part of a large metropolitan area would have a much higher new import/export capacity (i.e., to neighboring counties) than would a single-county city that was geographically a distinct urban area and at some distance from other urban areas. Table 15.20 suggests two possible sets of factor values for geographically “distinct” and “component” study regions based on expert opinion.

Table 15.20 Suggested Indirect Economic Loss Factors (Percentage Points)

Industry	Distinct Region				Component Region			
	Imports	Inv. Supply	Inv. Demand	Exports	Imports	Inv. Supply	Inv. Demand	Exports
AGR	5	0	0	20	6	0	0	35
MINE	5	0	0	30	6	0	0	45
CON	999	0	0	10	999	0	0	25
MFG	4	1	1	30	6	1	1	45
TRNS	2	0	0	0	4	0	0	0
TRDE	3	1	1	0	5	1	1	0
FIRE	3	0	0	0	5	0	0	0
SVC	3	0	0	0	5	0	0	0
GOVT	3	0	0	0	5	0	0	0
OTHER	4	0	0	0	6	0	0	0

Selection of appropriate restoration and rebuilding parameters presents a more complex problem because of the need to link these values to physical damage levels in the disaster. Industry functional restoration and rebuilding will generally proceed more slowly with increasing severity of the disaster and extent of physical damage. For this reason, it is recommended that to run a User-Supplied Data Analysis for Indirect Economic Loss, the user first run all of the preceding modules in Hazus, examine the damage results, modify the restoration and rebuilding parameters as appropriate, and then finally run the Indirect Loss module. Several example restoration and rebuilding parameter sets designed based on expert opinion to represent different scales of disaster are presented below, together with a suggested algorithm for the user to select the most appropriate one.

The following suggested procedure attempts to provide a rough but simple and credible link between restoration and rebuilding parameters in the Indirect Loss module and Hazus results on physical damage. Lifeline rebuilding and transportation industry functional restoration are linked to highway bridge damage. Manufacturing industry restoration is linked to industrial building damage. Buildings rebuilding and restoration for all other industries is linked to commercial building damage. The values of the industry functional restoration parameters are intended to reflect not only facility damage levels but also each industry’s resiliency to damage to its facilities, such as for example its ability to relocate or utilize alternative facilities. These parameters were derived judgmentally with consideration of observations from previous disasters. Note that values for “restoration” in Hazus represent the percent *loss of industry function* averaged over the year.

STEP 1. Calculate damage indices for highway bridges and commercial and industrial buildings, respectively. The damage index consists of the percent of structures in the “extensive” or “complete” damage states. For example, if results indicate that 5 percent of bridges will suffer “extensive” damage and 3 percent “complete” damage, the damage index is 8 percent. Damage results for bridges can be found in the Hazus summary report on Transportation Highway Bridge Damage. Damage results for commercial and industrial buildings can be found in the Hazus summary report on Building Damage by General Occupancy.

STEP 2. Select transportation industry restoration parameters and rebuilding parameters for lifelines. Use the highway bridge damage index from Step 1 to read off parameters from Table 15.21.

STEP 3. Select manufacturing industry restoration parameters. Use the industrial building damage index from Step 1 to read off parameters from Table 15.22.

STEP 4. Select restoration parameters for all other industries and rebuilding parameters for buildings. Use the commercial building damage index from Step 1 to read off parameters from Table 15.23.

Table 15.21 Transportation Restoration and Lifeline Rebuilding Parameters (Percentage Points)

Highway Bridge Damage Index	Impact Description	Parameter Set	Year 1	Year 2	Year 3	Year 4	Year 5
0%	None/ minimal	Restoration function - TRNS Ind.	0	0	0	0	0
		Rebuilding expenditures - Lifelines	100	0	0	0	0
0-1%	Minor	Restoration function - TRNS Ind.	2	0	0	0	0
		Rebuilding expenditures - Lifelines	100	0	0	0	0
1-5%	Moderate	Restoration function - TRNS Ind.	5	0	0	0	0
		Rebuilding expenditures - Lifelines	95	5	0	0	0
5-10%	Mod.-major	Restoration function - TRNS Ind.	10	2	0	0	0
		Rebuilding expenditures - Lifelines	90	10	0	0	0
10-20%	Major	Restoration function - TRNS Ind.	15	3	0	0	0
		Rebuilding expenditures - Lifelines	85	15	0	0	0
>20%	Catastrophic	Restoration function - TRNS Ind.	20	5	0	0	0
		Rebuilding expenditures - Lifelines	80	20	0	0	0

Table 15.22 Manufacturing Restoration Parameters (percentage points)

Industrial building damage index	Impact description	Parameter Set	Year 1	Year 2	Year 3	Year 4	Year 5
0%	None/minor	Restoration function - MFG Ind.	1	0	0	0	0
0-1%	Moderate	Restoration function - MFG Ind.	2	0	0	0	0
1-5%	Mod.-major	Restoration function - MFG Ind.	4	0	0	0	0
5-10%	Major	Restoration function - MFG Ind.	8	2	0	0	0
>10%	Catastrophic	Restoration function - MFG Ind.	20	10	5	0	0

Table 15.23 All Other Industries Restoration and Buildings Rebuilding Parameters (percentage points)

Commercial bldg. damage index	Impact description	Parameter Set	Year 1	Year 2	Year 3	Year 4	Year 5
0%	None/minor	Restoration function - AG Ind.	0	0	0	0	0
		Restoration function - MINE Ind.	0	0	0	0	0
		Restoration function - CNST Ind.	0	0	0	0	0
		Restoration function - TRDE Ind.	1	0	0	0	0
		Restoration function - FIRE Ind.	0	0	0	0	0
		Restoration function - SERV Ind.	1	0	0	0	0
		Restoration function - GOVT Ind.	1	0	0	0	0
		Restoration function - MISC Ind.	1	0	0	0	0
		Rebuilding expenditures - buildings	100	0	0	0	0
0-1%	Moderate	Restoration function - AG Ind.	0	0	0	0	0
		Restoration function - MINE Ind.	0	0	0	0	0
		Restoration function - CNST Ind.	1	0	0	0	0
		Restoration function - TRDE Ind.	2	0	0	0	0
		Restoration function - FIRE Ind.	1	0	0	0	0
		Restoration function - SERV Ind.	2	0	0	0	0
		Restoration function - GOVT Ind.	2	0	0	0	0
		Restoration function - MISC Ind.	2	0	0	0	0
		Rebuilding expenditures - buildings	80	20	0	0	0

Table 15.23 All Other Industries Restoration and Buildings Rebuilding Parameters (percentage points) (Continued)

Commercial bldg. damage index	Impact description	Parameter Set	Year 1	Year 2	Year 3	Year 4	Year 5
1-5%	Mod.-major	Restoration function - AG Ind.	0	0	0	0	0
		Restoration function - MINE Ind.	0	0	0	0	0
		Restoration function - CNST Ind.	2	0	0	0	0
		Restoration function - TRDE Ind.	4	0	0	0	0
		Restoration function - FIRE Ind.	2	0	0	0	0
		Restoration function - SERV Ind.	4	0	0	0	0
		Restoration function - GOVT Ind.	4	0	0	0	0
		Restoration function - MISC Ind.	4	0	0	0	0
		Rebuilding expenditures - buildings	70	30	0	0	0
5-10%	Major	Restoration function - AG Ind.	1	0	0	0	0
		Restoration function - MINE Ind.	1	0	0	0	0
		Restoration function - CNST Ind.	4	0	0	0	0
		Restoration function - TRDE Ind.	8	2	0	0	0
		Restoration function - FIRE Ind.	4	0	0	0	0
		Restoration function - SERV Ind.	8	2	0	0	0
		Restoration function - GOVT Ind.	8	2	0	0	0
		Restoration function - MISC Ind.	8	2	0	0	0
		Rebuilding expenditures - buildings	60	30	10	0	0
>10%	Catastrophic	Restoration function - AG Ind.	2	0	0	0	0
		Restoration function - MINE Ind.	2	0	0	0	0
		Restoration function - CNST Ind.	10	5	0	0	0
		Restoration function - TRDE Ind.	20	10	5	0	0
		Restoration function - FIRE Ind.	10	5	0	0	0
		Restoration function - SERV Ind.	20	10	5	0	0
		Restoration function - GOVT Ind.	20	10	5	0	0
		Restoration function - MISC Ind.	20	10	5	0	0
		Rebuilding expenditures - buildings	50	30	15	5	0

15.6 Example Solutions

The intended use of the module is to provide a rapid and reasonable projection of the economic consequences of an actual disaster, or a set of hypothetical disasters. These economic consequences include lost employment, income, and tax revenue, as well as the distributional (winners and losers) impacts of an event. Since local planners/emergency managers are unlikely to have experienced the economic repercussions of disaster, the module is as much an *educational tool* as it is a forecasting tool. The module is best suited:

1. to help provide information (loss estimates) to the news media;

2. to help in the development of disaster declaration applications;

3. to help evaluate the indirect benefits of mitigation efforts;

4. to help in the preparation of post disaster fiscal projections.

It is important to recognize the limitations of the module. Hazus is *not* a replacement for local economic/financial projections. It should be exercised in conjunction with the community's existing financial planning framework. It is intended to supplement and inform normal and ongoing economic projections.

The examples below are presented with several objectives in mind:

1. To educate users about the principles of indirect loss, e.g.,

    a. indirect loss as opposed to total economic impact

    b. the interaction of indirect stimulus and bottleneck effects

    c. the time profile of economic consequences (stimulus possibly followed by the dampening effects of indebtedness)

2. To illustrate how terms are used and what they mean

    a. indirect vs. direct

    b. indirect vs. total economic impact

    c. indirect gains and losses

    d. local vs. regional or national economic consequences

3. To provide examples of pitfalls (misunderstandings)

    a. how to avoid double counting losses

    b. how to account for postponed production vs. lost production

    c. how to separate the effects of the disaster from the effects of other factors occurring after the disaster but unrelated to the disaster (e.g., the effect of the terrorist attack from corporate accounting scandals)

4. To show how to account properly in order to arrive at a credible loss assessment

    a. what to include (income losses that flow directly of indirectly from the event) and exclude (financial repercussions)

    b. what to focus on (lost income rather than lost regional product)

5. To show how the results compare with observed economic consequences

Examples were chosen with these objectives in mind. The examples are intended to be realistic, highlighting the kinds of information needed by the media, FEMA and governor's office (the paper work and data needed for the declaration of disaster), and mitigation efforts that utilize cost benefit methods.

It is unlikely that users will need to contrast actual economic impacts with those forecast by the IELM. However, examples of how closely the IELM projections track the actuals are included so that users may gain some confidence in the IELM.

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Appendix 15A. Default Data Analysis, Synthetic Economies

Excluding agricultural counties, 113 state and county IMPLAN tables were analyzed to derive synthetic transactions matrices for the Default Data Analysis model. Four size classes were created resulting in the 12 way classification shown below (Table 15A.1). A frequency histogram of employment (See Tables 15A.2 through 15A.4) revealed that 90 percent of the tables could be classified as Manufacturing/Service, Service/Manufacturing, or Service/Trade. Since nearly two thirds of employment in these tables can be traced to these three sectors, it was decided that this means of classifying economies could be used as a basis for deriving Default Data Analysis interindustry trade flows. Further adjustments were made to reflect the size of the economy. The particular states and counties which were utilized to create the 12 synthetic tables are shown in Tables 15A.5 through 15A.6.

Table 15A.1 Classification of Synthetic Economies

Employment		Type		
Upper Bound	Lower Bound	Manufacturing/ Service	Service/ Manufacturing	Service/Trade
unlimited	2 million	SUP1	SUP2	SUP3
2 million	.6 million	LAR1	LAR2	LAR3
.6 million	30,000	MID1	MID2	MID3
30,000	0	LOW1	LOW2	LOW3

Table 15A.2 Manufacturing/Service

Sector	0	10	20	30	40	50	60	70	80	90	100	AVG
Manufacturing	0	0	0	9	25	10	4	1	0	0	0	37.5%
Government	0	0	14	35	0	0	0	0	0	0	0	21.5%
FIRE	0	3	44	2	0	0	0	0	0	0	0	13.6%
Trade	0	42	7	0	0	0	0	0	0	0	0	7.5%
Service	0	46	3	0	0	0	0	0	0	0	0	6.3%
Construction	0	46	3	0	0	0	0	0	0	0	0	6.3%
Transportation	0	48	1	0	0	0	0	0	0	0	0	6.1%
Agriculture	0	49	0	0	0	0	0	0	0	0	0	0.6%
Mining	0	49	0	0	0	0	0	0	0	0	0	0.6%

Table 15A.3 Service/Manufacturing

Sector	0	10	20	30	40	50	60	70	80	90	100	AVG
Government	0	0	1	20	11	1	0	0	0	0	0	28.6%
Manufacturing	0	0	12	18	2	0	1	0	0	0	0	23.4%
FIRE	0	2	29	2	0	0	0	0	0	0	0	13.9%
Trade	0	27	6	0	0	0	0	0	0	0	0	8.4%
Transportation	0	25	8	0	0	0	0	0	0	0	0	8.3%
Service	0	28	5	0	0	0	0	0	0	0	0	7.8%
Construction	0	28	5	0	0	0	0	0	0	0	0	7.1%
Mining	0	32	1	0	0	0	0	0	0	0	0	2.2%
Agriculture	0	33	0	0	0	0	0	0	0	0	0	0.4%

Table 15A.4 Service/Trade

Sector	0	10	20	30	40	50	60	70	80	90	100	AVG
Government	0	0	0	2	7	6	0	1	0	0	0	37.4%
Service	0	1	8	7	0	0	0	0	0	0	0	18.2%
Transportation	0	10	6	0	0	0	0	0	0	0	0	9.3%
Manufacturing	0	9	7	0	0	0	0	0	0	0	0	9.2%
Construction	0	13	3	0	0	0	0	0	0	0	0	7.8%
FIRE	0	13	3	0	0	0	0	0	0	0	0	7.4%
Trade	0	14	2	0	0	0	0	0	0	0	0	6.0%
Mining	0	13	2	1	0	0	0	0	0	0	0	4.1%
Agriculture	0	16	0	0	0	0	0	0	0	0	0	0.5%

Table 15A.5 Manufacturing/Service Economy

Super			Large		
Fips	**State/Cnty.**	**Employ.**	**Fips**	**State/Cnty.**	**Employ.**
39,000	Ohio	5,831,755	53,033	King, WA	1,112,072
26,000	Michigan	4,714,837	9,000	Connecticut	1,989,824
13,000	Georgia	3,673,183	19,000	Iowa	1,635,164
37,000	North Carolina	3,858,712	5,000	Arkansas	1,194,095
18,000	Indiana	3,064,277	28,000	Mississippi	1,186,175
29,000	Missouri	2,986,395	33,000	New Hampshire	655,638
53,000	Washington	2,777,829	6,059	Orange, CA	1,514,438
27,000	Minnesota	2,642,082	41,000	Oregon	1,621,333
47,000	Tennessee	2,733,161	23,000	Maine	709,529
55,000	Wisconsin	2,796,572			
1,000	Alabama	2,028,495			
Mid			**Low**		
Fips	**State/Cnty.**	**Employ.**	**Fips**	**State/Cnty.**	**Employ.**
8,059	Jefferson, CO	224,465	48,257	Kaufman, TX	19,758
53,061	Snohomish, WA	212,107	6,069	San Benito, CA	16,274
41,067	Washington, OR	179,331	55,029	Door, WI	15,682
55,009	Brown, WI	123,090	55,093	Pierce, WI	13,707
41,005	Clackamas, OR	129,712	55,099	Price, WI	8,637
55,087	Outagamie, WI	89,502	8,087	Morgan, CO	12,408
48,121	Denton, TX	88,726	41,015	Curry, OR	8,996
49,057	Weber, UT	77,041	48,285	Lavaca, TX	9,272
55,089	Ozaukee, WI	36,021	55,129	Washburn, WI	6,590
48,139	Ellis, TX	31,798	41,035	Klamath, OR	28,783
41,071	Yamhill, OR	30,416	55,109	St. Croix, WI	23,213
16,000	Idaho	547,056			
50,000	Vermont	345,166			
44,000	Rhode Island	554,121			
10,000	Delaware	414,343			

Table 15A.6 Service/Manufacturing Economy

Super			Large		
Fips	**State/Cnty.**	**Employ.**	**Fips**	**State/Cnty.**	**Employ.**
36,000	New York	9,747,535	19,000	Iowa	1,635,164
6,037	Los Angeles, CA	5,108,213	40,000	Oklahoma	1,614,109
48,000	Texas	8,900,073	4,013	Maricopa, AZ	1,212,392
34,000	New Jersey	4,327,815	22,000	Louisiana	1,969,967
25,000	Massachusetts	3,644,604	5,000	Arkansas	1,194,095
6,000	California	16,532,145	31,000	Nebraska	987,260
13,000	Georgia	3,673,183	54,000	West Virginia	769,662
51,000	Virginia	3,695,334	4,000	Arizona	1,870,344
24,000	Maryland	2,697,448	20,000	Kansas	1,485,215
8,000	Colorado	2,017,818	49,000	Utah	895,454
Mid			**Low**		
Fips	**State/Cnty.**	**Employ.**	**Fips**	**State/Cnty.**	**Employ.**
35,001	Bernalillo, NM	306,176	35,041	Roosevelt, NM	7,593
53,053	Pierce, WA	263,512			
41,051	Multnomah, OR	441,788			
53,063	Spokane, WA	192,662			
48,085	Collin, TX	103,086			
6,089	Shasta, CA	71,398			
48,485	Wichita, TX	74,491			
49,011	Davis, UT	78,170			
6,071	San Bernardino, CA	529,198			
49,035	Salt Lake, UT	436,832			
6,065	Riverside, CA	434,846			
6,111	Ventura, CA	313,911			

Table 15A.7 Service/Trade Economy

Super			Large		
FIPS	STATE/CNTY.	EMPLOY.	FIPS	STATE/CNTY.	EMPLOY.
	None		11,000	District of Columbia	761,680
			32,000	Nevada	741,574
			15,000	Hawaii	696,759
			35,000	New Mexico	745,539
Mid			**Low**		
FIPS	**STATE/CNTY.**	**EMPLOY.**	**FIPS**	**STATE/CNTY.**	**EMPLOY.**
30,000	Montana	433,623	48,397	Rockwall, TX	9,140
8,005	Arapahoe, CO	217,208	8,067	La Plata, CO	19,079
4,003	Cochise, AZ	39,611	56,001	Albany, WY	16,959
38,000	North Dakota	377,987	56,041	Uinta, WY	9,948
6,029	Kern, CA	262,422	55,125	Vilas, WI	8,364
56,021	Laramie, WY	44,438	35,061	Valencia, NM	11,787

The development of the synthetic tables for agricultural economies, according to nine Farm Resource Regions, was discussed in Section 15.4.6.1 in the main text. The counties from which the synthetic tables were developed for each region are shown in Table 15A.8.

Table 15A.8 Agricultural Counties Used in Synthetic Tables by Region

Fips Code	County	State	Population	Area	ERS Region
19123	Mahaska County	IA	21522	8977	1
29177	Ray County	MO	21971	8611	1
29163	Pike County	MO	15969	7128	1
18163	Vanderburgh County	IN	165058	72637	1
17161	Rock Island County	IL	148723	63327	1
55053	Jackson County	WI	16588	7627	2
26037	Clinton County	MI	57883	20959	2
50007	Chittenden County	VT	131761	52095	2
27129	Renville County	MN	17673	7442	2
42077	Lehigh County	PA	291130	118335	2
38083	Sheridan County	ND	2148	1061	3
31117	McPherson County	NE	546	257	3
38009	Bottineau County	ND	8011	4661	3
30091	Sheridan County	MT	4732	2417	3

Table 15A.8 Agricultural Counties Used in Synthetic Tables by Region (Continued)

Fips Code	County	State	Population	Area	ERS Region
46005	Beadle County	SD	18253	8093	3
48197	Hardeman County	TX	5283	2678	4
48205	Hartley County	TX	3634	1541	4
20057	Ford County	KS	27463	10842	4
20079	Harvey County	KS	31028	12290	4
48369	Parmer County	TX	9863	3685	4
21001	Adair County	KY	15360	6434	5
40089	McCurtain County	OK	33433	13828	5
51105	Lee County	VA	24496	10263	5
42019	Butler County	PA	152013	59061	5
1115	St. Clair County	AL	50009	20382	5
45071	Newberry County	SC	33172	14455	6
13123	Gilmer County	GA	13368	6986	6
24029	Kent County	MD	17842	8181	6
51075	Goochland County	VA	14163	5203	6
13131	Grady County	GA	20279	8129	6
4027	Yuma County	AZ	106895	46541	7
6107	Tulare County	CA	311921	105013	7
12107	Putnam County	FL	65070	31840	7
12117	Seminole County	FL	287529	117845	7
53035	Kitsap County	WA	189731	74038	7
32033	White Pine County	NV	9264	3982	8
8109	Saguache County	CO	4619	2306	8
56023	Lincoln County	WY	12625	5409	8
32017	Lincoln County	NV	3775	1800	8
41025	Harney County	OR	7060	3305	8
47069	Hardeman County	TN	23377	9174	9
22019	Calcasieu Parish	LA	168134	66426	9
28021	Claiborne County	MS	11370	4099	9
5017	Chicot County	AR	15713	6191	9
22063	Livingston Parish	LA	70526	26848	9

Chapter 16. Additional Capabilities

The Flood Model Oversight Committee identified specific items that they believed would enhance the user community's acceptance of the Flood Model. These capabilities provided a level of "What-if" functionality to the user allowing them to utilize the Flood Model as a planning tool. Identified as additional capabilities, the Flood Committee established assessing the impacts of a levee or upstream storage as additional capabilities necessary for user acceptance.

The following sections continue the discussion of the hazard development as related to the capability of performing this analysis.

16.1 Levees

The levee "What-If" is primarily intended for Level 1 users since the base assumption is that a Level 2 user will perform a detailed hydrologic and hydraulic analysis that would include the levee and that would be brought in through the FIT. In general, DEMs are not reliable for identifying a continuous embankment with relatively little width. Because grid cells are connected at the corners as well as the sides, an embankment that is not a straight line, in the strictest sense, must be at least two cells wide to be treated as a barrier to flow. A tool is available in Hazus to add a levee alignment, attribute the levee with a level of protection and, for Level 1 analyses determines (within the limits of a Level 1 analysis) the effects of a levee on flood depths within the unprotected portion of the floodplain.

In areas identified as protected by a levee, flood depths are zero for frequencies up to the recurrence interval of the level of protection provided by the levee. For recurrence intervals exceeding the level of protection, flood depths are those computed without consideration of the levee. Similarly, if the option to determine the ramifications of a levee is chosen, two sets of flood depth grids are created: one with the levee and one without the levee reflected in the DEM.

The levee option is applied by drawing a polyline with the mouse. Flood depth grids have been created for the reach and the user chooses a grid on which to draw the levee alignment. The alignment should cross the floodplain twice. The user is prompted to supply the recurrence interval, in years, corresponding to the level of protection provided by the levee.

If a flood depth grid has been created corresponding to the level of protection or if enough grids have been created to interpolate that particular grid, the floodplain associated with that grid is determined. The levee alignment and section of that floodplain between the points where the alignment crosses the floodplain are used to define a polygon. If the floodplain associated with the recurrence interval cannot be determined, the floodplain associated with the flood depth grid chosen to draw the alignment is used to define the polygon.

If the levee alignment does not cross the floodplain twice the user is notified and cautioned that the floodplain information and supplied levee alignment indicate that the levee does not provide the entered level of protection.

If flood depth grids were developed with Level 1 analyses, the user must re-create the depth grids if the user wants an added levee represented in the DEM. Note that because the default hydraulic analyses are performed using normal depth calculations (*i.e.*, no consideration of backwater effects), flood elevations and, consequently, flood depths and the extent of floodplains will change only at cross sections within the levied portion of the reach. The effects of the levee on upstream cross sections will not be reflected.

If the user chooses to investigate the local increases in flood depths resulting from a levee alignment, a buffer is created one cell size around the user-supplied polyline. The resulting polygon is attributed with a high elevation value and a grid is created from the polygon. Note that the grid, or levee, is everywhere at least two cells wide. That grid is merged with the DEM creating a new DEM that reflects a continuous levee. The “new” DEM is only being created as a “provisional DEM” with the levee represented, but the original DEM is still the one that remains displayed on the map and not replaced with a “new” DEM. The protected area is then treated as a “pool” and, consequently not included in the water surface elevation computations. Figure 16.2 shows a (buffered) levee alignment supplied by a user and upstream portion of the “without” levee flood depth grid shown in Figure 16.1.

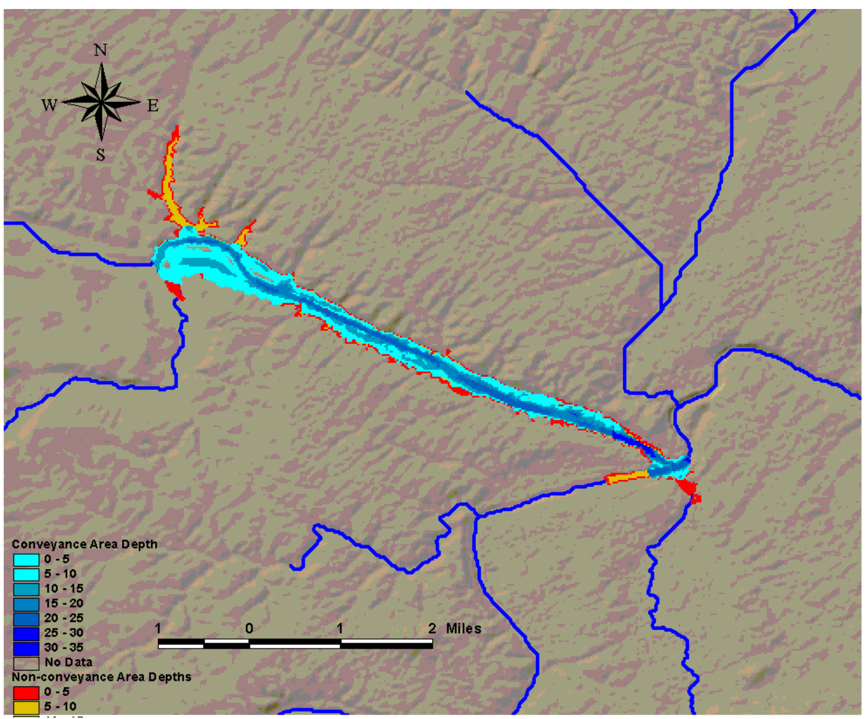

Figure 16.1 Flood Depths in Non-conveyance Areas

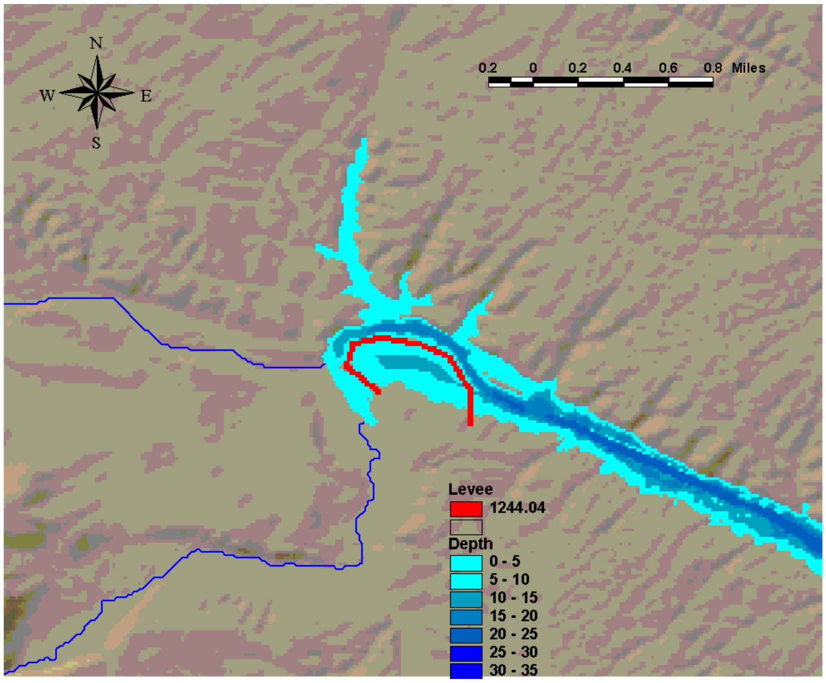

Figure 16.2 User-supplied Levee Alignment

Figure 16-3 shows the affects of the levee on the flood depth grid. Note, for example, the increase in the non-conveyance areas across the stream from the levee.

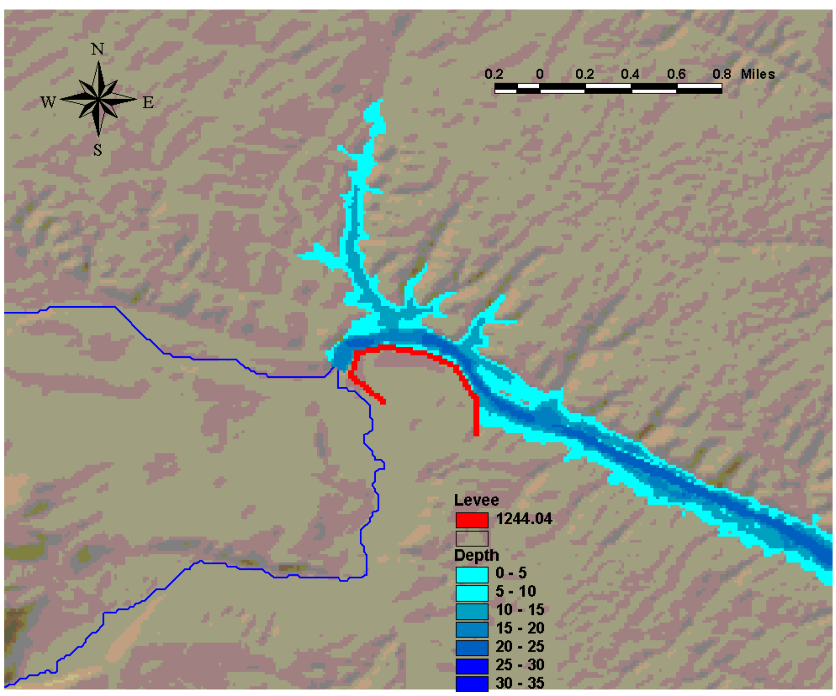

Figure 16.3 Affects of Levee on Flood Depths

16.2 Flow Regulation

The default hydrologic analyses apply to unregulated drainage areas. Regulation, through diversions and/or storage, changes the flood frequency curves downstream. Hazus provides a tool for incorporating the downstream effects of flow regulation. The tool allows users to modify the unregulated flood frequency curve at a specific location by entering one or more pairs of recurrence intervals and discharge values. Hazus identifies downstream reaches affected, and modifies the corresponding flood frequency curves as appropriate.

Users identify, with the mouse, the location of a regulating structure, such as a flood control reservoir. The algorithm finds the drainage area upstream of that location and defines the unregulated flood frequency curve. The curve is plotted and a table of recurrence intervals and associated discharge values is presented for the user to peruse and modify.

As the user enters and/or modifies values in the table, both the curve and the table are revised to reflect the changes. The first modification results in revising all discharge values associated with recurrence intervals (frequencies) less (greater) than the user supplied recurrence interval to be no greater than the modified discharge value. Graphically, the curve is revised by drawing a horizontal line from the modified point to the point where that line intersects the unregulated curve. The curve is not revised for recurrence intervals greater than recurrence interval of the user supplied point. Thus, graphically, a vertical line is drawn from the modified point to the point where that line intersects the unregulated curve.

For example, Figure 16-4 shows the unregulated flood frequency curve associated with the most downstream reach of the North Fork of the Shenandoah River (solid line). The drainage area there is approximately 1320 square miles.

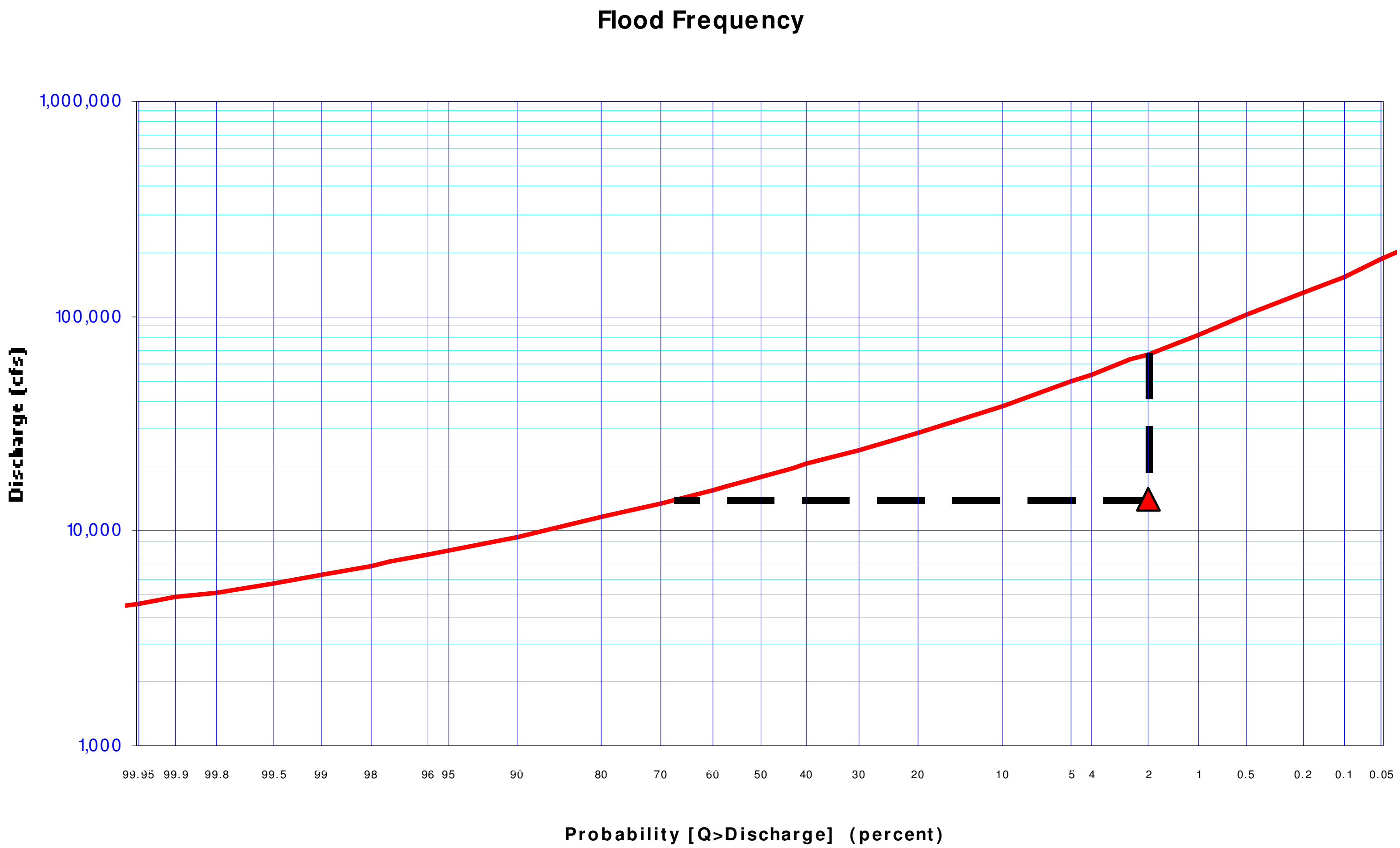

Figure 16.4 Flood Frequency Curve

Consider the ramifications of placing a dam within the reach and controlling the outflow at 14,000 cubic feet per second (cfs). The dam would be large enough to control up to a 50-year flood. The regulated flood frequency curve at the outflow point is shown on Figure 16.4. The revised part is shown as the dashed line. The modification was accomplished by entering a 50-year discharge value of 14,000 cfs, shown as the triangle on the curve.

Subsequent modifications are incorporated by assuming a log-normal distribution (straight line on the graph) between points. Again, the point associated with the smallest modified recurrence interval is connected to the unregulated flood frequency curve with a line of constant discharge value (horizontal line). The point associated with the greatest modified recurrence interval is connected to the unregulated curve with a line of constant frequency (vertical line).

The algorithm translates the effects downstream by assuming that the contribution to the unregulated flow at some point coming from any portion of the drainage area is proportional to the size of that portion. That is, a 132 square-mile area contributes 10 percent of the flow to our example reach. For a given recurrence interval, the reduction in flow at some point resulting from upstream regulation is determined as follows:

- The unregulated flow value is determined at the point.
- That value is multiplied by the ratio of the drainage areas of the regulated site and the point. The product is the unregulated contribution from the regulated site.
- The frequency associated with that unregulated contribution is determined.
- The regulated flow value associated with that frequency is determined and subtracted from the unregulated value.

That difference is the reduction in flow at the point resulting from the upstream regulation.

The South Fork of the Shenandoah River joins the North Fork to form the Shenandoah River at the downstream node of our example reach. The drainage area there is approximately 3000 square miles. The 100-year flood discharge is approximately 142,750 cfs. In the algorithm, the contribution from the North Fork is 62,810 cfs, a little less than the 50-year flood discharge value. The regulated flow at the potential dam site is 14,000 cfs and, therefore the reduction is 48,810 cfs. The effects of the dam downstream at the upstream node of the Shenandoah River would be to reduce the 100-year flood discharge value from 142,750 to about 93,940 cfs.

Such an analysis including the accompanying loss estimation in Hazus can be used to justify a more detailed investigation into regulating the flow some upstream.

16.3 Velocities

The velocity of floodwater can contribute to the flood hazard by carrying large amounts of sediment and debris, impacting structures, and eroding soils from stream banks and under foundations. Although there are limited specific velocity-damage curves at this time for use in a level loss analysis, the spatial distribution of the flood water velocities is estimated for and offered as supplemental hazard information. Like flood depths, the spatial distribution of velocities is presented as a grid. The Level 1 user can run a velocity grid for any reach that has ran the riverine hazard. The Level 2 user will have the option of running a velocity grid for their FIT areas in addition to the Level 1 hazard. Velocity grids are specific to a recurrence interval. Velocity-frequency relations are not developed.

The average velocity within a cross section is the discharge value of the flood flow through the cross section divided by the under-water area of the part of the cross section conveying the flow. Within a cross section, the velocities are generally greater in the deeper areas. The velocity in the channel, for example, is generally greater than the velocity in the shallow overbank areas.

Velocities in Hazus are calculated as the ratio of flood depth to the average depth within a cross section. Between cross sections, velocities are interpolated using the velocities determined at the up- and downstream cross sections at the same relative position (distance from the right and left conveyance boundaries) in the floodplain. The velocity grids are created using the same irregularly spaced grid of points used to create the flood depth grids.

Recall that points are placed for every cell size along buffers, also spaced one cell size apart, around the floodplain centerline. Those points are attributed with information needed to interpolate elevations. In particular each point is attributed with the upstream cross section number (and, so, implicitly, the downstream cross section number), and the weighting factor, based on the relative distance between cross sections, to be used for interpolating. Thus, given up and downstream values, the value at each point is quickly determined. Unlike interpolating water surfaces, the velocity along a cross section varies.

The algorithm samples each cross section to find the “widest” cross section in the reach. The widest cross section is the cross section with the greatest length within the conveyance area. That length is divided by the cell size to define a partitioning (into P segments) of the conveyance area. Each cross section is divided into P segments and the depth at the center of each segment is recorded and saved in a list.

The average depth in each list multiplied by the width of the conveyance area at the corresponding cross section is the aforementioned under-water area. Dividing the discharge value at the cross section with that area gives the average velocity of floodwater within the cross section. The average velocity times the ratio of the depth at a given segment and the average depth is taken to be the velocity within that segment.

Each point in the irregularly spaced grid that is outside of the conveyance polygon is attributed with a velocity of zero. For points within the conveyance polygon, a polyline connecting the closest (to the point) edges of the polygon through the centerline and point is created and the position, in percent of total length, of the point along that line is determined. The integer part of that percent times P, the number of partitions, is the position (entry number) of the corresponding velocity values in the up- and downstream lists. Using those list entries and the interpolating information associated with the point, the velocity is determined and assigned to the point for the recurrence interval studied.

Figure 16.5 shows the spatial distribution of velocities associated with the depth grids shown in Figure 16.1.

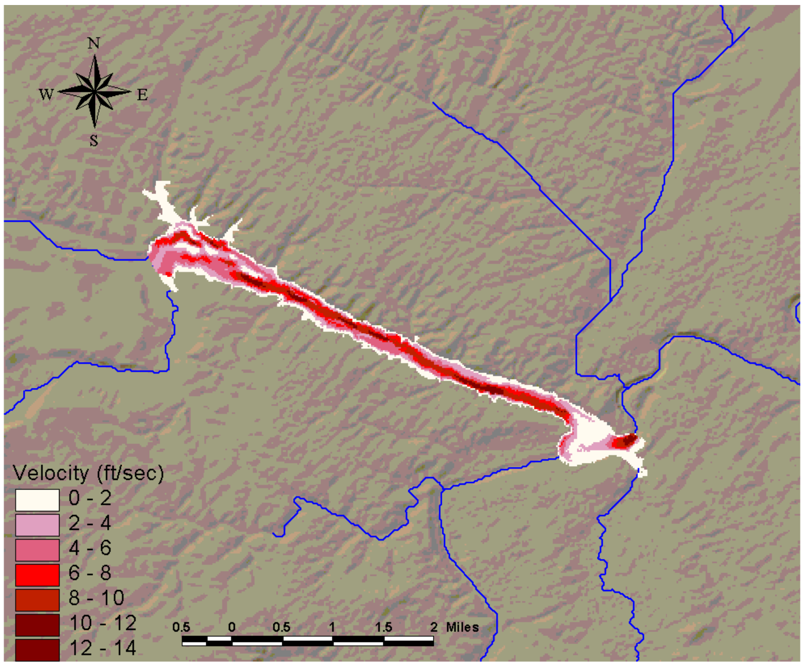

Figure 16.5 Distribution of Velocities in Floodplain

16.4 Policy Analysis

An example of each case has been performed in the Hazus software and a step-by-step discussion to guide the user through the process.

16.4.1 Floodplain Regulation – BFE+1 Foot

This example demonstrates how the user can determine the impacts of the creation of modification of the floodplain regulatory requirements. Base Flood Elevation (BFE) is the height of the base flood, usually in feet, in relation to the National Geodetic Vertical Datum of 1929, the North American Vertical Datum of 1988, or other datum referenced in the Flood Insurance Study Report, or average depth of the base flood, usually in feet, above the ground surface. Regulation sets BFE and development standards. Hazus will only show dollar loss associated with changes in first floor height to meet regulations. The example analyzes the impact of requiring that every house within the floodplain be either built or retrofitted to BFE+1 foot. The example includes a Level 1 analysis using the baseline general building stock data, and a Level 2 analysis using site-specific user-defined building inventory data.

In order to start the process, the user can run an analysis using the default mapping scheme to determine a baseline. For example, a community that is trying to identify the losses avoided from joining the NFIP program in 1980, could run the analysis with the default pre-FIRM settings and develop losses. To then determine the losses avoided, the Level 1 user should adjust the foundation heights using the *Flood Mapping Scheme* dialogs to simulate the implementation of floodplain regulations. The Flood Mapping Scheme dialogs are as appears in Figure 16.6 below.

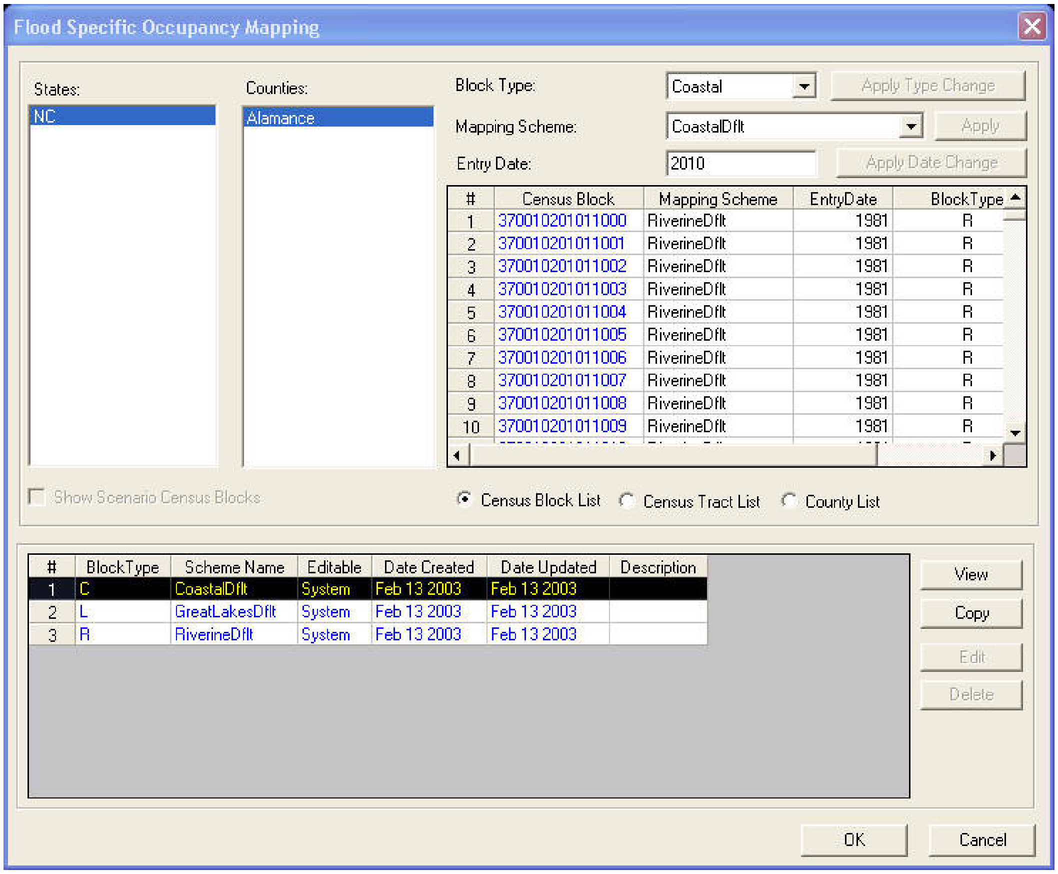

Figure 16.6 Flood Specific Occupancy Mapping

Once the user defined occupancy mapping has been created, as seen in Figure 16.7 below, the user should edit the foundation heights to meet the BFE to which they are interested in regulating, or are regulating to.

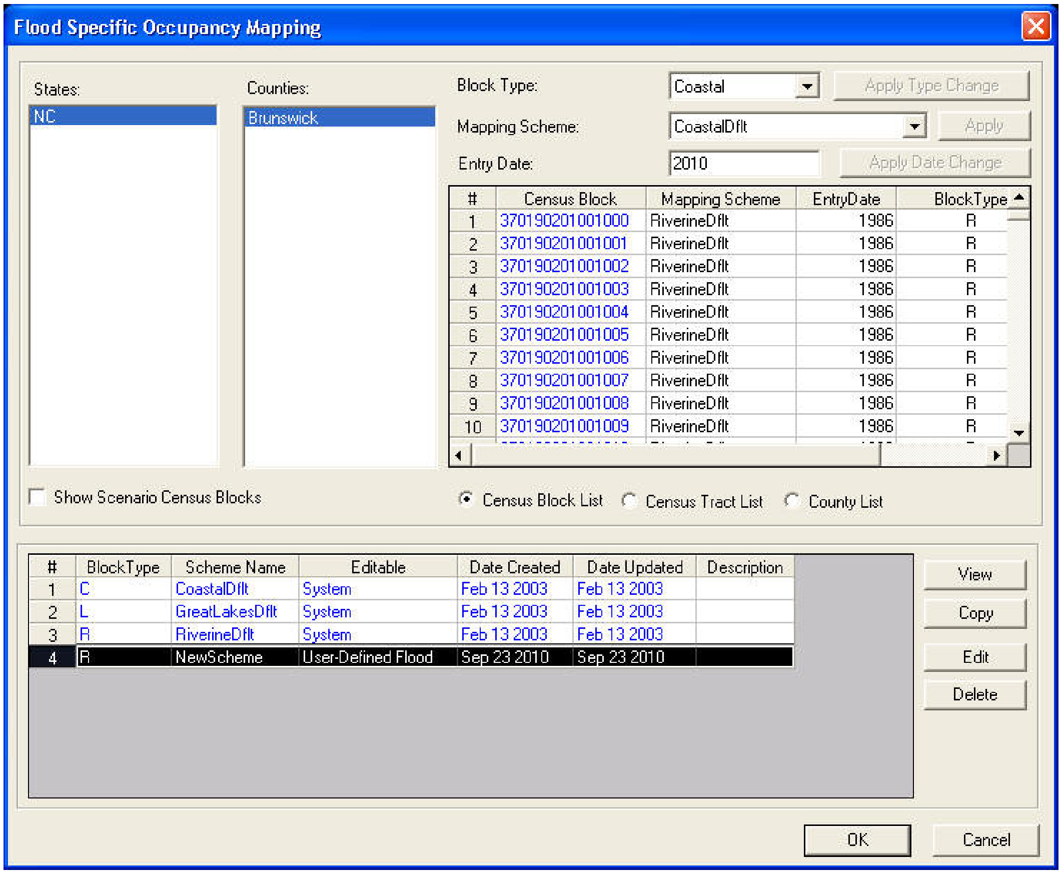

Figure 16.7 Flood Specific Occupancy Mapping Characteristics User Copy

For example in Figure 16.8 below the user has changed the Post-FIRM foundation heights to closely reflect a requirement to exceed a BFE of 4-feet by one foot. The user should also be aware to ensure that foundation types that become restricted because of this requirement are set to zero. In other words, the requirement to have a first floor height of at least 5-feet indicates that slab on grade foundations are not likely to be used, and other foundation types such as fill are limited in their use.

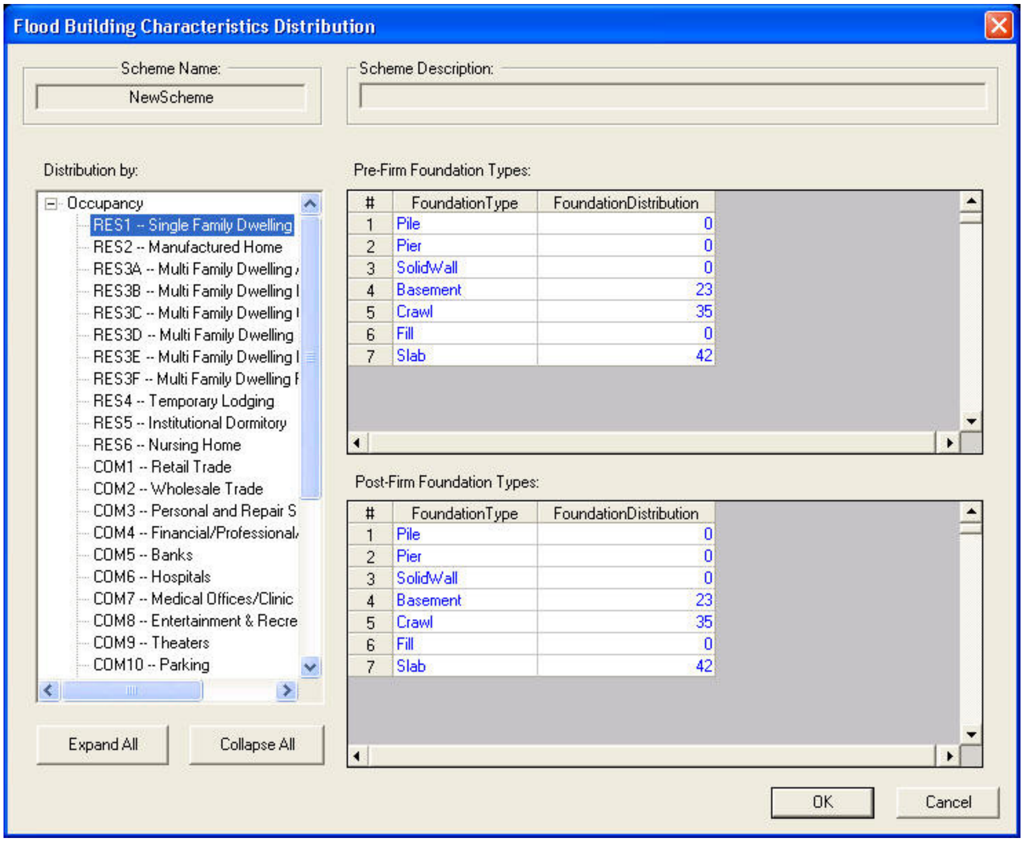

Figure 16.8 Building Characteristics

The user would then create or duplicate the previous scenario (where the user calculated all Pre-FIRM foundations) and re-run the analysis using the user defined *Flood Mapping Occupancy Scheme* and compare the results. This can be done by exporting the results into Excel or MS Access.

The Level 2 user has the advantage of using the *User Defined* data with the associated detailed information such as foundation height. As with the Level 1 user, the user would start by running a baseline analysis using the data as brought into Hazus. This could be done using the Comprehensive Data Management System (CDMS) or by importing a dataset previously formatted with the necessary information into the *User Defined* facility tables. The reader should refer to the CDMS User Manual for directions on how to use that tool. The baseline analysis will later be compared to results with using the modified inventory.

The modification is simple. The user can either perform a query in the initial database and create a duplicate database with the foundations elevated to meet the BFE+1-foot requirement. The revised data will then be analyzed and the results compared and the results can be defined as the losses avoided by the modification of the inventory.

16.4.2 Flood Mapping Restudies

This example demonstrates the use of Hazus to analyze losses through the use of updated floodplain boundaries that result from floodplain mapping re-studies. The purpose is to demonstrate the value of re-mapping in land use planning and the resultant reduction in flood losses. The use of Hazus to analyze potential losses under current and future land use scenarios is a valuable tool for policy makers.

For this analysis, the user would utilize the Flood Information Tool (FIT) to prepare their new study for use in the Flood Model. If possible, the user should also prepare the previous flood study for use in the Flood Model. If the original floodplain is in hardcopy or paper format, the user will need to digitize the maps. When digitizing, the user should ensure that the floodplain boundary is saved as an ArcGIS polygon and the Base Flood Elevation (BFE) lines are digitized as ArcGIS polylines attributed with the BFE elevation.

The process would be as follows:

1. Create one study region and duplicate the region, or create two duplicate regions where the user is interested in studying the differences between the two studies.

2. Prepare the original flood study (if the data is available) or digitize the flood maps as noted above using the FIT.

3. Prepare the restudy for use in the Flood Model. If the data is available in digital format, the user should ensure that the data is registered and process it through the FIT in preparation for use in the Flood Model.

4. Once the two datasets are prepared, the user can use the *Hazard* Menu, *User Data* submenu, and *FIT* tab, to point to the created FIT areas. It is suggested that the user assign one region to the original study and another region to the restudy.

5. Analyze the original flood study, either with the default Hazus data, or with local input data such as a county assessor data processed through the CDMS tool. This analysis should occur in one of the study regions created in the Step 1 above. The user should make sure that the inventories analyzed within the two regions are the same in order to ensure that the results represent the difference in the studies.

6. Analyze the restudy using study region 2 created in Step 1. The inventories should be the same inventory used in Step 5 above.

7. The user can use an ODBC connection through MS Access and link to the two databases and query the two results tables to draw a direct comparison. The tables to be linked are identified as flFRGBSEcLossTotal. The tables contain the total loss by census block for the two regions. Other tables provide the user with differences by occupancy and by building type, but the initial assessment should be based on the total difference. Other tables can be found in the Data Dictionary of the Flood User Manual.

There is no duplicate process for the Level 1 user. For assistance in processing the flood study data through the Flood Information Tool, the user should refer to the Flood Information Tool User Manual.

16.4.3 Building Acquisition and Removal

In this example the effects of the acquisition and removal of a single structure or a small number of structures on flood losses will be analyzed. The example discusses how the user prepares the flood hazard data within the FIT, utilizes the Comprehensive Data Management System (CDMS) tool to prepare the inventory data, and imports the data into Hazus. The example also demonstrates estimating annualized losses in the study area within and without the targeted structures.

Buyout and acquisition programs are one of the leading approaches for reducing a community's flood risk. The buyout program is most effective after a flood event, when people are more willing to relocate away from the floodplain, but communities should be mindful that a buyout program can occur at any time should the homeowner be willing to sell. The Flood Model will provide the user with an opportunity to identify those structures that are the best candidates for acquisition based on their exposure to flooding of different return periods or repetitive loss nature. For example one home that has the possibility of flooding from a 50-year flood and higher is a better candidate for acquisition than a home that is not likely to flood until the 100-year event.

While the user can use the Level 1 hazard for this analysis (i.e. using the default DEM, hydrology and hydraulics), it is not recommended that this analysis be the basis for determine the best candidates for an acquisition program unless no other studies are available. It is recommended that the user utilize the FIT tool and bring in a more accurate flood study to perform this analysis.

Recommendations for this analysis include: 1) using a high quality DEM and not the default USGS 1 arc-second data, 2) use a high quality flood study, preferably one done with the same DEM noted previously and it is preferred to use an HEC analysis, and 3) use GPS technology to identify the locations of the structures.

The user should use the Comprehensive Data Management System (CDMS) to capture the location, structure types, and occupancies of all structures of interest. In order to ensure the most accurate assessment of the losses and potential exposure to flooding, it is recommended that a Global Positioning Unit (GPS) be used to identify the location of the building within its parcel. With this location, the Flood Model can determine the depth of flooding at the location. It is also important to note the foundation type and subsequent first floor height. NOTE: The CDMS has a field for first floor elevation. The user will need to convert this to a height (either using a DEM or by also capturing the height at the time of the site visit). With the buildings loaded into the User Defined facility tables, the user should create a study region and select the FIT areas of interest.

The user then has two options that are really driven by the availability of data. Assuming that the user has been able to process their FIT analysis has three return periods and the associated discharge values, the user can perform an annualized loss estimate and develop their “benefit/loss” based on the annualized loss. To do this, the user must first perform the hazard assessment with enough return periods for the annualized loss. The Flood Model uses the suite (10, 50, 100, 200, 500) as the basis for extrapolating the Annual Losses. Under the *Hazard* menu, *Riverine/Delineate Floodplain* submenu, the user would select the Annualized Loss hazard assessment. Once this has been completed, the user can then select the *Annualized Loss* submenu on the *Analysis* menu. The final results present to the user the probable annualized loss that might be exceeded in a given year. Currently, Annualized Loss is performed on the general building stock only (polygon data).

The user can return to the *Inventory* Menu, *User Defined Facilities* submenu, and either delete the structures targeted for the acquisition program, or reduce the square footage to 1-foot thereby leaving the facility in the database. The user can then create a new scenario and reselect the FIT areas for a repeat of the previous analysis. Comparison of the results will provide the user with the necessary information to determine if an acquisition program has a potential positive benefit.

If the user does not have multiple return periods and/or discharges, it is recommended that the user perform a similar analysis for the available return period (most likely 100-year) and determine the loss for the structures. The results of this analysis will become the baseline for the analysis of the benefits of acquisition. They will not have a complete assessment, but something to work with.

16.4.4 Flood Forecasting

The current methodology allows the user to estimate the potential reduction in flood losses due to flood forecasting or warning. The current methodology uses the Day curves developed by the Chicago District of the US Army Corps of Engineers. The user should review the Flood Model User Manual to see how the dialog is used to modify the damage associated with any given flood. The user, however, should review the Day curves in the Technical Manual to estimate the amount of damage reduction that might be afforded for their community. For example, if the community has historically received only 15 minutes of flood warning, the user can view the curve and estimate the total expected damage reduction based on effective warning and effective response.

The effectiveness of the warning and the effectiveness of the response should drive the user’s selection of the expected warning reduction. For example, if the user believes that they can effectively warn the population, either via radio, TV, and perhaps police/fire notification (such as reverse 911) and the user also believes the population understands the notification and effectively responds, then they should select the value provided by the Day Curve. If the user believes there are limitations to this warning and response, then they should select a lower value.

16.5 References

1. EQE International, "*Flood Loss Estimation: Methods and Data Proof of Concept. Final Task 2 Report*", Report Developed for the National Institute of Building Sciences (NIBS), Washington D.C., July, 1999

2. EQE International, Inc., "*Phase 2, Year 1: Model Development Progress Report #2*," December 29, 1999, Prepared for the National Institute of Building Sciences (NIBS), Washington, D.C.

Appendix A. Limitations of Use for the Flood Model

A.1 Introduction

The user can expect the following limitations in using the Flood Model:

1. SQL Server 2008 R2 Edition has a size limit of 4 GB per database, which affects the size of the region you can analyze. The data for the 3 hazards share the 4 GB limit. To work-around the 4 GB database limit, the full version of Microsoft SQL Server 2008 R2 must be used. Refer to Appendix F of the User Manual for details.

2. Many functions take a long time to run. The speed of study region aggregation can be increase by copying the database to the local hard disk. The process is described in Section A.6 of the User Manual.

3. Components of independently developed data sets might not line up on maps, for example, the placement of bridges and roads, and facilities.

4. Inventory data and subsequently the Level 1 analysis functionality is unavailable for the US held territories.

5. When running the hydrology analysis (Riverine>Hydrology) the recommended limitations is 125 reaches, assuming the machine has 2 GB of RAM.

6. Due to lack of default riverine data, users in the State of Hawaii (except Honolulu County/Oahu island) will be unable to perform hydrologic analyses. These users may still compute riverine flood hazard; however, options of specific return period and suite of return periods will be unavailable. Instead specific discharge should be selected.

7. The coastal What Ifs, Long-term Erosion and Shore Protection are disabled.

A.1.1 Freeing Memory Using SQL Server Manager

SQL Server can often lock memory as a working set. Because memory is locked, Hazus or other applications might receive out of memory errors or run slower. To work around this problem, do one of the following:

1. Restart your computer by clicking **Start,** and then click **Shut Down.** In the "**What do you want the computer to do?"** list, click **Restart.** NOTE: Restarting will close all open applications, so be sure to save your work before choosing to re-start.

2. Restart SQL Server using the SQL Service Manager. Use the following process to open SQL Server Service Manager (SQL SSM) and restart the service:

    a. Close **Hazus** and related applications, if they are running.

    b. Open a Command window (Start | Run | Cmd)

    c. Type NET STOP MSSQL$HAZUSPLUSSRVR and hit Enter. You should see a message about the service stopped successfully.

    d. Type NET START MSSQL$HAZUSPLUSSRVR and hit Enter. You should see a message about the service started successfully.

    e. Close the Command window by typing Exit.

A.1.2 Increasing Virtual Memory to Run Large Study Regions

An "out of memory" error might occur when running a flood analysis for a large study region. This occurs if the current page file size is not enough to carry out updates to the SQL Server database. To work around this problem increase the page file size.

1. Open the control panel folder and locate the system icon. To open the control panel, click on **Start**, point to **Settings**, and then click **Control Panel**.

2. Double-click the system icon to open the **System Properties** dialog (shown in Figure A.1).

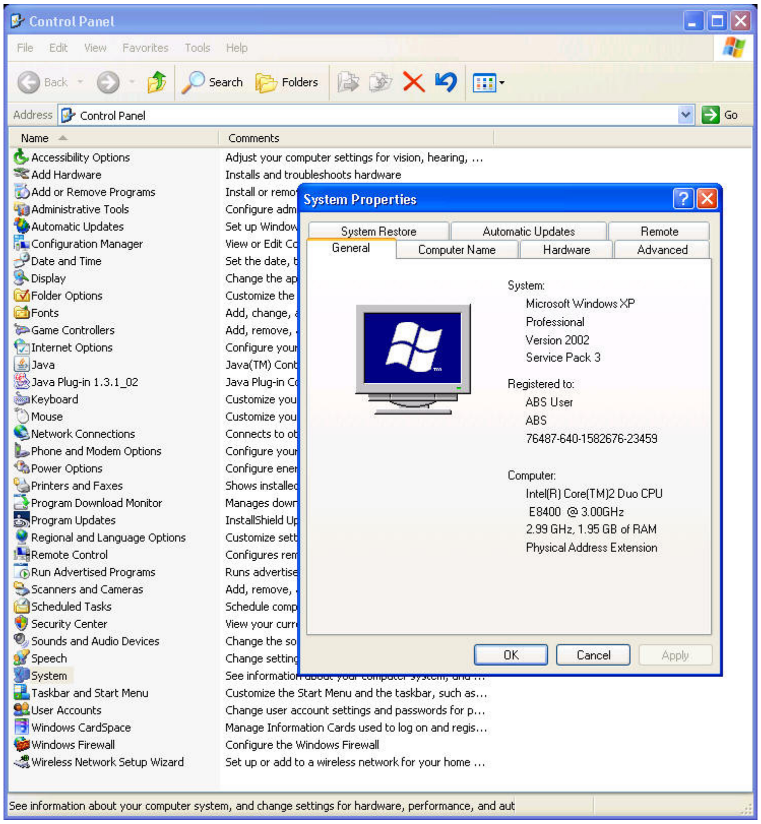

Figure A.1 Control Panel Folder and the System Properties Dialog

3. On the **Advanced** tab, click **Settings** under the **Performance** tab. In the **Advanced** tab, and under **Virtual memory**, click **Change**. (Figure A.2 through Figure A.3)

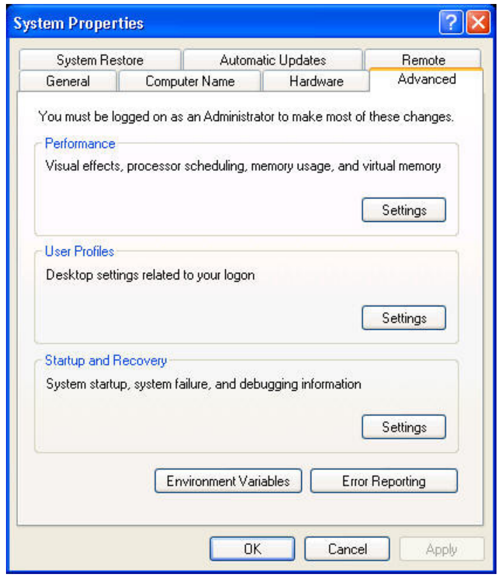

Figure A.2 Advanced Page on the System Properties Dialog

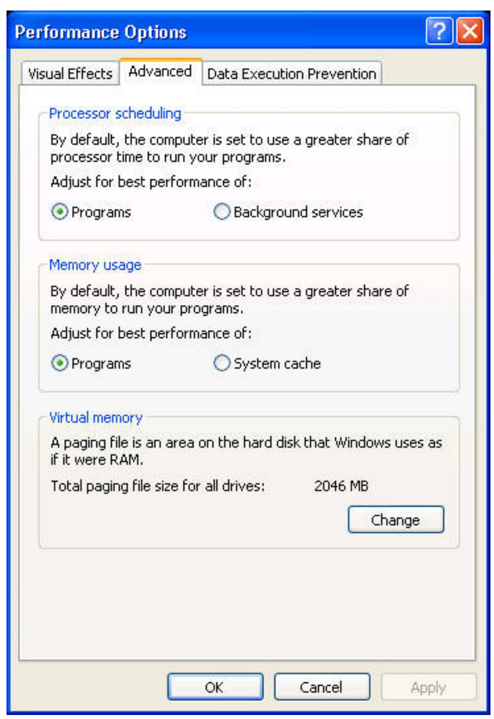

Figure A.3 Performance Options Dialog

4. In the **Drive** list, click the drive that contains the paging file you want to change. (Figure A.4)

5. Under **Paging file size for selected drive**, type a new paging file size in megabytes in the **Initial size (MB)** or **Maximum size (MB)** box, and then click **Set**. (Figure A.4)

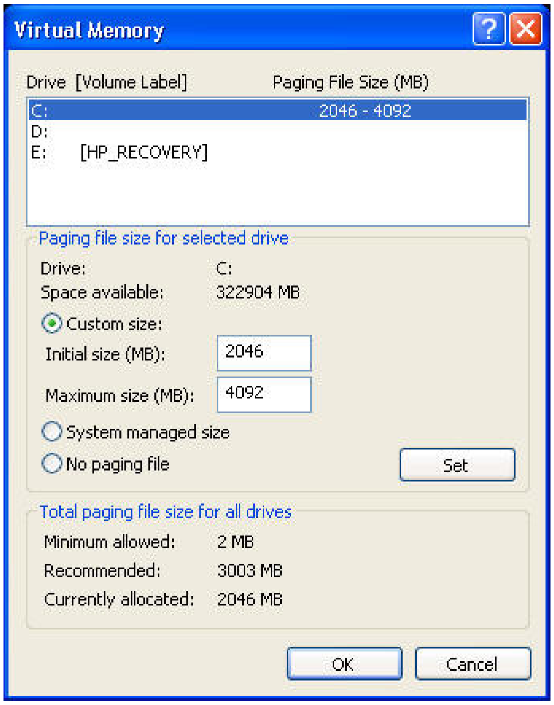

Figure A.4 Virtual Memory Settings

For best performance, set the initial size to not less than the recommended size under **Total paging file size for all drives**. The recommended size is equivalent to 1.5 times the amount of RAM on your system. If you cannot change the file size or cannot resolve the "out-of memory" error by increasing the page file size, consider creating smaller regions (each with less than 3000 census tracts or blocks).