

Working with HAZUS-MH

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Table of Contents

Table of Contents	3
List of Figures	4
List of Tables	6
Introduction	7
Background	7
Objective of this Working Paper	11
Scope	11
Overview of HAZUS-MH	11
The HAZUS-MH Software	13
Overview of the Working Paper	13
Understanding HAZUS-MH Flood Analysis	13
Step 1: Identify Hazards	16
Step 2: Profile Hazards	20
Step 3: Inventory of Assets	35
Step 4: Estimate Losses	39
Discussion and Evaluation – HAZUS Results	52
Application to the Case Study	54
Acknowledgments	59
References	60

List of Figures

Figure 1 CIR-DSS System Dynamics Diagram	7
Figure 2 FEMA HAZUS-MH Risk Assessment and Outputs	12
Figure 3 Flood Model Schematics for HAZUS-MH	14
Figure 4 Level 1 Analysis Summarized Output Example	16
Figure 5 - Region Created to Do Analyses in HAZUS-MH.....	17
Figure 6 Base Map built in HAZUS-MH for Seaford Area Study	18
Figure 7 – Flood Impact on Bridge on route US-13A	20
Figure 8 DEM Error Message in HAZUS-MH	22
Figure 9 Instructions for Obtaining Specific DEM for HAZUS-MH	22
Figure 10 New DEM for Seaford Area.....	23
Figure 11 DEM Integrated into HAZUS-MH	23
Figure 12 Building Stream Network in HAZUS-MH.....	24
Figure 13 Defining the Scenario for Analysis in HAZUS-MH	25
Figure 14 Defining Area for Further Analyses.....	25
Figure 15 Option for Riverine Analyses Type.....	26
Figure 16 HAZUS-MH Warning and Suggestion to Enable Software Operation.....	27
Figure 17 Time to Complete Single Return Analysis	27
Figure 18 Single Return Period Map	27
Figure 19 Annual Loss Map	28
Figure 20 “What if” Levee Protection Scenario	29
Figure 21 “What if” Flow Regulation Scenario Process	30
Figure 22 Warning and Suggestion to Run Riverine Flow Regulation Analysis	30
Figure 23 “What if” Flow Regulation Map	30
Figure 24 Floodwater Velocity Estimation Map	31
Figure 25 Federal Disasters Damage Graph - Sussex-DE	34
Figure 26 - Inventory Data for Highway Segments in HAZUS-MH.....	36
Figure 27 - Highway Segments in the HAZUS-MH Study Area Map	37
Figure 28 - Roads Tables from HAZUS-MH Software and DataMIL Centerline	37
Figure 29 Damage Function for Transportation System.....	41
Figure 30 Flood Date in Agricultural Parameter for Analysis	42
Figure 31 Setting up Indirect Economic Loss Parameters (1)	43
Figure 32 Flood Warning Assumptions for Analysis	44
Figure 33 Error Message for Annual Loss Analysis	44
Figure 34 Preparing for Annualized Loss Analysis	45
Figure 35 Selecting Available Results to View	46
Figure 36 Seaford Area Annual Losses Map of Depth	47
Figure 37 Summary Reports Options.....	47
Figure 38 Quick Assessment Report for a Single Return Period.....	51
Figure 39 Comparison between Global Summary for Annual Loss and Single Return Period – Levee.....	52
Figure 40 Damage related to US13 in Sussex County.....	54
Figure 41 Detours Set Up during the Flood of June 25, 2006.....	55

Figure 42 STAPLEE Criteria for Evaluating Mitigation Measures	56
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List of Tables

Table 1 GIS Analysis Results for Seaford Transportation Infrastructure	8
Table 2 HAZUS-MH MR3 Analysis Results for Seaford Transportation Infrastructure	9
Table 3 HAZUS-MH Flood Model Attributes for Level 1 Analysis	15
Table 4 Hazards Identification for Working with HAZUS-MH	19
Table 5 Hazard Identification and Characterization	19
Table 6 Identification of Required Hazard Data for Level 1 Analysis	20
Table 7 HAZUS Riverine Flood Hazard Analysis Process	21
Table 8 Types of Hazards Analyses	28
Table 9 Profile Hazard for Case Study	32
Table 10 Similar Federal Disasters and Damage between 1962 and 2006 in Sussex County	34
Table 11 FEMA’s Highway System Classification	38
Table 12 Summarized Report for Transportation System Dollar Exposure	48
Table 13 Summarized Report for Vehicle Dollar Exposure for Day and Night	48
Table 14 Summarized Report of Estimation for Debris	49
Table 15 Summary Report for Annualized Direct Economic Losses for Buildings	49
Table 16 Summary Report for Direct Economic Loss for Vehicles Day and Night	50
Table 17 HAZUS-MH Shelter Summary Report	50
Table 18 Summarized Mitigation Measures based on HAZUS-MH and History for Transportation Infrastructure - Roads	57

Introduction

Background

This working paper serves as background research for the PhD dissertation titled “Managing Critical Civil Infrastructure Systems for Disaster Resilience: A Challenge.” The overall objective of this research is to develop a Decision Support System to improve the resilience of critical infrastructure. This involves the exploration of the potential impacts of natural disasters on infrastructure operation and management. This includes understanding the nature of operations and management, the data and tools to support decision making and an analysis of the consequences of failure or degraded operations and performance. This also includes the use of existing computational systems to develop a geographical context, civil infrastructure systems analysis, asset management systems, and insights into mitigation strategies to development the system.

The model, referred to as the Critical Infrastructure Resilience Decision Support System (CIR-DSS), used the concept of resilience to support infrastructure decision making using Systems Dynamics. The framework is shown in Figure 1.

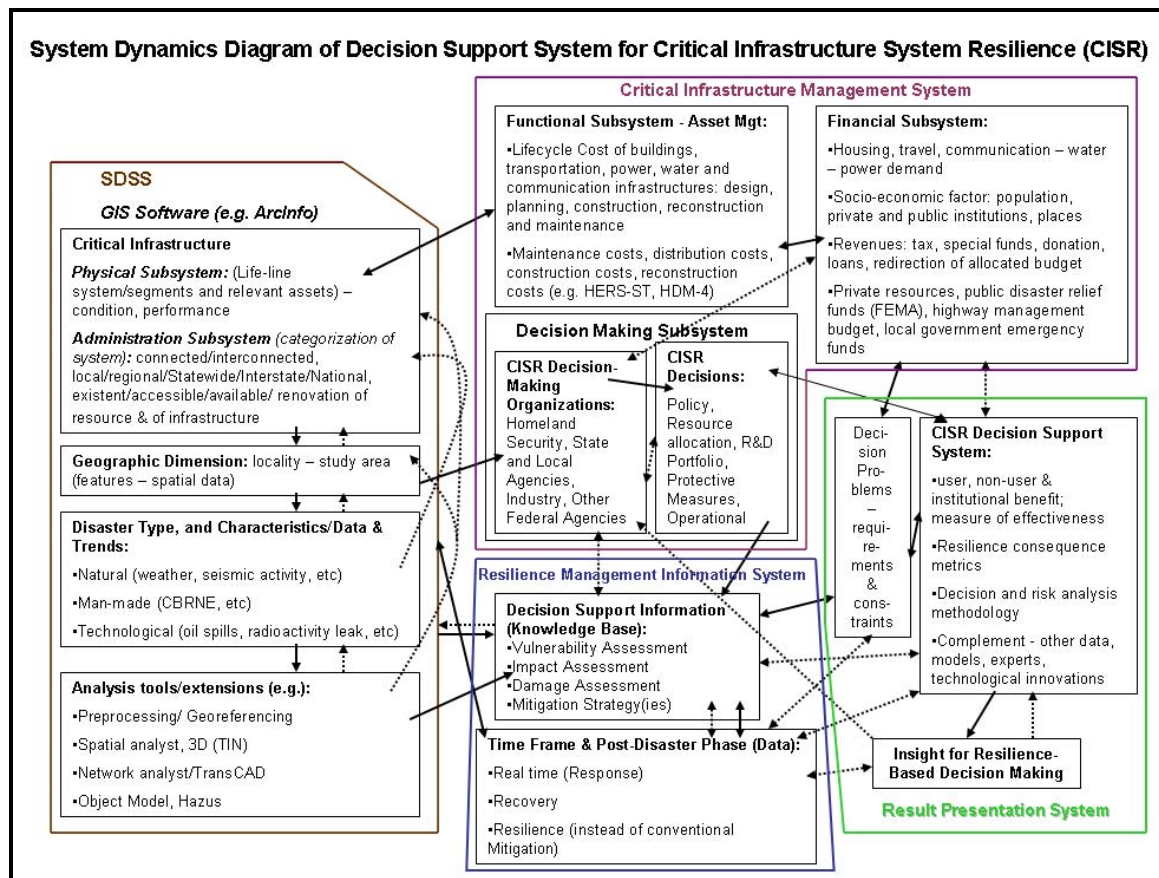
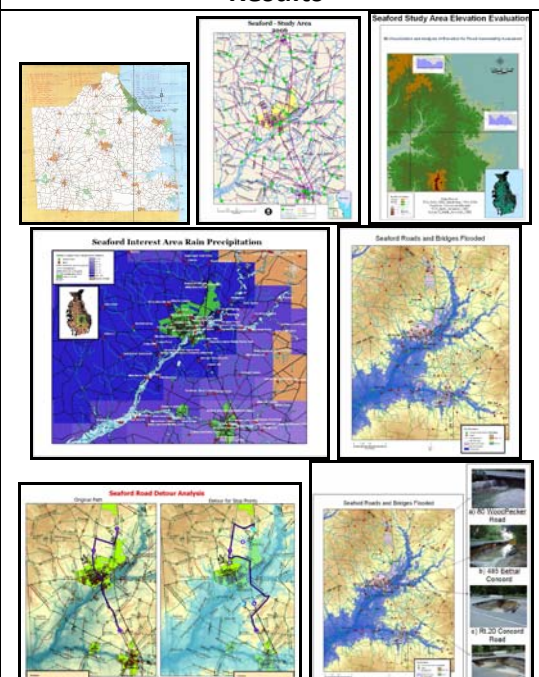


Figure 1 CIR-DSS System Dynamics Diagram

To implement this framework, inputs to the system dynamics model are generated using GIS and HAZUS-MH that describe the overall analysis of the resilience of an infrastructure system. The system is then analyzed using systems dynamics. STELLA is graphically oriented modeling software used to develop the systems dynamics models. The June 25, 2006 flood event in Seaford, Delaware is used to illustrate the concepts and demonstrate how the complex system changes over time.

The analysis developed in GIS and HAZUS-MH is not repeated in STELLA. GIS and HAZUS-MH are used to generate maps for vulnerability assessment, and estimate exposure. The Level 2 analysis in HAZUS-MH organizes and structures relevant data. The results from GIS are shown in Table 1. The maps originally developed are not readable in this table, but included to demonstrate how to organize results.

Table 1 GIS Analysis Results for Seaford Transportation Infrastructure

System	Results	Description
GIS (ArcInfo)		<p>From the left to the right:</p> <ul style="list-style-type: none"> • Detours Set Up during the Flood of June 25, 2006 (DeIDOT's paper map), • Seaford Study Area, • Seaford Area Elevation Profile in 3D Image, • Rain Precipitation over Seaford, • Seaford Flooded Area and Impacted Bridges, • Seaford Road Network and Detours Analysis, • Location of Damaged Infrastructure in the Seaford Flooded Area. <p>Event information supplied and maps developed can help direct relief supplies to areas of critical need and give out-of-state teams' knowledge of local terrain and access to places.</p>

The results from HAZUS-MH are shown in Table 2, including maps, tables and reports, helping organize all existing outputs.

Table 2 HAZUS-MH MR3 Analysis Results for Seaford Transportation Infrastructure

System	Results	Comments
HAZUS-MH MR3		<p>From the left to the right:</p> <ul style="list-style-type: none"> Base Map built in HAZUS-MH for Seaford Area (include limited area around US13), Seaford Area Annual Losses Map of Depth, "What if" Levee Protection Scenario, "What if" Flow Regulation Scenario, Floodwater Velocity Estimation Scenario, Damage related to US13 in Sussex County, <i>(There is an embedded mitigation measure for "warning" not reflected in the images).</i>
		<p>Organized information for helping interpret results (left to right)</p> <ul style="list-style-type: none"> Hazards Identification for Working with HAZUS-MH, Hazard Identification and Characterization, <i>Profile Hazard for Case Study,</i> <i>Similar Federal Disasters and Damage between 1962 and 2006 in Sussex County,</i> Federal Disasters Damage Graph - Sussex-DE,
		<p>Analyses Results</p> <ul style="list-style-type: none"> Summarized Report for Transportation System Dollar Exposure, Summarized Report of Estimation for Debris (require 112 truckloads), <i>Summarized Mitigation Measures based on HAZUS-MH and History for Transportation Infrastructure – Roads,</i> <p><i>HAZUS-MH gives no value for direct economic loss analysis for transportation.</i></p> <p><i>Transportation Inventory table is adjusted in excel for modeling.</i></p>

The items in *italics* in the Analysis Results for HAZUS-MH are important for the model in STELLA. These items in italics include data used in STELLA and mitigation options according to the FEMA STAPLEE criteria for being a feasible mitigation measure. The mitigation options include enhancing the resilience of the system as opposed to a regular rebuilding or repair of the infrastructure system segments according to its original design. The Highway inventory in HAZUS-MH is not in a proper format to be an input in STELLA. This data exported to EXCEL is used in the modeling and simulation process imported into STELLA, which each named column in EXCEL must match the elements in the model in STELLA. Also, to simplify the demonstration of the model, a sample size from this infrastructure was determined – US13.

The data related to US13 was obtained by comparing the Highway inventory from HAZUS-MH, and the road data from DataMIL clipping it to fit the study region in HAZUS-MH and then highlighting the HAZUS-MH segment links to identify their given identification code. This process used the Select Feature tool, because when opening the inventory table out from ArcMap or HAZUS-MH interface, the available tables did not carry together in the information for “name” of US13 segments and the value for “cost”. Also, to highlight US13 in GIS for a qualitative network assessment, the creation of this new layer helps set up the boundary for the analysis later on. The model in STELLA cannot handle these geographical spatial analyses, therefore the need for integrating the results from these different systems.

Working with STELLA implies working with both: model construction and learning process. During the model construction it is important to follow this sequence (isee systems. 2004):

- define the issue – dynamic thinking;
- develop the hypothesis – 10,000 meter and system as a cause thinking;
- test the hypothesis – to replicate the dynamic phenomenon, and for robustness (model in steady state, test one thing at the time, to find limitations and when it stops making sense). Robustness tests help building confidence in model’s formulations and identify high leverage points (big reaction);
- draw conclusions; and
- assess robustness.

These analyses developed in STELLA work with some elements of the framework (mostly not included in initial GIS and HAZUS-MH analyses), including

- Critical Infrastructure Management System including its subsystems
 - Functional (Asset Management) Subsystem (e.g. reconstruction cost),
 - Financial Subsystem (e.g. financial resource source – FEMA),
 - Decision Making Subsystem (e.g. DelDOT decision-maker and protective measures decisions);

- Resilience Management Information System (e.g. disaster timing and resilience of calculations), and
- Results Presentation System (e.g. user and agency benefits).

Objective of this Working Paper

This working paper describes how HAZUS-MH works and generates the outputs that are later included in the STELLA model to simulate different scenarios to support Decision Making for improving system resilience. The “Using HAZUS-MH for Risk Assessment – How-To Guide” for the HAZUS-MH (FEMA 2004) presents several ways to work with different hazards. The guide provides and suggests organizing principles in the form of worksheets, presents concepts, and documents basic commands required to perform analyses, how to interpret results, and examples.

Scope

The application of HAZUS-MH described here simply illustrates how the software is used to generate the outputs that are used as inputs to the model developed in STELLA. This means that not all options for and the full capabilities of HAZUS-MH are discussed here. Similarly the methods, models, data and interface used in HAZUS-MH are not evaluated or critiqued.

According to the HAZUS-MH manual (FEMA 2004), hazard mitigation is actions taken to reduce the destruction and disruption effects in the event of future disasters. These efforts often result in better and more cost-effective methods for responding to and recovering from a disaster. Mitigation Plans for natural hazards are mandatory for state and local entities to be eligible for FEMA funds under the Disaster Mitigation Act (DMA) 2000 enacted by the Congress (reference). Planning for mitigation is intended to help communities identify effective policies, actions and tools to decrease future losses. In this sense, hazard mitigation is based on risk assessments to estimate social and economic impact of hazards on people, buildings, services, facilities and infrastructure. The data inventory used in HAZUS-MH is from national and regional databases such as the United States Census, and can be tailored to more detailed analyses.

The focus is on floods using the HAZUS-MH level 1 analyses and existing embedded inventory. The analysis uses data from the real event that happened in June of 2006 in Delaware.

Overview of HAZUS-MH

The basic hazard mitigation planning process according to FEMA (FEMA 2004) includes organizing resources, assessing risk, developing a mitigation plan, implementing the plan, and monitoring the progress. HAZUS-MH integrates these phases of mitigation planning by identifying hazards, profiling hazards, inventorying assets, estimating losses,

and considering mitigation options. The details for each HAZUS-MH activities listed are shown in Figure 2.

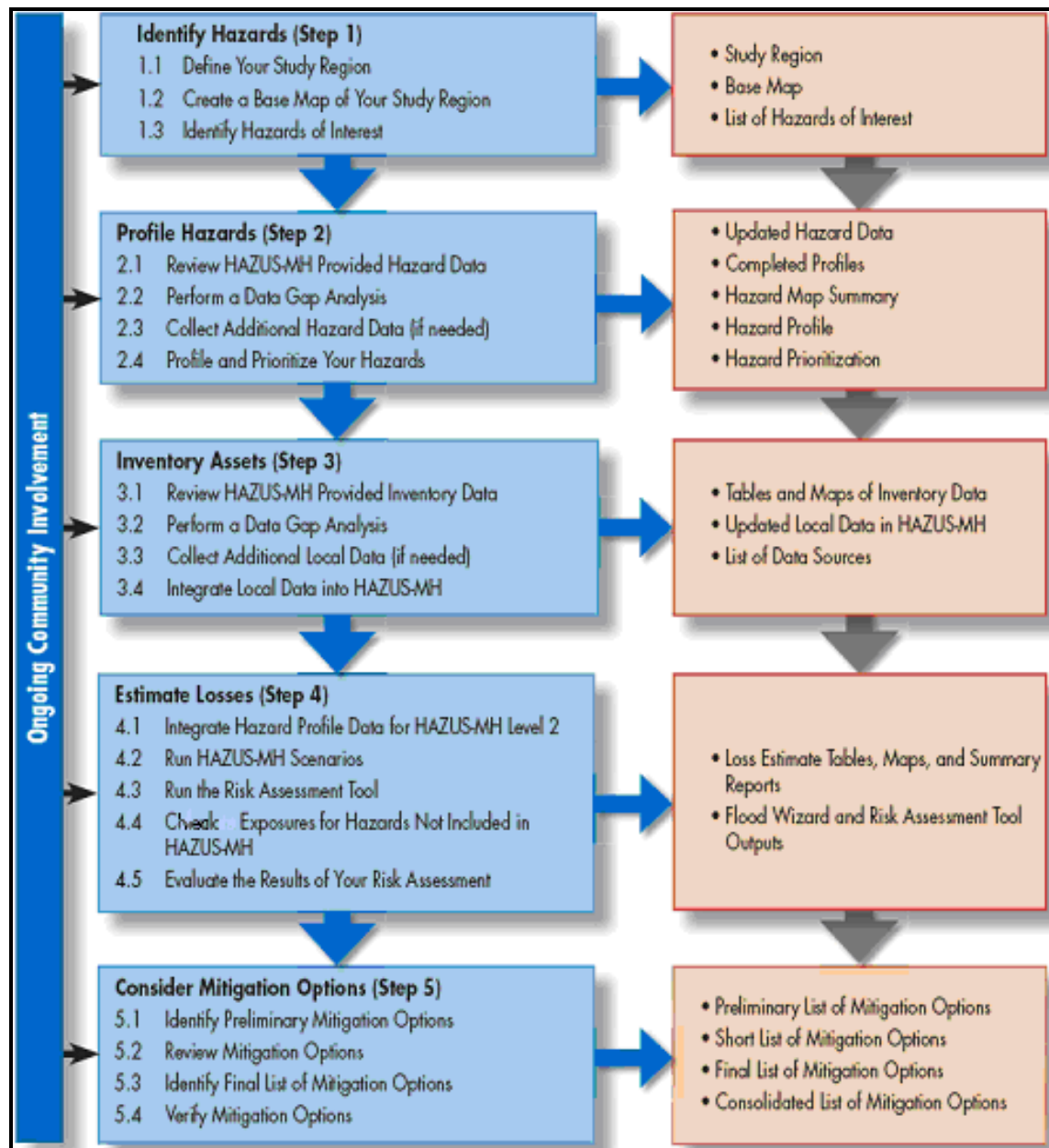


Figure 2 FEMA HAZUS-MH Risk Assessment and Outputs

Source: based on “Using HAZUS-MH for Risk Assessment – How-To Guide” (FEMA 2004).

Suggestions for how to work with HAZUS-MH for mitigation planning includes the participation of decision-makers as part of the team to assess risk. In fact in the CIR-DSS framework and in STELLA the decision-makers are included to define what is needed, what they want to have accomplished, and the boundaries and time for such work to be developed.

The HAZUS-MH Software

HAZUS-MH was developed by FEMA to start addressing the need for a national applicable standardized methodology to do risk assessment, analyzing potential losses from different and multi-hazards impacts. Based on the analyses results, its purpose is to help get insight for developing mitigation strategies and projects.

To properly work with HAZUS-MH it is important to keep track of updates, download and install additional “Patches”. These patches enable tools and fix problems with earlier versions of the software related to performance or functions in HAZUS-MH. The HAZUS-MH being described in this working paper is version 3 - HAZUS-MH MR3. Version MR3 includes Patch 2 from FEMA’s website under resource Record Details (FEMA 2007). Version MR3 also includes downloads for Service Pack releases from ESRI for the ArcGIS Desktop 9.2:

- Service Pack 3 (ESRI 2007b), and
- Service Pack 5 (ESRI 2007c).

Even though earlier versions of HAZUS-MH will work, it is important to work with the most recent version and companion manual (in this case MR3), because updates disable the function of icons in earlier versions. However, explanations in different HAZUS-MH documents helps get a more complete and better understanding of what is included and how to work with HAZUS-MH. Specifically, the application manual for the Flood Module is on the Application DVD (Bay Bridge Public Information Office 2007). The path to access this manual is

- insert the DVD > right click to open its contents (do not run the program);
- under Manuals > Flood > User Manual;
- identify/search for the other (“a second manual”) specific manual for flood: Flood Information Tool. Both these manuals define how to do the analysis for the study region defined in HAZUS-MH.

Overview of the Working Paper

This working paper begins by providing an overview of HAZUS –MH for flood analysis. Each of the four steps (Step 1: Identify Hazards, Step 2: Profile Hazards, Step 3: Inventory of Assets, Step 4: Estimate Losses) is then described in some detail. Finally, comments and observations are presented.

Understanding HAZUS-MH Flood Analysis

The process for estimating impacts using the Flood Model is shown in the schematic in Figure 3 (FEMA 2007).

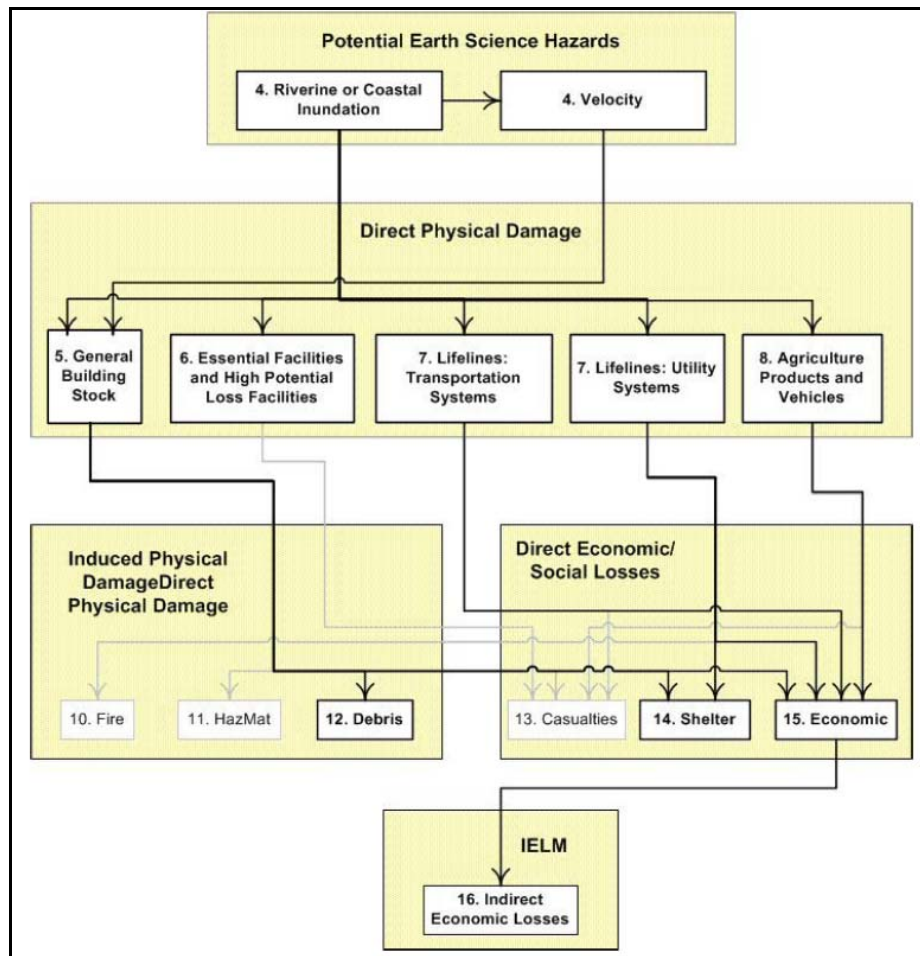


Figure 3 Flood Model Schematics for HAZUS-MH

Source: HAZUS-MH Application Flood Manual (FEMA 2007).

The model includes and summarizes inventories and calculations to give insight for mitigation plans in an easy-to-use version. The model includes two analytical processes: flood hazard analysis and damage analysis (loss estimation). The hazard analysis model includes the spatial variation in flood depth and velocity using frequency, discharge, and ground elevation. The outputs from these analyses are used to determine structural and economic damage through the use of vulnerability curves. Reports and maps are the final outputs from the model for users.

The flood hazard module models both riverine and coastal floods. A flood hazard is the result of the “relationship between depth of flooding and the annual chance of inundation to that depth” (FEMA 2007). Flood hazard is defined as the chance that a certain magnitude of flooding is exceeded in any given year (FEMA 2007). The primary factors that contribute to flood losses are water depth, duration and velocity in the floodplain. The HAZUS-MH Flood Model can be used to estimate flood losses due to depth of flooding. Flash floods are not included in the model’s capability. Flood warning is possible to integrate in the analysis as a “what if” scenario, which uses “Day” curves (a

representation of the relationship between lead time and damage reduction) from the U.S. Army Corps of Engineers approach (USGS 2006; EPA 2004).

Some different aspects of HAZUS-MH shown in the “User Manual of the Application” are highlighted to illustrate how HAZUS-MH can be used (FEMA 2007):

- has the capability for 3 levels of analysis:
 1. Works with embedded data from the HAZUS-MH software,
 2. Uses the input of recent and detailed data for specific analysis, and
 3. Adjusts existing models in the software. In this research this level of analysis is not used.
- offers enough flexibility support the evaluation of hazard types not included as models in the current software by using, for example, the existing GIS functions or using probability or historical data;
- offers 5 steps for doing risk assessment concluding with loss estimation and mitigation options (usually not included in risk assessments). These 5 steps were shown in Figure 2. The five Steps shown in Figure 2 show how HAZUS-MH is organized and the basic steps one should follow to get the desired outputs. Current HAZUS-MH capabilities include calculations of exposure and the use of special tools to do level 2 and level 3 analysis. Tools used for estimating losses have changed over time, therefore it is important to follow and upgrade the software according to the latest version released.

For the case study developed in this research a Level 1 Analysis is used.

Table 3 shows the Hazus Flood Model attributes for this level of analysis.

Table 3 HAZUS-MH Flood Model Attributes for Level 1 Analysis

Hazard	Digital Terrain or Elevation Model (DEM) - typically USGS 30-meter DEM. Flood Model uses default hazard data (Hydrologic Unit Codes and accumulation methodology) to develop approximate stream centerlines. USGS regression equations and gage records used to determine discharge frequency curves.
Inventory	HAZUS default data. Census blocks data allocation of via statistical analysis, and broad assumptions for first floor height (foundation distributions) Agriculture products, vehicles, essential facilities, some transportation and utility facilities.
Damage Curves	Broad regional default curves based on FIA or USACE depth damage curves. Library of curves available for user selection. User may create their own function using library curves as guides.
Damage Estimation	Area weighted damage estimates based on the depth of flooding within a given census block. Losses developed for general building stock, essential facilities, vehicles, agricultural products, select transportation and utility features.
Direct Loss/Impacts	Cost of repair / replacement, shelter needs, temporary housing, vehicles, crop & livestock losses.
Induced Losses	Debris developed from direct damage to buildings (floor areas from the general building stock).
Indirect Loss/Impacts	Sectorial economic impacts.

Continue Table 3.

Typical Applications	<ul style="list-style-type: none"> • Flood mitigation / regulatory policy-making, regional, state, federal levels • Pre-feasibility studies • Real-time emergency response with no warning • Preliminary planning, zoning development
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Source: Modified from HAZUS-MH Application Flood Manual (FEMA 2007).

A Level 1 analysis using default data involves a great deal of uncertainty associated with the loss estimate. This transfers a greater responsibility for interpreting results to experts. Figure 4 summarizes the possible losses included in the analysis output.

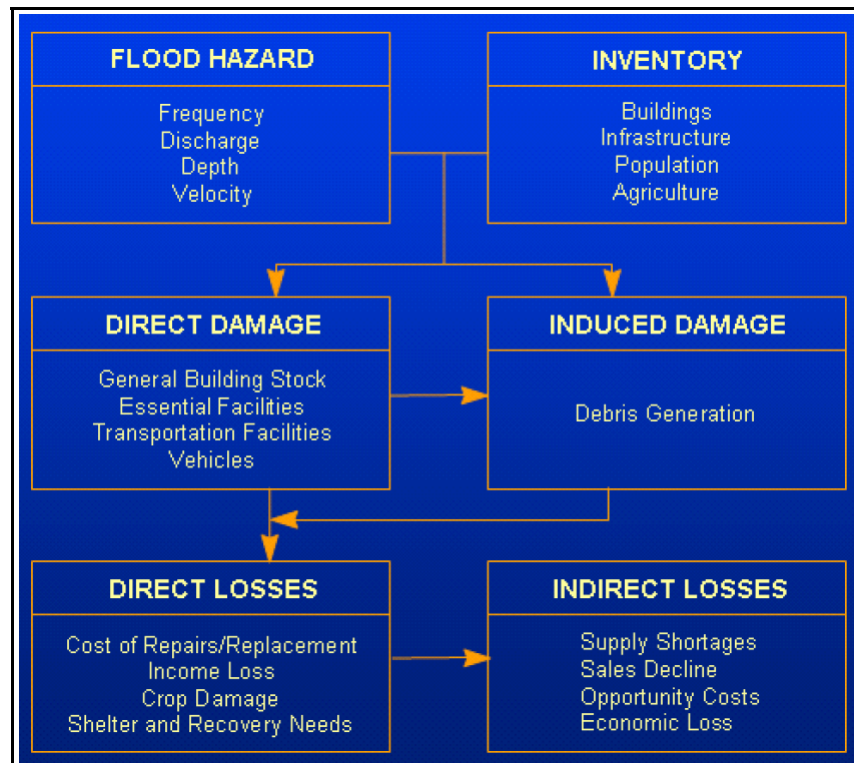


Figure 4 Level 1 Analysis Summarized Output Example

Source: HAZUS-MH Application DVD Flood Manual (FEMA 2007).

Step 1: Identify Hazards

Step 1 in HAZUS-MH is to identify hazards, which includes defining the region for study, creating a map for the area, and identifying the hazard. Consequently the outputs are the study region, a base map, and a list of hazards of interest.

Choose the DVD for the region selected to be analyzed. In this case, the area selected is Seaford in the southern part of the State of Delaware. The region is identified as a single-jurisdiction area. The study area map should include a bigger region to help develop solutions that are not constrained due to the small or limited area. However,

because HAZUS-MH includes several calculation functions, a smaller area will give results in a smaller amount of processing time, and avoid errors due to heavy processing demands. This is very important when including the results from HAZUS-MH in the model in STELLA because it impacts in the quality of support for decision making.

Put the DVD for the chosen region in the computer; this helps run the program with no further requests for data source access input. Opening the HAZUS-MH software, choose “create a new region” and follow these steps:

- > next, name and describe the region, if desired
- > next, select a hazard module
- > next, select an aggregation level (State, County, Census Tract, Census Block) (If the DVD-ROM containing the inventory data for the State selected is not available prior to the selection of the county area, a request for loading the DVD will come up in the screen. Census blocks are the smallest geographic unit for this methodology, generally bounded by streets, streams and statistical entities (i.e. metropolitan area, census tracts). Census block are defined to be as homogeneous as possible in terms of income, population and other characteristics. Independent of the aggregation level chosen the flood model results are computed at the census block level, not affecting the resolution of results.)
- > next, select the State by using the dropdown arrow or by using the “show map” and clicking on the desired places)
- > next, select a county or counties
- > next, select “census tracts” from the list or from the map
- > next or selection done.

A prompt shows that the region was created successfully, and that now it is time to “open a region” > “Select a Region” (the one created with the name given) > next > finish. The GIS software from ESRI starts to process and displays the map, but the interface is specific for the HAZUS-MH software. For this research, Figure 5 is the defined region for the analysis.

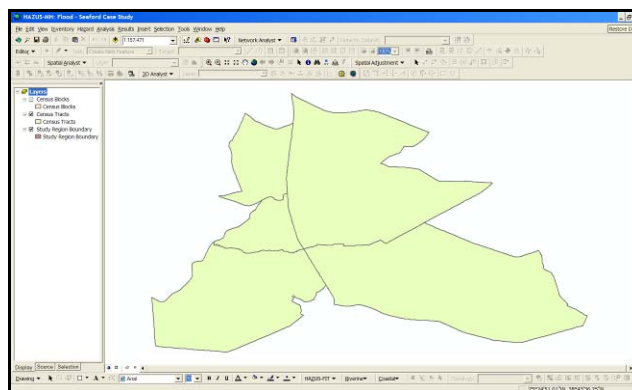


Figure 5 - Region Created to Do Analyses in HAZUS-MH
Source: Created using HAZUS-MH (FEMA 2007).

The next tasks are to create the base map, and check the Geographic Coordinate System, Datum and Units used by HAZUS. These are important details for matching up with the other detailed data that can be added to the analysis with the proper matching scale and analysis, not only projections on the fly enabled by ArcGIS ArcInfo. These projections are:

- GCS_North_American_1983,
- D_North_American_1983,
- Degree.

In this case, if the available complementary data to be integrated into HAZUS is in another Coordinate System, the layers must be projected to that specification. The additional available data to complement the analysis in HAZUS-MH for Delaware for the study include the Shapefile for bridges and the centerline given by DelDOT, and the data downloaded from DataMIL. However, this case study uses the existing inventory data in HAZUS-MH and considers the road data from DataMIL to analyze and validate the outputs for mitigation strategies developed in HAZUS-MH. This dataset is clipped to properly match with the other datasets. The clip process is the same as in ArcInfo - under the Analysis Tools in ArcToolbox. The enhanced area is shown in Figure 6. This additional data not integrated into HAZUS-MH, is just brought in and displayed, and is not used in the analysis for risk assessment.

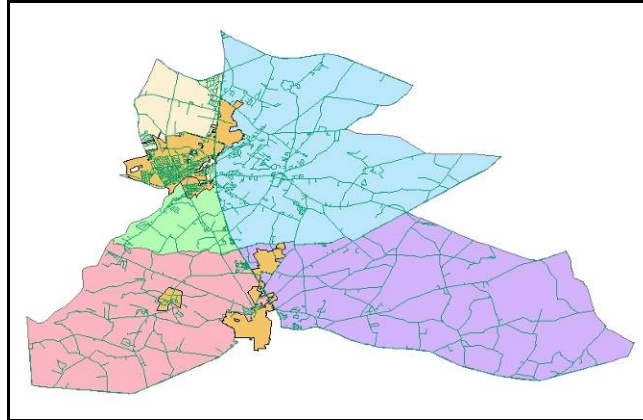


Figure 6 Base Map built in HAZUS-MH for Seaford Area Study

The next task is to identify the hazard type for the impact assessment. The particular event on which the analyses are focusing is one that occurred on June 25, 2006. This event was of the scale of a 100-year flood. The Seaford flood is classified as riverine flooding. Riverine flooding is characterized by “the accumulation of runoff from rainfall or snowmelt such that the volume of flow exceeds the capacity of waterway channels” (FEMA 2004), with water spreading out over the adjacent land. The flow is downstream, for which inundation, duration, and velocity depends on several factors including topography and storm characteristics. The specific flood under investigation of June 2006 can be characterized as shown in Table 4.

Table 4 Hazards Identification for Working with HAZUS-MH

Potential Hazard	Hazard of Interest	Description	Source of Information
Riverine Flood	Riverine Flood	On 6/25/06 a 100-year flood occurred due to a huge amount of rainfall (12 inches in some areas) which caused serious damage and destruction to roads and bridge infrastructure (49 road network points in Sussex County). The 49 identified points consisted of: 28 roads (segments) with high water, 6 road closures, 2 washed out bridges, 12 road failures, 1 sink hole. Later inspections showed 9 bridges with major problems (i.e. replace structures, flow-in fill to restore stream bed under the bridge). Minor bridges problems included repairs of eroded embankments, and fill and riprap replacement. Flood elevation was 30 feet. State of Emergency declared at 2:30 PM – 6/26/2006. Seaford is located at 38°38′41″ N, 75°36′58″ W (38.644654, -75.616107).	DelDOT – TMC and other Sectors, DEOS, DataMil, SpatLab

Source: Modified from How-To Guide Worksheet 1-1 (FEMA 2004).

Table 4 is a simplified version of the Worksheet 1-1 in the HAZUS-MH guide (FEMA 2004) that facilitates the implementation of tasks generating outputs for the risk assessment process. The next worksheet in HAZUS-MH is a hazard or event summary description, where a match is made between the hazard identified by decision-makers and the hazard to be used in further analysis. The worksheet is shown in Table 5. Here the available information relative to the risk of each regional hazard is used. As this hazard has been specified for this case study, one would complete column A (decision-makers) and B (technicians/researchers) with the same hazard: flood (riverine). Table 7 completes the addition of relevant/historic information. The flood events selected from historical available data included in this table excluded events classified as coastal floods but included severe storm events.

Table 5 Hazard Identification and Characterization

A	B	Hazard	Hazard	Years	No. of Events	Impacts (2006 US\$)	Available Data Sources and Maps
✓	✓	Flood (Riverine)	Flood (Riverine)	1962 to 2006	4	#126 - \$21,391,487 #1017 - \$8,907,958 #1205 - \$3,721,100 #1654 - \$370,000 40 families temporarily homeless.	FEMA Disaster Research Results for Sussex County (2007). PERI Presidential Disaster Declarations (2007). WBOC News (Parsons 2006).

Source: modified from How-To Guide (FEMA 2004).

Sources of information for this table are varied. The impact in dollars of each declared disaster is public information available at FEMA's website. However, this value does not reflect the total amount granted because in practice damage assessment by FEMA

technicians includes a field visit to check the most damaged sites and in general, only 30% of the value specified by local engineers is awarded. To have a Federal disaster an event must cause a minimum of US\$ 1 million in damage. In this sense one could assume that there was around US\$3 million in damage to the transportation infrastructure at this particular event. News media also provides information. For example, the image in Figure 7 shows the flood impact on a bridge in the case study area.

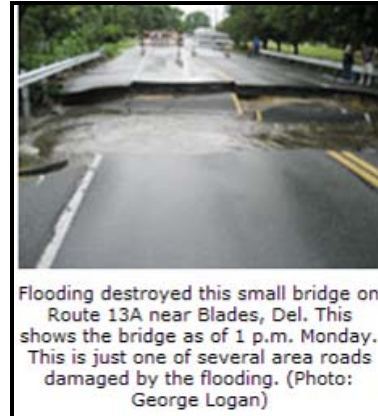


Figure 7 – Flood Impact on Bridge on route US-13A
Source: Image in WBOC (Parsons 2006).

The other table used in the HAZUS How-To guide for the flood analysis is shown in a simplified view in Table 6. The hazard of interest is consistent with the choice made in Table 4.

Table 6 Identification of Required Hazard Data for Level 1 Analysis

Hazard of Interest (Table 3)	Hazard Data/Map Requirement	Local Data Status Criteria		
		Required Format (ArcView required)	Required Coordinate System (Lat/Long required)	Ready for HAZUS-MH
Flood	Flood Zone Maps			
	Digital Elevation Model	✓	✓	✓
	Base Flood Elevation			

Source: modified from HAZUS-MH How-To Guide Worksheet 2-1 (FEMA 2004).

Step 2: Profile Hazards

Step 2 profiles the hazards. Here the information related to flooding that is provided by HAZUS-MH is used to assess risk. The historic event data for the flood is not provided by HAZUS-MH, but it provides stream gauge data showing high water marks reached in past floods not related to the year. Flood zone maps can help flood analysis by mapping flooding prone areas according to different categories of events. This helps defining the chance that a particular flood can occur at a given location considering rain fall or levee/dam failure for example.

A data gap analyses considers the data given and the data sources required for completing the data for analyses in HAZUS-MH. Since flooding is one of the model options in HAZUS-MH, and a multi-hazard analysis is not needed, there is no need to obtain other maps of characteristics of other hazard types not included in this software package. Possible other types of data include written profiles instead of maps.

The analysis process for the riverine flood hazard is shown in Table 7.

Table 7 HAZUS Riverine Flood Hazard Analysis Process

Action	Results
Define Terrain	Input Digital Elevation Model (DEM)
Create New Scenario	Select Reaches
	Hydrologic Analysis
	Compute Flood Hazard (hydraulics analysis) for suite, specific return period, specific discharge, and annualized return periods.
Develop Flood depth grid	Optional hazard analysis Perform What if Levee Assessment, Flow Regulation, and/or Velocity Grid

Source: modified from HAZUS-MH Application DVD Flood Manual (FEMA 2007).

Before defining the terrain, go to Hazard menu > Flood Hazard Type > Riverine only > OK. This helps define the correct Digital Elevation Model (DEM) and enables the menu items needed to support the hazard selected. The DEM covers both the study region and all the watersheds that intersect that study region. After this a stream network needs to be developed before any other menu item is enabled.

In the HAZUS-MH guide Appendix D, Job Aid 2-1 (FEMA 2004), in the column for flood (riverine), there is the indication of complementary data for the analyses in HAZUS-MH. In our case study, these complementary data are the USGS Digital Elevation Model (DEM) for the watershed of Sussex County – Seaford. There are different ways for getting USGS DEM data. One way is through the GeoCommunity (USGS 2007), where after subscribing one can download data for free. The HAZUS-MH software has a prompt that shows the path to obtaining the necessary dataset from USGS. However the best data source for the study area for this research is the elevation model from the Spatial Analysis Laboratory (SpatLab) at University of Delaware. The data with specific coordinates is what is used.

To get and download the correct data into HAZUS-MH, it's important to find the specifications for it. To integrate a DEM click the Hazard menu > User Data. If the dataset is not the correct DEM for integration into HAZUS-MH, the error message shown in Figure 8 appears.

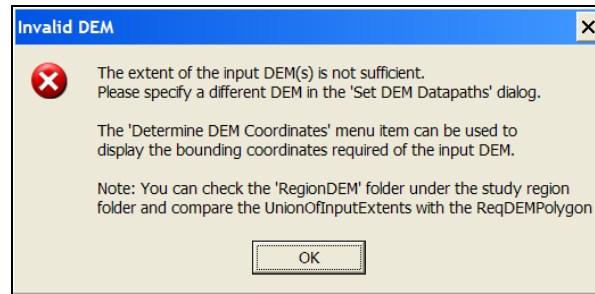


Figure 8 DEM Error Message in HAZUS-MH
Source: HAZUS-MH software (FEMA 2007).

This error message helps the user to find the proper DEM. The integration of data does not occur as a simple transfer of data by clicking on a selected layer in ArcCatalog and dropping in HAZUS-MH. This process does not enough information for the HAZUS-MH software to recognize the layer and include it in the analyses. In the dialog box for adding a DEM into HAZUS-MH, click on the button at the bottom of the dialog box “Determine required DEM extent”. This button opens a dialog box with the instructions for getting the correct DEM from USGS as shown in Figure 9. Follow the instructions.

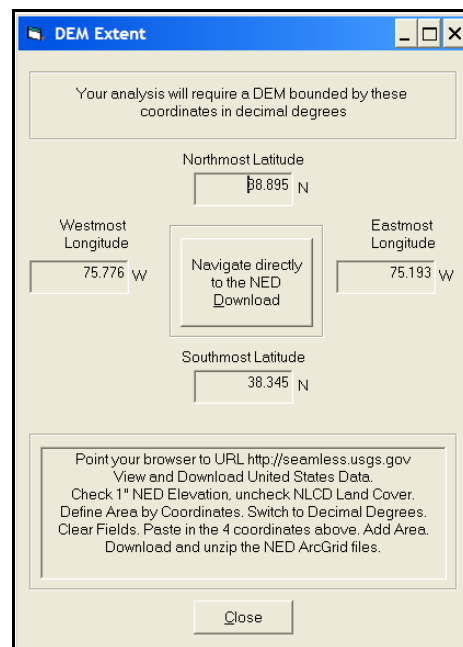


Figure 9 Instructions for Obtaining Specific DEM for HAZUS-MH
Source: HAZUS-MH software (FEMA 2007).

The DEM file specifications downloaded from USGS are shown in Figure 10.

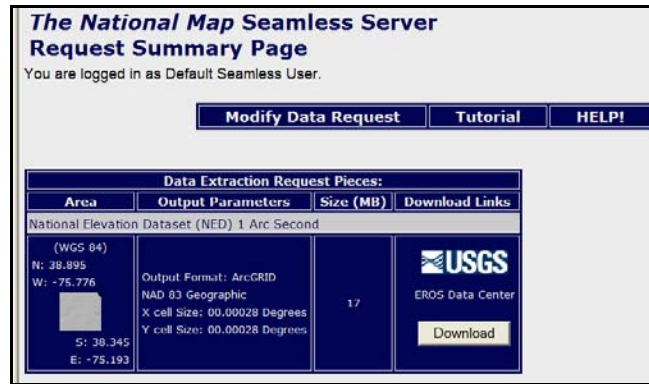


Figure 10 New DEM for Seaford Area
Source: DEM Dialog Box image from (USGS 2008).

The correct DEM recognized by the system and integrated into HAZUS_MH is shown in Figure 11. As one can see, the DEM covers a bigger area than the selected specified base map.

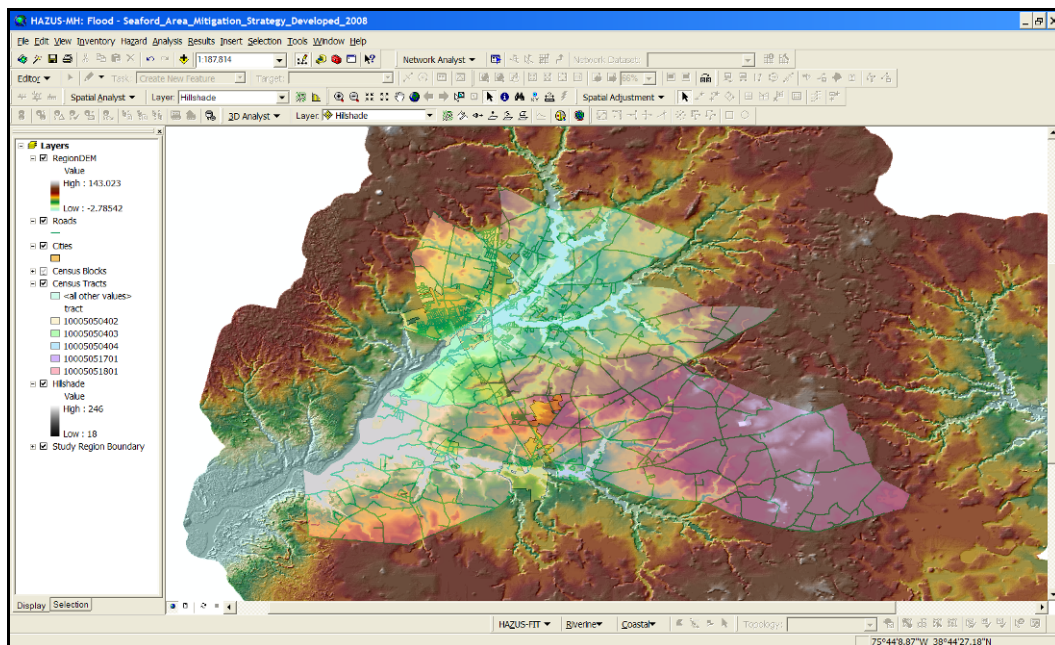


Figure 11 DEM Integrated into HAZUS-MH

After downloading the data, the tasks are to generate a stream network, specify the drainage area of at least 1 (one) square mile, and select a scenario to do the flood case study.

The stream network is generated by using a DEM output from the Flow Accumulation function. This flow accumulation, as explained by ESRI ArcGIS Desktop Help (ESRI 2007a), “is the number of upslope cells that flow into each cell”.

In HAZUS-MH there is a specific function for generating a stream network, which is done one time only to establish the river network identity for all following scenarios (FEMA 2007). A drawback in the system at this point is that if you start to integrate the DEM and you do not complete the other tasks for generating the stream network, even after saving, turning off and later coming back to continue, the interruption may disable some tools. This problem can be solved by integrating the DEM again into HAZUS-MH software.

Using the software, on the Hazard menu select Develop Stream Network > put “1.0” for drainage > OK. This process is shown in Figure 12.

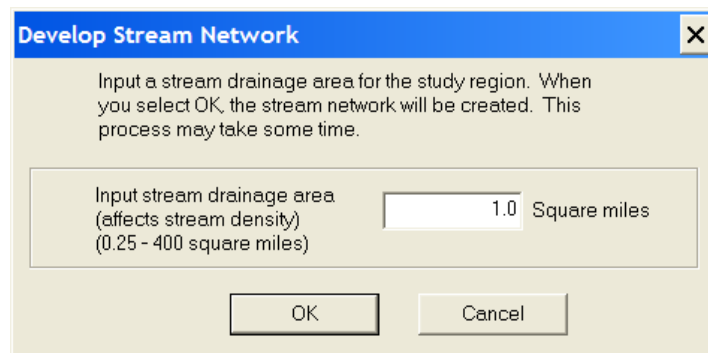


Figure 12 Building Stream Network in HAZUS-MH
Source: completed in (FEMA 2007).

By defining the drainage area as a higher square mileage (e.g., 30 square miles), the streams are far from each other in this area and this is not appropriate for this research. The 1 square mile drainage area results in a stream network highly defined within the total land area. The water drains into any given reach with the exception of the starting node of the reach (which is the downstream node of the prior reach).

Confirm the process by clicking “yes” in the next dialog box that comes up. The time required for this dialog box to appear depends on the size of the area selected. If it is a large area, it may take a longer time to finish the process to develop the Stream Network. When finished click OK on the prompt to confirm success on building the Stream Network. The software then generates a layer called “Reaches”.

Select a scenario to do the flood case study. Hazard menu > Scenario > New > OK. This scenario defines the specific stream reaches and the hydrologic and hydraulic characteristics include in one analysis run. A window opens for giving a title to the new scenario, and if desired, space for a brief additional description. This scenario name must not have spaces. A new dialog box shows up as shown in Figure 13.

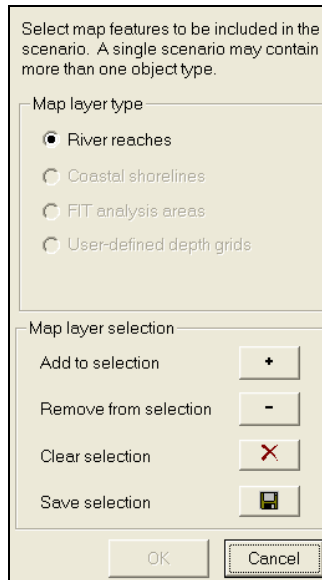


Figure 13 Defining the Scenario for Analysis in HAZUS-MH
Source: completed in (FEMA 2007).

Click “Add to selection”. Go over the area you want to be analyzed, click and drag the mouse to the extension of area you desire, or use select features tool to define specific streams. Click “Save selection” > OK. It generates a new layer called “ChosenReaches” shown in Figure 14 in red.

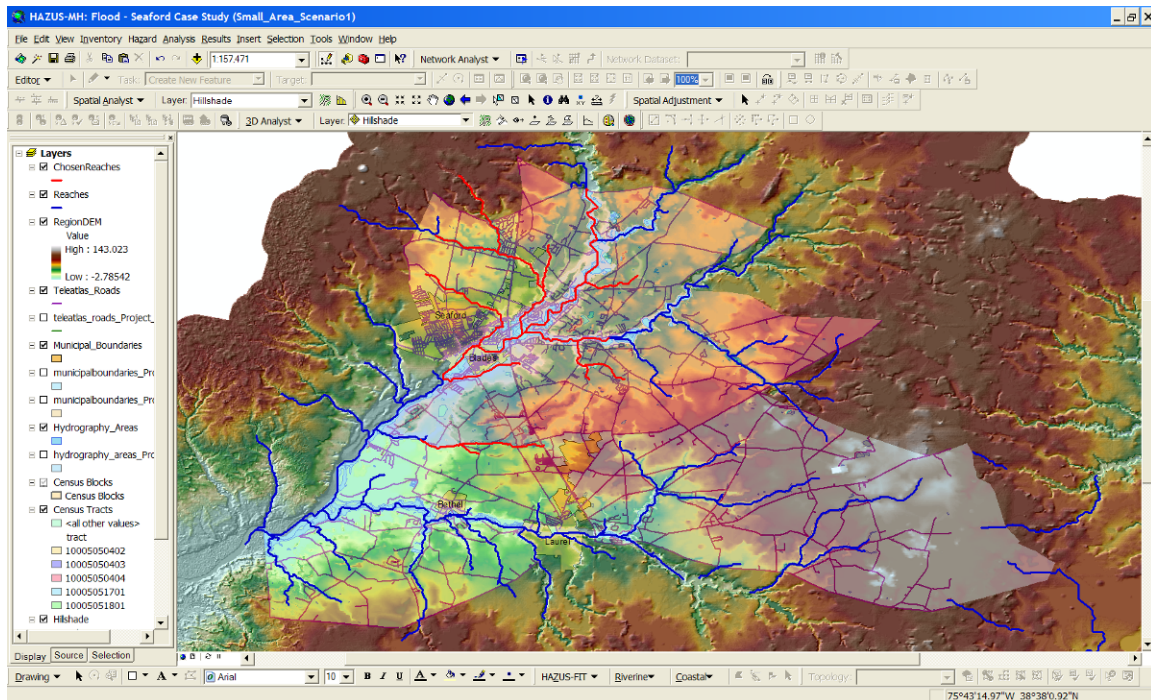


Figure 14 Defining Area for Further Analyses

The option “Save As” under Scenario allows the user to skip the hazard analysis to run different parameters in the Inventory or Analysis menu (i.e. modifying functions/parameters in the Damage & Loss Estimate Analysis to compare results between scenarios). This saves time. Also to rerun the Analysis, preserve previous results without duplicating a Study Region, and generates new results for the other analysis while maintaining old results. The “Save As” works for an open scenario only. Name the scenario and add a description.

To continue doing analyses, click Hazard menu > Riverine > Hydrology. HAZUS-MH analyzes the discharge frequency relationship for all of those reaches defined in the case study. This is when HAZUS-MH uses the stream gage data, and includes topographic parameters. This demands time for calculations and it is possible to have computer memory limit problems. Wait for processing to finish. This analysis is important to perform frequency-related flood analyses such as the 100-year return period, or the annualized loss. If the analyses are for specific reaches discharges, skip Hydrology and go to the Delineate Floodplain (Riverine) menu > Single Discharge.

Once the hydrologic analysis is finished, select the analysis type as shown in Figure 15.

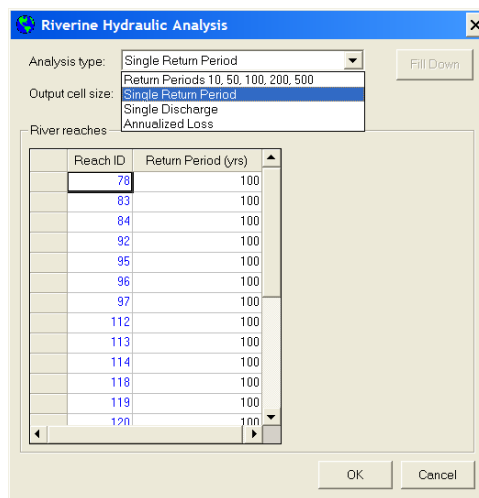


Figure 15 Option for Riverine Analyses Type
Source: chosen in HAZUS-MH software (FEMA 2007).

Hazard > Riverine > Delineate Floodplain > Single Return Period.

Failure of the software can be due to some bugs, for example, this one shown in Figure 16.

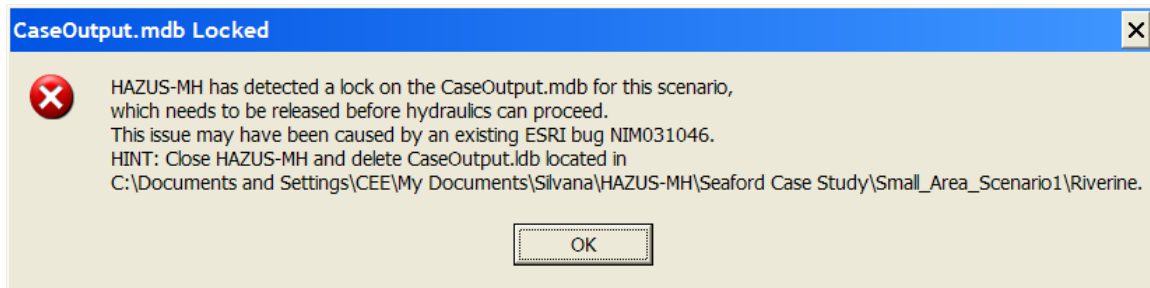


Figure 16 HAZUS-MH Warning and Suggestion to Enable Software Operation
Source: HAZUS-MH software (FEMA 2007).

After fixing the problem, and getting the software running, this particular case study took more than 2 hours to process the analyses using an Intel® CPU T2500 2 GHz processor as shown in Figure 17.

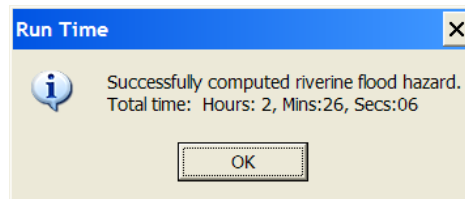


Figure 17 Time to Complete Single Return Analysis
Source: HAZUS-MH software (FEMA 2007).

This analysis generated a layer named “BoundaryPolygon” together with a layer called RPD100 in the map shown in Figure 18. Use “Save As” to keep current results.

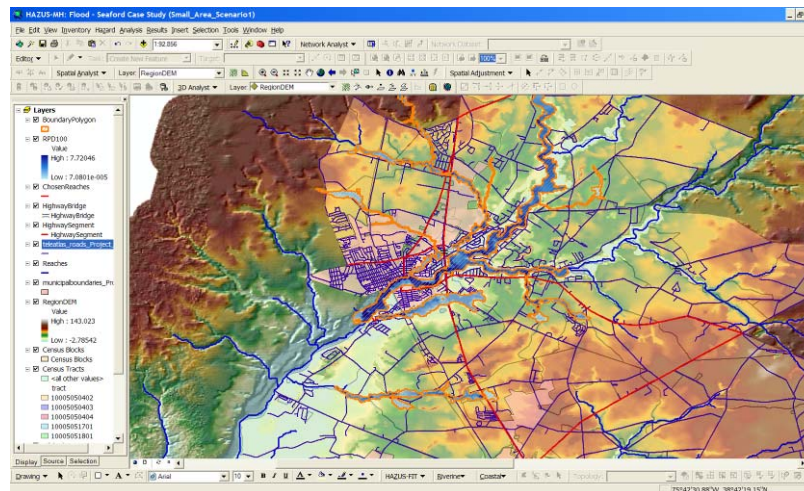


Figure 18 Single Return Period Map

The other analysis completed was for Annual Losses. This analysis generated a new map with a “BoundaryPolygon” layer and another layer called RPD500 shown in Figure 19. The layout is a predetermined format in the HAZUS-MH software.

the levee alignment. Cross the alignment over the floodplain twice, enter recurrence interval (in years) corresponding to the level of protection provided by the levee > OK. Figure 20 shows a hypothetical levee line alignment in an upside-down white “u” shape in the left, and the new map after calculations on the right. The model integrates the levee into the DEM and recomputes the flood hazard for the scenario. The Levee analysis only works for riverine hazards based on a specific return period, which means Annual Losses scenario will not run with the Levee analysis.



Figure 20 “What if” Levee Protection Scenario

The place for the Levee was chosen to coincide with the area where US13 passes. This area appears vulnerable. The floodwater now reaches different depths and covers a slightly different area.

The HAZUS-MH default hydrologic analyses are applied to unregulated drainage areas. The other analysis provided in HAZUS-MH is for riverine flow regulation, which can be through diversions and/or storage, which changes the flood frequency curves downstream. The tool for flow regulation incorporates the flow regulation in the downstream effects by modifying the unregulated flood frequency curve at specific locations by entering one or more pairs of recurrence intervals and discharge values. The downstream reaches affected are identified, and the corresponding flood frequency curves are modified as appropriate, and thus the flood hazard is re-computed.

To use this tool, go to the Hazard menu > Riverine > Flow Regulation > click Draw button and identify the location of a regulating structure (i.e. flood control reservoir) > click Apply button. Figure 21 shows the selected place for flow regulation and all the return period and discharge options for doing the analysis. This uses the algorithm for find “the drainage area upstream of that location and defines the unregulated flood frequency curve” (FEMA 2007), plots a curve, and a table of recurrence intervals and associated discharge values. Enter the return period for the discharge of the regulating structure > OK. “Yes” in the next dialog box.

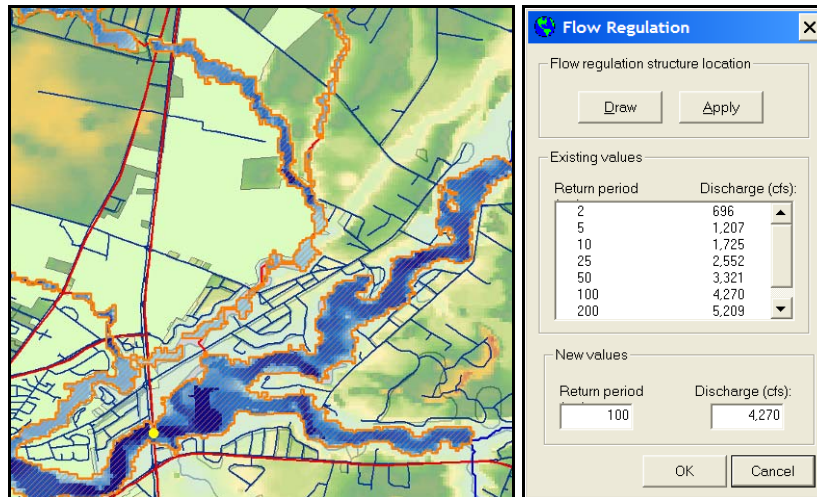


Figure 21 “What if” Flow Regulation Scenario Process

This function generated another “bug”. Figure 22 shows the error message and solution to the problem. After solving the problem, continue to the next analysis.

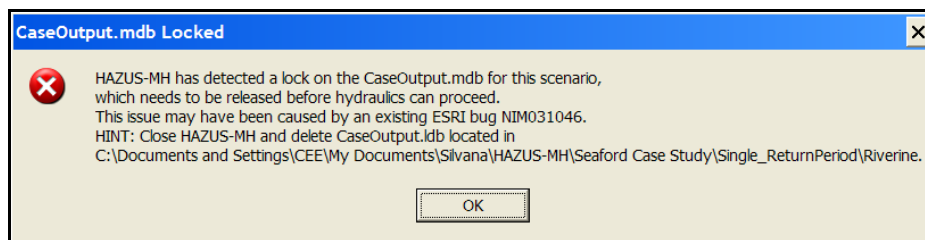


Figure 22 Warning and Suggestion to Run Riverine Flow Regulation Analysis
Source: warning dialog box in (FEMA 2007).

For each “What if” scenario, do a specific “save as”. Make sure to have the single return period to do each of the new “what if” scenarios. This avoids running into errors. Figure 23 shows the Flow Regulation map output.

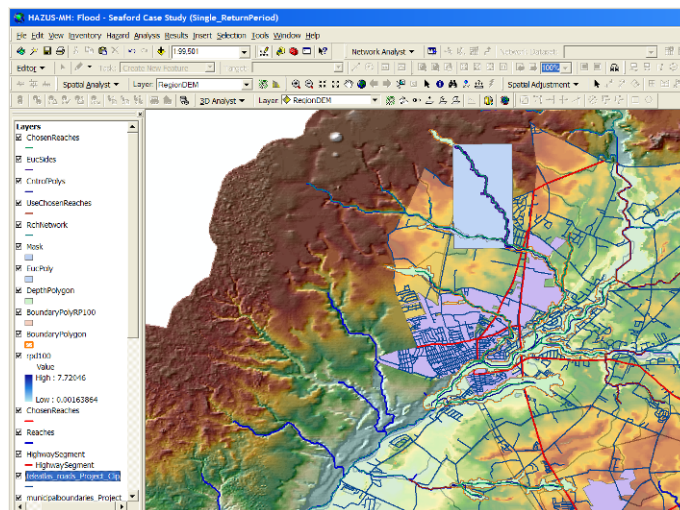


Figure 23 “What if” Flow Regulation Map

Another possible analysis in HAZUS-MH is the riverine flow velocity. Floodwater velocity can increase the “hazard by carrying large amounts of sediment and debris, impacting structures, and eroding soil from stream banks and under foundations” (FEMA 2007). The velocity analysis includes estimation of the spatial distribution of the floodwater velocity. Go to Hazard menu > Riverine > Velocity > Yes. Figure 24 shows the resulting map with the different floodwater velocity estimation.

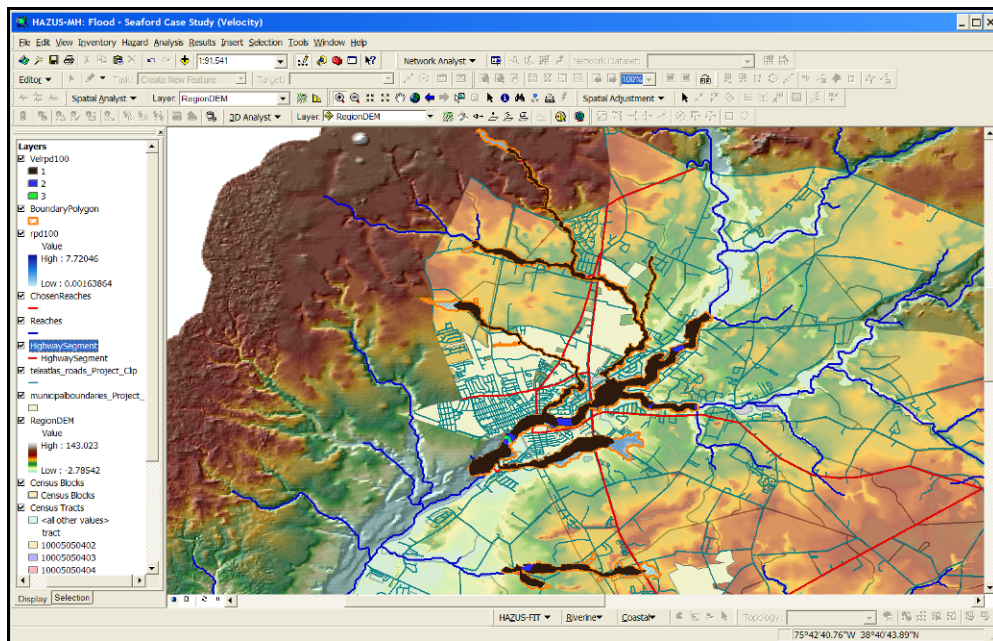


Figure 24 Floodwater Velocity Estimation Map

Under the Hazard menu there is a Quick Look option. This quickly produces a rough estimate of flood damages, without generating a stream network or Delineate Floodplain, by entering anticipated flood depths for the area selected. Then, based on the existing infrastructure in this area, this option estimates approximate damages. This crude method of analysis is limited as the estimates:

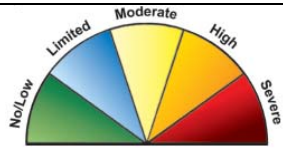
- are based only on the General Building Stock (GBS),
- are only appropriate for small areas with similar elevations,
- do not use any topology (DEM),
- do not verify the veracity of the flood depths input, and
- assumes that locations with similar elevations have the same depth of flooding.

The limitations can produce incorrect results. Therefore this function was not used for the case study. The Enhanced Quick Look analysis option works in a similar way to the basic Quick Look function (using a polygon to represents the floodplain boundary that is then used to estimate the flood depth) this function was also not used.

For level of analysis 2 or 3, additional data is required. Choosing the level of analysis requires consideration of the feasibility of such an effort depending on schedule, resources available, and end uses of data. For Level 2 Analysis, not only is the Elevation Model needed, but also, additional local flood and terrain data. This additional data includes flood-prone areas, and updated inventory data for 1st floor elevation data for buildings. This type of detailed analysis is better used for small areas (project management level). A specific tool, the Flood Information Tool (FIT) is needed if the data available is other than DEM (triangulated irregular network – TIN, or contour lines). The FIT is meant to facilitate the preparation of flood risk assessment by automatically processing the flood data to evaluate exposure and develop loss estimates for the inventory.

All these hazard analyses so far are meant to help understand real events. In the case study, the focus is on the flood event that occurred on June 25, 2006 in Seaford area. Therefore, to help organize and communicate hazard information to the target audience, each different hazard must have separate worksheets such as the one shown in Table 9. For this case study, where there is only one type of hazard, only one worksheet is completed. Hazard area maps, graphic illustrations and histograms of past events must be attached to this table. When doing a multi-hazard analysis for a specific area and/or community, the way to prioritize hazards using a qualitative approach proposed by HAZUS-MH, is to weight the factors differently, assigning a rating for each factor from 0 (low) to 5 (high). The factors considered are: frequency, duration, severity, intensity. The ranking system must be specified according to the different levels as shown in the rainbow figure in Table 9.

Table 9 Profile Hazard for Case Study

HAZARD: <u>Flood – Seaford-DE</u> 	
Summary of Risk Factors	
<i>Rank of factors for local profile</i>	Period of occurrence: June 25, 2006
Severity score: high	Probability of event: 1% (100-year flood)
History: (similar events) 40	Warning time: 1 to 2 days very certain, 10 days trends.
Vulnerability: (Guessing) 75	Major contributor(s): Low elevation, East coast State, Major river
Maximum Threat: 80	Risk of injury? Yes, and risk of death
Probability: 80	Potential for facilities shutdown? Yes. Major roads for 30 days or more
Total score: 275	Percent of affected properties that may be destroyed or suffer major damage: guessing 10% of local road network

Continue Table 9.

FLOOD (HAZARD) PROFILE (DATA)
Background and Local Conditions
Delaware has moderate risk for snowfall, has more than just a few but not frequent risk for thunderstorms, has moderate to low risk for wind, and some risk for hurricanes. The overall composite risk is moderate. Sussex County in Delaware is along with other U.S. counties with the greatest number of federal disaster declarations (USGS 2006). Seaford is located at 38°38'41" N, 75°36'58" W (38.644654, -75.616107), in southwestern Delaware. This area has low elevation, prone to flooding. Seaford's weather has a mild subtropical climate consisting of hot, humid summers and mild winters, moderated by the Atlantic Ocean. Common to have flooding event occurring also in the Maryland neighboring area, having to share solutions for traffic. Local transportation infrastructure usually in good and fair conditions, the traffic Level of Service is A to C. Area likely to be heavily impacted by climate change and global warming.
Historic Frequency and Probability of Occurrence
Flooding is the most common disaster type in the U.S. and for Sussex County. Considering similar events since the 1960's registered as a Federal Disaster Declaration, the number of events are 4. Earlier events lack easily accessible sources of information. Table 5 shows the events and their related damages. Figure 25 shows the related graph considering the time trend among Federal Disaster Declarations (Other different and minor events have taken place in other years).
Severity
Considering other areas in the U.S. areas, Delaware is considered a moderate risk area. However, Sussex County, Delaware is the area that most frequently experiences disasters, which matches (on a par with other areas that have received about the same number of Federal Disaster Declarations) (USGS). In this sense the risk for Flooding can be considered high. According to the flooded area map developed in ArcGIS and studies about global warming, events like the 100-year storm and other more rare events (i.e. 500-year storm) can increase in frequency and strength.
Historic Losses and Impacts
Great damage has occurred to transportation infrastructure, crops, buildings, and some loss of lives (NOAA). The 2006 flood impacts list for Seaford area includes: <ul style="list-style-type: none"> • damage to the police department situated in the city of Seaford, and the Seaford School District parking lot, • barricades and high water signs emergency repairs and placement in the Town of Georgetown, totaling \$1,905, • traffic control and other security measures of the Delaware State Police, totaling \$9,822, • road and bridge repair under the responsibility of the Delaware Department of Transportation, totaling \$341,888, and • road repair work at the Delaware Technical and Community College, totaling \$13,340.
Designated Hazard Areas
The elevation profile map and the flooded area map developed earlier using ArcInfo show the areas most prone to flooding. They were built prior to the base map developed in HAZUS-MH. The use of HAZUS-MH software is to do a deeper analysis of the problem.

Source: based on HAZUS-MH How-To Guide Worksheet 2-2 (FEMA 2004).

This Table 9 shows key information and data that is later included in the model in STELLA (e.g., period of occurrence, probability of event, facility shutdown, 4 similar events, cost of repair for roads and bridges). STELLA allows the inclusion of qualitative information to build the connection to quantitative data, although all variables need a mathematical representation. The use of qualitative and quantitative information in STELLA is included in the document that shows the development of the model for the CIR-DSS. HAZUS-MH deals with the physical and geographical condition of the

infrastructure by calculating damage and overall impacts. Table 9 puts in perspective the event focus of analysis and helps understand the scope of the problem, plus giving insights about where to allocate resources as part of mitigation strategy options for the transportation infrastructure. To have a better approach to the problem of damaged infrastructure and disrupted traffic flow is important to consider condition and performance measures together, this relating to the concept of resilience network (system must work). The HAZUS-MH outputs help to identify areas in need of rebuilding from the perspective of recovery and/or mitigation. HAZUS-MH better addresses issues related to infrastructure physical condition, which maps, calculations and reports demonstrate the problem. For performance in terms of traffic flow disruption, there is no mechanism in place in the software at present. Recovery for damaged infrastructure is understood to be simple structural repair or rebuilding, and mitigation is understood to be infrastructure system improvement including reinforcement. Mitigation is the phase in the disaster cycle which activities can be directed to privilege improvement in the resilience of infrastructure systems, the desired outcome of the present research.

The following tables and figures shown are the documentation that completes this Case Study Hazard Profile. First, Table 10 shows events of similar origin, the years they happen and the impact for the specific study region of Seaford in Sussex County.

Table 10 Similar Federal Disasters and Damage between 1962 and 2006 in Sussex County

Events	Event Number	Year	Damage (US\$ Million)
1	126	1962	21,391,487
2	1017	1994	8,907,958
3	1205	1998	3,721,100
4	1654	2006	3,000,000

Figure 25 Figure 25 is a plot of the data in Table 10 showing the decrease in value in millions of dollars through time. This suggests that policies, improvements, and learning experiences are increasing the resilience of Sussex County, resulting in less exposure and less vulnerability. Also the time between disasters seems to be decreasing, which means that the chance of exceeding the 100-year flood elevation is more common than the 1 in 100 year occurrence. These hypotheses warrant further exploration.

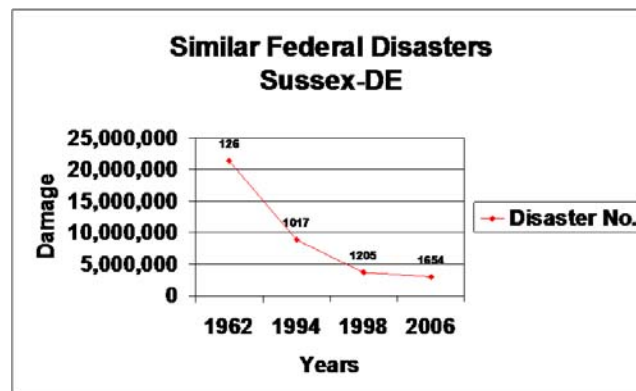


Figure 25 Federal Disasters Damage Graph - Sussex-DE

After all these analyses are finished for the hazard, the loss analysis is undertaken in HAZUS-MH. For the study region the characteristics of the structures and people are identified and analyzed for vulnerability to the flood or floods. The HAZUS-MH defaults provide damage functions to “estimate percent damage relative to the depth of floodwater as measured from the top of the first finished floor” for riverine floods (FEMA 2007). Other damage functions collected or developed analyze impacts on vehicles, bridges, and utilities.

Step 3: Inventory of Assets

Step 3 in the HAZUS-MH guide is to inventory the assets. These are the assets that can be impacted by the hazard specified earlier. Risk combines exposure, vulnerability and hazard. The information and documentation about population, structures, and lifelines provided by HAZUS-MH must be reviewed and can be used for a Level 1 analysis. The information and documentation for other levels of analysis must be tailored and completed, after a data gap analysis, and then integrated with the information into HAZUS-MH. The outputs for all three levels of analysis are tables, maps, updated local data, and lists of data sources.

Analysis of natural hazards includes the verification of “likelihood of occurrence, severity, and geographic location of the inventory” (FEMA 2004). This data and information is used to support loss estimates and risk studies. The basic terms used in the guide for inventory are:

- Asset – human-developed/natural feature that has value (i.e. people, buildings, lifelines);
- Inventory – the population, lifelines, and other assets in the study region;
- Buildings – general types including user-defined buildings and critical facilities;
- Lifelines – systems such as transportation and utility;
- Exposure – an inventoried asset present in a hazard-prone area;
- Vulnerability – how much an asset is exposed or susceptible to a hazard.

HAZUS-MH provides detailed inventory data, which are represented in the study region maps as points, lines, and polygons. These features are (FEMA 2004):

- general building stock,
- essential facilities (i.e. hospitals, police, emergency operation centers),
- hazardous material facilities,
- high potential loss facilities (i.e. nuclear power plants, dams, military installations),

- transportation lifeline systems (i.e. air, road, rail, and water systems),
- utility lifeline systems (i.e. potable water, wastewater, oil, natural gas, electric power, communication systems), and
- demographic data.

The data sources for each category used in HAZUS-MH, which must be reviewed for accuracy, are from organizations such as the U.S. Census Bureau, the American Hospital Association, and InfoUSA, Inc.

Needed changes to the location including modifications and supplements to this and other data can be done in HAZUS-MH. To access the data, click on the Inventory menu > Transportation Systems. The information is in tables, which can be viewed in the map through the map function at the bottom of the menu. Figure 26 shows the inventory table for Highway Segments, and Figure 27 shows the map for the Highway Segments with the specific study area shown in red. Figure 28 shows the HAZUS-MH Highway Segment table in the top and the centerline data table at the bottom. Taking a close look at the tables, one can see they have different columns, but one important detail in the data coming from HAZUS-MH is the column for segment cost, which is used analysis performed by the model in STELLA.

ID	Name	Owner	SegmentClass	Description	Length	Traffic	Cost
1	DE000043	Front St	HDFLT	Default Road	1.31	0	\$3,883.40
2	DE000045	Georgetown Rd	HDFLT	Default Road	0.98	0	\$2,925.90
3	DE000046	Georgetown Rd	HDFLT	Default Road	0.37	0	\$1,109.17
4	DE000060	Sussex Hwy	HDFLT	Default Road	10.83	0	\$32,206.20
5	DE000066	Sussex Hwy	HDFLT	Default Road	0.88	0	\$2,628.50
6	DE000068	Sussex Hwy	HDFLT	Default Road	2.54	0	\$7,543.80
7	DE000069	Sussex Hwy	HDFLT	Default Road	0.33	0	\$987.20
8	DE000085	United States Highway	HDFLT	Default Road	3.62	0	\$21,534.20
9	DE000139	Bowdens Garage Rd	HDFLT	Default Road	2.88	0	\$8,572.60
10	DE000139	Bowdens Garage Rd	HDFLT	Default Road	1.04	0	\$3,095.40
11	DE000144	Bridgeville Hwy	HDFLT	Default Road	3.66	0	\$10,877.10
12	DE000212	Concord Rd	HDFLT	Default Road	10.98	0	\$32,643.30
13	DE000215	County Seat Hwy	HDFLT	Default Road	4.74	0	\$14,103.40
14	DE000217	County Seat Hwy	HDFLT	Default Road	0.55	0	\$1,635.40
15	DE000255	High St	HDFLT	Default Road	0.94	0	\$2,780.20
16	DE000355	Market St	HDFLT	Default Road	0.13	0	\$377.60
17	DE000378	Norman Eskridge Hwy	HDFLT	Default Road	1.33	0	\$3,960.70
18	DE000389	Old Bridgeville Hwy	HDFLT	Default Road	0.91	0	\$2,691.00
19	DE000399	Poplar St	HDFLT	Default Road	0.59	0	\$1,751.40
20	DE000444	Seashore Hwy	HDFLT	Default Road	0.91	0	\$2,702.90
21	DE000509	United States Highway	HDFLT	Default Road	0.77	0	\$4,555.40
22	DE000511	United States Highway	HDFLT	Default Road	0.27	0	\$1,623.50
23	DE000515	United States Highway	HDFLT	Default Road	0.19	0	\$1,153.70
24	DE000516	United States Highway	HDFLT	Default Road	0.37	0	\$2,200.40
25	DE000520	United States Highway	HDFLT	Default Road	1.99	0	\$11,852.40

Figure 26 - Inventory Data for Highway Segments in HAZUS-MH
Source: FEMA (2004) and HAZUS-MH software (FEMA 2007).

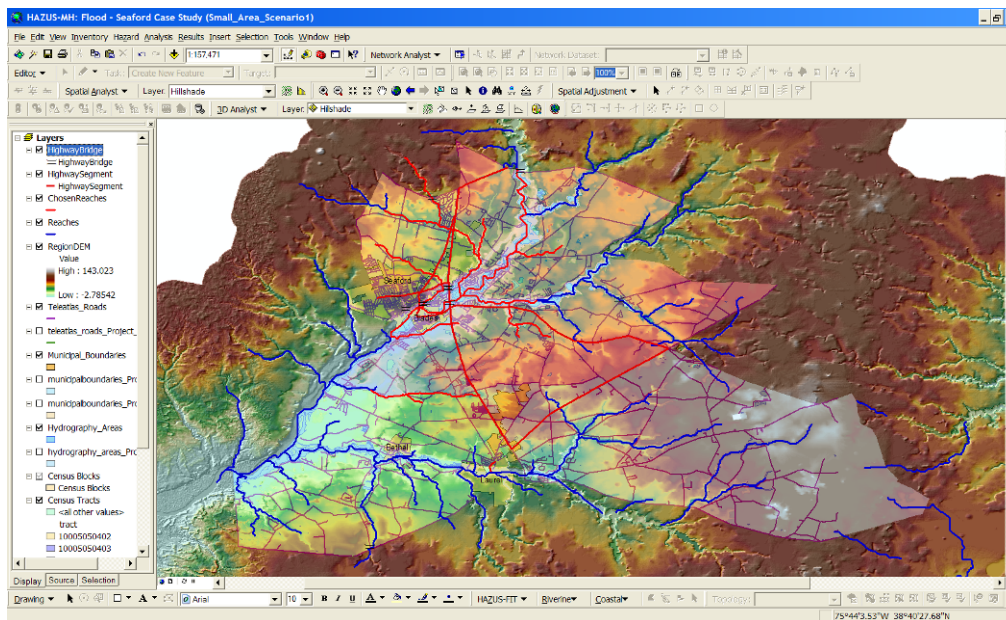


Figure 27 - Highway Segments in the HAZUS-MH Study Area Map

Transportation Systems Inventory Data

Highway | Railway | Light Rail | Bus | Port | Ferry | Airport

Table Type:

Highway Segments

Highway	ID	Name	Owner	SegmentClass	Description	Length	Traffic	Cost	NumLanes	Pavement	Width	Capacity	CountyFips	Comment
1	DE000043	Front St		HDFLT	Default Road	1.31	0	\$3,883.42				0 10005	A31	
2	DE000045	Georgetown Rd		HDFLT	Default Road	0.98	0	\$2,925.54				0 10005	A21	
3	DE000046	Georgetown Rd		HDFLT	Default Road	0.37	0	\$1,109.12				0 10005	A21	
4	DE000060	Sussex Hwy		HDFLT	Default Road	10.83	0	\$32,206.20				0 10005	A25	
5	DE000066	Sussex Hwy		HDFLT	Default Road	0.98	0	\$2,628.59				0 10005	A25	
6	DE000068	Sussex Hwy		HDFLT	Default Road	2.54	0	\$7,543.82				0 10005	A41	
7	DE000069	Sussex Hwy		HDFLT	Default Road	0.33	0	\$987.21				0 10005	A41	
8	DE000095	United States Highway		HDFLT	Default Road	3.62	0	\$21,534.23				0 10005	A25	
9	DE000138	Bowdens Garage R		HDFLT	Default Road	2.88	0	\$8,572.66				0 10005	A31	
10	DE000139	Bowdens Garage R		HDFLT	Default Road	1.04	0	\$3,095.43				0 10005	A31	
11	DE000144	Bridgeville Hwy		HDFLT	Default Road	3.66	0	\$10,877.14				0 10005	A21	
12	DE000212	Concord Rd		HDFLT	Default Road	10.98	0	\$32,543.30				0 10005	A31	
13	DE000215	County Seat Hwy		HDFLT	Default Road	4.74	0	\$14,103.41				0 10005	A21	
14	DE000217	County Seat Hwy		HDFLT	Default Road	0.55	0	\$1,635.44				0 10005	A21	
15	DE000255	High St		HDFLT	Default Road	0.94	0	\$2,780.24				0 10005	A31	
16	DE000255	Market St		HDFLT	Default Road	0.12	0	\$377.64				0 10005	A41	
17	DE000276	Norman E. Bridges H		HDFLT	Default Road	1.32	0	\$3,960.73				0 10005	A35	
18	DE000289	Old Bridgeville Hwy		HDFLT	Default Road	0.91	0	\$2,631.04				0 10005	A21	
19	DE000289	Pepper St		HDFLT	Default Road	0.59	0	\$1,751.40				0 10005	A21	
20	DE000444	Seashore Hwy		HDFLT	Default Road	0.91	0	\$2,702.93				0 10005	A31	
21	DE000509	United States Highway		HDFLT	Default Road	0.77	0	\$4,555.43				0 10005	A25	
22	DE000511	United States Highway		HDFLT	Default Road	0.27	0	\$1,623.54				0 10005	A41	
23	DE000515	United States Highway		HDFLT	Default Road	0.19	0	\$1,153.73				0 10005	A21	
24	DE000516	United States Highway		HDFLT	Default Road	0.37	0	\$2,200.40				0 10005	A21	
25	DE000520	United States Highway		HDFLT	Default Road	1.93	0	\$11,852.45				0 10005	A41	
26	DE000620	Steen Hwy		HDFLT	Default Road	8.75	0	\$26,024.25				0 10005	A31	

Attributes of Teleatlas_Roads

FID	Shape*	L_F_ADD	L_T_ADD	R_F_ADD	R_T_ADD	PREFIX	PRETYPE	NAME	TYPE	SUFFIX	FCC	POSTAL_L	POSTAL_R	NAME_TYPE	SHIELD	HWY_NUM	AREA	LEN
0	Polyline	23698	23500	23599	23501			German	Rd		A41	19973	19973	R			0	612.901421
1	Polyline							Alley		A73	19973	19973	19973	R			0	157.969185
2	Polyline	30220	30022	30161	30023			Fire Tower	Rd		A41	19956	19956	R			0	403.266058
3	Polyline	1104	1100	1103	1101	W		Locust	St		A41	19973	19973	R			0	16.810619
4	Polyline	8296	8232	8365	8217			Hearns Pond	Rd		A41	19973	19973	R			0	398.520222
5	Polyline	12358	12392	12399	12399			Chipmans Pond	Rd		A41	19956	19956	R			0	24.607171
6	Polyline			15500	15998			Pepper Pond	Ln		A41	19956	19956	R			0	364.310738
7	Polyline	748	700	749	701			Petunia	Pl		A41	19973	19973	R			0	40.946406
8	Polyline	9957	9999	9962	10014			Middleford	Rd		A41	19973	19973	R			0	191.736324
9	Polyline							Connecting Road		A60	19973	19973	R			0	23.228402	
10	Polyline	23798	23688	23699	23647			Burton	St		A41	19973	19973	R			0	200.985364
11	Polyline	28698	28692	28699	28693			Boyce	Rd		A41	19956	19956	R			0	57.625648
12	Polyline	12601	12799	12600	12798			Lily Meadow	Dr		A41	19933	19933	R			0	55.791961

Figure 28 - Roads Tables from HAZUS-MH Software and DataMIL Centerline

Source: HAZUS-MH Software and DataMIL (FEMA 2007; University of Delaware Research and Data Management Services 2008).

The data in HAZUS-MH for the Transportation Systems are:

- Highway – segments, bridges, and tunnels;
- Rail – segments, bridges, tunnels, and facilities;

- Light Rail – segments, bridges, tunnels, and facilities;
- Bus;
- Port;
- Ferry; and
- Airport – facilities and runways.

The data provided in HAZUS-MH are organized by component classification based on their vulnerability to flooding described in the Technical Manual. “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” (FEMA 2007). The Flood Model can estimate the level of damage for the bridge network and subsequent functionality of the bridges, but the other transportation components lack this capability in the current model. The bridge baseline database was compiled from the National Transportation Atlas and updated in 2001.

The inventory data included for analysis are geographical location, classification, and replacement cost of system components. Although assessment of losses for highway segments is not available in the current Flood Model, the bridge approach is useful and the estimate of the percent damage and the probability of being functional depending on the estimated damage can be used in the STELLA model (FEMA 2007). The classes of highway systems are presented in Table 11.

Table 11 FEMA’s Highway System Classification

<i>Flood Label</i>	<i>General Occupancy</i>	<i>Specific Occupancy</i>	<i>HAZUS Valuation (1000’s \$)</i>
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 (includes 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

Source: (FEMA 2007).

The data provided by HAZUS-MH is sufficient to complete a risk assessment. Adding data to perform a Level 2 or 3 analyses requires a data gap analysis. Figure 28 serves as a good start for data gap analysis as the different columns show the data and help to identify sources. The other tasks for this gap analysis include the evaluation of schedule, resources, priorities, and needs for local inventory data collection. The road data downloaded from DataMIL serves as the background for the map to help with the resilience analysis and mitigation strategy development. Eventually for this level of analysis, one must add fields and make assumptions or collect field information to allow for further risk assessment.

Other tasks related to the Data Tables are editing to improve inventories, import other inventory data tables into HAZUS-MH, collecting data using InCAST (a FEMA Risk Assessment System tool), organize and import data using BIT-MH (a FEMA Risk Assessment System for building datasets).

Step 4: Estimate Losses

Step 4 in HAZUS-MH estimates losses. This step involves running the loss estimation models and scenarios, and evaluating the chosen hazard events and inventory results for the specific geographic location. The outputs for loss estimates are tables, maps, and summary reports. The Flood Wizard and Risk Assessment Tool also provide similar results when used for Analysis Levels 2 and 3.). The Flood Wizard facilitates flood risk assessment for riverine flooding evaluating exposure and doing loss estimates for large extents of area (e.g., county level), using DEM and floodplain boundary information. The Risk Assessment Tool produces the risk assessment outputs for a multi-hazard region (earthquake, flood, and hurricane).

The specific terms used for loss estimation are (FEMA 2004):

- Loss – structural, content, and loss of function;
- Functional downtime –estimated average time in days for which business or services are unable to function because of losses due to the hazard event;
- Displacement time – average number of days occupants are displaced because of damage resulting from the hazard including time building’s occupants operate from a temporary location ;
- Function loss – “functional downtime costs + displacement time costs”;
- Casualties – impacts on humans including injury and death;
- Return period loss – “average loss over a certain period of time for all hazard events”.

The loss estimation results (average expected value per year) are obtained for deterministic and probabilistic scenarios in HAZUS-MH. The average value of loss can help decision-makers’ planning efforts to focus on a cost-effective manner for developing priorities for addressing natural hazards. The average annualized losses can also help identify cost-effective mitigation measures, which can produce savings in terms of avoided losses recognizing budgetary issues and constraints.

The probabilistic analyses are used to develop annualized losses and return period losses estimations of damage and loss. The standardized hazard outputs estimate damage and losses (direct, induced, social, and business interruptions). The analyses consider the likelihood of occurrence of a specific event, its resulting losses and consequences. The likelihood estimate can be based on both statistics and historical

information. HAZUS-MH processing capability accounts for a limited a number of events per return period, specifically:

- 5 flood events,
- 7 hurricanes, and/or
- 8 earthquakes.

The deterministic analyses are based on the laws of physics, and correlations among experience or tests to predict a particular hazard scenario outcome. One or more worst credible possible scenarios can be developed, but the frequency of events must be evaluated.

The functions used to estimate damage can be seen from the Analysis menu. The current Analysis menu includes Damage Functions, Restoration Functions, Parameters, 3rd Party Models, Flood Warning, and Annualized Loss. Included in Damage Functions are Buildings, Essential Facilities, Transportation Systems, Utility Systems, Agricultural Products, and Vehicles. Included in Restoration Functions is Essential Facilities. Included in Parameters are Debris, Casualties, Shelter, Agricultural, Direct Social Loss, and Indirect Economic Loss. Included in 3rd Party Models there are ALOHA, MARPLOT, FLDWAV, and Flood View. These models only work when the proper tool is downloaded and installed to work with HAZUS-MH.

The Transportation Systems damage function dialog box only has the structure damage function with no contents or inventory. The tabs allow shifting between Highway, Railway, and Light Rail facilities. The current flood model has damage functions for bridges only, which are based on standard return periods. Bridges cannot be analyzed using different return periods for different reaches.

The Damage Function for Transportation Systems includes coefficients for return periods from 0 to 1000 years as shown in Figure 29. The Library tab shows further details about each item in the “Occupancy” column, and it also allows for a “User Defined Library”.

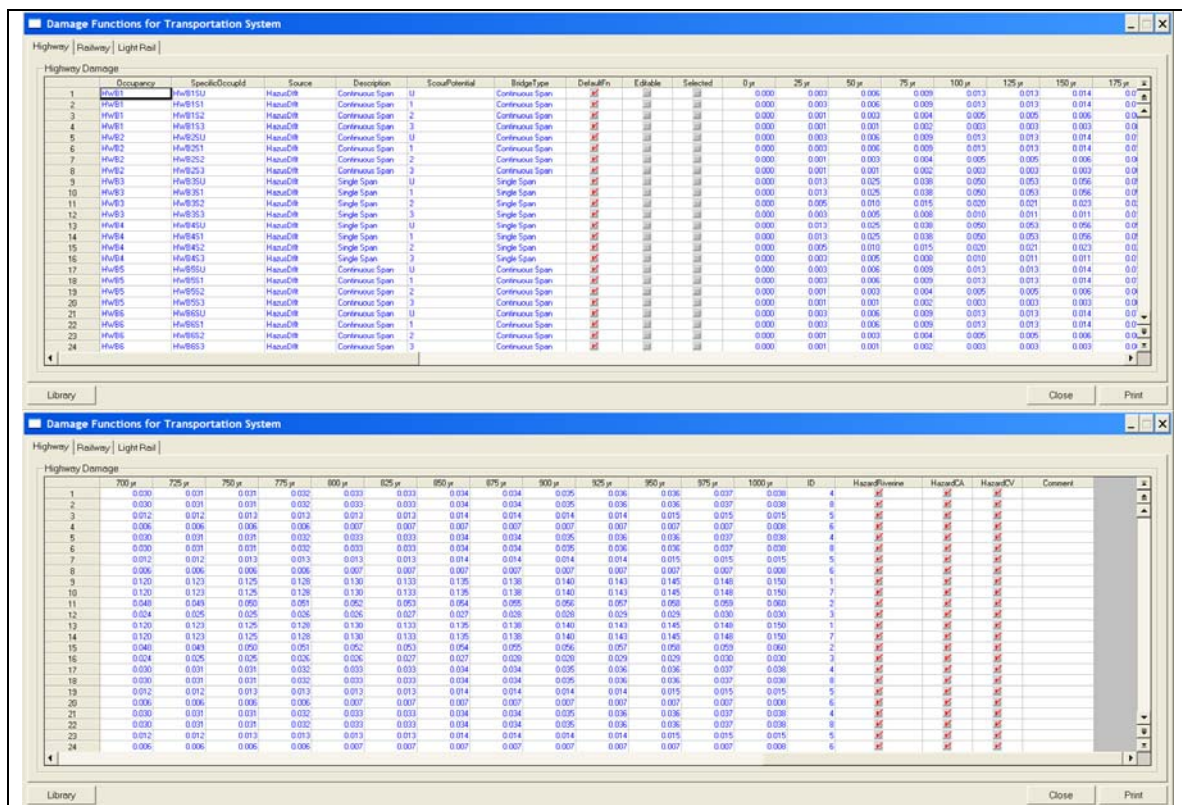


Figure 29 Damage Function for Transportation System
Source: HAZUS-MH Software (FEMA 2007).

The damage and loss functions for infrastructure consider the most vulnerable segments to inundation in terms of impact. The functions identify the facilities/components that are most expensive to replace or if/when damaged results in an extended closure disabling the use of the critical infrastructure by the community. Further sub-hazards that may affect lifeline components and the level of vulnerability include inundation, scour/erosion, and debris impact/hydraulic loading. Examples are bridges/foundations that are not vulnerable to inundation, buried pipeline crossings that are vulnerable to scour, and bridge decks that are vulnerable to hydraulic pressure (FEMA 2007).

Before doing any analysis it is important to view and/or modify the analysis Parameters. The Debris menu opens an editable dialog box allowing the user to view the default debris values, which are estimated based on the depth of flooding within the structure, specific occupancy, and if the foundation has a footing or a slab (FEMA 2007). There are three main classifications for debris: finishes (i.e., dry wall, flooring, and insulation), structure (i.e., framing, walls, exterior cladding), and foundation (i.e., concrete slab, concrete block or other foundation). Foundations substantially damaged due to flooding require the structure to be removed.

The Casualties menu opens a word document that provides some guidance on the national average for casualties because the flood model does not provide estimates.

The Shelter menu opens a dialog box with multiple tabs allowing access to the parameters that affect the number of displaced/evacuated people and the number of people that need short term sheltering. This analysis assumes that local authorities will have time to alert the residents and evacuate them from the areas that will flood. The flood model does include flash flooding or long-duration flooding. The model establishes the flood depth at which people are not allowed into or out of the flooded area. This helps to think about local plans and access controls. The evacuation buffer is added to the current floodplain polygon increasing the area over which the total displaced population is estimated (that is, the population within the floodplain and the buffer). The utility factors tab is used for determining short-term shelter needs. Weighting factors allows modification of the demographic characteristics (i.e., income, age, ethnicity, home ownership). Modification factors are a sub classification of weighting factors to place more emphasis or increase the importance of some factors.

The Agriculture menu requires the flood date input in order for the analysis to run properly. Figure 30 shows the event of June 25.

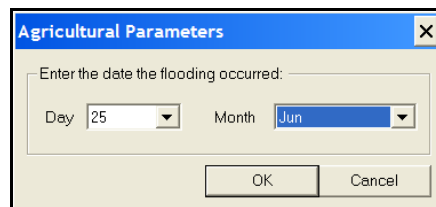


Figure 30 Flood Date in Agricultural Parameter for Analysis
Source: completed in (FEMA 2007).

The Direct Economic parameter menu provides access to default parameters controlling the estimation of direct damages to the general building stock with impact on its wages, income, inventory and the maximum restoration time. The Direct Economic Loss Parameters include Business Inventory, Restoration Time, and Income Loss Data (i.e., rental, owner occupied, wages and capital, recapture factors). The estimates are based on the demographic and building square footage databases.

The Indirect Economic Loss analysis starts by defining the type of analysis. This data refers to the post-flood change in the demand and supply of products, employment, and tax revenues. The potential increased levels of imports and exports, inventories for supply and product, and unemployment rates can be specified (FEMA 2007).

HAZUS-MH defaults suggest numbers for the study region economy, the type of synthetic economy, global factors, supplemental economic factors, restoration functions for which one can choose the period for view (i.e. year), rebuilding expenditure (i.e. year), and stimulus values. The analysis is completed by clicking on Finish. Figure 31 shows the 8 steps for setting the indirect economic loss parameters.

1/8 Indirect Economic Loss Parameters

Determine the type of indirect economic loss analysis to be performed.

Type of analysis:

☐ Use IMPLAN data files

☒ Model a synthetic economy

Next > Cancel

2/8 Indirect Economic Loss Parameters - Synthetic Economy

Define the current level of employment, income and composition of the economy

Study region economy:

Total number of employees: 20.0587

Annual income (\$millions): 0.492392

Type of synthetic economy:

☐ Primarily manufacturing economy

☐ Service economy with manufacturing being the secondary sector

☒ Service economy with trade being secondary sector

☐ Primarily agricultural economy

3/8 Indirect Economic Loss Parameters - Global Factors

Define the global study region economy factors.

Global factors:

Percentage of rebuilding: 95

Unemployment rate at the time of disaster: 6

Level of outside aid and/or insurance: 50

Interest rate on loans: 5

< Back Next > Cancel

4/8 Indirect Economic Loss Parameters - Economic Factors (per sect...)

Define the supplemental imports as percentage of current annual imports, inventory supplies and demands as percentage of current annual sales and new export markets as percentage of current annual exports.

Supplemental economic factors:

#	Sector	Imports	Supplies	Demands	NewExports
1	AGRI	5.00	0.00	0.00	0.00
2	MINE	5.00	0.00	0.00	0.00
3	CNST	99.00	0.00	0.00	0.00
4	MNFG	4.00	1.00	1.00	0.00
5	TRNS	2.00	0.00	0.00	0.00
6	TRDE	3.00	1.00	1.00	0.00
7	FIRE	3.00	0.00	0.00	0.00
8	SERV	3.00	0.00	0.00	0.00
9	GOVT	3.00	0.00	0.00	0.00
10	MISC	4.00	0.00	0.00	0.00

5/8 Indirect Economic Loss Parameters - Restoration

Define restoration function as a percentage (per industry, per time interval for a total of 5 years)

Restoration function:

#	TimeInterval	AGRI	MINE	CNST	MNFG	TRNS	TRDE
1	w01	0.00	0.00	2.00	4.00	10.00	4.00
2	w02	0.00	0.00	2.00	4.00	10.00	4.00
3	w03	0.00	0.00	2.00	4.00	10.00	4.00
4	w04	0.00	0.00	2.00	4.00	10.00	4.00
5	w05	0.00	0.00	2.00	4.00	10.00	4.00
6	w06	0.00	0.00	2.00	4.00	10.00	4.00
7	w07	0.00	0.00	2.00	4.00	10.00	4.00
8	w08	0.00	0.00	2.00	4.00	10.00	4.00
9	M01	0.00	0.00	2.00	4.00	10.00	4.00
10	M02	0.00	0.00	2.00	4.00	10.00	4.00
11	M03	0.00	0.00	2.00	4.00	10.00	4.00
12	M04	0.00	0.00	2.00	4.00	10.00	4.00
13	M05	0.00	0.00	2.00	4.00	10.00	4.00
14	M06	0.00	0.00	2.00	4.00	10.00	4.00

View by: ☐ Week ☐ Month ☒ Year

6/8 Indirect Economic Loss Parameters - Restoration

Define restoration function as a percentage (per industry, per time interval for a total of 5 years)

Restoration function:

#	TimeInterval	AGRI	MINE	CNST	MNFG	TRNS	TRDE
1	w01	0.00	0.00	2.00	4.00	10.00	4.00
2	w02	0.00	0.00	2.00	4.00	10.00	4.00
3	w03	0.00	0.00	2.00	4.00	10.00	4.00
4	w04	0.00	0.00	2.00	4.00	10.00	4.00
5	w05	0.00	0.00	2.00	4.00	10.00	4.00
6	w06	0.00	0.00	2.00	4.00	10.00	4.00
7	w07	0.00	0.00	2.00	4.00	10.00	4.00
8	w08	0.00	0.00	2.00	4.00	10.00	4.00
9	M01	0.00	0.00	2.00	4.00	10.00	4.00
10	M02	0.00	0.00	2.00	4.00	10.00	4.00
11	M03	0.00	0.00	2.00	4.00	10.00	4.00
12	M04	0.00	0.00	2.00	4.00	10.00	4.00
13	M05	0.00	0.00	2.00	4.00	10.00	4.00
14	M06	0.00	0.00	2.00	4.00	10.00	4.00

View by: ☐ Week ☐ Month ☒ Year

7/8 Indirect Economic Loss Parameters - Stimulus

Define the amount of reconstruction stimulus anticipated in addition to building and lifetime repairs, and reconstruction.

Stimulus values:

#	TimeInterval	Sector	Stimulus
1	M01	TRNS	32.00
2	M13	MINE	22.00
3	M14	AGRI	0.00
4	w01	CNST	12.00
5	Y03	MISC	0.00
6	Y03	MNFG	0.00
7	Y03	TRDE	0.00
8	Y04	FIRE	0.00
9	Y05	GOVT	0.00
10	Y05	SERV	0.00

8/8 Indirect Economic Loss Parameters - Completed!

You have successfully completed the Indirect Economic Loss Parameters collection. You have specified the following settings:

Study Region Economy

Annual Income (mil) = \$0.492392

Number of Employees = 20.0587

Synthetic Economy Type = Service economy with trade being secondary sector

Percentage of rebuilding = 95%

Unemployment rate = 6%

Outside Aid = 50%

Interest Rate = 5%

To complete the Indirect Economic Loss Parameters collection, click Finish.

< Back Finish Cancel

Figure 31 Setting up Indirect Economic Loss Parameters (1)

Source: HAZUS-MH Software (FEMA 2007).

The other type of analysis is Flood Warning – a “What-If” type analysis. People in general assume that damage and losses can be reduced with effective flood warning although there are disagreements over possible reduced damage based on effective

warning, and about the amount of reduction. The Flood model bases the calculations on the USACE Day curve, which tries to quantify the maximum level of damage reduction according to the time a flood warning has been available (EPA 2004). The curve itself assumes around 35% each for structural, content, and business inventory losses independent of how much warning is available. The flood model provides the Day curve in the Technical Manual and allows input of time of warning and expected reduction in damage, and calculates damage accounting for the anticipated reduction. There is no guidance on the amount of vehicular damage. Although HAZUS-MH suggests that this value is relatively high, the value is open (0-100% of the vehicles value). Values are input based on assumptions or knowledge as shown in Figure 31. The values assumed in Figure 32 take into consideration a two day weather forecast (48 hour warning) that reduces the impacts. For example, the Seaford area is just a part of the State of Delaware, and special transportation services can be used for evacuation (i.e., car pooling, Paratransit buses).

Category	Parameter	Value
Structure loss reduction	Enter expected reduction in structure flood loss due to flood warning (0-35%)	10
Content loss reduction	Enter warning time (hrs)	48
	Expected loss reduction (0-35%)	10
Inventory	Enter warning time (hrs)	48
	Expected loss reduction (0-35%)	10
Vehicles	Expected percentage of vehicles to be moved from flood plain (0-100%)	20

Figure 32 Flood Warning Assumptions for Analysis
Source: completed in (FEMA 2007).

The analysis for annualized loss is only enabled if the flood hazard annualized loss was calculated. Here one can determine their maximum potential annual loss. If trying to do this analysis an error message like the one shown in Figure 33 comes up, is because some steps are missing.

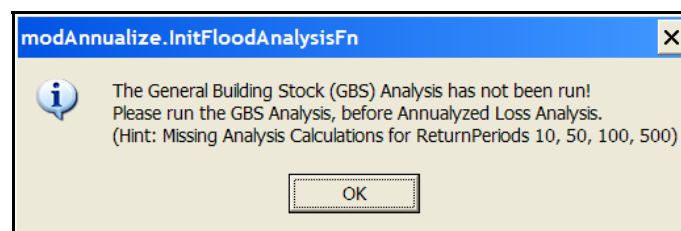


Figure 33 Error Message for Annual Loss Analysis
Source: HAZUS-MH Software (FEMA 2007).

To run the analyses the following steps are required:

Go to Hazard > Riverine > Delineate Floodplain submenu > Annualized Loss.

This ensures all necessary flood depth grids to perform the analysis are available. Then:

Go to Analysis menu > Run > check for general building stock (as shown in Figure 34) >

OK. This “creates the analysis results from the return periods analyzed” (FEMA 2007).

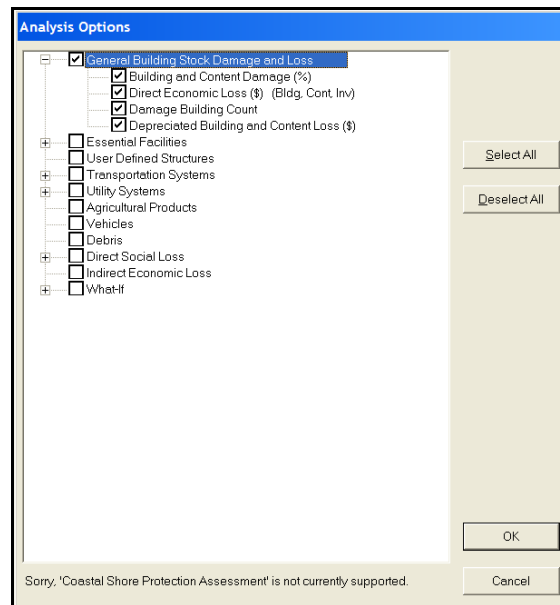


Figure 34 Preparing for Annualized Loss Analysis

Source: completed in (FEMA 2007).

Go to Analysis Menu > Annualized Loss > OK.

This sets up the flood model analysis for interpolating and extrapolating for other return periods, developing a maximum annual loss probability. Only if the General Building Stock (GBS) analysis for Annualized Losses is successfully done in the Hazard phase will this new phase under the Analysis menu work and give answers for building analysis results. For the other options simply based on estimations and no detailed analysis, such as for Transportation Systems and “What If” scenarios mitigation possibilities, the Annualized Losses do not need to be completed. Click OK in the prompt and HAZUS-MH then informs the user that the procedure has been successful.

The way the HAZUS-MH data inventory was built to serve damage and loss estimation did not include features/specifications for enabling other type of analysis such as Network Analyst. The HAZUS-MH data inventory limits the use of a system-of-systems analysis and the inclusion of performance measures for the road network. For example, the rerouting analysis is intended to provide alternatives for traffic flow continuity. This is why the GIS software even without HAZUS-MH is essential for doing a better analysis and the development of mitigation strategies.

To run the complete Analyses, go to Analysis menu > Select All > OK. HAZUS-MH will run the default analyses including General building stock, Essential facilities, Selected infrastructure (bridges and water systems), Agriculture products, Vehicles, Debris, and Shelter requirements.

To obtain the loss estimation results first specify the desired scenario. This selection includes Scenario Name, Return Period, and Analysis Options. Results can be maps, tables and summary reports. Select “Results” menu > View Current Scenario Results By > select one of the available hazard analyses (i.e., Annual_Losses). Figure 35 shows the dialog box for creating a scenario. Click OK. The available results even include a 500-year return period scenario. Choosing 100-year produces the same results as for a Single Return Period when no “What-If” options are added to the analysis.

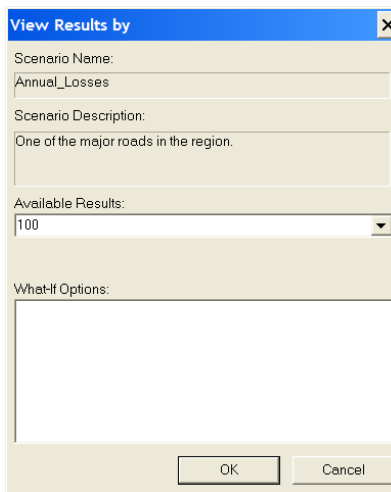


Figure 35 Selecting Available Results to View
Source: completed in (FEMA 2007).

In this scenario there are no “What-If” options. However, one must remember the flood warning was set up and this is a what-if option. Go to the Results menu > Flood Hazard Maps > Thematic Map of Depth. Verify layers and legend. The exported map is shown in Figure 36.

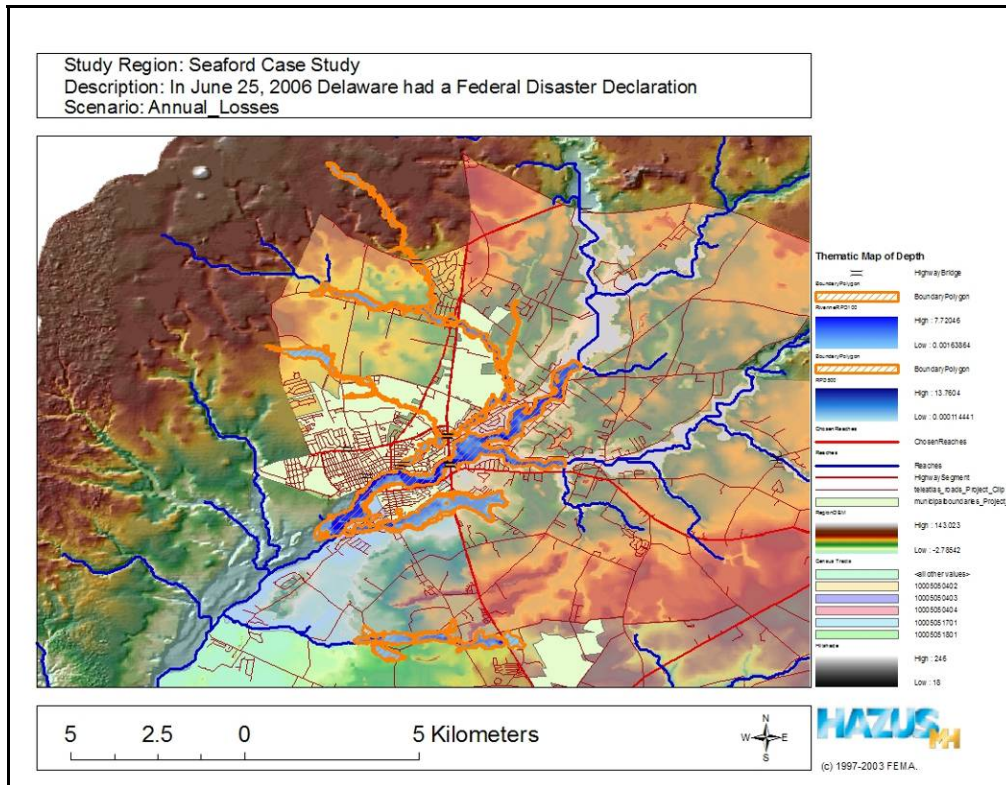


Figure 36 Seaford Area Annual Losses Map of Depth

Go to Results menu > Summary Reports as shown in Figure 37. This opens a dialog with different Tabs for accessing the resulting analysis.

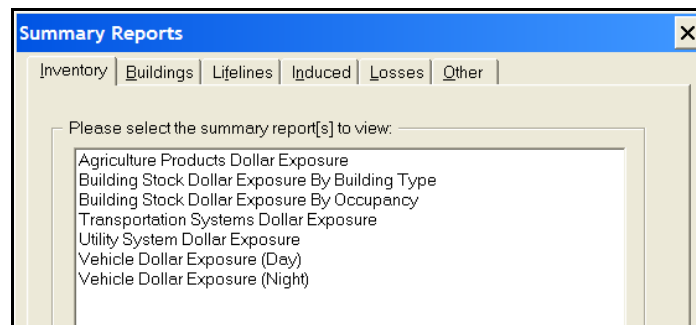


Figure 37 Summary Reports Options

Source: HAZUS-MH software (FEMA 2007).

A detailed table for Transportation System Damage/Economic Loss cannot be found under the Results menu, but the estimation totals mentioned earlier can be read under the Summary Reports > Inventory > Transportation System Dollar Exposure, shown in the HAZUS-MH output Table 12. The only information that is going to be used in the simulation in STELLA is the total for Highway Segments. The exposure estimate value is quantification for measuring asset vulnerability to the hazard (FEMA 2004).

Table 12 Summarized Report for Transportation System Dollar Exposure

Transportation System Dollar Exposure								
October 27, 2008				All values are in thousands of dollars				
	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airport	Total
Delaware								
Sussex								
Segments	205,419.68	31,130.00	0.00	0.00	0.00	0.00	67,754.40	304,304.08
Bridges	14,754.85	0.00	0.00	0.00	0.00	0.00	0.00	14,754.85
Tunnels	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Facilities	0.00	0.00	0.00	1,188.10	0.00	0.00	5,940.50	7,128.60
Total	220,174.53	31,130.00	0.00	1,188.10	0.00	0.00	73,694.90	326,187.53
Total	220,174.53	31,130.00	0.00	1,188.10	0.00	0.00	73,694.90	326,187.53
Study Region Total	220,174.53	31,130.00	0.00	1,188.10	0.00	0.00	73,694.90	326,187.53

Source: output from (FEMA 2007).

Other exposure estimates are available in the Summary Reports option for vehicles for day and for night. Estimates are shown in Table 13.

Table 13 Summarized Report for Vehicle Dollar Exposure for Day and Night

Vehicle Dollar Exposure (Day)				
October 27, 2008		All values are in dollars.		
	Cars	Light Trucks	Heavy Trucks	Total
Delaware				
Sussex				
	\$18,348,379	\$7,716,041	\$14,283,286	\$40,347,705
Total	\$18,348,379	\$7,716,041	\$14,283,286	\$40,347,705
Study Region Total	\$18,348,379	\$7,716,041	\$14,283,286	\$40,347,705
Vehicle Dollar Exposure (Night)				
October 27, 2008		All values are in dollars.		
	Cars	Light Trucks	Heavy Trucks	Total
Delaware				
Sussex				
	\$31,063,632	\$13,063,184	\$24,181,468	\$68,308,285
Total	\$31,063,632	\$13,063,184	\$24,181,468	\$68,308,285
Study Region Total	\$31,063,632	\$13,063,184	\$24,181,468	\$68,308,285

Source: output from (FEMA 2007).

While none of this information is used in the simulation in STELLA, the analysis provides some insight into the amount of damage in dollars related to the number of cars in the area at different periods of time.

The estimated debris can be seen by going to the option “Induced” > Debris Generated > View. Table 14 shows the totals by all debris types for Sussex.

Table 14 Summarized Report of Estimation for Debris

Debris Summary Report				
October 27, 2008		All values are in tons.		
	Finishes	Structures	Foundations	Total
Delaware				
Sussex	1,709	323	765	2,797
Total	1,709	323	765	2,797
Scenario Total	1,709	323	765	2,797

Source: output from (FEMA 2007).

The information about debris is useful to organize resources for cleaning up the region, and designating proper places to dispose of this material. This is a typical activity in the recovery phase following a disaster.

The only Summary Report available for Annualized Loss – Annual return period, is the Annualized Direct Economic Losses for Buildings under the Losses tab. This is because HAZUS-MH focuses on building assets using a more complete inventory and analysis. Table 15 shows the details for capital stock losses and income losses.

Table 15 Summary Report for Annualized Direct Economic Losses for Buildings

Direct Economic Annualized Losses for Buildings									
October 28, 2008		All values are in thousands of dollars							
	Capital Stock Losses			Building Loss Ratio %	Income Losses				Total Loss
	Cost Building Damage	Cost Contents Damage	Inventory Loss		Relocation Loss	Capital Related Loss	Wages Losses	Rental Income Loss	
Delaware									
Sussex	8,259	12,815	204	1.9	34	45	255	12	21,624
Total	8,259	12,815	204	1.9	34	45	255	12	21,624
Scenario Total	8,259	12,815	204	1.9	34	45	255	12	21,624

Source: output from (FEMA 2007).

Under the Losses tab, HAZUS-MH shows zero direct economic losses for transportation. However, the estimate of economic losses for vehicles is shown in Table 16.

Table 16 Summary Report for Direct Economic Loss for Vehicles Day and Night

Direct Economic Losses For Vehicles (Day)				
October 28, 2008				
All values are in dollars.				
	Car	Light Truck	Heavy Truck	Total Loss
Delaware				
Sussex	\$657,077	\$165,625	\$80,197	\$902,899
Total	\$657,077	\$165,625	\$80,197	\$902,899
Scenario Total	\$657,077	\$165,625	80,197	\$902,899
Direct Economic Losses For Vehicles (Night)				
October 28, 2008				
All values are in dollars.				
	Car	Light Truck	Heavy Truck	Total Loss
Delaware				
Sussex	\$661,819	\$169,697	\$86,853	\$918,369
Total	\$661,819	\$169,697	\$86,853	\$918,369
Scenario Total	\$661,819	\$169,697	86,853	\$918,369

Source: output from (FEMA 2007).

There are no results for Indirect Economic Impact with or without Aid for Income and Employment Impact with outside aid. This result accounts for several different economic sectors including agricultural, mining, transportation, trade, services, and government.

The shelter needs under the Losses tab are shown in Table 17.

Table 17 HAZUS-MH Shelter Summary Report

Shelter Summary Report		
October 28, 2008		
	# of Displaced People	# of People Needing Short Term Shelter
Delaware		
Sussex	1,035	678
Total	1,035	678
Scenario Total	1,035	678

Source: output from (FEMA 2007).

To assemble the results, Go to Results > Summary Reports > Other > Quick Assessment Report> Single Return Period Scenario. There are no differences in the Quick Assessment Report when the year of analysis chosen for both is for a 100-year event. The report is shown in Figure 38 for a Single Return Period. This report shows no specific information for transportation. Most of this information is not essential for the STELLA model for analyzing the transportation infrastructure.

Quick Assessment Report	
October 28, 2008	
Study Region :	Seaford Case Study
Scenario :	Single_Return_Period
Return Period:	100
Analysis Option:	0
Regional Statistics	
Area (Square Miles)	135
Number of Census Blocks	915
Number of Buildings	
Residential	11,414
Total	12,291
Number of People in the Region (x 1000)	27
Building Exposure (\$ Millions)	
Residential	1,078
Total	1,480
Scenario Results	
Shelter Requirements	
Displaced Population (# Households)	
Short Term Shelter (# People)	
Economic Loss	
Residential Property (Capital Stock) Losses (\$Millions)	12.16
Total Property (Capital Stock) Losses (\$ Millions)	21.28
Business Interruptions (Income) Losses (\$ Millions)	0.35

Figure 38 Quick Assessment Report for a Single Return Period

Source: Output from (FEMA 2007).

Another result option is the overall summary of the analysis. Go to Results > Summary Reports > Other > Global Summary Report. This option generates a report with many pages. This report is not relevant, because, once again, it focuses in buildings, and the best result possible to use for transportation infrastructure analysis is the value of exposure. Therefore the actual report is not replicated in this working paper. This type of report generated is identical to that for the Single Return Period with no “What-If” scenario added, both for 100-year event. However if a “What-If” scenario for a Levee is considered for the Single Return Period, and the analysis for GBS is not completed, the differences are:

- Building Exposure by Occupancy Type for the Scenario values do vary as shown in Figure 39,
- GBS Damage is not estimated because the analysis was not done,
- Induced Flood Damage – Debris Generation numbers vary (i.e., 2,797 tons requiring 112 truckloads to remove debris in the Annual Loss Scenario, and 2,965 tons requiring 119 truckloads to remove debris in the Single R.P. Levee Scenario),
- Social Impact – Shelter Requirements numbers vary (i.e., 345 households displaced and 678 people needing temporary shelters in the Annual Loss Scenario, and 353 households displaced and 673

people needing temporary shelters in the Single R.P. Levee Scenario), and

- Economic Loss – Building-Related Losses are not estimated because analysis was not done.

Building Exposure by Occupancy Type for the Scenario			Building Exposure by Occupancy Type for the Scenario		
Occupancy	Exposure (\$1000)	Percent of Total	Occupancy	Exposure (\$1000)	Percent of Total
Residential	307,736	72.7%	Residential	319,933	74.2%
Commercial	89,543	21.1%	Commercial	85,604	19.9%
Industrial	12,150	2.9%	Industrial	12,221	2.8%
Agricultural	1,515	0.4%	Agricultural	1,645	0.4%
Religion	7,296	1.7%	Religion	7,213	1.7%
Government	3,098	0.7%	Government	2,286	0.5%
Education	2,248	0.5%	Education	2,248	0.5%
Total	423,586	100.00%	Total	431,150	100.00%

Figure 39 Comparison between Global Summary for Annual Loss and Single Return Period – Levee
Source: output from (FEMA 2007).

Discussion and Evaluation – HAZUS Results

These results show how some possible mitigation options impact the overall problem. The option of building a Levee at the location shown in Figure 20 aggravates the flooding problem instead of minimizing it.

Therefore, it is important to evaluate the results to determine if they are reasonable and ready to be used. The decision-makers should give their inputs, and also there should be a comparison to the real event that took place and the historical, documented losses such as Table 10 and the related graph in Figure 25. Considering the factors that can impact the study region, the results can be rerun and documented to support mitigation strategies. At this stage one can identify the assets that are subject to the greatest potential damage (FEMA 2004).

The outputs from HAZUS-MH in relation to the type of transportation infrastructure this research focuses on favors bridges. Because the goal of this research focuses on mitigation measures for roads, the broader perspective provided by HAZUS-MH only gives limited insights into specific measures to mitigate damage and losses. This leads to the last step in the process for considering the mitigation options developed.

The last step in HAZUS-MH is to consider mitigation options associated and responsive to the losses calculated with an emphasis on the building inventory. In “HAZUS-MH, losses are estimated based on the *cost to repair or replace damage to, or loss of, the building inventory*” (FEMA 2004). The effectiveness of regulatory or technical (protection or control) mitigation measures must rely on the expertise of professionals and the knowledge of local perspectives and needs. Mitigation options must be evaluated for effectiveness, acceptability, and feasibility with respect to prevailing conditions in the community. This evaluation is meant to help narrow and prioritize options considering the ones that have the greatest chance for effective implementation, including local and state resources. The questions to be answered, based on FEMA (FEMA 2004) and tailored to transportation infrastructure, are

- Which mitigation measures are most appropriate for the risk associated to the local roads for the community?
- Is there sufficient capability to implement these measures and assistance needed?
- How will the implementation of these measures impact the road condition for the community?

As one can imagine, these answers require further analysis that the present version of HAZUS-MH does not provide. The STELLA model is designed to provide this analysis.

The evaluation of mitigation options in HAZUS-MH follows these steps (FEMA 2004)

1. identify the range of preliminary mitigation options by structure (and by hazard);
2. review the appropriateness of measures according to needs and desires of the community;
3. evaluate implementation of possible mitigation options in terms of effectiveness for reducing risk; and
4. determine mitigation option conflicts if considering a combination of hazards, and help integrate options into the mitigation plan.

The identification of preliminary mitigation options based on HAZUS-MH loss estimates starts by selecting the area of major loss. This was already defined as the transportation infrastructure, independent of other areas. This information is not present in the Global Summary Report for Annualized Losses, and as explained earlier, there is no value calculated in HAZUS-MH for direct economic loss analysis for transportation. The basic information available is the estimation for transportation exposure presented in Table 11. For the study region, the highway segments are valued at US\$205,419.68 (thousands of dollars). However, exposure and loss are not the same. Making the assumption that the segments at risk are 15% of the total exposure value; losses can be estimated as US\$30,812.95 (thousands of dollars). This accounts for the highway segments that are vulnerable due to proximity to rivers and flood-prone areas. For these segments mitigation measures are needed that consider the site/location. These mitigation measures may include regulatory measures in the form of design standards (building codes). This vulnerability also leads to looking at structural needs. In other words, mitigation measures can be both structural and regulatory measures that include options for rehabilitation, protective and control (FEMA 2004). Examples of regulatory measures include

- legislation intended to protect community from hazards (organizes and distribute responsibilities),
- financial and social impact reduction regulations (i.e., insurance),
- building codes,
- land use and zoning regulations,

- incentives for implementing mitigation measures,
- emergency preparedness measures to help protect people and property against hazard (during and after event),
- education (public awareness),
- natural resource protection (preserve and restore natural systems).

Regulatory mitigation measures for floods can be used to guide development to non-flood prone areas and to ensure that flooding hazards are addressed in new developed flood-prone areas through floodways and/or riverine flooding. Floodplain regulations and building codes recognize hazards and address flood loads in planning and design of new buildings and infrastructure. The codes can be/are applied to damaged buildings that need repair or reconstruction, imposing the same degree of protection for new constructions (old buildings rehabilitation, elevation-in-place, floodproofing design to flood levels).

The rehabilitation of infrastructure facilities is related to structural and non-structural modifications of its elements. The idea is to improve safety and reduce the impact of hazard events. The risk to the infrastructure is often because of its location in a hazard-prone area. The level of damage relates the structural design and construction quality with respect to the capability for resisting the forces of nature and the intensity of the event. Location and structure combined can increase infrastructure vulnerability, which mitigation measures must take in consideration. Mitigation measures could be to remove, relocate, and/or to elevate structures in-place. Each of these possible measures has different costs. That is when the community and stakeholders must prioritize options by importance and vulnerability.

Application to the Case Study

These options guided the further assessment of US13 using the STELLA model for the case study. Damage to transportation infrastructure related to US 13 due to the flood of June 25, 2006 are shown in Figure 40.



Figure 40 Damage related to US13 in Sussex County
Source: (Parsons 2006; DelDOT-TMC 2006).

Three traffic detours were also set up during the event. These detours was defined and documented using a physical map as shown in Figure 41.



Figure 41 Detours Set Up during the Flood of June 25, 2006
Source: (DelDOT-TMC 2006).

Rehabilitation of existing structures recognizing a preselected flood level can reduce damage provided more severe flooding does not occur. Acquisition and demolition of building in flood-prone areas reduces exposure and helps restore the natural function of floodplains. Relocation of buildings to higher ground, and retrofit of infrastructure (i.e. modified bridges that reduces backwater flooding) are examples of other possible measures.

Protective and control measures focus on “deflecting the destructive forces from vulnerable structures and people, or erecting protective barriers” (FEMA 2004). Examples are levees, dams and reservoirs, discharge canals, floodwalls, shelters, and protective vegetation belts. These measures modify the source/path of flooding to direct floodwaters away from developed areas (structural flood control measures). They include decreasing runoff, and augmenting the capacity for discharge, floodwater containment, diversion, and storage. These measures may not be feasible in all contexts or locations.

The review of mitigation measures must consider FEMA’s evaluation criteria for proposals. The criteria, referred to as the STAPLEE evaluation criteria, are already partially taken in consideration in the HAZUS-MH software. These evaluation criteria --

social, technical, administrative, political, legal, economic, and environmental – capture opportunities and constraints for mitigation measures as follows:

- Social criteria looks to develop a community consensus for implementing the mitigation measures.
- Technical criteria take care of technical feasibility, which includes effectiveness, secondary impacts, implementation and sustaining technical capabilities.
- Administrative criteria look at organizations, staff, and funding sources.
- Political criteria include the support for mitigation measures from stakeholders, political organizations and institutions inside and outside the community.
- Legal criteria look for the appropriate legal authority to implement each individual measure, besides codes, ordinances, and more.
- Economic criteria looks at cost-effectiveness and impacts of measures even to future development, which benefits are expected to exceed costs.
- Environmental criteria look for benefiting the environment.

These evaluation aspects can be better included in the analysis in the model developed in STELLA. These criteria begin to provide a timeframe for mitigation and avoid problems such as obsolescence or infeasibility. Figure 42 shows the factors being considered for evaluating and adopting a mitigation measure, where a (+) sign must be assigned for favorable evaluations, a (-) sign for less favorable evaluations, and an N/A if not applicable. The assumption made here is that some mitigation measures developed have less favorable evaluations, and thus are taken out of the list of mitigation options.

STAPLEE Criteria	S Social	T Technical	A Administrative	P Political	L Legal	E Economic	E Environment
Considerations → For Alternative Actions ↓	Community Acceptance Effect on Population Segment	Technical Feasibility Long-term Solution Secondary Impacts	Staffing Funding Allocated Maintenance Operations	Political Support Local Champion Public Support State Authority	Existing Local Authority Potential Legal Challenge	Benefit of Action Cost of Action Contributes to Economic Goals Outside Funding Required	Effect on Land/Water Effect on Endangered Species Effect on HAZMAT Sites Consistent w/ Community Environmental Goals Consistent w/ Federal Laws
Comments:							

Figure 42 STAPLEE Criteria for Evaluating Mitigation Measures

Source: (Rock Island County 2008).

The final identification of the options for mitigation is based on the evaluation and comparison of measures. “The flood model has a built-in feature specifically designed to support mitigation planning” (FEMA 2004), with “what if” scenarios (i.e., levee for flood depths, flow regulation for new reservoirs) that tests mitigation measures producing

new loss estimates. As shown before, the available mitigation option for Levee applied to that location does not lessen the problem. The following analysis considers the results for the Annualized Losses scenario from HAZUS-MH, principally because current results do little for transportation infrastructure.

The verification of mitigation options first considers conflicting measures among different hazards. As this case study is only assessing flooding issues, there are no conflicting mitigation measures in relation to different hazards. Then there is the confirmation of options (a decision) and the integration of it in the mitigation plan which must meet the DMA 2000 requirements.

A summary of the outputs for recovery and mitigation measures for this case study is shown in Table 18 modified from FEMA's guide (FEMA 2004).

Table 18 Summarized Mitigation Measures based on HAZUS-MH and History for Transportation Infrastructure - Roads

Mitigation Activities	Output	Completed Items
Preliminary options	<p>Regulatory measures:</p> <ul style="list-style-type: none"> • reinforcement of construction codes (i.e., elevate degree of protection for rehabilitation, elevate-road design to flood level, engineering design improvement, site access points, roadway/pedestrian paths) • incentives for mitigation measures implementation, flow regulation • education measures (public awareness) • natural resource protection measure (preserve and restore natural systems) <p>Rehabilitation measures (cost, importance, vulnerability?):</p> <ul style="list-style-type: none"> • structural and non-structural modifications of road segments (i.e. increase structural resistance – impact load, retrofit roadways, enlarge road shoulders) • improve highways lights and signs • remove, relocate, and/or to elevate roads/road segments to meet new performance objectives <p>Protective and control measures</p> <ul style="list-style-type: none"> • floodwalls, levee, warning system (i.e., based on weather forecast) • protective vegetation belts • review and build connections 	<p>HAZUS-MH mitigation insights</p> <p>✓</p>

Continue Table 18.

Review of options	<p>Regulatory measures:</p> <ul style="list-style-type: none"> • reinforcement of construction codes (i.e., elevate degree of protection for rehabilitation, elevate-road design to flood level, engineering design improvement, site access points, roadway/pedestrian paths) <p>Rehabilitation measures (cost, importance, vulnerability?):</p> <ul style="list-style-type: none"> • structural and non-structural modifications of road segments (i.e. increase structural resistance – impact load, retrofit roadways, enlarge road shoulders), • improve highways lights and signs • remove, relocate, and/or to elevate roads/road segments to meet new performance objectives <p>Protective and control measures</p> <ul style="list-style-type: none"> • floodwalls, warning system (i.e., based on weather forecast) • review and build connections 	STAPLEE ✓
Final list of options	<p>“Impossible with current HAZUS-MH functions, for exception for the adoption of warning system already included in current results.”</p> <p>Although the listed mitigation options could all be analyzed for US13, these options are later carefully reviewed to reach an improved resilience of transportation system goal. HAZUS-MH does not discuss resilience.</p>	To be further explored in STELLA
Verification of options	No conflicting measures to mitigate hazard impact.	✓

Source: modified from (FEMA 2004).

The integration of measures into mitigation plans is considered only for the transportation infrastructure at the local level, which in Delaware in general is under the responsibility of the Department of Transportation. The impacts affecting the community also fall under the responsibility of the Delaware Emergency Management Agency (DEMA). Therefore these are the two primary decision-makers in the process. However because FEMA is the primary agency responsible for disaster related funding, this agency is also included as a decision-maker. (Also HAZUS-MH was specially developed for FEMA and this is reflected in the analysis.) While there are suggestions that include these decision-makers in the HAZUS-MH analysis process, there is no input in the current model of the decision process. The only inputs are for data and alterations to the current models.

The current data, inventory, analysis and estimation results, and mitigation insights coming from HAZUS-MH included in the STELLA model are described in the “Developing the STELLA Model for a DSS for Mitigation Strategies for Transportation Infrastructure” working paper. There are no realistic results to be communicated to the public, stakeholders or decision makers from the current results. Decision-makers and the decision-process are represented in STELLA in terms of developing mitigation measures focusing on improving the resilience of transportation system, using as an example highway US13.

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References

- Bay Bridge Public Information Office. 2007. *Fact sheet – Self-anchored Suspension Span: The San Francisco-Oakland Bay Bridge Seismic Safety Projects.* , ed. Caltrans, Bay Area Toll Authority, California Transportation Commission.
- DelDOT-TMC. 2006. *Detours map for June 25, 2006.*
- . 2006. *Pictures of US13 damage.* US13 damage due to flooding 06/25/2006., ed. Delaware Department of Transportation, Transportation Management Center.
- EPA. 2004. *Appendix B - flood damage analysis.* Government of California, Environmental Protection Agency, http://www.economics.water.ca.gov/downloads/Colusa/appendixb_fdr_analysis.pdf (accessed 06/02/2009).
- ESRI. 2007a. *ArcGIS desktop - ArcInfo.* Vol. 9.2.
- . 2007b. *ESRI service pack 3.* Patches and service packs - ESRI support. <http://support.esri.com/index.cfm?fa=downloads.patchesServicePacks.viewPatch&PID=17&MetaID=1315> ed. Vol. 2008ESRI (accessed 10/23/2008).
- . 2007c. *ESRI service pack 5.* Patches and service packs - ESRI support. <http://support.esri.com/index.cfm?fa=downloads.patchesServicePacks.viewPatch&PID=66&MetaID=1377> ed. Vol. 2008ESRI (accessed 10/23/2008).
- FEMA. 2007. *FEMA library - HAZUS-MH MR3 patch 2.* FEMA library - HAZUS-MH MR3 patch 2. <http://www.fema.gov/library/viewRecord.do?id=3369> ed. Vol. 2008Federal Emergency Management Agency (accessed 10/23/2008).
- . 2007. *FEMA: HAZUS-MH MR3 Technical Manual,* ed. National Institute of Building Sciences. Washington D.C.: FEMA (accessed 10/23/2008).
- . 2007. *Multi-hazard loss estimation methodology - flood model.* HAZUS-MH MR3 flood user manual., ed. National Institute of Building Sciences. 2007th ed. Vol. 2007. Washington D.C.: FEMA, <http://www.fema.gov/library/viewRecord.do?id=2898> (accessed 07/07/2007).
- . 2004. *FEMA: FEMA 433 - using HAZUS-MH for risk assessment.* HAZUS-MH risk assessment and user group series - how-to guide. http://www.fema.gov/plan/prevent/hazus/dl_fema433.shtm ed.FEMA, <http://www.fema.gov/pdf/plan/prevent/hazus/fema433.pdf> (accessed 09/02/2008).
- FEMA. 2007. *HAZUS-MH MR3 software.* Vol. MR3. Washington D.C.: Federal Emergency Management Agency.
- isee systems, Inc. 2004. *An introduction to systems thinking - STELLA software* isee systems, www.iseesystems.com (accessed 02/07/2008).
- Parsons, Kye. 2006. Victims of flooding seek state, federal help. , <http://www.wboc.com/Global/story.asp?S=5087000> (accessed 09/15/2008).
- Rock Island County. 2008. *III. RISK ASSESSMENT.* Rock Island County, 2008 (accessed 10/28/2008).

- USGS. The national map seamless server viewer. in U.S. Department of Interior; U.S. Geological Survey [database online]. 2008 [cited 10/28/2008 2008]. Available from <http://seamless.usgs.gov/website/seamless/viewer.htm> (accessed 10/28/2008).
- . Free GIS data - GIS data depot. in GeoCommunity and Digital Data Services [database online]. 2007 [cited 09/02/2008 2008]. Available from <http://data.geocomm.com/dem/demdownload.html> (accessed 10/02/2008).
- . 2006. *Flood management benefits of USGS stream gauging program*, http://water.usgs.gov/osw/pubs/Flood_Management_benefits_complete.pdf (accessed 06/02/2009).
- . USGS Science Helps Build Safer Communities, Flood Hazards-A National Threat. Fact Sheet 2006 – 3026. in U.S. Department of the Interior; U.S. Geological Survey. 2006 [cited 04/10/2007]. Available from <http://pubs.usgs.gov/fs/2006/3026/2006-3026.pdf> (accessed 04/10/2007).
- University of Delaware Research and Data Management Services. Delaware DataMIL. in State of Delaware Department of Technology and Information [database online]. 2008 [cited 10/28/2008 2008]. Available from <http://datamil.delaware.gov/> (accessed 10/28/2008).