Potential Contribution of Hazus-MH to Flood Risk Assessment in the Context of the European Flood Directive

by

Giedrius Kaveckis

Master Thesis

Submitted in partial fulfillment of the requirements for the degree

Master of Science in Engineering

Spatial Information Management

Carinthia University of Applied Sciences

School of Geoinformation

Supervisors:

Dr. Gernot Paulus

Dr. Karl-Heinrich Anders

Carinthia University of Applied Sciences

Kevin Mickey

Polis Center, Indiana University-Purdue University Indianapolis

Villach, September 2011

Science Pledge

By my signature below, I certify that the thesis is entirely the result of my work. I have cited all sources that I used in my thesis, and I always indicated their origin.

________________ 2011 September, Villach

(Giedrius Kaveckis)

Abstract

Floods are one of the deadliest hazards and affect the most people when they occur. Because of the increasing population in the floodplains and the nature cataclysms, the number of casualties and the cost of damage from flooding increases every year. For that reason the European member states enacted the European Flood Directive. One of its requirements is to deliver flood hazard and risk maps. In this thesis, the European flood mapping requirements and best practices are described. This master's thesis primarily focuses on the Hazus-MH tool, which was successfully used in the United States for flood mapping needs. The main problem is that Hazus was created only for use in the U.S., and existing administrative limitations presents a challenge for users from other countries. The challenge of this research is to create implementation that would enable a Hazus user to perform flood analysis for Europe by using the same methodology. To this end, this thesis analyzed the default Hazus methodology of flood assessment in detail and provides the overview and evaluation of flood hazard and inventory data taken from the Hazus-MH tool. As implementation, it was decided to create the new study region in Europe, based on standardized European administrative units. This task was achieved by adding new geographical regions to the default Hazus datasets. The step-by-step implementation and the new framework for applying the Hazus Flood Model in Europe is briefly described in the thesis. The essential input data parameters and requirements are also described. The implementation's testing and validation was carried out by applying it to a local Austrian case study. The tests showed a successful non-U.S. dataset integration in the Hazus tool and affirmed the result's dependency on the quality of input data. Additionally, this research is also intended to assist communities that have no financial support but that want to perform flood assessments at the local level. The additional tools and datasets, together with Hazus, as freely available tool would enable communities to perform their own flood assessments with ease.

Acknowledgements

This project would not be successful without support from many people and agencies. First of all, I would like to thank the Marshall Plan Foundation, who financed my visit to and research at The Polis Center in Indianapolis, Indiana. I hope that mine and my colleagues' efforts improved the scientific relations between the United States of America and Austria.

Big thanks to both my supervisors, Gernot Paulus and Kevin Mickey, who provided constructive criticism and feedback on my research. I especially want to thank Grace Colette and Dave Coats; their guidance and support helped me get comfortable in Indianapolis pretty quickly and made my visit unforgettable. The new experience of various projects and meetings gave me much knowledge in such a short time than I could have imagined possible. For that I want to thank The Polis Center staff: Jack and Chris Schmitz, John Buechler, Kevin Mickey, Melissa Gona, John Hayes, Sonia Davidson, Jim Dowling, Goutami Nalla, Laura Danielson, Neil Devadasan, Miranda Ritchie, Ryan Richard Stevens, Matthew Riggs, Ellen Van De Voorde, Dave Coats, Jennifer Gilles, and many others. They are the best colleagues that I have ever had. All of these people helped me to feel at home during my time in Indianapolis.

Also I want to thank the FEMA Mitigation Division, and the Indiana state NRCS and DNR agencies for their support and cooperation during this project.

Special thanks to the Carinthia University International Office, Aleksandra Jama; and the IUPUI International Affairs Department, Mary Upton and Brittany Lowe. Their help coordinating my visa and financial arrangements was very useful.

And finally, I would like to thank my friend Maria, my family, relatives, and all of my friends for their support.

List of Abbreviations

AEP – Annual Exceedance Probability
ASTER – Advanced Spaceborne Thermal Emission and Reflection
CDMS – Comprehensive Data Management System
CRED – Centre for Research on the Epidemiology on Disasters
DEM – Digital Elevation Model
DF – Debris Factor
DMA – Disaster Mitigation Act
EC – European Commission
ECE – Economic Commission for Europe
EFD – European Flood Directive
EU – European Union
EXCIMAP – European Exchange Circle on Flood Mapping
FAO – Food and Agriculture Organization
FEMA – Federal Emergency Management Agency
FIRM – Flood Insurance Rate Map
FIT – Flood Information Tool
GAUL – Global Administrative Unit Layers
GBS – General Building Stock
GIS – Geographical Information Systems
GRS –Geodetic Reference System
ISDR – International Strategy for Disaster Reduction
Hazus-MH – Hazards U.S. Multi-Hazards
HEC- HMS – Hydrologic Engineering Center – Hydrologic Modeling System
HEC-RAS – Hydrologic Engineering Center – River Analysis System
HPL – High Potential Loss (facilities)
HR – Hazard Rating
LAU – Local Administrative Units
LIDAR – Light Detection and Ranging
MCDC – Missouri Census Data Center
NAD – North American Datum
NADA – National Automobile Dealer Association
NED – National Elevation Dataset
NRCS – Natural Resources Conservation Service
OPW – Office of Public Works
OSM – Open Street Map
RPC – Regional Planning Commission
SCS – Soil Conservation Service
SIC – Standard Industrial Code
SFVI – Social Flood Vulnerability Index
UDF – User Defined Facilities
USACE – Unites States Army Corps of Engineers
USDA – Unites States Department of Agriculture
UN – United Nations
UNOSAT – United Nations Operational Satellite Applications Programme
WGS – World Geodetic System

Table of Contents

1. Introduction

In the first half of 2011, the world suffered from major flooding disasters: the 9.0 magnitude earthquake that caused a tsunami in Japan; floods in Australia, Brazil, and Sri Lanka; the enormous flooding in the central part of the USA. All these events caused extensive property damage and human casualties, and many people lost their homes and were displaced. Nevertheless, the occurrence of these disasters and the gravity of the damage does not decrease the number of people who relocate to these cities and river valleys that are predisposed to flooding. Human nature likes the challenge and thinks that it is possible to deal with whatever nature throws at them.

Instead of thinking about how to protect ourselves from flooding, we should focus more on how to decrease our vulnerability and reduce risk. Yet even this issue is a huge headache for many experts who are trying to mitigate flood hazard effects.

1.1. Motivation

Floods cause severe damage and affect at least 20 million people worldwide every year (Smith et al., 2009, pp.13). In the last few decades Europe has suffered from many floods. Although there are many flood protection efforts within the EU (European Union), it has proven impossible to provide 100% flood protection against flood damages (Mostert & Junier 2009).

For this reason the main focus in Europe has changed from complete protection against floods to flood risk management. In October 2007 the European Flood Directive (EFD) was enacted by twenty-seven EU member states. The focus of this directive was to reduce the adverse consequences on human health, environment, cultural heritage, and economic activity associated with floods. As a requirement of the EFD, each member state has to develop various products concerning flood risk assessment.

Imagine the situation in the United States if each state had their own data structure, requirements, methodology, framework, and even language. How would the United States work to manage the risk of floods and their aftermath? Like other natural disasters, floods do not care about boundaries. Only the unity of countries can help to fight disaster. The same stand applies to everything—in war, a basketball game, during the typical work-day in the office, even in the family. Only by working together can people accomplish great tasks.

As part of the requirements of the EFD, European scientists started to search for suitable tools to develop flood risk and hazard maps. For many years, the Hazus-MH Flood Model (figure 1) has been known as a well proven tool for flood hazard mitigation in the United States, but the system's limitation is that Hazus-MH was originally designed to work with U.S. datasets, not global datasets.

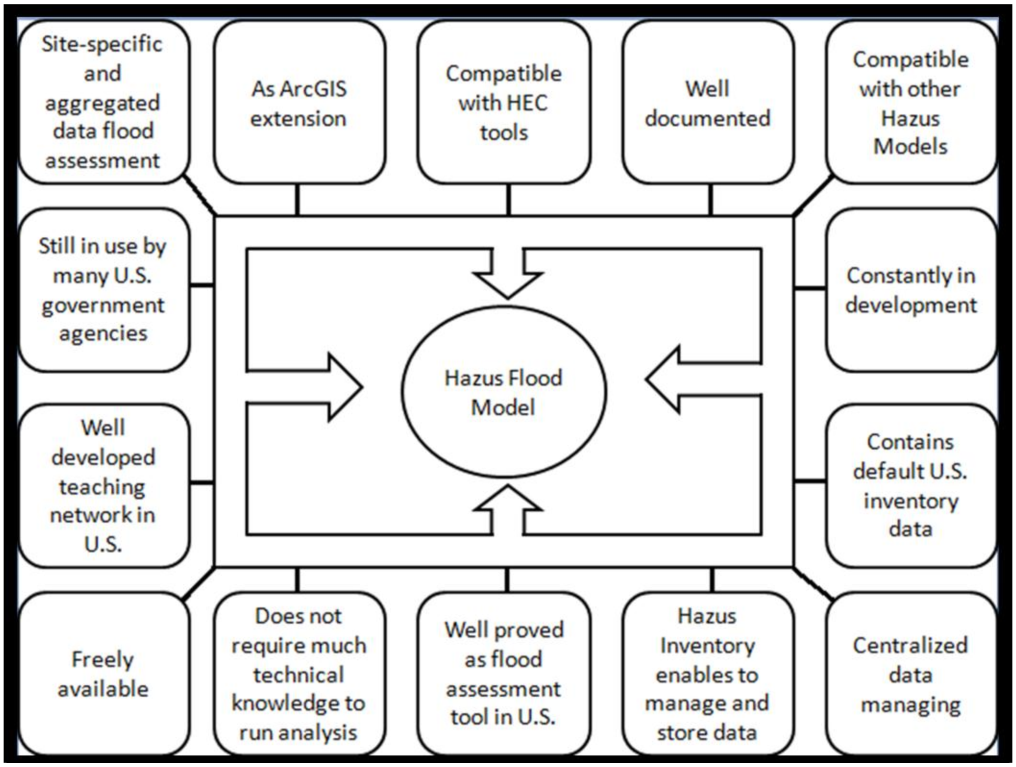


Figure 1: The advantages of the Hazus-MH Flood Model

The huge challenge and interest of this master's thesis is to find a solution for the semi-automatical integration of non-U.S. data into Hazus-MH.

1.2. Research Questions

Flood Assessment is a complicated field in which many problems and uncertainty occur. Hazus-MH is not an open source tool. Therefore, even more possible problems should be considered. To be able to handle that, it is important to answer many research questions:

- What is the meaning of common used terminology in flood assessment?
- What are the requirements of the European Flood Directive?
- What are the requirements of flood mapping in Europe?
- What are the best examples of flood mapping in Europe?
- What is Hazus-MH and what are its applied outcomes?
- What are the capabilities of Hazus-MH?
- How can Hazus-MH contribute to the needs of the EFD?
- What is the step-by-step riverine flood assessment in the Hazus Flood Model, and how is damage estimated?

- What contains flood hazard and inventory data in Hazus?
- What are the existing Hazus Flood Model's limitations to applying it internationally?
- What are the possible solutions to integrating non-U.S. datasets into Hazus-MH?
- What is the framework of flood damage functions adjustment in Hazus, and is it possible to apply them internationally?
- What are the existing administrative units, and what part do they play in Hazus?
- How can the implementation be created and tested?
- What are the existing limitations of implementing Hazus-MH for Europe, and what should be done to eliminate them?
- What is the resulting framework of flood assessment in Europe using the Hazus Flood Model by using created implementation?
- What are the requirements for the European input data for flood assessment in Hazus?
- What are the additional tools and datasets that could improve Hazus by achieving more efficient results?
- What are the perspectives, existing issues, and future research initiatives of Hazus?

1.3. Methods of Solutions

The research questions can be answered only by performing research activities and following the specified methodology:

- The common used terminology would be explained by researching literature related to risk estimation and hazard assessment;
- The analysis of the European Flood Directive and other supportive directives would declare the EFD requirements;
- The analysis and overview of existing best flood mapping solutions and examples in Europe would define the existing best flood mapping practice in Europe and requirements of the flood maps;
- The literature review and historical outcome of various projects where Hazus was applied would outline Hazus-MH as a tool and its successful outcomes;
- The practical courses and testing of Hazus-MH would reveal the Hazus Flood Model's capabilities and limitations;

- The possible contribution of Hazus-MH to EFD would be declared by creating the flood maps with original Hazus inventory data;
- The step-by-step riverine flood assessment in Hazus would be defined and explained in detail by analyzing Hazus Flood Model's technical/user manuals, following tutorial guides, and performing practical tasks with Hazus Flood Model;
- The analysis of Hazus technical/user manuals and practical courses would describe the Hazus flood hazard and inventory data;
- The inner Hazus data and inventory analysis would identify the existing limitations to applying Hazus-MH internationally;
- The solution for international data use in the Hazus-MH Flood Model would be achieved by integrating European geographical divisions into Hazus;
- The adjustment of flood damage functions in Hazus would be tested by using original and later European datasets;
- The research of existing European and worldwide administrative units and their geographical features would outline the best way to be integrated as geographical divisions into Hazus;
- Implementation would be created by modifying the existing Hazus datasets and creating relations between European geographical divisions;
- The testing of the implementation would be done by initiating a case study for a local Austrian community—Micheldorf—and performing flood assessment;
- The limitations of implementation would be defined by evaluating the implementation, and the introduced data integration framework would define the needed steps to eliminate the existing limitations;
- The new framework would be established by analyzing the differences between international and U.S. datasets and listing all needed intermediate steps to perform successful flood assessment;
- The requirements would be defined by analyzing the Hazus default data integration possibilities;
- The additional tools and datasets would be listed and evaluated in terms of their direct support to Hazus;
- The conclusions, future use of, and existing problems with the Hazus-MH tool would be described by summarizing the whole thesis.

1.4. Expected Results

That the research would be approved and declared as successful, these further results are expected:

- Explanation of common used terms in flood assessment;
- The listed requirements of the European Flood Directive;
- The requirements of flood mapping in Europe;
- The methodology and examples of best flood mapping practices in Europe;
- The Hazus-MH definition and the applied experience (case studies);
- The listed Hazus-MH capabilities and possible contributions to support EFD;
- The step-by-step Hazus riverine flood analysis;
- The detailed description of implementation's creation, its limitations, and effective solutions;
- The new framework of flood assessment in Europe that would be followed by using the created implementation;
- The flood assessment case study for a local Austrian community, Micheldorf, in the Hazus Flood Model by applying the created implementation;
- The detailed list of requirements for international input data into Hazus Flood Model and implementation;
- The description and overview of other freely available tools and data which would improve Hazus capabilities in the field of flood assessment;
- The summarized statements of Hazus issues, future focus, and whole research.

Be advised that some of the results are quite complex. Therefore, they are not included in the results chapter.

1.5. Audience

The primary audience of this master's thesis are the European flood mapping and flood risk assessment experts who are searching for efficient and cost-effective solutions to fulfill the EFD requirements. This research provides plenty of guidelines and examples on how to produce and deliver significant flood maps. For the emergency managers and flood hazard mitigation specialists, this research should increase the motivation to study the Hazus methodology and use it worldwide. The flood vulnerable communities should be interested in the possibility of affordable flood risk assessments and the ability to raise flood risk awareness in their communities.

1.6. Structure of the Thesis

This master's thesis is structured in 13 chapters. The first chapter introduces the research, the motivation, rough methods, results, and the audience of the study. The third chapter describes the theoretical background, such as the terminology of flood assessment, important European laws, the use of flood maps, Hazus-MH introduction, and successful outcomes, as well as other flood assessment tools and administrative units. The fourth chapter overviews the Hazus-based methodologies and framework used to create implementation and produce flood assessment. The properties of additional datasets and Hazus inventory, such as flood hazard data, are described to outline the importance of different data types. Chapter five presents the step-by-step Hazus riverine framework. The sixth chapter introduces the process of implementation that enables Hazus to perform flood assessment in Europe. The new framework of flood assessment in Europe as derived from the Hazus model is presented in chapter seven. The eighth chapter describes the proceedings of a flood assessment case study in Austria with the results presented in the ninth chapter. The future focus, conclusions, existing problems, and Hazus Flood Model issues are described in chapter ten.

2. Literature Review

Flood risk assessment has always been known as a complicated field of research because of the complexity of moving water calculations. Various experts released plenty of reports to provide the best solutions to identify or predict flood damage. In this master's thesis, the most intense literature research was performed by analyzing the existing flood mapping methods in Europe and the Hazus Flood Model's technical manuals. Because one of the goals of this research is to contribute European Flood Directive, a large part of the time was devoted to analyzing the Directive's requirements and the current best solutions for satisfying them. To this end, many European flood maps were analyzed and evaluated. The common theoretical knowledge about floods was acquired from many well known books and articles.

Literature about Hazus-MH is quite limited. It's a unique tool that is mainly used for federal and local U.S. government agencies. The typical users do not care about the methods and processes involved in Hazus; they need only to know the capabilities, features, and framework of the system and how to proceed with tasks and get results. For that reason there are plenty of tutorials and step-by-step frameworks for specified practical tasks with Hazus, but there is no technical information about the system. The core literature are the official Hazus Flood Model technical and user manuals, released by FEMA Mitigation Division. Both of these documents contain details about methods and processes in Hazus. All of the Hazus information is in these manuals, but there is no alternative literature.

There exist many reports and case studies of Hazus use in the U.S., and some of these examples are provided in this thesis. Many accounts describe the situation, reasons why Hazus was used, and what the outcome was. Some of the authors (Muthukumar 2005) also evaluate the flood hazard modeling and capabilities of the Hazus flood model.

There is little literature recounting the use of Hazus internationally. In 2010 Kulmesch (Kulmesch 2010, AGIT) evaluated the Hazus flood loss estimation methodology for a case study in Austria, and this master's thesis is based on Kulmesch's research. The newest interest in Hazus comes out of Canada, where they established the Canadian Hazus Users Group (CanHUG) in January 2011 and are testing the potential to use Hazus-MH in Canada. One of the most successful and well-known international applications of Hazus tools is the Hazus Earthquake model implementation for the case study by Doug Bausch on the earthquake in Haiti in early 2010 (Bausch 2010). He used similar methodology described in this and Kulmesch's research, but the main focus was the aggregated data.

3. Theoretical Background

Theoretical background presents the common used terminology in flood assessment, how floods are evaluated in Europe, and the laws and regulations that are in place to deal with floods. Hazus-MH's background and its tools provide the general overview about the capabilities of each model and the methodology.

3.1. Terminology

This chapter introduces the most common terminology used in Hazus, the EFD, and flood mapping. Some of the terms can be defined somewhat differently by various authors, but the essence of the meaning is the same.

Risk

The risk concept applied in Hazus-MH was analysed by Kulmesch et al (2010) and follows the risk definitions given by Crichton (1999, 2001) and Fedeski & Gwilliam (2007). The term is expressed as a function, where risk is related to the periodic cost of damage caused by a hazard. The parameters of the function are: the exposure which represents the extent and value of by hazard affected buildings, the vulnerability which describes the susceptibility of these buildings to a hazard, and the characteristics of the hazard itself (Kaveckis et al 2011a).

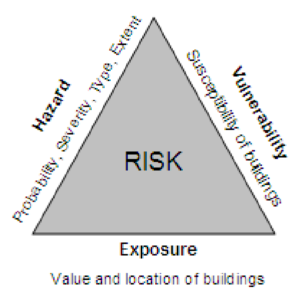


Figure 2: The risk triangle by Crichton (1999, 2001)

While Smith et al (2009) describes the risk as relationship between a hazard's probability and severity, it is determined that hazards to human life are rated higher than damage to economic goods and environment. Together, the risk is an actual exposure of human or property value. Figure 3 presents theoretical relationships described by Smith et al (2009) between the risk, probability, and severity of a hazard.

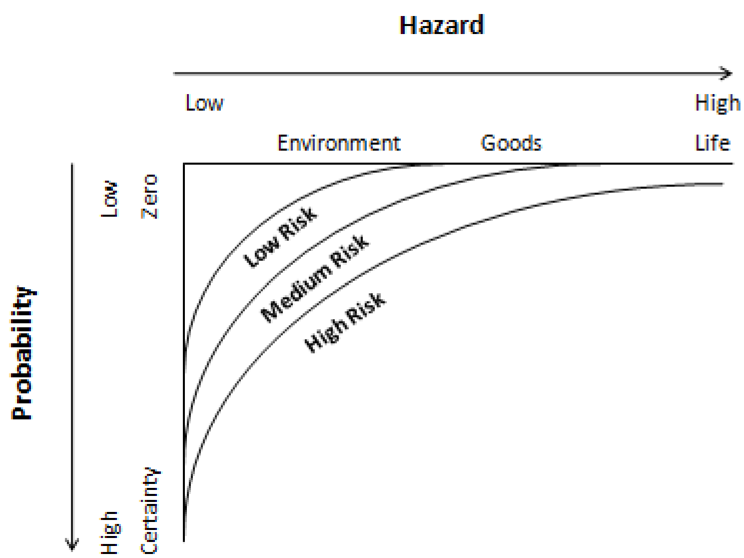


Figure 3: Hazard, probability and risk relations (Smith et al 2009, pp. 13)

This figure shows a concept similar to Crichton's, but instead of 3 edges, there are only two: probability and severity of the hazard. The severity in this case could be described as vulnerability differences between the environment, goods, and life. As mentioned earlier, Smith includes this exposure into risk itself. This figure is easier to understand than Crichton's.

HR Wallingford (2002) declares the risk as a combination of the chance of a particular event and the impact (that the event would cause). In another words, risk contains two components: the probability of an event to occur and the consequences of the overall impact associated with that event, while the European Flood Directive describes flood risk as the combination of the probability of a flood event and of the potential adverse consequences to human health, the environment, and economic activity associated with a flood event (Excimap 2007, pp.9).

The United Nations Strategy for Disaster Reduction (UN/ISDR) approach for an interdisciplinary multi-hazard analysis and risk assessment is similar to the Hazus methodology (UN/ISDR 2004). The UN/ISDR approach defines risk as the probability of harmful losses resulting from interactions between natural and human-induced hazards and vulnerable conditions. This strategy determines the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that could pose a potential threat or harm to people, property, livelihoods, and the environment on which they depend (Kaveckis et al 2011a).

Hazard

Quite often the two terms—risk and hazard—can be confusing. According to Smith et al (2009), hazard as a cause is a potential threat to humans and their welfare, while the risk as a likely consequence is the probability of that hazard which is occurring and creating the loss. Hazards can be recognized as threats to different groups of assets:

- Hazards to environment – pollution, loss of amenity, loss of flora and fauna;
- Hazards to goods – property damage and economic loss;
- Hazards to people – death, disease, mental stress, injury.

A good example of how to distinguish between risk and hazard is provided by Okrent (1980): Two people are crossing the ocean. One of them is in a rowboat, another in a big ship. The hazards in this case are described as deep water and large waves. The risk—probability of capsizing and drowning. In this example, it is clear that the person in the rowboat has the greater risk (Smith et al 2009, pp. 13).

Vulnerability

According Smith et al (2009), vulnerability is described as a possible future state that implies high risk combined with an inability to cope. In another words – vulnerability is the susceptibility of resources (human and material) to negative impacts from hazard events. For example, improving a foundation's ability to resist flood water would decrease the foundation's vulnerability to the floods. *Human* vulnerability is a more comprehensive term, as described by Timmerman (1981). Human vulnerability is a degree of resistance offered by a social system to the impact of a hazardous event (Smith et al 2009, pp. 15).

Flood

A flood is any relatively high stream flow that overtops the natural or artificial banks in any reach of its stream. The reasons for flood can vary—from long lasting rainfall, heavy rain from a thunderstorm, rapid snow melting, a dam break, or even a tsunami. Since 1900, the Centre for Research on the Epidemiology of Disasters (CRED) has added more than 3,000 recorded flood disasters its database. Flooding is described as a common environmental hazard because of the widespread population distribution in river flood plains and the increasing density near rivers. Floods can cause and be caused by other disasters. They can cause landslides and epidemics of disease, or they can occur as the result of storms and tsunamis. That is why it is hard to determine exact numbers in flood losses (Smith et al 2009, pp. 232).

Flood Depth

Flood depth can be described as the difference between flood water elevation and ground elevation (see figure 4). It should be also considered that normal stream elevation is defined as ground elevation. In the correct way, the flood depth grid should show only the depth of the flood. Very often this is not correctly depicted, but that does not influence the results, because usually there are no assets at risk in the stream itself. There are exceptions like bridges and utilities, but this can be considered in damage functions (in Hazus).

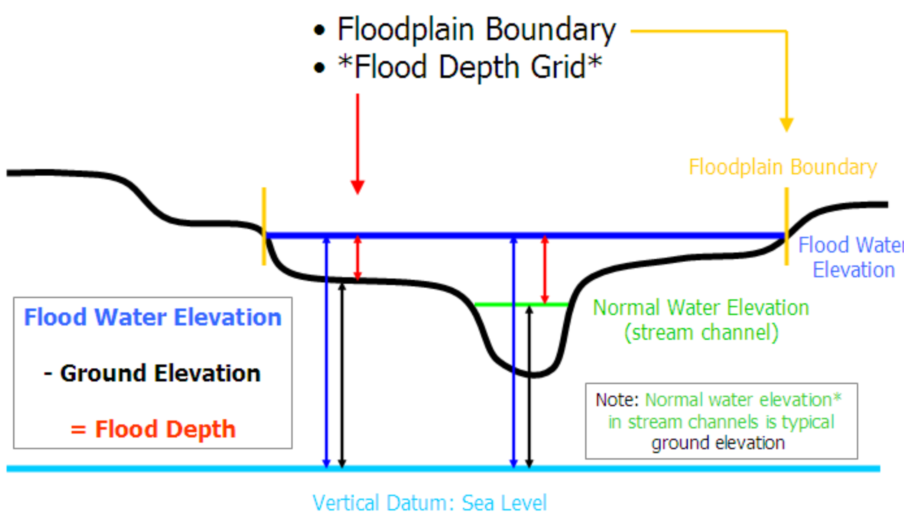


Figure 4: Flood depth described as difference between flood water and ground elevation (FEMA 2009c)

Flood Probability

It is hard to describe the severity of a flood. Not all floods are equal in the context of duration, effect, or severity. One way to describe the severity of a flood is the probability of occurrence. According Holmes et al (2010), the term "100 year flood" was born in the 1960s in the United States, when they decided to use 1 percent annual exceedance probability (AEP) flood as the basis for the National Flood Insurance Program. The 1-percent AEP flood has a 1 in 100 chance of being equaled or exceeded in any One year, and it has an average recurrence interval of 100 years. That is why it is called a "100 year flood."

More often, scientists use statistical probability (chance) to evaluate floods. To determine statistical probability, they measure the annual peak stream flow and examine the stream gages. This analysis helps scientists to estimate AEP for various flood magnitudes.

How accurate are these estimations in determining flood severity (magnitude)? The accuracy varies depending on the amount of available data, the accuracy of that data, climate conditions, etc. Holmes et al (2010) provide a good example. Figure 5 shows the flood probability of Big Piney River. The flood probability is represented as solid black line. Below and above that solid black line are two dashed lines. They represent the 90 percent confidence intervals of this relation. That means that there is a 10 percent chance that the true flood magnitude will lie somewhere outside the dashed area and the solid black line. The issue is different with discharges (discharge meaning the volume of water). According to figure 5, let's assume that the 1 percent AEP flood (100 year flood) for Big Piney River has an estimated magnitude of 44,300 cubic feet per second. We can also declare that there is a 90 percent chance that the true value of 1 percent AEP flood is between 36,600 and 56,400 cubic feet per second (Holmes et al 2010).

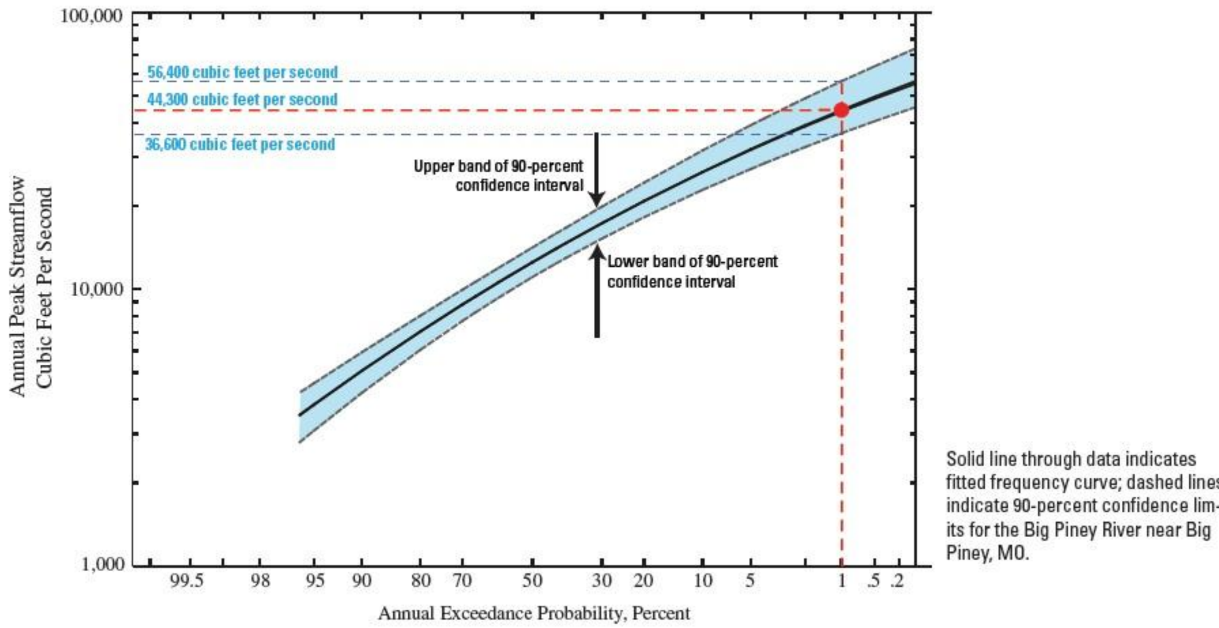


Figure 5: The flood probability relation for the Big Piney River near Big Piney, Montana, USA (Holmes et al 2010)

How accurate are the estimations in the case of these occurrences? Many people interpret this incorrectly. They think that if a 500 year flood happened last week, another will come after 500 years. That is totally incorrect. Holmes et al (2010) writes that during the span of a 30 year mortgage, a property in the 1 percent AEP (100 year flood) floodplain has a 26 percent chance of being flooded at least once during those 30 years. This value of 26 percent is based on probability theory that accounts for each of the 30 years having a 1 percent chance of flooding.

Flood Damage

Flood damage is the damage caused by water. The damage can be presented as a percentage or as a monetary expression. A percentage expression shows which part of the subject is damaged, and the monetary expression shows the market value of the damages that occurred. Quite often it would be represented as replacement costs (not the same as market value).

The damage can be direct and indirect. Direct damage is the damage that inflicts direct loss and can be noticed directly, while indirect damage can't be immediately determined or is just not directly related to the flood or to another disaster (job loss, psychological effects, etc.)

In Hazus methodology, the term "substantial damage" is used. According FEMA (2009a), the substantial damage of the building is the 50 percent threshold of the damage. When it passes 50 percent of the structure's total replacement cost, the building is considered a total loss. That means that the building is no longer operational, it uninhabitable, and is cheaper to demolish and build anew. The term "substantial damage" can be used when assessing flood damages to count how many buildings need to be replaced and how many shelters would be needed if these buildings were declared uninhabitable.

Flood Loss

Flood loss is the flood inflicted disappearance of something cherished, such as a person, possession, or property. In flood damage estimations, flood loss can be expressed as a monetary value or as a quantity. Flood loss in Hazus methodology is direct and indirect. The loss in Hazus is separated from direct physical damage and uses the form of direct economic/social loss and indirect economic loss. For sure, indirect social loss caused by the flood exists; for example, people who experience physiological problems because of their lost relatives or property, etc.

Direct economic and social loss in Hazus is related to demographics, building damage, and lost building functionality in the community. The expression of direct economical loss is presented as financial consequences to the community's business due to business interruption, the financial resources that will be needed to repair the damage, and an indication of job and housing losses. In another words, the capital investments and value of an income produced by the investment that created the building or inventory, while the social loss is measured as displaced households due to loss of housing habitability and short term shelter needs.

The indirect economic loss represents the economic disruption, or ripple effects, that follow from directed losses. A good example would be when a factory is damaged in a flood. It is likely that the factor would have to be shut down for the period of time until repairs could be made, which means that the factory is not operational and can't produce goods. That is called economical disruption (FEMA 2009a).

Flood Damage Function

The flood damage function is the relationship between flood depth and occurred flood damage. The damage functions are used to relate the level of damage to the flooding conditions. Flood depth is used as the main parameter. There are two types of damage functions: the absolute and the relative. They differ in the combination of information on land use and values and susceptibility of assets (MRC 2009, pp. 68-70).

The absolute or direct damage estimation approach represents the combination of inundation and land use information. This combination allows individuals to estimate the absolute damage amount for each property or unit of property (see figure 6).

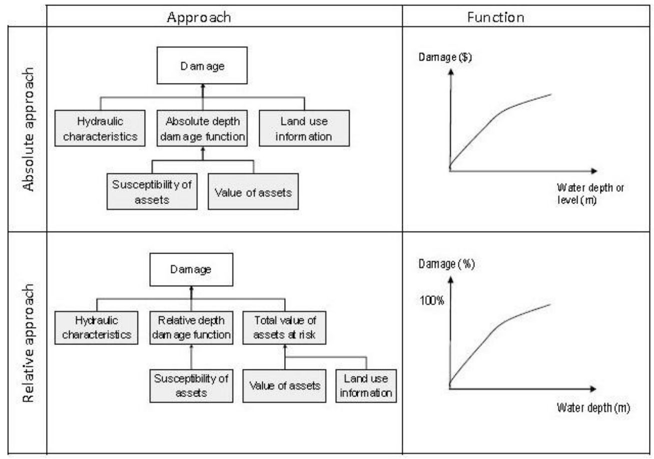


Figure 6: Absolute and relative damage functions (MRC 2009, pp. 71)

The relative or percentage of property value approach describes the combination of inundation, land use, values of assets, and total value of assets at risk. The resulting damage for each asset or unit of assets is calculated by means of relative damage function, which shows the damaged share in terms of the total value (see figure 6) (FLOODsite 2007, pp. 25-26).

Mapping Scheme

The mapping scheme is a scheme that describes the data mapping framework. The mapping itself is described as a relationship between datasets. So, the mapping scheme is the framework of relations' creation between datasets (Alexe et al 2008). The mapping schemes are widely used in data transformation and integration, analysis of data relations, etc. In Hazus, the meaning of a mapping scheme is slightly different. Hazus uses mapping schemes to define properties of attribute information for aggregated data, such as setting the distribution of building types for a specified geographical division.

3.2. Floods in Europe

Floods are natural phenomena that cannot be prevented, however, human activity (like the expansion of settlements, economic assets in the floodplains, natural water retention, etc.) and climate change both contribute to the increase of flood events (European Flood Directive 2007, pp. 27).

The following handbook of good practices provides the table of the types of floods with additional information like the causes of a flood, consequences, and key parameters.

Table 1: Flood type table (EXCIMAP 2007, pp. 10)

Type of flooding	Causes of flooding	Effect of flooding	Relevant parameters
River flooding in flood plains	• Intensive rainfall and/or snowmelt • Ice jam, clogging • Collapse of dikes or other protective structures	• Stagnant or flowing water outside the channel	• Extent (according to probability) • Water depth • Water velocity • Propagation of flood
Sea water flooding	• Storm surge • Tsunami • High tide	• Stagnant or flowing water behind the shore line • Salinisation of agricultural land	• Same as above
Mountain torrent activity or rapid run-off from hills	• Cloud burst • Lake outburst • Slope instability in watershed • Debris flow	• Water and sediments outside the channel on alluvial fan; erosion along channel	• Same as above; • Sediment deposition
Flash floods in Mediterranean ephemeral water courses	• Cloud burst	• Water and sediments outside the channel on alluvial fan • Erosion along channel	• Same as above
Groundwater flooding	• High water level in adjacent water bodies	• Stagnant water in flood plain (long period of flooding)	• Extent (according to probability) • water depth
Lake flooding	• Water level rise trough inflow or wind induced set up	• Stagnant water behind the shore line	• Same as above

It is possible and important to reduce the risk of negative consequences, especially for human health and life, the environment, cultural heritage, economic activity, and infrastructure when dealing with floods. The measures that reduce the risks, especially if they are effective, should be coordinated throughout a river basin.

3.2.1. Water Framework Directive

The Water Framework Directive was released by the European Council and European Parliament on 23rd of October in 2000. This directive was defined as a framework for community action in the field of water policy. The purpose of this directive was to establish a framework to protect the inland surface, transitional, coastal waters and groundwater, and develop a sustainable river basin management plan for each river basin district. However, the flood risk reduction was not the main goal of this directive (Water Framework Directive 2000, European Flood Directive 2007).

3.2.2. European Flood Directive

History has shown that the Water Framework Directive is not efficient in reducing flood risk. The change of the situation was reflected in the European Flood Directive of October 2007, which is an important legal framework for the current 27 EU member states (Mostert & Junier 2009). The European Flood Directive (EFD) aims to reduce the adverse consequences on human health, environment, cultural heritage, and economic activity associated with floods in the community. As part of this initiative, the EFD sets out the requirement for EU member states to develop three types of products:

Preliminary Flood Risk Assessment – An evaluation of flood risks in the river basin districts, or certain coastal areas or individual river basins and determination of the areas of potential flood risk. The preliminary flood risk assessment should be completed to the 22.12.2011.

Flood Hazard Maps and Flood Risk Maps - Cover the geographical areas that could be flooded according to the specified scenarios: flood risk maps should show the potential adverse consequences associated with specified flood scenarios expressed in terms of the specified values. The flood hazard and flood risk maps should be completed to the 22.12.2012.

Flood Risk Management Plans – Should address all aspects of flood risk management, focusing on prevention, protection, and preparedness, including flood forecasts and early warning systems and taking into account the characteristics of the particular river basin or sub-basin. Flood risk management plans should be completed to the 22.12.2015 (European Flood Directive 2007, pp. 30-31).

According to the European Flood Directive, each member state must prepare flood hazard and flood risk maps at the most appropriate scale for each river basin district and coastal area (European Flood Directive, 2007). In this context a detailed overview of the requirements for flood hazard risk maps is needed. It is worth considering that some member states already created flood risk and flood hazard maps by fulfilling the EFD requirements (Kaveckis et al 2011a).

3.2.3. Requirements for Flood Risk and Flood Hazard Maps

Flood hazard maps should cover the geographical areas which could be flooded according the following scenarios:

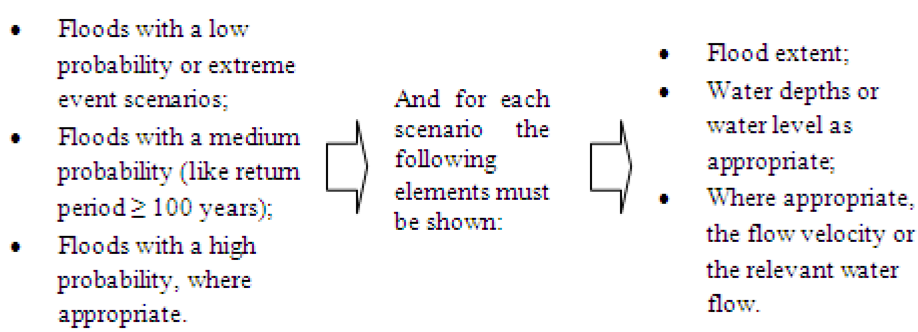


Figure 7: Requirements for flood hazard maps (European Flood Directive 2007)

Flood risk maps should show the potential adverse consequences associated with flood scenarios expressed in the following terms:

- The indicative number of inhabitants potentially affected;
- Type of economic activity of the area potentially affected;
- Accidental pollution sites in case of flooding and potentially affected protected areas;
- Other information which the member state considers as useful, such as the indication of areas where floods with a high content of transported sediments and debris can occur and information about other significant sources of pollution (European Flood Directive 2007).

3.3. The Use of Flood Maps

The knowledge of hazards and risks throughout a river basin and coastal area is the key element in efficient flood risk management. This also includes information about the type of flood (river, lake, groundwater, coastal), the flood magnitude expressed as flood extent, the probability of a particular flood event, water depth or flow velocity, and the possible magnitude of damage caused by floods (EXCIMAP 2007, pp. 6).

In June 2003, at the Water Directors meeting in Athens, the core group led by the Netherlands and France presented "the best practice document" on flood prevention, protection, and mitigation. The document is an update of the United Nations and Economic Commission for Europe (UN/ECE) Guidelines on Sustainable Flood Prevention (UN/ECE, 2000). That document holds the combined improvements and experience of all of the countries of the European Union and beyond (WDEU 2003, pp. 2).

Flood hazard maps outline risk areas and are important for planning. Hazard and risk maps must be easily readable and show the different hazard levels. They are a planning tool, and it is important that all officials have the same information on the spatial extent of a certain hazard. Flood risk maps should be used for the reduction of damage potential to lives, property, and economic assets by integrating risk maps into spatial and emergency planning. Both types of utilization require that the flood hazard, zoning, and risk maps should include the worst-case scenario as well (Best Practices on Flood Prevention, Protection and Mitigation 2003, pp. 16).

According the current practice of flood mapping in Europe, the flood hazard maps and flood risk can be identified by the following characteristics (table 2).

Table 2: Properties of flood hazard and flood risk maps in Europe (EXCIMAP 2007, pp 11)

	Flood hazard map	Flood risk map
Content	Flood parameters such as • flood extent according to probability classes, • according to past events • flood depth • flow velocity • flood propagation • degree of danger	Risk parameters such as • assets at risk • Flood vulnerability • Probable damage • Probable loss (per unit time)
Purpose and use	• Land use planning and land management • Watershed management • Water management planning • Hazard assessment on local leve • Emergency planning and management • Planning of technical measures • Overall awareness building	• Basis for policy dialogue • Priority setting for measures • Flood Risk Management Strategy (prevention, mitigation) • Emergency management (e.g. the determination of main assets) • Overall awareness building
Scale	• Local level: 1:5,000 to 1:25,000: various parameters • National level, whole river basin: 1:50,000 to 1:1,000,000: in general only flood extent	• 1:5,000 to 1:25,000 • 1:50,000 to 1:1,000,000
Accuracy	• high: cadastre level for detailed maps • low: whole river basin, national level	• high: cadastre level • low: whole river basin, national level
Target group / use	• National, regional or local land-use planning • Flood managers • Emergency services • Forest services (watershed management) • Public at large	• Insurance • National, regional or local emergency services • National, regional or local water and land use managers

Both types of maps can be used for various purposes. For each purpose, the scale and the content must be different. The attention also should be paid to the accuracy and the spatial content, while the maps can be designated for different target groups (spatial planners and community representatives have different objectives). The maps should contain the information, which has to achieve one of three purposes:

- Prevent the build-up of new risks (planning and construction);
- Reduce existing risks;
- Adapt to changing risks factors.

Depending on the purpose, the demands of the stakeholders can vary:

- Land-use planning and land management;
- Emergency planning;
- Flood risk management strategy (prevention, mitigation);
- Raising public awareness;
- Insurance.

Each stakeholder needs a different set of information. In that case, the content, essential parameters (defined by the EFD), scale, and other factors are defined. It is nonsense to put all possible information in one map. When the stakeholders are known, the following aspects are considered:

- Content (extent of flooding, dynamic parameters of floods, hazard and risk level);
- Level/scale (overview of large area, detailed information);
- Readership (expert, practitioner, decision maker, community) and complexity (simple, complex) (EXCIMAP 2007).

3.4. Hazus-MH

This chapter introduces the theoretical background and the features of Hazus-MH and its tools. The general Hazus model description reveals the capabilities of each of the models.

3.4.1. Background

Hazus-MH is a powerful risk assessment software program for analyzing potential losses from floods, hurricane winds, and earthquakes, and uses Esri software to run its calculations. Hazus-MH is an extension for ArcGIS Desktop.

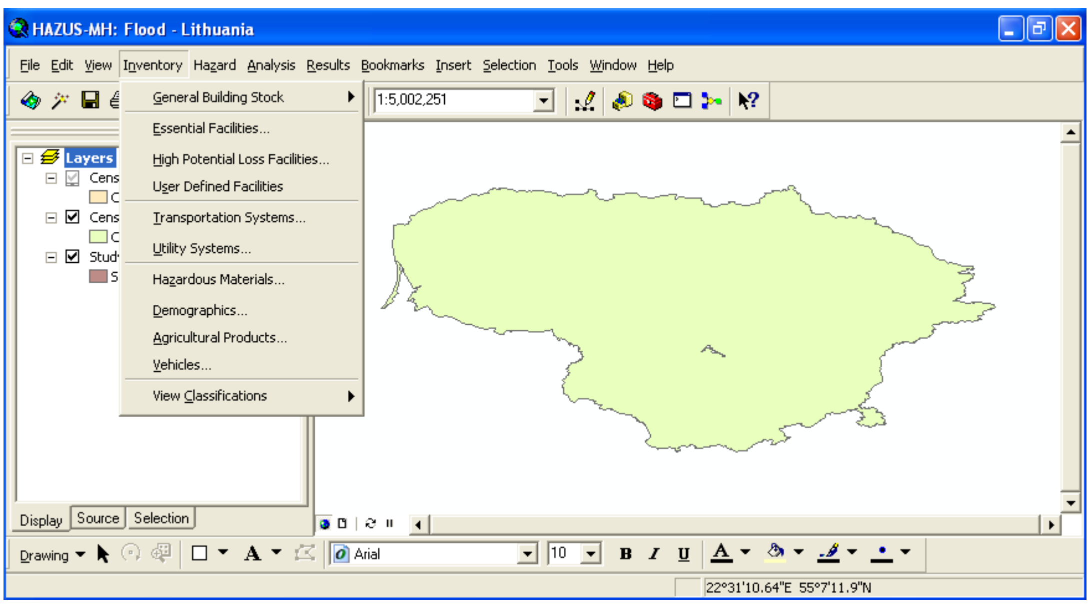


Figure 8: Hazus-MH Flood Model interface

Interoperability between Hazus-MH and ArcGIS is a huge advantage; the input/intermediate/output Hazus data can be exported or modified using all known ArcGIS tools. The same standards allow users to share information at ease.

Hazus was developed by the Federal Emergency Management Agency (FEMA) under contract with the National Institute of Building Sciences, and started in 1992 as a project related to the National Earthquake Hazards Reduction Program (ESRI 2006, pp. 1). Hazus-MH is intended for use by U.S. local, state, and regional officials, and consultants who assist in mitigation planning, emergency response, and recovery preparedness.

Currently, Hazus-MH estimates losses for three types of natural hazards: earthquake, hurricane wind, and flood. These models are continuously revised and updated through input from scientists, engineers, software developers, and hazard specialists to provide increasingly accurate loss estimates. The big advantage of Hazus is the common inventory for each of the three hazards. Hazus-MH initially comes with large quantities of U.S.-specific data that can be easily updated and shared.

The strength of Hazus-MH is not floodplain delineation, but flood risk assessment. For floodplain delineation in the U.S., Flood Insurance Maps (FIRM) are used. They are known as the primary tool for state and local U.S. governments to mitigate the effects of flooding in their communities. FIRMs are defined as official maps of a community on which FEMA has delineated hazard and risk zones applicable to the community (FEMA 2010b). Hazus-MH offers the user multiple options for integrating enhanced user-provided hazard data. These options range from characterizing a flood inundation area based on a boundary assigned a constant flood depth to more refined approaches that empower users with the ability to use the results from detailed flood studies with a higher local resolution. In the case of communities that do not have access to more refined flood hazard data, FEMA advised that flood inundation areas, generated by Hazus-MH analysis, can be accepted as they are. This declaration enabled financially disadvantaged US counties to use Hazus-MH as a tool to meet the initial requirements of the Disaster Mitigation Act 2000 (DMA 2000, Muthukumar 2005, pp. 4, Kaveckis et al 2011a).

3.4.2. Hazus Models

Hazus-MH contains three models, but the main focus of this research is the flood model. The advantage of Hazus is that the same common inventory data can be used in each of the model analysis. This master's thesis can also fully contribute to the research in developing other Hazus models for international use.

Flood Model

The Flood Model allows users to carry out a wide range of flood hazard analyses, such as:

- Studies of specific return intervals of floods (e.g., 100-year return interval);
- Studies of discharge frequencies;
- Studies of annualized losses from flooding;
- Quick look assessments;
- "What if?" scenarios and other mitigation measures.

The flood loss estimation methodology consists of two modules that carry out basic analytical processes: flood hazard analysis and flood loss estimation analysis. The flood hazard analysis module uses characteristics, such as frequency, discharge, and ground elevation to estimate flood depth and flood elevation. The flood loss estimation module calculates physical damage and economic loss (FEMA 2011a).

Earthquake Model

The Hazus-MH earthquake model is one of the oldest and most advanced Hazus-MH models. This model estimates damage and loss to buildings, lifelines, and essential facilities from scenario and probabilistic earthquakes, including:

- Ground shaking and ground failure;
- Estimates of casualties;
- Displaced households and shelter requirements;
- Damage and loss of use of essential facilities;
- Estimated cost of repairing damaged buildings;
- Quantity of debris;
- Damage to buildings;
- Direct costs associated with loss of function (e.g., loss of business revenue) (FEMA 2011b).

Hurricane Model

The Hazus-MH Hurricane Wind Model uses an existing state-of-the-art windfield model and allows users to estimate the economic and social losses from hurricane winds. This model has been calibrated and validated using full-scale hurricane data, and it incorporates sea surface temperature in the boundary layer analysis and calculates wind speed as a function of central pressure, translation speed, and surface roughness.

This model is an improvement over existing loss estimation models because it uses a wind hazard-load-damage-loss framework. The model addresses wind pressure, windborne debris, duration/fatigue, and rain. It also includes the following features:

- A building classification system that depends on the characteristics of the building envelope and building frame;
- The capability to compute damage based on building classes and the effects of rain and progressive failure;
- The capability to compute damage to contents and building interior;
- The capability to estimate tree and structural debris quantities;
- Loss estimates that include direct and indirect economic loss, shelter requirements, and casualties;
- Modules that facilitate future assessment of mitigation, benefit-cost, and building code issues (FEMA 2011a).

3.4.3. Hazus Tools

Hazus data preparedness and integration is complicated. The additional Hazus tools like FIT and CDMS support the user to prepare the flood hazard data and manage the inventory datasets.

Comprehensive Data Management System

The CDMS (Comprehensive Data Management System) is an additional tool of Hazus-MH that provides users with the ability to update and manage statewide datasets, which are currently used to support analysis in Hazus-MH. The Hazus 2.0 version comes together with CDMS and is not installed separately as it was in the earlier versions.

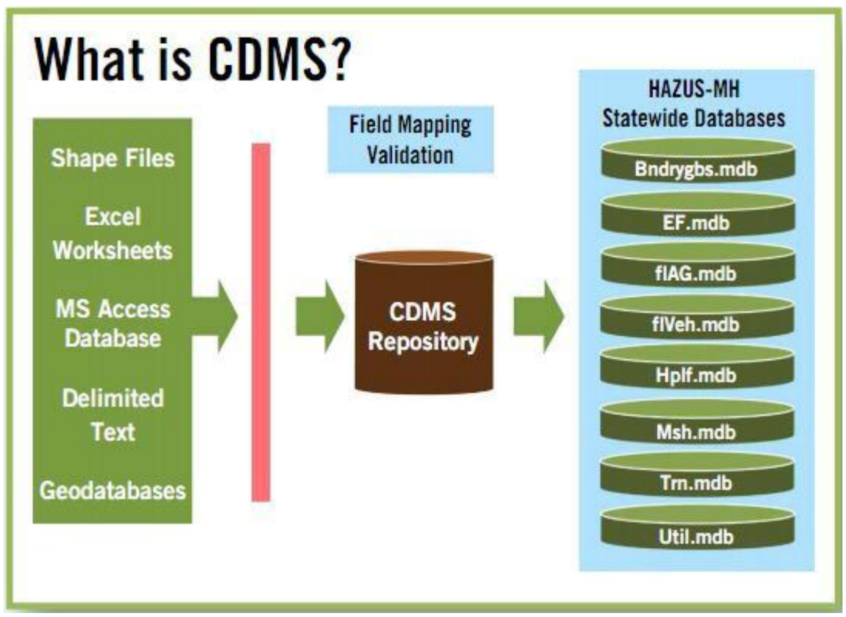


Figure 9: Data integration framework using CDMS (HUG 2008)

When Hazus-MH users are required to undertake a large amount of manual effort to incorporate new data into the statewide datasets, CDMS comes to the help. To reduce this effort, CDMS can automate raw data processing to convert external data sources into Hazus-MH compliant data and transfer the data into and out of the statewide datasets. This process is often quite complicated due to pre-defined formats of input data. CDMS uses data field and data value matching, which enables the user to integrate data into Hazus-MH without reorganizing input data. CDMS has a validation module which validates the input data and confirms that input data was identified and understood by Hazus.

Flood Information Tool

The Flood Information Tool (FIT) is an ArcGIS extension that processes user-supplied flood hazard data into the format required by the Hazus-MH Flood Model. FIT computes the extent, elevation, and depth of flooding when flood hazard inputs as ground and flood elevation and flood boundary are provided. In other words, FIT processes the raw geographical data and delivers the results that fit for Hazus-MH Flood Model as input data (see figure 10) (ABS Consulting 2003, pp. 8)

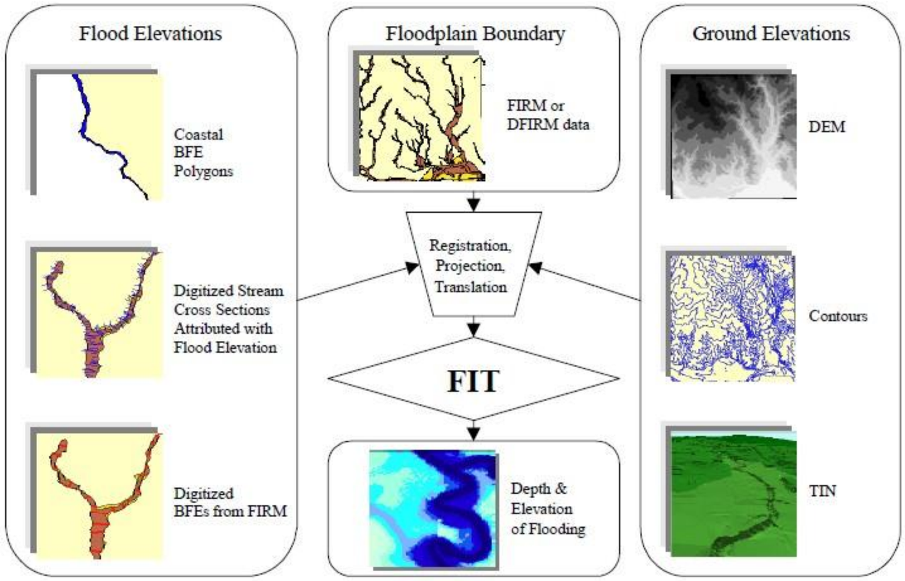


Figure 10: FIT Schematic View (ABS Consulting 2003, pp. 8)

It is important to consider that FIT does not provide hydrologic and hydraulic calculations because the FIT methodology was created to assist the user by incorporating the results of third party hydraulic models. FIT is able to process flood hazard data for riverine and coastal flooding conditions. The main inputs to FIT riverine model are digital elevation model (DEM), a set of polylines (cross sections) which are attributed with flood elevations, and the floodplain boundary. As the final result, FIT delivers a flood depth grid. If a user already has a flood depth grid, there is no need to use FIT (ABS Consulting 2003, pp. 12 -13).

3.4.4. Best practice of Hazus-MH

Hazus-MH as an efficient hazard and risk assessment tool is widely used by many US agencies and communities for a long time. This chapter presents few Polis Center projects using Hazus-MH. The Polis Center is the research institution at Indiana University-Purdue University Indianapolis. One of the focuses of the Polis Center is to teach communities how to use Hazus and cooperate with other agencies by successfully applying Hazus methodology in real life situations.

Hazus-MH Flood Damage Reduction Feasibility Study for Rocky Ripple

In the spring of 2011, the US Army Corps of Engineers (USACE) asked The Polis Center to perform a flood damage reduction feasibility study for the Rocky Ripple community in Indianapolis. Rocky Ripple is in the northern territory of the city of Indianapolis and is surrounded by a water channel in the east and the White River in the west and north. For a long time this community was suffering from floods. For that reason, USACE built a dike (levee) along the channel. The objective of the dike was to protect the Rocky Ripple community from flooding when water in the channel overflowed the banks. The community rejected the proposal to build a similar dike along the river; it was apparent that the community did not want to lose its beautiful view of the river.

Unfortunately, the community still suffers from flooding from the river, and they asked the US Army Corps of Engineers and The Polis Center for help.

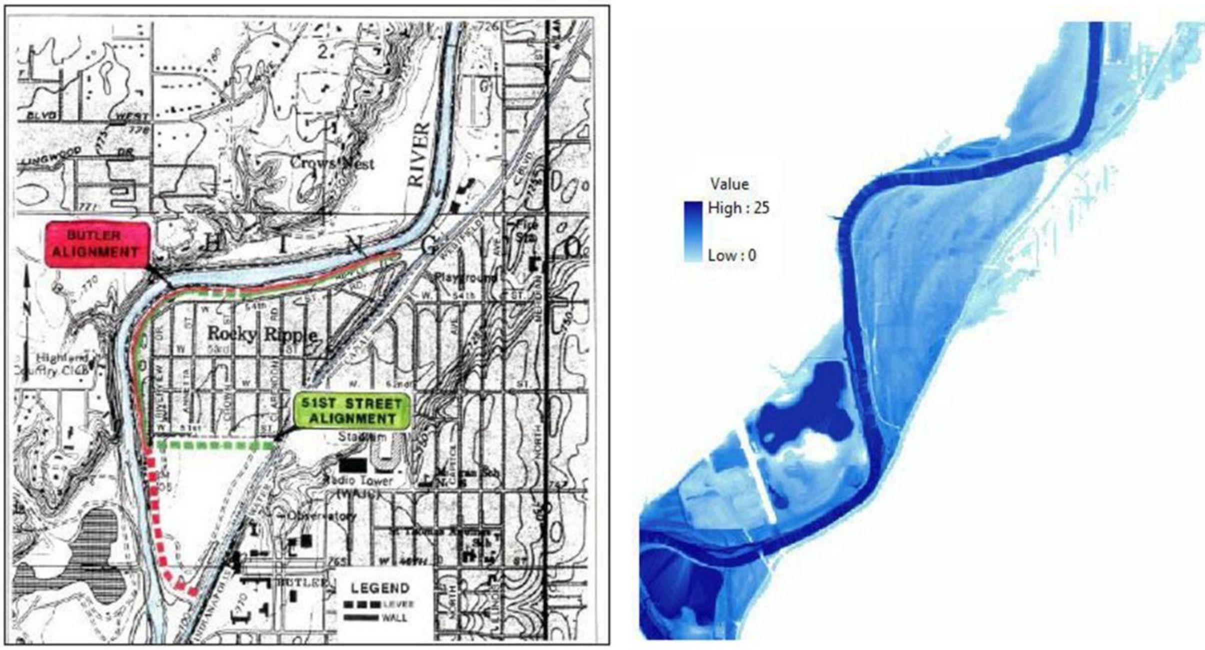


Figure 11: Left- alignments for Rocky Ripple Feasibility Study, right - Historical 1913 year Rocky Ripple flood depth grid (Kaveckis 2011)

Before building another dike along the river (see figure 11, left), the USACE wanted to be sure that the building of the dike would cost less than the flood occurred damages. The objective of the flood damage reduction feasibility study was to perform flood analysis using Hazus-MH MR5 flood model and declare the building loss in an extreme flood scenario.

The Hazus-MH Flood Model needs flood hazard and flood inventory data. Flood hazard data was processed from the Indianapolis Mapping and Geographic Infrastructure System (IMAGIS) acquired 1 m horizontal accuracy digital elevation model (DEM). It was also known the elevation of the extreme historical flood (March of 1913) flood crust – 713,9 feet. To get the flood depth grid, simple methodology was used (same, as described in 4.4.1. chapter) – distraction of DEM from historical flood elevation. The result was presented as flood depth grid (figure 11, right).

The inventory data is one of the most problematic data sets to get. It was collected by joining the local township (Washington) parcel data and the assessor data. The polygons of the parcels were created as centroids (points) which were moved manually over the buildings using aerial imagery. This action was performed to get more precise geographical position. Parcels contained a “Parcel ID“ data field, a unique parcel number, which was used as a link between the parcel (geographical location) and assessor data (attribute information). The next operation was “join“ – to link both of these datasets. As an output, now inventory data contained building type (even this does not play any role in flood damage estimation, but it is needed in older Hazus versions before Hazus 2.0), occupancy type, foundation type, building and content values. But the first floor height was unknown for all 338 buildings in the Rocky

Ripple community. Therefore, the field survey was performed to find out the approximate first floor heights of the buildings. During the field survey it was noted that 34 buildings had slab type foundations with 5 feet of first floor height. It was decided to create two different scenarios for the remaining 304 buildings: 0 and 2 feet first floor height. Both flood hazard data and building inventory data were uploaded as user defined facilities (UDF) into Hazus-MH MR5 Flood Model. Two colorful maps, the chart and table were delivered as a result. Figure 12 represents the map of the second scenario.

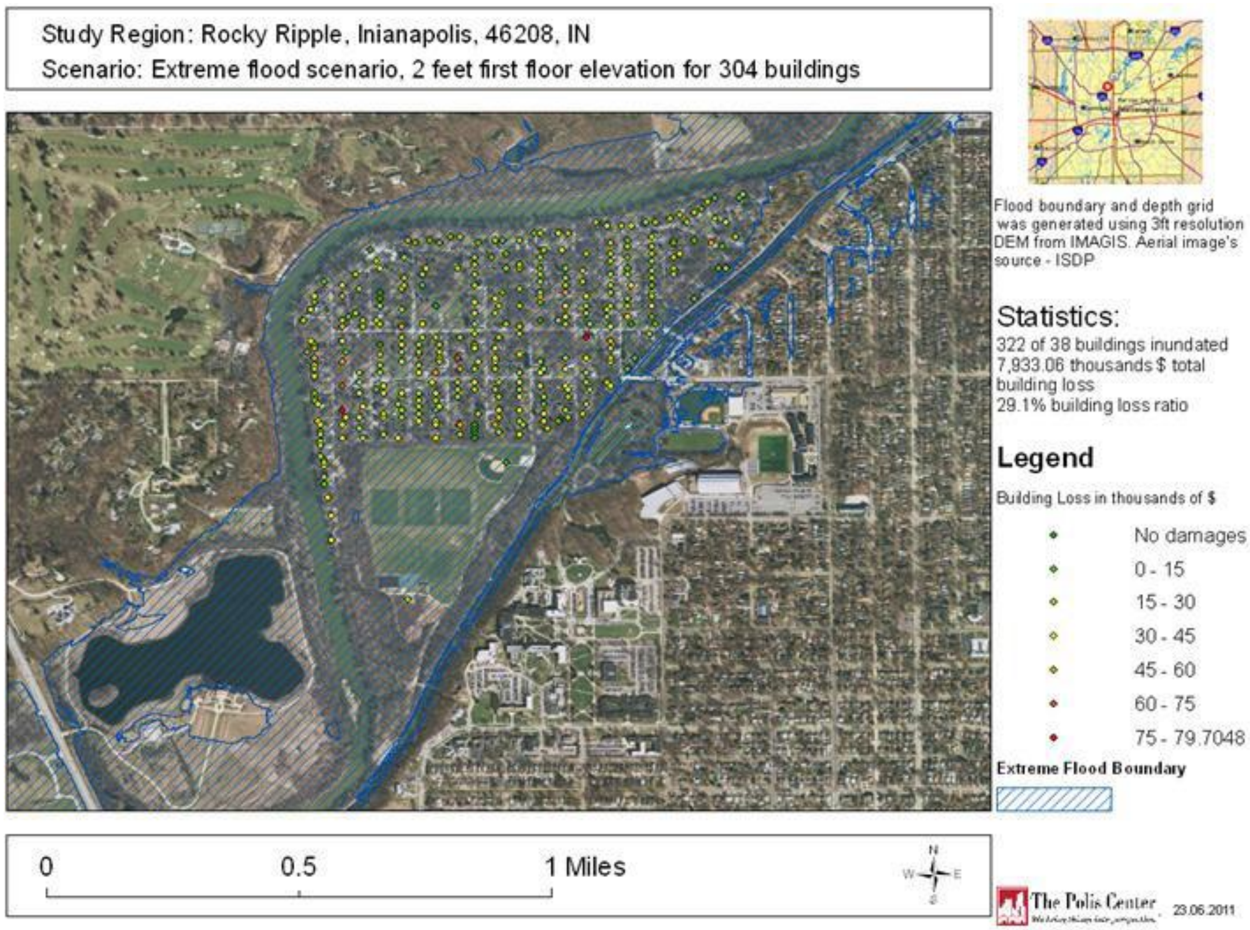


Figure 12: Result map of Rocky Ripple extreme flood building loss analysis (Kaveckis 2011)

This map may help to identify the buildings that are most vulnerable to extreme flood and predict what the damages could be. Also in the map such information as building loss ratio and total building loss is visualized.

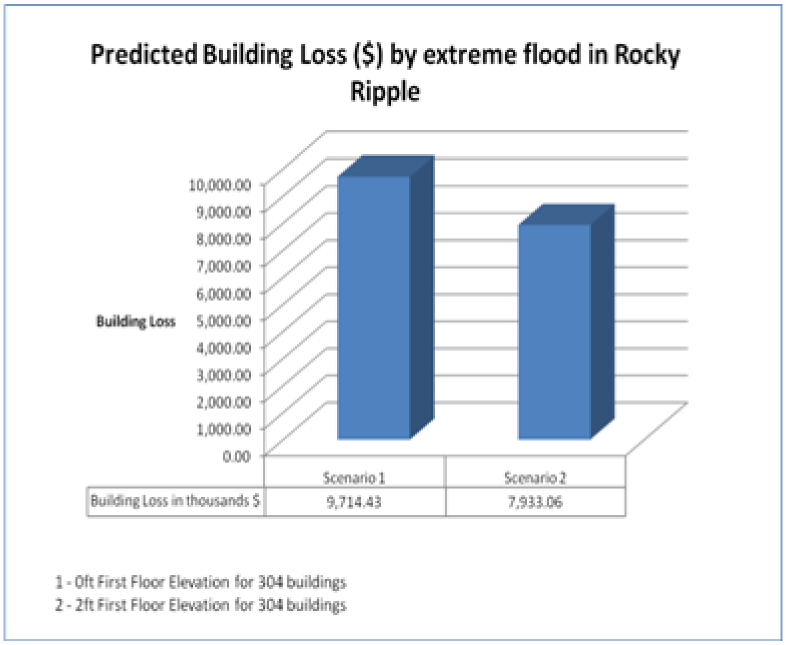


Figure 13: Building loss chart for both scenarios (Kaveckis 2011)

The chart (figure 13) shows the total building loss for both scenarios. The loss is expressed as thousands of dollars. When most of the buildings' first floor height is 0 feet, the total building loss is almost two million dollars higher.

The results of the analysis were delivered as a report with the hope that the decision to build the dike would be made correctly.

Pre-Disaster Mitigation Plans for U.S. counties

The Polis Center, at the request of Mitigation Division of Indiana Department of Homeland Security, has developed a process to assist counties and incorporated cities and towns in the creation of mitigation plans that would comply with the Disaster Mitigation Act of 2000 (DMA 2000, Polis Center 2010). DMA 2000 requires communities to develop and maintain a risk management (pre-disaster mitigation) plan in order to be eligible for federal disaster funds. The Federal Emergency Management Agency (FEMA) developed a tool to meet this objective—Hazus-MH (The Polis Center 2008). The Polis Center's assistance to communities has proven very effective and efficient in producing pre-disaster mitigation plans for the whole state of Indiana and some counties from other states.

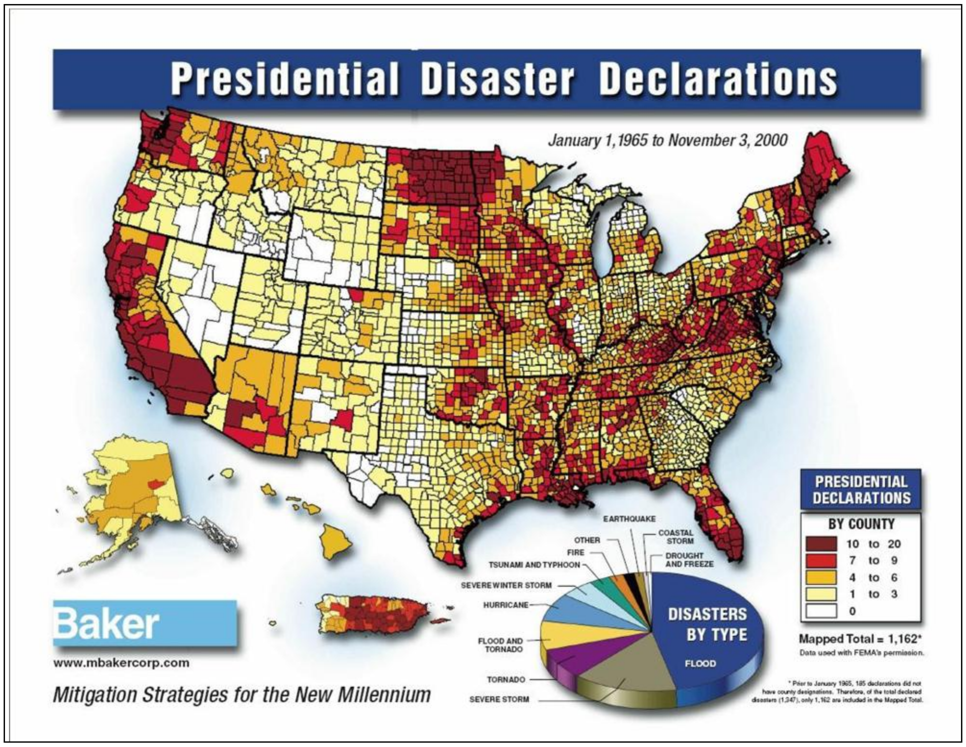


Figure 14: Disaster declaration quantity map for 35 years in USA. Notice the main disaster type (Polis Center 2008)

The mitigation plan is based on a risk assessment that maximizes the value of Geographic Information System (GIS) technology and Hazus-MH. Each county participating in this process is a beneficiary of a state-awarded grant that allows the county to develop its plan without any “out of pocket“ expenses. The cooperation by preparing mitigation plan consists from following partnerships:

- A county interested in developing a DMA 2000 compliant mitigation plan;
- The Polis Center;
- An appropriate university center or department in the host state; and
- The Regional Planning Commission (RPC) in which the county participates.

The responsibility to assemble and provide leadership for a planning team is dedicated to the county. The Polis Center and the host state university assume the responsibility of overseeing the overall process and producing a risk assessment for each county using Hazus-MH and various GIS tools.

The whole process continues over a period from six to eight months and requires a series of meetings for the county planning team. The representatives of the county in the meeting usually are the director of the local Emergency Management Agency, the county GIS coordinator, the mayor, fire and police chiefs, the city manager, school corporations, and health care and business representatives.

The group of meetings are arranged according their needs. Quite often the “meeting 0” (the initial meeting) is arranged only to organize the participants for other meetings, to introduce the framework of the process, and to increase the interest of participants. The purpose of "meeting 1" is to assemble all the data about the critical facilities in the county and create the map (figure 15).

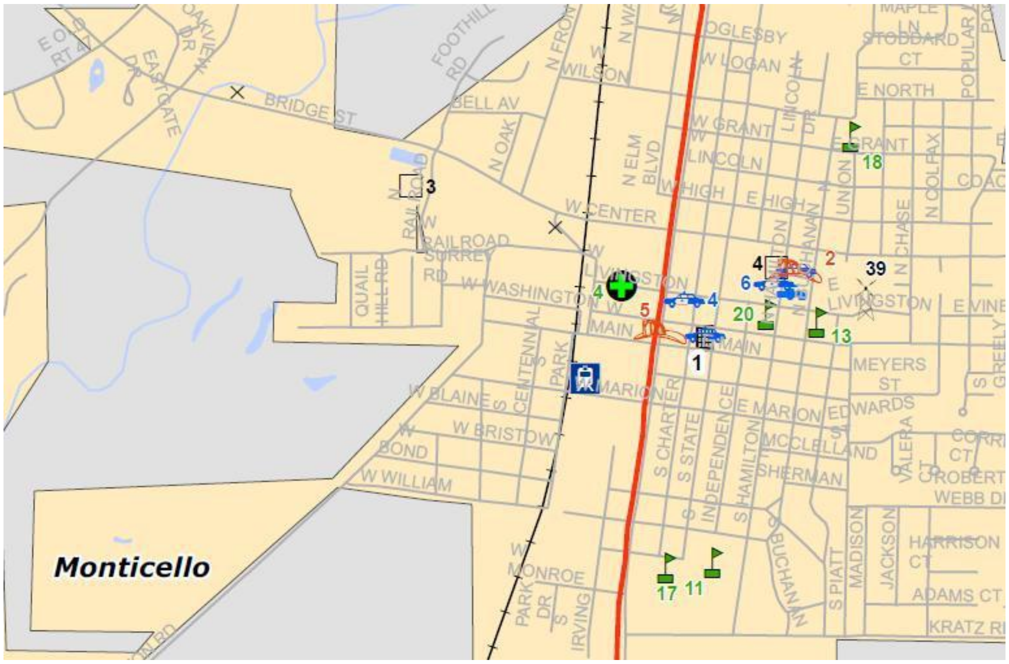


Figure 15: Fragment from Pre-Disaster Mitigation Plan –Critical Facilities Map in Piatt County, city of Monticello, Illinois, USA (Polis Center 2011a)

Before this meeting, The Polis Center staff uses default Hazus inventory to acquire critical facilities. During the meeting, The Polis Center staff introduces to county representatives what data they have and what they would need, while community members help them to validate and acquire more data if needed. Before "meeting 2," The Polis Center staff creates the historical hazard map (figure 16) of the county. This map shows all historical hazards which threaten the county and prioritizes them according to the degree of risk. By having this information, a community can realize what potential hazards can threaten its county. During the meeting, the community is asked to declare which severe hazards are they interested in. An example would be a F5 tornado (most severe according Fujita scale) through the city center or an extreme flood in a residential area.

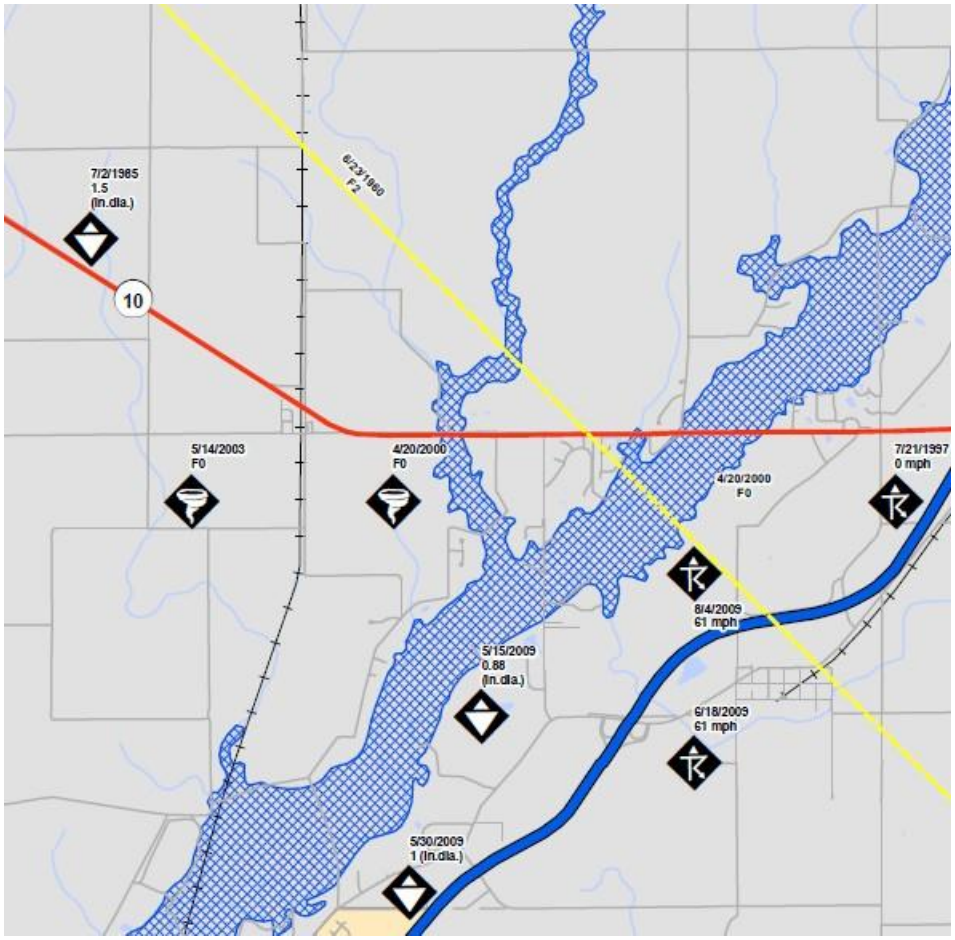


Figure 16: Fragment from Pre-Disaster Mitigation Plan –Historical Hazards Map in Piatt County, Illinois, USA (Polis Center 2011b)

Before “meeting 3”, The Polis Center processes the information of critical facilities, updates the aggregated data with the newest assessors data from the county, and uploads everything onto default Hazus inventory. Hazus-MH as a tool is used quite often for risk assessment. According the requirements, it is compulsory to model low magnitude earthquakes for each county. When a county is interested in adding flood risk assessment in their plans, Hazus-MH does that quite well. At “meeting 3”, The Polis Center presents the draft risk assessment to the planning team and invites the general public from the community. In meetings 4, 5, and 6, the lower participation is noticed, while the further process consists of identifying and prioritizing mitigation strategies, reviewing the draft plan, and submitting it to FEMA (Polis Center 2010).

3.5. Administrative Units

An administrative unit is a unit with administrative responsibilities. In the context of geography, administrative units can be described as a partition of territory that has its administrative responsibilities. The national territory is partitioned in many ways for different purposes. One of these purposes is the population census. The Census is mostly a government agency and enumerates districts of the lowest level of administrative units. Census data contains such information as population, housing, income etc. and is a valuable source to define and analyze geographic regions. In most cases, the census data is the aggregated data (more about aggregated data see chapter 4.5.1.) and is stored as attribute information of geographical features. For this reason, it is important to know the common scale/level of the geographical features, known also as administrative units.

3.5.1. Global Administrative Unit Layers

Global Administrative Unit Layers are known as GAUL. The GAUL project was implemented by the European Commission Food and Agriculture Organization (EC-FAO). The aim of the project is to compile and disseminate reliable spatial information on administrative units for all the countries in the world and provide a contribution to the standardization of the spatial dataset which represents administrative units (Grita 2011). The tasks of GAUL are to:

- Overcome the fragmentation of the global dataset;
- Promote a unified coding system which would reduce the efforts of maintenance; and
- Keep the historical track of changes occurring on the extents and shapes of administrative units (FoodSec 2011).

The implementation of the GAUL project is based on cooperative work among many international and national agencies that are collecting spatial information on administrative units. The data collecting methodology consists of:

- Collecting the best available data from the most reliable sources;
- Establishing validation periods of the geographic features when possible;
- Adding selected data to the global layer, which is based on the international boundaries provided by the UN Cartographic Unit;
- Generating codes using the Gaul Coding System; and
- Distributing the data to the users.

GAUL maintains the global layers with a unified coding system at the country, first (e.g. regions) and second (e.g. districts) administrative levels. When the data is available, GAUL provides layers on a country by country level down to the third, fourth, and lower levels. The delivery of GAUL data holds the consistent framework. Once a year, the Geonetwork (http://www.fao.org/geonetwork/) releases an updated version of GAUL, which includes all updates made in the previous year (Grita 2011).

The characteristics of the GAUL project:

- Level 0 (country), Level 1 (province), Level 2 (district) are provided as global layers. Level 3, Level 4, and Level 5 are provided when available and are carried out on individual country layers.

- The country boundaries comply with the latest version of the UNCS International Boundaries Map (November 2005).
- GAUL tracks the changes of administrative units for political reasons;
- The coastal line is mostly compliant with the International Boundary map from UNCS;
- Data is not always officially validated by national authorities and cannot be distributed to the general public. A disclaimer should always accompany any use of GAUL data;
- If the country maps were validated and copyrighted by the second administrative level boundaries, they were integrated into GAUL layer.

The beneficiary of GAUL data is the UN community and other authorized international and national institutions or agencies (FoodSec 2011).

3.5.2. Nomenclature of Territorial Units for Statistics

Nomenclature of territorial units for statistics is also known as NUTS. The NUTS classification is a hierarchical system for dividing up the economic territory of the EU for such purposes:

- To collect, develop, and harmonize EU regional statistics;
- To analyze the socio-economic situation of the regions;
- To frame EU regional policies.

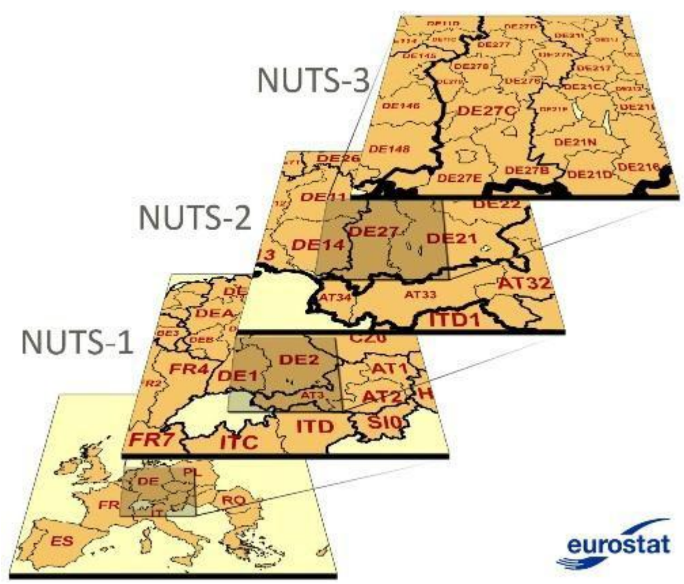


Figure 17: NUTS levels (Eurostat 2011)

NUTS are divided into three levels:

- NUTS 1: major socio-economic regions;
- NUTS 2: basic regions for the application of regional policies;

- NUTS 3: small regions for specific diagnoses.

Principles and characteristics of NUTS:

- The NUTS regulation defines the level according the population in the region;

LEVEL	MINIMUM	MAXIMUM
NUTS 1	3 million	7 million
NUTS 2	800 000	3 million
NUTS 3	150 000	800 000

Figure 18: NUTS levels according region's population (Eurostat 2011)

- For practical reasons the NUTS classification is based on the administrative divisions applied in the member states that generally comprise two main regional levels. The third level is created as additional by aggregating administrative units;
- NUTS favors general geographical units.

Eurostat has set up a system of Local Administrative Units (LAU) to meet the demand for statistics at the local level. The upper LAU (LAU Level 1, formerly NUTS Level 4) Level is defined for most but not all of the European member states. The lower LAU (Lau Level 2, formerly as NUTS Level 5) Level consists of municipalities or equivalent units. The NUTS regulation makes provisions for EU member states to send the detailed list of their LAU to Eurostat (Eurostat 2011). So far, the list of LAU of each member state is only in the form of an Excel spreadsheet, not as geographical features.

3.5.3. Administrative Units in the United States of America

Hazus also uses the additional geographical units as a supplement to the administrative units. In the US, Hazus uses four level (State – County – Census Tract – Census Block) geographical units (in figure 19 marked by dash line). The census block and census tract are not defined as administrative units. They were chosen because of census data aggregation. These geographical units not only are needed to create the study region, but also to contain the aggregated data. The smallest aggregated unit in the Flood Model is the census block, while in Earthquake and Hurricane Models it is the census tract.

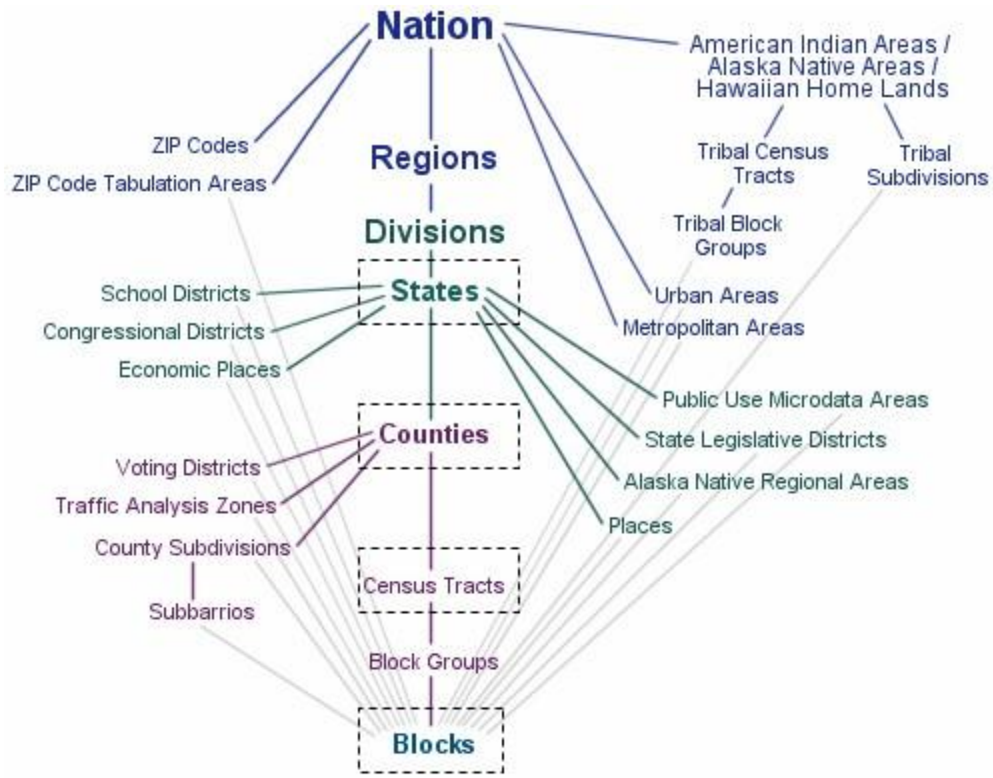


Figure 19: Geographical hierarchy of 2000 US Census. In Hazus used geographical units are surrounded by dashed line (MCDC 2011)

Counties and states are more like administrative geographical units and do not contain the aggregated data in Hazus. For users, it is easier to create the study area by selecting the defined states and counties.

The Census block is declared as the smallest unit of data tabulation and covers the entire USA. The divisions and boundaries of the census block change once every ten years and do not cross census tracts or county boundaries. The average demographic size of a census block is about 100 people. Each census block is identified by a unique 15 digit number. Part of this number is the state, county, tract, and block code. The whole 15 digits are used to find or determine the relations between each of these geographical units (FEMA 2009a, pp.111).

Census tract is the second smallest geographical unit. For the 2000 U.S. Census, first time census tracts cover the entire nation. The census tract contains relatively homogenous population characteristics, and the average demographic size is about 4,000 people, ranging between 1,000 and 8,000 (Parmenter 2003).

The newest Hazus version 2.0 and the older MR5 are also capable of creating study regions by watershed. This method is more comprehensive because most of the hydrologic analyses are performed within the watersheds, and even EFD asks to prepare flood maps for watersheds and catchment areas. Though there is such possibility to create the study region as a watershed, the watershed is not counted as a census or administrative unit.

3.5.4. Administrative Units in Austria

The administration units in Austria are based on NUTS. The hierarchy consists from three NUTS levels (from 1 to 3). The constitution of Austria defines a federal form of government and the duties and responsibilities in Austria are divided between central government and the nine constituent states (NUTS Level 2). There are subordinated districts (NUTS Level 3) within the states. Their basic function is to carry out state and government tasks. The smallest administrative units in Austria are municipalities (Quick 1994), which are not defined as NUTS.

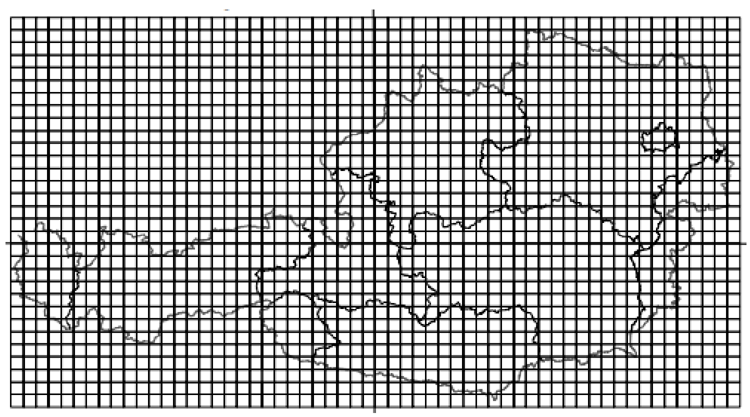


Figure 20: Planquadrat Austrian grid (10 x 10 km cell size) which contains aggregated data

However, the Austrian Statistics Department released the national grid, called *Planquadrat* (figure 20). This grid divides Austria into regular 125, 250, 500, 1000, 5000 and 10 000 meter quadrant cells. These cells contain such attribute data as building count and demographic data (Kulmesch 2010).

3.6. Other Flood Assessment and Modeling Tools

This chapter introduces the additional outside tools and platforms that could supply Hazus flood assessment with data or even change Hazus. Some of them are used for more professional tasks than Hazus is created for, and others for totally different purposes. One of the most important things is that all these tools are free to use, and even Hazus is free, and probably the reader who is reading this thesis did not pay anything. This means that with all these tools and provided methodology, it is possible to create something from nothing, and this something can save lives and property.

HEC-FIA

HEC-FIA abbreviation means Flood Impact Assessment tool, created by the US Army Corps of Engineers (USACE) Hydrological Engineering Center. The aim of HEC-FIA is to calculate post-flood or forecasted-flood impacts for a user-specified event, determine flood damage reduction benefits, and to create real time response activities.

HEC-FIA computes the urban and agricultural flood damage, inundated area, number of inundated buildings, population at risk, and loss of life. Loss of life is computed by such factors as initial population distribution for day and night, redistribution on dam failure warning situations, evacuation potential, and sheltering opportunities. The damage analysis of crops is similar to Hazus and involves the type of crop, season, cropping patterns, duration, and magnitude of flooding (USACE 2010).

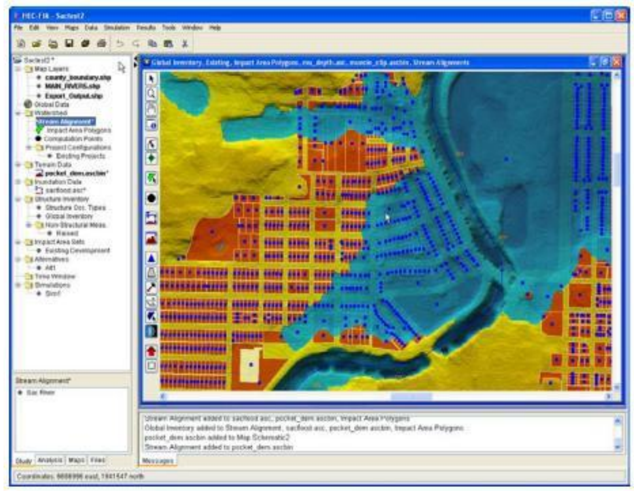


Figure 21: The interface of HEC-FIA (USACE 2010)

HEC-FIA is a great alternative of Hazus Flood Model, especially for the international use. The disadvantage is that instead of Hazus, HEC-FIA has no relation with the inventory. As with many other software programs, the user imports the data and exports the results; there is no possibility to store the data in inventory as Hazus does (there is also no possibility to store the data as User Defined Facilities in Hazus, only for the specified study in scenario). HEC-FIA uses the same methodology as Hazus uses, even most of the data types are the same as in Hazus, but the main advantage is that HEC-FIA is not restricted by study region, as Hazus is. There is hope that this thesis and research will make these tools equal, not in the context of bugs, but in functionality. When talking about bugs, there was a problem in applying new damage functions in HEC-FIA, but this is the open space for future research.

HEC-FIA can be downloaded from USACE ftp server: ftp://ftp.hec.usace.army.mil/public/HEC-FIA/. If the server is down, please contact Jason Needham, Hydrologic Engineering Center, E-mail: Jason.T.Needham@usace.army.mil

HEC-HMS

HEC-HMS is the Hydrological Modeling System created by the USACE's Hydrological Engineering Center. The aim of HEC-HMS is to simulate the precipitation-runoff processes of watershed systems. This tool is quite complex but can solve the widest possible range of problems: from large river basin water supply and flood hydrology to small urban or natural watershed runoff (USACE 2011a). The inputs for HEC-HMS are rainfall, soil type, land use, DEM, etc. The general output is the discharge (volume of water), which can also be input into Hazus.

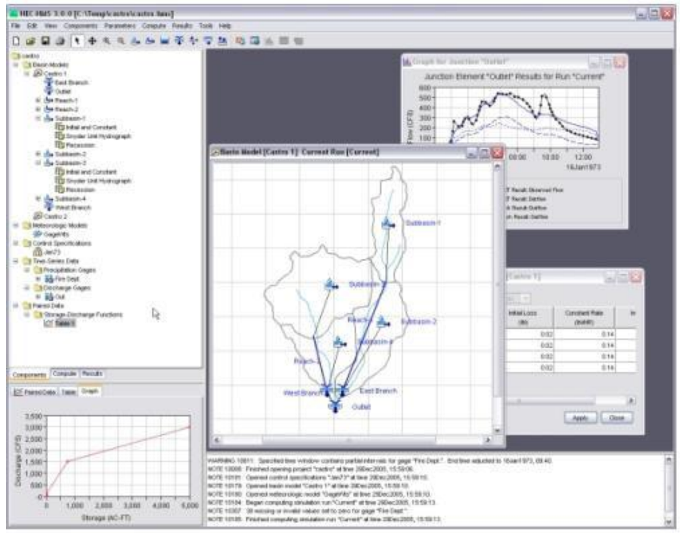


Figure 22: HEC-HMS interface (USACE 2011a)

To make the integration of input data easier, it is possible to use the ArcGIS extension – HEC-GeoHMS (free Arc Hydro tools are needed), which helps to process the inputs and prepares various watershed data (river length, river slope, basin slope, longest flow path, etc.) in ArcMap and export as project files. Then the user needs only to create the new project, import project files, and run the analysis to get the discharge.

HEC-HMS and HEC-GeoHMS can be downloaded from this website:

http://www.hec.usace.army.mil/software/hec-hms/

HEC-RAS

HEC-RAS is another free software tool released by the USACE's HEC. The purpose of this tool is to perform one-dimensional steady and unsteady flow and water temperature modeling and sediment transport bed computations (USACE 2011b). The geometry of the river and the discharge data can be directly imported from HEC-HMS to HEC-RAS.

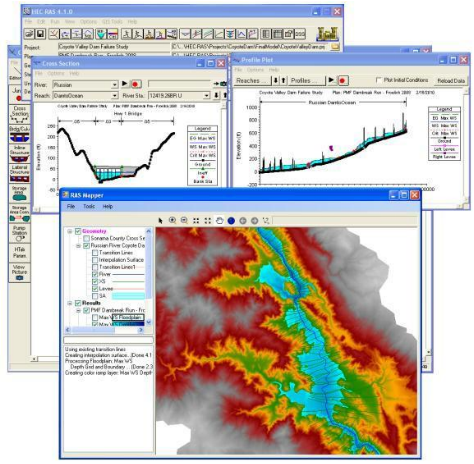


Figure 23: Interface of HEC-RAS (USACE 2011b)

For easier data input process for HEC-RAS, the user also has the ability to use ArcGIS extension HEC-GeoRAS by preparing the data for hydraulic modeling directly in ArcMAP. The output of HEC-RAS is the flood boundaries, flood depth grid, and computed water surface profiles. Hazus has the ability to import flood depth grids directly as HEC-RAS format.

HEC-RAS and HEC-GeoRAS can be downloaded from the website:
http://www.hec.usace.army.mil/software/hec-ras/

TR-20

TR-20 is an old but proven hydrologic tool released by the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS), now known as Natural Resources Conservation Service (NRCS). TR-20 provides a hydrological watershed analysis under present conditions. This tool develops run-off hydrographs from storm rainfall, drainage areas, and run-off curves (NRCS 2011). The output of TR-20 can be delivered to HEC-RAS or to Hazus hydraulic modeling.

To download TR-20, browse to NRCS website: http://www.nrcs.usda.gov

4. Methodology

This chapter describes the best flood mapping outcomes in Europe and introduces the recommended methodology to achieve most efficient flood maps. The Hazus riverine methodology shows the general methods and level of analysis in the flood model. The analysis and presented methodology of choosing geographical divisions for implementation should convince the reader of the most efficient ways to interchange default Hazus geographical divisions. The description and properties, inputs and outputs of Hazus inventory and flood hazard data, are provided to improve the understanding of the meaning of different data types in Hazus. The additional freely available datasets are presented as useful worldwide data inputs into Hazus. The flood parameters describe the key datasets that are essential in Hazus flood assessment, and should be considered.

4.1. Best Flood Hazard and Flood Risk Mapping Methods in Europe

The EXCIMAP (European Exchange Circle on Flood Mapping) group, formed of flood mapping experts from most EU member states, released a handbook of good practices in flood mapping in Europe (EXCIMAP 2007). Therefore, the evaluation of experience and the results from individual European member states is very important. The combination of good flood mapping practices and risk assessment tools like Hazus-MH could be an effective approach to tackling EFD requirements (Kaveckis et al 2011a). This chapter presents the guidelines for flood hazard and flood risk mapping. The guidelines reveal the content of the maps, scale, coloring issues, and map use.

4.1.1. Flood Hazard Mapping

As explained by the EFD, the maps according the visualized elements can be defined into few types:

Flood extent map/flood plain map - Flood extent map shows the boundaries of the occurred flood. The EFD requests flood extent map for two scenarios: low (extreme) probability, medium probability (likely return period ≥ 100 years) and where appropriate—high probability. Most examples of the flood hazard maps available in Europe are more advanced than other flood maps (EXCIMAP 2007, pp. 17).

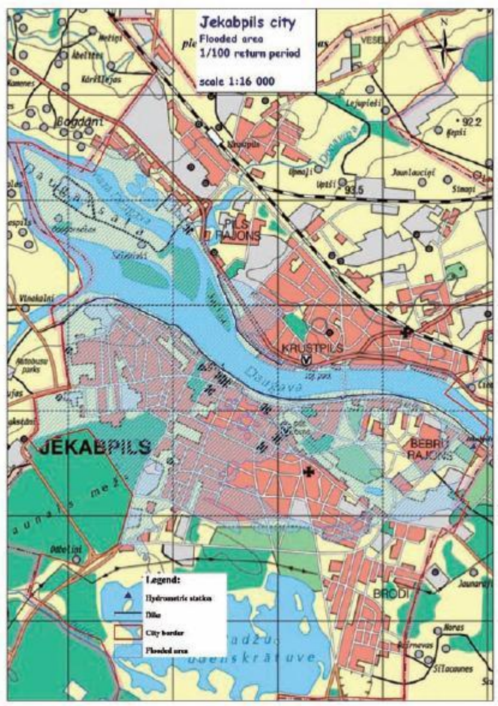


Figure 24: Flood extension map with a return period of 1/100 yr, for the city of Jekapils, Latvia, on the Dauguva River (Atlas of Flood Maps 2007, pp. 97)

The map in figure 24 is simple to read and not overcrowded. The topography layer is overlaid with flood extent map.

Map use

- Serves as a basic map to establish risk and danger maps;
- Land use planning;
- City and village planning;
- Rural planning;
- Risk management;
- Awareness building (when combined with past events).

Scale considerations

- If map is used for urban planning or the target territory is in the mountainous or hilly areas, the detailed scale is required (1:2 000 to 1:25 000);
- For the rural planning in large flood plains the large scale is possible (1:100 000 to 1:1 000 000).

Color scheme

In practice, the color that express the flood extent is represented in blue: dark blue shows the frequent floods, light blue the less frequent floods (EXCIMAP 2007, pp. 18).

Flood depth map - Flood depth map shows the values of water level. Depth can be derived from flow 2D or 1D flow models for river flooding, the same as from statistical analyses or observations. Depth (level) of the water must be shown in flood hazard maps according to the EFD.

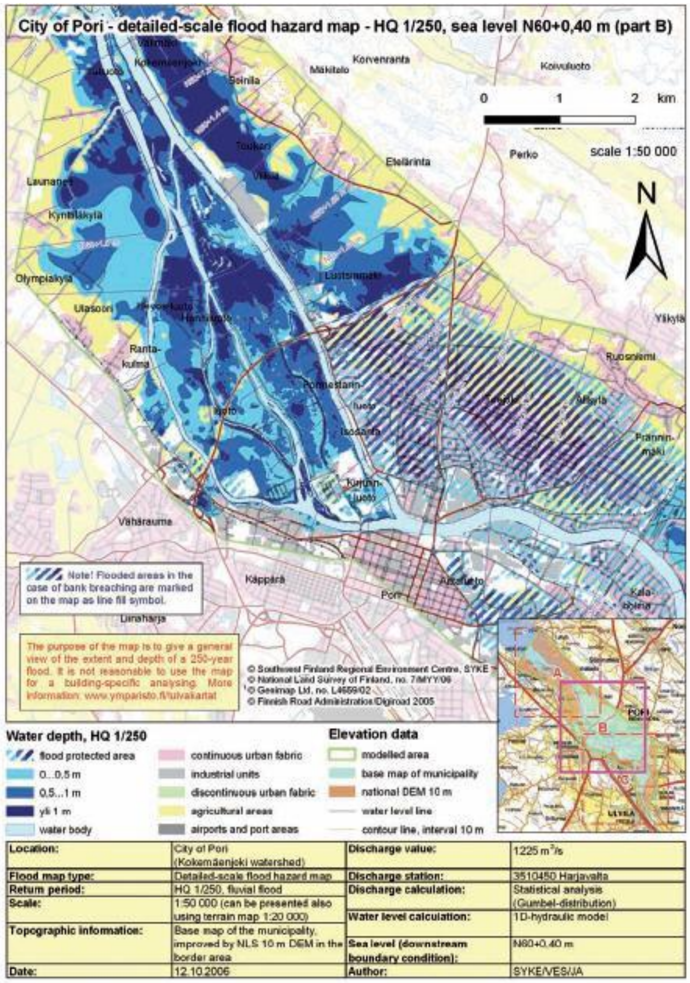


Figure 25: Flood hazard map (water depth for 1/125 yr. event) for the city of Pori, Finland (The Atlas of Flood Maps 2007, pp. 57)

The water depth scale in the flood hazard map for the city of Pori is presented as non-linear and ranges from 0 to 0,5m; 0,5 to 1m and above. The integration of land use and the colors is very successful and easy to understand. The dashed areas show the worst case scenario, the breach of dikes, which is very useful. Additional technical information is provided, which could be unimportant to the reader.

Map use

- Serves as a basic map to establish risk and danger maps;
- City and village planning;
- Risk management (evacuation).

Scale considerations

- Maximum inundation depth maps exist on national, regional, and local scales (1: 2 500 000 – 1: 10 000);
- For local land-use, planning, and emergency management, the flood depth maps in urban areas have a large scale;
- For large areas, like Hungary or the Netherlands, the medium and small scales can be applied successfully.

Color scheme

In most maps the depths are represented as a variety of blue shades (highest depth dark blue, light depth, light blue). Some countries use red, yellow, and green colors (EXCIMAP, 2007, pp. 18-19).

Flow velocity and flood propagation map - Flow velocity describes the speed /acceleration of moving water. Based on velocity, the damage and the danger can be assessed. One of the provisions in the EFD dictates that, where appropriate, the flow velocity or the relevant water flow should be presented. But the flow velocity information is more complicated to derive than the water depth. Usually the flow velocity information can be derived only from the 2D-flow models and in some cases also from 1D-flow models. The production of velocity maps is more technically advanced.

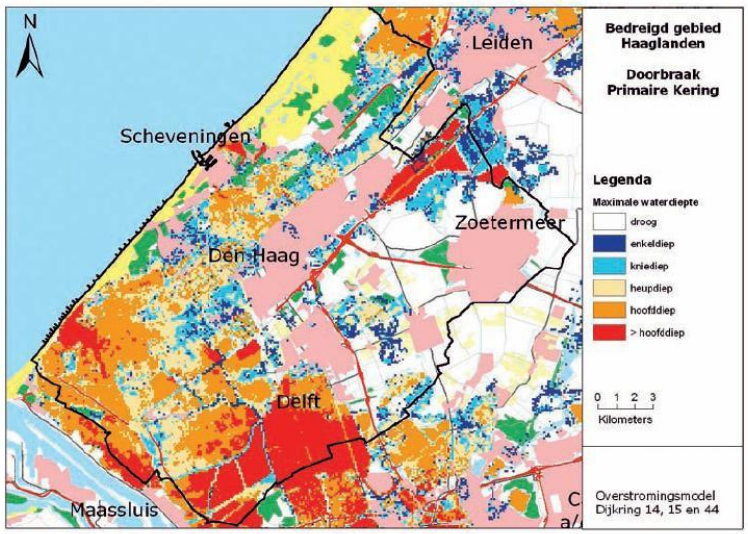


Figure 26: Flood hazard map with indication of expected water depth with “human terminology” (The Atlas of Flood Map 2007, pp. 107)

This map is very useful not only for evacuation planners, but also for the community to plan their actions in the case of flood. The map provides information as the flood classes in the “human terminology” how the flood can affect the human body: dark blue – ankle deep, light blue – knee deep, light rose – hip deep, orange – head deep, red – submerged (The Atlas of Flood Map 2007, pp. 102).

Map use

- Flow velocity maps: flood defense planning or structure planning. Tool for technicians.
- Flood propagation: planning tool for emergency response to create evacuation schemes, organize and implement temporal flood protection measures, and plan safe zones. Flood propagation should closely cooperate with early warning and alert systems.

Scale considerations

- Flow velocity: has to be represented in a detailed scale. The map scale ranges from 1: 1 000 to 1:5 000;
- Flood propagation: these maps cover large areas so the scale is small. The Netherlands’ example map (figure 26) has 1: 250 000 scale.

Color scheme

There exist many possibilities in both maps. The discrete scale is easier to read and understand than a steady (ramp) scale (EXCIMAP 2007, pp. 19-20).

Flood Danger Map - Flood danger maps may be classified as flood hazard maps, though they do not fit exactly with the definition of hazard maps. A flood danger map combines various flood parameters to define a level (degree) of danger (velocity, depth). The information can be provided in such maps as qualitative or quantitative. This type of map is not compulsory by the EFD but it is useful for land use planning.

Great Britain uses interesting methodology to classify the danger maps. They rate the hazard by hazard rating (HR). HR is calculated as a function of velocity (v), depth (d) and a debris factor (DF): HR= d x (v + 0,5) + DF. HR assesses the direct risk to life, which rises from the combination of flow velocity and water depth. That methodology is based on experiments and includes a debris factor which recognizes that debris-filled flowing water increases the danger to people. Below are some values from the formula that define the degree of Flood Hazard.

Table 3: Hazard to People as a Function of Velocity and Debris (HR Wallingford 2006, pp. 49)

d x (v + 0.5)	Degree of Flood Hazard	Description
<0.75	Low	Caution *"Flood zone with shallow flowing water or deep standing water"*
0.75 - 1.25	Moderate	Dangerous for some (i.e. children) *"Danger: Flood zone with deep or fast flowing water"*
1.25 - 2.5	Significant	Dangerous for most people *"Danger: flood zone with deep fast flowing water"*
>2.5	Extreme	Dangerous for all *"Extreme danger: flood zone with deep fast flowing water"*

Another table defines the debris factor (DF) for different land uses according to the probability of debris in the flood flow.

Table 4: Guidance on debris factors for different flood depths velocities and dominant land uses (HR Wallingford 2006, pp. 49)

Depths	Pasture/Arable	Woodland	Urban
0 to 0.25 m	0	0	0
0.25 to 0.75 m	0	0.5	1
d>0.75 m and/or v>2	0.5	1	1

The example flood danger map from Great Britain shows the applied methodology.

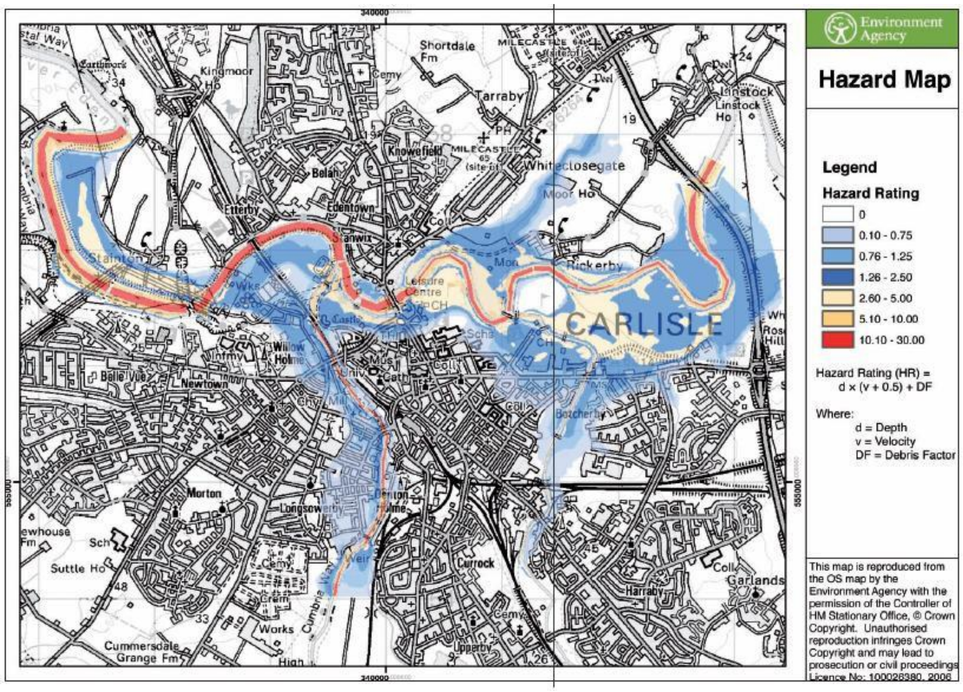


Figure 27: Flood hazard rating map of the region of Carlisle (The Atlas of Flood Maps 2007, pp. 48-49)

Such kind of map could be useful for emergency planning (evacuation routes), where there is the highest potential for danger.

Map use

- Town/level planning. Danger levels integration to land-use plans are possible;
- Awareness rising;
- Emergency response.

Scale considerations

- The scale can vary in the range from 1: 1 000 to 1: 20 000 (figure 27);
- The topographic background is needed for city and village plans when the assets need to be identified.

Color scheme

Mostly there are variations of red (highest level of danger) – orange (moderate danger) – yellow (light danger) colors used. The use of blue in the graduation could be a mistake. That visualization could lead to confusion with water depth and water extent (EXCIMAP 2007, pp. 20).

Event Map - The common step in accessing the flood hazards is the analysis of past flood events. The delineation of past flood events grants perfect basis for awareness building and flood risk management. That kind of information is easy to understand and the effect is stunning. Historic flood incident maps (the presentation of floods that have occurred in the past as the point locations) may be presented using defined symbols either separately from, or overlain on, flood extent maps. Associated data, such as date of the event, magnitude, damage and costs may be attached to a specific flood incident and visualized on the map. Usually in event maps the simple but striking information is presented. This information must be understandable to a non-expert, as well as such data as photos, dates, and drawings that explain the causes of consequences of the flood and fit very well (EXCIMAP 2007, pp. 21).

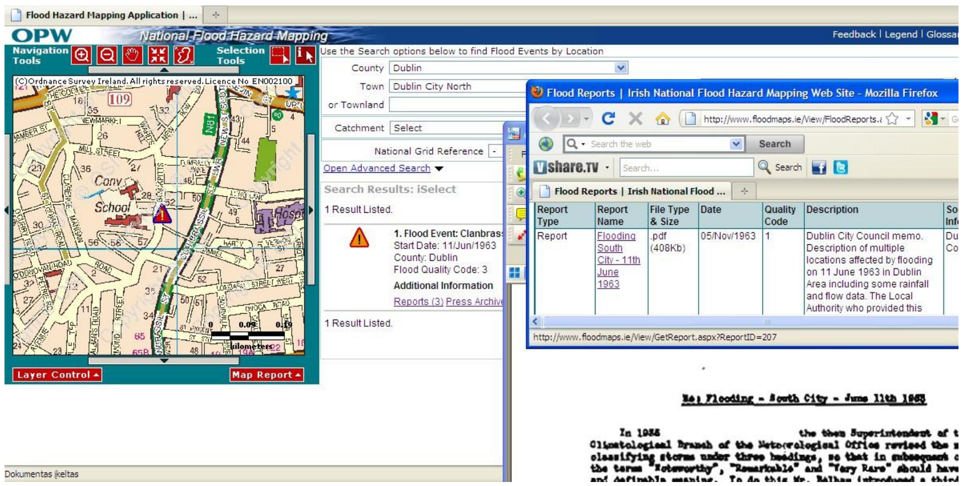


Figure 28: Screen view from Irish Office of Public Works website (OPW 2010)

The Office of Public Works (OPW) is the leading state agency in flood-related matters in the Republic of Ireland. On its website the information about past flood events is displayed. The users can search over there on the name of location or interactively choose it. For each location, special icons are presented where a flood occurred. By clicking on the icon the additional information (photographs, hydrometric, reports, and other relevant data) shows up (Atlas of Flood Maps 2007, pp 90).

Map use

- Awareness rising: simple and stunning information;
- Basis for follow-up flood hazard assessment, calibration models, etc.
- Emergency management and planning if continuously updated (Irish example).

Scale considerations

The scale depends on the size of flooded areas. It can vary from 1: 10 000 in hilly areas to 1: 250 000 in large flood plain areas (whole province).

Color scheme

Past events could be presented as transparent layer (or dashed) in various shades of blue color (EXCIMAP 2007, pp. 21).

4.1.2. Flood Risk Mapping

The EFD requires only the vulnerability parameters, but the implication of the risk should also be integrated. Flood risk maps are more flexible, as there are no strict requirements as for flood hazard maps. Therefore, it is more complicated to create (at the conceptual level) flood risk maps. In most European countries the flood risk maps are much less developed than flood hazard maps (EXCIMAP 2007, pp. 26). The flood risk maps can be assigned to two different types:

Vulnerability map –assets at risk. Mapping the assets at maps means to deliver vulnerability parameters, as described above as the EFD requirements for flood risk mapping (population, assets and economic activity, etc. affected by the flood). In short, create vulnerability maps.

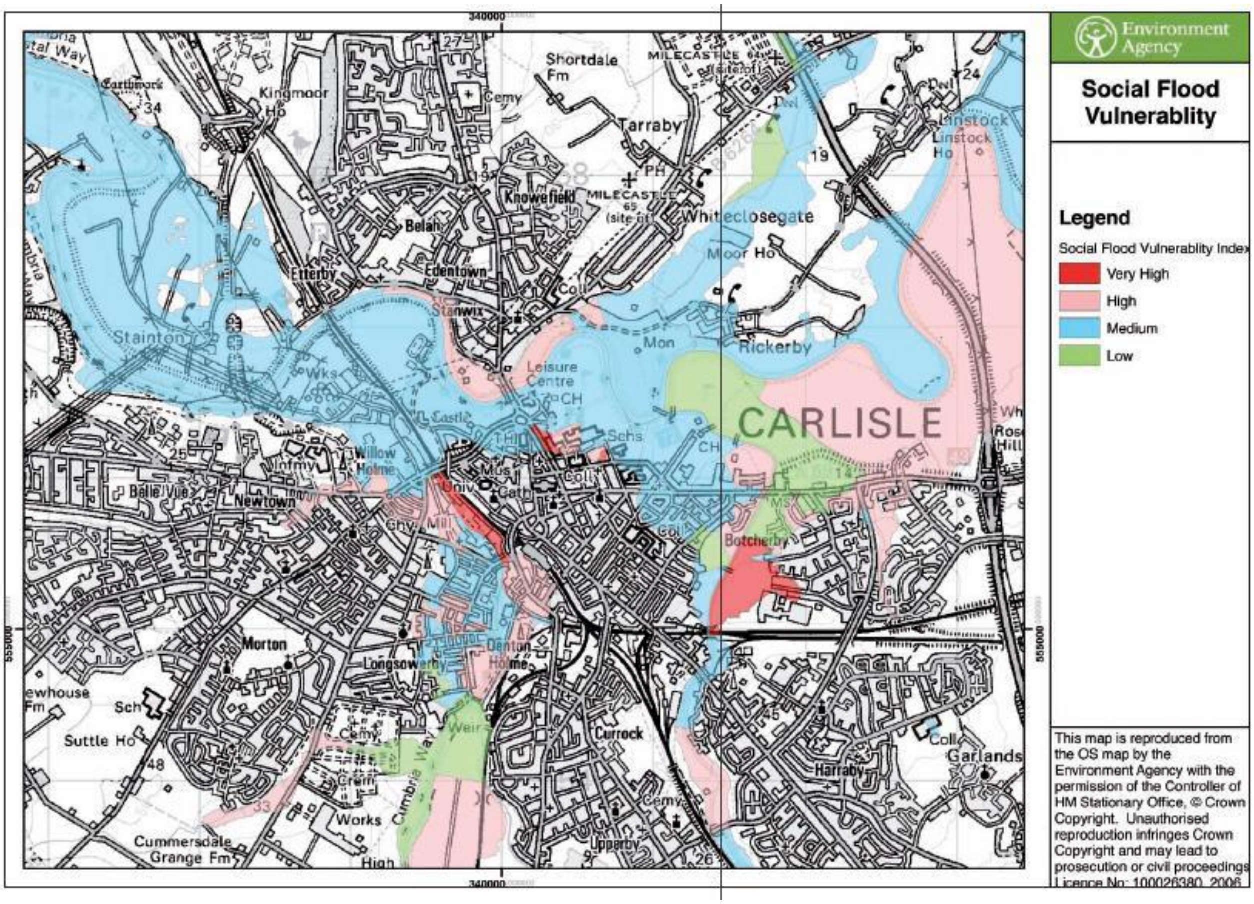


Figure 29: Social Flood Vulnerability map of the region of Carlisle (Atlas of Flood Maps 2007, pp. 51)

One example is the social vulnerability map (figure 29). This map gives a good view of vulnerability of either a person or property at different locations within extreme flood outline. The Flood Hazard Research Centre at Middlesex University developed a Social Flood Vulnerability Index (SFVI) based on three social groups: long term sick, single parents, the elderly, and four indicators of financial deprivation: unemployment, overcrowding, non-car ownership, non-home ownership. The SFVI can take a range of values, and these are divided into ranges from 1 (very low vulnerability) to 5 (very high vulnerability). Each output area of the UK National Census has a SFVI band calculated, and the number of districts within each score in a flood risk area such as Carlisle is used to calculate the overall social vulnerability of that area (Atlas of Flood Maps 2007, pp. 41).

Map use:

- Basis to determine damage and risks;
- Emergency management;
- Flood expert tool (planning of flood defense measures);
- Land-use planning and land management;
- Priority setting on small scale (large areas).

Scale considerations

- Overview information on village or town level. On large areas only the approximate population per municipality, village, or town can be represented. Scale ranges from 1: 100,000 to 1: 500, 000. Only feasible for large flood plains;
- Small and medium scales (1: 100 000 to 1: 250 000) may be used for broad-scale infrastructure like roads, rail networks, or agriculture and forestry;
- Large scale (1: 5 000 to 1:25 000; city or village plan) maps are required for detailed information about individual buildings, facilities, parcels, social structures, and social groups.

Color scheme

Colors can vary in many cases, as there are no restrictions, while the risk maps are quite flexible. It is essential to avoid overcrowding the map and avoid similar shades of colors when visualizing different parameters (EXCIMAP 2007, pp. 24-25).

Other flood maps (flood defenses and flood damage) - According to the EFD, the other information that the member states consider useful is the indication of areas where floods with a high content of transported sediments and debris floods can occur and information on other significant sources of pollution that may be mapped.

Flood defenses and dikes and their capacity for protection may be outlined on risk maps. According to the guide of best practices on flood prevention, protection and mitigation (WDEU 2003, pp. 2), the defense structures (structural measures) are important elements that focus on the protection of human life, valuable goods, and property. It shouldn’t be forgotten that there is always a risk that flood defense can fail. Then the potential new risk should be taken into consideration (WDEU 2003, pp. 26).

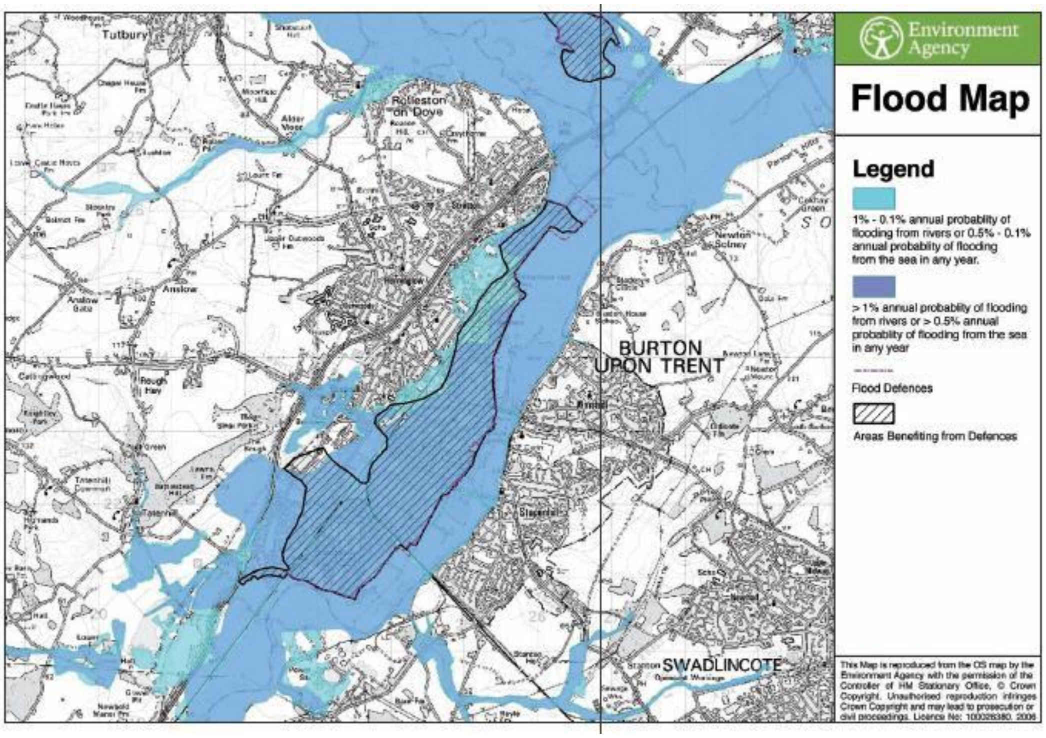


Figure 30: Flood extension map for the events of various return periods with the benefit areas from the defenses for the area of Burton Upon Trent (Atlas of Flood Maps 2007, pp. 44-45)

This example from Great Britain shows the flood extension map with the benefits of the flood defenses. It’s likely that the dashed area wouldn’t be inundated.

A flood damage map represents the potential damage caused by a particular flood event (having a certain probability of occurrence) and giving the number of causalities or damage (in Euros) per land unit. A presentation format may be used to indicate a degree of risk for a given location or town using different sizes of bars or circles to indicate different degrees of risk (EXCIMAP 2007, pp. 26).

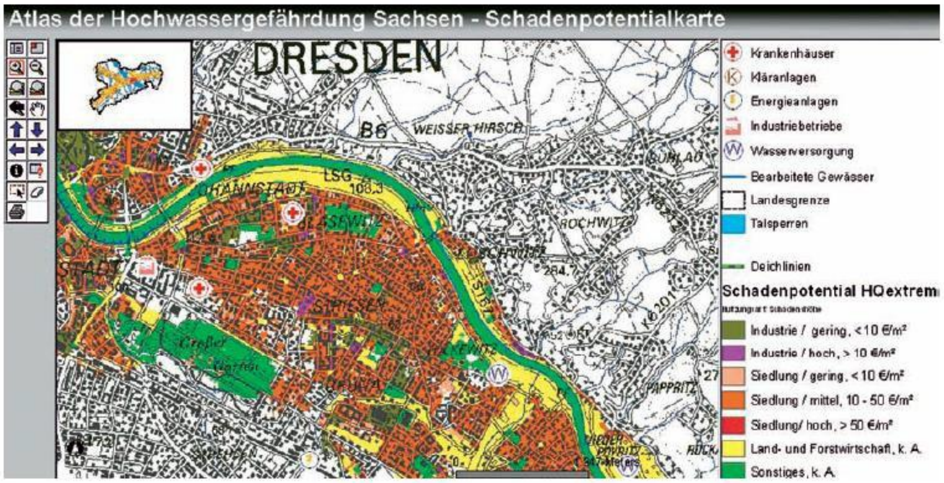


Figure 31 Flood damage map of the region of Dresden, Germany (Atlas of Flood Maps 2007, pp. 82)

The flood damage map of Dresden gives the detailed information on the potential damage during "extreme" floods, with a distinction between industry and urban damage. The expected damage is graded by land-use zones (residential areas from low 10€/m2 to high 50€/m2, industrial areas from moderate < 10€/m2 to high >€/m2 etc.) as the Euros per square meter.

Map use (flood defense and flood damage)

- Flood risk management, decision making: prioritizing to set up flood defense measures, to identify greatest risk areas;
- Flood risk management, planning: selecting the best options and range of measures to reduce flood risk :
    - Spatial planning and control of development (avoidance);
    - Asset system management (defenses, flood storage areas, managing the pathways of rivers, estuaries and coasts);
    - Flood preparation (flood detection, forecasting, emergency planning);
    - Flood incident management and response (flood warning, actions of emergency services, healthcare providers and flood risk management authorities, public, community, support organizations);
    - Recovery (insurance, local authorities, re-construction).
- Emergency and crisis management at national/local level: number of people involved, evacuation routes, safe heavens/temporary refuge centers, hospital response plans, transport disruption (road & rail).

Scale considerations (flood defense and flood damage)

- Flood damage maps require detailed information, so the large scale (1:5 000 to 1:25 000) is required.
- For large flood areas a less detailed scale (1:250 000) is possible.

Color scheme (flood defense and flood damage)

Colors can vary in many cases. There are no restrictions, while the risk maps are quite flexible. It is essential not to overcrowd the map and to avoid using similar shades of colors when visualizing different parameters (EXCIMAP 2007, pp. 26-27).

4.2. Riverine Flood Loss Estimation Methodology in Hazus

The users of the Hazus Flood Model are the people who are responsible for protecting citizens and property from the damaging effects of flooding. Hazus provides decision support to communities, enabling them to make the right decisions regarding land use, evacuation, risk assessment, and damage estimation within their flood prone areas (FEMA 2009b, pp. 26).

As it was mentioned earlier, this study focuses mainly on riverine flood risk assessment (originally, there are riverine and coastal flood studies in Hazus Flood Model). The Flood Model methodology consists of two analytical processes (see figure 32): the Flood Hazard Analysis and the Damage Analysis (i.e. Flood Loss Estimation Analysis). If Hazus is used to define the hazard, then in the first process, the values of frequency, ground elevation, and discharge are used to model spatial variation in flood depth. In the second process (loss estimation) the structural and economic damages are calculated based on the combination of the results of hazard analysis and damage functions. Final results are provided as tables, reports, and maps (FEMA 2009b, pp.25-26).

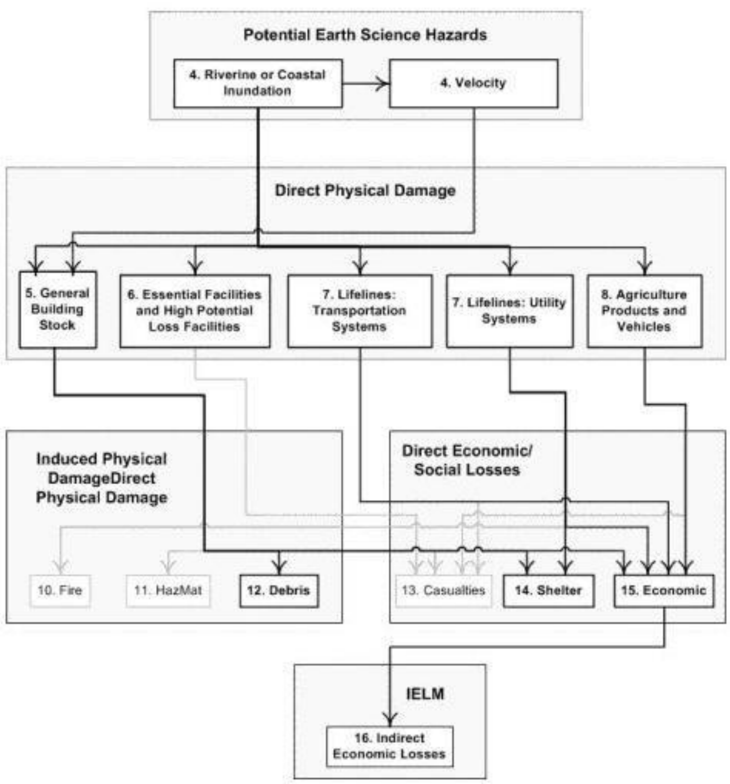


Figure 32: Schematic Flood Model view of Hazus-MH (FEMA 2009b, pp. 38)

4.2.1. Level of Analysis

The Hazus-MH Flood Model has three levels (from one to three) of analysis (figure 34). The level is defined according to the data input into Hazus-MH; the more detailed and accurate the data, the higher level of analysis. At the same time, the analysis, data preparation, and integration needs more effort from the user and data sophistication. The outputs of different levels of analysis are recommended to use for specified purposes (figure 33).

	Level 1	Level 2	Level 3
Typical Applications	• Flood mitigation / regulatory policy-making, regional, state, federal levels • Pre-feasibility studies • Real-time emergency response with no warning • Preliminary planning, zoning development	• Planning, zoning, development • Selecting mitigation alternatives • Pre-feasibility engineering studies • Emergency planning and real-time response • Environmental impact analysis • Education	• Analysis for essential, cultural, high-loss potential facilities • Emergency planning and real-time response • Mitigation and engineering research • Scientific research

Figure 33: Recommended use of an output of different analysis levels in typical applications (FEMA 2009b, pp.31)

It is clear that outputs of level 3 analysis also successfully can be used in lower level of detail required studies like pre-feasibility studies or education.

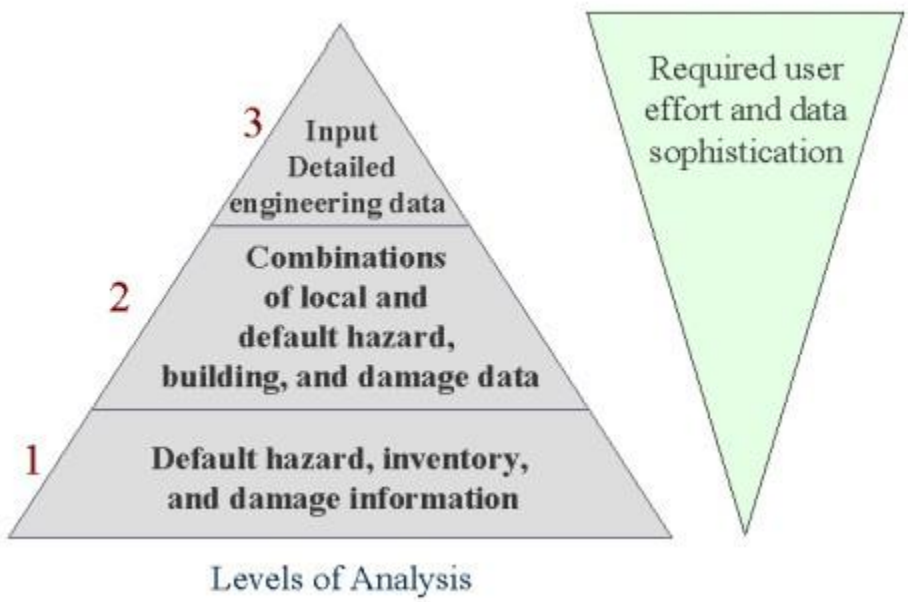


Figure 34: Levels of analysis in Hazus-MH Flood Model (FEMA 2009b, pp. 29)

About each of the analysis level in details:

Level 1 – Default Hazus data

This level is the simplest type of analysis and requires minimum effort by the user. Level 1 is based on data provided by Hazus inventory, like census information, critical facilities, aggregated building count, etc. The user is not expected to have extensive technical knowledge, because the methods used in level 1 analysis do not require complicated data input to run. In this level users do not need to acquire flood hazard data (for US study region), while Hazus Flood Model contains the tools that are able to create a drainage network and perform hydrologic and hydraulic analysis using regression equations and other mathematical methods (FEMA 2009b, pp.28). For more about Hazus produced flood hazard data, see chapter 4.4. and 5.

According to the U.S Disaster Mitigation Act 2000 (DMA 2000), communities in the U.S. need to develop and maintain a risk management (pre-disaster mitigation) plan in order to be eligible for federal disaster funds. In case of communities not having access to more refined flood hazard data, FEMA advised that flood inundation areas, generated by Hazus-MH level 1 analysis, can be accepted as they are. This declaration supported financially deficient US counties to use Hazus-MH as a tool to meet the initial requirements of DMA 2000 (Muthukumar 2005, pp. 4).

When a user reviews the default Hazus inventory data, it can seem that this data is very accurate because the numbers are exact. That is a mistaken opinion. As experience has shown, the critical facilities of default Hazus inventory data have incorrect geographical positions and attribute information (around only 5% of critical facilities in analyzed counties in Illinois and Indiana had correct positions where the point was on the building). The same situation presented with most of the bridges and high potential loss facilities and aggregated data. Even for a simple study, the recommendation would be to check the geographical position of all critical facilities in your study area using aerial imagery. But after such corrections, when the user supplies the data, the analysis will be a more detailed level 2 analysis.

Level 2 – User supplied data

Level 2 improves level 1 results by considering additional data that is available. Level 2 requires more extensive inventory data and effort from the user. As it was described earlier, the user has to update default Hazus data by checking geographical positions of facilities, other objects, the attribute information like the number of students in the school, addresses, the value, etc. Also it is important to update aggregated data with building count and demographic information, and mapping schemes. This step can be performed by cooperating with local emergency agencies, universities, and GIS departments.

The level two analysis for flood hazard data differs from level 1. The user can import a user-supplied flood depth grid or process flood hazard data with the Flood Information (FIT) tool to get it. FIT pre-processes flood hazard data for the use in the Flood Model (see chapter 3.4.3.).

Level 3 – Detailed engineering data

The level 3 analysis is the highest quality analysis possible in the Hazus-MH Flood Model. This analysis requires extensive efforts by the user in developing information on the flood hazard and exposure. At this level the analysis incorporates the results from economic and engineering studies carried out using the methods and software which are not included within the Hazus methodology. Huge support is needed from technical experts to provide the very accurate data to perform detailed damage and loss analysis. The inventory data should be acquired from the owners of the facilities. The level 3 analysis includes the change of damage functions, the detailed crop loss analysis, etc. where extensive engineering knowledge is significant (FEMA 2009a, pp.29).

Level of Analysis in Europe and world-wide

Because there is no inventory data when starting the analysis in the study region in Europe or worldwide, the user needs to supply the data. That automatically will bring the whole process to level 2 analysis. If the user will need sophisticated results, the need to modify the damage functions is also important. Because the damage function of the buildings differs from place to place, the development of it needs the engineering skills. And the implementation of a new damage function would bring the analysis into the highest level-level 3. It should be also considered that if the user supplied Hazus with new damage functions, but the user-supplied flood depth grid is not accurate, then the user should not expect to use results in high efficiency studies.

4.3. Geographical Divisions and Administrative Units in Hazus

The geographical divisions in Hazus are used for two purposes:

- To create and define a study region;
- To deliver aggregated data.

As it was mentioned earlier, Hazus has 4 levels of geographical divisions: state, county, census tract, and census block. The first two divisions can be described as administrative units, while the other two are census geographical units. The census units contain aggregated data as attribute information of geographical features (figure 35). The existing problem is that there is no common structure in Europe as there is in the USA, neither is there the same scale of Census information or such hierarchy for all European member states.

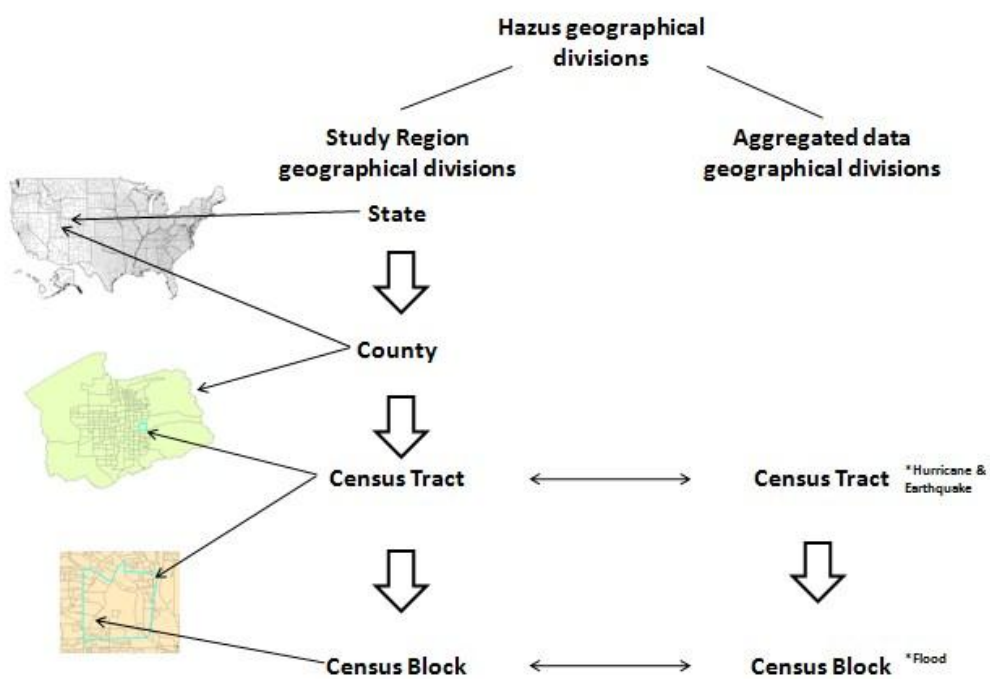


Figure 35: Hierarchy of original Hazus geographical divisions for study region and aggregated data

The advantage is that Hazus geographical divisions are not strictly combined with Hazus inventory. All these geographical divisions are located in the inner Hazus geodatabase and contain geographical features and attribute information (figure 36). The geographical features and attribute properties can be changed at ease. For any solution which will be found, there is the possibility to integrate any geographical feature into Hazus geographical feature datasets instead any of four level features. But then another question occurs: What kind of data should be interchanged with default Hazus geographical divisions?

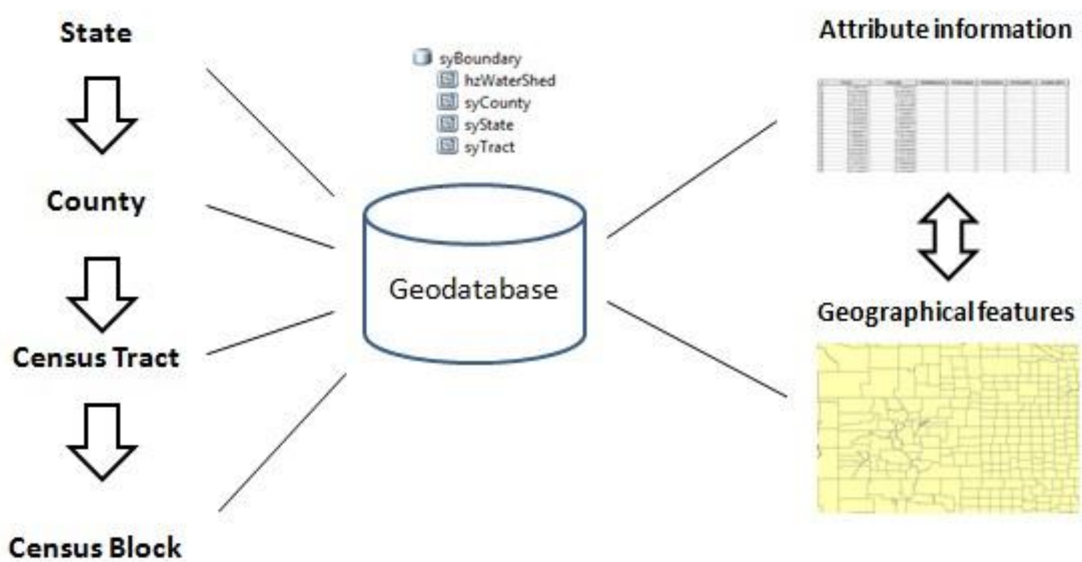


Figure 36: Hazus geographical divisions' storage scheme in the inventory

The solution that would fit for the whole of Europe is needed. The new geographical divisions should satisfy two purposes: to act as study regions and as aggregate data holders. For both of the purposes, the common data structures for all European member states are needed. That means that all geographical features must be adjacent, do not overlap, and contain the same attribute information with the same data types and same structure. Looks like mission impossible. For the study region purpose it is needed:

- Correct (non-overlapping) geographical features;
- Attribute information to maintain relations of geographical divisions.

Both requirements can be satisfied by implementing NUTS (more about NUTS see chapter 3.5.2.), because NUTS satisfies the first requirement for each of the European member states. Another issue is the attribute information that would maintain the relationships between geographical divisions. This problem can be solved by creating those relationships, the same as Hazus uses (figure 35). Actually, the study region's geographical divisions for Europe can be implemented by exchanging the original Hazus geographical features with NUTS and creating the relations with data managing and integration tools like ArcCatalog, ArcMap, Microsoft Access, etc. (For more about implementation see chapter 6).

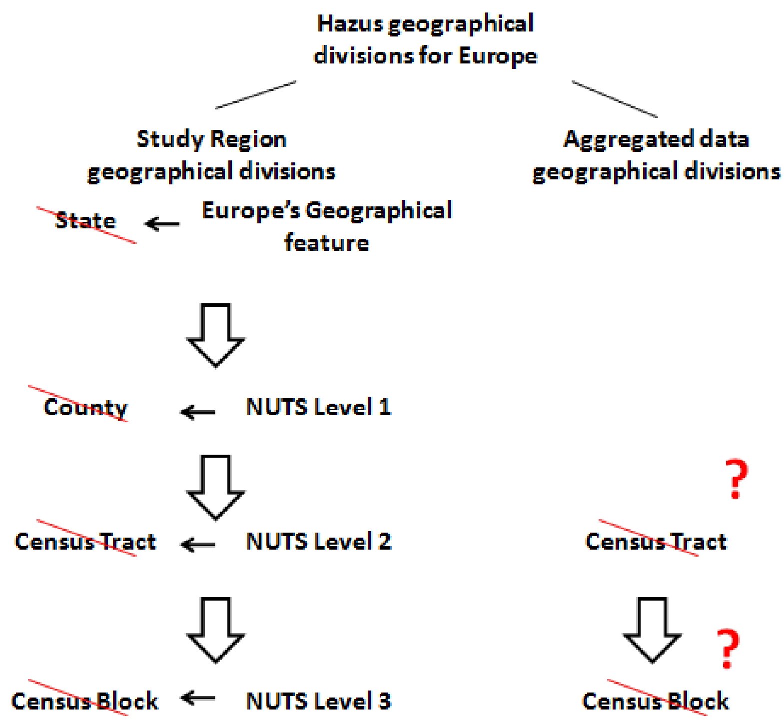


Figure 37: Implementation's framework of European geographical divisions for Hazus

Another big issue are the geographical divisions for aggregated data in Hazus. The existing problem is that there is no common aggregated data structure for each European member state. This makes the integration of European aggregated data very complicated, because how it is possible to integrate data when there is no common standard? First of all, such a standard should be defined and all European member states should convert from older datasets or directly store as new standardized data and only then should the implementation be possible.

However, it is possible to integrate the existing aggregated data for individual countries. It is not efficient, because then the whole implementation procedure should be proceeded for each country that has different standards of aggregated data. And the data sharing and cooperation between different countries via Hazus should also be complicated.

The further method could be applied to Austria (figure 38). There are many possible variations with higher ranking position geographical divisions for a study region like "state" and "county" in original Hazus. If the purpose of the implementation is to use the Hazus Flood Model worldwide, the suggestion would be the first level chosen is the continent (if Europe) or worldwide.

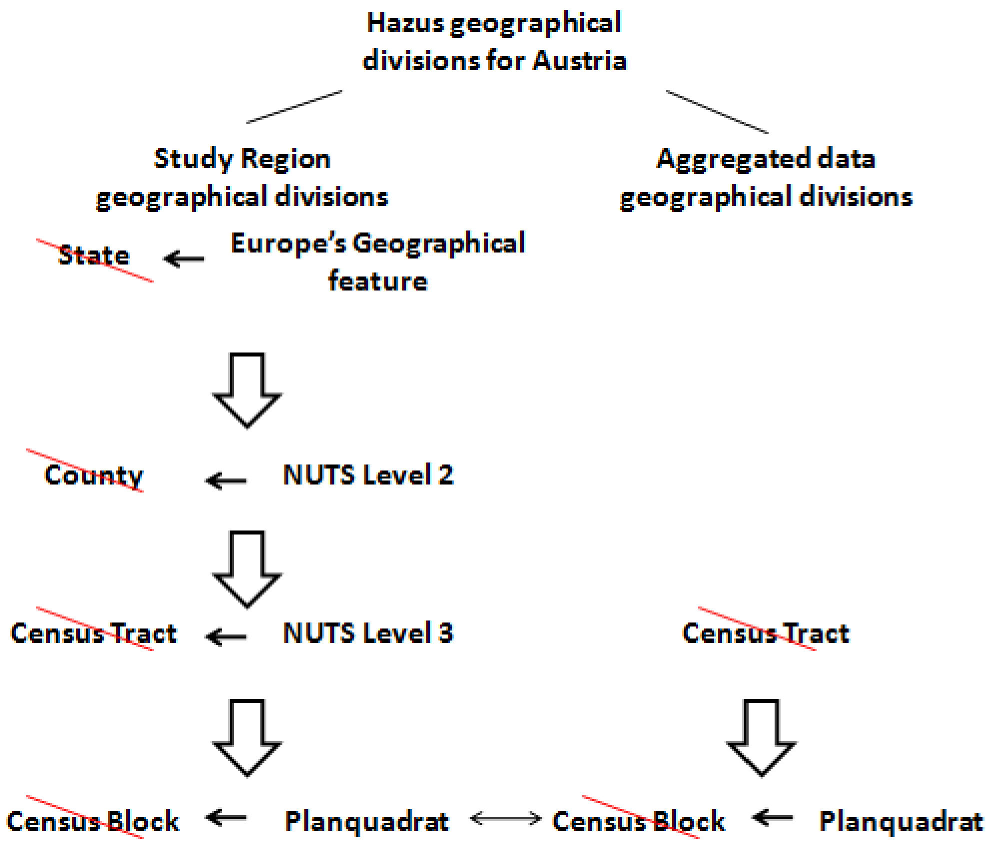


Figure 38: Implementation framework of Austrian geographical divisions for Hazus

The second level could be any standardized administrative unit, like NUTS Level 2 in Europe. Because this research focuses on the Flood Model, where only census blocks—the smallest geographical units—are used, there is no need to integrate aggregated data into the third level. The last level for Austria should be the *Planquadrat.* The procedure of implementation of the aggregate data for the geographical features is the same, only more tables and features should be populated with attribute information.

Because there is no common standard of aggregated data for Europe, it was decided not to integrate aggregated datasets of individual countries right now and wait until some or all European countries standardize the structure of data.

4.4. Flood Hazard Data

Flood hazard data is the data that describes a flood hazard. The most significant output of the Hazus Flood Model is the flood depth grid (figure 39).

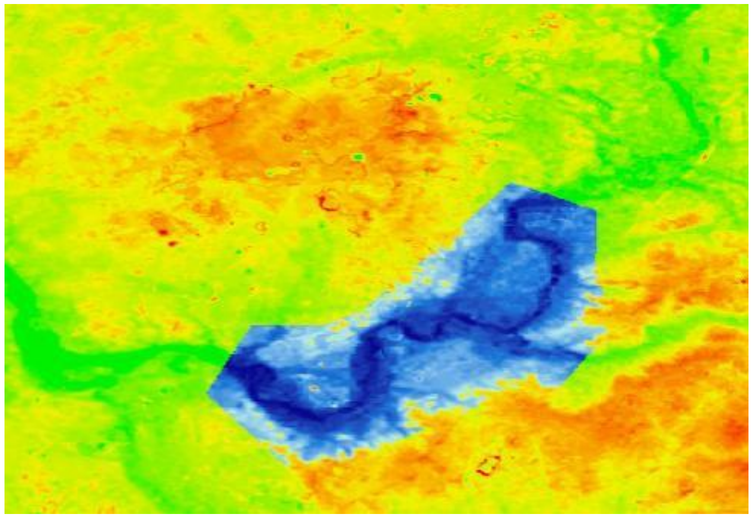


Figure 39: Flood depth grid in the background of DEM

Flood depth is the difference between flood and ground surface elevations at each grid cell. The flood surface model is a grid-cell based the same as ground surface model, which is a grid-cell based Digital Elevation Model (DEM). There exist algorithms that define the extent of the floodplain and interpolate flood elevation between digital river cross sections. The specified algorithms were developed to accommodate the available digital topographic and flood elevation data and to minimize required user interaction.

The approach (figure 40) used in Hazus finds the elevation difference between two surfaces: flood and ground surface at each cell in the grid. The floodplain cells are identified as the cells where the flood surface elevation exceeds the ground surface elevation. The collection of cells where the flood elevation equals the ground elevation form the floodplain boundaries (FEMA 2009a, pp.135).

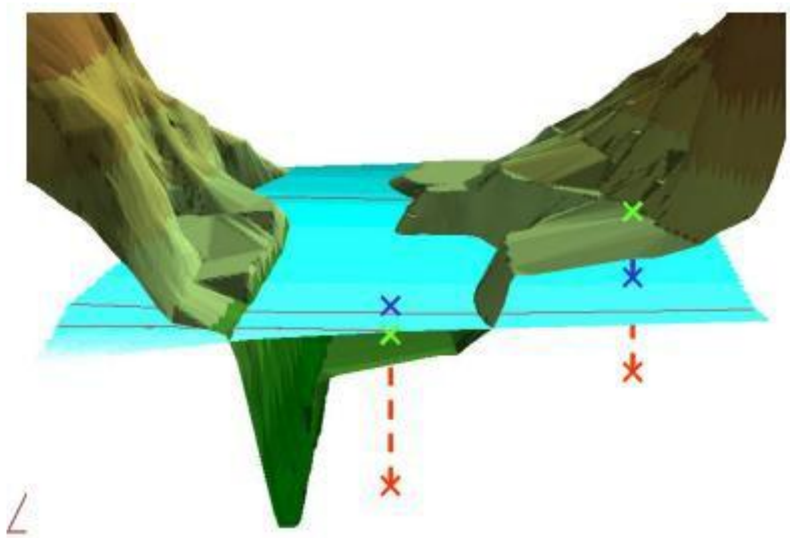


Figure 40: Surfaces used to develop flood depth grid (FEMA 2009a, pp. 169)

The Hazus Flood Model is capable of producing the flood hazard data within the software (more about framework see the chapter 4.4. and 5.1.); only DEM and regression equations are needed. For areas in the US, the regression equations are already provided. Regression equations (figure 41) are used in hydrologic modeling and contain such parameters as snow melting, precipitation, etc.

Hydrologic analysis is performed for each node by using the regional regression equations. The results of applying the equations are adjusted using stream gage data where the drainage area at the gage is between 50 and 150 percent of the drainage area of the node. Discharge values for reaches on main streams are interpolated from the corresponding values in the default flood frequency database (FEMA 2009a, pp.149).

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

Figure 41: The form of regression equation (FEMA 2009a, pp. 149)

For each region there are different regression equations. The general form of a regression equation can be seen in figure 41. The Q_T is the discharge value with a return period of T, C is a constant, and the $f_i(P_i)$ is the parameter of equation. The parameters can vary from equation to equation (Hazus 2009a, pp.149).

The parameters of regression equations are from the drainage area at the node, the average slope, the elevation, to the precipitation and snow melting factor and others. Each of these parameters are stored in the Hazus polygons (shape files), known as hydrologic regions (FEMA 2009a, pp.149). The "FlAnRivHydro" geodatabase in "Hazus\Data\FL\Hydro" folder contains these parameters.

Within Hazus, the hydraulic analysis is performed using Manning's equation with a friction slope equal to the slope of the reach (i.e., normal depth calculations) to estimate flood elevations. Manning's equation relates the velocity of a unit mass of floodwater to the friction slope, the roughness and hydraulic radius of the floodplain. The hydraulic radius is the area divided by the perimeter of the submerged portion of the river cross section. More details about the use of Manning's equation in hydraulic modeling in Hazus can be found in the Hazus MR4 Flood Technical Manual, page 182 (FEMA 2009a).

4.4.1. Suggested Flood Depth Grid Methodology

One of the simplest methods to produce a flood depth grid is to subtract the flood elevation (flood crust elevation) from the DEM (figure 40). For that reason the accurate DEM is needed. The flood crust elevation can be delivered from the flood boundary (the polyline which connects same elevation points) or from field measurements on the flood scene. When the flood boundary is available, it is recommended to find out the mean of flood level if the elevation varies. Also, in some areas there are water marks on the walls of buildings. In figure 42, the water marks in Villach (Austria) can be seen. The marks describe the elevation and the date of the flood. This value (elevation) can be used in further flood depth grid methodology.

Figure 42: The flood elevation marks in Villach, Austria (elevation and year of the flood are known)

The methodology is simple, but it can be complicated to apply it in GIS. The possible solution is to create an ArcMap tool that would be able to deliver the flood depth grid in a few steps. For this reason the tool was developed in ArcMap Model Builder (figure 43). The model needs only three inputs: *flood elevation, the interest area, and accurate DEM* (in figure 43, the inputs marked as parameters – variables). The interest area is a simple polygon which defines the bounding box of the final result, the flood depth grid.

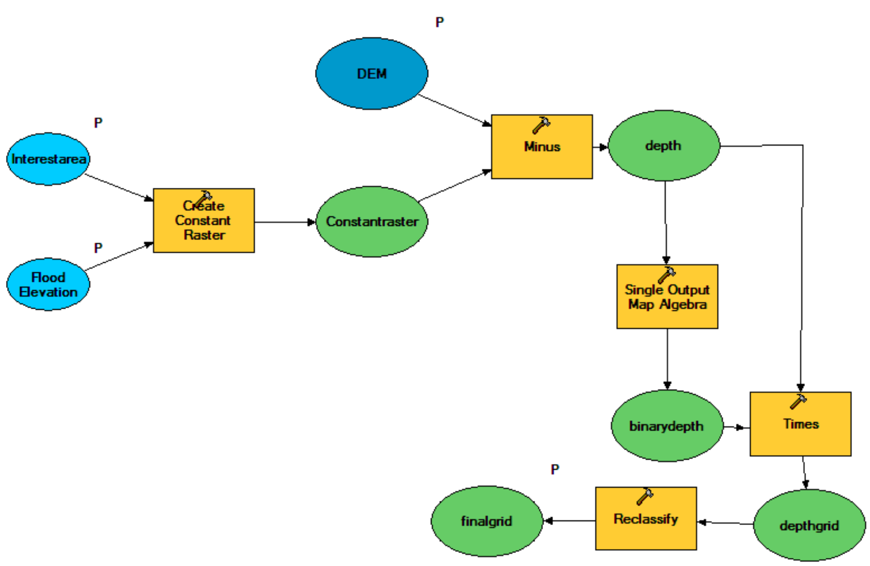


Figure 43: The ArcMap Model Builder view of the flood depth grid model

For the user it is comfortable that only three variables are needed to define, all other processes are done by mode. Model creates the constant value (flood elevation) raster and subtracts it from DEM. The result is the height difference between DEM and flood elevation. In the cells, where flood elevation is lower than DEM, the height difference is negative. To eliminate the negative values the map algebra is needed. The Map algebra tool takes all the positive values by creating the binary grid and multiplies it with the same height difference grid. The reclassification module eliminates the zero values (the flood elevation), and only negative values as depth are delivered. Figure 39's flood depth grid was produced in such a way.

The quality of this methodology is questionable. The same methodology was applied for the Flood Damage Reduction Feasibility Study for Rocky Ripple (chapter 3.4.4.) and showed good results. It is also clear that the water never stands still; it moves all the time, especially along the riverbed. Probably for huge areas, even where the high accuracy DEM is available, it is not a good idea to use this methodology. The advantage is that this methodology is simple and free. The outputs can be successfully integrated into Hazus as user-defined flood depth grids. In this case, only the inventory data is needed for flood assessment.

4.4.2. Advanced Shuttle Thermal Emission Radiometer Digital Elevation Model

The Advanced Shuttle Thermal Emission Radiometer is known as ASTER, and it provides 30 meter worldwide DEM for free. Everyone interested can register online, visit the website, and download the tiles of DEM. The geographical limits of available DEM are 80 degrees north and south latitude. U.S. users have the similar ability to use the NED (National Elevation Dataset) website.

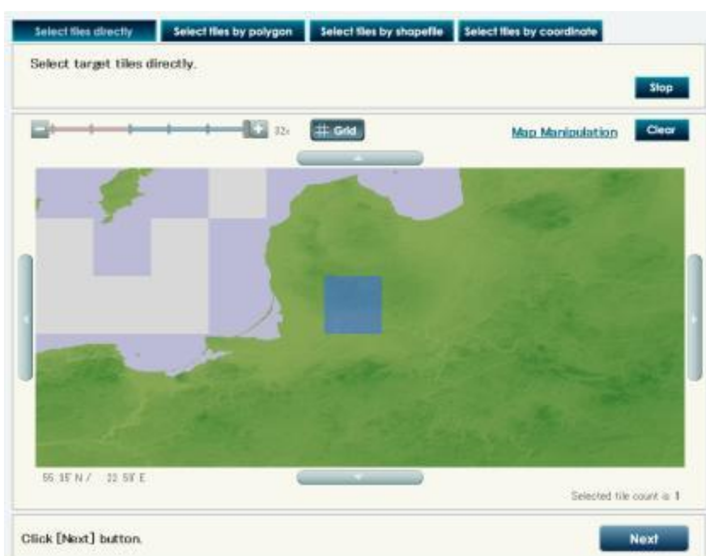


Figure 44: Interface of ASTER website (ASTER 2011)

Hazus calculates the bounding box coordinates of the study region and diverts the user directly to the needed DEM datasets. In ASTER, the user has to do that manually. So far the quality is not perfect, but the ASTER DEM is constantly updated.

ASTER DEM can be reached by URL: http://www.gdem.aster.ersdac.or.jp .

4.5. Inventory Data (Aggregated and Site-Specific)

The identification and valuation of inventory is an important requirement for estimating losses from floods. The Hazus Flood Model uses a comprehensive inventory in estimating losses. When users do not have better available data, the default Hazus inventory very often serves the user.

The inventory data in Hazus is stored in the state folders—the geodatabases and tables. When the user is creating a region, Hazus connects the inventory and acquires all the information, like the aggregated and site specific data, mapping schemes, etc.

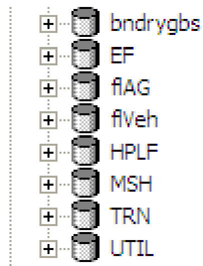


Figure 45: The datasets in state folder

The inventory can be updated easily by CDMS (more about CDMS see chapter 3.4.3.). CDMS is also able to query and export data if needed. The advantage of the inventory is that all the data is stored in inventory, not in the Hazus files. Hazus only acquires them when the region is created. A user can not only update inventory, but also share it. For example, in the agency there are state folders on the network drive. One department is responsible for updating inventory weekly while another department uses Hazus-MH and acquires data from inventory. Florida and South Carolina (United States) even developed web CDMS portals. The functionality of these portals is the same as the Hazus inventory. This development enables the agencies to work with the same updated data.

4.5.1. Aggregated data

Aggregated data is combined data. Usually that can be census or demographic data. In Hazus the aggregated data is the polygon features that contain the attribute information. There are many types of aggregated data in Hazus. The most significant is the General Building Stock (GBS) data.

General Building Stock (GBS)

The GBS data includes residential, commercial, industrial, agricultural, religious, educational, and government buildings. All these buildings are stored as attribute information in each census block (A Census block is the smallest geographical unit in Hazus. For more details see chapter 3.5.3.). The composition of these buildings and other information is evenly distributed within the census block. For GBS, the damage is estimated using area-weighted flood assessment. The model uses the necessary inventory information to determine a given percent damage for the inundated area by identifying the occupancy and building types (FEMA 2009a, pp. 52).

All three Hazus models (Earthquake, Flood, and Hurricane) use the common data to ensure that users do not have discrepancies when switching from hazard to hazard. Earlier it was mentioned that the smallest aggregated unit differs through models (flood has census block, earthquake and hurricane models have census tract). Whenever the Flood Model is included in the study region, all three models require the user to edit the common inventory data at the census block level (FEMA 2009a, pp.52).

The common data of all three models for GBS are:

- Demographics – housing and population statistics;
- Square footage by occupancy – estimated floor area by specific occupancy (e.g., RES1);
- Full replacement value by occupancy – estimated replacement values by specific occupancy;
- Building count by occupancy – estimated building count by specified occupancy;
- General occupancy mapping – inventory data from specific occupancy to general building type (e.g., Steel) (more details about mapping schemes, see chapter 4.8.).

There are 33 specific occupancy classifications for GBS in Hazus. The purpose of classification is to group the buildings with similar valuation, damage, and loss characteristics. Table 5 shows the fragment of occupancy classes and subclasses. For a full list, see Hazus MR4 Flood Model Technical Manual, pages 54 – 55 (FEMA 2009a).

Table 5: Fragment of GBS occupancy classes and subclasses (FEMA 2009a, pp.54)

HAZUS Label	Occupancy Class	Standard Industrial Codes (SIC)
Residential		
RES1	Single Family Dwelling	
RES2	Mobile Home	
RES3A	Multi Family Dwelling - Duplex	
RES3B	Multi Family Dwelling – 3-4 Units	
RES3C	Multi Family Dwelling – 5-9 Units	
RES3D	Multi Family Dwelling – 10-19 Units	
RES3E	Multi Family Dwelling – 20-49 Units	
RES3F	Multi Family Dwelling – 50+ Units	
RES4	Temporary Lodging	70
RES5	Institutional Dormitory	
RES6	Nursing Home	8051, 8052, 8059
Commercial		
COM1	Retail Trade	52, 53, 54, 55, 56, 57, 59
COM2	Wholesale Trade	42, 50, 51
COM3	Personal and Repair Services	72, 75, 76, 83, 88
COM4	Business/Professional/Technical Services	40, 41, 44, 45, 46, 47, 49, 61, 62, 63, 64, 65, 67, 73, 78 (except 7832), 81, 87, 89
COM5	Depository Institutions	60
COM6	Hospital	8062, 8063, 8069
COM7	Medical Office/Clinic	80 (except 8051, 8052, 8059, 8062, 8063, 8069)
COM8	Entertainment & Recreation	48, 58, 79 (except 7911), 84
COM9	Theaters	7832, 7911

In table 5, not only the occupancy classes (e.g., Residential) but also the subclasses (e.g., Single Family Dwelling) can be seen. Each subclass unit has the same (nearly the same) properties in Hazus.

The abbreviation “SIC“ in table 5 means the Standard Industrial Code. The purpose of these codes is to classify industries in the United States. The Hazus label in table 5 is the abbreviation of occupancy subclasses. These abbreviations are commonly used in Hazus and should be known for easier identification. The RES3A means Residential class, 3A means subclass. Example, the abbreviations for damage functions differ because the unit needs to be identified: Does it have a basement or not? In this case the damage function for RES3A 3-4 story building will be R3A3B, without – R3A3N. There are more details about damage functions and their abbreviations in chapter 4.7.(FEMA 2009b, pp. 319).

The input information as attribute information of census block of GBS in Flood Model for damage assessment contains:

- Occupancy class;
- Foundation type;

- Assumed first floor height;
- Replacement value;
- Contents value.

The flood damage assessment's output is the following data:

- Estimated damage as a percentage and
- Estimated loss in monetary value.

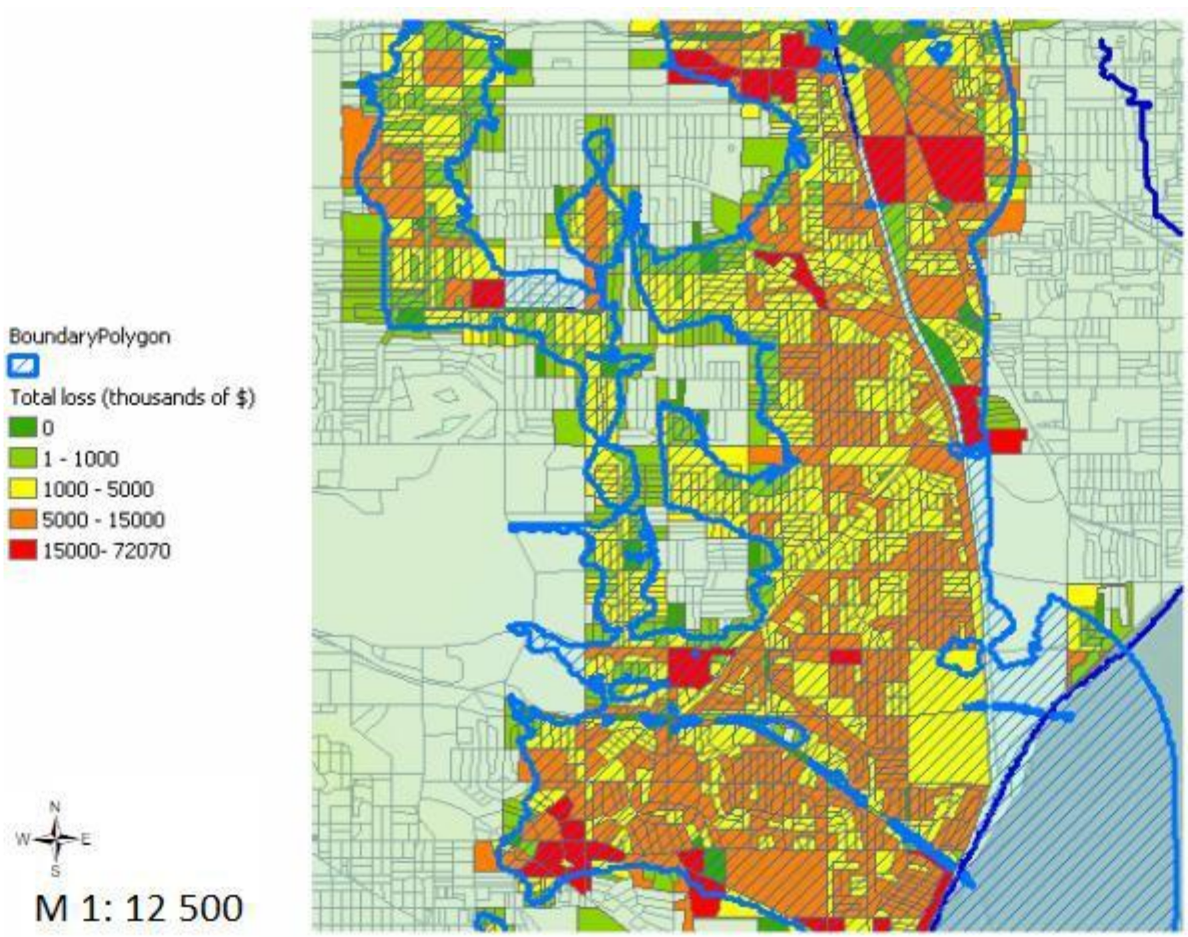


Figure 46: The example of total building loss visualization by census blocks in Hazus for Los Angeles City 500 year flood

Hazus is also capable of delivering direct and indirect economic loss, displaced persons, and the amount of flood debris. All that information is delivered from GBS flood assessment. The direct economic loss is gathered from GBS damages and loss functionality, and business relocation expenses, wage, and rental building loss. The indirect economic loss is based on the regional economy. The main parameters in Hazus for indirect economic loss are total number of employees, annual income, type of synthetic economy, unemployment rate at the time of disaster, interest rate on loans, percentage of rebuilding, restoration time of each building class, etc. More details about direct and indirect economical loss can be found in the Hazus User and Technical Manuals (FEMA 2009b and FEMA 2009a). The shelter or displaced persons assessment is based on demographic aggregated information. The shelter parameters like the income weighting factor for shelters can be changed by the user. The amount of debris in tons is calculated by the specified foundation types and the flood depth values.

Agriculture

The Hazus Flood Model uses a crop loss estimation approach currently used by the US Army Corps of Engineers (USACE) (FEMA 2009a, pp.102). The agriculture dataset is unique in Hazus. It was developed using merged US counties, drainage basins, land use, and land cover data. This set of data allowed the flood model to define agriculture products data at the county and sub-county levels. These sub-county levels do not correlate with census tracts or census blocks, but they correlate with county boundaries. Agriculture data contains such attribute information as average annual yield, unit of measure (e.g. bushel), price per unit, harvest cost or the farmers' investment, etc. (FEMA, 2009b, pp. 357).

There is a huge variety of agricultural products—around 40— but only the top 20 were chosen within each state in the U.S. The full list of agricultural products can be seen in table 6.

Table 6: Crop types currently available within the Hazus Flood Model (FEMA 2009a, pp. 311)

Crop Type	Crop Type	Crop Type
Alfalfa Hay	Apples	Bahiagrass
Barley	Bromegrass-Alfalfa Hay	Common Bermudagrass
Corn	Corn Silage	Corn, Sweet
Cotton Lint	Crested Wheatgrass-Alfalfa Hay	Flax
Grain Sorghum	Grapes, Wine	Grass Hay
Grass-Clover	Grass-Legume Hay	Improved Bermudagrass
Kentucky Bluegrass	Oats	Oranges
Orchard Grass	Orchardgrass-Alfalfa Hay	Peanuts
Pears	Potatoes, Irish	Reed Canarygrass
Rice	Smooth Bromegrass	Soybeans
Sugar Beets	Tall Fescue	Tall Fescue-Ladino
Timothy-Red Clover Hay	Tobacco	Tomatoes
Trefoil-Grass Hay	Watermelons	Wheat
Wheat, Winter		

The input information in flood assessment for agriculture is based on:

- Crop type;
- Current market value of the product;
- The planting season of the crop as it relates to the time of flooding.

The output is:

- Estimated loss in monetary value.

Vehicles

During flash floods the most major damages are inflicted to vehicles, especially where flood warnings are limited. The Hazus Flood Model is capable to estimate the monetary loss value of flood related damages to motor vehicles for flood events of various vehicle sizes (FEMA 2009a, pp. 303).

Unlike other property, the motor vehicles can be moved away from the inundated area. The available time for relocating vehicles is important because of safety issues for drivers. However vehicles are found in flood areas for several reasons:

- Parked at residences, in structures or on the street;
- Parked in parking lots at transportation facilities;
- Parked in parking lots at business locations;
- Parked at motor vehicle sales and repair facilities.

There is a different likelihood for each location and vehicle profile that the vehicle will be damaged. For example, if an operator is in the residence and there is an appropriate alternative location for the vehicle, the vehicle can be protected. This is also a function of the time available between the warning and the flood event (FEMA 2009a, pp. 305). Also the important factor for the vehicle locations is the day time changes (e.g. During the nighttime the majority of light cars are located in the residential areas, while during the day-time they are located in commercial and governmental areas).

Hazus inventory data contains three types of vehicles as the attribute information in the census blocks for night and day time: car, light truck, and heavy truck, as well as information on total vehicles.

Hazus uses a different data input system for vehicles than other aggregated data. Before it processes the flood assessment, Hazus performs these procedures:

- Calculates vehicle inventory within the study area in the census blocks;
- Allocates the vehicles by time of the day (the census blocks contains the attribute information as vehicle count for different time of the day);

These two steps can be assigned as vehicle location estimator (figure 47).

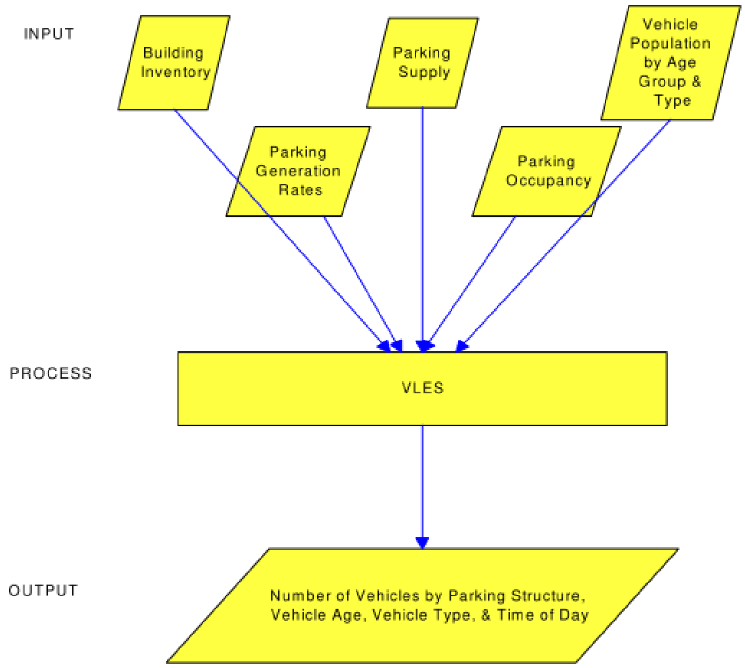


Figure 47: Vehicle location estimation system (FEMA 2009a, pp.105)

The input to determine the vehicle location are the parking generation rates (the associated number of parked vehicles, according to business hours), parking supply, and parking occupancy (according to the population density in urban areas, by parking area types), and the vehicle population by age group and type (table 7) (FEMA 2009a, pp. 109).

Table 7: Vehicle age distribution by vehicle classification. Data based on US Automobile Dealers Association (NADA) (FEMA 2009a, pp. 109)

Percentage Distribution

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

As input information for the flood assessment, the Hazus Flood Model uses:

- Vehicle count;
- The value of the vehicle.

The output is:

- Estimated damage as a percentage and

- Estimated loss in monetary value.

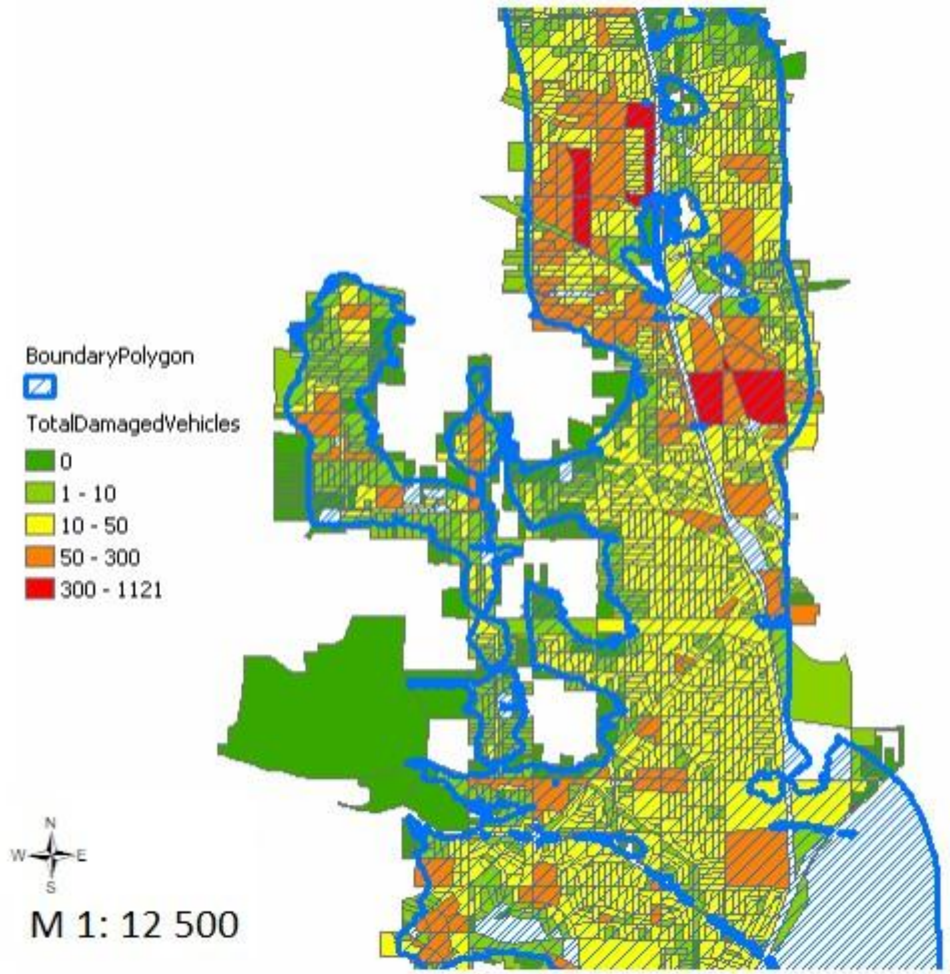


Figure 48: The example of extreme flood affected vehicle count visualization by census blocks in Hazus for Los Angeles City 500 year flood

4.5.2. Site-Specific Data

The site-specific data also includes line objects, such as roads, rails, pipes, etc. Unfortunately, even the newest Hazus 2.0 is not capable of assessing flood damage to the line objects. For this reason all line objects will be excluded from site-specific data.

Site-specific data in Hazus contains essential facilities, high potential loss facilities (quite often the essential and high potential facilities are defined as critical facilities), transportation and utility systems, and user defined facilities. Each class of these facilities will be explained.

Essential Facilities

Essential facilities in Hazus include police and fire stations, health care facilities, schools and emergency operation centers—all facilities that provided services to the community and that should be functional in the case of a flood. The difference between other facilities and essential facilities is that essential facilities contain additional information, such as the number of beds in a hospital, number of students and shelter places in a school, number of fire trucks in a fire station; however, none of these parameters are used in flood assessment. They are only for data collecting purposes.

The essential facilities are classified by facility function and other properties, as the number of beds to identify the size of the hospital (table 8) (FEMA 2009a, pp. 276).

Table 8: Essential facilities occupancy classes (FEMA 2009a, pp. 278)

No.	Label	Occupancy Class	Description
Medical Care Facilities			
1	EFHS	Small Hospital	Hospital with less than 50 Beds
2	EFHM	Medium Hospital	Hospital with beds between 50 & 150
3	EFHL	Large Hospital	Hospital with greater than 150 Beds
4	EFMC	Medical Clinics	Clinics, Labs, Blood Banks
Emergency Response			
5	EFFS	Fire Station	
6	EFPS	Police Station	
7	EFEO	Emergency Operation Centers	
Schools			
8	EFS1	Schools	Primary/ Secondary Schools (K-12)
9	EFS2	Colleges/Universities	Community and State Colleges, State and Private Universities

Some of the essential facilities include certain special equipment such as emergency generators which would allow the hospital to operate. Such contents are considered to be sensitive to flooding and can impact the functionality of the hospital. In this case, the additional value of the depth threshold to consider as non-operational essential facilities in attribute information is stored (table 9) (FEMA, 2009a, pp. 279). When the Hazus Flood Model in the essential facility location identifies that the flood depth is higher than the sum of this threshold and first floor height, this facility is no longer operational. This information is significant to plan the resources for emergency managers in the case of specified flood.

Table 9: Default parameters of essential facilities (FEMA 2009a, pp. 279)

Occupancy Class	Description	Age	Model Building Type	Basement	First Floor Elev. (ft)	Building Height	Damage Function	Depth Threshold for Functionality (feet)
EFHS	Small Hospital	Median	Concrete	Yes	3	Low	COM6	0.5
EFHM	Medium Hospital	Median	Concrete	Yes	3	Mid	COM6	0.5
EFHL	Large Hospital	Median	Concrete	Yes	3	Mid	COM6	0.5
EFMC	Medical Center	Median	Concrete	Yes	3	Low	COM7	0.5
EFFS	Fire Station	Median	Concrete	No	0	Low	GOV2	2
EFPS	Police Station	Median	Concrete	Yes	0	Low	GOV2	1
EFEO	Emergency Operations	Median	Concrete	Yes	0	Low	GOV2	1
EFS1	School	Median	Brick	No	0	Low	EDU1	0.5
EFS2	University	Median	Concrete	No	0	Low	EDU2	0.5

The following attributes of essential facilities are used by Hazus Flood Model:

- Foundation type;
- First floor height;
- Replacement costs;
- Facility class (defines damage function);
- Longitude (NAD1983);
- Latitude (NAD1983).

These are recommended to be defined by the user. All other attributes can be assigned automatically via CDMS.

The output of flood assessment for essential facilities is:

- Estimated building and content damage as a percentage;
- Estimated building and content loss in the monetary value;
- Estimated days to reach functionality (from restoration functions).

High potential loss facilities

The high potential loss (HPL) facilities in Hazus are described as the facilities which would result in heavy flood losses if significantly damaged in the case of flood. Such facilities are nuclear power plants, dams, and military and industrial facilities.

HPL facilities have only three classes, but plenty of subclasses (table 10). These subclasses help to identify HPL facilities faster and easier.

Table 10: Fragment of HPL facilities classes and subclasses (FEMA 2009a, pp. 88)

HAZUS Label	General Occupancy	Specific Occupancy
Dams		
DDFLT	Dam Default	Default
HPDA	Dams	Arch
HPDB	Dams	Buttress
HPDC	Dams	Concrete
HPDE	Dams	Earth
HPDG	Dams	Gravity
HPDM	Dams	Masonry
HPDR	Dams	Rock fill
HPDS	Dams	Stone
HPDT	Dams	Timber Crib
HPDU	Dams	Multi-Arch
HPDZ	Dams	Miscellaneous
Nuclear Power Plants		
NDFLT	Nuclear Plant Default	Default
HPNP	Nuclear Power Facilities	Nuclear Power Facilities
Military Installations		
MDFLT	Military Default	Default
HPMI1	Military Installations	Barracks/Group Quarters
HPMI2	Military Installations	Officer/Enlisted Quarters - Multi-Unit

The following attributes of essential facilities are used by Hazus Flood Model:

- Analysis (facility) class (only for military and nuclear facilities);
- Replacement costs;
- Longitude (NAD1983);
- Latitude (NAD1983).

All other attributes can be assigned automatically via CDMS. Many attributes are defined as additional information of HPL facilities and do not play any role in flood model, remaining as documentation of HPL facilities.

The existing problem is that Hazus is not able to produce any analysis with HPL facilities. Hazus uses these facilities only to store in the inventory and visualize the location. Therefore, the HPL facilities can be integrated as UDF and used in UDF flood assessment.

Transportation Systems

As mentioned earlier, even the newest Hazus 2.0 Flood Model is not able to assess line objects such as roads and railways, even when this data is stored in the inventory for the Earthquake model. For this reason, the line data was excluded from this research. Hazus is able to assess flood risk to highways, railroad bridges and tunnels, railways, light rails, buses, harbors, and ferry and airport facilities. All these objects are as point objects with specified longitude and latitude.

Transportation facilities and bridges are part of the lifelines—part of transportation infrastructure which provides mobility, transportation to contain governance and economic health. In the case of disaster, these facilities are the target of first responders to restore mobility and communications. Most of these facilities are vulnerable to flood, except bridges/foundations (bridge decks are still vulnerable to hydraulic pressure) (FEMA 2009a, pp. 282).

The flood analysis for transport facilities uses the same methodology as for all site-specific data—flood depth grid overlapped with latitude and longitude of points. In the analysis, the Hazus Flood Model does not account for the impact of flood borne debris against transportation features like bridges. The existing Flood Model estimates the level of damage to the bridge and the subsequent functionality of the bridge (FEMA 2009a, pp. 89).

Each transport type (highways, rails, airports, etc.) is classified by type of facility. Table 11 shows the classification of bus system facilities. The last column, HAZUS valuation, shows the default value in thousands of dollars.

Table 11: Bus facilities' classification (FEMA 2009a, pp.93)

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

The input for the flood assessment Hazus uses follows attribute data of transport facilities and bridges:

- Analysis (facility) class (only for airport runways);
- Replacement costs;
- Bridge class (only for bridges, defines damage function);
- Scour index (a function of floodwater velocity and duration, damage to the bridge. For more details, see 4.9 section);
- Longitude (NAD1983);
- Latitude (NAD1983).

The attributes like elevation of bridge deck for bridges, the number of spans, length, etc. do not play any role as a first floor height parameter for other facilities. The transportation facilities do not have such attributes as first floor height and foundation type (bridges have a foundation type, but the change of it does not affect the results; the same applies to bridge deck elevation). Moreover, it is not clear how the damage functions are assigned. All other attribute information can be assigned automatically via CDMS or leave the fields plain.

The output of flood assessment for transport facilities and bridges is following:

- Estimated damage in percentage expression;
- Estimated loss in monetary value;

- Functionality.

Utility Systems

Utilities are known also as lifelines to provide communications, water, power, gas, and other resources to maintain governance and economic operational. In Hazus the utilities facilities are known as water and wastewater facilities, telecommunication, power, gas, oil and petroleum facilities. Even when Hazus inventory contains such data as pipelines, the Hazus Flood Model is not able to assess flood damage. For this reason, the line features of utilities are excluded from this research.

The Hazus Flood Model uses the same methodology for transport facilities and bridges as for other site-specific data by overlapping the flood depth grid with latitude and longitude of the facility. Most of the components of utilities facilities are expensive, difficult to repair/replace (controllers, motors), and vulnerable to inundation (electrical components) (FEMA 2009a, pp. 288). For this reason, instead of first floor height as was used for buildings, the height of the component is used. This parameter is identical to first floor height and plays the same role in the analysis. Utility facilities also are not affected by flood borne debris in Hazus (in the same way as for transport facilities and bridges).

Each utility type (potable water, waste water, oil, power, etc.) is classified by type of facility. Table 12 shows the classification of waste water facilities. The last column, HAZUS valuation, shows the default value in thousands of dollars.

Table 12: Waste water system classification (FEMA 2009a, pp. 99)

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

Hazus uses the following data of utility facilities for flood assessment:

- Average height of electronic equipment;

- Foundation type;
- Replacement costs;
- Damage Function ID (damage function is assigned by ID, not by facility class);
- Longitude (NAD1983);
- Latitude (NAD1983).

All other attributes like facility class can be assigned automatically via CDMS. The output

of flood assessment for utility facilities follows:

- Estimated damage in percentage expression;
- Estimated loss in monetary value;
- Functionality.

User defined facilities

There are no user defined facilities (UDF) in the Hazus inventory by default, but a user has the ability to import it in a different way. The name "user defined facility" means that a user has to define the facility. These facilities are also used as points and have the common properties of other facilities in Hazus. The more common things are that UDF use the same occupancy type and damage functions as General Building Stock (GBS).

The aim of use of UDF is to get a more precise analysis than that obtained from GBS. For example, say a user is not satisfied with the results of the aggregated data (GBS), and would like to know exactly which residential buildings would be damaged during a specified flood. That requires new data. The user has the building point and attribute data for each of the residential buildings—everything that is needed to prepare the data so that it would match Hazus needs and import it into inventory, run the analysis, and observe the results. Now the results will be for each of the points and for each of the buildings. The UDF flood assessment framework is the same as for other site-specific data; the flood depth overlaps with the latitude and longitude of each of the points (facilities).

The UDF is classified in the same way as GBS (table 13). The advantage is that there are many occupancy types in GBS, but even that can be not enough.

Table 13: GBS occupancy classes, the same are used for UDF (FEMA 2009a, pp.54)

HAZUS-MH MR2 Label	Occupancy Class	HAZUS-MH MR2 Label	Occupancy Class
RES1	Single Family Dwelling	COM7	Medical Office/Clinic
RES2	Mobile Home	COM8	Entertainment & Recreation
RES3A	Multi Family Dwelling - Duplex	COM9	Theaters
RES3B	Multi Family Dwelling – 3-4 Units	COM10	Parking
RES3C	Multi Family Dwelling – 5-9 Units	IND1	Heavy
RES3D	Multi Family Dwelling – 10-19 Units	IND2	Light
RES3E	Multi Family Dwelling – 20-49 Units	IND3	Food/Drugs/Chemicals
RES3F	Multi Family Dwelling – 50+ Units	IND4	Metals/Minerals Processing
RES4	Temporary Lodging	IND5	High Technology
RES5	Institutional Dormitory	IND6	Construction
RES6	Nursing Home	AGR1	Agriculture
COM1	Retail Trade	REL1	Church/Membership Organizations
COM2	Wholesale Trade	GOV1	General Services
COM3	Personal and Repair Services	GOV2	Emergency Response
COM4	Business/Professional/Technical Services	EDU1	Schools/Libraries
COM5	Depository Institutions	EDU2	Colleges/Universities
COM6	Hospital		

Hazus Flood Model uses the following data of UDF for the flood assessment:

- Occupancy class;
- Foundation type (basement existence included);
- First floor height;
- Building type (practically, this parameter does not influence the results, but is needed in MR4 and MR5 Flood Models);
- Number of floors/stories (used to define damage function);
- Replacement costs;
- Contents value;
- Longitude (NAD1983);
- Latitude (NAD1983).

The listed attributes are essential for flood assessment. Other attributes like the build date and function ID do not affect the results but are recommended to be populated if integrated not one by one through Hazus (UDF) interface. The full list of data can be found in the appendix.

If the contents value is not defined, the Hazus model assigns the value depending on the building's value (table 14).

Table 14: Content Cost value's assignation

Occupancy	ContentCost
RES1 To RES6 & COM10	Cost * 0.5
COM1 To COM5, COM8, COM9, IND6, AGR1, REL1, GOV1 and EDU1	Cost * 1.0
COM6 To COM7, IND1 To IND5, GOV2 and EDU2	Cost * 1.5

The output of flood assessment for utility facilities follows:

- Estimated building and content damage expressed as a percentage;
- Estimated loss in monetary value.

4.5.3. Open Street Map (OSM) Inventory Data

Open Street Map is a collaborative project with the purpose of making free, editable maps of the world. OSM is an open source platform. Each user can freely go to the website and download the vector information like points (points of interest), polygons (buildings, areas), lines (rivers, roads) as "osm" extensions and, using many different tools (one example would be free available software Quantum GIS), convert to the shape files and import to Hazus.

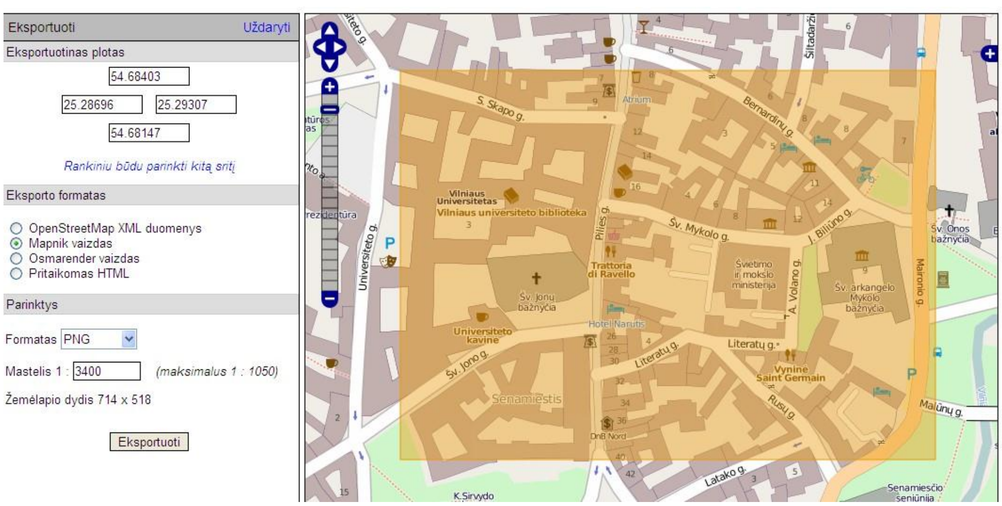


Figure 49: Lithuanian-language interface of OSM website, the location of Vilnius downtown. It is possible to create the bounding box and download the building blueprints as vector files (OSM 2011)

The data is uploaded via specified software “JOSM” or just directly imported as traces from a GPS device. Because this project is an open source project, the big question is quality. Quality is very important, especially in emergency response and risk assessment, but sometimes there is nothing that you can trust and you have two possibilities: do nothing or take a risk and use the questionable quality data.

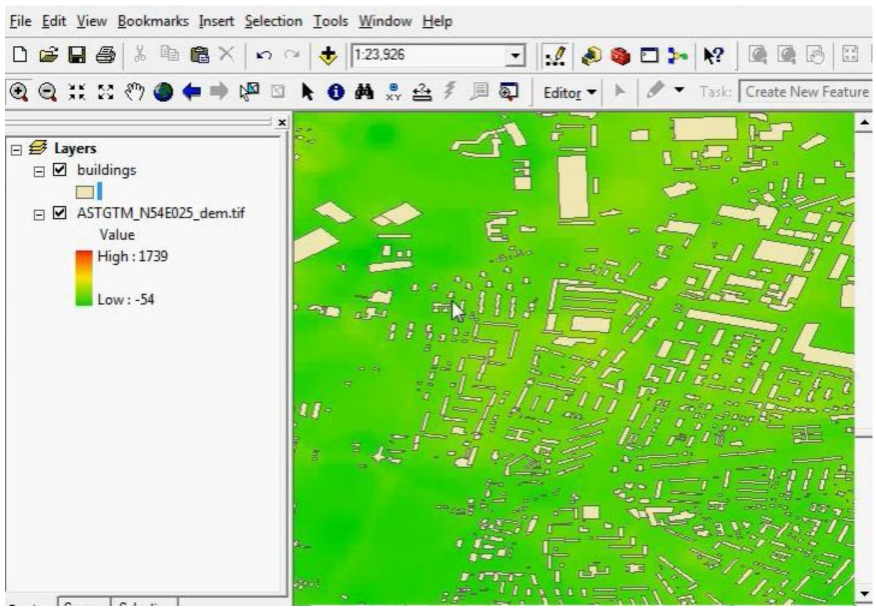


Figure 50: OSM buildings converted to the shape files and uploaded to ArcMap

A similar situation happened on 12th of January, 2010, when a 7.0 earthquake struck Haiti. The GIS resources were limited so experts from the entire world used remote sensing and captured significant information. Some information was stored on an OSM platform. Agencies like the United Nations used the OSM road data as basis (figure 51).

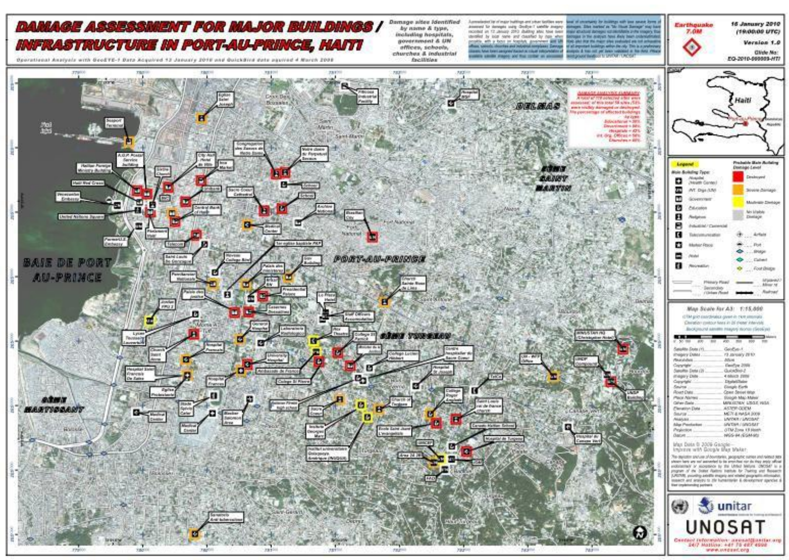


Figure 51: UNOSAT produced map on 16th of January, 2010. The source of the road network is OSM (UNOSAT 2010)

There was no time to check the quality of the data; the essential factor was trust. It was impressive how fast the OSM data bank in Haiti grew. Figure 52 shows the difference between the first day and the second, and after three weeks. Together, the community, using the OSM, can be a strong force by acquiring essential data which could be used in many fields, and one of them is Hazus. Very often, the rural areas in the world are not mapped. OSM gives the possibility for the community to collect their own data.

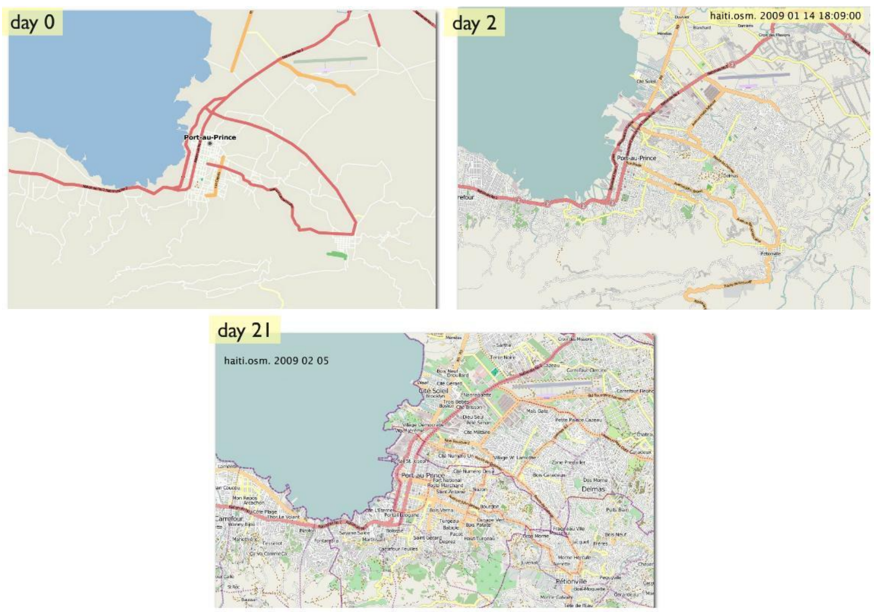


Figure 52: OSM data bank view of Haiti capital Port-au-Prince in 3 weeks after the earthquake (Burq 2010)

Another question would be the interoperability between Hazus and OSM. Using the tools as Quantum GIS it is possible to convert the polygons and points from OSM (XML) to shape format. The issue is the attribute information. So far, OSM can offer us only the occupancy type, which is not the same as used in Hazus. This problem can be solved easily (more details in chapter 7.1.1.) by using mapping schemes. From another point of view, Hazus uses a similar methodology: it uses the mapping schemes and, according occupancy class, defines such parameters as foundation and building type, first floor height, etc. The same is possible with OSM data, even it is better. Instead of aggregated GBS data, the user can get the data directly as User Defined Facilities.

The potential to use freely available DEM, OSM, and Hazus is huge, especially for the communities that have no financial support from the government to hire high quality flood modelers. OSM is a community tool, and the quality of the data depends mostly on local data assessors. With the fast advancing remote sensing technologies (LIDAR) and increasing open source mapping, the data quality and availability is only a question of time.

OSM can be reached by URL: http://www.openstreetmap.org .

Quantum GIS (when opening, activate OSM plug-in) can be downloaded from the website: http://www.qgis.org .

4.6. Flood Parameters

This chapter introduces the essential parameters that are needed to perform flood assessment. Depending on data type, the different parameters are needed as user input before the assessment. Such values as replacement cost or contents value are not considered as parameters (contents value can be delivered as part of building costs). The flood model can successfully generate flood inflicted damage without loss assessment. During the data integration/import process, if some of the parameters are missing in some cases, Hazus assigns default parameters or declines to import the data (UDF case). Also some parameters like building age are needed to identify the value of FIRM, which should set the value of the foundation type, but it does not do that because of the technical Hazus issues. Such parameters are also excluded from this chapter.

Occupancy class

Each facility or building in Hazus must have an occupancy class. GBS, essential, and all other facilities also have an occupancy class. Occupancy class shows the functionality and groups the familiar or same properties that have buildings/facilities. Through the occupancy class, Hazus is able to assign different damage functions (figure 53). The exception is for utility systems, where damage is assigned by ID.

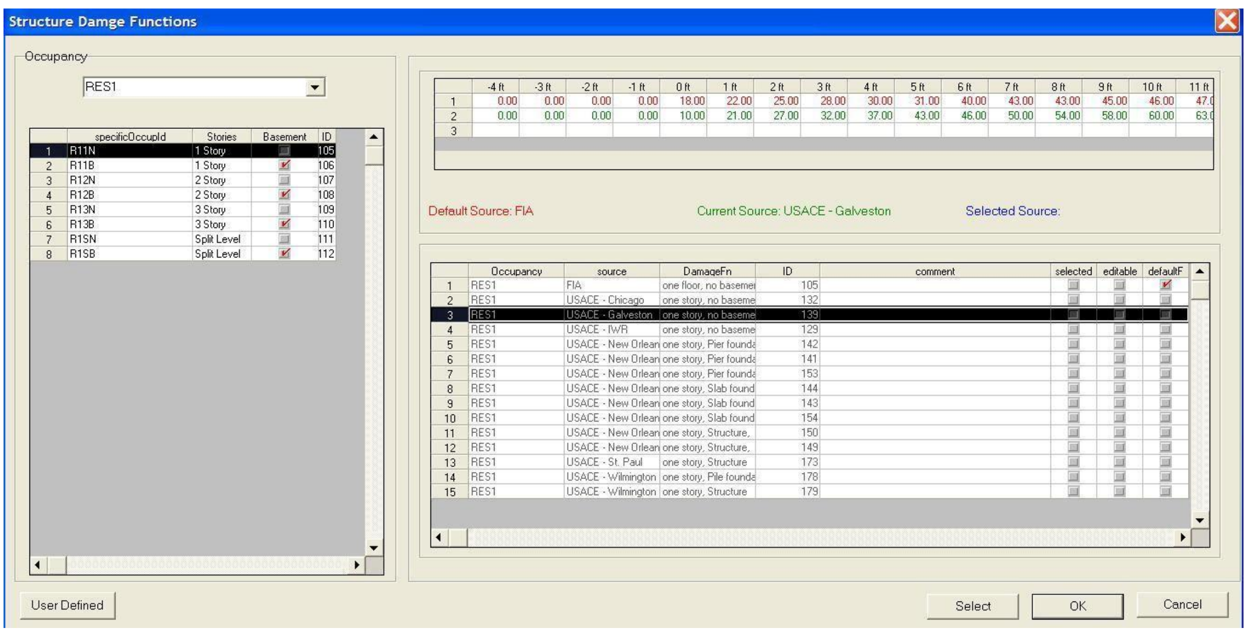


Figure 53: Assignment of the damage function according occupancy subclasses (FEMA 2009c, pp. 20)

For some data, according the occupancy class, Hazus defines the default parameters to each of the facilities using the mapping schemes (For more about use of mapping schemes see chapter 7.1.1.). Very often, the most essential parameter for the flood assessment is the occupancy class; when it is defined, Hazus can assign all other parameters by default.

Number of floors/stories

The parameter of floor/stories number is directly connected with the damage function. Hazus checks the occupancy class and the number of stories. Different story buildings have their own damage functions. That framework works for GBS and UDF, but not for Essential Facilities.

Foundation type

According to the Hazus Technical Manual, the foundation type is associated with the first floor height and the Pre/Post-FIRM (Flood Insurance Rate Map) relations. The abbreviation "Pre/Post-FIRM" means the different construction improvements before the Flood Insurance Program in the U.S. and after. Post-FIRM structures must comply with the FIRM and floodplain management requirements at the time of construction. There should be no changes to the structure to alter it in violation of the subject FIRM (Bogs 2008). The construction improvements mean lowered flooding effects to the building. The differences can be seen in table 15.

Table 15: Default first floor heights in Hazus riverine model (FEMA 2009a, pp. 71)

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

Source Data: Expert Opinion

Notes:

1 Typically not allowed, but may exist

This table has no influence when the Hazus Flood Model is used with non-US datasets, because there is no common worldwide standard like FIRM in Europe. FIRM value is needed as input for User Defined Facilities (UDF) in MR4 and MR5 versions. In the U.S., the user has to know at least the building age or building built date. According to that information, Hazus defines the FIRM and first floor height, but the existing technical problem is that Hazus does not assign these parameters. The newest Hazus 2.0 version still has this issue. Let's hope that in the future Hazus versions this technical problem will be solved. For this reason it is important to know the meaning of different foundation types:

- Pier: Pier is an open foundation, usually built of masonry units and supported by shallow footings. The height of piers usually ranges from approximately 2ft (60 cm) to 8 ft (240 cm);
- Solid wall: Solid wall consists of a load-bearing perimeter greater than 4 feet (120 cm) in height walls, supported by shallow footings (FEMA 2009a, pp. 70);
- Pile: Pile is a single element, but is not built on site like a pier. It is an open foundation and composed of slender and tall members which are embedded into the ground. The cast-in-place

columns are supported by a deep foundation as pile cap. For some pile-supported buildings, the shear walls can be used to transfer shear from upper building to the embedded foundation elements;

- Basement or garden level basement: Any level or story that has its floor sub-grade on all sides by masonry or concrete walls. Shallow basements with windows are defined as a garden level basement;
- Crawlspace: That is usually less than 4 feet (120 cm) high masonry or concrete walls bearing footprint around the perimeter of the building;
- Fill: Above the natural ground elevation build soil, used to support slab or shallow footings;
- Slab-on-Grade: Concrete slab on the ground. It may have thickened or turned down edges and does not rely on another wall's footings.

It is recommended to define the foundation anyway. The Hazus model identifies the existence of a basement (foundation type #4) and if it was found, will assign different damage functions. Also using other tools, the different properties of the buildings can be assigned according to foundation type.

Building type

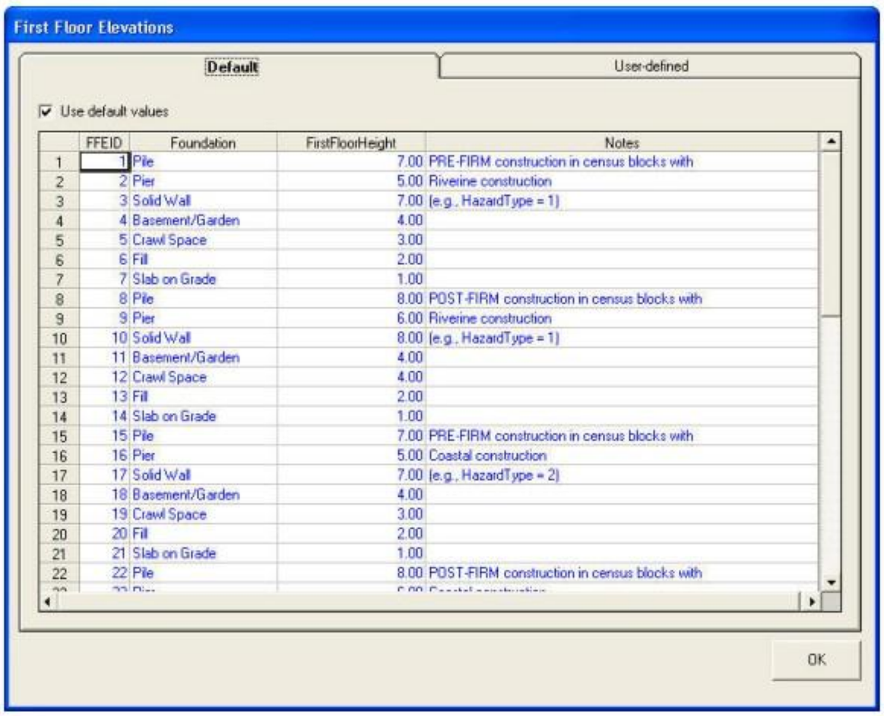
Building type describes the structural system or construction material, although this parameter has no influence to the flood assessment and must be defined before data integration in previous Hazus MR4 and MR5 versions. The common inventory data requirements must be satisfied for all three Hazus models. Building type is a basic parameter for estimation of earthquake and hurricane damage estimation in other Hazus models. There exist 5 building types (table 16).

Table 16: Building types (FEMA 2009a, pp. 247)

No.	Label	Description
1	Wood	Wood (light frame and commercial and industrial)
2	Steel	Steel frame structures including those with infill walls or concrete shear walls
3	Concrete	Concrete frame or shear wall structures including tilt-up, precast, and infill walls
4	Masonry	All structures with masonry bearing walls
5	MH	Mobile Homes

First floor height

First floor height is the height from the ground to the end of the foundation (figure 56), the elevation of the first story/floor. Sometimes in Hazus first floor height is named as first floor elevation, but that statement is false. The elevation is above the sea level. Theoretically, first floor height should be assigned by foundation type in Hazus, but unfortunately this option does not work. First floor height is an important parameter for flood damage assessment and is directly related to damage function. The Hazus Flood Model subtracts the first floor height from the value of the flood depth, assigns the result to the damage function, and assesses the damage.



	FFEID	Foundation	FirstFloorHeight	Notes
1	1	Pile	7.00	PRE-FIRM construction in census blocks with
2	2	Pier	5.00	Riverine construction
3	3	Solid Wall	7.00	(e.g., HazardType = 1)
4	4	Basement/Garden	4.00	
5	5	Crawl Space	3.00	
6	6	Fill	2.00	
7	7	Slab on Grade	1.00	
8	8	Pile	8.00	POST-FIRM construction in census blocks with
9	9	Pier	6.00	Riverine construction
10	10	Solid Wall	8.00	(e.g., HazardType = 1)
11	11	Basement/Garden	4.00	
12	12	Crawl Space	4.00	
13	13	Fill	2.00	
14	14	Slab on Grade	1.00	
15	15	Pile	7.00	PRE-FIRM construction in census blocks with
16	16	Pier	5.00	Coastal construction
17	17	Solid Wall	7.00	(e.g., HazardType = 2)
18	18	Basement/Garden	4.00	
19	19	Crawl Space	3.00	
20	20	Fill	2.00	
21	21	Slab on Grade	1.00	
22	22	Pile	8.00	POST-FIRM construction in census blocks with

Figure 54: Default first floor heights (FEMA 2009b, pp. 77)

For example: If the building has flood improvements and 1 meter high first floor height and no basement, in the case of 30 cm flood there will be no significant damages to the building. The Hazus Flood Model includes all these parameters into the flood assessment.

4.7. Damage Functions in Hazus

Fundamentals about flood damage functions (curves) can be found in chapter 3.1. In Hazus methodology the relative approach is used and the flood damage function is described as “the form of depth-damage curves, relating depth of flooding as measured from the top of the first finished floor, to damage expressed as a percent of replacement cost.” Instead of absolute flood depth, Hazus uses the flood damage depth.

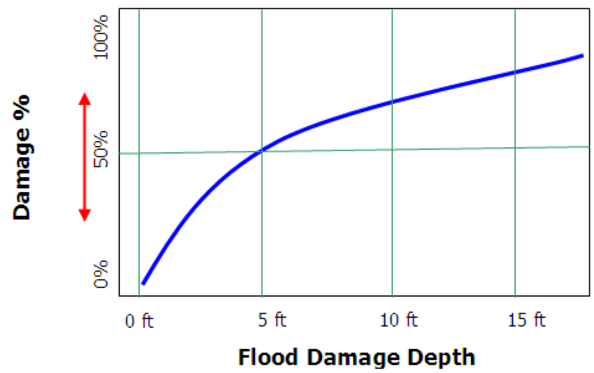


Figure 55: Hazus uses relative damage functions (FEMA 2009c, pp. 15)

Flood damage depth can differ from flood depth because of the first floor height. If the foundation is tall enough (example: pier foundation) and is higher than flood depth, then naturally there will be no damages. This applies not only to the depth-damage functions for buildings, but also for the contents of buildings (FEMA 2009a, pp.246).

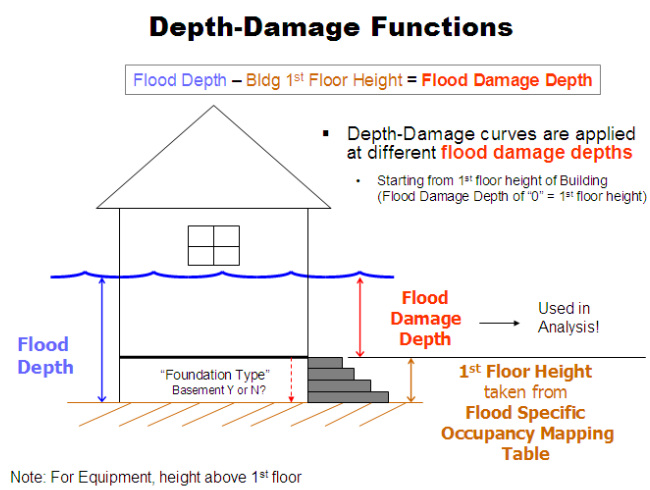


Figure 56: Framework of damage identification for General Building Stock (FEMA 2009c, pp. 14)

As mentioned earlier, the damage functions are related to occupancy class (or bridge class for transport systems) because of the different object properties in utility systems damage function is related by ID, and bridges are related by bridge class. A Hazus user has the ability to review the damage function of each class and to find out the damage at different flood depth levels (figure 57).

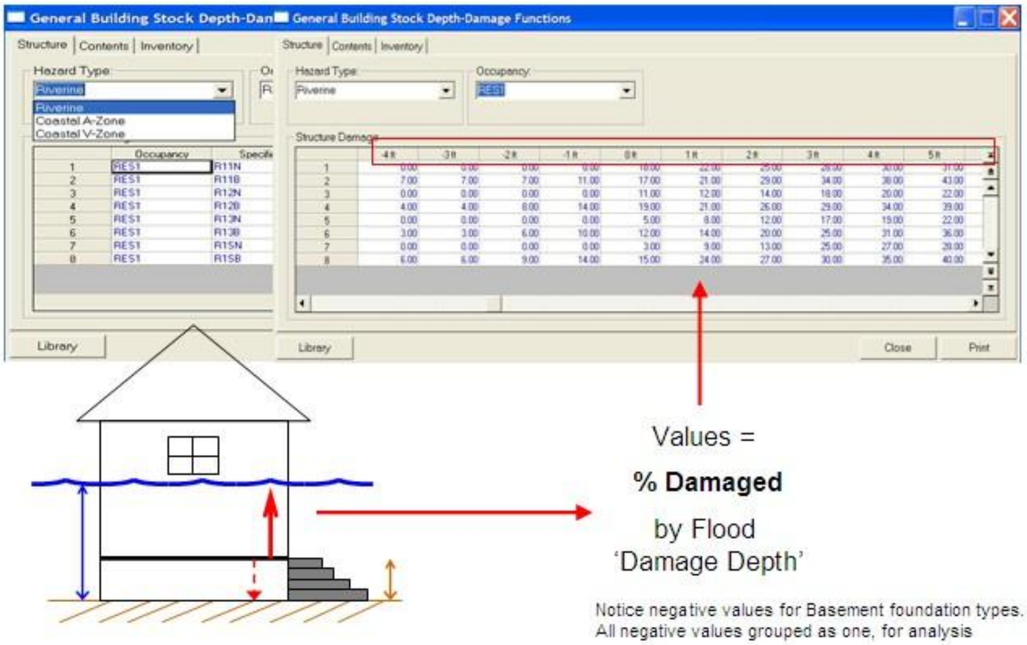


Figure 57: GBS damage functions (FEMA 2009c, pp. 21)

Moreover, the different damage functions are assigned to the same class but to a different number of story buildings and it depends on whether or not the building has a basement. So, the damage function depends on three parameters: class, number of stories, and basement existence (for buildings). If a basement exists, the model assigns a different damage function (with basement). For some specified facilities like utility, the damage functions are assigned by ID. While for GBS and UDF, assignment by ID does not work (MR5 and MR4 versions, not yet tested in Hazus 2.0).

Naming damage functions varies from the data type; for GBS and UDF the abbreviation (Hazus title) R13N means residential class, RES1 subclass (single-family dwelling), 3 story buildings with no basement.

There can be a problem that the existing classes are not enough or, for example, a fire station in one study region has a different damage function (different building properties) than one in another study region. This can be solved by modifying the damage functions (default Hazus ability – figure 58).

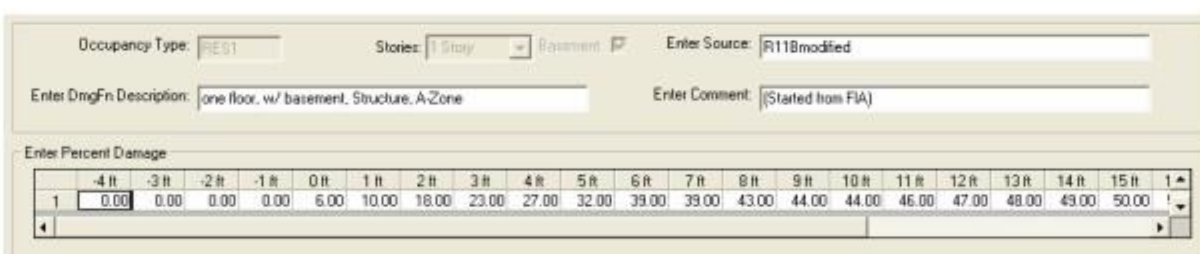


Figure 58: Development window of RES1 damage function

The user can also create a new damage function (for specified existing class), modify the existing one, or use pre-defined damage functions, but there is no possibility to create a new class with a new damage function. Figure 58 shows the GBS damage function development window in the Hazus interface. Pay attention to the scale by feet. For GBS, essential, and other facilities the range of the damage function is from -4 feet to 20 feet. Practically, if the flood depth is more than 20 feet, the Flood Model assigns the 20 foot damage value to the results. If first floor height was zero, a -4 feet as the initial start of the damage function is assigned to assess the damages for the buildings with basement foundations. The development window of the damage function can differ. Figure 59 shows the damage values for bridges (transportation objects) and utility components.

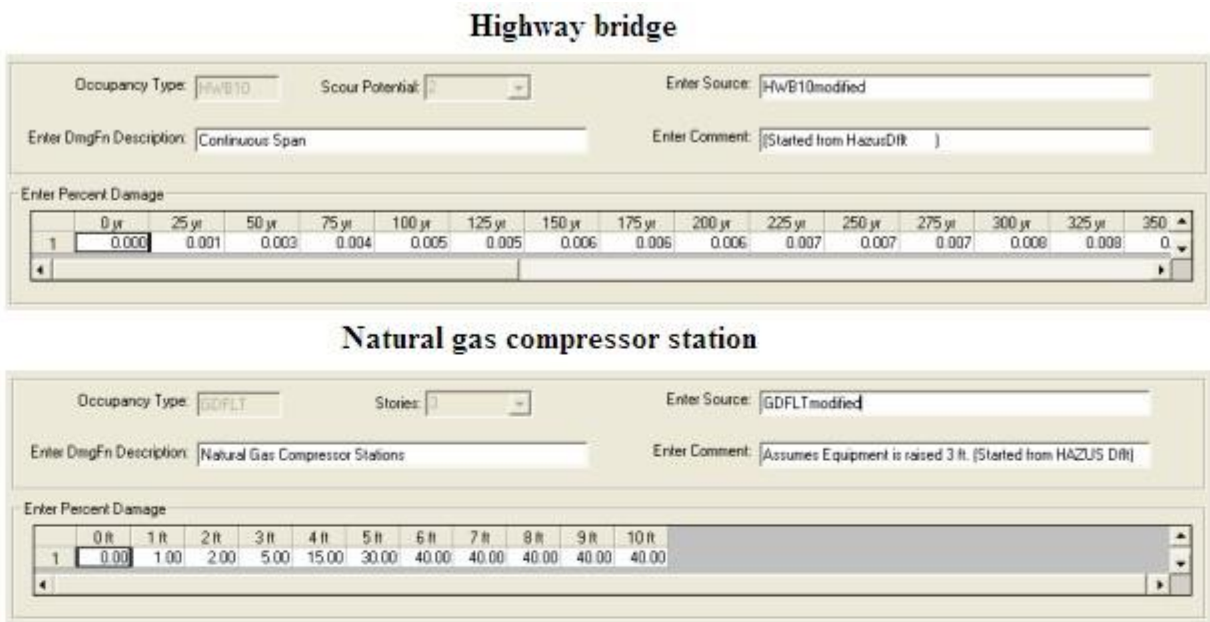


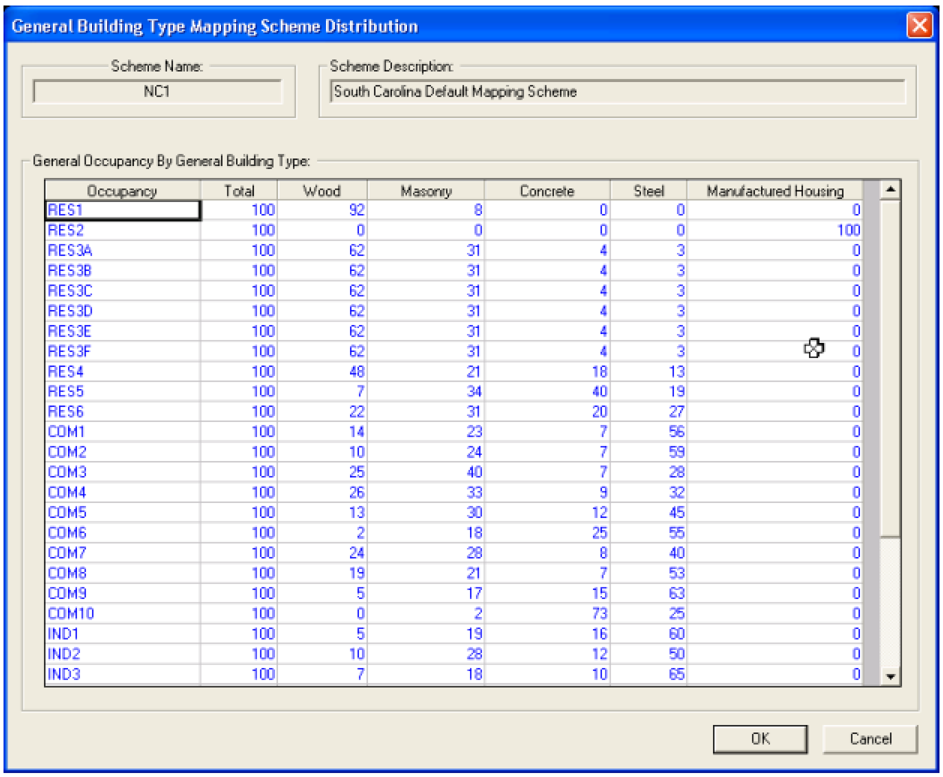
Figure 59: Development window of transportation and utility objects damage functions

Some utility components are required to have the height of the component above the ground value. There is no basement for the components as for GBS or facilities, so there is no negative value in the damage function. Bridges are a totally different situation. Hazus uses different calculations of the damage. It uses the flood return period as a parameter for the different types of span (single, continuous, etc.) bridges. The relationship between damage and the span should be strictly defined. According to the FEMA Technical Manual, the type of span should influence the damage. But the practical test runs showed that the scour (erosion) index influences flood damage to bridges. More about damage functions for bridges can be found in the Hazus MR4 Technical Manual pages 289-290 (FEMA 2009a).

When the damage function is created or modified, the user has to apply it in the Hazus interface. Officially, the newly created damage functions for GBS should work, but that is false. Only pre-defined damage functions are used. With the damage functions for other types of data there are no problems. For more about this Hazus issue see chapter 10.1.

4.8. Mapping Schemes in Hazus

Hazus supports mapping schemes. In Hazus, the mapping scheme acts differently than a regular mapping scheme. The mapping scheme in Hazus allows the user to define the distribution of specified characteristics for some of the data. For example, the general building type mapping scheme (figure 60) shows the building type distribution among the occupancy in GBS data for a specified region. It would be very hard and almost impossible to assign correct characteristics to each census block where the aggregated building data is stored. The easy way is to distribute the characteristics. That is the job of the mapping scheme. The user has the ability not only to review the mapping scheme but also to edit it or create a new one.



Occupancy	Total	Wood	Masonry	Concrete	Steel	Manufactured Housing
RES1	100	92	8	0	0	0
RES2	100	0	0	0	0	100
RES3A	100	62	31	4	3	0
RES3B	100	62	31	4	3	0
RES3C	100	62	31	4	3	0
RES3D	100	62	31	4	3	0
RES3E	100	62	31	4	3	0
RES3F	100	62	31	4	3	0
RES4	100	48	21	18	13	0
RES5	100	7	34	40	19	0
RES6	100	22	31	20	27	0
COM1	100	14	23	7	56	0
COM2	100	10	24	7	59	0
COM3	100	25	40	7	28	0
COM4	100	26	33	9	32	0
COM5	100	13	30	12	45	0
COM6	100	2	18	25	55	0
COM7	100	24	28	8	40	0
COM8	100	19	21	7	53	0
COM9	100	5	17	15	63	0
COM10	100	0	2	73	25	0
IND1	100	5	19	16	60	0
IND2	100	10	28	12	50	0
IND3	100	7	18	10	65	0

Figure 60: General Occupancy Mapping scheme distribution by building type (FEMA 2009b, pp.72)

If the user arranged a new building survey in the community, for example, the majority of the owners of single dwelling buildings in a specified area have masonry material buildings instead of wood. The user needs to change or create the new mapping scheme for the specified geographical unit (census block, county, etc.) and allocate a specified percentage for masonry building type in subclass RES1.

The general mapping scheme described above applied to any Hazus model (hurricane, flood, and earthquake) but then there's the flood mapping scheme (figure 61). This mapping scheme is valid only for the flood model and enables the user to distribute such building characteristics as foundation type.

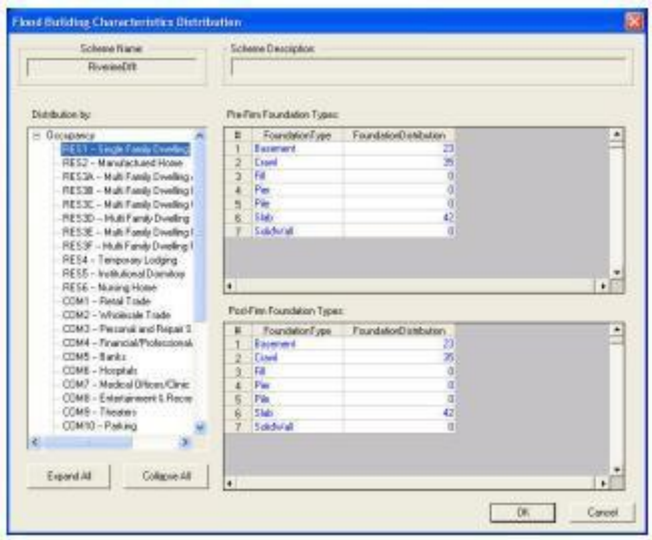


Figure 61: Riverine flood specific occupancy mapping scheme (FEMA 2009b, pp. 76)

When talking about regular mapping schemes, it is possible to use mapping schemes outside Hazus for data preparation when the user does not have the sufficient data that would be able to be integrated into Hazus. For more about this issue see chapter 7.1.1.

5. *Step-by-Step Hazus Riverine Flood Analysis*

This chapter introduces the reader to the steps required to produce the Hazus riverine flood loss estimation analysis. The differences of the steps according to different levels of analysis are explained in the form that a user would be able to bypass these steps if not needed. This analysis can be applied anywhere if implementation enables the Hazus Flood Model's capabilities to perform that.

To be able to perform flood loss estimation analysis, the Hazus Flood Model must be supplied with two types of data: flood hazard and inventory data (figure 62). Let's assume that inventory data is already prepared and successfully integrated, and there is no need to demonstrate the preparation of the inventory data (see chapter 4.5. for more details about inventory data). Figure 62 shows that flood hazard data in Hazus can be delivered in two ways with user supplied flood hazard data: by using river cross-sections and flood boundaries or with a final flood depth grid. The truth is that to produce a flood depth grid within Hazus, the user input of DEM is needed. Hazus just can't create a flood depth grid from scratch, even in the U.S. But in nowadays, Hazus provides the potential to download DEM easily from the National Elevation Dataset (NED) website when the study region is in the US. When the study region is worldwide, the user can manually and freely download DEM from the ASTER (Advanced Spaceborne Thermal Emission and Reflection) website. (For more about ASTER see chapter 4.4.2.) The important fact is that before integration of DEM, it should be reprojected into NAD83 (North American Datum). For more about projection see chapter 10.1.

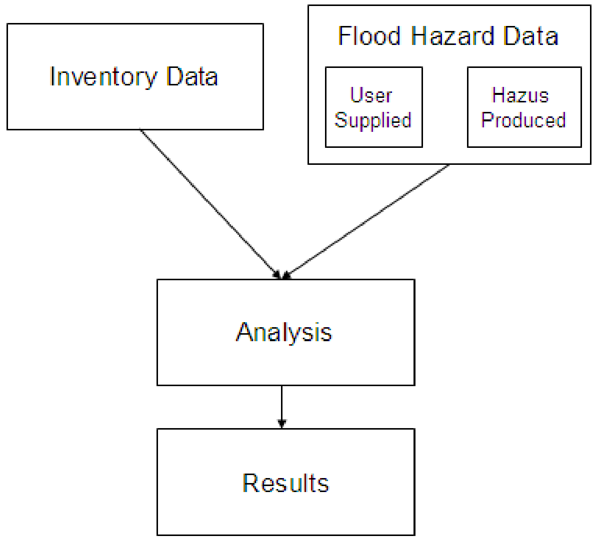


Figure 62: Hazus riverine flood loss estimation input data (FIT processed inputs considered as user supplied)

When all the data is prepared for flood assessment, the initial step for each flood loss estimation in Hazus is to create the study region (figure 63, step marked as "Initial Step"). The area for a study region can be selected as geographical or administrative units (For more information see chapter 3.5.). Then Hazus knows where the focus of the study is and acquires the data from inventory datasets.

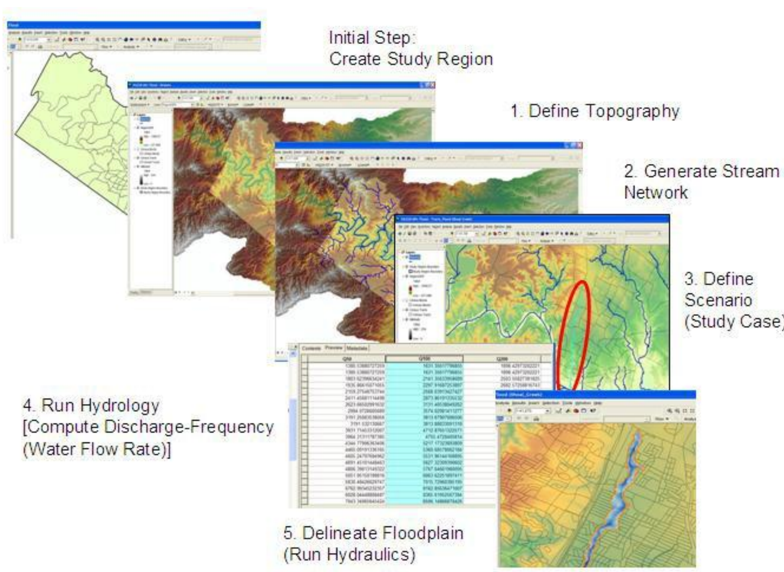


Figure 63: Hazus framework to create flood hazard data (FEMA 2009c)

5.1. Hazus Flood Hazard Data

The next five steps are needed when a user has no flood depth grid. In this case a user can use Hazus as a tool to deliver it. The compulsory inputs to gather the flood depth grid in Hazus are the digital elevation model (DEM) and regression equations. Regression equations are specified equations that contain such values as snow melt, temperature, soil type, precipitation, etc. and are used by mathematical methods to deliver discharge values (the volume of water). By default, for US regions the regression equations are available, so the concern for a US Hazus user would be only DEM. The first step (figure 63) is to import DEM into the study region. Pay attention to the vertical units of your DEM if they are not in feet; the user has to use standard tools to perform DEM reclassification.

In step 2 the Hazus Flood Model uses the standard hydrological tools from Spatial Analyst (ArcMap) to generate the stream network by processing DEM. The same methodology is used in well-known, freely available Arc Hydro tools like ArcMap extension.

Step 3 asks users to choose the portions of the stream (segments) the user is interested in and to choose the scenario. The user is able to create many scenarios with different properties: different discharge values, streams, etc. That helps to save computing resources and time by producing hydrological and hydraulic analysis for a whole study region and each segment of the stream.

The hydrologic analysis is performed in step 4. Before this procedure, the user is asked to input probability (return period) of the flood. In the inner data, Hazus stores regression equations which are needed to calculate discharge values. Each stream segment is assigned to a regression equation, and during hydrologic analysis Hazus calculates discharge values for user-requested return periods.

The last step is hydraulic analysis. During this step Hazus uses discharge values and calculates the flood boundaries and flood depth grid. The outputs of these 5 steps are the flood depth grid and flood boundaries. This flood hazard data is an essential input of flood loss estimation.

5.2. User Supplied Flood Hazard Data

When a user supplies Hazus with flood hazard data (flood depth grid), the same framework (figure 63) can be used. But instead of going through all the steps, steps 1, 2, and 4 are eliminated. That is because the user already has the final product—the flood depth grid. The initial step, the creation of the study region, is needed in any case.

Instead of defining topography and generating stream network, a user needs to import the flood depth grid and define the vertical units. If the origin units of flood depth grid are meters, Hazus reclassifies the flood depth grid and converts units to feet. It should be also considered that a user-supplied flood depth grid should be reprojected into NAD83 coordinate system. To reproject, use Spatial Analyst tools in ArcMap. The next step, step 3, is valid for user-supplied hazard data. A user has to create the scenario and choose the segment of the supplied flood depth grid.

Only step 5 is needed in order to delineate flood boundaries. During this operation, Hazus processes the flood depth grid and delivers the vector polygon feature, which is an essential input of flood loss estimation. After inventory and flood hazard data are input into Hazus, the user can proceed with analysis.

5.3. Site-Specific Data Loss Analysis

Site-specific data contains all data for which a specific site or position (longitude and latitude) is known.

In other words, the point data. In the context of Hazus that would be essential facilities, transportation and utility systems, and user-defined facilities (For more about site specific data see chapter 4.5.2). During the analysis, Hazus combines the flood depth grid and overlaps it with these facilities (figure 64). The exact locations of the facilities are marked as arrows in figure 64. The dashed lines represent the grid. It is clear that the fire station is inundated, but not the hospital. The numbers mean the flood depth values for each cell.

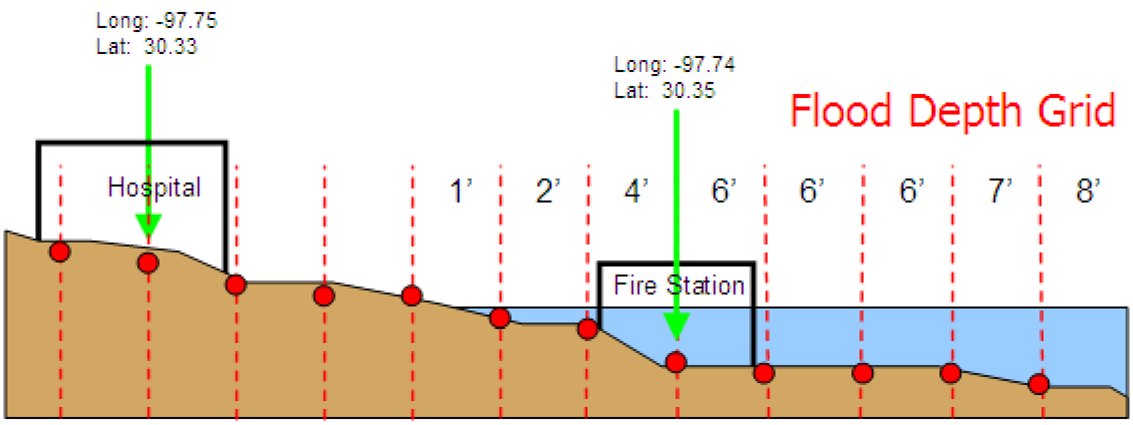


Figure 64: Site-specific flood assessment (FEMA 2009c)

The model checks what facilities are within the flood boundary and then their attribute information, such as occupancy and facility type, first floor height, etc. According occupancy type, the model acquires the damage function for each point. When the damage function (relation between damage and flood depth) is known, the model checks each point and the value of the flood depth cell, overlapping the facility. It then subtracts the first floor height from the flood depth grid value (figure 56) and assigns the damage. According to the inflicted damage, the model computes the loss. The loss is computed for each flood affected building and facility by this formula:

*($ Loss) = (% Damage) * ($ Value)*

(% Damage) – the value in percents, determined according to the damage function, the relationship of damage and the flood depth at the location of the facility and/or object.

($ Value) – the value as a monetary expression, can be the replacement cost of the building, value of contents, or components.

The only exception is in the loss calculation of the bridges. For more information about the framework see Hazus MR4 Flood Technical Manual page 411 (FEMA 2009a).

5.4. Aggregated Data Loss Analysis

Another type of inventory data is aggregated data. (For more details about aggregated data in Hazus see chapter 4.5.1.) It is complicated to produce an accurate flood loss estimation analysis on aggregated data. (For more details about this issue see chapter 10.1.) Aggregated data in Hazus contains buildings (GBS– General Building Stock), demographics, vehicles, and agriculture.

Because aggregated data is polygon data with attribute information, there is no way to deliver the same positional accuracy as for site-specific facilities. In that case the other method—area weighted assessment—is used (figure 65).

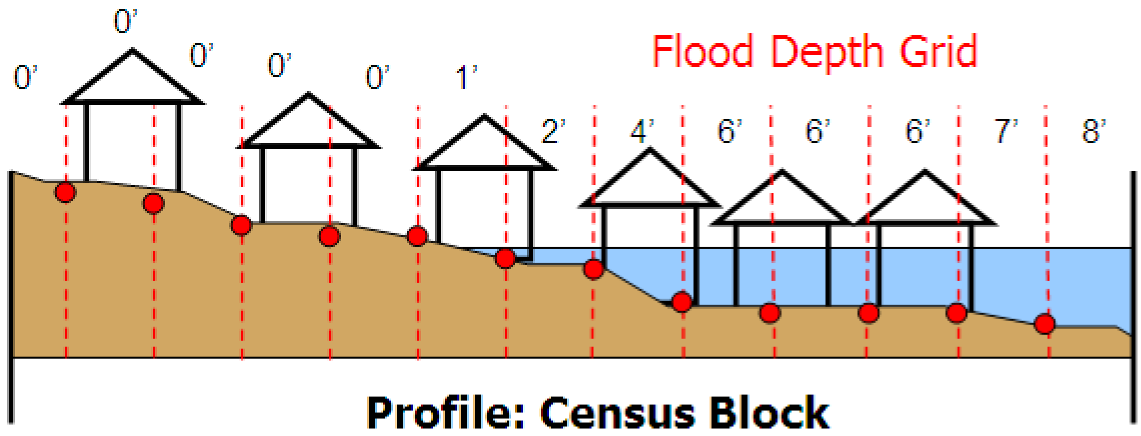


Figure 65: Area weighted flood assessment (FEMA 2009c)

The census block as aggregated unit contains specified attribute data as building count. Figure 65 shows that the not the whole census block is inundated (13 cells represent the whole census block, but only 8 are inundated). One cell has 7 feet of flooding, and that cell represents $1/13^{th}$ of the census block; 3 cells have 6 feet of flooding, and these 3 cells represent $3/13^{th}$ of the census block. For each grid cell and associated flood depth, the model performs similar operations as for site-specific data (identification of attribute data which is significant for flood assessment, the combination of flood depth grid and damage function) to assess the damage. But in area weighted analysis, the model multiplies the percentage (the part) of the inundated census block with calculated damages and assesses the loss. The bigger problem exists where sparse data is aggregated and only a small part of the polygon is inundated. Then the model still identifies loss even if there is no chance of inundation if the more accurate site-specific data would be used. The following methodology describes slightly different loss and damage estimation for different types of aggregated data (FEMA 2009c).

Hazus Flood Model steps to calculate loss for GBS:

The damage and loss is estimated for GBS in the same way as for vehicles. The model multiplies the percent damaged by percentage of census block at the flood depth and multiplies the building count. The estimated loss is calculated by multiplying the damage by the dollar exposures:

*Count of damaged buildings = FP*DP*OccupCount*

Loss ($) = FP*DP*OccupExp($)

FP – percentage of the census block at the given flood depth;

DP – the damage percent at the given flood depth for the given occupancy;

OccupCount – total count of buildings for given census block;

OccupExp – total building exposure (FEMA 2009a).

Hazus Flood Model steps to calculate loss for agriculture:

Determines the affected area as the intersection of the floodplain polygon with the agriculture polygon (acres);

Identifies the quantity of the crops in the polygon and the affected area (yield/acre * area);

Identifies damage (reads from the damage function for Julian day);

Calculates the initial loss: *Initial Loss = Yield in the flooded area * $ * % damaged crop*;

Calculates the duration loss: *Duration Loss = Initial Loss * duration modifier* (input from user) (FEMA 2009a, pp. 415).

Hazus Flood Model steps to calculate loss for vehicles:

This is a very similar methodology as that used for GBS. To get the damage, the model multiplies the percentage damage by percentage of census block at the flood depth, and multiplies by day and night vehicle count. The estimated loss is calculated by multiplying the damage by the dollar exposures:

*Count of damaged cars = FP*DP*OccupCount*

Loss ($) = FP*DP*OccupExp($)

FP – percentage of the census block at the given flood depth;

DP – the damage percent at the given flood depth for the given occupancy;

OccupCount – total count of cars, light and heavy trucks for given census block;

OccupExp – total exposure of new and used vehicles (FEMA 2009a, pp. 414).

6. Implementation

This chapter describes the main problem of the Hazus-MH Flood Model, which is the limitation to be adopted worldwide and provides simple solutions to show that integration of non-U.S. datasets into Hazus-MH is possible.

6.1. Problem Definition

The main problem is that Hazus originally was created to work with US datasets. The creation of study regions is limited only to areas in the US (figure 66) and prevents users from performing flood analysis outside US soil. The same situation remains with inventory and flood hazard data. The first step was to find out why the study space is limited and what factor played the main role in Hazus: data, inner Hazus algorithms, or something else? After some experiments it was clear that the new data inputs and analysis are based only on the study region.

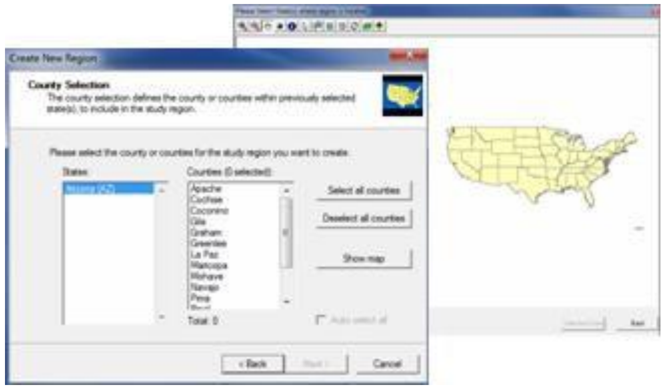


Figure 66: Default Hazus creation of new region window, the user can select the region by name or by map (Kaveckis et al 2011)

As it was mentioned earlier, the problem could be solved by implementing new geographical divisions in Hazus. The problem with aggregated data still exists, and it was decided to delay this question because of the lack of a common aggregated data structure (standardized aggregated data) in Europe. Now the question is how to integrate European geographical divisions into Hazus (figure 67).

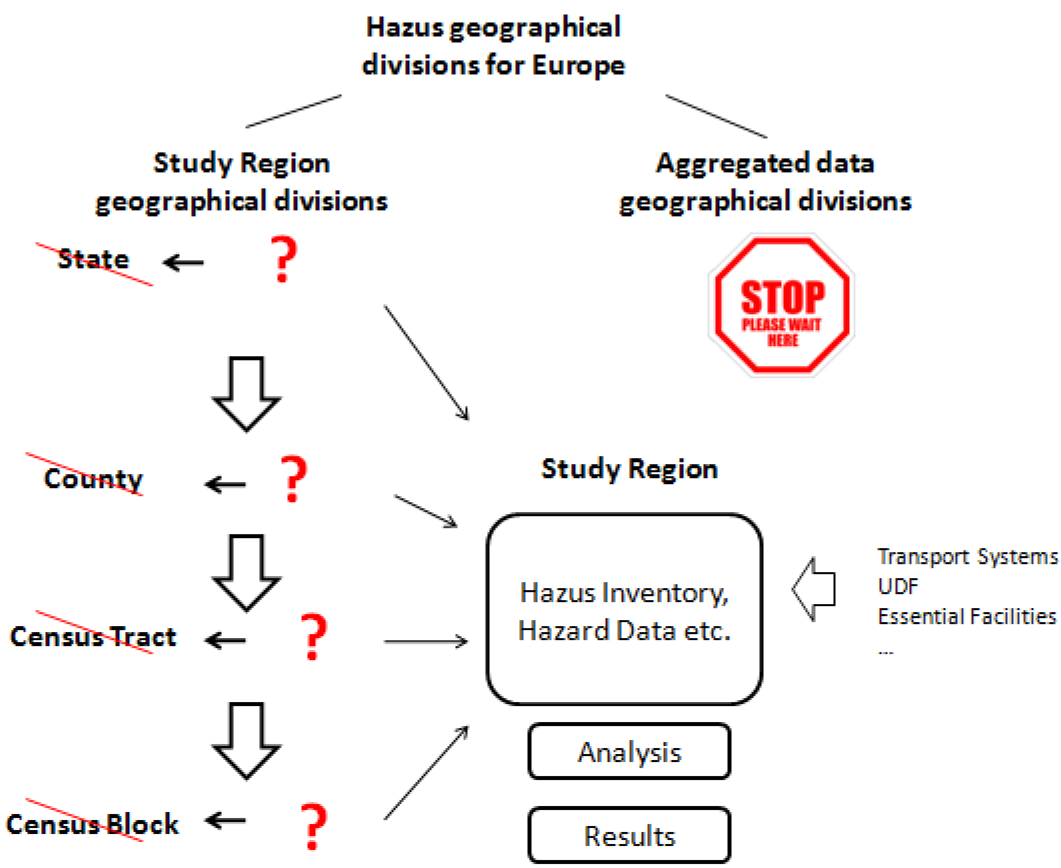


Figure 67: The problem definition of the study region in Hazus for Europe

6.2. Possible Solutions

A year ago, Kulmesch succeeded in creating a study region in Austria by interchanging the features of the state of Louisiana and Austria. Kulmesch did not explained in detail these steps in his master's thesis (Kulmesch et al 2010). He duplicated the existing Hazus dataset and modified it. He replaced the existing datasets in such order: the state of Louisiana into the Carinthia province, some of the Louisiana counties into Klagenfurt City area, Census tracts into municipalities, and Census blocks into plan-quadrant cells. Plan-quadrant cells are rectangular 10 x 10 km cells dividing the whole of Austria. These plan-quadrant datasets were delivered by the Austrian Statistics Department and contain aggregated data (population) (Kulmesch et al 2010, pp. 31). During the integration, Kulmesch replaced and renumbered the geographical units by maintaining the same existing numbering and abbreviations. He also mapped the aggregated and site-specific data (Kulmesch et al 2010). The problem was that no detailed steps of integration were described, and entire process of the integration was manual, complicated, and time consuming. There would be no pleasure for any country interested in Hazus to follow that methodology manually.

An automatic tool was needed. But before that, it was necessary to repeat everything that Kulmesch did, but from scratch and with different datasets. A simple methodology was used: the specified state was chosen, and additional county, census tracts, and census blocks were added by creating new ID numbers and maintaining the same relations as standard Hazus data. Now it was possible to create the region in the area outside the US. Hazus generated the flood hazard data instead of using a user-supplied depth grid, as Kulmesch used. The process worked fine through the steps until the creation of the scenario. During the creation of the new scenario, Hazus reported an internal error and the system crashed. For this reason, the search for another solution was initiated.

The new idea was to create the geographical divisions for all European countries to create the schema, where every country still would need to create them. Then it was decided to find hierarchical relations between geographical units in Europe. The attention was to focus on NUTS (Nomenclature of Territorial Units for Statistics) (for more about NUTS see chapter 3.5.2.). NUTS contained all the needed geographical structures of the countries.

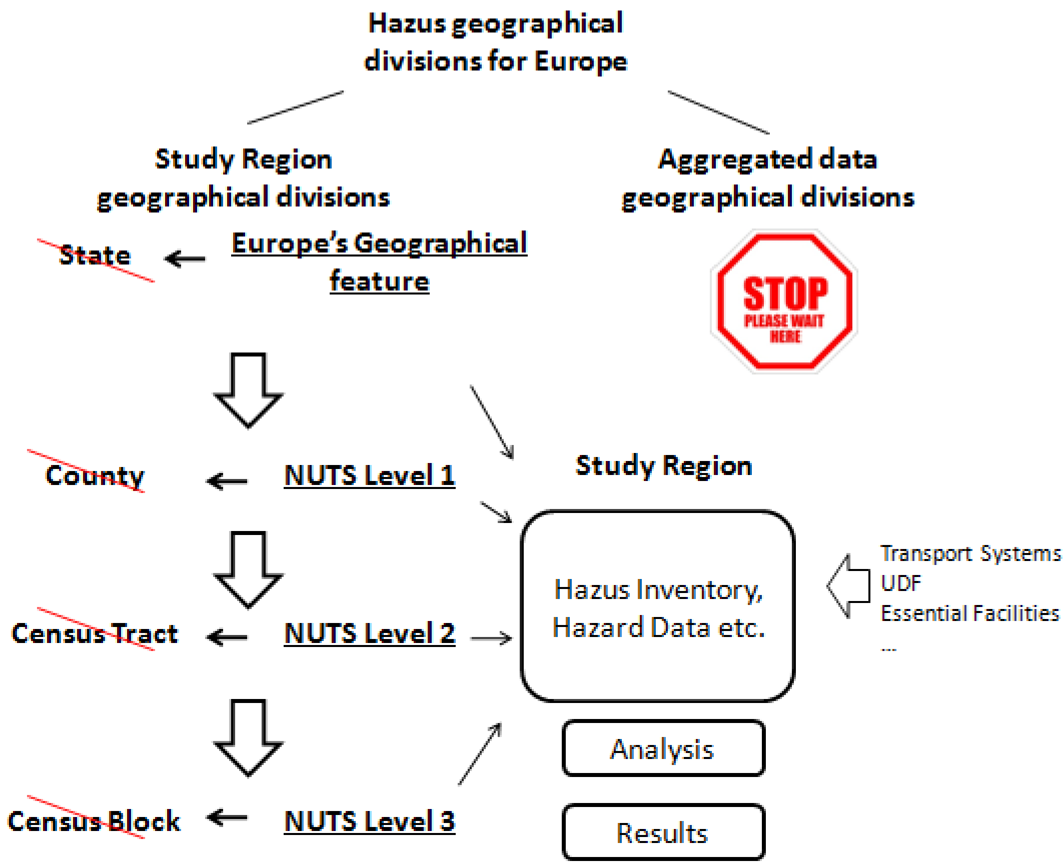


Figure 68: The solution of geographical divisions' integration into Hazus for Europe

Because only 3 levels of NUTS were available, it was decided to interchange the default Hazus geographical units with NUTS in such order (table 17).

Table 17: Interchange of Hazus and NUTS geographical units

HAZUS	State	County	Census Tract	Census Block
NUTS	Europe	NUTS1	NUTS2	NUTS3

Even the most detailed NUTS 3 level was not sufficient compared to census block (In the US, a census block contains about 100 inhabitants). By rough estimation, the geographical equality of NUTS 3 level is the county level. The "state" level was changed to the geographical territory of Europe in order to maintain all the European data in one dataset. It is possible to define a country instead of "state" geographical level, but this would take great space, because each country would have its own folder and its own properties.

For the purpose of integrating the whole European region, it is not enough to add one feature and create a few attribute values, because the subject is thousands of features with unique and common values. The Hazus system is based on strict relationships between datasets so the next step was to figure out the relationships between existing Hazus geographical units and bring them to NUTS.

6.3. Analysis of Hazus Geographical Units' Relations

It was known that during the creation of the region process, Hazus uses the datasets from two geodatabases. These two geodatabases are known as "syBoundary" and "bndrygbs." syBoundary is located in the main Hazus data folder, and the Bndrygbs is in the "State" folder (example, Indiana's folder is named "IN," California's as "CA" etc.). Each state folder contains bndrygbs geodatabase. syBoundary is the initial dataset Hazus addresses when the study region is being created. This dataset contains three types of feature sets (shape files): syState, syCounty, and syTract. It is clear from the names that these datasets store the features of 3 levels Hazus geographical units. There is no aggregated inventory data in these features, only the geographical features and relations.

Bndrygbs is the second file Hazus addresses when the study region is being created, when the user wants to create the study region at the census block level (the most detailed geographical level), or when Hazus is preparing the data for the study region. Bndrygbs containts three types of feature sets (shape files): hzCounty, hzTract, and hzCensusBlock. The hzCensusBlock stores the aggregated inventory data, like building count or income ratio, etc. (census tract stores higher level aggregated data).

Because both of these geodatabases play a role in the study region, it was necessary to analyze the data types and relations of all of these shape files to determine the common values, how each of them are dependent, etc. The results of the analysis delivered the names of the common data columns for each of the feature sets. Figure 69 shows the relations, the common data column names in each of the feature sets. The lines represent one-to-one relations.

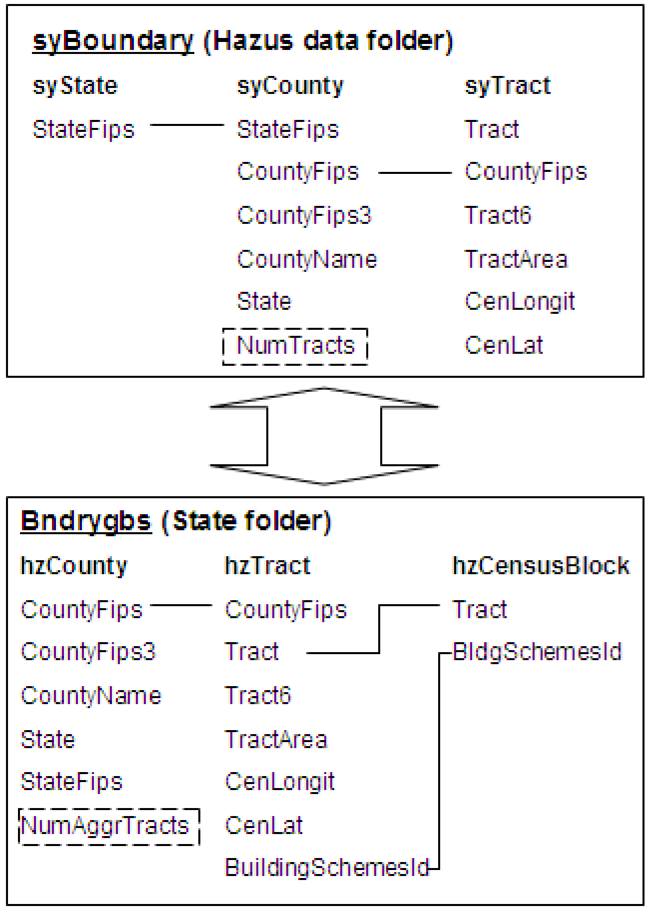


Figure 69: Data column names and relations between two Hazus datasets

The names in the dashed rectangles contain the same data types, although the names are different. According to the relationships, each data value must be identical not only between datasets, but also between geodatabases. The same names represent these relations. Each data type is strictly described and the contained data must comply with the following restrictions (table 18):

Table 18: Description of the common data between syBoundary and Bndrygbs

Field name	Data type	Length	Meaning	Example
CountyFips	Text	5	County ID	28001
CountyFips3	Text	3	Part of County ID	001
CountyName	Text	40	Name of the county	Adams
State	Text	2	State abbreviation	IN

StateFips	Text	2	State code	28
NumTracts or NumAggrTracts	Long Integer		Number of tracts in the county	2218
Tract	Text	11	Census tract ID	28001000200
Tract6	Text	6	Part of Census tract ID	000200
Tract Area	Float		Area of tract	98.920
CenLongit	Double		Longitude of tract (dec)	16.150
CenLat	Double		Latitude of tract (dec)	51.208333
BldgSchemesId	Text	3	Building mapping scheme ID	IN1

The common colors in the "example" column show the relationships of the data values. The data where the names are in *Italic* font are essential to Hazus, but it does not have to be exact. For example, Hazus does not take an area of the census tract into account. It only needs this column to be included in the dataset. All these data fields must be populated in mentioned feature sets and the data values in both geodatabases must be identical. Table 18 describes the data, which must be in both geodatabases, but this is not enough. There are some additional requirements for the Bndrygbs geodatabase, hzCensusBlock, and hzTracts feature set. Tables 19 and 20 show which additional data columns are taking a part in the creation of the study region.

Table 19: Additional essential data columns in hzCensusBlock feature set

Field name	Data type	Length	Meaning	Example
CensusBlock	Text	15	Census block ID	280010002001006
BlockType	Text	1	Riverrine: R	R
BlockArea	Float		Area of block	00.486654

Table 20: Additional essential data columns in hzTract feature set

Field name	Data type	Length	Meaning	Example
Length	Float		Length of tract	261.95
NumAggrBocks	Long Integer		Number of blocks in the tract	119

The relationships between the geodatabases and feature sets were clear. There were attempts to change the relationships, using letters instead of the 15 digit ID, for example. Unfortunately, there was no success. We also tried to create a new state in the syState dataset and create new relationships, but Hazus could not identify the new state folder. For this issue, the existing state folder has to be used. The search for the solution could be included in future research.

6.4. Data Organization and Integration

When the relationships between the geographical units were known, the next task was to bring all these relationships to NUTS and populate all the data columns. Manually, it would be a disaster: 1 461 NUTS3, 317 NUTS2, and 115 NUTS1 features. There are many ways to make it easier. One of the possibilities was to use Microsoft Access, Microsoft Excel, and ESRI ArcMap 9.3 to prepare NUTS data (create relationships). Also there are different approaches when preparing the data with ArcMap:

- ***Merge NUTS with Hazus data* – *Delete Hazus data (US datasets)* – *Populate fields***
- *Create data columns in NUTS data – Populate fields*

There are probably more ways, but in this case, the first, the easier solution was chosen. Also the different steps can produce each of the approaches. By using both of these approaches, it is possible to integrate any 3 geographical level units into Hazus. The following framework (figure 70) was used for NUTS integration into Hazus:

1. All NUTS regions were reprojected from WGS84 (or other coordinate system) to NAD1983 projection (See chapter 10.1. for more details). The tool “Project” from “Data Management Tools” in ArcMap 9.3 can be used.

2. The NUTS and Hazus features were merged using ArcMap Tool “Merge” in this order: NUTS1 with syCounty and hzCounty; NUTS2 with syTract and hzTract; NUTS3 with hzCensusBlock. All new NUTS features now contain the Hazus data structure, but the fields are unpopulated;

3. All feature sets (5 shape files) were exported into a temporary geodatabase;

4. Using Microsoft Access, the default Hazus features were deleted for improved processing and disk space. It is not recommended to delete records using ArcMap or ArcCatalog, it will take a very long time;

5.The feature sets now contained NUTS geographical features with names of the NUTS regions, Hazus data structure but no populated data;

6. Populate the empty data fields;

7. Ensure that the feature sets (shape files) are in both geodatabases and the names are correct.

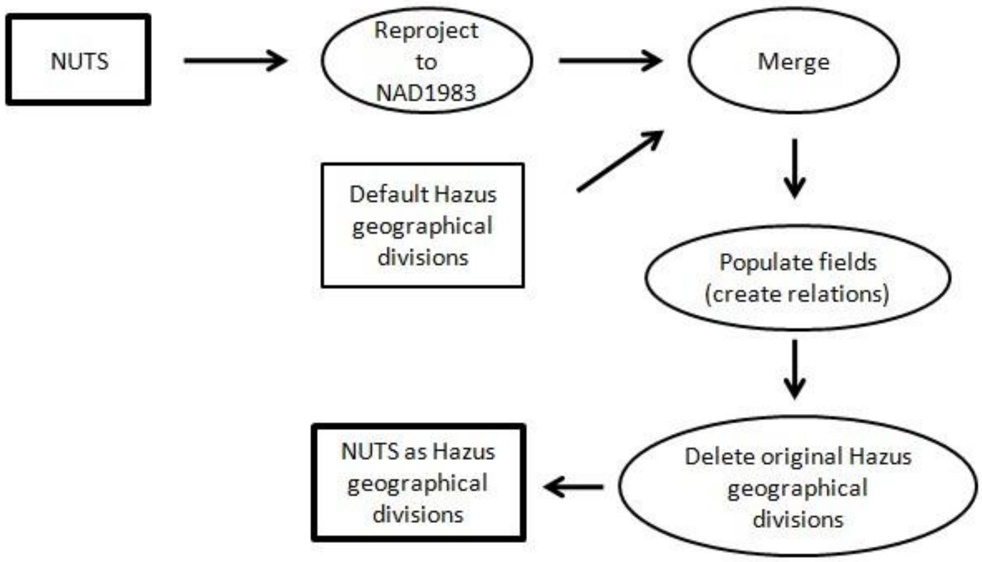


Figure 70: Workflow of NUTS integration into Hazus

Tips and guidelines to populate the data fields:

- The most important value in this case is the ID—the main relationship between different geodatabases and feature sets. Firstly, the unique ID for each of the features were created using Microsoft Access (MS Excel can be used too). For example: "StateFips" was common for each cell, because Europe was chosen as a state. For this reason, the new geographical feature of Europe (join NUTS1 region using ArcMap tools) was added using the "Merge" tool and populating the fields (new two digit state ID was created) of added new features. When "StateFips" was known, the data field "CountyFips" was unique for each NUTS1 region in the syCounty and hzCounty features were populated.

- To achieve better efficiency, it is recommended first to process hzCounty and then hzTracts features, and later copy and rename them to syCounty and syTracts and slightly modify them. This will spare much of the time and will help avoid mistakes in mismatching of values.

- The question could occur when populating hzTract and syTract (NUTS2) features' "CountyFips" field. The same issue occurs when populating hzCensusBlocks "Tract" field. The solution is simple —using spatial join (to improve the spatial join it is possible to create points from hzCensusBlocks polygons instead of spatially joining polygons. To get back to the features, just perform a simple join of hzCensusBlocks point and polygon data, join the tables, and each Census block will have an ID of where the census tract is contained. Another problem during the spatial join can occur, as some NUTS3 regions as small islands could not be joined. Populate these regions manually;

- Another issue could occur when populating the “CensusBlock” field in hzCensusBlock feature. “CensusBlock” field stores 15 digit IDs, which consist of “StateFips,” “CountyFips3,” “Tract6,” and unique census block IDs. A problem can occur when joining all 15 digits together. The solution would be to use a field calculator in ArcMap or in Excel use “&” symbol to join the text cells;

- To populate “CenLong” and “CenLat” fields, use the ArcMap editor in the attribute table and calculate geometry in NAD1983 as decimals;

- When all fields are populated, check the types of data and values again. If Hazus reports an error, check again.

6.5. Results and Conclusions

If the steps were performed correctly and there are no problems with populated data, the user should be able to see a similar view as figure 71. Notice that in the front of the names is the code, and the name of the country in local language and the font. When clicking

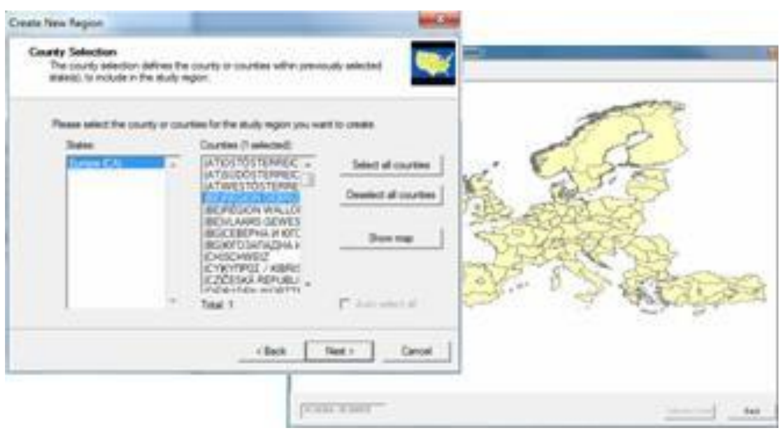


Figure 71: Region creation window in Hazus after applying NUTS (Kaveckis et al 2011)

the “Show Map” button, the map of NUTS geographical features should appear. The functionality is the same as in Hazus with the potential to choose multiple regions for analysis.

The implementation opened new opportunities for Hazus in Europe. Now Hazus users can import European datasets into Hazus and produce flood assessments. The huge advantage is that the usual framework for flood assessment using site specific data stays unchanged and the user has the ability to follow the default Hazus Flood Model manuals, training courses, and guidelines. For more about the framework and how to produce flood assessments in Europe using Hazus and implementation, see chapter 7.

Another one problem with the NUTS scale is the Hazus flood hazard analysis, described in chapter 4.4. and 5. The flood hazard analysis in Hazus is available only if the DEM and regression equations are available (international context). The problem with existing NUTS scale is that to preceded flood hazard analysis, Hazus needs that whole study area would be covered with DEM. The default census blocks in the US are not huge, so there is no problem covering the small study area, but this is not true for NUTS regions.

Also, the presented framework shows how to integrate any region in Hazus, independent from geographical position. Future research will focus on the integration of a worldwide region dataset and will enable people to use the Hazus Flood Model worldwide.

Unfortunately, although this implementation allows the user to integrate the aggregated data, the level of detail is not enough to perform sufficient analysis. This means that Hazus is only able to assess site-specific data. If worldwide geographical units would be available, populated with attribute data and by size equal or smaller than US census blocks, then the research could be rearranged. For the integration of aggregated data into existing NUTS regions, first it would be necessary to collect the data and then integrate it. The toughest task would be to collect the data, but is it worth it when the smallest NUTS regions are the size of a metropolitan city area? Probably not.

Another opportunity would be to integrate plan-quadrants from the Austrian Statistics Department, the same geographical units which were integrated for a small area by Kulmesch (Kulmesch et al 2010). For this case, it would be necessary to populate plenty of tables in Bndrygbs and other geodatabases with such values as demographics, building count, exposure, vehicle count, agriculture, etc. The main reason why this was not performed is because a plan-quadrant aggregated data system is not common in Europe. The integration of plan-quadrant would solve only Austrian needs, and then that asks a new question: Is it worth it?

7. New Framework of Riverine Flood Assessment in Europe with Hazus

This chapter introduces the steps to producing flood assessment in Europe using implementation and Hazus. The framework follows the step-by-step flood riverine analysis (except aggregated data analysis and some limitations in level 1 analysis for flood hazard data) presented in chapter five.

7.1. Data Preparedness

Data preparedness is one of the most complicated and time consuming tasks in Hazus. The task to integrate European datasets, where every country has its own standards, means converting all the data to Hazus understandable language. Hazus standards contain not only data types, but also the specified values and even the projection.

7.1.1. Flood Inventory Data

The inventory data structure of European datasets remains the same as US datasets. The difference between the US and Europe is that the US had state inventory datasets, while there are no European datasets in Hazus data format. For this reason, all the data has to be uploaded/imported. The good thing is that uploaded data stays in the inventory where it can be updated centralized. The datasets can be integrated into Hazus inventory by various ways and formats. The main platform of inventory data integration is the CDMS. CDMS makes the integration easier and allows the user to perform data field and value matching. Data field matching is when the input data does not have the same field name as Hazus requires. Data value matching is when the values are different than Hazus requires. During the integration, CDMS identifies the values and data fields which do not match Hazus requirements and asks the user to match the fields and values. The huge advantage is that the user does not have to change everything manually. This stands for all types of aggregated and site specific data, except User Defined Facilities (UDF). UDF data can be integrated only through the Hazus interface and the import function.

Default Data

A majority of the required data can be assigned by default in Hazus. The default Hazus data descriptions for each of the facility types are located in the CDMS data dictionary. The default values are useful when it is clear that all specified types of facilities have the same properties. Hazus assigns default values when it can't locate the required data field during integration via CDMS. Unfortunately, this option does not work during UDF integration. The fields must be populated manually.

Requirements

The requirements for input data are the descriptions of data types and examples. All these data type descriptions are in the CDMS Data Dictionary and in the Hazus Inventory window by right-clicking the mouse button and selecting "Data Dictionary." The CDMS Data Dictionary can be found in the FEMA Library (FEMA 2011b). In the CDMS Data Dictionary, not all information is compulsory for flood assessment. For example, the address does not play any role; it is only additional information to improve inventory management. Insignificant data are marked as "FALSE" in the "Required" data column in the CDMS Data Dictionary.

When the required fields are not populated, Hazus assigns the default data. For example, when the building damage function is not assigned by ID, Hazus will assign it by occupancy type, or if the user does not include the facility class (occupancy) for fire stations, Hazus knows it is a fire station from the selection in CDMS and assigns the default fire station code.

The requirements of the data also depend on the input data type. When the input is a MS Excel or MS Access table, the essential data columns are Latitude and Longitude (in NAD83 coordinate system), which must be populated always when imported from tables.

Because the aggregated data integration was not implemented in this research study, the main focus is delivered to site-specific data. However, the most part of the site-specific data parameters contains the same structure as aggregated data parameters.

The requirements must be followed when the user wants to spend less time in the process of integration. Some of the requirements can be handled by applying field matching or value matching in CDMS, but in any approach, it will take time.

Hazus will leave blank the data columns not mentioned as requirements or that do not exist in the input file at all. The following data columns must be populated, or some of the data will be assigned as default data.

Table 21: The most common data requirements for input data. All of these data fields can be assigned by default. For some facilities the names of the columns can differ. See CDMS Data Dictionary for details (FEMA, 2010a). The parameters marked in *Italic* are compulsory only for MR4-MR5 Hazus Flood Model versions.

Field Name	**Field Description**	**Data Type**	**Units**	**Comments**
BldgDamageFnId	*ID of building damage function*	*Varchar (10)*		*Can be set as any small number. Does not assign other damage function as it should*
BldgType	*Flood Building Type*	*Varchar (15)*		*Does not play any role in flood assessment. Can be assigned by default.*
ContdamageFnId	*ID of contents damage function*	*Varchar (10)*		*Can be set as any small number. Does not assign other damage function as it should*
Occupancy	Facility class (Occupancy)	Varchar (5)		The code of facility or object
InvDamageFnId	ID of inventory damage function	*Varchar (10)*		*Can be set as any small number. Does not assign other damage function as it should*
NumStories	Number of floors/stories	Int		Hazus defines damage function according number of floors
FirstFloorHt	Height of the first occupied floor	Float (8)	Feet	One of the most important value of flood assessment in Hazus
Costs	Building replacement cost	Float (8)	Thous. of monetary units	This field is compulsory when the building loss is needed to be estimated
ContentCost	*Content replacement cost*	*Float (8)*	*Thous. of monetary units*	*This field is compulsory when the contents loss is needed to be estimated*
FoundationType	Flood Structure Foundation Type	Varchar (1)		Practically only value “4” assigns other damage function
YearBuilt	*The years when the building was built*	*Int*		*No affect, can be set 1900 as default*
DesignLevel	*Defines the FIRM level of building*	*Int*		*No affect, can be set 0 as default*
FloodProtection	*Defines the return period of flood*	*Int*		*No affect, can be set 100 as default*
Latitude	Latitude in NAD1983	Double	Decimals	Project to NAD1983 and populate using geometry calc.
Longitude	Longitude in NAD1983	Double	Decimals	Project to NAD1983 and populate using geometry calc.

Some of the unique requirements, such as "Elevation over the bridge deck" and "Average height of electrical equipment," are specific to a minority of the facilities and are not mentioned in the table. For details, see CDMS data dictionary. The general view of the data requirements can be found in the appendix.

Mapping Scheme and Semantics

Because there is no possibility of integrating UDF through CDMS and using the value matching option, the mapping schemes have a huge advantage in this case. In this chapter presented mapping schemes perform the value and data matching before the integration process, not in Hazus or CDMS. This means that any data mapping tool can be used. For this research, MS Access was chosen. Figure 72 shows the mapping scheme of the occupancy class for Open Street Map (OSM) data in MS Access.

Occupancy

ID	Occupancy	HazusOcc
1	arts_centre	GOV1
2	bank	COM5
3	college	EDU2
4	courthouse	GOV1
5	embassy	GOV1
6	fast_food	COM1
7	fire_station	GOV2
8	fountain	COM10
9	fuel	IND2
10	hospital	COM6
11	kindergarten	EDU1
12	library	EDU2
13	marketplace	COM1
14	parking	COM10
15	place_of_wors	REL1

Record: 1 No Filter Search

Figure 72: Mapping scheme for OSM and Hazus occupancy types (Kaveckis et al. 2011)

The mapping schemes are very useful for fast data transformations. In MS Access the template of specified data types can be created. For example, the occupancy types in OSM or building types in Austria in the German language can be assigned to such values that Hazus could understand. The user needs only to modify the template by assigning the imported values to the correct values, and saving and running the query. The data will quickly be transformed, and if the data fields are the same as those in Hazus, there will be no data field matching.

7.1.2. Flood Hazard Data

The preparation of flood hazard data is simpler than inventory data. The main requirement is that the user defined flood depth grid has to be in GRID format and be projected to NAD83 coordinate system. As it was mentioned in chapter 5, there are a few approaches to delivering flood hazard data in Hazus. One of these approaches is to let Hazus generate the flood depth grid when DEM and regression equations are available. The huge coverage area of NUTS3 regions requires the same area covered DEM. For this reason, the flood hazard data can be a limitation in Hazus (especially when talking about high accuracy DEM).

7.2. Data Integration

The data integration process for international datasets is the same as US datasets; the same rules apply. If more efforts were made in the data preparation stage, the integration process should be very simple. Three approaches of integration exist: through the Hazus interface and through CDMS, and all facilities can be integrated one-by-one through the inventory window. During this process, the user has to input everything by hand. This is time consuming and the bug with UDF visualization of the results appears (the results available only as a table).

Data integration for UDF is more complicated than other facilities because it is performed through the Hazus interface and is slower than CDMS. The most complicated part is the data field matching when no template for field matching is available. Be sure that data types are correct (the data column names can differ).

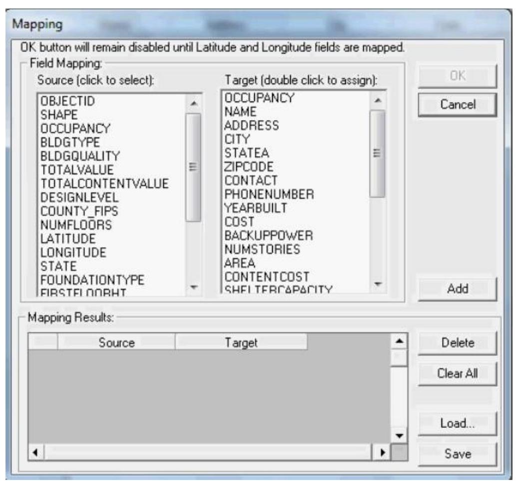


Figure 73: The UDF data field matching window

If there are mismatched values (ex: the value “RS1” was defined instead of “RES1”), Hazus can crash and the user will have to do everything again. The integration of UDF is possible only from a database (MS Access, geodatabase). The UDF input data must be stored as a table with longitude and latitude (NAD1983) data fields. If the user has the UDF data as the feature dataset (shape files), the best idea would be to create and populate the longitude and latitude data fields and export the data into a database where the values can be modified if needed and the data can be imported into Hazus. If there is common use of specified data field matching, it is recommended that the user save the template and use it for every integration.

Integration through CDMS is easier. CDMS has the ability to integrate data from three sources: geographical features (shape files), MS Excel tables, or databases. If the input is shape file, there is no need to have longitude and latitude as attribute information because Hazus identifies the geographical position. When integrating from Excel and geodatabase tables, have the latitude and longitude fields populated by decimal degrees in NAD1983. Before the integration, be sure that the source state folder is the same where the new study region was integrated. The inventory should be empty by default. Do not pay attention to the name of the state in the lower left side of the CDMS window. During the integration process, CDMS asks to select (figure 74) the inventory category (essential facility, aggregated data, etc.) and the latitude/longitude if imported from a table.

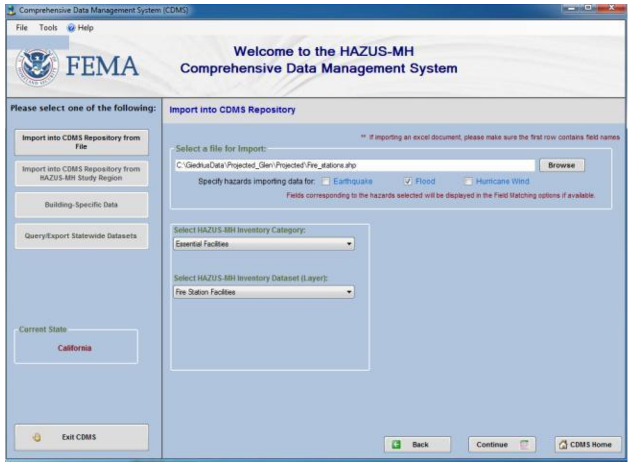


Figure 74: Integration process of essential facilities through CDMS

The next step is data field matching, where the user has to match input data fields to the Hazus data fields. If all the data fields are defined according to requirements, Hazus will assign them automatically and CDMS will go directly to the value matching procedure (figure 75).

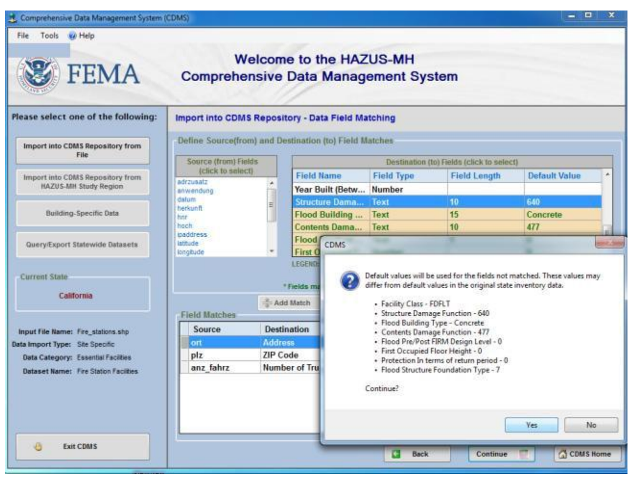


Figure 75: Data value matching in CDMS

If Hazus can't find the values it needs for flood assessment, it will ask your permission to assign the default values. It is possible that the user would need to integrate only the points with the coordinates; the user would define the inventory category and all other default values would be assigned by Hazus. The imported facilities can be queried by CDMS or viewed in the inventory when the study region is created.

7.3. Analysis and Delivery of Results

The analysis is probably the fastest step (if there is not much data) of the whole framework. Because all inventory data is in place, the user needs only to choose the analysis type and run the analysis (Figure 76). The analysis is performed by a point-to-point method. Hazus checks each of the facilities separately.

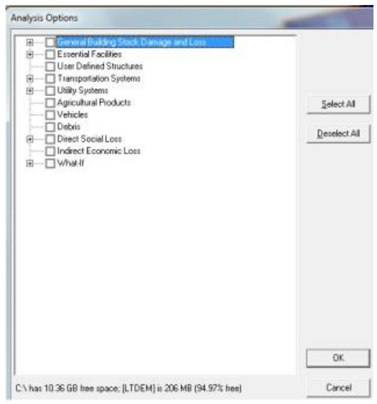


Figure 76: Hazus Flood Model analysis window

That can take a long time if there are many facilities, for example, in a case where there are more than 16,000 residential buildings in the city defined as UDF. In this case, it would be recommended that the user import only flood affected UDF into Hazus. This simple step can be done via spatial selection using a flood depth grid and UDF.

The results are delivered as inflicted damages or losses (if content and building values were provided). The results can be visualized as maps (Figure 77) and tables.

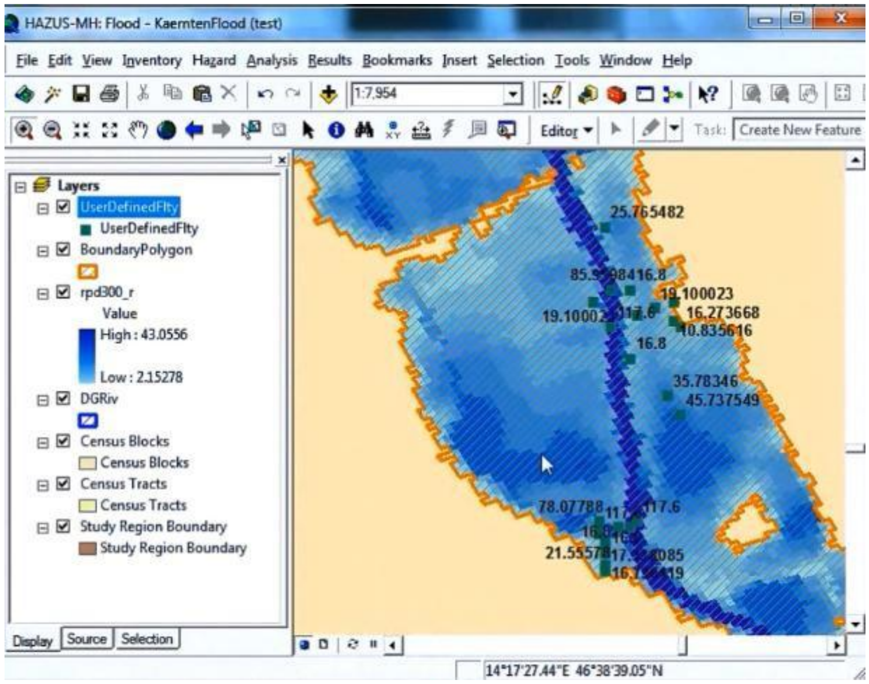


Figure 77: Example of results- UDF percentage damages of OSM data in Glan region (Carinthia, Austria) (Kaveckis et al 2011b)

8. Case Study – Flood Damage Assessment in Micheldorf

This chapter will test and reveal the possibilities of the implementation, and how the local Austrian datasets can be easily be integrated into the Hazus Flood Model and the flood assessment can be performed.

8.1. Study Area

The study area is the community of the small Austrian town named Micheldorf. Micheldorf is located in southern Austria in the Carinthia region, in a valley of beautiful mountains.

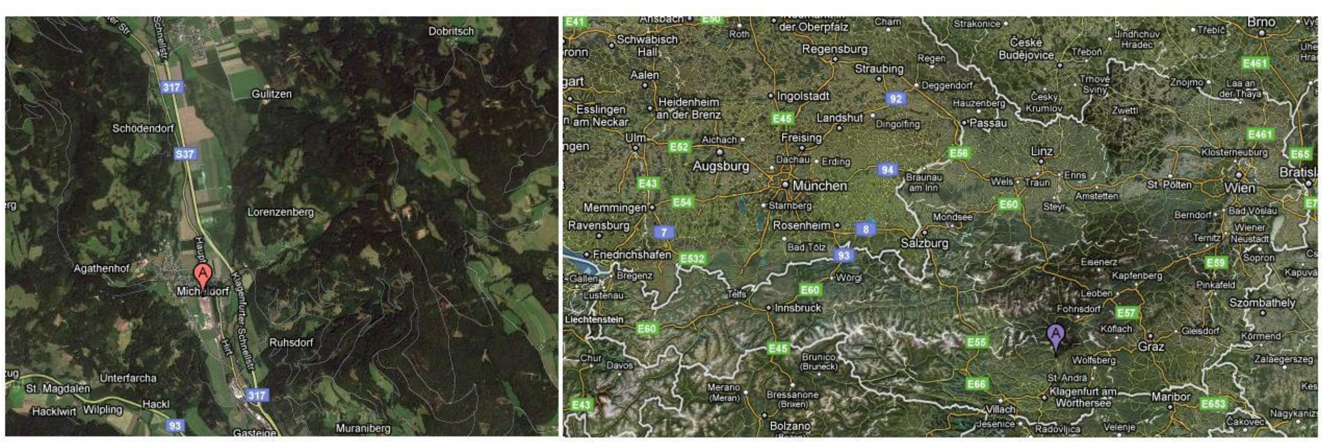


Figure 78: Location of Micheldorf in the aspect of Austria (right) (Google 2011)

The population of Micheldorf is slightly over 1,000. This tiny community is threatened by the local river, Glan. The objective of this case study is to integrate all input data into the Hazus Flood Model and perform a flood damage assessment.

Figure 79: Outlook of Micheldorf (Gemeinde Micheldorf 2011)

8.2. Input Data Analysis

The significant input data is the key contribution to the efficient analysis. For this case study, the data was gathered from the Water Resource Management Department of the regional government in Carinthia, Austria. The earliest step of data preparation is to project all geographical input data into NAD1983 projection. This can be performed via ArcMap tool “Project” for features and “Project Raster” for raster data. Both of these tools are in the “Data Management” toolbox.

The availability of flood depth grids always was a huge issue. The same problem occurs for the Micheldorf region. One of the solutions would be to use the flood depth grid methodology presented in chapter 4.4.1. All that is available as flood hazard data for Micheldorf are the flood boundaries of three return periods (Figure 80). The return periods are presented as polygon features. Because there is no known elevation of the flood crust, there should be an additional data preparation step for this case study. As usual, for cases when the flood depth grid is not available, the Digital Elevation Model is needed. For this study, only the 25 meter resolution DEM was available.

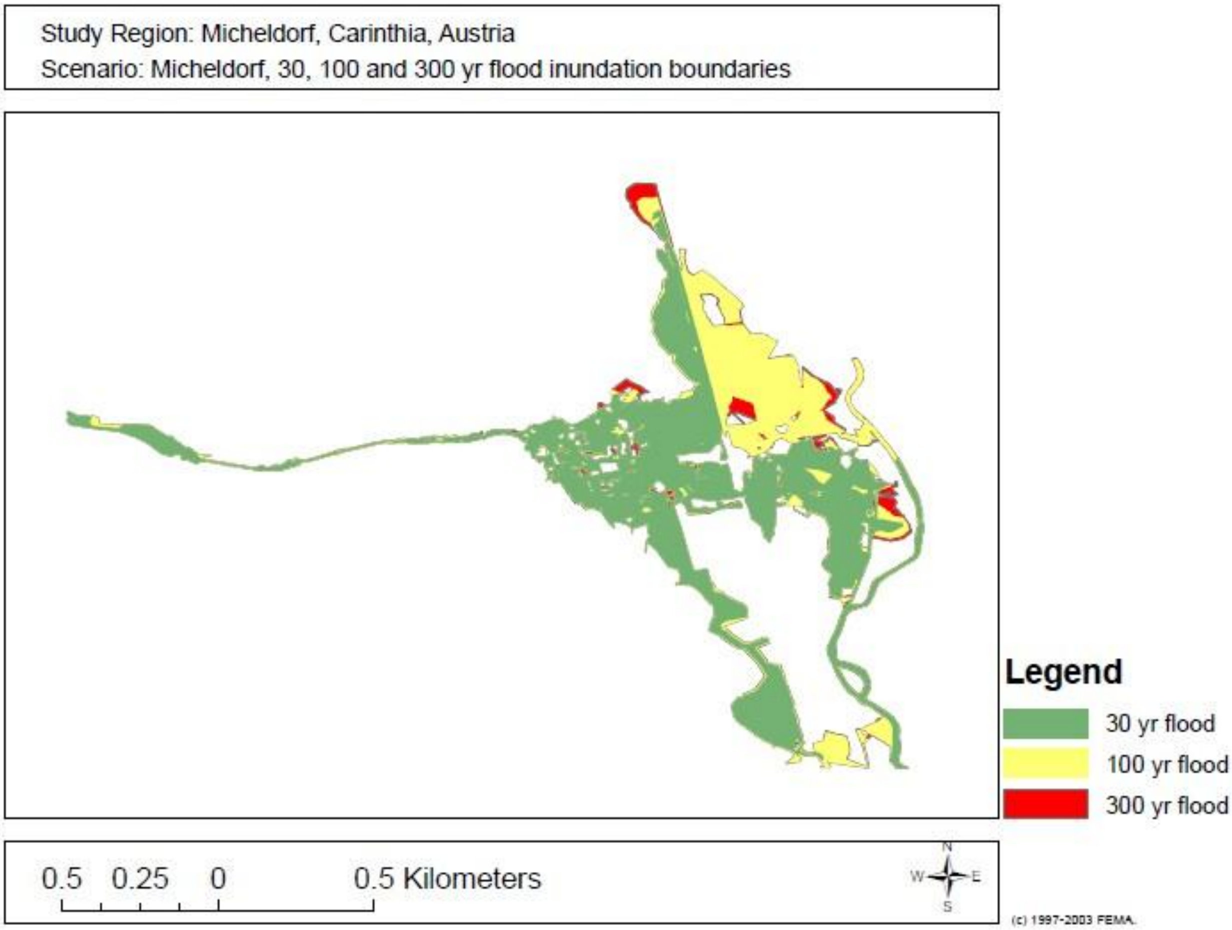


Figure 80: The polygons of three flood extents with different return periods in Micheldorf

The next task is to find the mean of the elevation of every flood extent in the area. The outer line of the flood extent is defined as the flood boundary, and the flood boundary is the line which connects the same elevation points. For the calculation of the mean elevation, the ArcGIS Spatial Analyst tool "Zonal Statistics" can be used. For this tool two inputs are needed: first, the flood extent and second, the DEM. The output of the analysis is the mean raster value of the cells, limited by specified flood extent. The results showed quite similar flood elevation means for all three return periods (table 22).

Table 22: Flood crust mean elevations for three flood extents

	Mean flood crust elevation in meters
HQ30	618,83
HQ100	617,07
HQ300	617,00

The result looks strange because the elevation of extreme flood is lower than the elevation of low probability flood. This should be the issue with the roughness of DEM and the accuracy of flood extents.

When the elevation of the flood crust is known, the discussed flood depth grid methodology can be followed (chapter 4.4.2.). The standard input is the DEM. The flood extend polygon can be used as the interest area. The model takes the extreme coordinates (bounding box) of the interest area and subtracts the DEM from the specified elevation. It was decided to use the extreme flood polygon (HQ300) with the return period of 300 years. The last needed input is the flood crust elevation, which here is 617. The model produces and there is the flood depth grid (Figure 81).

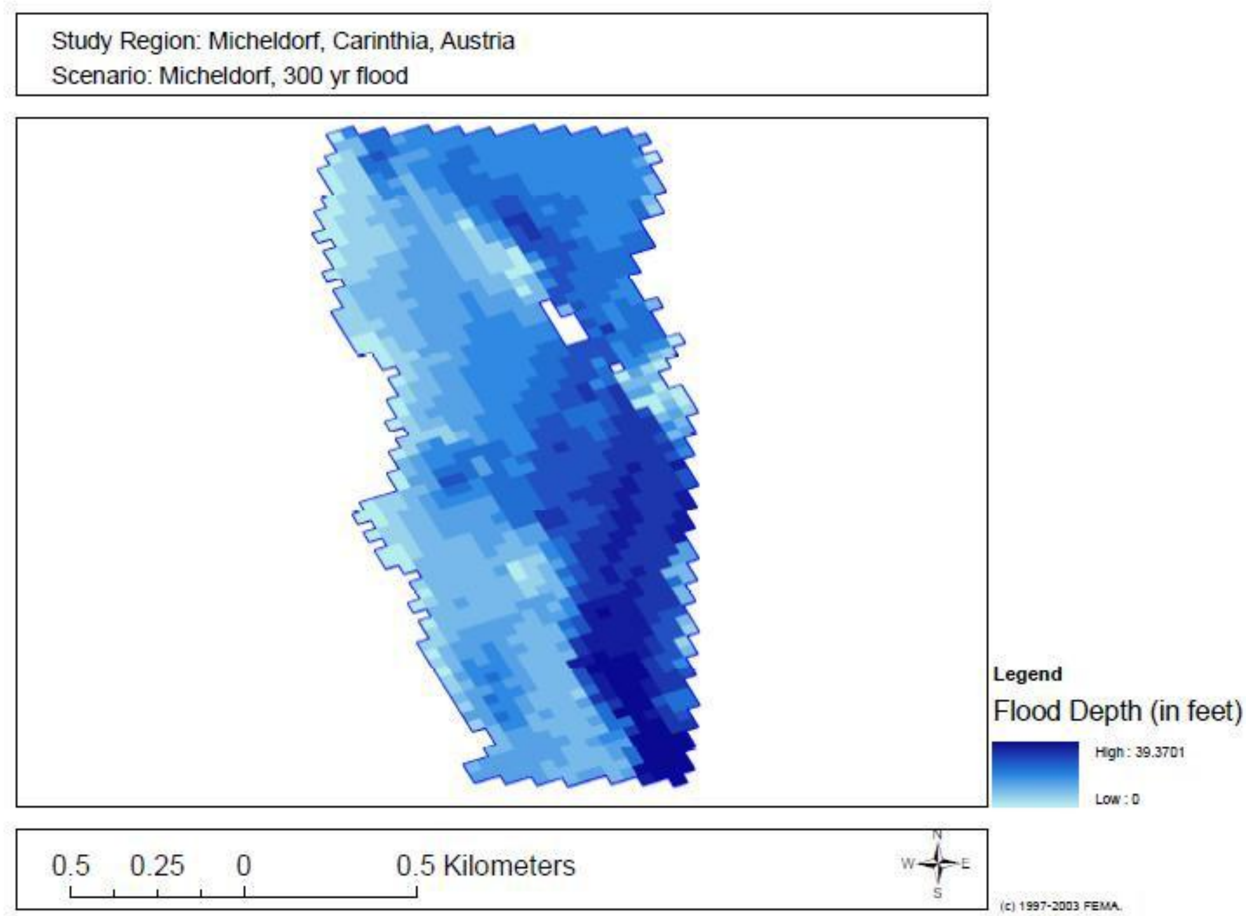


Figure 81: Flood depth grid of 300 year flood in Micheldorf

When the flood hazard data is available, the next step should be to focus on the inventory data. The available building data are the polygons of various occupancy type buildings (figure 82). The occupancy type is defined in the attribute information.

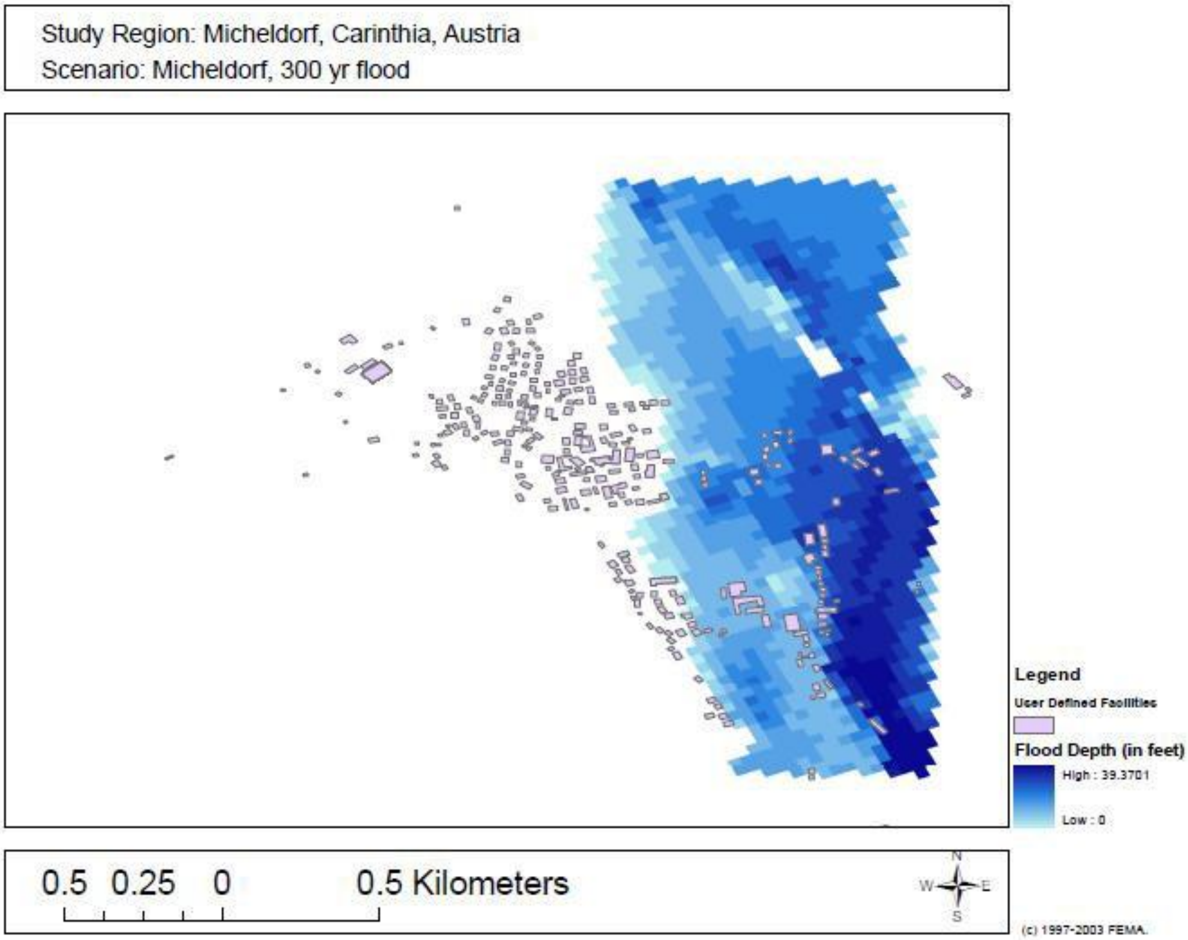


Figure 82: Local Micheldorf data – the buildings blueprints as polygons

The most efficient approach when individual buildings are available is to use them as user-defined facilities. For this reason, the points are needed instead of polygons. The polygon conversion to the points can be performed by using another ArcMap Data Management Tool —“Feature to Point.” This tool is in the “Features” subclass. ArcMap uses this tool to create centroids from the polygons without losing the attribute information.

The next step is part of UDF data preparedness. Because UDF cannot be integrated as geographical features, only as a table, the additional columns with coordinates in the attribute information are needed. This task can be done by adding new fields (Longitude and Latitude) as double for data type and calculating the geometry —x and y coordinates in NAD83 coordinate system. When this is done, it is possible to export the UDF point layer to the geodatabase, where further steps will be followed.

Another important step before data integration is attribute information preparedness. The original input data most of the times is not the same as the data Hazus requires. The same problem exists in this situation. The existing occupancy classes have to be changed to the Hazus occupancy classes. For this reason, the mapping scheme in MS Access can be used (Figure 83).

ID	Hazus	Micheldorf	Meaning
2	RES1	1	Gebaude mit Wohnung
3	RES3	2	Gebaude mit mehren Wohnungen
4	RES3	3	Wohngebaude fur Gemeinschaften
5	COM8	4	Fremdenverkehr/Touristische Zwecke
6	IND2	5	Industrie Gebaude
7	IND2	6	Industrie Gebaude
8	GOV1	7	Offentliche Einrichtungen
9	IND2	8	Industrie Gebaude
10	GOV1	9	Offentliche Einrichtungen
11	EDU1	10	Schule oder Krankenhaus
13	RES1	11	Sonstige

Figure 83: The mapping scheme of Hazus and local data occupancy classes

Because no other UDF significant attribute information is available, the default values will be used. The basement foundation type—0 feet first floor height and concrete for building type—is defined as a default parameter. The main role here is for first floor height and the basement type to act as damage functions for each occupancy class. The building type is needed, but no influence of this parameter is in the flood assessment. The assignment of default values can performed via an MS Access query. After a few mouse clicks, the result is the pure UDF table, which Hazus can easily identify.

8.3. Creation of Study Region

When UDF facilities are used as data input, the study region has to be created first (when using CDMS for integration of other facilities, the data is uploaded to the inventory, and when the study region is created the data can be used directly from inventory).

During the creation of the study region procedure, the Hazus model collects all the needed data for this specified study region (like inventory data, mapping schemes, etc.)

Figure 84: The creation of the study region window in Hazus

The selection of the region (figure 84) is possible in two ways—by name or by map. It is even possible to create one region where the part would take two smaller regions from different countries (flood hazard does not know such words as “country boundaries”).

The process of region creation can take some time, but it depends on the size and quantity of inventory and other data. When the region is created (figure 85), the user can check inventory, mapping schemes, damage functions, etc.

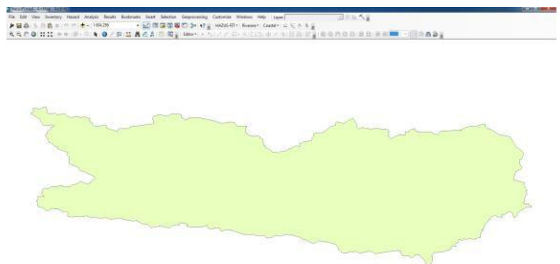


Figure 85: The created study region of the smallest geographical region – NUTS3 (Carinthia)

8.4. Inventory Data Integration

Because the building data will be used as UDF, the integration process is more complicated than using CDMS. But for this case, there should be no problem, because all data values are correct and no data value matching is needed. The same stands for data field matching as long as the correct data field names were defined in the table. Figure 86 shows the data field mapping scheme.

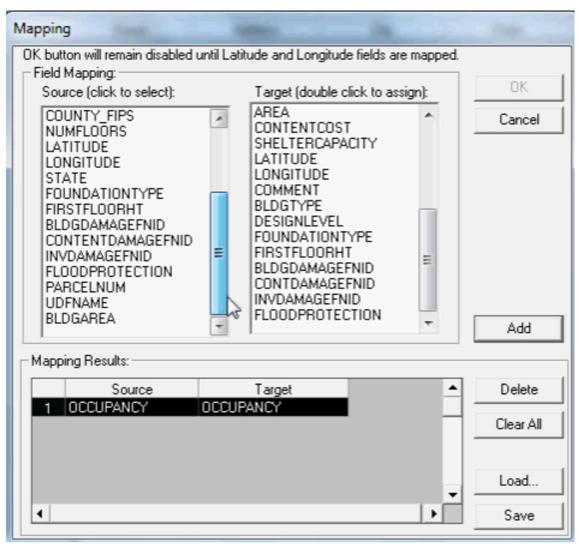


Figure 86: UDF data field mapping in Hazus interface

8.5. Flood Hazard Data Integration

The next step is flood hazard data integration. Because the reason of the flood in our study area is river water discharge, the flood hazard type should be defined as riverine. The next step is to choose the user-defined flood depth grid as input data. The model asks to choose the units and probability period (Figure 87). The units are define as meters and the probability period, 300.

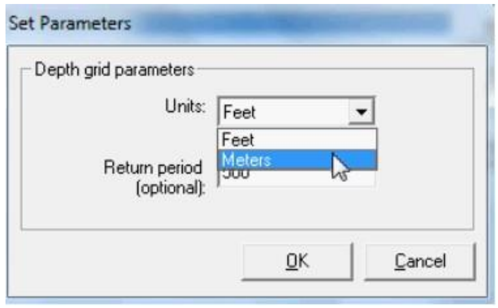


Figure 87: Flood hazard data integration

Because the user-defined flood depth grid was used, there is no hydrology analysis needed. The user can directly delineate the floodplain. During this operation, the model generates the boundaries of the flood plain.

8.6. Scenario Creation and Analysis

Creating the scenario is a common step in Hazus flood assessment. During this step the user has to choose the segments of flood depth grid, or the different streams if level 1 flood hazard analysis is performed. The different scenarios can be created using different properties and parameters. Because all the needed data is integrated, the analysis can be performed. The results of flood assessment analysis are provided in chapter 9.

9. Results

This chapter presents the results of the analysis Hazus-MH contributed to EFD and the ways it could fulfill EFD requirements. It also shows the flood map examples that the Hazus-MH Flood Model is able to produce from original US inventory data. The implementation itself is also defined as a result, and for that reason, the schema and workflow is provided in the appendix. The other part of the results is the flood assessment in Micheldorf using the created implementation.

9.1. Flood Hazard and Flood Risk Maps in Hazus

When all the requirements of EFD and the specifications of flood maps were known, it was possible to evaluate the Hazus-MH contribution to EFD by producing flood maps. To get the outline of how the Hazus-MH Flood Model could contribute to EFD, the table of Hazus-MH capabilities was created:

Table 23: The capabilities of Hazus-MH to create flood hazard and flood risk maps ("X" = Hazus-MH capability to create that type of map) (Kaveckis et al 2011a)

Type of map	Map contents	Capability of Hazus-MH
Flood hazard map	Flood extent/flood plain map	X
	Flood depth map	X
	Flood velocity and propagation map	
	Flood danger map (hazard zoning map – combination of flood extent and flood depth)	X
	Flood event map (historical floods)	
Flood risk map	Distribution of population	X
	Distribution of vulnerable groups	X
	Distribution of buildings	X
	Social vulnerability (shelter requirements and displaced population)	X
	Type of industry susceptibility to damage	X
	Impact of damage on economy	X
	Agriculture flooding	X
	Various classifications for land-use	

As is evident, Hazus-MH can create most of these maps. The key issue is the input data. Some of the maps can be created using site specific point data, some using aggregated data. In the Hazus-MH Flood Model, the flood extent map can be created from DEM if the regression equations are known. If not, there are few other possibilities—integrate the user defined flood depth grid, use the suggested methodology in chapter 4.4.1., or import the flood depth grid from HEC-RAS or other hydraulic modeling tools. The same procedure belongs to flood depth map. The flood danger map is the combination of the flood depth and the flood extent map.

It is clear that historical flood data depends on accurate past flood event data. The Hazus Flood Model is not capable of storing historical flood data as it can in the earthquake and hurricane models. It could be a great opportunity to enable it to upload historical floods into the Hazus database and then, using few mouse clicks, compare it with an existing flood threat. Right now there is only a possibility of adding the historical information as additional input data.

Therefore, Hazus can easily deliver information about population, vulnerable groups, and displaced population during specified flood hazard conditions, direct and indirect flood impacts to economy, etc. A big part of that information in Hazus is presented by default as aggregated data. That brings some difficulties in integrating non-U.S. datasets into Hazus-MH.

Land-use data cannot be visualized in Hazus. In Hazus the occupancy type could be presented as land-use. For example, all RES subclasses would be set as residential areas, GOV as government property, etc. But such areas as forests, recreation, and other specified areas cannot be represented in Hazus.

The further flood hazard and flood risk maps were produced by Hazus-MH using default inventory (U.S. state datasets) and flood hazard data (produced using inner Hazus hydrological and hydraulic modeling):

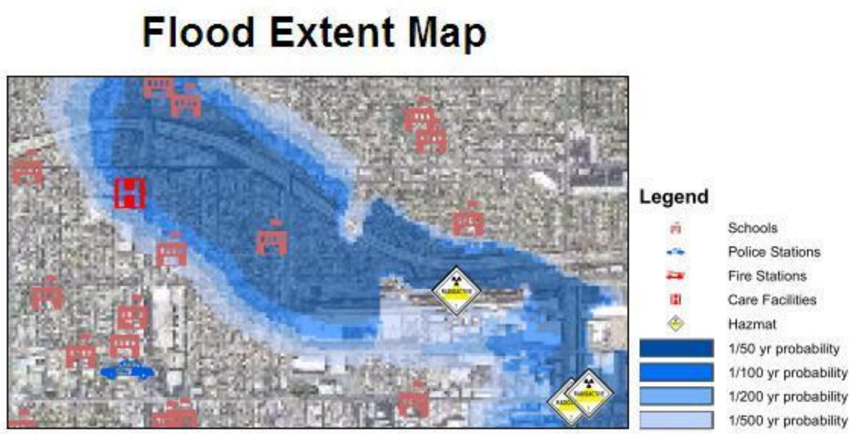


Figure 88: Flood extent map, produced with Hazus-MH Flood Model. Different flood extent periods are visualized in blue shade colours

The flood extent map was produced using the EXCIMAP suggested methodology, visualizing various probability flood extents and some critical facilities on the same map. This flood extent map provides great information to city planners, communities, emergency, and other agencies to identify and assess risk.

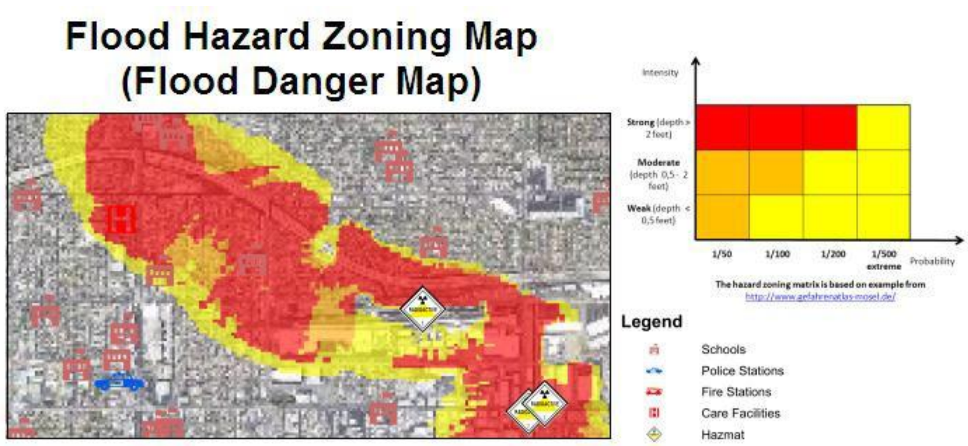


Figure 89: Flood hazard map – flood danger map. The Hazus-MH can't create danger maps automatically. In this case various combinations between flood depth and flood extent map were used, and thresholds for intensity of the hazard were defined

The flood hazard map was created using a German example from EXCIMAP. This map helps to identify the hazard level. Very often people do not understand the concept of flood probability and flood depth. For this case, it is more helpful to associate the three different colors with the flood danger that could be described as a function of the flood frequency (probability) and flood depth. A flood danger map could be very useful for communities and public audiences to increase flood risk awareness.

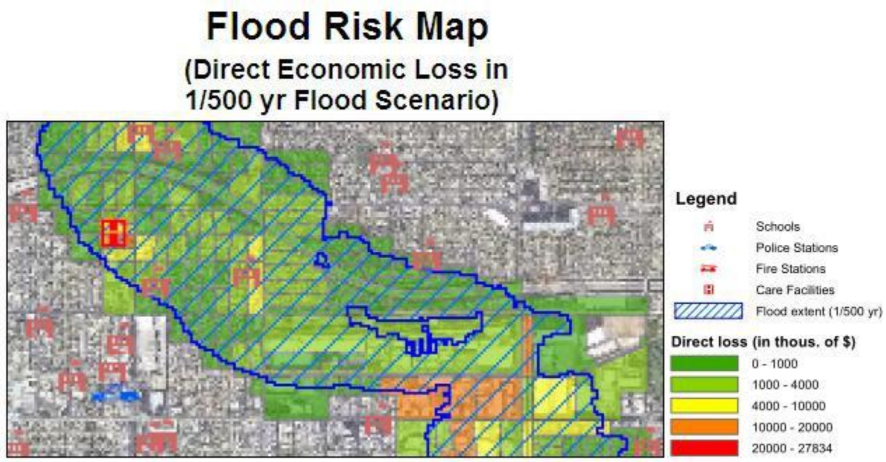


Figure 90: Flood Risk Map – distribution of direct economic loss in extreme flood scenario. The direct loss is generated by Hazus-MH using aggregated inventory data

The flood risk map (Figure 90) shows the direct economic loss under specified flood hazard conditions. The loss is presented as a monetary value—the loss of damaged buildings, contents, and inventory of the buildings by combining flood depth and aggregated data (building count, building content, and inventory value.) This map could be useful for insurance agencies and communities.

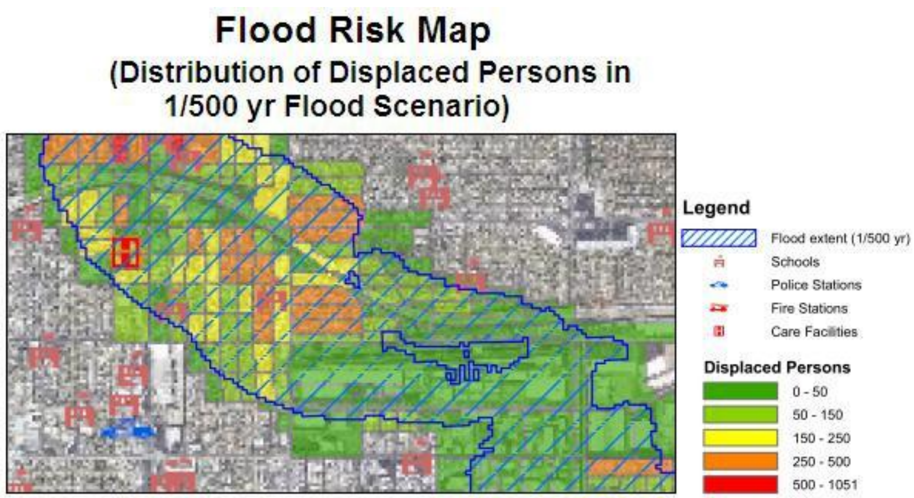


Figure 91: Flood Risk Map – distribution of displaced persons in the extreme flood scenario. The displaced persons data is generated by Hazus-MH Flood Model using aggregated demographic data

The last presented flood risk map (Figure 91) shows displaced persons. Hazus combines flood depth grid and aggregated demographic data to deliver the results. This map could help humanitarian and emergency agencies to prepare for flood disasters.

All these maps were created using default Hazus inventory data, aggregated demographic and building count data, and critical facilities. It should be considered that without that data there is no potential to produce such maps.

9.2. Micheldorf Flood Damage Assessment

The data preparation and integration procedure of the flood damage assessment in Micheldorf is described in chapter 8. The results of this analysis show the flood inflicted building and content damages (Figure 92) for each of the buildings in the inundated area. The results can be provided as a table or visualized on the map. Because there were no building values or replacement costs provided for this dataset, there is no loss estimation. The same stands for content value.

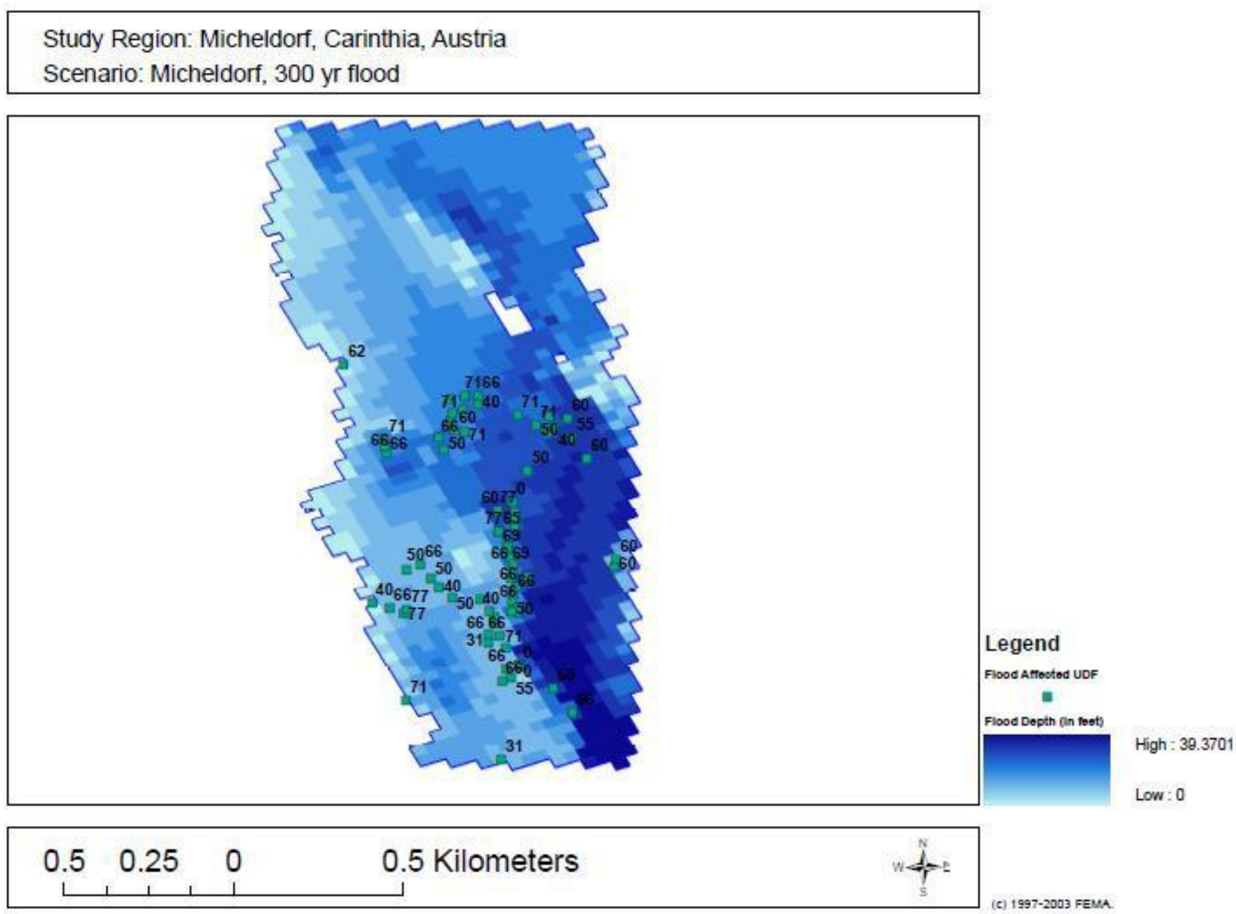
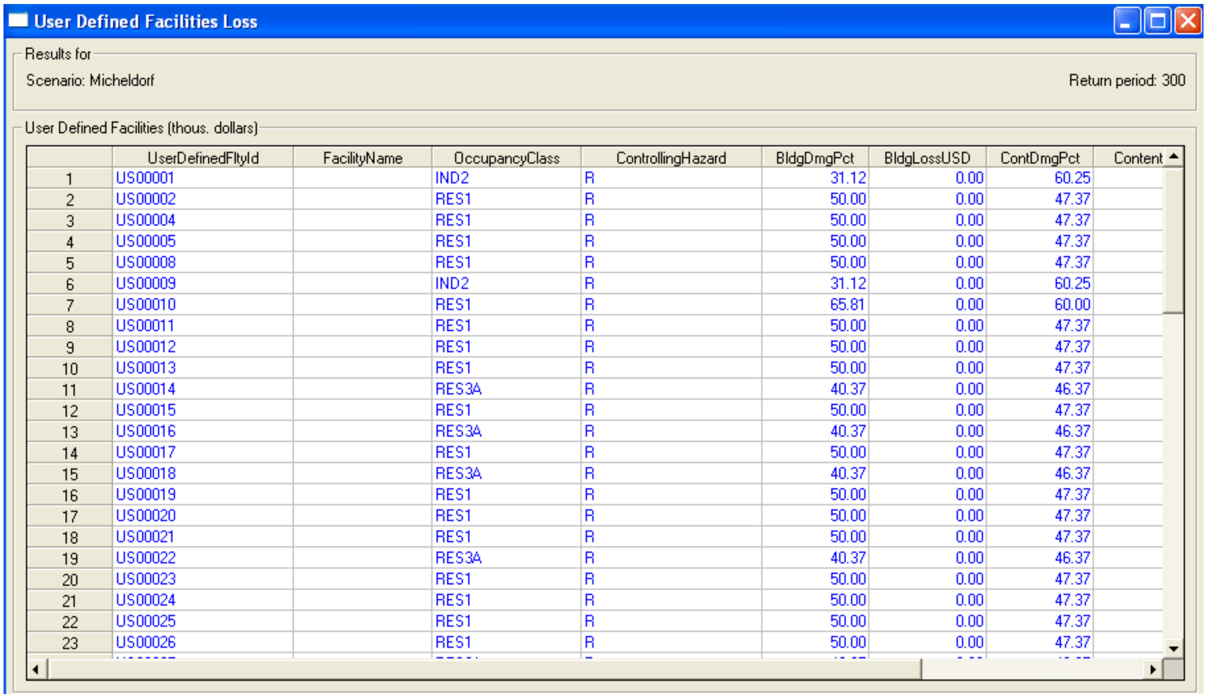


Figure 92: 300 year flood damage assessment for 77 buildings in Micheldorf

According Hazus methodology, if the damage exceeds 50%, the damage considered substantial damage. The building that was inflicted by substantial damage is no longer in use.


User Defined Facilities Loss

Results for
Scenario: Micheldorf
Return period: 300

User Defined Facilities (thous. dollars)

	UserDefinedFltyId	FacilityName	OccupancyClass	ControllingHazard	BldgDmgPct	BldgLossUSD	ContDmgPct	Content
1	US00001		IND2	R	31.12	0.00	60.25	
2	US00002		RES1	R	50.00	0.00	47.37	
3	US00004		RES1	R	50.00	0.00	47.37	
4	US00005		RES1	R	50.00	0.00	47.37	
5	US00008		RES1	R	50.00	0.00	47.37	
6	US00009		IND2	R	31.12	0.00	60.25	
7	US00010		RES1	R	65.81	0.00	60.00	
8	US00011		RES1	R	50.00	0.00	47.37	
9	US00012		RES1	R	50.00	0.00	47.37	
10	US00013		RES1	R	50.00	0.00	47.37	
11	US00014		RES3A	R	40.37	0.00	46.37	
12	US00015		RES1	R	50.00	0.00	47.37	
13	US00016		RES3A	R	40.37	0.00	46.37	
14	US00017		RES1	R	50.00	0.00	47.37	
15	US00018		RES3A	R	40.37	0.00	46.37	
16	US00019		RES1	R	50.00	0.00	47.37	
17	US00020		RES1	R	50.00	0.00	47.37	
18	US00021		RES1	R	50.00	0.00	47.37	
19	US00022		RES3A	R	40.37	0.00	46.37	
20	US00023		RES1	R	50.00	0.00	47.37	
21	US00024		RES1	R	50.00	0.00	47.37	
22	US00025		RES1	R	50.00	0.00	47.37	
23	US00026		RES1	R	50.00	0.00	47.37	

Figure 93: Hazus Flood Model table output of the flood assessment analysis for UDF in Micheldorf

Because the number of inhabitants in the buildings is known, it is possible to perform a query and get a list of substantial damage inflicted buildings and calculate the sum of displaced people during the specified flood hazard conditions. Because no substantial damage for this case study was estimated, there are no displaced people for this scenario.

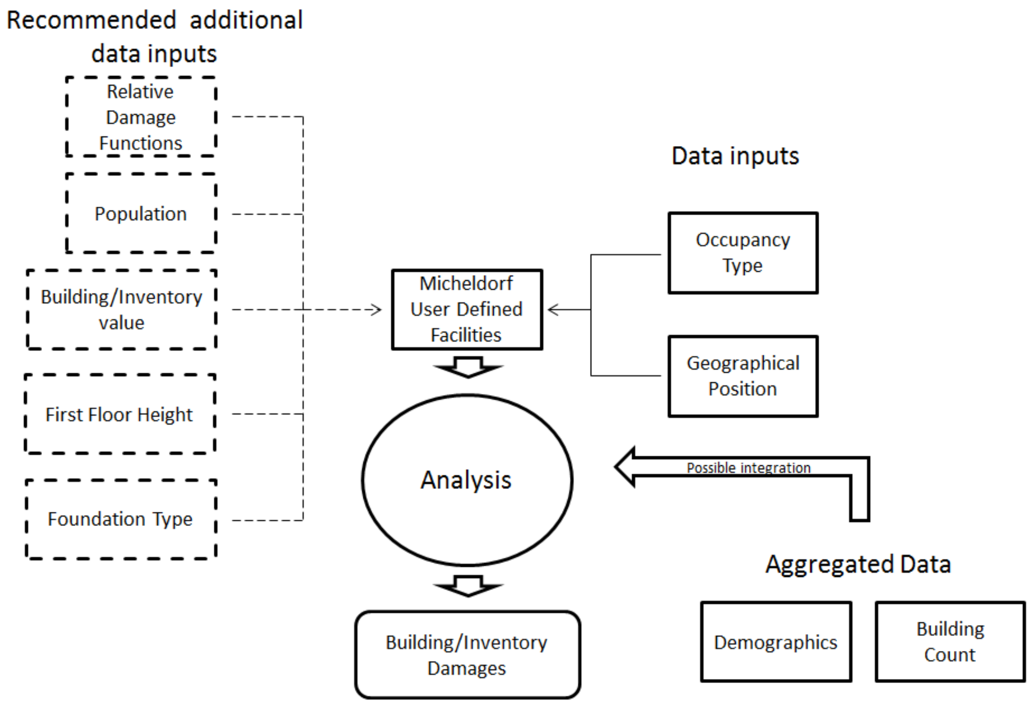


Figure 94: Schema of inventory data possibilities for Micheldorf in Hazus flood assessment

The accurate input data is essential to a successful analysis. That was proved again. There is a question about the quality of the input data, but the model uses the correct methodology accepted by many agencies. Also the existing Hazus limitations of UDF do not allow the model deliver additional results. However, there is much room for improvement. One possibility would be to define the mean replacement value for each of the occupancy classes (Ex: the RES1—the average cost of the single dwelling residential house in the area could be defined as 150 000€ pro building). This would help not only to estimate the preliminary building losses, but also the loss of inventory (Hazus methodology suggests rating the value of the contents as a specified part of a building's value). Another suggestion would be to define the first floor height for the buildings. The possible solution would be to assign a default first floor height according the occupancy. For example, 1 foot of elevation for each of the residential buildings, etc. Only the foundation type of the basement plays a role in damage estimation, but the future Hazus version hopefully will be able to produce a more precise analysis according to foundation type.

And together with high accuracy flood depth grids, another possible improvement is correct, scientifically approved damage functions. This would increase the significance of damage estimation.

10. Discussion

This section summarizes the thesis, provides the evaluation, and discusses the main issues of the Flood Model and potential future research focus. The existing problems and limitations are also considered and summarized.

10.1. Hazus Flood Model Issues

Although development of Hazus gets support from FEMA, there are many problems with this product. Some of the issues are bugs, some could be described as lack of functionality. Most of the problems were already mentioned in this thesis. Unfortunately, Hazus users find many bugs every day; even the newest Hazus 2.0 version has plenty of them, if not more than previous version-MR5. Some of the bugs and problems were not noticed by the creators at all as they wandered from version to version. In this chapter the main Hazus Flood Model issues will be mentioned.

Hazus internationally

One of the most important issues with Hazus-MH is that by default there is no possibility to integrate non-U.S datasets. As this research and practice showed, this is no longer an issue for the flood model, and a good future is also possible for the earthquake model. The processes and framework that enables users to use non-U.S. datasets in the Hazus Flood Model are described in chapter 6.

Foundation type and first floor height

According to the framework, the foundation type as a parameter should play a significant role in flood assessment, but that is false. The model does not use the default first floor assigned values for a specified foundation type. This means that it does not matter which foundation type will be chosen, because there will be no effect. There is one exception with foundation type #4—basement. The model takes only one foundation type into account, the basement, and assigns a different damage function. For all of the six other foundation types there is no difference in which one will be chosen. This issue was proved by many test runs and reported to FEMA.

Another problem with UDF is the first floor height. By default, when importing the data, the column for first floor height should be populated. If there is no value in this field, the model cannot produce an analysis. This means that Hazus is not using any mapping scheme to populate the first floor height as it should do by using building age/built year, foundation type, and design level. Then the question becomes: Why do we need all these values populated? Practically, it should be enough to populate first floor height, the existence of a basement (foundation type 4), occupancy class, number of stories, and costs.

The Hazus model also does not take into account the elevation of a bridge deck (alternate of first floor height for facilities and buildings) and some other parameters. It is confusing that the same concept parameters are used by the model for one type of data but not for others.

Damage functions for GBS data

During many analysis runs it was noticed that newly created damage functions do not work in the Hazus Flood Model for the GBS data. The model just excludes the data where new damage functions were applied. For example, the community consists of ten census blocks, and all of them contain different types of RES2 and RES1 sub-class buildings (as attribute information of census blocks). The user uses default damage functions, runs the analysis, and observes the results. Now the user wants to see the changes by applying different damage functions. The user creates the new damage function for RES2 sub-class and runs the analysis. The results will show that all RES2 data are not in the result table. The model just do not add them. The problem also occurs when the existing damage function is modified. Only there is no problem for site specific-data and the changes can be noticed if the Hazus pre-defined damage function was used. This whole issue only occurs with GBS aggregated data, but with other facilities, vehicles, and agriculture the changes of newly applied damage functions were noticed and were identified as significant and working well.

Building type

The Hazus MR4 and MR5 Flood Models require the user to define the building type for flood assessment on buildings and facilities. It is clear that this characteristic is not counted as a parameter of flood assessment. The Hazus creators probably defined it as compulsory parameter to use the same inventory data for earthquake and hurricane assessment (building type is important in these Hazus models).The user who is interested only in flood assessment can populate this field randomly.

No new occupancy classes and damage and restoration functions

Another slight problem is the limited ability to create additional occupancy classes with the newly assigned damage functions. This functionality would be very useful for international use of the Flood Model. Now, when users have unique occupancy types and want to run an analysis for standard Hazus occupancies at the same time, the following problem occurs. One of the default damage functions has to be replaced by the newly applied damage function, but all of them are significant for the same analysis.

There is no ability to define not only the damage functions to the transport facilities, but also the restoration functions for transport and utility systems.

Disadvantage of aggregated data in flood assessment

Most of the Census data like buildings and demographics exist as aggregated data. The problem of aggregated data in flood assessment is that the location of aggregated objects is unknown. The area weighted analysis used in Hazus helps, but there is a huge problem with inaccuracy.

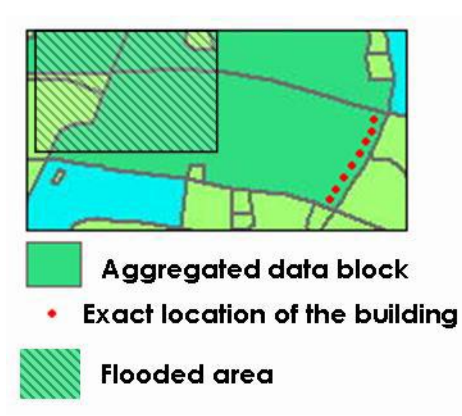


Figure 95: Visualization of disadvantage of aggregated data in flood assessment

Figure 95 demonstrates the situation when the aggregated data is used in flood assessment. The aggregated data block is defined as a unit. The Hazus model calculates how much of the block is inundated and disperses the damages to all the buildings in the block. This happens with aggregated data, but let's imagine that all the buildings in the reality are not dispersed in the block evenly. All of them are located along the street (Figure 95 as dots). In the case of a predicted flood (dashed area in Figure 95), they would not suffer any flood damage if they would be in UDF. But because they are in aggregated data, the damage for these buildings will be estimated. This example shows that if it is possible, try to avoid aggregated data and use point data. The other correct statement is that it is always possible to aggregate the point data, but you can't disperse the aggregated data and get the exact location back.

Projection

Hazus works only in the NAD83 coordinate system. NAD83 is known as the North American Datum, the geodetic network, used in North America. It is a satellite-based system that uses the center of the earth as a reference point for the measurements. NAD83 was taken in 1980 and adopted internationally as GRS80 (Geodetic Reference System 1980). The question is: What are the differences between NAD83 and the frequently used World Geodetic System 1984 (WGS84)? WGS84 is a refined version of GRS80 and used by the US military and GPS (Global Positioning System). For the most geographic purposes, the NAD83, WGS84, and GRS80 are equivalent (Conner 2003) to one another. According to Conner and Neascu, NAD83 and WGS84 use the same GRS80 ellipsoid and the difference is in the range of few millimeters (Neascu 2010).

In Hazus, the run tests showed a few centimeters inaccuracy between the point of the same user defined facility in WGS84 and NAD83 coordinate systems in the Lithuanian area (54 north). The inaccuracy should be higher closer to the equator. For flood assessment in Hazus, even those few centimeters are not an obstacle. The user just should not forget to transform the input datasets to the NAD83 coordinate system (It can be done in ArcMap using the "Project" tool for vector data and "Project Raster" for raster data. Both tools are located in "Data Management Tools" (ArcGIS 9.3). If the local datasets has to be integrated, the user minimum should be able to transform from local coordinate system to the WGS84, then the referencing to NAD83 leave for ArcGIS or other tools.

10.2. Conclusions

The outcome of the research could be defined in such statements:

- Hazus-MH is a well developed and documented risk assessment tool that is still widely used for many purposes in the U.S. This master's thesis developed Hazus' ability to be applied in a worldwide context. The created implementation enables the user to perform flood damage and loss estimation for essential, lifelines, and user defined facilities across Europe. The presented methodology helps flood mapping experts find the best solution to satisfy the European Flood Directive's requirements for flood hazard and flood risk maps. Moreover, the applied methods offer an inexpensive way to produce sufficient flood hazard data and perform flood damage estimation, where user interaction is minimized.

- Some of the existing limitations and complicated aggregated data integration can be dissatisfying to some of the users. But still, Hazus-MH does not replace the professional hazard modeling and risk assessment tools. The big part of Hazus' success depends on the input data.
- As discussed earlier, the aggregated data is not sufficient for flood assessment as the points. But from another point of view, if the building is 100 x 150 meters in size and the location is described only as a point, this would cause huge inaccuracies in flood damage estimation. One of the possibilities as discussed with Jack Schmitz from the Polis Center would be to define building blueprints as census blocks. Then, a weighted analysis would be performed for each of the building areas. For this case, that would be the most effective flood damage estimation analysis. But the other issues are the computer resources and the Hazus technical limitations. Even with the existing size and number of census blocks, Hazus is working quite slowly. But if the Hazus algorithms were improved, then this topic could be defined as future research.
- The potential of using the implementation and presented methodology is important for local communities who want to raise flood risk awareness. The suggested methods and solutions like OSM and freely available DEM would help them to evaluate local vulnerability to floods and maybe create a new way to protect against flood damage. Right now the problem is the quality of data, but with the advancement of data collecting technologies everything can change in years.

In the end of this master's thesis the general question might be: Why is all of this useful? Who is this useful for? The main answer to the first question is the availability. All tools and methodologies described in this thesis are freely available. There are many fields where this methodology could be applied. One of the application fields are the European countries that have to fulfill the EFD requirements. Most of the countries have flood depth grids produced by local water resource agencies. The GIS offices can provide the necessary inventory data, and all that is necessary is to prepare the inventory data using mapping schemes that would satisfy Hazus requirements. As the research showed, many of the EFD maps can be produced using Hazus, and all of that is with minimal costs.

Another potential area for Hazus are small communities that have no money at all to perform flood assessment. Imagine the situation: the local fire chief in a small community in the valley got a call from a colleague living in the upstream that the river level was rising fast. The fire chief expects a huge flood, but the problem is that they have no financial support. By using the methodology presented here, the community can get the DEM, but there would be no inventory data. Then the fire chief checks the OSM and is surprised, because two years ago one person in the community got a GPS device and mapped all the buildings. All they need to do is download the data, but the attribute information is not enough. The community members know the area very well, and using mapping schemes define that 80 percent of the residential buildings have a 60 cm basement foundation and define the needed parameters. And now the community is able to assess the flood risk. Of course, it will not be an effective flood study, but it will help to raise flood risk awareness. It is important for everyone who cares about his or her community and the people in it.

10.3. Existing Problems

The existing problems is a big headache even for the current Hazus users in the U.S. Some of the problems were already discussed in detail.

- The main issue with using the implementation described in this master's thesis is the lack of a common aggregated data structure in Europe. It is obvious that the huge task of defining a common structure should be done, but the another question is it worth it when the aggregated data is not effective in flood assessment? The new approaches and applied technologies like LIDAR (Light Detection and Ranging) reveal easier data collecting for individual buildings and pushes the necessity for aggregated data backwards.

- The availability of detailed scale NUTS regions also should be considered. The problem with available DEM is that it's not accessible to users who can't afford professional hydrologic and hydraulic tools but would like to produce a flood depth grid through the Hazus methodology. The possible solution would be to apply the simple flood depth grid approach, but this can be insufficient for effective flood studies. Or, in another case, use other suggested flood modeling tools. Another missing feature is the availability of regression functions for European regions in hydrologic analysis.

- Some of the issues are technical Hazus problems and that makes the user annoyed. These issues would be the dissolution of GBS results when the user defined damage functions are applied, and many other problems like the compulsory information of the building type, which is not used in flood assessment, or the inability to define damage and restoration functions for transport and utility facilities. The ability to store HPL facilities but no flood assessment availability also looks strange from the user's perspective.

- There is hope that in future the Hazus Flood Model will be able to assess the damages for line objects, such as roads, railways, pipelines, etc, as it does in the earthquake model. Also, the existing implementation enables users to integrate only site-specific data, while much of the information in Hazus is provided from the assessment of aggregated data. That would be economic loss, displaced people, etc. The alternative is to adopt the existing methodology on UDF.

- The minor problems like the currency of the units should not be considered a big issue. The results as attribute information can be changed immediately from feet to meters using the standard calculations. The monetary value in dollars does not play any role; instead of dollars the user can use any preferable currency. The model only generates the losses by using the input value of the assets.

10.4. Future Work

The existing Hazus limitations and achieved results give prospectives and motivation for future research on many issues:

- One of the future focuses are UDFs. UDFs as a dataset in Hazus is quite limited. All that is available from UDFs in the way of flood assessment is the building/inventory damage and loss estimation. UDFs are not included into reports. These limitations show the huge potential interest. One of the possibilities is to statistically or individually predict the count of people in each of the building occupancy types and populate the new UDF column “peoplecount.” The other step would be to research how many people are harmed or lost by specified flood depth grid. Then for each UDF analysis the count of casualties can be generated for each of the buildings. The other possibility is using FEMA methodology to define that a substantially damaged (more than 50%) building is no longer operational. When the people count in the building is known, the displaced number of people for a specified flood can be generated. Another idea is to define how much worth economical, industrial, and agriculture assets are produced. That could be also provided as statistical information. For example: in the specified area, the light factory produces ~500 000€ worth annually. In the Hazus flood estimation, when 55 percent damage is inflicted to this factory, it means that the area will lose half a million euros per year, and that will be not the building loss, but economic loss. Some of this methodology is applied for aggregated data but not for UDFs.

- Another future research possibility is the development of regression equations used in mathematical hydrological analysis in Hazus. The original regression equations in Hazus are valid only for areas in the U.S. The solution would be to produce new regression equations that would describe the local (European) hydrological parameters and add them to Hazus. Another, easier solution (but not better in quality) would be to research similarities between the US and European regions in hydrologic parameters, and define the same regression equations to European regions.

- It is extremely important to adopt damage functions according to European needs. Future cooperation should be focused with research institutions, which contain the technical information about flood damages in a European context.

- The framework of the implementation showed the potential to use the Hazus Flood Model in Europe. The next research will focus on implementation to enable Hazus use worldwide. Also the accidental discovery in the Hazus lab enabled us to integrate a Lithuanian dataset into the Hazus earthquake model. That is a huge achievement and shows even more potential research areas in Hazus.

Many potential aspects of future research are still unknown and would be revealed only in the further studies. Hopefully this research will not only increase Hazus’ popularity at the international level, but also will force the Hazus creators to improve its capabilities. My personal wish would be that my research and efforts would be useful and could serve by saving lives and property.

11. References

ABS Consulting (2003), Flood Information Tool User Manual, ABS Consulting Inc.

ASTER (2011), ASTER DEM website: http://www.gdem.aster.ersdac.or.jp [accessed on 2011.06.02].

Atlas of Flood Maps (2007), Atlas of Flood Maps, European Exchange Circle on Flood Mapping (EXCIMAP).

Bausch, D. (2010), HAZ Haiti - Implementing the Hazus Earthquake Model for Haiti, FEMA Region VII

Bogs, C. (2008), Pre-FIRM vs Post FIRM structures, Insurance Journal: http://www.mynewmarkets.com/articles/93031/pre-firm-vs-post-firm-structures [accessed on 2011.08.05].

Burq, S. (2010), Mapping of Haiti, 2010 – presentation.

Conner, D., (2003), Projections, Coordinate Systems and Datums – Explained . Ohio Geospatial Technology Conference for Agriculture and Natural Resource Applications, National Geodetic Survey.

Crichton, D. (1999), The Risk Triangle, Natural Disaster Management, Tudor Rose, London, S. 102-103.

Crichton, D. (2001), The Implications of Climate Change for the Insurance Industry, Building Research Establishment, Watford, England.

ESRI (2006), Quick Guide to Hazus-MH MR-1, New York.

European Flood Directive (2007), Directive 2007/60/EC on the assessment and management of flood risks, European Commission accessible at http://ec.europa.eu/environment/water/flood_risk/index.htm .

Eurostat (2011), NUTS - Nomenclature of territorial units for statistics: http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction [accessed on 2011.07.19].

EXCIMAP (2007), Handbook on good practices for flood mapping in Europe, European Exchange Circle on Flood Mapping.

FEMA (2009a), Hazus-MH MR4 Flood Model Technical Manual, Department of Homeland Security, FEMA Mitigation Division, Washington, D.C.

FEMA (2009b), Hazus-MH MR4 Flood Model User Manual, Department of Homeland Security, FEMA Mitigation Division, Washington, D.C.

FEMA (2009c), Unit 4 Hazus Riverine Flood Loss Estimation Analysis, Presentation.

FEMA (2010a) – CDMS Data Dictionary 2.6, Department of Homeland Security, FEMA Mitigation Division, Washington, D.C.

FEMA (2010b), Flood Insurance Rate Map (FIRM):

http://www.fema.gov/plan/prevent/floodplain/nfipkeywords/firm.shtm [accessed on 2011.04.07].

FEMA (2011a) FEMA's Methodology for Estimating Potential Losses from Disasters: http://www.fema.gov/plan/prevent/hazus/ [accessed on 2011.07.27].

FEMA (2011b), FEMA Library: http://www.fema.gov/library/index.jsp [accessed on 2011.08.04].

FLOODsite (2007), Evaluating flood damages: guidance and recommendations on principles and methods.

FoodSec (2011), Food Security Information for Decision Making: http://www.foodsec.org/web/tools/datasharing/gaul/en/ [accessed on 2011.08.25].

Gemeinde Micheldorf (2011), Micheldorf Photo Albums: http://www.micheldorf.gv.at/ [accessed on 2011.08.25].

Google (2011), Google Maps: http://maps.google.com [accessed on 2011.08.26].

Grita, F. (2011), GAUL Project, Group on Earth Observations, Information Services, Geoportal: http://www.geoportal.org [accessed on 2011.08.25].

Holmes, R., Jr., and Dinicola, K. (2010), 100 – Year Flood – It's All Abount Chance, USGS, Office of Surface Water, Reston, Virginia.

HR Wallingford, (2002), A Review, R&D Technical Report FD2302/TRI (HR Wallingford Report SR587) - Risk, Performance and Uncertainty in Flood and coastal defence, Crown Copyright, London.

HR Wallingford, (2006), Flood Risks to People: Phase 2 , DEFRA (Department for Environment Food and Rural Affairs) and Environment Agency, Flood Hazard Research Centre, Middlesex University, Risk & Policy Analysis Ltd., 2006, London.

HUG (2008), Hazus User Group Success Story, South Caroline Hazus User Group.

Kaminger, I, Wonka, E. (2004), Von Einer Österreichgliederung nach Gemeinden zu Planquadraten: Statistik Austria erweitert sein regionalstatistisches Angebot, 9th International Symphosium on Planning & IT, pp. 549-554.

Kaveckis, G., Paulus, G., Mickey, K. (2011a), Potential Contribution of Hazus-MH to Flood Risk Assessment in the Context of the European Flood Directive, GI_Forum Proceedings 2011, Salzburg, Austria.

Kaveckis, G., Paulus, G., Mickey, K. (2011b), Potential Contribution of Hazus-MH to Flood Risk Assessment in the Context of the European Flood Directive, Central Hazus User Group hosted presentation on the European Flood Directive and the role Hazus plays in it, CHUG, Indianapolis: http://www.usehazus.com/uploads/main/Hazus_International.pdf [accessed on 2011.08.03].

Kaveckis, G. (2011), Hazus-MH Flood Damage Reduction Feasibility Study for Rocky Ripple, Polis Center, Indianapolis – unpublished report.

Kulmesch, S. (2010), Evaluation of Hazus-MH Loss Estimation Methodology for a Natural Risk Management Case Study in Carinthia, Austria – unpublished Master thesis.

Kulmesch, S., Leitner, M. & Paulus, G. (2010), Konzeptionelle Überlegungen zur Einsetzbarkeit von Hazus-MH in Österreich – Eine Fallstudie zur Abschätzung des Schadenpotentials bei Hochwasserfällen in Kärnten, Angewandte Geoinformatik 2010 Beitrage zum 22. AGIT-Symposium, Salzburg, 872-880.

MCDC (2011), All about Census Geography and Summary Levels, Missouri Census Data Center, Missouri: http://mcdc.missouri.edu/allabout/sumlevs/ [accessed on 2011.08.09].

Mostert, E. and Junier, S.J. (2009), The European Flood Risk Directive: Challenges for Research, Delft University of Technologies, The Netherlands.

MRC (2009), Mekong River Commission, Best Practise Guidelines for Flood Risk Assessment.

Alexe, B., Chiticariu, L., Miller, R.J., Wang-Chiew, T. (2008), Muse: Mapping Understanding and design by Example", Data Engineering, 2008, ICDE 2008, IEE 24th International Conference, pp. 10-19, Cancun.

Muthukumar, S. (2005), Riverine Flood Modeling in HAZUS-MH: Overview of the implementation, Proceedings of the 2005 Georgia Water Resources Conference, Research Associate, Center for GIS, Georgia Institute of Technology, 2005 Georgia, USA.

Neascu, M. (2010), What is the difference between WGS84 and NAD83?, HYPACK Inc.

NRCS (2011), TR-20: Project Formulation – Hydrology, website: http://www.hydrocad.net/tr-20.htm [accessed on 2011.08.02].

Okrent, D., (1980), Comment on societal risk. Science 208, 372-5.

OSM (2011), Open Street Map website: http://www.openstreetmap.org [accessed on 2011.08.08].

OPW (2010), Office of Public Works Website: http://www.floodmaps.ie [accessed on 2010.11.18].

Quick., M. (1994), Regional Territorial Units in Western Europe since 1945. Mannheimer Zentrum für Europäische Sozialforschung (MZES), EURODATA/ Nr. 5.

Parmenter, B. (2003), Census 2000: Geographic Concepts & Products, PhD Dissertation, GIS for Urban and Environmental Analysis, Tuffs University: http://ocw.tufts.edu/data/54/675198.pdf [accessed on 2011.08.08].

Polis Center (2010), Pre-Disaster Mitigation Planning Process, Polis Center, Indianapolis.

Polis Center (2008), Boone County Multi-Hazard Mitigation Planning (MHMP), Project Kickoff, Polis Center, Indianapolis.

Polis Center (2011a), Pre-Disaster Mitigation Critical Facilities Map for Piatt County, PDM Meeting #1, Polis Center, Indianapolis.

Polis Center (2011b), Pre-Disaster Mitigation Historical Disasters Map for Piatt County, PDM Meeting #2, Polis Center, Indianapolis.

Smith, K. and Petley D.N. (2009), Environmental Hazards – Assessing risk and reducing disaster, New York, Routhledge;

Timmerman, P. (1981), Vulnerability, Resilience and Collapse of Society. Environmental Monograph 1. Toronto: Institute for Environmental Studies, University of Toronto.

UN/ECE, 2000, Guidelines on Sustainable flood prevention, United Nations and Economic Commission for Europe (UN/ECE).

UN/ISDR (2004), Living with Risk: A Global Review of Disaster Reduction Initiatives, Geneva, UN Publications.

UNOSAT (2010), Damage Assessment for Major Buildings and Infrastructure in Port-Au-Prince, Haiti – Map.

USACE (2010), Flood and Coastal Storm Damage Reduction R&D Program, Hydrologic Engineering Center, United States Army Corps of Engineers.

USACE (2011a), Hydrological Engineering Center Hydrologic Modeling System website: http://www.hec.usace.army.mil/software/hec-hms/ [accessed on 2011.08.02].

USACE (2011b), Hydrological Engineering Center River Analysis System website: http://www.hec.usace.army.mil/software/hec-ras/ [accessed on 2011.08.02].

Water Framework Directive (2000), Directive 2000/60/EC, European Commission, Brussels.

WDEU (2003), Best Practices on Flood Prevention, Protection and Mitigation, Water Directors of European Union, Water Directors Meeting, Athens.

12. List of Figures

13. List of Tables

Appendix

Flood Assessment in Europe using Hazus-MH Flood Model and Implementation