Development of a Framework for the International Implementation of Hazus-MH Earthquake Model

by

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Master's Thesis

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Spatial Information Management

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Department of Geoinformation & Environmental Technologies

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Villach, Austria

Science Pledge

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

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List of Abbreviations

BI – Building Inventory

CDMS - Comprehensive Data Management System

ESRI - Environmental Systems Research Institute Inc

EU - European Union

FEMA- Federal Emergency Management Agency

FIPS - Federal Information Processing Standards

GBS- General Building Stock

GIS - Geographical Information Systems

GPS - Geographical Positioning System

Hazus-MH - Hazards U.S. Multi-Hazards

HPL - High Potential Loss (facilities)

OSM- Open Street Map

PAGER - Prompt Assessment of Global Earthquakes for Response

PGA - Peak Ground Acceleration

PSA - Pseudo Spectral Acceleration

PGV - Peak Ground Velocity

PESH - Potential Earth Science Hazards

UDF - User Defined Facilities

USGS - United States Geological Survey

VGI - Volunteered Geographic Information

Vs - Shear-Wave Velocity

WGS - World Geodetic System

Abstract

Natural disasters have tremendous effects on human life and high costs on economy, infrastructure and environment all over the globe. Although this kind of phenomena cannot be prevented, the severity of effects can be reduced with robust hazard assessment, planning and preparation and it is possible to implement strategies in order to mitigate their consequences. Earthquakes, like many other natural disasters are not bound by the administrative boundaries of the countries and only an organized collaboration between the countries can help to mitigate the effects of them.

Hazus-MH represents an extensive framework for analyzing hazard related risks and potential losses. Hazus-MH is developed by Federal Emergency Management Agency (FEMA) of the U.S. Government and has a standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. Hazus-MH uses GIS technology based on the ArcGIS software of ESRI to estimate physical, economic, and social impacts of disasters. It is predominantly and extensively used in the U.S. for Hazard/Risk Management and Disaster Planning/Mitigation.

This Master`s Thesis study provides a state of the art overview about international best practice application of the Hazus-MH Earthquake Model. A conceptual analysis model and a prototype for the Hazus-MH Earthquake Model are implemented. This implementation is tested and evaluated in a seismically active hazard region in Austria. The results derived from the local proof of concept discussed for the goal of extending to a regional conceptual framework and further development requirements and suggestions are provided for the future works.

Keywords: *Earthquake Hazard Damage Assessment, Disaster Management and Mitigation, Hazus-MH Earthquake Model, Geographic Information Systems*

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Table of Contents

1. Introduction

This Master`s Thesis presents the studies achieved in terms of the "Development of a Framework for the International Implementation of Hazus-MH Earthquake Model" project continuing in collaboration of School of Geoinformation of Carinthia University of Applied Sciences (CUAS), Austria and The Polis Center of Indiana University Purdue University, USA.

"Development of a Framework for the International Implementation of Hazus-MH Earthquake Model" project is planned as a continuation of previous studies extending the research projects on international applications of Hazus-MH that have been undergoing successfully in CUAS.

This project will provide a state of the art overview about international best practice application of the Hazus-MH Earthquake Model. A conceptual analysis model and a prototype for the Hazus-MH Earthquake Model will be implemented and this implementation will be tested and evaluated in seismically active regions in Austria.

Structure of the Thesis

This thesis is structured in nine chapters:

In the first chapter the motivation of the project, overview of the thesis research, goals of the project, main research questions, methods of solution, audience of the study and the results to be expected at the end of the thesis.

The second chapter contains state of the art in the field and related works on the subject both in CUAS and other international sources for the background of the project covering the terminology on the field.

It is followed by chapter three which covers the theoretical and technical background which presents the common used terminology in disaster risk management and mitigation; description of earthquakes, their structure and earthquake hazard risk management and general overview about Hazus-MH software, functions, usage fields and its models.

Chapter four focuses on methodology, starts with conceptual analysis model, and continues with inventory and hazard data structure, the level of analysis for the international framework of Hazus-MH Earthquake Model.

Chapter five explains Hazus-MH earthquake analysis workflow explaining the data interoperability extension, data preparation and integration phases for the international framework. It also covers the importing the data into Hazus-MH with CDMS interface.

Chapter six explains the proof of concept and implementation starting with the study region and following with from inventory and hazard datasets to Earthquake hazard analysis using these datasets.

Chapter seven discusses the results covering structural, non-structural and total damage results and following with essential facilities, generated debris and shelter requirements.

Chapter eight is the discussions part which covers the discussion of the local proof of concept, the main issues affecting the model results and the limitations of the Earthquake Model. It finalized with a conclusions section covering the whole study.

Chapter nine is reserved for the future work which will help further development of this framework and future studies to extend it.

Following chapters concludes of the References, List of Figures, List of Tables and the Appendices.

1.1. Motivation

Earthquakes worldwide cause severe damage and monetary losses every year. An earthquake is a sudden and violent shaking of the earth when large, elastic strain energy is released and spread out through seismic waves that travel through the body and along the surface of the earth. Up to the present, earthquakes cannot be controlled or forecasted and consequently, disasters cannot be avoided. However, there are ways to improve safety, minimize loss and injury, and increase public awareness of the risks involved. One of the most effective ways to lessen the impact of earthquake disaster on people and property is through risk assessment and mitigation.

A proper coordinated mitigation activity cannot only save human lives but can also reduce the potential effect of disasters. Proper disaster management strategy is expected to improve the overall functioning of the national emergency agencies and help to mitigate the damage effects of disaster. Loss estimates are a key tool in prioritizing the allocation of limited resources, as well as preventing the cascading of events, which can exacerbate the initial effects of a disaster.

Effective emergency response depends on quick and precise estimates of extent of damage and magnitude. Advanced loss estimation programs can provide managers with quantitative loss projections for planning purposes, including cost benefit analysis of building codes and proposed mitigation efforts. After an event, loss estimation programs can provide answers at the critical time when the damage extent and distribution are unclear.

The main motivation of the study is identifying the extents of the US based Hazus-MH Earthquake Model and proving the functionality of the model tools, in the local level, in European context. After that providing a conceptual framework model for further development of this concept to a regional level with the identification of the model requirements and limitation is also a leading interest of this thesis.

Another motivation is to continue the collaboration between Geoinformation School of CUAS and The Polis Center of Indiana University Purdue University, USA, sharing the collaborative knowledge for coordinated loss estimation and mitigation activities extending the studies of disaster management and mitigation in both institutes.

1.2. Project Goals

The main goals of this research project are:

- Identification of data requirements, capabilities and limitations of Hazus-MH Earthquake Module.
- Development of boundary layers for selected study regions in Austria which will be used as a base layer while populating the country specific inventories for the international framework of Hazus-MH.
- Development of a conceptual analysis model and a prototype implementation of the Hazus-MH earthquake Model for Carinthia (Austria)-Slovenia-Italy border regions. All regions show historical earthquake records with high magnitudes and are therefore at potential risk from earthquake hazards.

1.3. Research Questions

The scientific research questions to be addresses in terms of the project are,

- What are the capabilities and limitations of Hazus-MH Earthquake Module?
- What are the best examples of earthquake damage assessment in the USA with Hazus-MH?
- What are the existing components and what is the structure of Hazus-MH inventory?
- What are the existing limitations of implementing Hazus-MH Earthquake Module? What impediments exist for using Hazus-MH Earthquake Module on a wide scale international basis and what should be done to eliminate them?
- What are the data requirements for international datasets specific to study focus?
- What type of GIS processes and unit conversions needed and how can they be used as a base layer for international implementations in the study regions?
- How can a conceptual analysis model and a prototype implementation for the so called earthquake module be developed?

- Is the international framework model applicable for successful earthquake analysis in the selected study regions? How can it be extended into a regional context at the future?

1.4. Methods of Solution

The research questions will be answered by following the specified methods of solutions while performing the research project,

- Working on various sources like user and technical manuals and evaluating the software with obtained datasets to reveal the capabilities and limitations;
- Reviewing the outcomes of various projects in the U.S. where Hazus-MH was applied as a successful tool for disaster planning and mitigation;
- Reviewing the existing components and inventory structure of Hazus-MH -MH;
- Literature research and evaluation of the outcomes of the successful studies that have tested the usage of Hazus-MH Earthquake Module both in Europe and on a wide scale international basis and evaluation of the proposed methodologies in those projects;
- Evaluation of the data requirements of the international framework and analyzing the differences between U.S. and international datasets specific to earthquake module and review of data conversion processes between U.S. and European units;
- Development of a conceptual analysis model and a prototype implementation of the earthquake module for selected seismically active study regions;
- Application of earthquake module analysis to the selected study regions and evaluation and optimization of the upcoming results for identification of the level of analysis for disaster management;
- Review of the international framework methodology and comparison in terms of the data specifications of Hazus-MH;

1.5. Expected Results

With the successful development and implementation of the methods of solution these results are expected:

- Listing of the capabilities and limitations of current version of Hazus-MH Earthquake Module;

- Explanations of the outcomes of previous Hazus-MH projects and definitions of important terminology in earthquake damage assessment;
- Listing of Hazus-MH Earthquake Module components and inventory structure specific to research;
- The methodology and examples of best practices of earthquake damage assessment in Europe. State of the art overview about international best practice applications of Hazus-MH Earthquake Module;
- Workflow for GIS processes and data conversions between U.S. and European units.
- Detailed explanation of proposed conceptual framework analysis model, points on its limitations and effective solutions;
- Description of implementation and application of proposed international framework model to selected study regions in Carinthia, Austria;

1.6. Audience

The primary audience of this thesis project will be international disaster risk assessment experts who are searching for efficient and cost-effective solutions for disaster risk mitigation and management. For the emergency managers this research should increase the awareness and motivation to study the Hazus-MH methodology and use it in an international basis with the developed framework.

2. Theoretical and Technical Background

Theoretical and technical background chapter presents the common used terminology in disaster risk management and mitigation; description of earthquakes, their structure and earthquake hazard risk management and about Hazus-MH structure and its tools provide the general overview about the capabilities of each model and the methodology.

2.1. Natural Hazards Risk Management

This chapter introduces the most common terminology used in disaster risk management and mitigation and related models structure of Hazus-MH.
The following definitions describe the main concepts covered in terms of the study.

Risk
The risk concept applied in Hazus-MH was analyzed by Kulmesch et al (2010) and follows the risk definitions given by Crichton (1999, 2001). 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 (Crichton 1999, 2001).

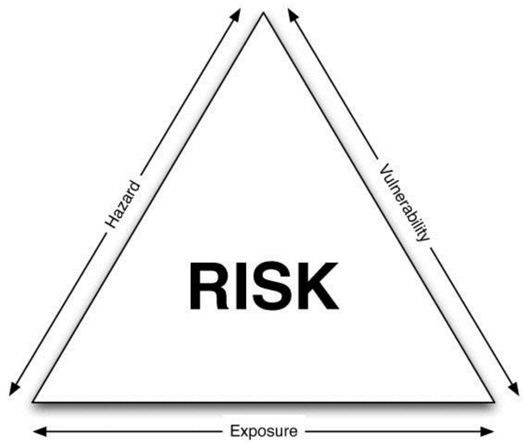

Figure 1: The Risk Triangle (Crichton 1999, 2001).

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 (Smith et al 2009).

The United Nations Strategy for Disaster Reduction (UN/ISDR) approach for an interdisciplinary multi hazard analysis and risk assessment is similar to the Hazus-MH 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 2011).

Hazard

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 (Figure 2). 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.

Vulnerability

According to 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 earthquake damage would decrease the foundation's vulnerability to the earthquakes. Human vulnerability is a degree of resistance offered by a social system to the impact of a hazardous event (Smith et al 2009).

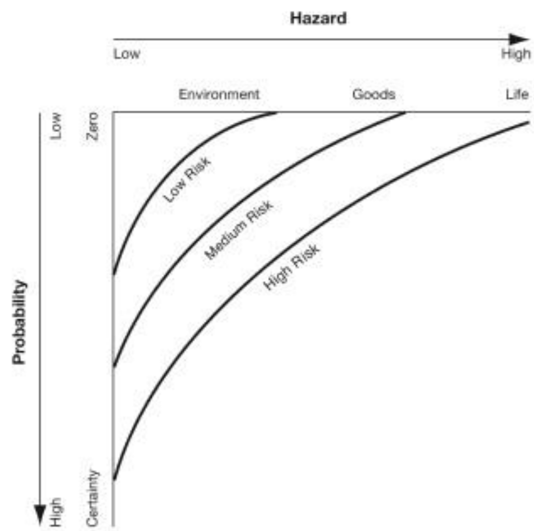

Figure 2: Theoretical relationship between the severity of hazard, probability and risk (Smith et al 2009, pp. 15)

2.2. Earthquake Hazard Overview

Ground shaking is the primary cause of earthquake damage to man-made structures. Seismologists have observed that some districts tend to repeatedly experience stronger seismic shaking than others. This is because the ground under these districts is relatively soft. Soft soils amplify ground shaking. If you live in an area that in past earthquakes suffered shaking stronger than that felt in other areas at comparable distance from the source, you are likely to experience relatively strong shaking in future earthquakes as well. The influence of the underlying soil on the local amplification of earthquake shaking is called the site effect.

Other factors influence the strength of earthquake shaking at a site as well, including the earthquake's magnitude and the site's proximity to the fault. These factors vary from earthquake to earthquake. In contrast, soft soil always amplifies shear waves. If an earthquake is strong enough and close enough to cause damage, the damage will usually be more severe on soft soils.

2.3. Earthquake Hazard Risk Assessment

The basic steps in earthquake hazard risk assessment according to King and Kiremidjian (1994) are,

Hazard Analysis which includes Identification of earthquake sources, modeling of the occurrence of earthquakes from these sources, estimation of the attenuation of earthquake motions between these sources and the study area, evaluation of the site effects of soil amplification, liquefaction, landslide and surface fault rupture.

Inventory Collection which is identification of infrastructure (buildings and lifelines) that are exposed to damage, classification of the buildings and lifelines according to their vulnerability to damage, classification of the occupancy of the buildings and facilities.

Damage Modeling which is modeling of the performance of the inventory classes under earthquake shaking and consequent effects such as ground damage, development of damage functions (relationship between levels of damage and corresponding levels of shaking) and estimation of the damage to the inventory from the earthquake motion at the inventory locations.

Loss Estimation which consists estimation of direct losses due to damage repair costs, estimation of indirect losses due to loss of function of the inventory and estimation of casualties caused by the damage. (King and Kiremidjian 1994)

These steps are illustrated in the Figure 3.

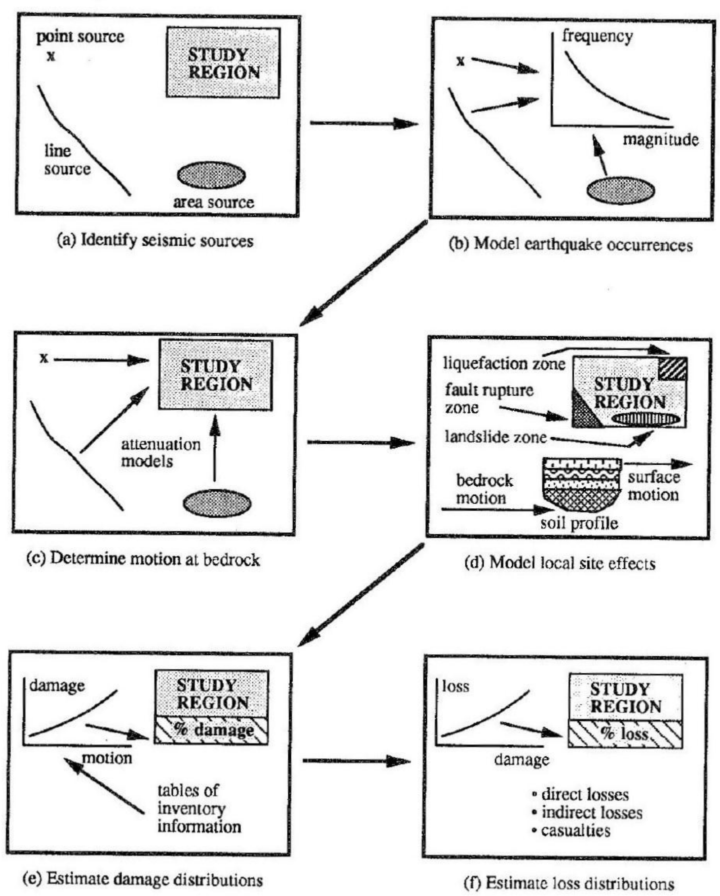

Figure 3: Basic Steps in Earthquake Risk Assessment (King and Kiremidjian, 1994)

2.4. Hazus-MH Structure in Earthquake Risk Assessment

Hazus-MH offers a comprehensive framework for risk assessment and damage potential analysis for different natural hazards. It is designed for use by state, regional and local governments in planning for earthquake loss mitigation, emergency preparedness planning and response and recovery. Hazus-MH uses GIS (Geographic Information Systems) technology based on the ArcGIS software of ESRI to estimate physical, economic, and social impacts of disasters, estimate physical, economic, and social impacts of disasters. This approach has the advantage of using industry standard software and having further capabilities for GIS analysis.

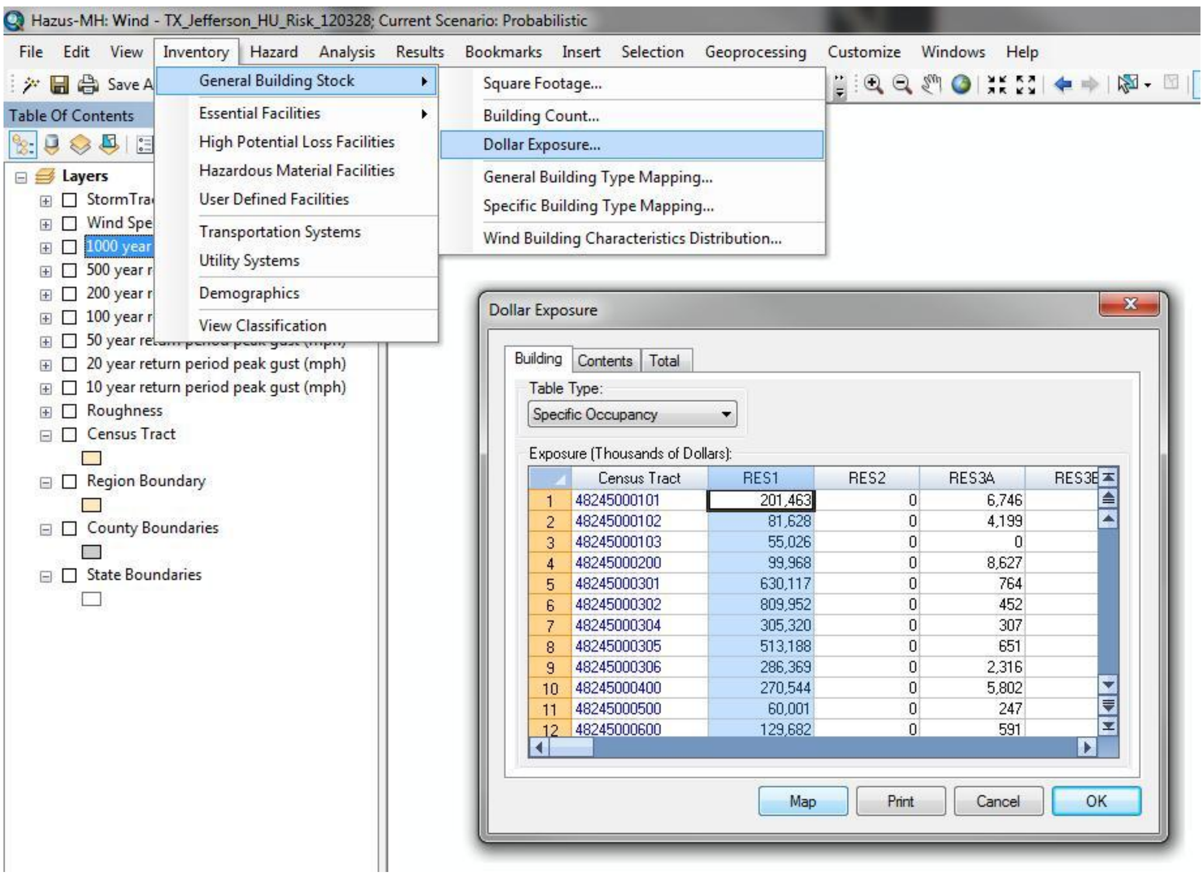

Figure 4: Hazus-MH Interface built on ArcGIS software

Use of the methodology will generate an estimate of the consequences to a city or region of a "scenario earthquake", i.e., an earthquake with a specified magnitude and location. The resulting "loss estimate" generally will describe the scale and extent of damage and disruption that may result from a potential earthquake. The following information can be obtained:

- **Quantitative estimates of losses** in terms of direct costs for repair and replacement of damaged buildings and lifeline system components; direct costs associated with loss of function (e.g., loss of business revenue, relocation costs); casualties; people displaced from residences; quantity of debris; and regional economic impacts.

- **Functionality losses** in terms of loss-of-function and restoration times for critical facilities such as hospitals, and components of transportation and utility lifeline systems and simplified analyses of loss-of-system-function for electrical distribution and potable water systems.
- **Extent of induced hazards** in terms of fire ignitions and fire spread, exposed population and building value due to potential flooding and locations of hazardous materials.

To generate this information, the methodology includes:

- Classification systems used in assembling inventory and compiling information on the building stock, the components of highway and utility lifelines, and demographic and economic data.
- Methods for evaluating damage and calculating various losses.
- Databases containing information used as default (built-in) data that are useable in the calculation of losses.

Since this study has a special focus on earthquake damage assessment the methodology of Hazus-MH Earthquake Model will be analyzed for further development of an international framework for earthquake model.

Hazus-MH Earthquake Model methodology consists of two analytical processes, Hazard Analysis and the Damage Analysis (Loss Estimation Analysis). A flow chart illustrating this methodology is shown in Figure 5.

To define the hazard in the first process, the values of ground motion are used to model ground failure. In the second process (Damage Analysis) 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 2009a).

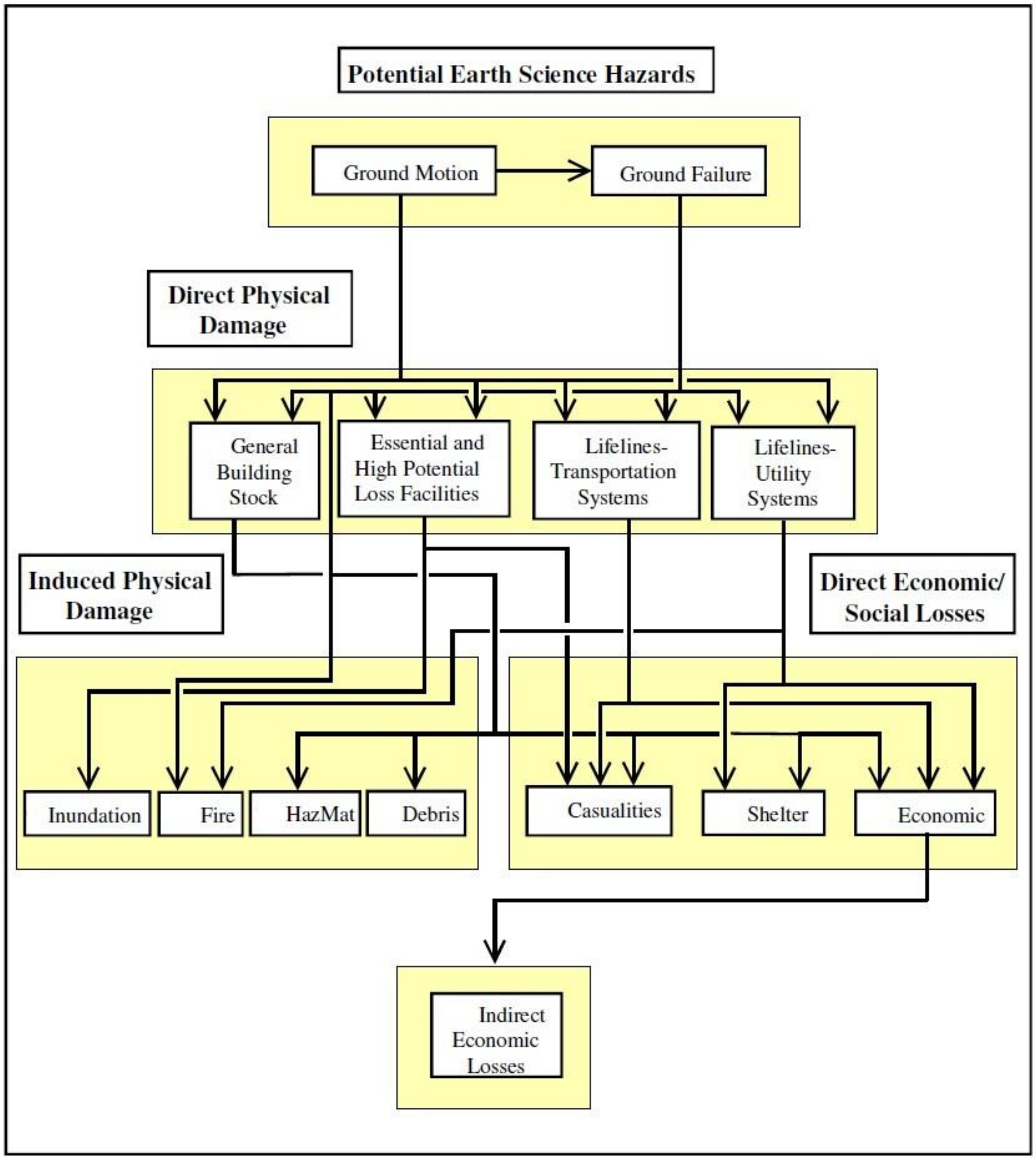

Figure 5: Flow Chart of the HAZUS-MH Loss Estimation Methodology

2.4.1. Hazus-MH Models

Hazus-MH has a modular structure for each model working for different Hazard analysis earthquake, flood and hurricane respectively. The advantage of this structure is common inventory datasets can be used for different analysis specific for each model. This study will be specially focusing on the earthquake model and internationalization efforts with respect to earthquake damage analysis.

2.4.1.1. Hazus-MH Flood Model

The Flood Model allows users to carry out a wide range of flood hazard analyses. The flood loss estimation methodology consists of two modules that carry out basic analytical processes, which are 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 2009a).

2.4.1.2. Hazus-MH Hurricane Model

The Hazus-MH Hurricane Wind Model uses an existing state-of-the-art wind field 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 (FEMA 2009a).

2.4.1.3. Hazus-MH 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 2009a).

Details of the Earthquake Model are explained in the Methodology Chapter with elaborated descriptions of the inventory and hazard data structures.

2.5. Comprehensive Data Management System (CDMS)

The Comprehensive Data Management System (CDMS) is a complimentary tool to Hazus-MH that provides users with the capability to update and manage statewide datasets, which are currently used to support analysis in Hazus-MH. CDMS will function for a single user or shared desktop application.

Previously, Hazus-MH users are required to undertake a large amount of manual effort to incorporate new data into the statewide datasets according to their pre-defined formats. To reduce this effort, CDMS streamline and automate raw data processing, the conversion of external data sources into Hazus-MH compliant data, and the transfer of data into and out of the statewide datasets. Processing site-specific level and aggregate information at the census block and tract levels is supported. All new data brought into the system is validated. Once data are imported into the statewide datasets, CDMS will allow users to query, sort, export and print information.

2.5.1. CDMS Modules

CDMS is comprised of four modules: the aggregate, site-specific, backward compatibility, and import modules. The aggregate, site-specific, and backward compatibility modules work together. Raw data can be used to generate aggregated data, and if the raw data has location information, then site specific data can also be generated at the same time. Similarly, aggregated data can be generated when generating site-specific data. The backward compatibility component will apply the data conversion and use the aggregate data and site-specific data components to generate the data in Hazus-MH format. The updated data in a study region can also be applied to the state data geo-databases (FEMA 2009a).

2.5.2. Aggregate Module

The aggregate module allows the user to capture demographic data; update the aggregated data (square footage, building count, building and content exposure, and demographics) and Occupancy to Building Type Mapping Schemes to state data geo-databases.

2.5.3. Site-Specific Module

The site-specific module has the following capabilities:

Allows the user to update for earthquake, hurricane, and flood parameters for essential facilities capture bridge and tunnel data; capture various transportation and utility facilities data, and update Hazus-MH state data geo-databases with the data captured,

2.5.3.1. Site-Specific Features and Census Tracts

For site-specific features, CDMS requires that users provide a latitude/longitude coordinate in one of the following systems: Geographic Projection, Decimal Degree Coordinate System, or North American Datum 1983 (NAD83). A Census Tract ID is not required but recommended. Site-specific features can consist of the following: user-defined, high potential loss, essential, transportation and utility facilities.

If a Census Tract ID is not provided, CDMS will utilize the latitude/longitude coordinate to identify the census tract in which a feature falls and will associate the feature with that Census Tract ID. If a site-specific feature, such as a highway bridge, does not have a Census Tract ID and does not fall within a census tract boundary, CDMS will not accept that feature and will warn the user that the feature requires a Census Tract ID before it can be accepted.

2.5.3.2. Null Values

When importing data into Hazus-MH via CDMS, required fields for features in Hazus-MH should be populated before the data are uploaded and mapped in CDMS. Fields not populated prior to loading into Hazus-MH via CDMS will result in null values being transferred to Hazus-MH, and Hazus-MH will not be able to count these features in its analysis.

2.5.3.3. SQL Server 2005 Express Limitations

CDMS operates on a free version of Microsoft SQL Server 2005 Express relational database software that enables Hazus-MH users to run the CDMS without requiring a software purchase. However, SQL Server 2005 Express has the following limitations:

• Supports only 1 CPU but can be installed on any server,

• 1 GB addressable RAM,

• 4 GB maximum database size.

3. State of the Art and Related Work

A review has been undertaken for state of the art and related work on earthquake risk assessment. Search of relevant information for the study was carried out in Carinthia University of Applied Sciences (CUAS), which has access to a variety of databases and search facilities which allowed it to search a variety of papers and reports in journals, conference proceedings, research publications and studies.

The seminal paper "Regional seismic hazard and risk analysis through geographic information systems" describes the development of a geographic information system (GIS) based methodology for a regional seismic hazard and risk analysis, and illustrates this with a case study. It is particularly useful as it provides a good framework for a GIS based risk assessment. (King and Kiremidjian 1994)

A flow chart of the basic procedure that was developed for this risk assessment is shown in Figure 6.

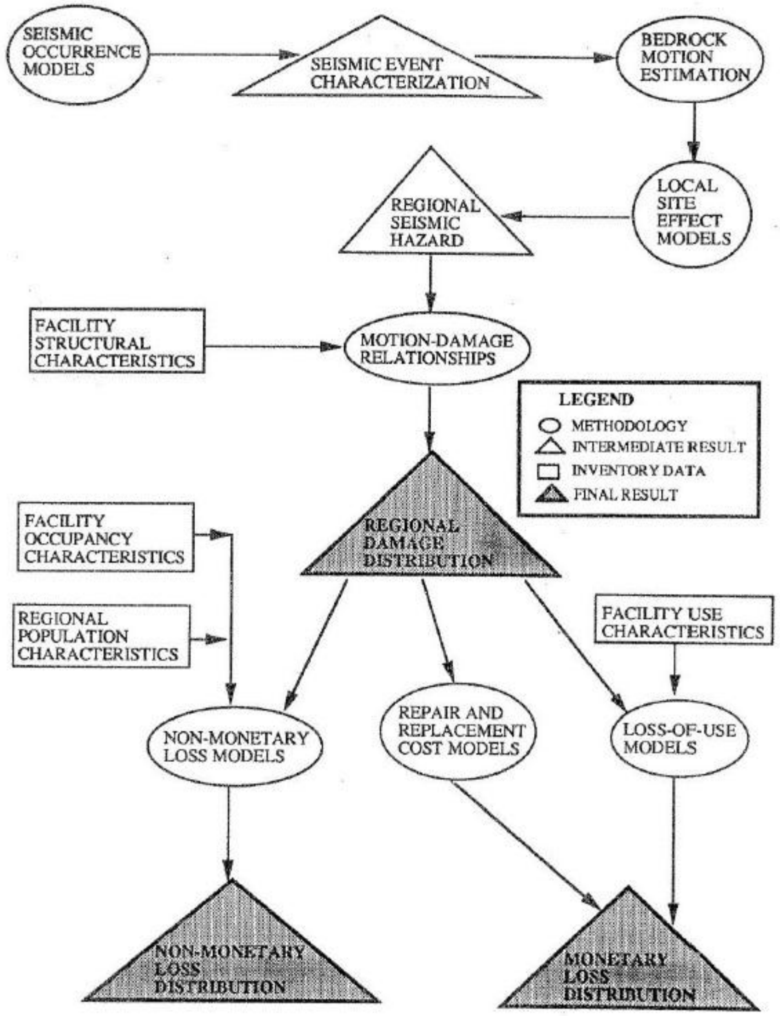

Figure 6: Flowchart Showing the Basic Regional Risk Assessment Process (King and Kiremidjian, 1994)

The data and models that are the fundamental building blocks of regional risk assessments referred to in the Figure 6 are,

Models:

- Seismicity
- Bedrock motion (attenuation)
- Local site effects (liquefaction)
- Repair cost
- Loss of use (repair time)
- Non-monetary loss (casualties)

Inventory Data:

- Facility (building, lifelines) structural characteristics
- Facility occupancy characteristics
- Regional population distribution

"*The Design Of Structures For Earthquake Resistance*" (EN 1998-1) is the main European standard document covering the fundamental requirements, compliance criteria and design structure for characteristics of earthquake resistant buildings and specific rules in EU legislation.

Structures in seismic regions shall be designed and constructed in such a way that the following requirements are met, each with an adequate degree of reliability.

- No-collapse requirement: The structure shall be designed and constructed to withstand the design seismic action without local or global collapse, thus retaining its structural integrity and a residual load bearing capacity after the seismic events.
- Damage limitation requirement: The structure shall be designed and constructed to withstand a seismic action having a larger probability of occurrence than the design seismic action, without the occurrence of damage and the associated limitations of use, the costs of which would be disproportionately high in comparison with the costs of the structure itself.

Target reliabilities for the no-collapse requirement and for the damage limitation requirement are established by the National Authorities for different types of buildings or civil engineering works on the basis of the consequences of failure.

Reliability differentiation is implemented by classifying structures into different importance classes. An importance factor is assigned to each importance class. Wherever feasible this factor should be derived so as to correspond to a higher or lower value of the return period of the seismic event as appropriate for the design of the specific category of structures.

The different levels of reliability are obtained by multiplying the reference seismic action or, when using linear analysis, the corresponding action effects by this importance factor. Detailed guidance on the importance classes and the corresponding importance factors is given in the relevant parts of standard document (EN 1998-1 2004).

Identification of ground types

Ground types A, B, C, D, and E, described by the stratigraphic profiles and parameters given in Table 1 and described hereafter, may be used to account for the influence of local ground conditions on the seismic action. This may also be done by additionally taking into account the influence of deep geology on the seismic action. The site should be classified according to the value of the average shear wave velocity, Vs (EN 1998-1 2004).

Table 1: Ground types classification

Soil type A	*Vs > 800 m/sec*	Includes unweathered intrusive igneous rock. Soil types A and B do not contribute greatly to shaking amplification.
Soil type B	*800 m/sec > Vs > 360 m/sec*	Includes volcanics, most Mesozoic bedrock, and some Franciscan bedrock. (Mesozoic rocks are between 245 and 64 million years old.)
Soil Type C	*360 m/sec > Vs > 180 m/sec*	Includes some Quaternary (less than 1.8 million years old) sands, sandstones and mudstones, some Upper Tertiary (1.8 to 24 million years old) sandstones, mudstones and limestone, some Lower Tertiary (24 to 64 million years old) mudstones and sandstones, and Franciscan melange and serpentinite.
Soil Type D	*180 m/sec > Vs > 100 m/sec*	Includes some Quaternary muds, sands, gravels, silts and mud. Significant amplification of shaking by these soils is generally expected.
Soil Type E	*100 m/sec > Vs*	Includes water-saturated mud and artificial fill. The strongest amplification of shaking due is expected for this soil type.

Seismic zones

For the purpose of EN 1998-1, national territories shall be subdivided by the National Authorities into seismic zones, depending on the local hazard. By definition, the hazard within each zone is assumed to be constant. For most of the applications of EN 1998-1, the hazard is described in terms of a single parameter, i.e. the value of the reference peak ground acceleration on type A ground. The reference peak ground acceleration, chosen by the National Authorities for each seismic zone, corresponds to the reference return period of the seismic action for the no-collapse requirement chosen by the National Authorities. In cases of low seismicity, reduced or simplified seismic design procedures for certain types or categories of structures may be used (EN 1998-1 2004).

In terms of the internal research initiatives two research projects showing the possibility to apply Hazus-MH for international case studies have been implemented successfully in the School of Geoinformation at Carinthia University of Applied Sciences (CUAS) in cooperation with Louisiana State University and the Polis Center at Indiana University Purdue University in the USA.

The first study by Kulmesch (2010) focused on evaluation of Hazus-MH loss estimation methodology for a Natural Risk Management Case Study in Carinthia, Austria. He investigated the flood model of Hazus-MH and possible usage with Austrian data. He tested and evaluated it based on a pilot study located in Carinthia, Austria and suggested requirements for implementation of derived projects working with international data (Kulmesch et al. 2010).

In a second study Kaveckis (2011) discussed comprehensively potential contribution of Hazus-MH to Flood Risk Assessment in the context of European Flood Directive. Major results are the challenge of administrative limitations of Hazus-MH flood model being specific to U.S. administrative sections and performing flood analysis using Hazus-MH methodology on standardized European administrative units. He achieved this goal by adding new geographical regions to the default Hazus-MH dataset showing a non-US dataset can be integrated into the Hazus-MH flood model successfully depending on the quality of the input data. (Kaveckis et al. 2011)

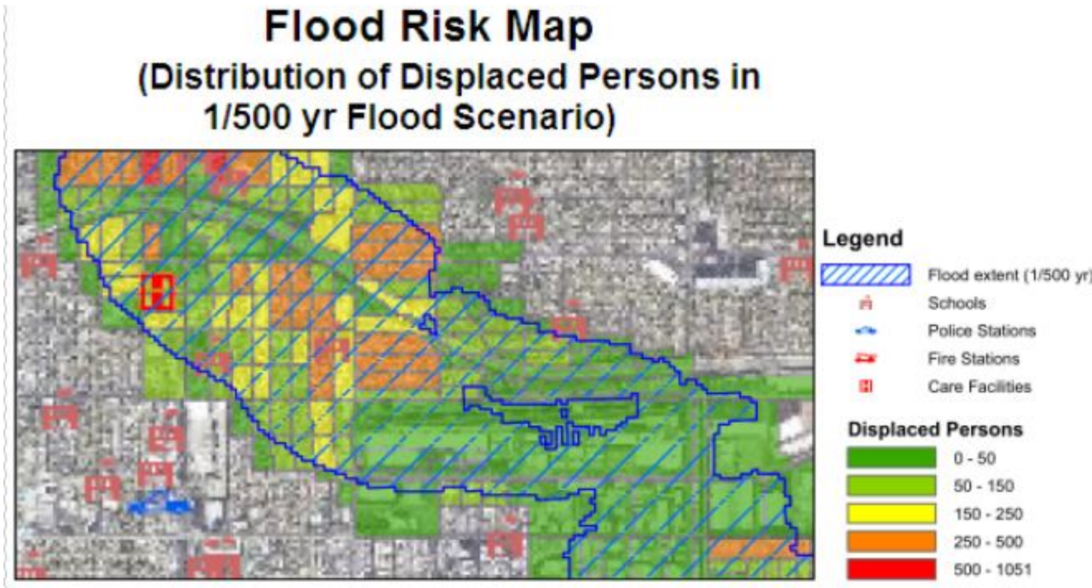

Figure 7: Flood Risk Map from the study of Kaveckis et al., 2011

These two studies have shown that Hazus-MH can be successfully applied to international datasets and further development of the study will have significant outcomes for the study regions.

In terms of the international applications of with the specific focus on the earthquake model of Hazus-MH, research has been done for different regions of the world (Bausch & Hansen 2006); (Ploeger 2008).

Bausch and Hansen (2006) discusses the export of a U.S. building stock that best fits the population and the built environment for the application to other areas of the world based on a user defined grid. This method allows the user to benefit from an existing methodology using the free Hazus-MH software application and to concentrate resources on developing good building inventory information to replace the U.S. proxy data. Additionally, a framework starting with a U.S. proxy building stock for developing inventories, engineering parameters and hazard data with Haiti building data to be used for Hazus-MH analysis is presented.

This method allows the user to benefit from an existing methodology and free software application and to concentrate resources on developing good building inventory information to replace the U.S.

proxy data. In addition, the required building inventory format is readily apparent since the U.S. proxy data are in a format that can be followed by the user.

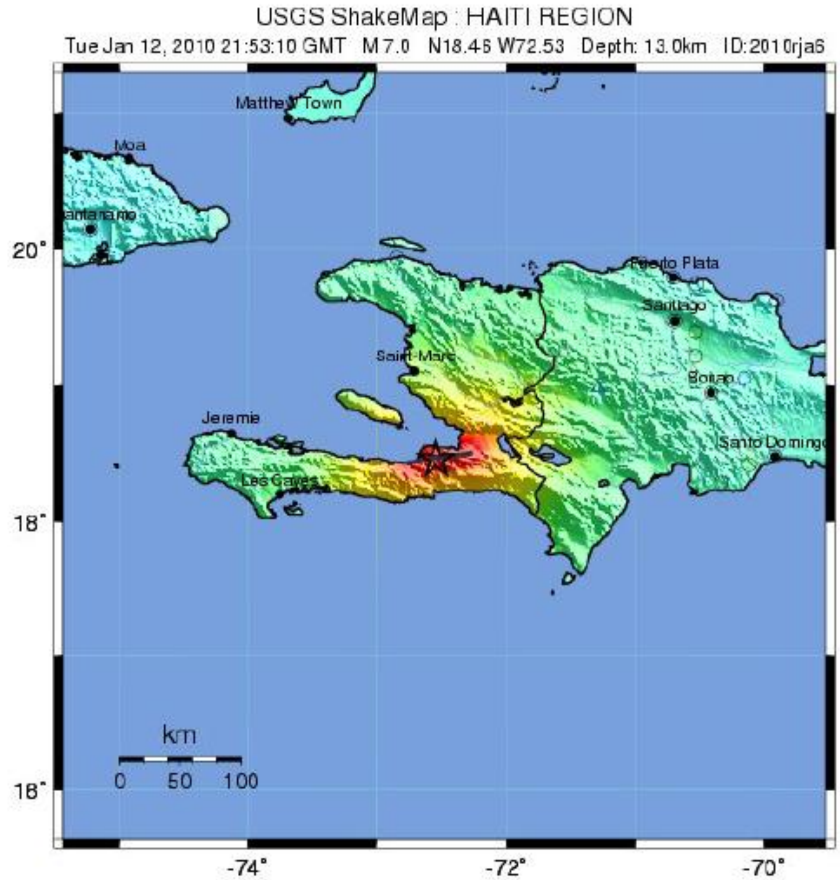

Figure 8: Haiti region shakemap used in the study of Bausch & Hansen (2006)

This concept requires the use of PAGER (Prompt Assessment of Global Earthquakes for Response) shakemaps as the source for ground motion data based on scenario earthquakes and LandScan 2004 as the source for a high resolution population grid. It is possible to develop ground motion and population data from other sources, but these two provide global capabilities that are already available in a useable GIS format. In the case of PAGER, Hazus-MH.zip files are provided that includes the necessary HAZUS-MH ground motion inputs Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Spectral Acceleration (SA) for 0.3 and 1.0 seconds.

The LandScan Global Population Database, 2004 is produced by the Oak Ridge National Laboratory and requires a license agreement to utilize and has some access constraints. PAGER uses earthquake parameters to calculate estimates of ground shaking by using the methodology and software developed for ShakeMap. Several global scenarios have been developed including a repeat of the Sicily earthquake of 11 January 1693, with an estimated magnitude of 7.4. A similar event also took place in 1169.

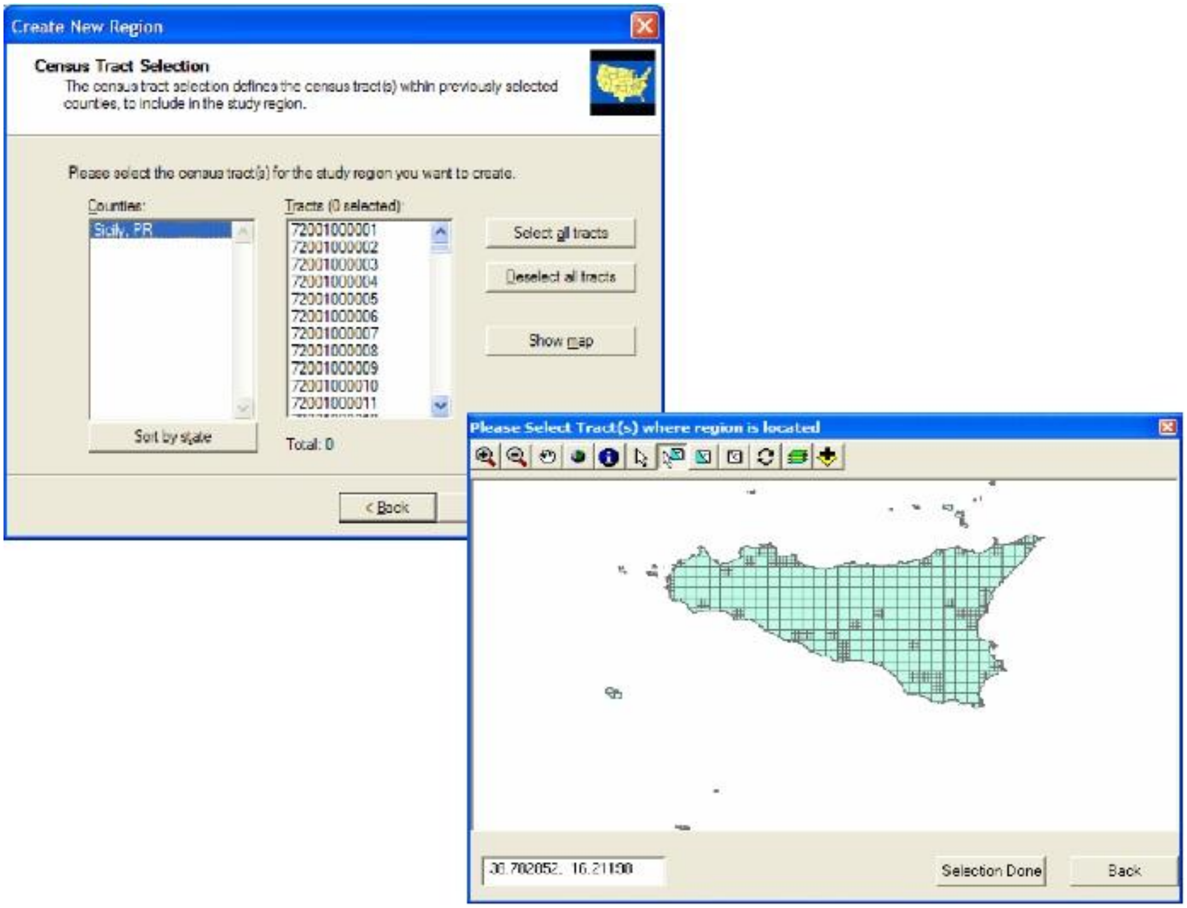

Figure 9: Sicily, Italy is used as a study region in the study of Bausch and Hansen (2006)

Another study focusing on using the Hazus-MH for international earthquake assessment is an Msc. study titled “Applying the HAZUS-MH software tool to assess seismic hazard and vulnerability in downtown Ottawa, Canada” by S. Katie Ploeger.

Ploeger (2008) describes in her study a detailed building inventory of downtown Ottawa, Canada. Relevant census information was collected and microzonation studies were conducted to allow mapping of the study area by site classes and earthquake induced hazards were assessed. In the study, seismic losses were estimated for ground-motions given in the 2005 National Building Code of Canada for expected motions at a 2% exceedence probability in 50 years. All collected data were assembled into a set of standard geodatabases that are compatible with the HAZUS-MH software using a GIS specific procedure.

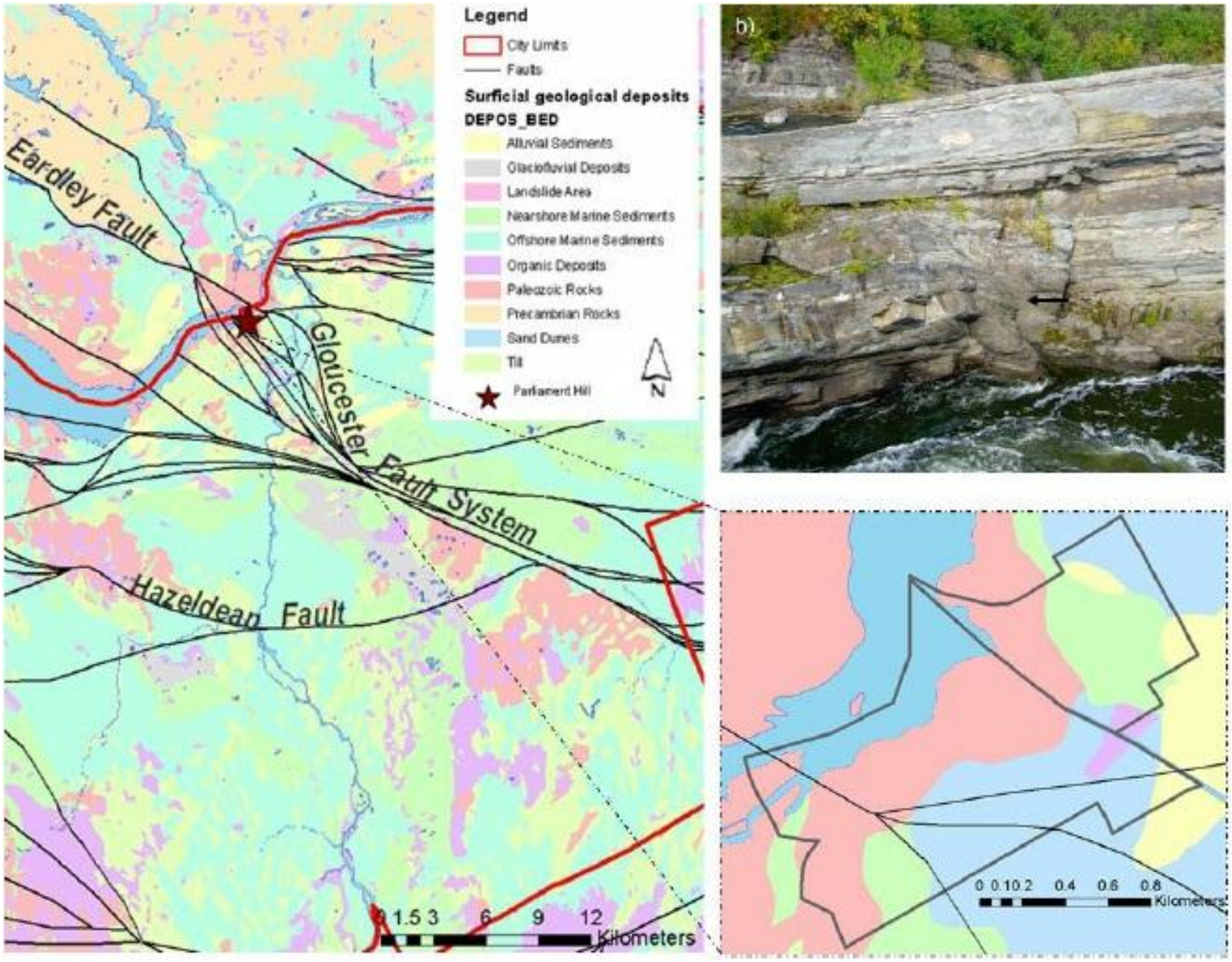

Figure 10: Map of major faults in the city limits of Ottawa and within the study area (GIS data sources: NRCan, City of Ottawa). b) A classic example of faulting in the area. (Photograph taken by S. K. Ploeger).

The aim of the study was to identify areas most physically and socially vulnerable to earthquake ground shaking and to present earthquake loss estimations for downtown Ottawa, Canada, using the HAZUS-MH software tool. The study area consists of two census tracts, which can be further divided into 10 dissemination areas, and contains 597 buildings, including the Federal Parliament. The study was accomplished by:

1. Characterizing seismic hazard and vulnerability for the City of Ottawa.
2. Establishing and executing a set of procedures in data collection, including specifying ground motion, developing hazard maps, compiling inventories and tallying demographic data.
3. Preparing and inputting data, and manipulating HAZUS-MH.
4. Interpreting loss estimations for downtown Ottawa.

Results from this study provide means to evaluate the nature and scope of potential losses due to a moderate to large earthquake in the Ottawa area, and assess HAZUS-MH' applicability to Canadian settings at a local scale.

According to the conclusions, the following points provide the important results she reached in the study:

The City of Ottawa is an area of significant seismic risk. Previous earthquakes in eastern Ontario include the 1935 M6.2 Temiscaming and the 1944 M5.8 Cornwall-Massena earthquakes; additional evidence suggests pre-historic M7.0 earthquakes have also occurred in this area. The seismic risk in Ottawa is heightened by its large and unprepared population. Microzonation studies play an integral role in estimating the intensity of ground shaking at the surface within the study area.

Earthquake loss estimations are heavily influenced by the ground shaking amplitudes, which are controlled by earthquake magnitude, distance and site condition.

Earthquake loss estimations are heavily influenced by the urban environment. The most vulnerable building types are unreinforced masonry and concrete buildings, primarily because of their lack of structural integrity and frame design. The majority of these building types are also pre- or low-code. The damage to these building types is also associated with the total amount of debris generation and direct economic losses for each dissemination area.

The most vulnerable occupancy class is the commercial class, which includes retail stores, restaurants and office buildings. Although occupancy class does not influence building damage, it does play a leading role in casualties. HAZUS-MH can be utilized for level 2 earthquake loss estimation analysis in a Canadian setting, at a local scale.

And finally, the greatest amount of losses occurred in scenarios with stronger ground shaking, unreinforced masonry buildings, commercial buildings, and at 2:00pm.

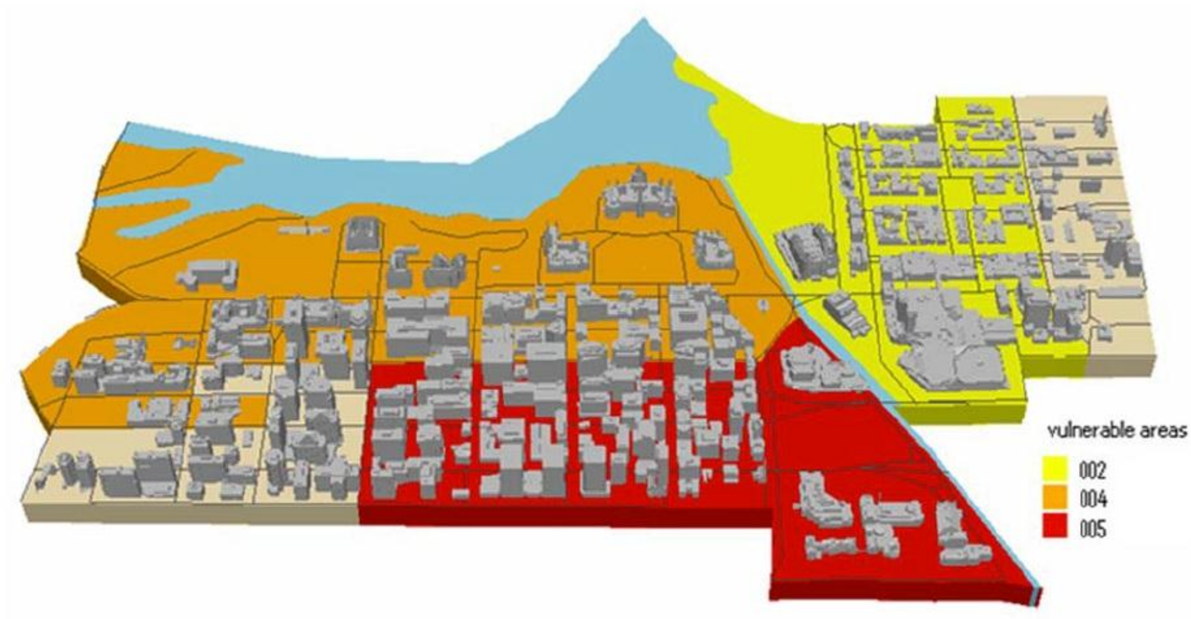

Figure 11: The most vulnerable areas in the study area. Area 002 is the most vulnerable to building damage, area 005 is the most vulnerable to debris generation and most vulnerable to fatalities (GIS data sources: City of Ottawa, NRCan).

According to FEMA and NIBS (2001), uncertainty in loss estimations is large, perhaps as much as an order of magnitude. However, upgrades to information on soil classification, ground motions and amplifications, and building inventory are shown to produce results closer to documented data. This research provides an important stepping stone in the implementation of HAZUS-MH in Canada and provides a good indication into the vulnerable areas within Ottawa.

4. Methodology

In Hazus-MH structure all models use common boundary and inventory layer for general structure and each model has its specific data tables for hazard specific analysis. To be able to perform earthquake loss estimation analysis, the Hazus-MH Earthquake Model must be supplied with two types of data: inventory data and earthquake hazard data.

4.1. Conceptual Analysis Model

Flowchart of the original HAZUS-MH Loss Estimation Methodology has been presented in Figure 5. To clarify the methodology for the international framework a new classified flowchart has been prepared presenting the units according to their functionality. Using this model datasets are grouped based on Hazard, Inventory and Damage. The conceptual model of the international framework is shown in Figure 12.

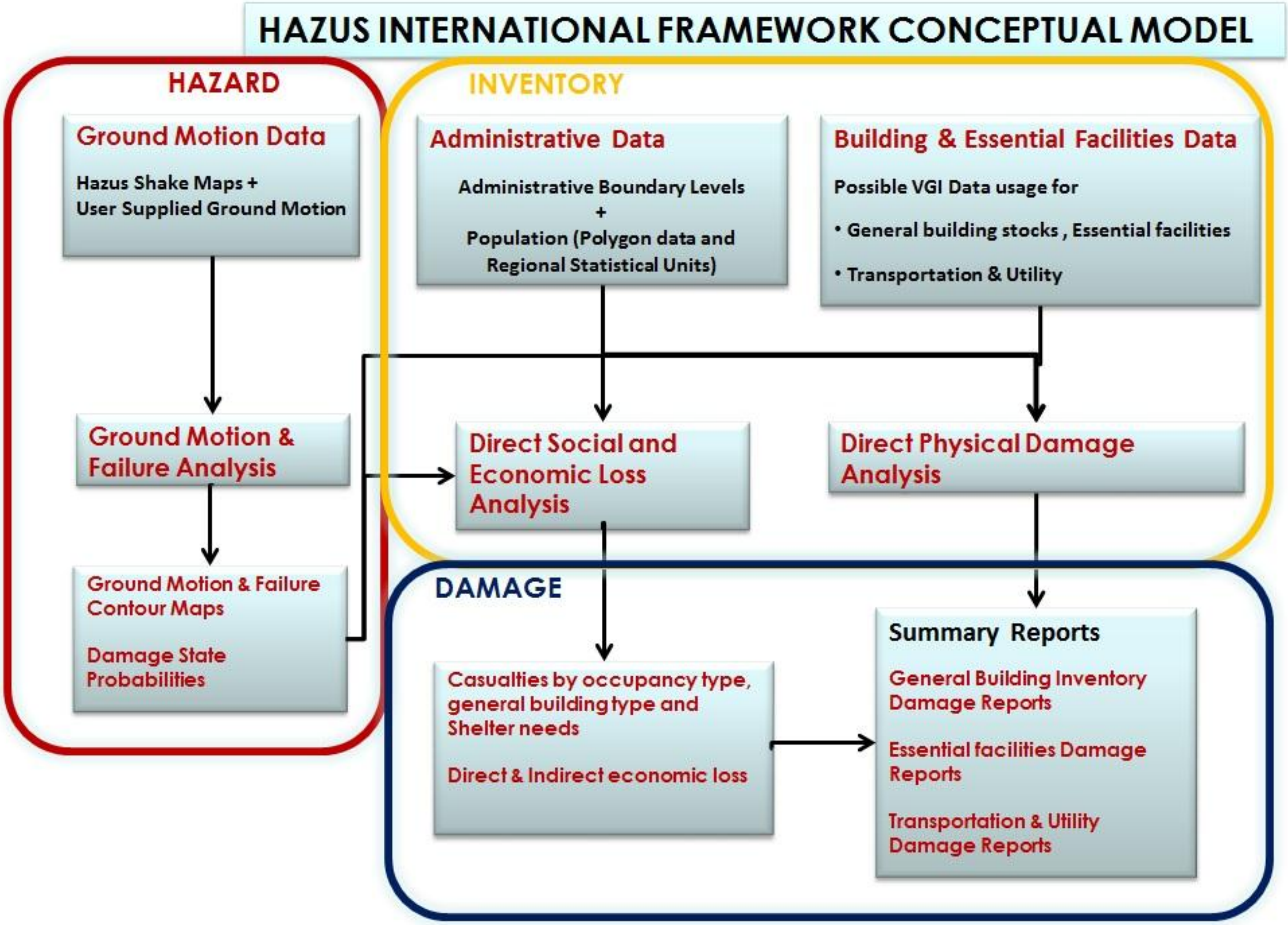

Figure 12: Hazus international framework conceptual model

Following sections describe the details of this model. The first section describes inventory dataset that serves as source for creating study regions. It introduces the inventory organization and storage as a system of folders and files; lists the major database components or databases and how they are organized by theme; and explains the naming conventions of feature classes and tables.

The latter sections describe each database that are specific for the Earthquake Model containing system boundaries, administrative boundaries, essential facilities, transportation systems, lifeline utility systems, high potential loss facilities. It is followed by the sections of requirements for hazard related data, ground shaking and shake maps, attenuation functions and ground types.

4.2. Inventory Data Structure

The inventory data in Hazus-MH is stored in the geodatabases and tables classified under the state

folders. When the user is creating a region, Hazus-MH connects the inventory and acquires all the information and site specific data from this inventory.
The inventory can be edited and updated by Comprehensive Data Management System (CDMS). The advantage of this approach is that users have the all the data is stored in inventory in same structure and they don`t have discrepancies while working on different type of hazards. Hazus-MH only acquires them when the region is created.

4.2.1. Administrative Boundary Layers

Administrative boundary layers are built for each country of selected study region. Population data are collected and distributed on these administrative boundaries relatively.

The original Hazus-MH Earthquake Model has three levels of geographical divisions: state, county, census tract (a fourth level of census block is included for other model requirements). The first two divisions can be described as administrative units, while the other two are census geographical units. (Kaveckis et al. 2011)

In the international framework these three levels will be identified in a country – administrative division – grid based on population distribution structure.

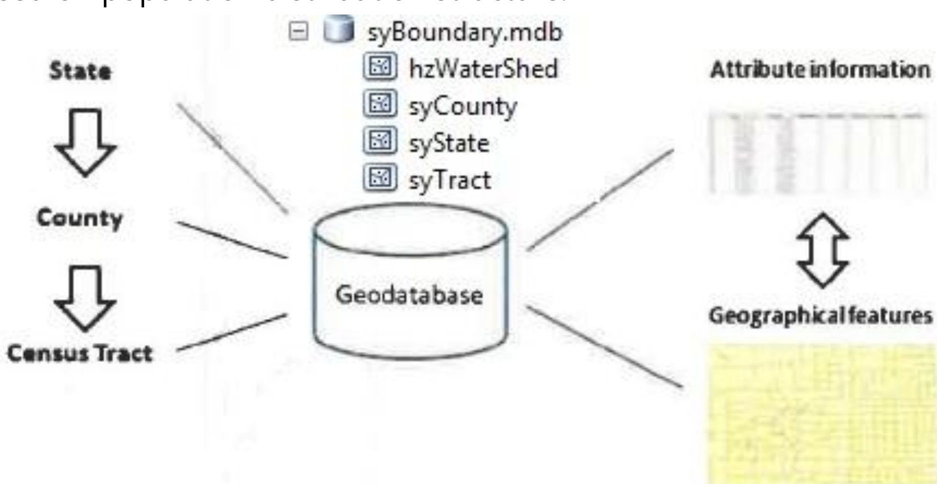

Figure 13: Hazus-MH geographical division storage scheme

Hazus-MH geographical divisions are not strictly combined with Hazus-MH inventory. All these geographical divisions are located in the Hazus-MH geodatabase and contain geographical features and attribute information (Figure 13). This approach outcomes the advantage, that the geographical features and attribute properties can be changed at ease. For any study region, there is the possibility to integrate any geographical feature into Hazus-MH geographical feature datasets instead any of the original level features. (Kaveckis et al. 2011)

Table 2 shows the Hazus-MH inventory geodatabase names and their descriptions. The international framework is built in the same structure but containing data for the specific study region.

Table 2: Hazus-MH Inventory Geodatabases (FEMA 2009a)

Database Name	Description	Location Relative to Hazus-MH Data DVD:
syBoundary.mdb	Contains GIS boundary information for the entire United States relative to states, counties, and census tracts.	Located in the root directory
Bndrygbs.mdb	Contains GIS boundary information for counties, census tracts, and census blocks for a given state. Also contains aggregated data including demographics, building square footage, building counts, structure exposure, and content exposure for a given state.	Located in root/state
Ef.mdb	Contains GIS location and hazard information for essential facilities including schools, hospitals, medical care facilities, police stations, and fire stations.	Located in root/state
HPLF.mdb	Contains GIS location and hazard information for high potential loss facilities (HPLF) that include dams, hazardous materials, levees, military installations, and nuclear facilities.	Located in root/state
TRN.mdb	Contains GIS location and hazard information for transportation facilities including airports, buses, ferries, highways, light rail, railways, bridges, ports,	Located in root/state
UTIL.mdb	Contains GIS location and hazard information for utility features and facilities including communications, electric, natural gas, oil, potable water, and wastewater.	Located in root/state

4.2.2. System Boundaries Database

The System Boundaries is an ESRI Access personal geodatabase that contains the definition of state, county, and census tract boundaries in three feature classes. The geographical extent is nationwide, including features for the 50 states, the District of Columbia, and territories. This geodatabase is crucial during the aggregation process. It is used by Create Region Wizard to guide the user through the definition of a region.

In the international framework structure this database contains data related to the country boundaries, administrative boundaries and population grid layers. Details of system boundary database contents, feature classes and tables are provided in the Appendix 1.

4.2.3. Boundaries Database

The bndrygbs.mdb is an Access personal geodatabase that contains boundary feature classes and tables with demographic (population, housing, age, etc.) and building inventory profiles aggregated at the census track level. Original Hazus-MH geographical domain of the database is the state.

In the international framework structure geographical domain of this database will be country of the selected study region. In that case, there is one bndrygbs.mdb database for each country, located in the appropriate country folder.

Data stored in individual tables include the following:

Square footage by occupancy: These data are the estimated floor area by specific occupancy.

Full replacement value by occupancy: These data provide estimated replacement values by specific occupancy.

Building count by occupancy: These data provide an estimated building count by specific occupancy.

General occupancy mapping: These data provide general mapping for the general building stock (GBS) inventory data from the specific occupancy to general building type (e.g., wood).

Demographics: These data provide housing and population statistics for the study region.

During the creation of a study region, boundary geometry from feature classes is transferred to a geodatabase named RegionBndry.mdb in the Region folder for all hazards. Demographic, building stock related data, and attributes from the feature classes as well as tables are transferred to the SQL Server database in the Region folder. Details of boundaries database contents, feature classes and tables are provided in the Appendix 2.

4.2.4. Essential Facilities Database

The Essential Facilities Database, EF.mdb is an Access personal geodatabase that contains feature classes for essential facilities with fields that are relevant for all hazards. Essential facilities are those that provide services to the community and should be functional after an earthquake event. Essential facilities include:

- Fire stations
- Police stations
- Emergency centers
- Care facilities (hospitals and medical clinics)
- Schools (K-12 and colleges)

Original Hazus-MH geographical domain of the database is the state. In the international framework structure geographical domain of this database will be country of the selected study region. In that case, there is one EF.mdb database for each country, located in the appropriate country folder.

During the creation of a study region, for all hazards, essential facilities geometries from feature classes are transferred to a geodatabase named EF.mdb in the region folder. Feature classes are named with the prefix hz, meaning they are relevant across all Hazus-MH models. Police stations, for instance, are stored in hzPoliceStation feature class with fields containing information common to all hazards, such as name and address. This information is transferred to a table with the same name (for police station, hzPoliceStation) in the SQL Server database in the Region folder. Details of essential facilities database contents, feature classes and tables are provided in the Appendix 3.

4.2.5. Transportation Systems Database

The Transportation Systems Database, TRN.mdb is an Access personal geodatabase that contains feature classes for transportation systems with fields relevant to all hazards. Transportation systems include:

- Highway segments, bridges, and tunnels
- Railway tracks, bridges, and tunnels, facilities
- Light rail tracks, bridges, and tunnels, facilities
- Bus stations
- Ports
- Ferries
- Airports and runways

Original Hazus-MH geographical domain of the database is the state. In the international framework structure geographical domain of this database will be country of the selected study region. In that case, there is one TRN.mdb database for each country, located in the appropriate country folder.

During the creation of a study region, for all hazards, transportation system geometries from feature classes are transferred to a geodatabase named TRN.mdb in the Region folder. Feature classes are named with the prefix *hz* that means that are relevant across all Hazus-MH- MH Models. Highway bridges, for instance, are stored in *hzHighwayBridge* feature class with fields containing information common to all hazards, such as name and address. This information is transferred to a table with the same name (for highway bridges, *hzHighwayBridge*) in the SQL Server database in the Region folder. Details of transportation systems database contents, feature classes and tables are provided in the Appendix 4.

4.2.6. Utility Systems Database

The Utility Systems Database, UTIL.mdb is an Access personal geodatabase that contains feature *classes* for lifeline utility systems with fields relevant for all hazards. Lifeline utility systems include potable water, wastewater, oil, natural gas, electric power, and communication systems.

Original Hazus-MH geographical domain of the database is the state. In the international framework structure geographical domain of this database will be country of the selected study region. In that case, there is one UTIL.mdb database for each country, located in the appropriate country folder. Details of utility systems database contents, feature classes and tables are provided in the Appendix 5.

4.2.7. High Potential Loss Facilities Database

HPLF.mdb is an Access personal geodatabase that contains feature *classes* for HPLF with fields relevant to all hazards. HPLFs are those likely to cause severe loss if damaged. Damage and loss estimation calculations for HPLFs are not performed by Hazus-MH.

HPLFs include nuclear power plants, dams, levees, and some military installations. Hazardous material facilities and levees are also included in HPLF.mdb. Hazardous material facilities contain substances that can pose significant hazards because of their toxicity, radioactivity, flammability, explosiveness, or reactivity. Similar to other facilities with high potential loss, Hazus-MH models do not estimate losses caused by hazardous material releases and levee failures based on the inventory data.

During the creation of a study region, for all hazards, HPLF geometries from feature classes are transferred to a geodatabase named HPLF.mdb in the Region folder. Feature classes are named with the prefix hz that means that are relevant across all Hazus-MH models. Dams, for instance, are stored in hzDams feature class with fields containing information common to all hazards. This information is transferred to a table with the same name (for dams, hzDams) in the SQL Server database in the Region folder.

Original Hazus-MH geographical domain of the database is the state. In the international framework structure geographical domain of this database will be country of the selected study region. In that case, there is one HPLF.mdb database for each country, located in the appropriate country folder. Details of high potential loss facilities database contents, feature classes and tables are provided in the Appendix 6.

4.3. Hazard Data Structure

The main data source for hazard data in the international framework is Shakemaps, which is a product of the U.S. Geological Survey Earthquake Hazards Program in conjunction with regional seismic network operators. ShakeMap sites provide near-real-time maps of ground motion and shaking intensity following significant earthquakes. These maps are used by federal, state, and local organizations, both public and private, for post-earthquake response and recovery, public and scientific information, as well as for preparedness exercises and disaster planning.

A ShakeMap is a representation of ground shaking produced by an earthquake. The information it presents is different from the earthquake magnitude and epicenter that are released after an earthquake because ShakeMap focuses on the ground shaking produced by the earthquake, rather than the parameters describing the earthquake source. So, while an earthquake has one magnitude and one epicenter, it produces a range of ground shaking levels at sites throughout the region depending on distance from the earthquake, the rock and soil conditions at sites, and variations in the propagation of seismic waves from the earthquake due to complexities in the structure of the Earth's crust (USGS 2006).

4.3.1. Ground Motion Maps

Peak Acceleration Map

Peak horizontal acceleration at each station is contoured in units of percent-g (where g = acceleration due to the force of gravity = 981 cm/s/s). The peak values of the vertical components are not used in the construction of the maps because they are, on average, lower than the horizontal amplitudes and ground motion prediction equations used to fill in data gaps between stations are based on peak horizontal amplitudes. The contour interval varies greatly and is based on the maximum recorded value over the network for each event (USGS 2006).

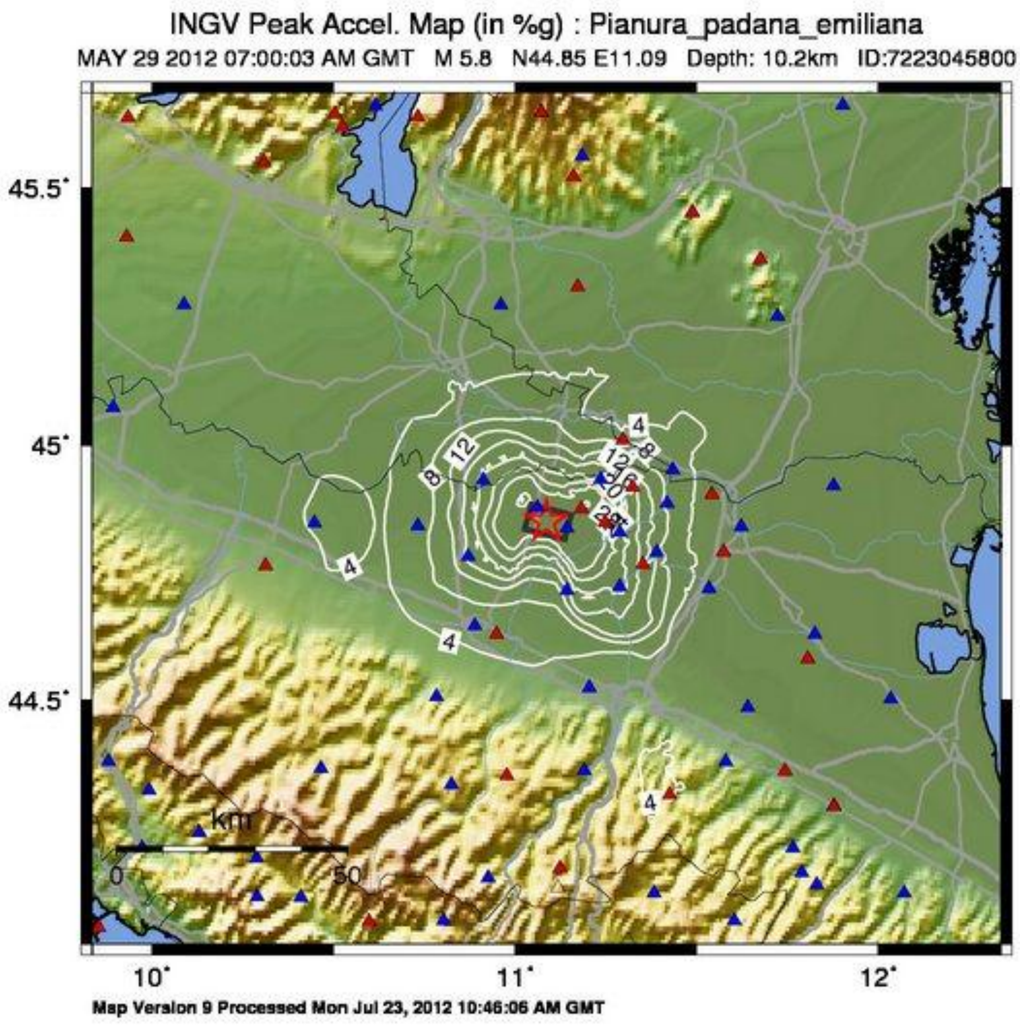

Figure 14: Peak Acceleration Map for region in Northern Italy. The numbers on contours show peak acceleration in percentage of g force unit.

Peak Velocity Map

Peak velocity values are contoured for the maximum horizontal velocity (in cm/sec) at each station. As with the acceleration maps, the vertical component amplitudes are disregarded for consistency with the regression relationships used to estimate values in gaps in the station distribution. Typically, for moderate to large events, the pattern of peak ground velocity reflects the pattern of the earthquake faulting geometry, with largest amplitudes in the near-source region, and in the direction of rupture (directivity). Differences between rock and soil sites are apparent, but overall pattern is normally simpler than the peak acceleration pattern (USGS 2006).

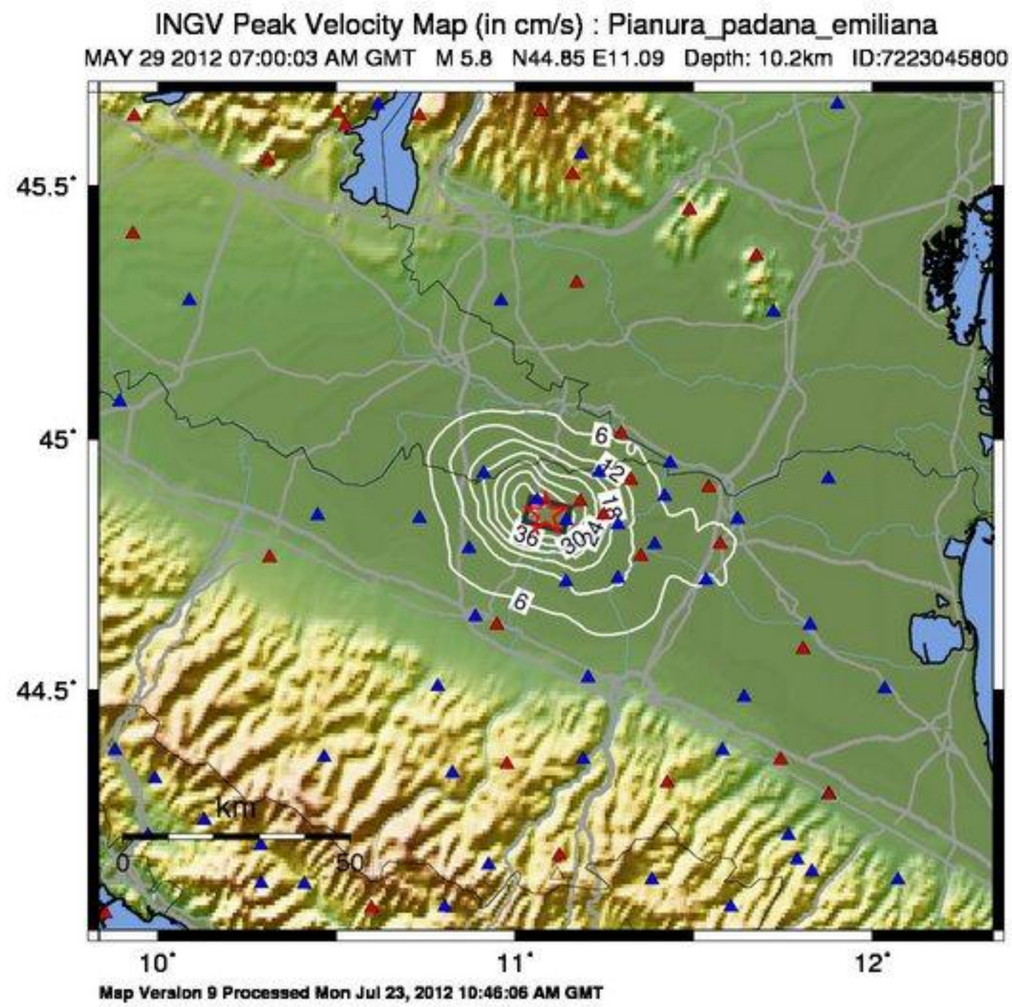

Figure 15: Peak Velocity Map for region in Northern Italy. The numbers on contours show peak velocity in cm/s unit.

Spectral Response Map

For the earthquakes larger than magnitude 5.5, spectral response maps are made. Response spectra portray the response of a damped, single-degree-of-freedom oscillator to the recorded ground motions. This data representation is useful for engineers determining how a structure will react to ground motions. The response is made for three UBC reference periods: 0.3, 1.0, and 3.0 seconds (USGS 2006).

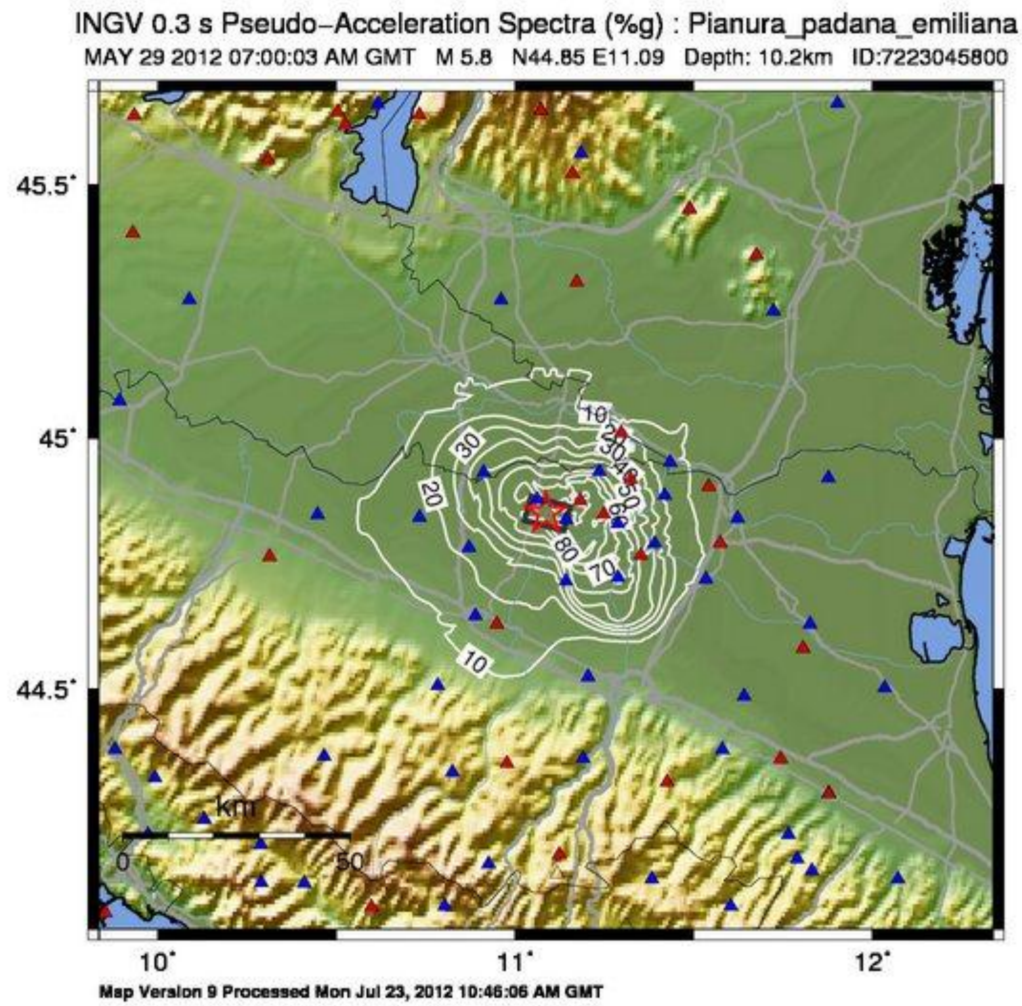

Figure 16: Spectral Response Map for a region in Northern Italy. The numbers on contours show spectral acceleration in percentage of g force unit.

4.3.2. Attenuation Functions:

Ground shaking is attenuated with distance from the source using standardized relationships models. Table 3 lists the 14 ground motion relation proposed for use by Hazus-MH to model ground motions, the number of different types of faulting modeled by each relation, and the definition(s) of fault distance parameter used by each relation. The three new ground motion relations are indicated by yellow shading.

Table 3:Attenuation functions

No.	Ground Motions Relation Modeler(s)	Year	Fault Type(s)	Distance Parameter(s)		
				Primary	Other	Other
1	Toro et al.	1997	Shallow	R_{JB}		
2	Frankel et al.	1996	Shallow	R_{JB}		
3	Campbell	2003	Shallow	R_{JB}		
4	Atkinson & Boore	2006	Shallow	R_{JB}		
5	Tavakoli & Pezeshk	2005	Shallow	R_{JB}		
6	Silva et al.	2002	Shallow	R_{JB}		
7	Somerville et al.	2001	Shallow	R_{JB}		
8	Boore & Atkinson	2008	SS, RV, NM	R_{JB}		
9	Campbell & Bozorgnia	2008	SS, RV, NM	R_{RUP}	R_{JB}	
10	Chiou and Youngs	2008	SS, RV, NM	R_{RUP}	R_{JB}	R_X
11	Youngs et al.	1997		R_{RUP}		
12	Atkinson & Boore GM	2003		R_{RUP}		
13	Zhao et al.	2006		R_{RUP}		
14	Sadigh et al.	1997		R_{RUP}		

Shallow: Shallow Faulting SS:Strike Slip Faulting; RV: Reverse Slip/Thrust; NM: Normal Faulting

In terms of an international study, specific geophysical and geoseismical characteristics of the study region in focus should be identified and most suiting attenuation function will be selected depending on the faulting characteristics in the region. Then this best available function can be used in the international framework to address the ground shaking attenuation.

4.3.3. Ground Types and Shaking Amplification

One contributor to the site amplification is the velocity at which the rock or soil transmits shear waves (S-waves). Shaking is stronger where the shear wave velocity is lower. The National Earthquake Hazards Reduction Program (NEHRP) has defined 5 soil types based on their shear-wave velocity (Vs).

ShakeMaps used to integrate the hazard datasets into the model structure also includes the effects of the soil type amplification in the study region based on the predefined soil classes. This simplifies the hazard data integration into the Hazus-MH Earthquake model and avoids the separate soil map preprocessing needs.

4.4. Level of Analysis

A Level 1 analysis is a situation where a HAZUS-MH user runs a complete hazard assessment using nothing but the information that comes with the software. This can typically be done with relevantly little effort and training.

A Level 2 analysis integrates information that local communities might have, for instance, an assessor's dataset, or a file which has locations of fire stations, or information from a flood study that you might want to actually provide to HAZUS-MH so that it can do improved loss estimations.

And then a Level 3 analysis, expertise in actually how hazards are estimated and how losses are calculated, and that expertise can then be integrated as part of your analysis process as well. (FEMA 2009a)

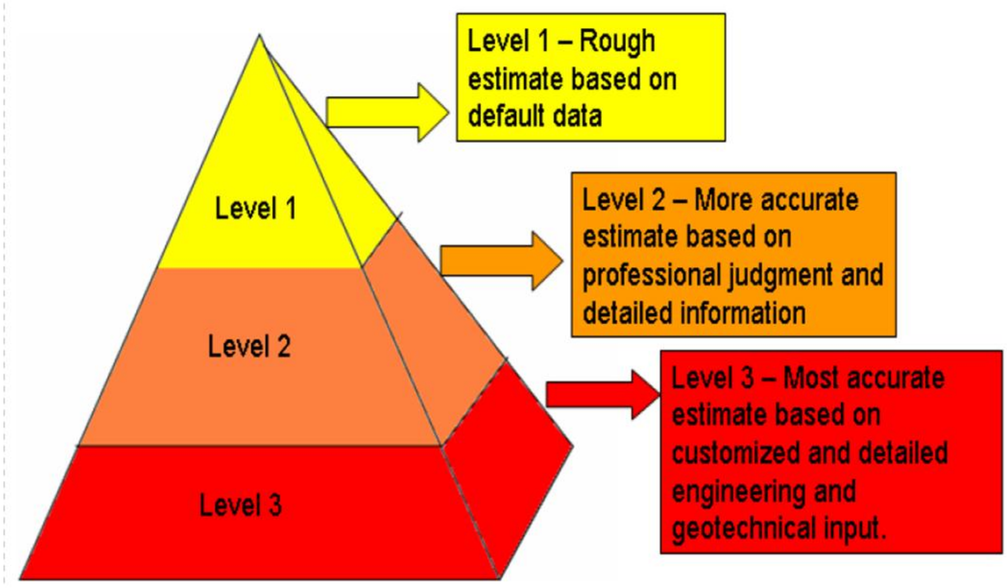

Figure 17: Level of Analysis in tiered triangular structure

5. Hazus-MH Earthquake Analysis Workflow

This chapter introduces the steps required to produce the earthquake loss estimation analysis in the Hazus-MH analysis model structure. This workflow structure can be applied any location if the data requirements are satisfied and implementation enables the Earthquake Model's capabilities.

5.1. Data Preparation

In the international framework the inventory data structure of the earthquake framework structure remains the same as the original Hazus-MH datasets. The difference is identified by the imported datasets for each region between the original US and international framework structure.

The data preparation phase is one of the most complicated and time consuming parts of the workflow. However, if this phase is constructed correctly following steps are performed much more smoothly and the analysis on the datasets can be performed without any failures.

A majority of the required data can be assigned by default in Hazus-MH. The default Hazus-MH 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-MH assigns default values when it can't locate the required data field during integration via CDMS.

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-MH Inventory window by right-clicking the mouse button and selecting "Data Dictionary." 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. (Kaveckis et al. 2011)

5.1.1. Data Interoperability Tool

To perform the necessary data preparation processes first the datasets are assessed, modified and converted with various GIS operations and translation scripts. During this data preparation phase, data translation operations are made on the integrated Data Interoperability Tool add-on for ESRI ArcGIS to prepare and aggregate the datasets to be imported into Hazus-MH structure.

Data Interoperability Tool add-on for ESRI ArcGIS is an integrated model of the FME Software Suite. It consists of set of tools that provides access to spatial data and translation and processing of these spatial and attributes data.

FME Suite has three core components:

- Universal viewer, which is the component to view multiple datasets before, after and even during a translation, examine features, identify attributes and values, and enhance the display using color, symbols and labeling
- Universal Translator, which performs basic translations using the supplied defaults and perform more sophisticated processing by creating and running your own mapping files.
- Workbench which is used to graphically create workflow from source data to destination data and manipulate geometry and attribution for all FME formats.

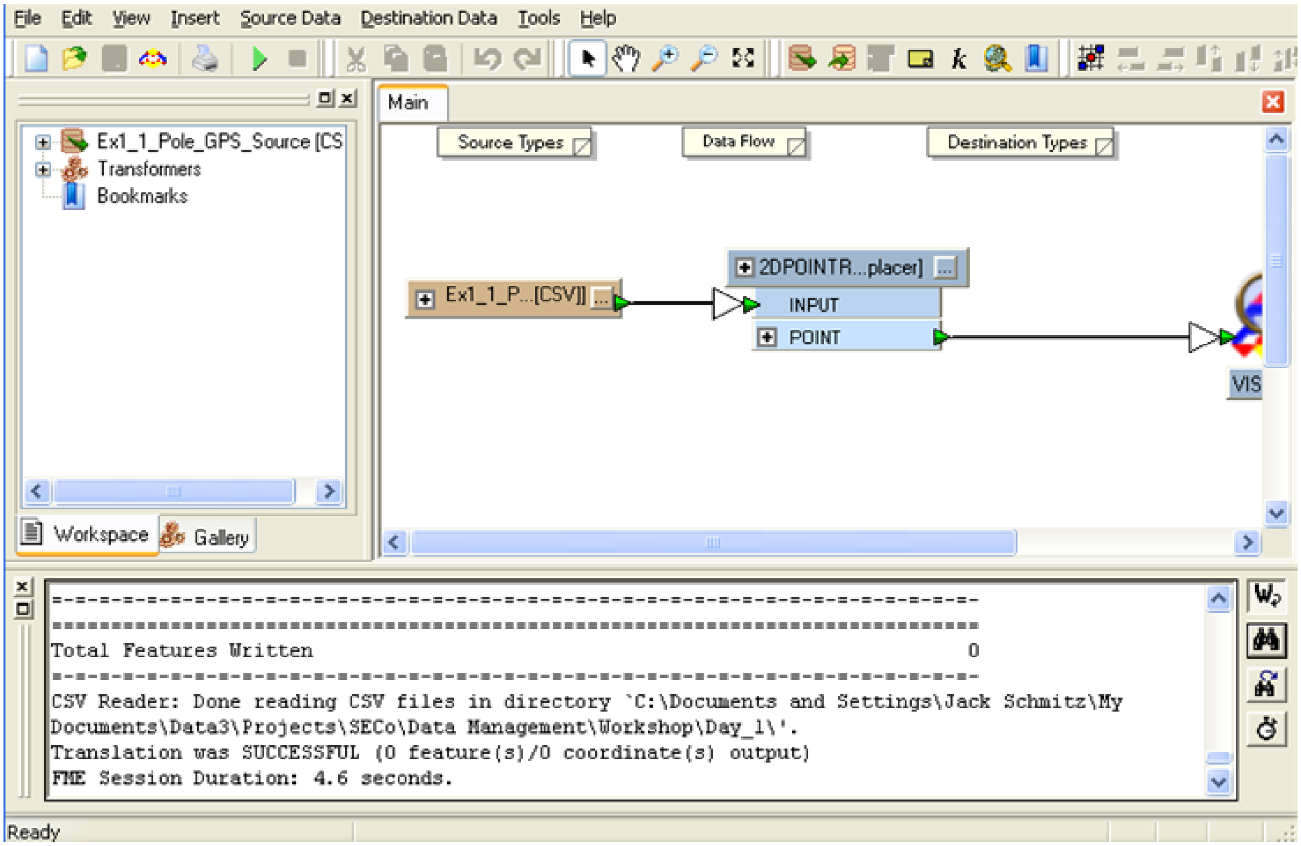

Figure 18: FME Workbench to create graphical workflow

5.1.2. Data Interoperability Algorithms for Building Inventory

For each dataset data transformers and field mapping schemes are created manually on the graphical interface of the workbench. Every table and category needs to be checked and matched manually and linked to each other in a workflow structure which is a time and effort consuming task but it guarantees that the data is in complienace with the further steps of integration. This approach assures that CDMS will be able to import data without any failure in intermediate steps.

The 'hz' and 'fl' fields are specifically built for Hazus-MH data integrity. The unit for building cost (BldgCost) is Euros. The unit for building area (BldgArea) is square meters. . Hazus building area (hzBldgArea) and Hazus building cost (hzBldgCost) are in thousands for the integrity of Hazus-MH analysis and reporting structure.

The following filters and mapping schemes were applied to create the building inventory.

Occupancy code category mapping has been performed to prepare Hazus readable occupancy codes. Records that don't match will be defaulted to ‘RES1’.

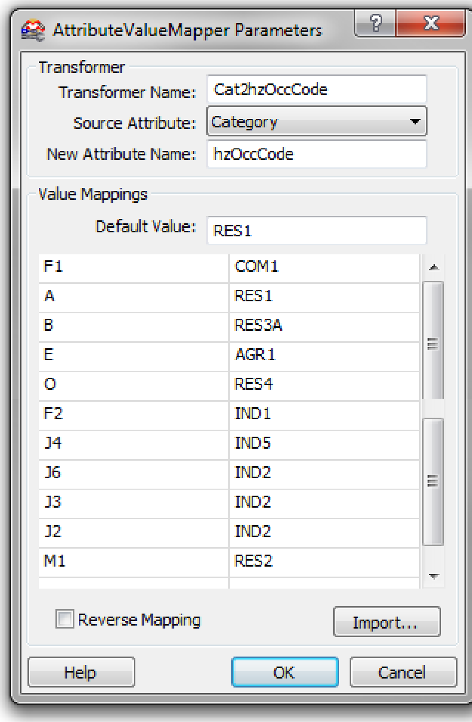

Figure 19: Data transformer for occupancy code

Building area transformation has been performed to assign building areas to each occupancy class. The multiplication factors for building area are determined from average square meter value for each occupancy class. This approach requires the prerequisite of collecting data for the square meters from a reliable statistical source.

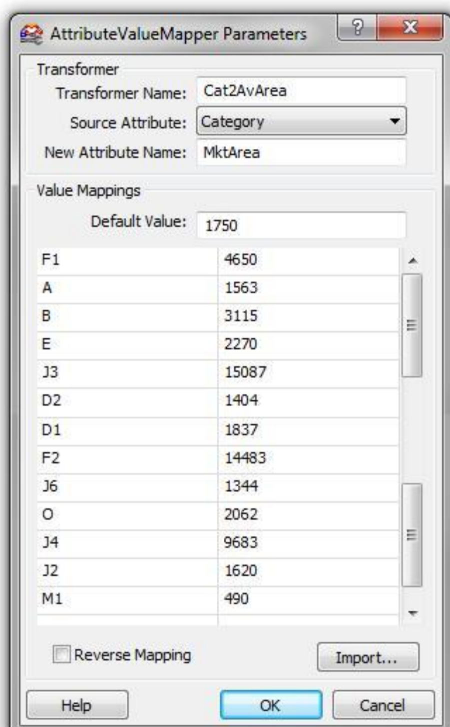

Figure 20: Data transformer for building area

'hzBldgArea' (Hazus-MH building area) is determined from Building Area. Hazus-MH areas are denominated in thousands. This is needed for the integrity in Hazus-MH analysis and reporting structure.

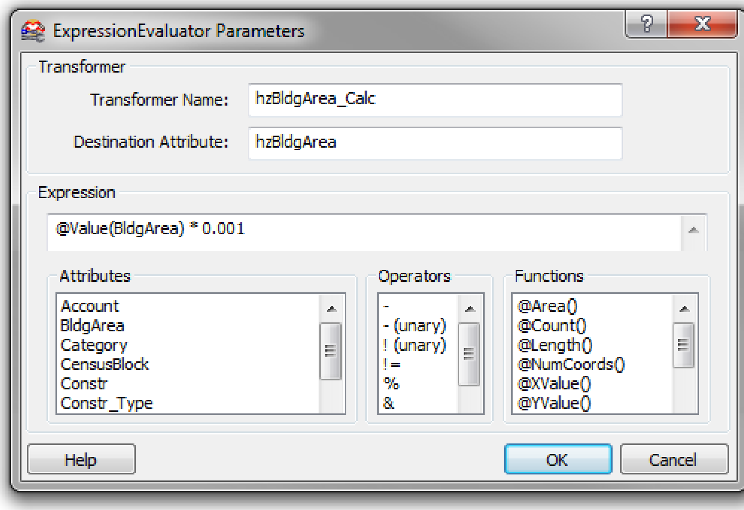

Figure 21: Data transformer for 'hzBldgArea' (Hazus-MH building area)

The replacement cost is calculated from the building area. The multiplication factors are determined for each Occupancy Class. For this goal study region specific construction costs based upon average square meter needs to be collected. This approach requires the prerequisite of data collection for the cost per square meter from a reliable statistical source.

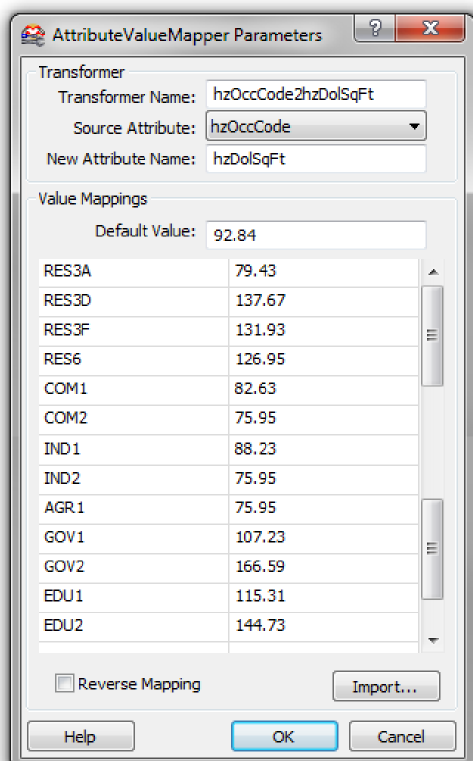

Figure 22: Data transformer for replacement cost

Hazus building cost (hzBldgCost) is determined from building area and square meter value. Hazus costs are denominated in thousand Euros.

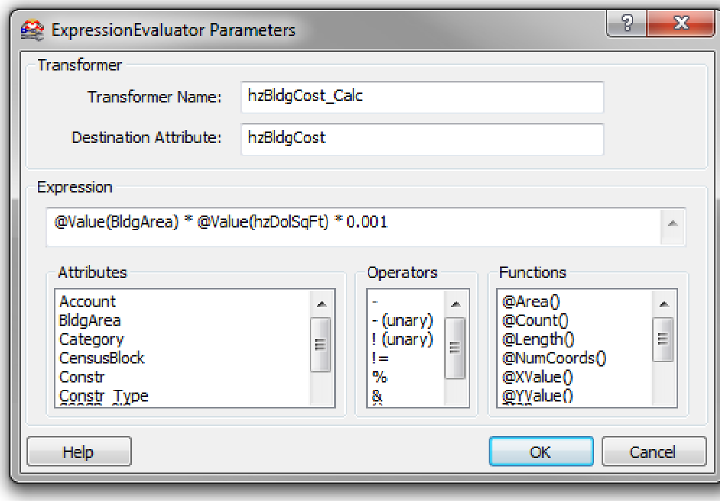

Figure 23: Data transformer for 'hzBldgCost' (Hazus-MH building cost)

As a final steps these prepared datasets are matched with the Hazus attributes to create a building inventory which is ready to be imported into Hazus. Although some of the attributes which are related to other models doesn`t contain any data, they should be kept intact as the original Hazus structure for the next steps of data integration which is explained in the next chapter.

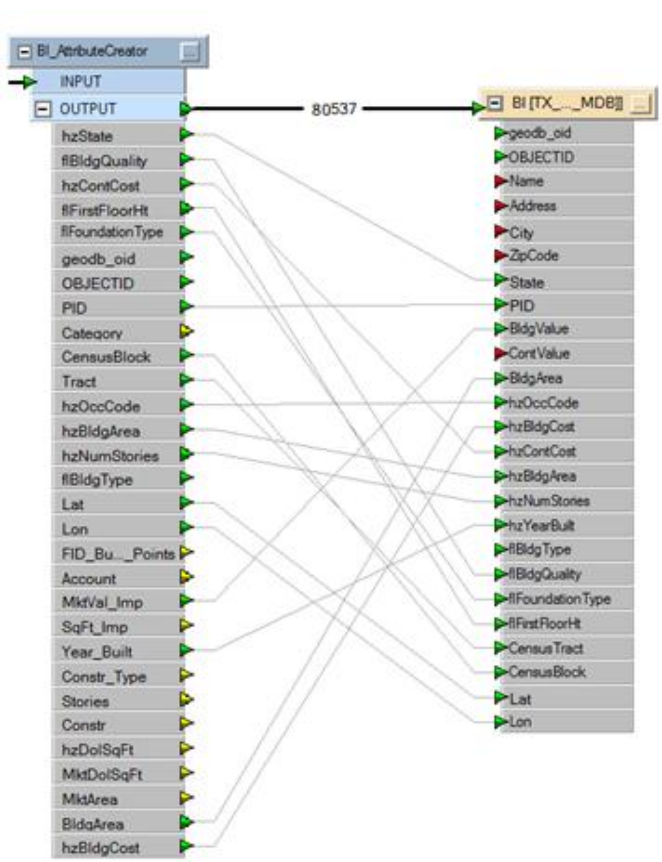

Figure 24: Attribute creator for building inventory

5.2. Data integration

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-MH 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-MH interface and the import function. (Kaveckis et al. 2011)

5.3. Inventory Data Integration

Then, Comprehensive Data Management System (CDMS) of original Hazus-MH data infrastructure is used for importing, aggregating and updating the modified geodatabases. CDMS is a standalone module provided by FEMA to manage the modeling data in and out of Hazus-MH. After achieving those steps a study region can be defined and populated directly within Hazus-MH.

After selection of the Hazus-MH Data folder location in the CDMS, the inventory category is selected as aggregated data and the building inventory database prepared in the Data Preparation chapter is selected from Import Site Specific data to Aggregate Data button. CDMS shows the fields that are required for updating the inventory.

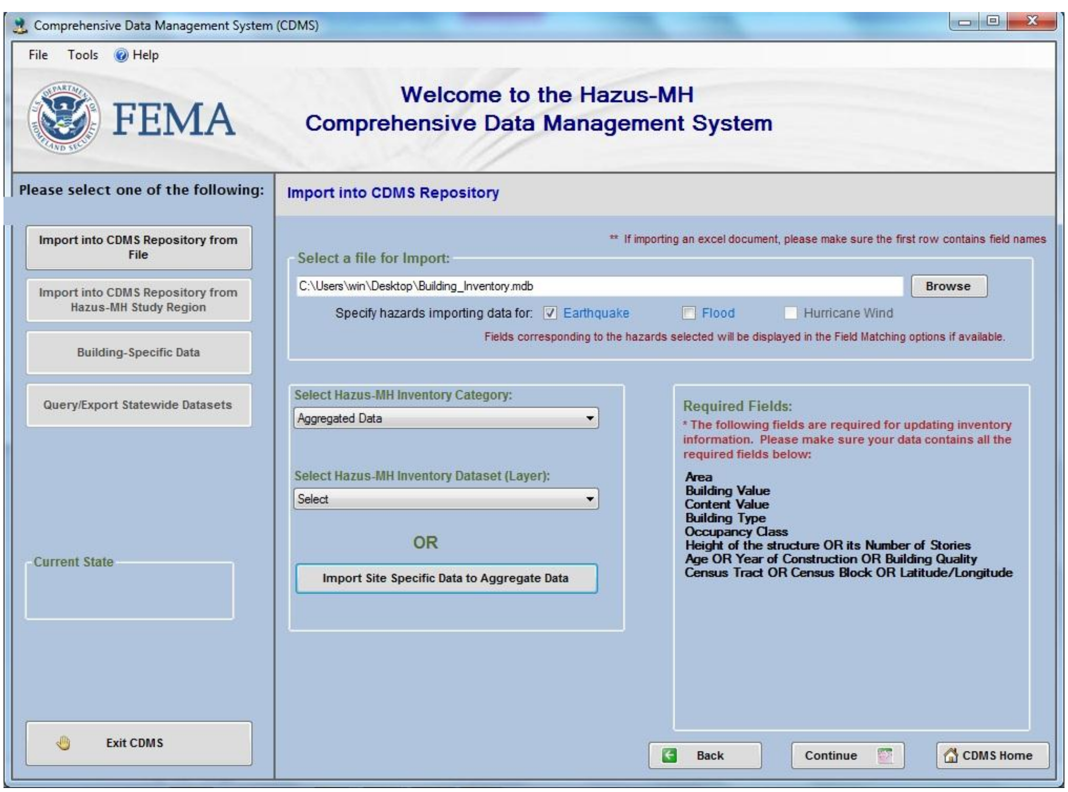

Figure 25: Selection of Building Inventory database to import as aggregate data in CDMS

The next step is data field matching, where the user has to match input data fields to the Hazus-MH data fields.

5.4. Data Field Matching

CDMS automatically matches the data fields it recognizes. For the other fields the remaining source values should accurately match the destination values.

Since the data fields are prepared taking the Hazus-MH data classification into consideration most of the fields will be automatically recognized. User will match the required fields properly for other the unmatched sections.

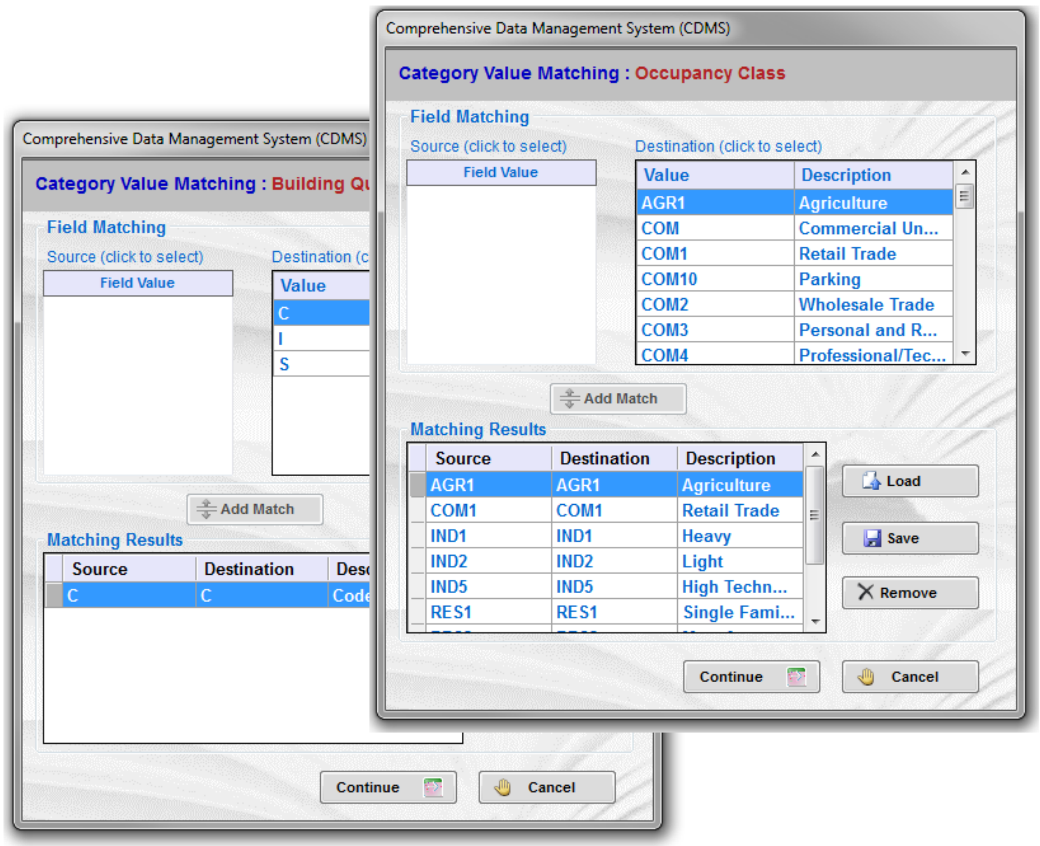

Figure 26: Data field matching for occupancy class.

Building Inventory field hzBldgArea is in thousand square meters. The required Hazus unit for building area is 1,000s of square feet. Since the results will be presented in square meters and the units in the source data are already prepared to represent the thousands in the Data Preparation chapter there is no need for the conversion factor.

Building Inventory field hzBldgCost is in thousand euros. The Hazus unit for building replacement cost is in thousand dollars. Since the results will be presented in euros and the units in the source data are already prepared to represent the thousands in the Data Preparation chapter there is no need for the conversion factor. ` Use as is` option should be selected

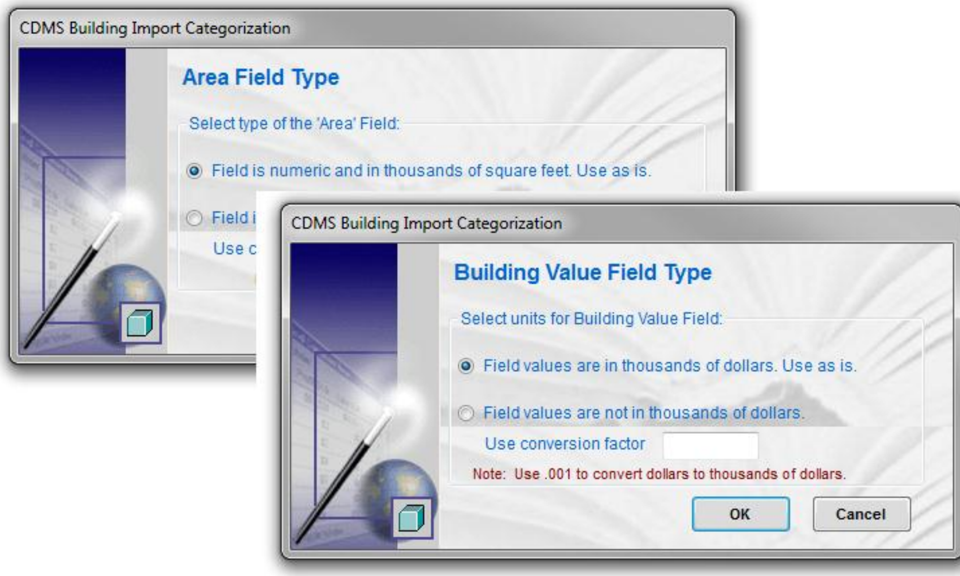

Figure 27: Area and Building Value field selection.

A CDMS Data Import Success message box will appear after the successful completion of the data field matching process.

After reviewing the imported records by clicking on the View button, the aggregated data layer will be transferred from the repository into Hazus-MH with the selection of transfer to statewide dataset button. Selection of process all tracts/blocks section is needed to replace all of the contents from all Tracks and Blocks. With the successful initiation of this process user will have a custom inventory with the required data for the study region.

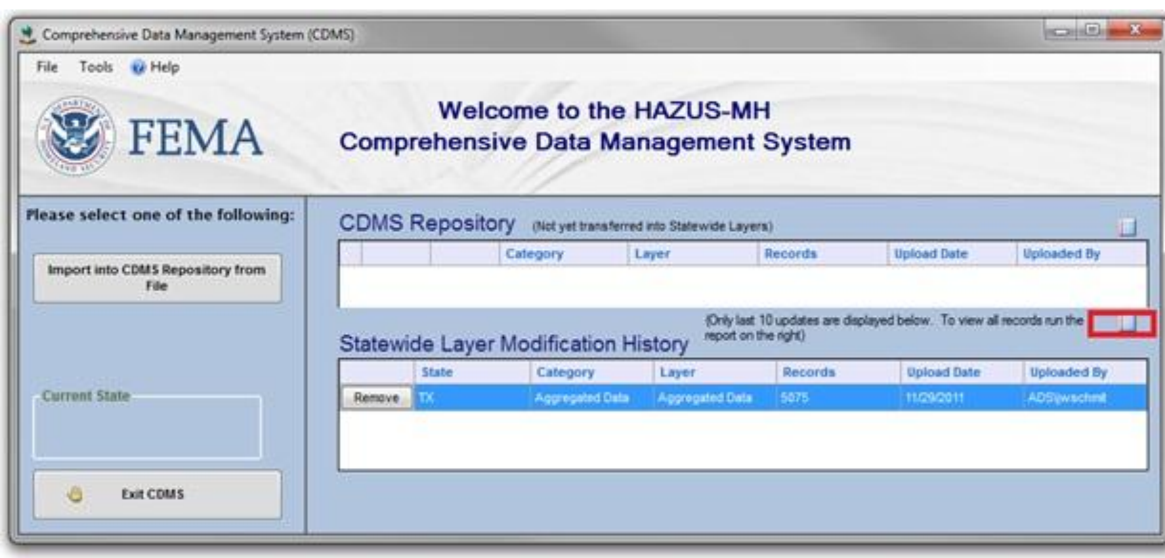

Figure 28: Custom Building inventory imported with CDMS

The advantage of this approach is having all the data stored in inventory in same structure. The datasets doesn`t have discrepancies while working on different type of hazards. Hazus-MH only acquires them when the region is created.

5.5. Earthquake Hazard Data Integration

This section describes the integration of earthquake related hazard data and gives an explanation of how to define a scenario earthquake in Hazus-MH. Hazus-MH has a number of options for defining the potential earth science hazards. It also allows you to estimate losses based on one of three characterizations of the earthquake hazard:

- Scenario earthquake (deterministic hazard),
- Probabilistic seismic hazard analysis,
- User-supplied map of ground motion.

The deterministic hazard can be a historical epicenter event, a source event, or an arbitrary event. The probabilistic hazard option allows the user to generate estimates of damage and loss based on probabilistic seismic hazard for eight return periods. The user-supplied hazard option requires the user to supply digitized peak ground acceleration (PGA) and spectral acceleration (SA) contour maps. Spectral accelerations at 0.3 second and 0.1 second (SA at 0.3 and SA at 1.0) are needed to define the hazard. The damage and losses are computed based on the user-supplied maps (FEMA 2009a).

In this study **user-supplied hazard** option will be used to define the earthquake hazard in the international framework of the Hazus-MH. User will supply the ground shaking maps for estimating damage and loss. The ground shaking maps must be in geodatabase format and be added to the list of available data maps defined under using the Hazus-MH menu Hazard | Data Maps (Figure 29).

After the creation of the study region with supplied region specific inventory data from the Hazard menu / Data Maps Dialog should be opened and the program needs to be pointed to each of the 4 data tables to define the ground motions used by HAZUS-MH. The Data Map Attributes dialog will automatically open when the ShakeMap.mdb file is opened. The Map name (typed by the user), Map type (selected using the combo box and scroll arrows) and table name (scroll toward bottom of list and do not select the Shape Index files) need to be defined as shown below. This process needs to be completed until all four map table names are defined.

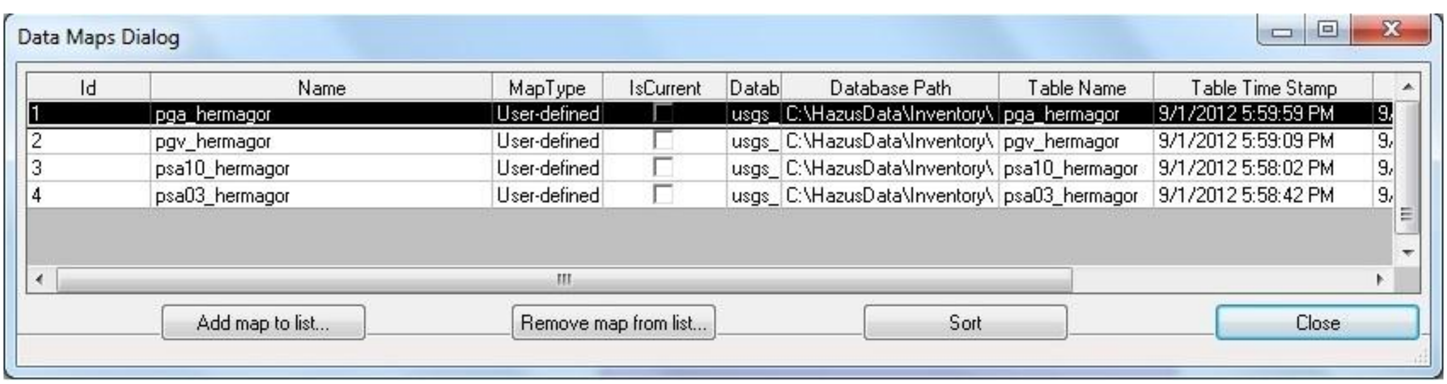

Figure 29: Data Maps Dialog for user supplied hazard

For the analysis of Earthquake Module a User Supplied Scenario should be selected for the Seismic Hazard type at the Scenario Wizard. And for the User-defined Hazard Option each Ground shaking map should be pointed to the relevant map table with the dropdown menus. Than ground shaking and seismic hazard analysis can be run as defined at the Hazus-MH User Guidelines (FEMA 2009a).

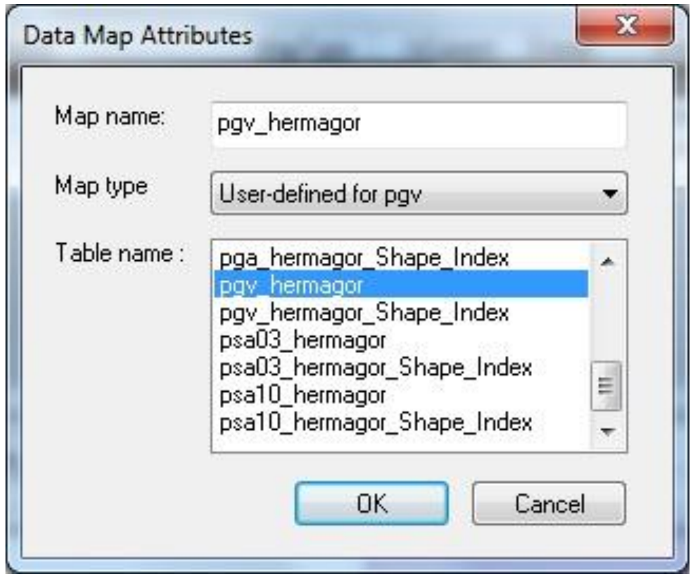

Figure 30: Shake map selection in data map attributes

6. Proof of Concept and Implementation

This chapter discusses the possibilities of the implementation, and the integration of local Austrian datasets into the Hazus-MH Earthquake Model.

A study region with relevant data in the Carinthia region, in southern Austria is selected for the proof of concept. Earthquake scenario was simulated using Hazus-MH to estimate property losses within the study region. Properties that were updated from inventory datasets are explained in the following sections.

6.1. Study Region

The highest earthquake hazard risk zones residing in Austria are in the Carinthia-Slovenia-Italy (Friulia-Venezia-Giula) border region, where tectonic activity of the Eastern and Southern Alps creates high seismically active zones (Hawkesworth et al. 1975). In 1976 the failure of the Periadriatic Fault Line passing through this region created a major earthquake measured at 6.4 on the Richter scale, killing about 1000 people, injuring 2500, leaving 160,000 homeless and causing major economical, structural damage in the regional countries (Finetti et al. 1979).

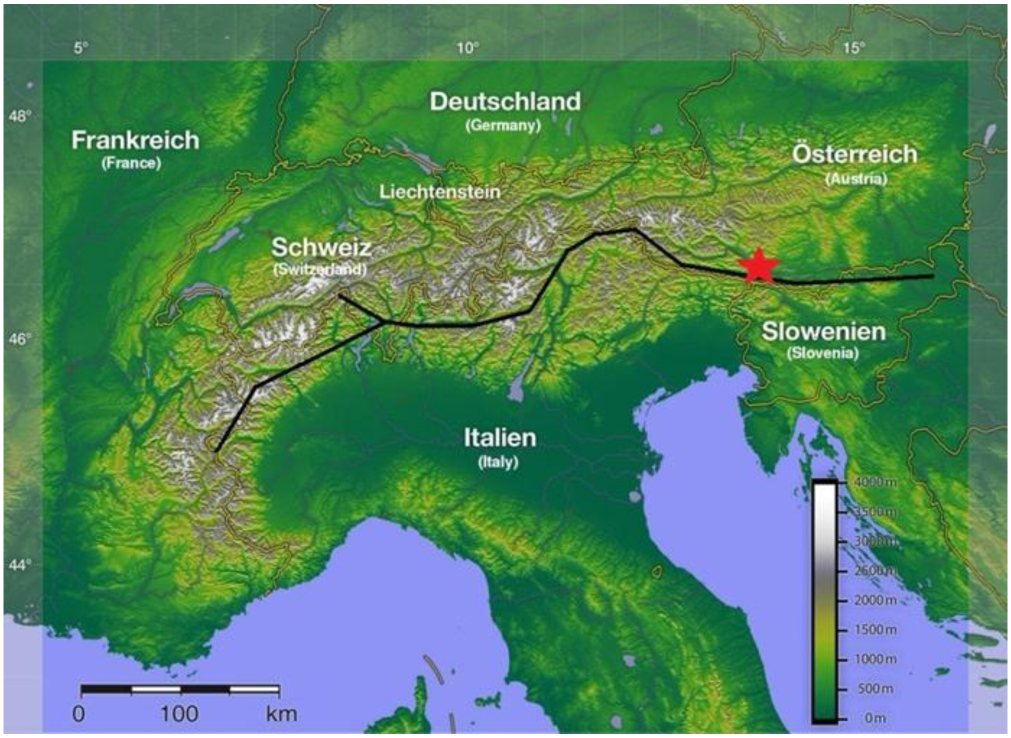

Figure 31: Earthquake risk zones in Austria-Slovenia-Italy border divided by Periadriatic Fault Line. Red star indicates the study region .

In the eastern part of the Alps, several tonalitic, granodioritic and granitic intrusions are found in the vicinity of, or directly at, the Periadriatic Fault. There is obviously a close relationship between the Periadriatic Fault and these intrusions. The Klagenfurt Basin formed in Late Miocene to Pliocene as a flexural basin in front of the NW-directed over trust of the Karawanken Mountains. This over trust was probably related to dextral shearing along the Periadriatic Fault (McCann 2008).

The study region is selected as the community of the Austrian town Hermagor-Pressegger See and surrounding regions in the Hermagor district which is located in southern Austria in the Carinthia region. The population of Hermagor-Pressegger See town and vicinity is slightly over 7,000.

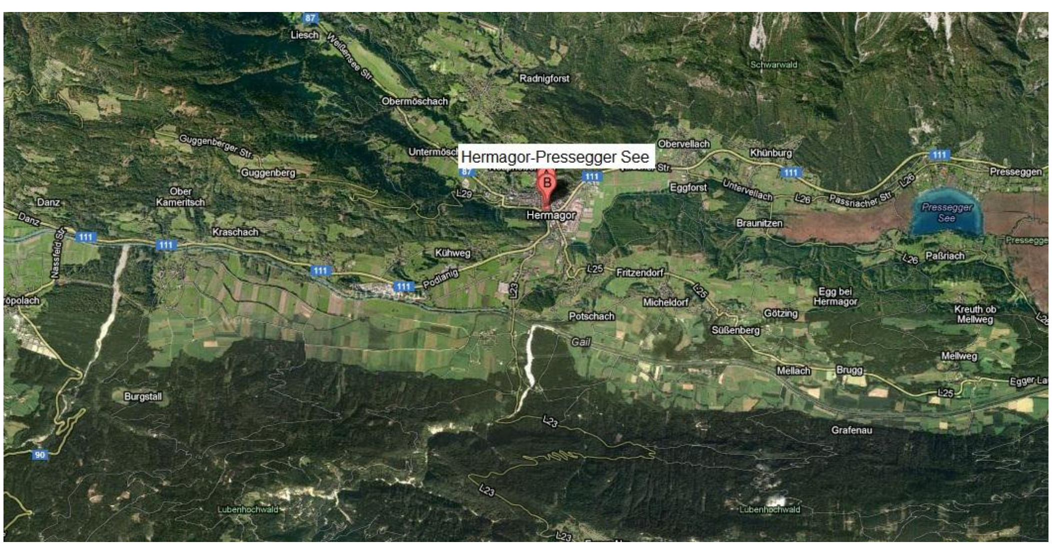

Figure 32: Location of Hermagor-PresseggerSee and surroundings (Google Maps 2012)

The earthquake loss estimates are evaluated for this region which is close to the Italian border and the Friulia-Venezia-Giula region which is threatened by the effects of Periadriatic Fault line.

The objective of this proof of concept is to integrate all input data into the Hazus-MH Earthquake Model and perform an earthquake damage assessment for this region. (Figure 33)

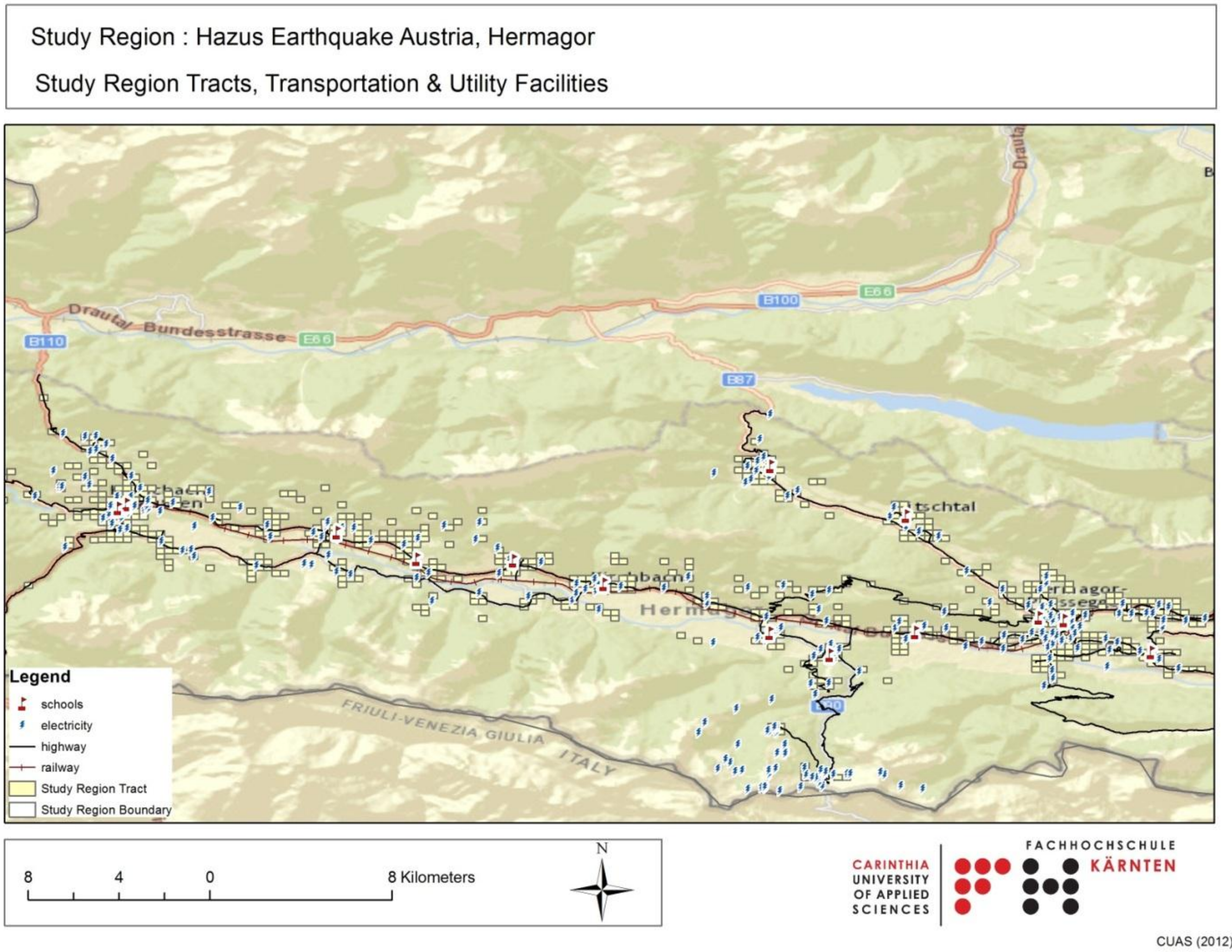

Figure 33: Datasets in the study region

6.2. Inventory Datasets for Study Region

The inventory data in Hazus-MH is stored in the geodatabases and tables classified under the country folders. The source data for the Hermagor region in Austria is collected by Statistics Institute of Austria and provided by Dr. Gernot Paulus of Carinthia University of Applied Science.

The source datasets edited to produce an inventory contains:

- **Regional Statistical Units B:** 250x250 Meter for population and age demographics (Table 4) (Due to Privacy issues, only cells with more than 30 persons are included in this package)
- **Regional Statistical Units C:** 250x250 Meter for building counts based on occupancy (Table 5)
- **Point data for grade schools** (imported into Essential facilities)
- **Point data for electricity and potable water facilities** (imported into Utilities)
- **Line data for highway and railroad segments** (imported into Transportation)

Table 4: Demographic classification for Population in the study region.

Name	Alias	Description
POP	Population	Inhabitants (permanent residence)
M_ALL	Male	Male
W_ALL	Female	Female
ALL_01	Age 0-2 (Total)	Number of Inhabitants 0-2
ALL_02	Age 3-5 (Total)	Number of Inhabitants 3-5
ALL_03	Age 6-9 (Total)	Number of Inhabitants 6-9
ALL_04	Age 10-14 (Total)	Number of Inhabitants 10-14
ALL_05	Age 15-19 (Total)	Number of Inhabitants 15-19
ALL_06	Age 20-24 (Total)	Number of Inhabitants 20-24
ALL_07	Age 25-34 (Total)	Number of Inhabitants 25-34
ALL_08	Age 35-44 (Total)	Number of Inhabitants 35-44
ALL_09	Age 45-64 (Total)	Number of Inhabitants 45-64
ALL_10	Age 65-84 (Total)	Number of Inhabitants 65-84
ALL_11	Age over 84 (Total)	Number of Inhabitants over 84

Table 5: Occupancy type classification for buildings in study region.

Name	Alias
OBJ	Building
OBJ_01	Residence building with 1 apartment
OBJ_02	Residence Building with >1 apartments
OBJ_03	Building for communities
OBJ_04	Hotel, Restaurant, Pension
OBJ_05	Office Building
OBJ_06	Commerce Building
OBJ_07	Building for Transportation & Telecommunication
OBJ_08	Industry/ Storage Building
OBJ_09	Building for Cultural activities, education, Health
OBJ_10	Other Building
OBJ_WG	Residence buildings
NTZ_ALL	Apartments
NTZ_HWS	Apartments with permanent residency
NTZ_NWS	Apartments with secondary residency

The original Hazus-MH Earthquake Model has three levels of geographical divisions: state, county, census tract (a fourth level of census block is included for other model requirements). The first two divisions can be described as administrative units, while the other two are census geographical units. (Kaveckis et al. 2011)

In the international framework these three levels are kept intact but identified as,

- Country
- Administrative division
- Grid based on population distribution structure.

The region contains 993 census tracts. There are over 5 thousand households in the region which has a total population of 18,767 people. Figure 34 indicates that the population is mostly concentrated in the center of old settlements like Hermagor – Presseger See city center location.

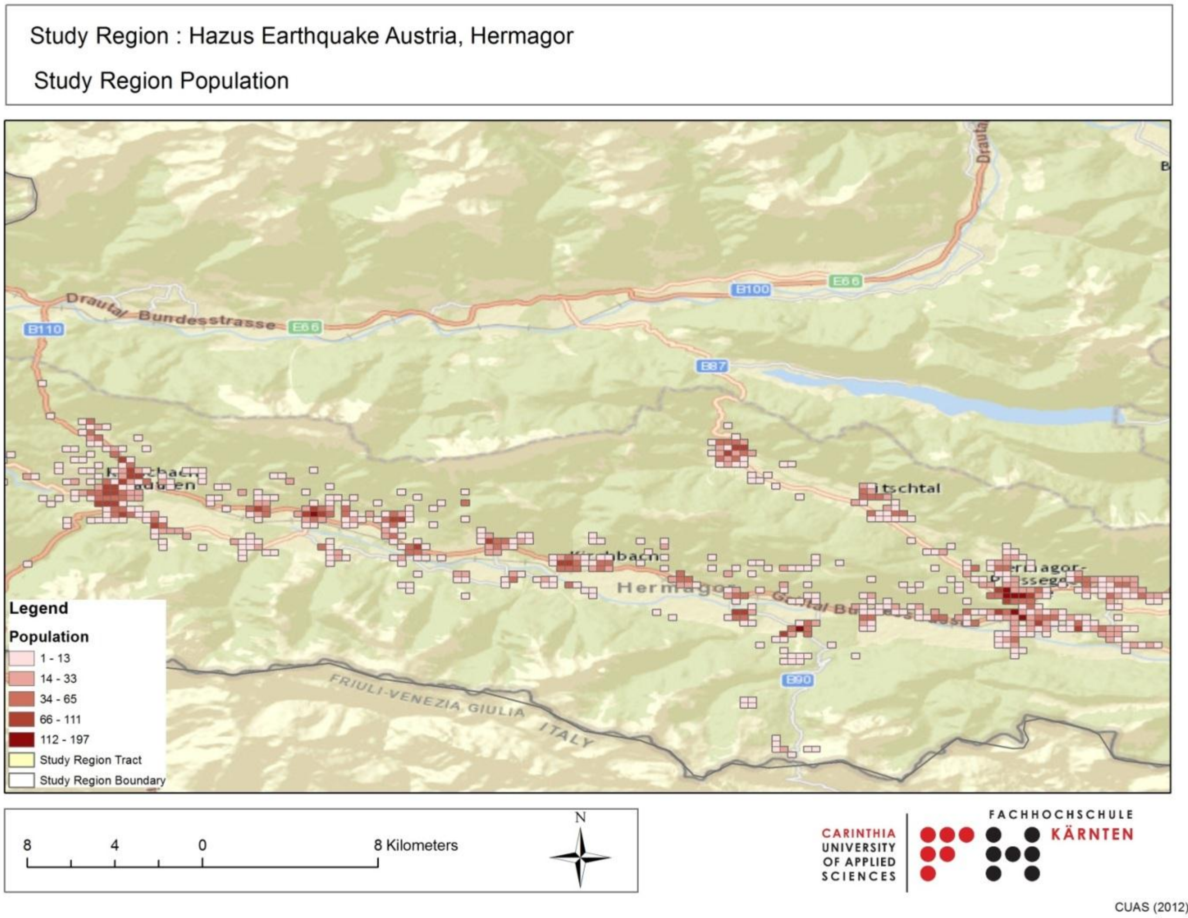

Figure 34: Demographics map showing the population distribution in the region.

6.2.1. Building and Lifeline Inventory

There are an estimated 5 thousand buildings in the region with a total building replacement value (excluding contents) of 35,815 million euros.

6.2.2. Building Inventory

Approximately 99.00 % of the buildings (and 95.00% of the building value) are associated with residential occupancy. The rest is commercial occupancies.

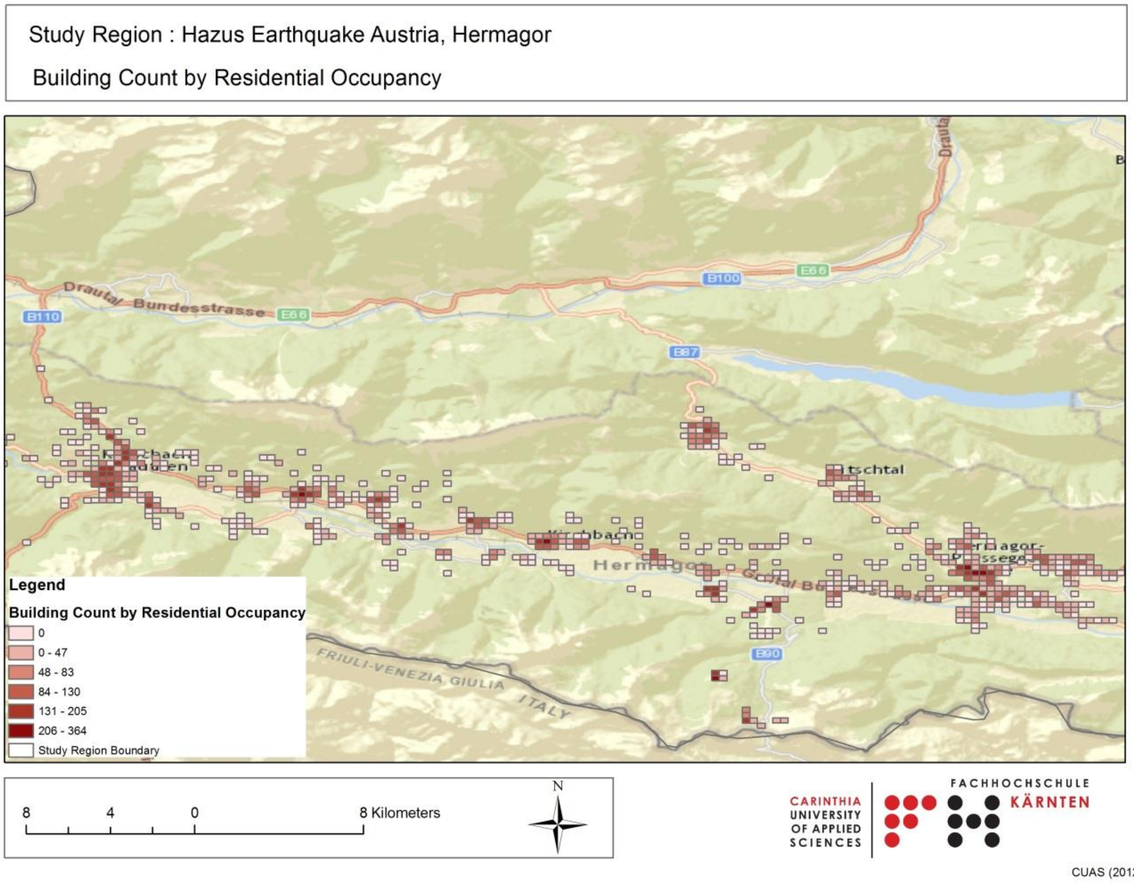

Figure 35: Building Count by Residential Occupancy

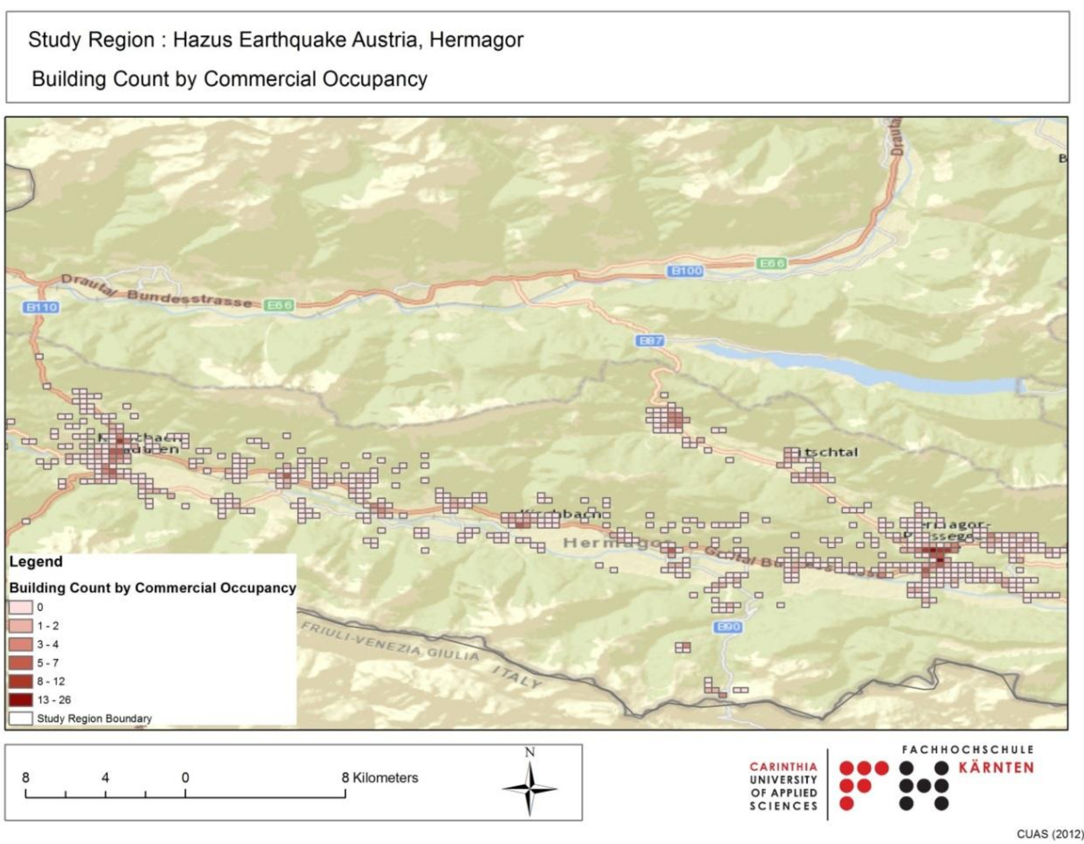

Figure 36: Building Count by Commercial Occupancy

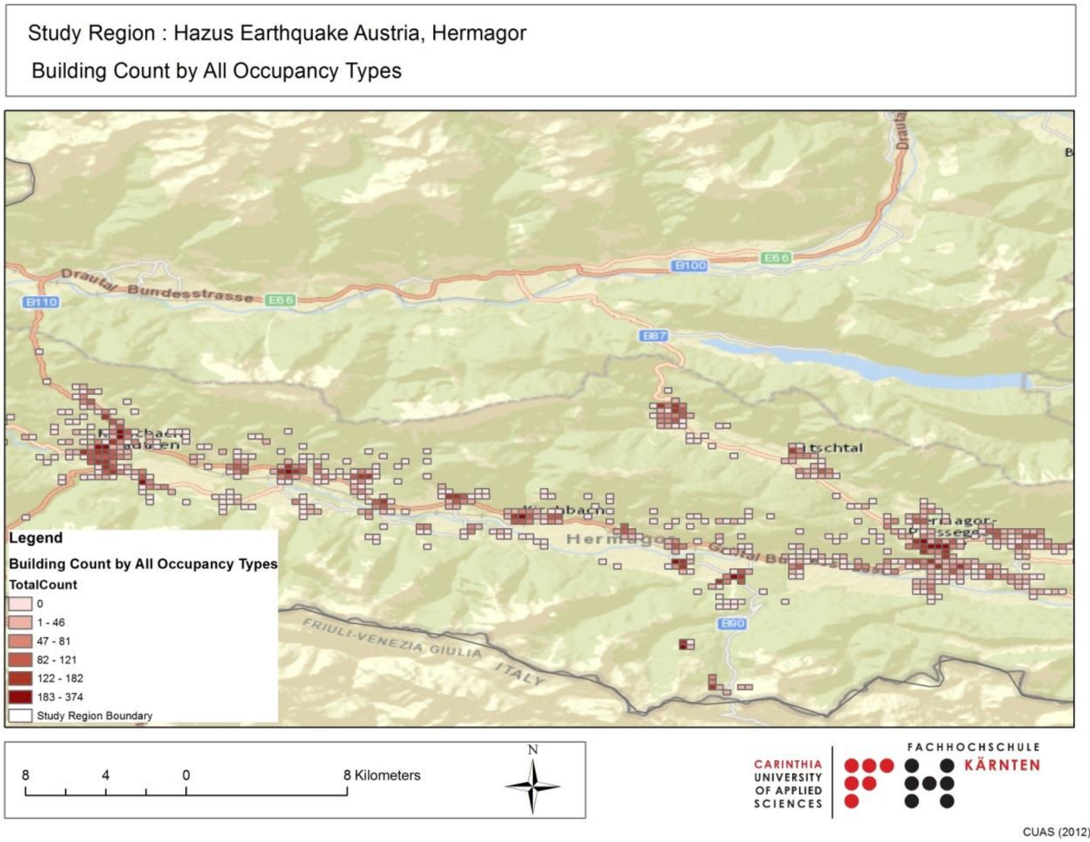

Figure 37: Total Building Count

6.2.3. Buildings Square Meter Values

The square meter values for the buildings are needed to evaluate the total square meters per tracks and to calculate the exposure values for each tract. Since the original datasets doesn`t include any value for the square meters, assumptions have to be made considering the building inventory structure in the study region and average values for each occupancy class for the inventory. Evaluating the characteristics of the building inventory the region consists of low to mid rise building. So the following average square meter values are chosen for each occupancy class:

Residential building class – 1000 m^2

Commercial building class – 2500 m^2

All tracts are calculated and aggregated using this assumption for the square meters and maps shown in Figure 38, 39 and 40 are generated.

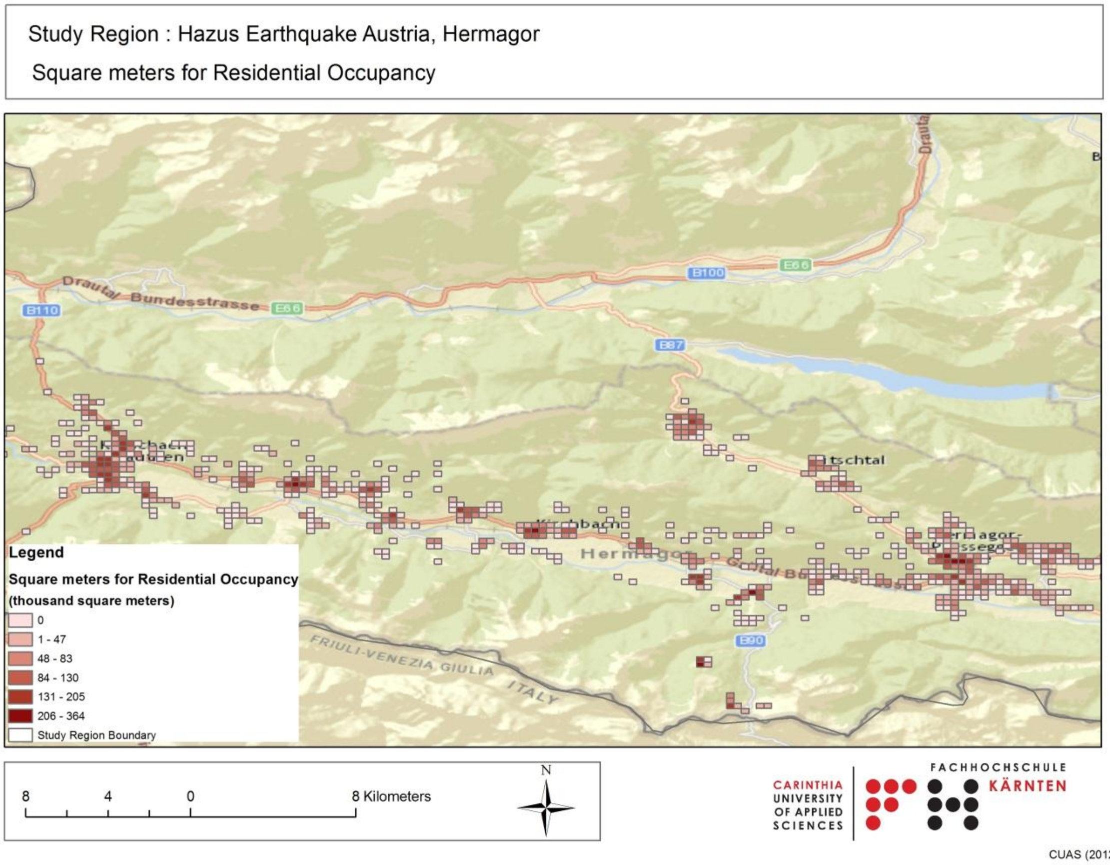

Figure 38: Square Meters for Residential Buildings (in thousand m^2)

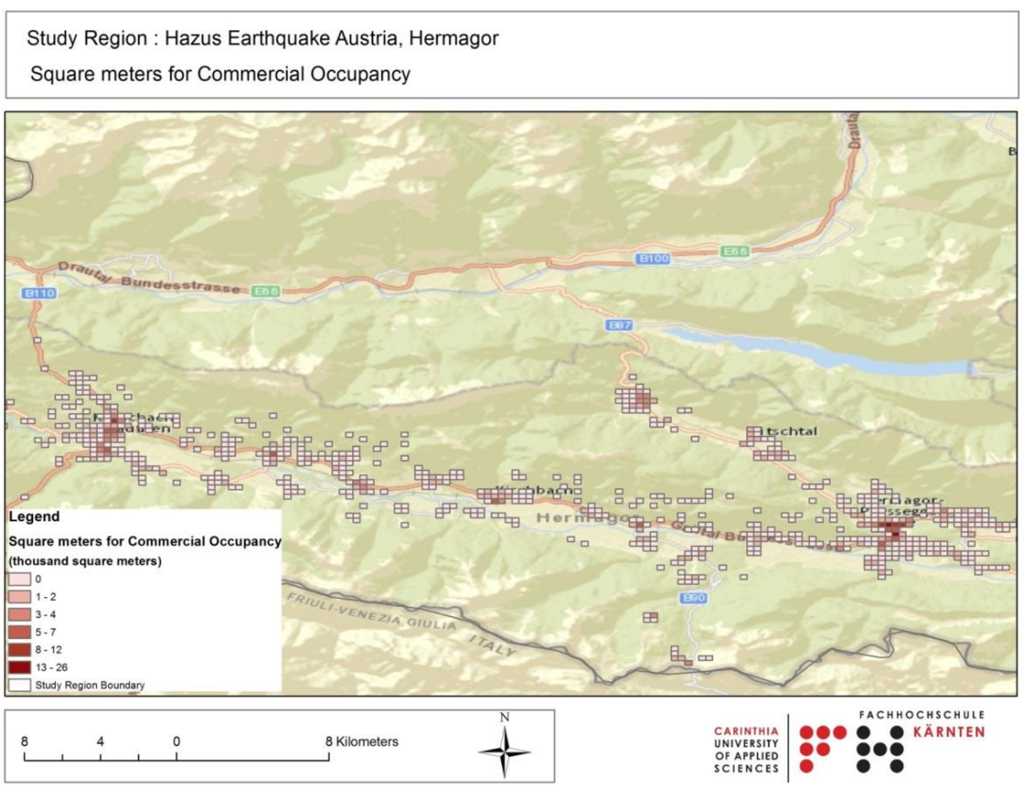

Figure 39: Square Meters for Commercial Buildings (in thousand m^2)

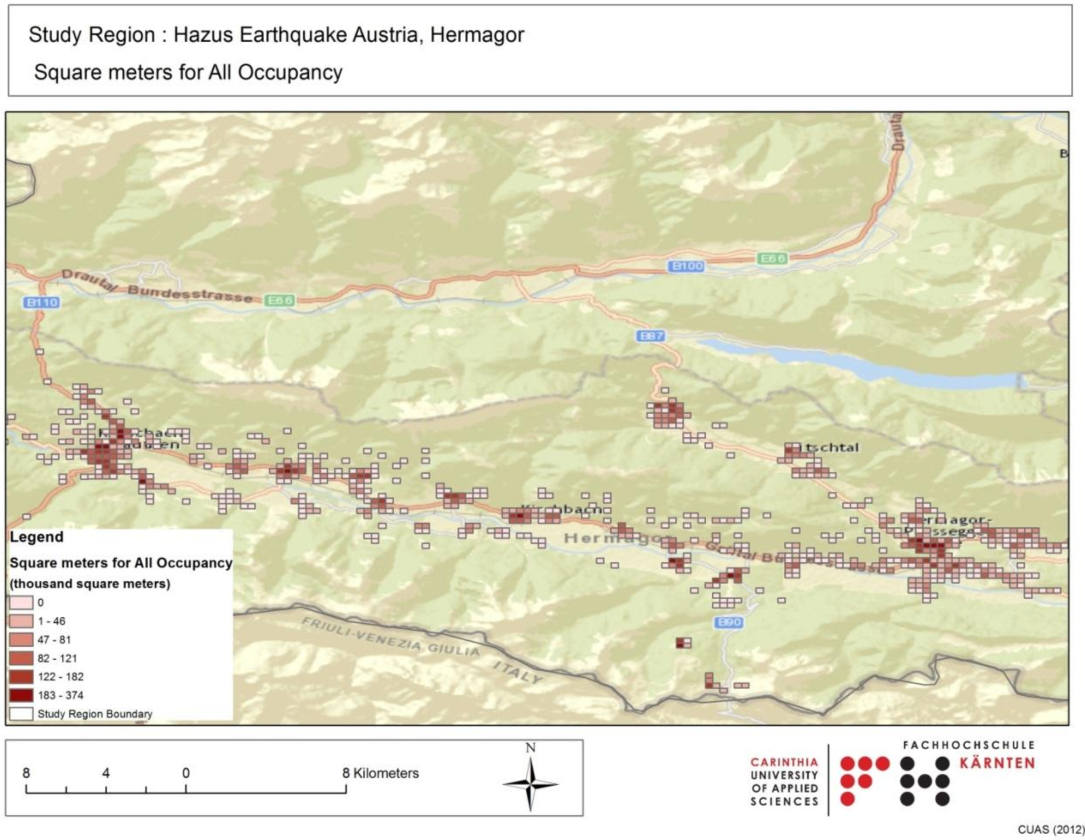

Figure 40: Square Meters for Total Buildings (in thousand m^2)

6.2.4. Buildings Exposure Values

After calculating needed square meter values for each tract, euro per square meter value is needed for the region to reach the total building exposure values for each tract in the region.

According to Statistics Institute of Austria, in 2011, the average housing costs per square meter of available area amounted to EUR 405.

In the western provinces Vorarlberg (EUR 436), Salzburg (EUR 431) and Tyrol (EUR 414) as well as in Vienna (EUR 418) the housing costs were higher than in the other eastern provinces such as Upper Austria (EUR 401), Lower Austria (EUR 388) and Burgenland (EUR 369). (Statistics Austria 2012).

Since the study region is located in the Carinthia state of Austria the average value of EUR 400 is selected as replacement cost value as a reference for the calculations. This value should not be confused with the market value of the building; it represents the replacement value of building structure not the market value. The total exposure per tract in the study region is calculated by the multiplication of square meter value and reference euro per square meters.

Figure 41, 42 and 43 presents the total exposures in thousand Euros for the occupancy classes of residential and commercial with total exposure as combined value respectively.

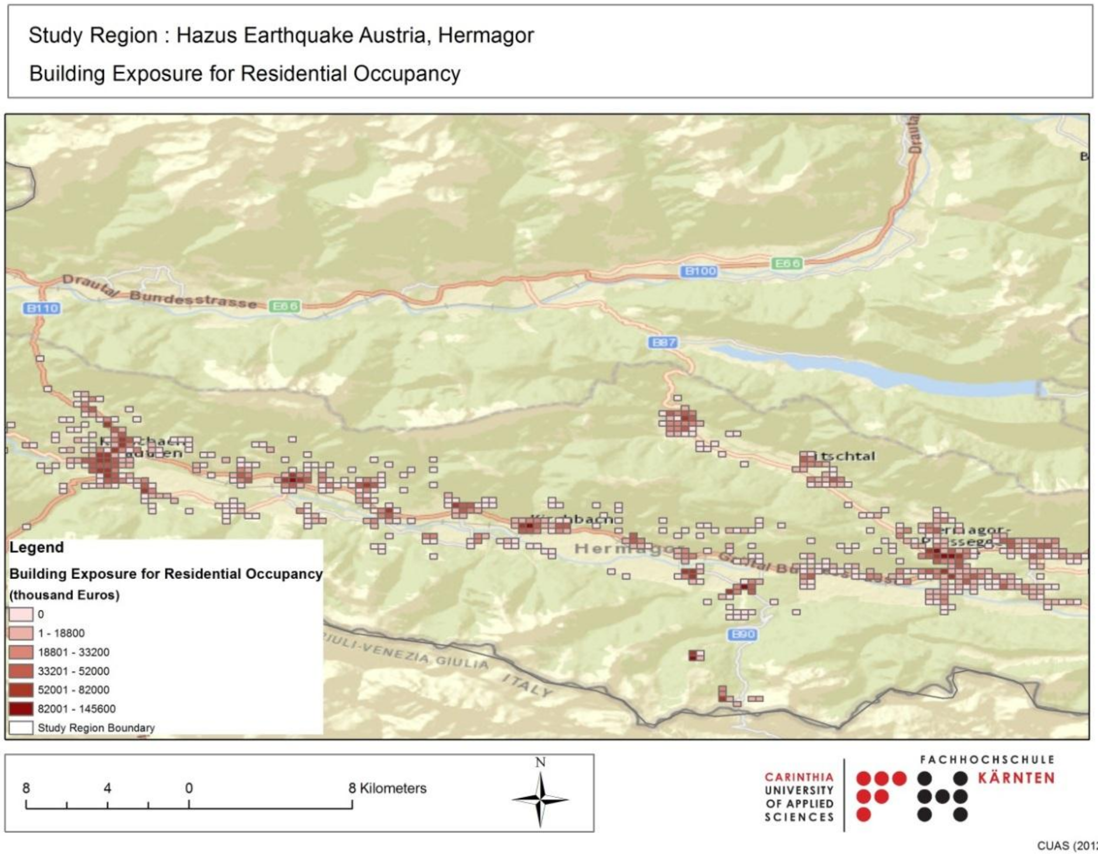

Figure 41: Residential Building Exposure (in thousand Euros)

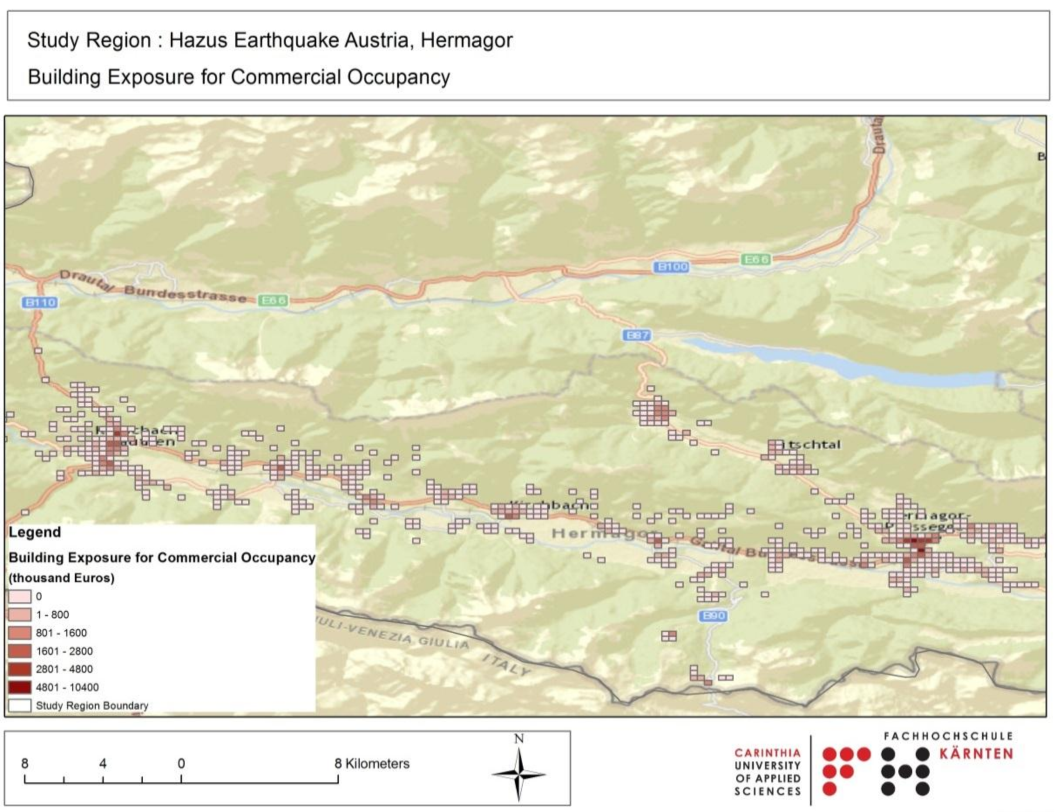

Figure 42: Commercial Building Exposure (in thousand Euros)

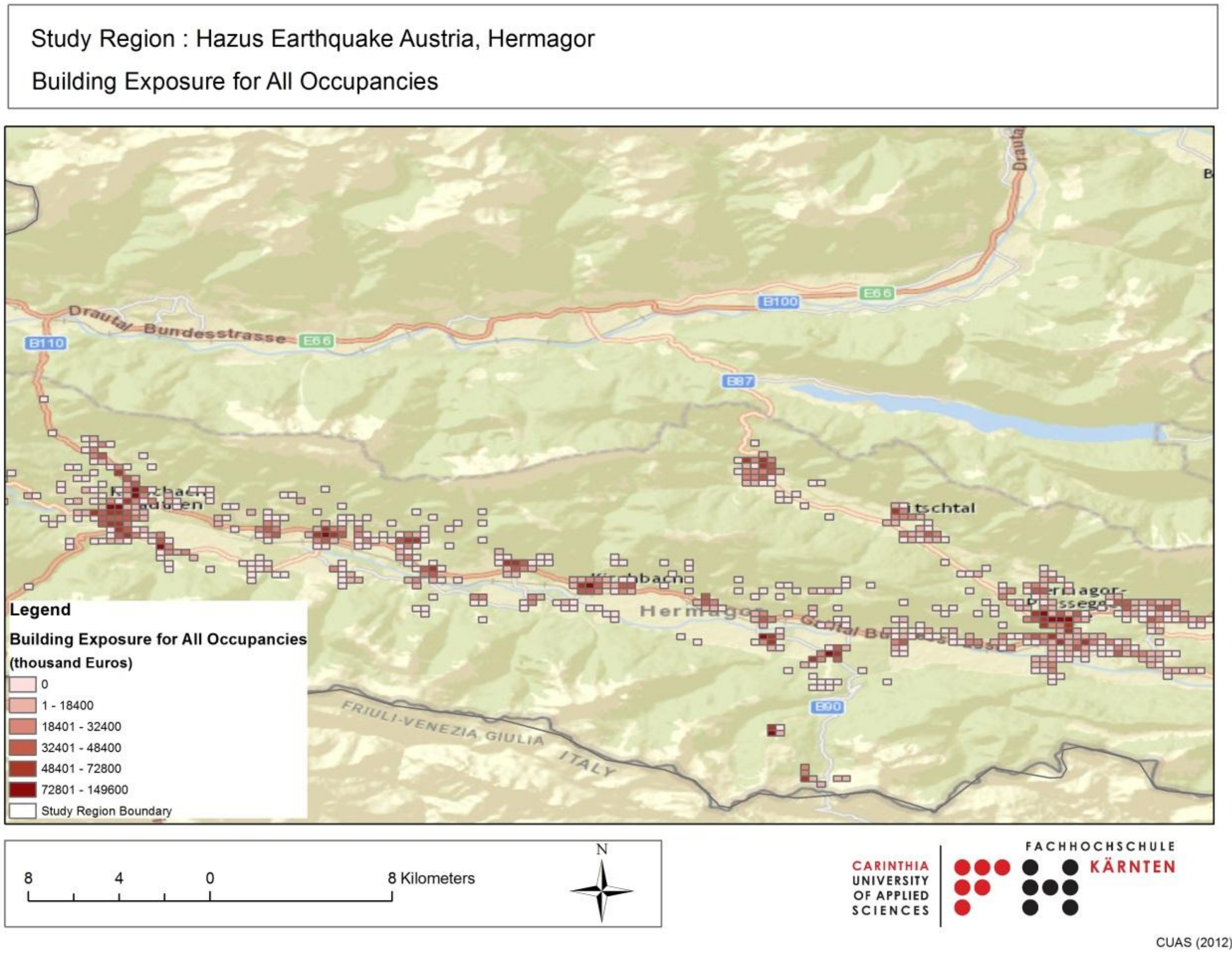

Figure 43: Total Building Exposure (in thousand Euros)

6.2.5. Critical Facility Inventory

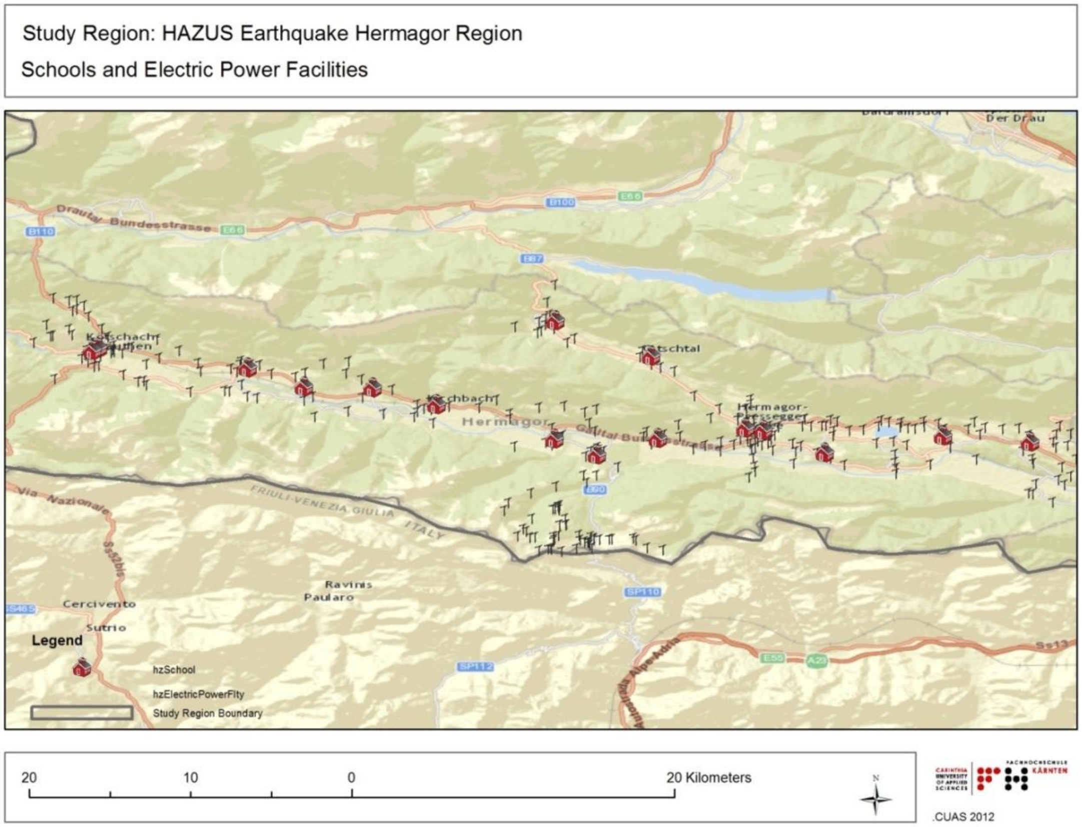

Figure 44: Essential Facilities: Schools & Electric Power Facilities

Hazus-MH breaks critical facilities into two (2) groups: essential facilities and high potential loss facilities (HPL). Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. For essential facilities, there are 22 schools in the region.

6.2.6. Transportation and Utility Lifeline Inventory

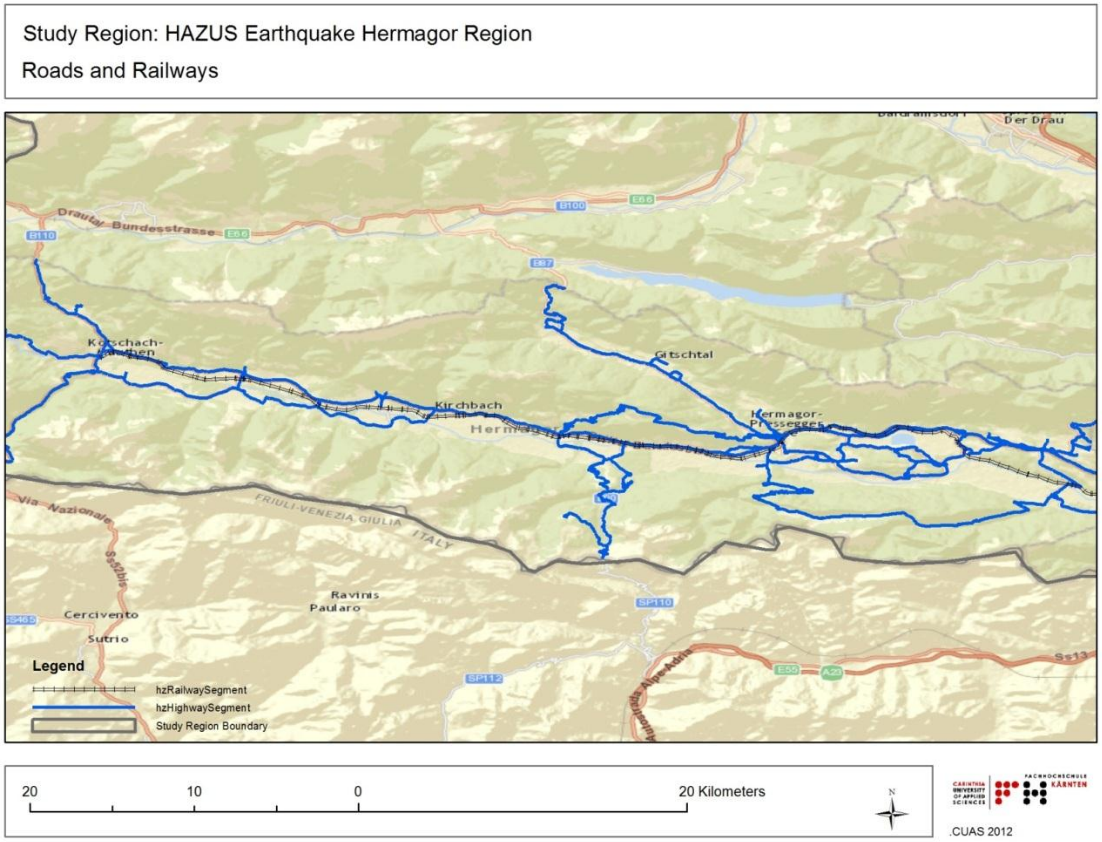

Figure 45: Transportation: Roads and Railways

Within Hazus-MH, the lifeline inventory is divided between transportation and utility lifeline systems. There are transportation systems that include highways, railways, light rail, bus, ports, ferry and airports. There are utility systems that include potable water, wastewater, natural gas, crude & refined oil, electric power and communications. This inventory includes over 276,468 kilometers of highways.

Table 6: Transportation System Lifeline Inventory

System	Component	# Locations/ # Segments
Highway	Bridges	0
	Segments	806
	Tunnels	0
	Subtotal	806
Railways	Bridges	0
	Facilities	0
	Segments	135
	Tunnels	0
	Subtotal	135

6.3. Hazard Datasets for Study Region

6.3.1. Ground Motion Shakemaps

The main data source for ground motion is Shakemaps which is a product of the U.S. Geological Survey Earthquake Hazards Program in conjunction with regional seismic network operators. ShakeMap sites provide near-real-time maps of ground motion and shaking intensity following significant earthquakes.

A ShakeMap is a representation of ground shaking produced by an earthquake. The information it presents is different from the earthquake magnitude and epicenter that are released after an earthquake because ShakeMap focuses on the ground shaking produced by the earthquake, rather than the parameters describing the earthquake source. So, while an earthquake has one magnitude and one epicenter, it produces a range of ground shaking levels at sites throughout the region depending on distance from the earthquake, the rock and soil conditions at sites, and variations in the propagation of seismic waves from the earthquake due to complexities in the structure of the Earth's crust (USGS 2006) .

For the study region the characteristics of the earthquakes generated in the Northern Italy regions close to the Frulia-Gulia region at the Austrian border are selected and they are simulated with a scenario where epicenter is generated in the eastern part (specifically Hermagor town center) of the study region where the population distribution is denser. With those assumptions in mind four different maps generated in the study region

Peak Acceleration Maps:

Peak horizontal acceleration is contoured in units of percent-g (where g = acceleration due to the force of gravity = 9.81 cm/s). The peak values of the vertical components are not used in the construction of the maps because they are, on average, lower than the horizontal amplitudes and ground motion prediction equations used to fill in data gaps between stations are based on peak horizontal amplitudes (USGS 2006).

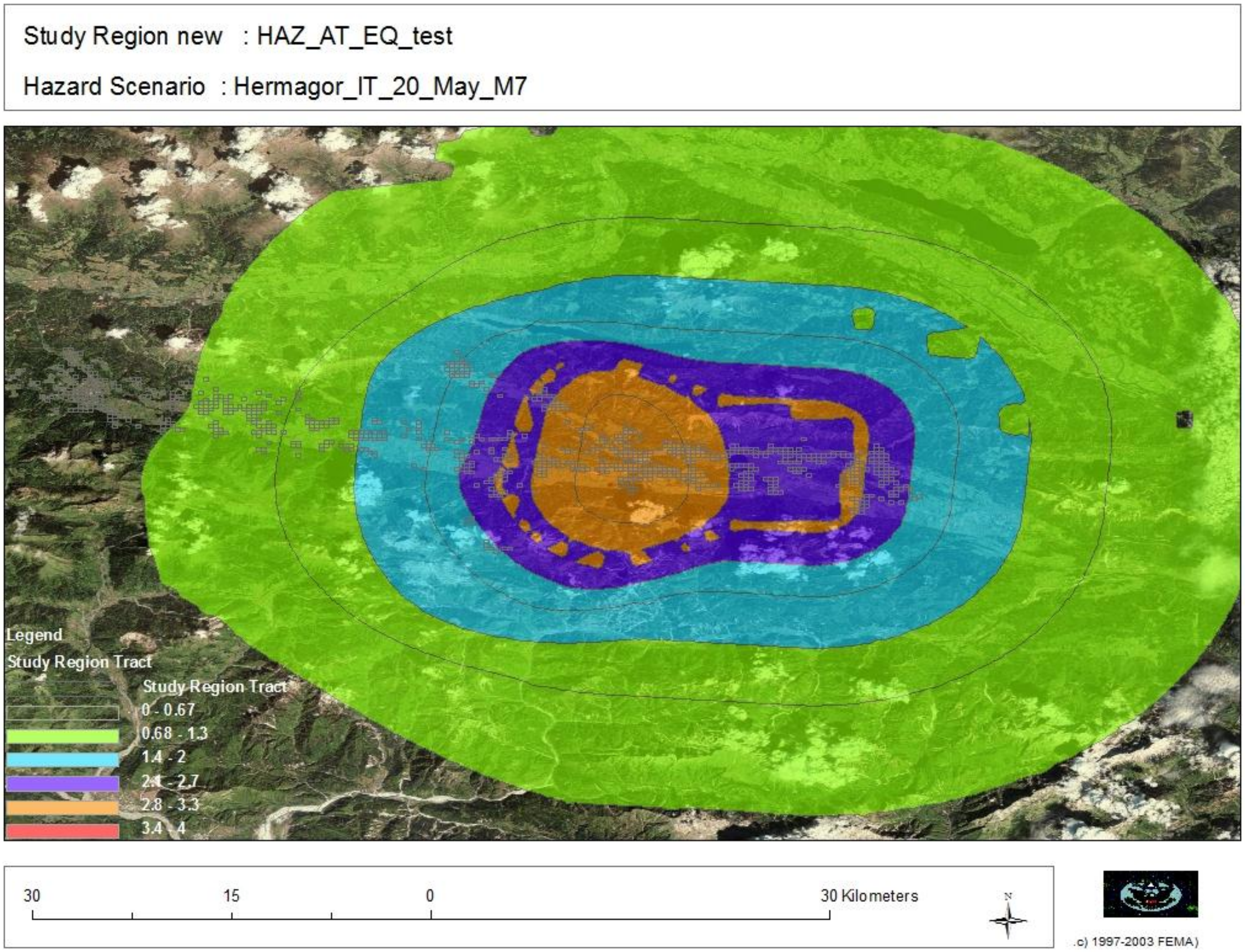

Figure 46: Peak Acceleration Map for study region in Austria (in g unit).

Peak Velocity Maps:

Peak velocity values are contoured for the maximum horizontal velocity (in cm/sec). As with the acceleration maps, the vertical component amplitudes are disregarded for consistency with the regression relationships used to estimate values in gaps in the station distribution. Differences between rock and soil sites are apparent, but overall pattern is normally simpler than the peak acceleration pattern (USGS, 2006).

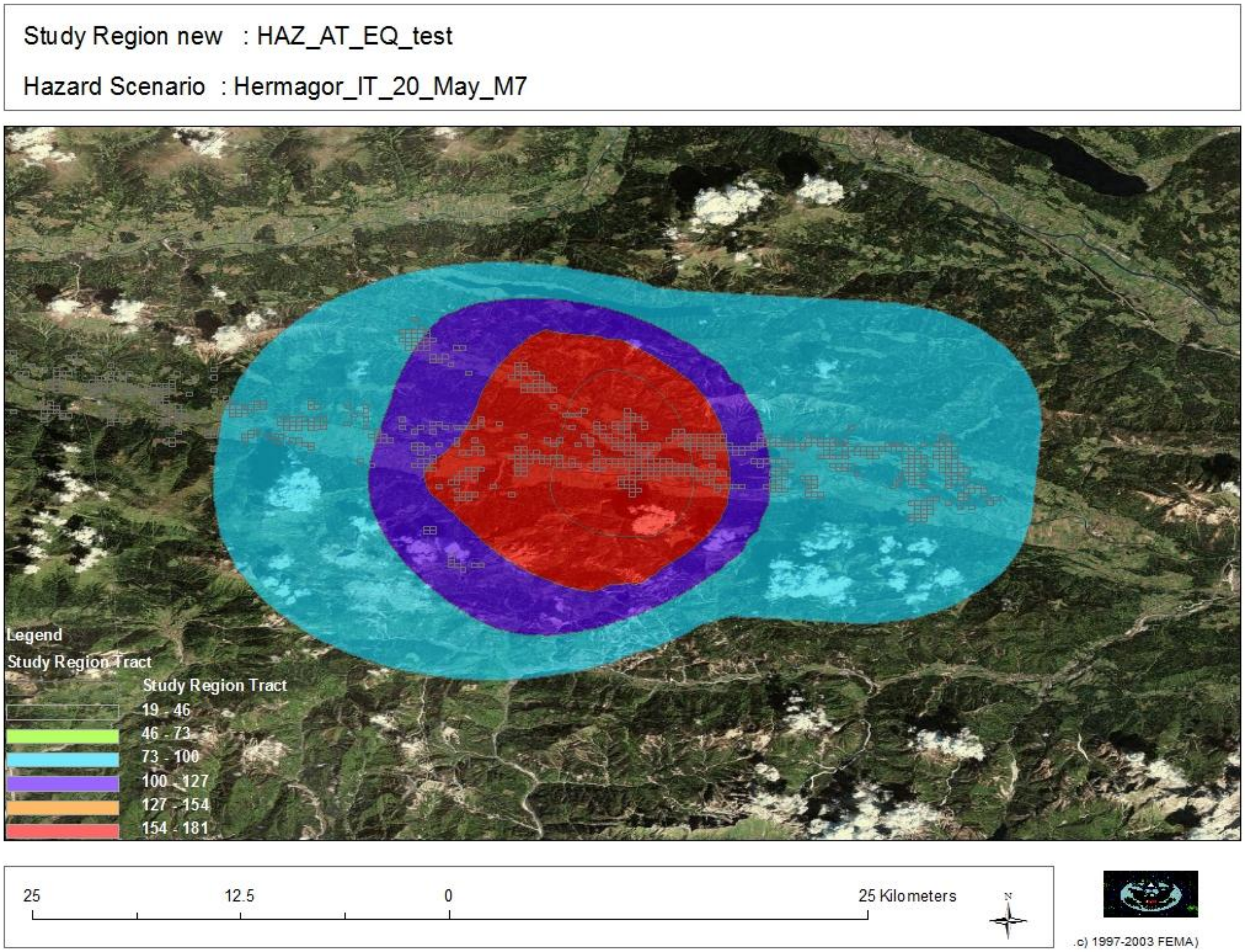

Figure 47: Peak Velocity Map for region in Austria (in cm/sec).

Spectral Response Maps:

For the earthquakes larger than magnitude 5.5, spectral response maps are made. This data representation is useful for engineers determining how a structure will react to ground motions. The response is represented in two different reference periods for 0.3 and 1.0 seconds (USGS, 2006).

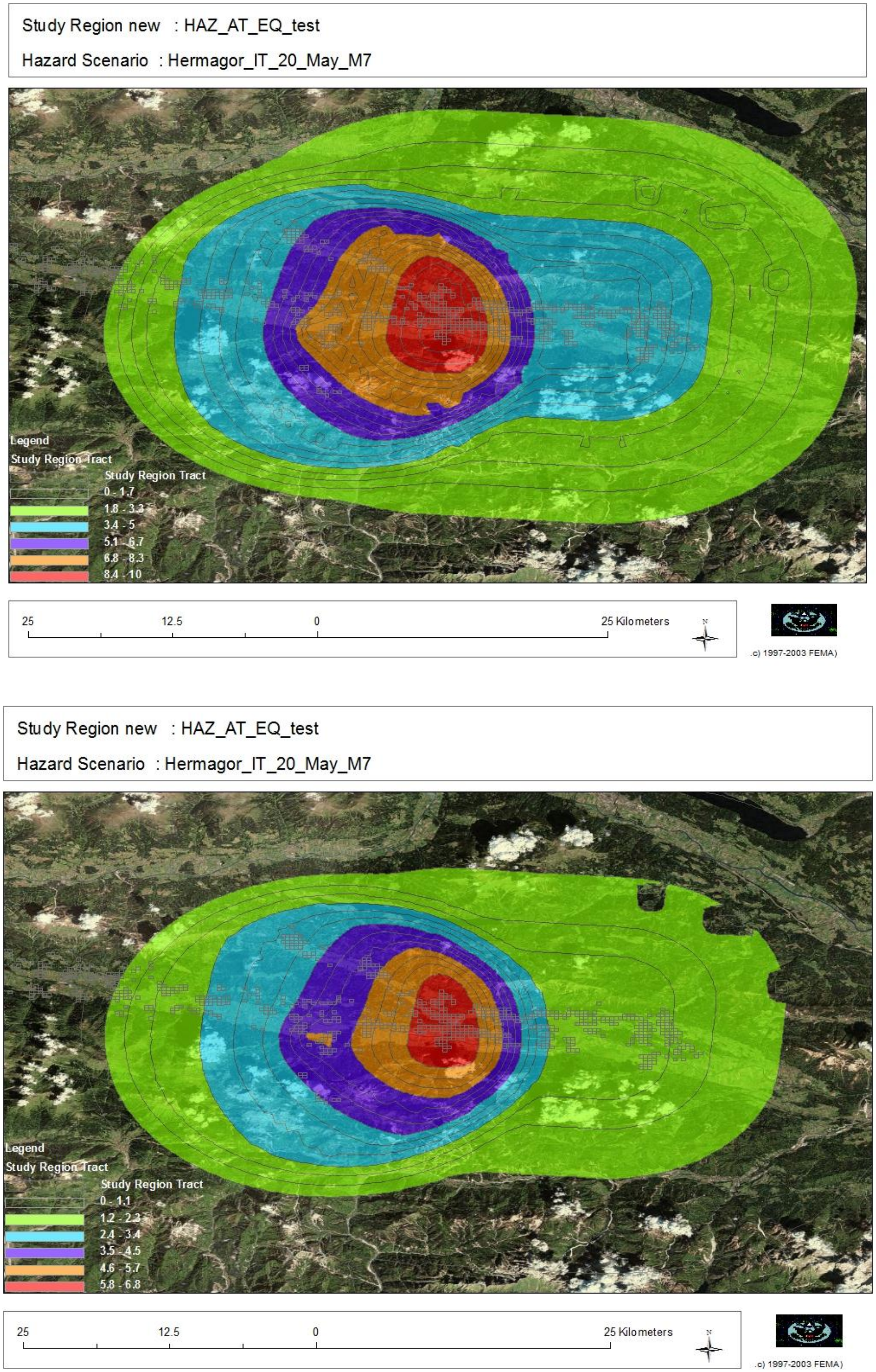

Figure 48: 0.3 and 1.0 second Spectral Response Maps respectively for study region in Austria (in g unit).

6.4. Earthquake Analysis

This section describes overview of how to define a scenario earthquake in Hazus-MH and follows by introducing the analysis made to assess the earthquake damage on the created inventory.

6.5. Earthquake Hazard Analysis

Hazus-MH has a number of options for defining the potential earth science hazards (PESH). Loss based estimation of hazards are explained in the Earthquake Hazard Data Integration section of the Methodology chapter.

To run the analysis with integrated hazard data, **user-supplied hazard** option is selected. In this option user will supply the ground shaking maps for estimating damage and loss. The ground shaking maps must be in personal geodatabase format and should be added to the list of available data maps defined under Hazard | Data Maps menu, as explained in the Data Integration section.

After the creation of the study region with specific inventory data, "Create new Scenario" option from the Hazard menu is selected. At the new scenario definition wizard the user supplied hazard option should be selected (Figure 49).

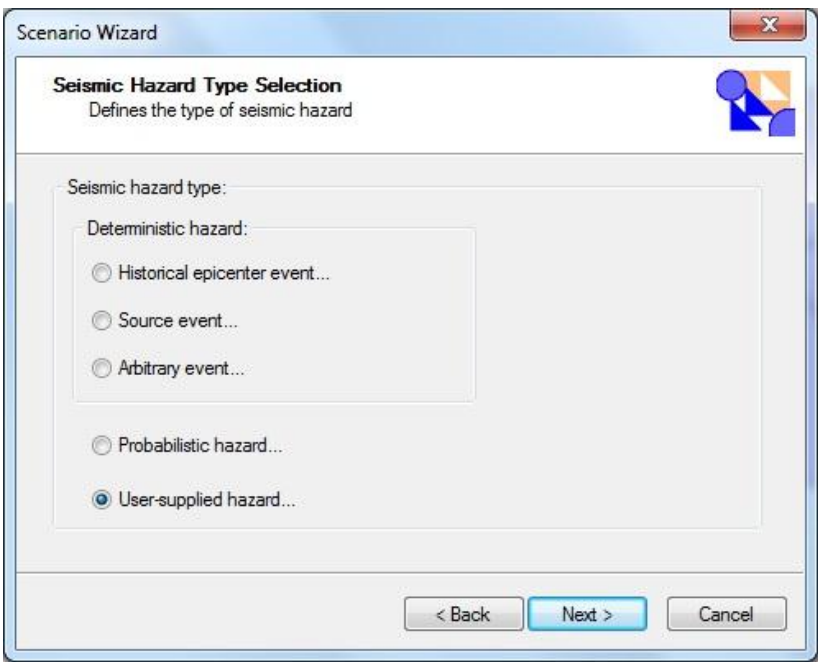

Figure 49: User supplied hazard option selection

After the selection of user defined scenario, each ground motion shake map corresponding to the hazard specifications should be selected from the dropdown menus and the specific magnitude generating the earthquake event should be defined (Figure 50).

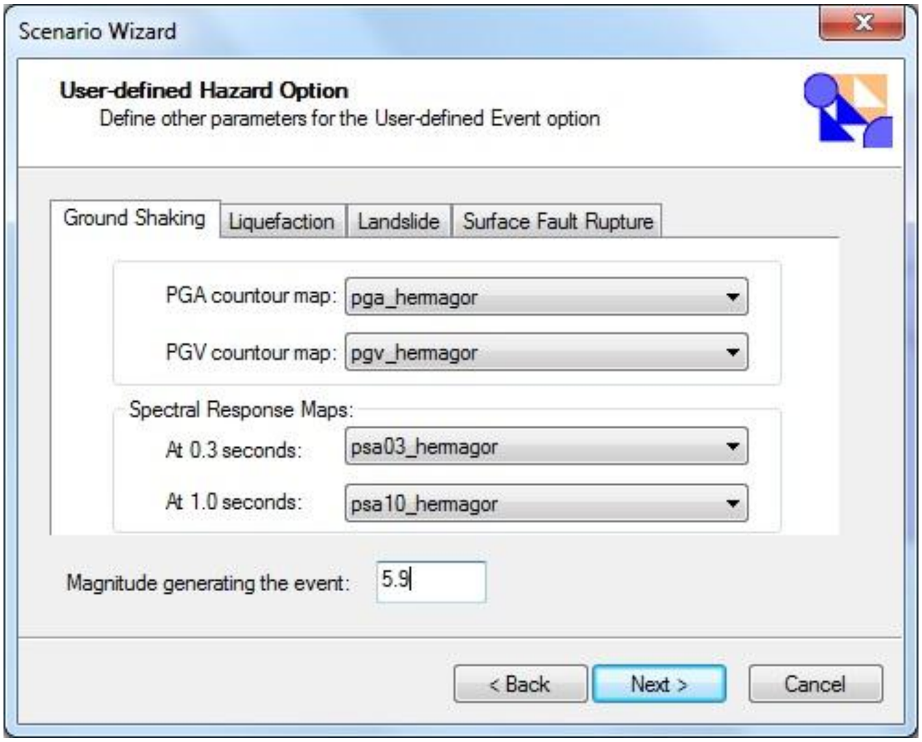

Figure 50: Ground motion shake maps selection

After defining the specifications hazard is ready to be run as a user defined scenario. The summary of the scenario settings is shown at the "Show Current" scenario menu (Figure 51).

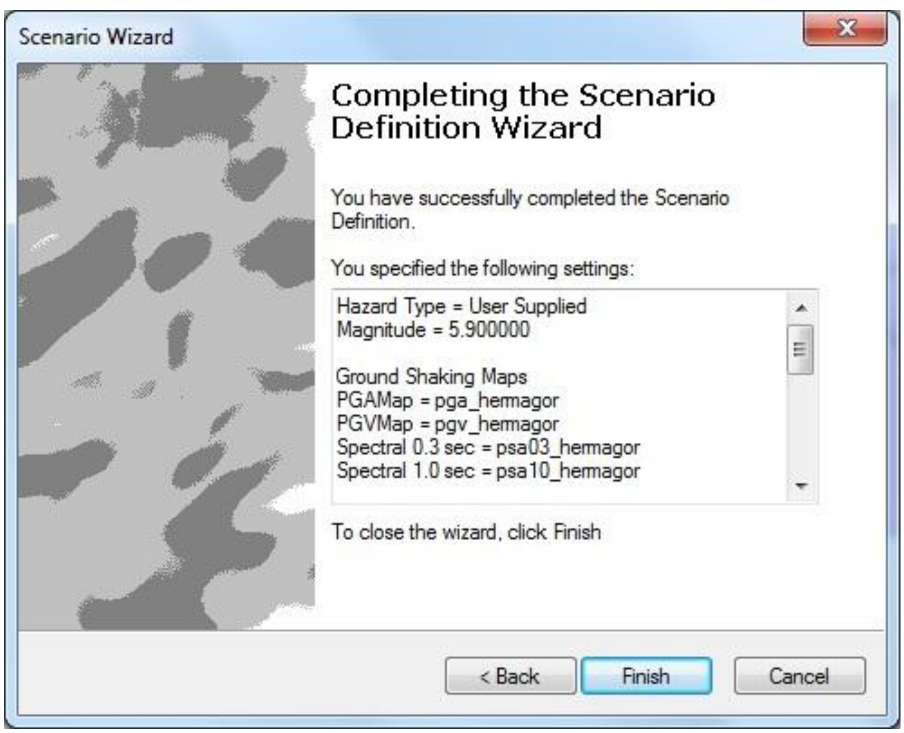

Figure 51: Hazard scenario settings

The analysis are run from the Analysis | Run menu. User can either select each model specifically to be run or choose the select all option to run all the analysis models consecutively.

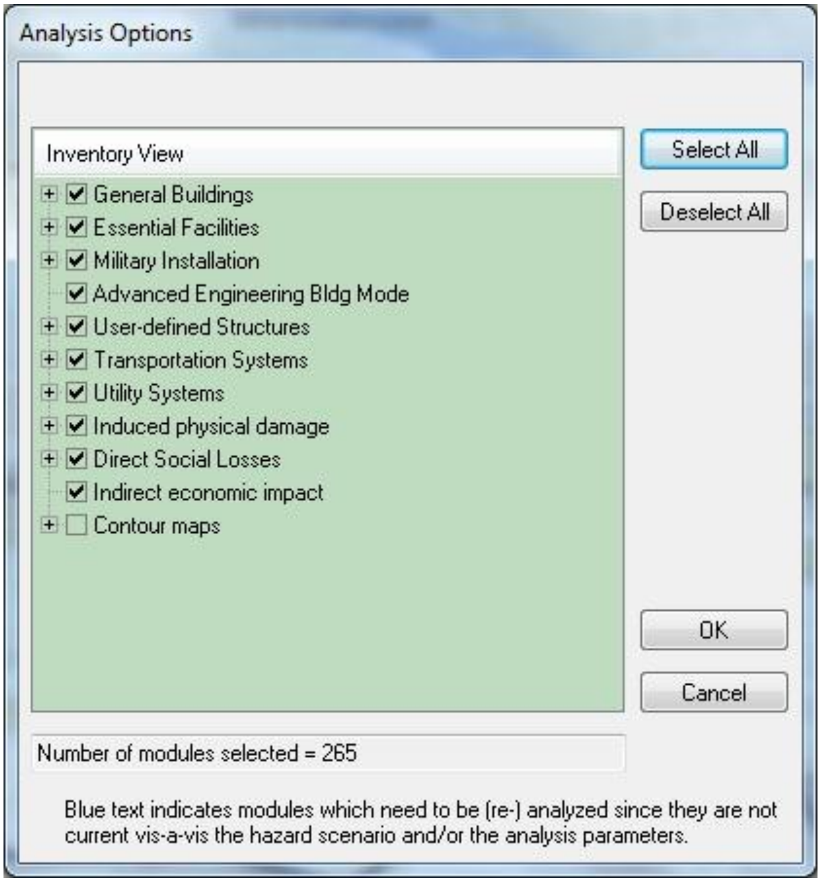

Figure 52: Selection of analysis options

7. Results

The results of damage estimation methods are used to estimate: (1) casualties due to structural damage, including fatalities, (2) monetary losses due to building damage (i.e. cost of repairing or replacing damaged buildings and their contents); (3) monetary losses resulting from building damage and closure (e.g., losses due to business interruption); (4) social impacts (e.g., loss of shelter); and, (5) other economic and social impacts.

7.1. Damage Results

The building damage predictions may also be used to study expected damage patterns in a given region for different scenario earthquakes (e.g., to identify the most vulnerable building types, or the areas expected to have the most damaged buildings).

Damage to nonstructural components of buildings (i.e., architectural components, such as partition walls and ceilings, and building mechanical/electrical systems) primarily affects monetary and societal functional losses and generates numerous casualties of mostly light to moderate severity. Damage to structural components (i.e., the gravity and lateral-load-resisting systems) of buildings, Hazard mitigation measures are different for these two categories of building components as well. Hence, it is desirable to separately estimate structural and nonstructural damage.

Building damage varies from “none” to “complete” as a continuous function of building deformations (building response). Wall cracks may vary from invisible or “hairline cracks” to cracks of several inches wide. Generalized “ranges” of damage are used by the Methodology to describe structural and nonstructural damage, since it is not practical to describe building damage as a continuous function.

The Methodology predicts a structural and nonstructural damage state in terms of one of four ranges of damage or “damage states”: Slight, Moderate, Extensive, and Complete. For example, the Slight damage state extends from the threshold of Slight damage up to the threshold of Moderate damage. Damage predictions resulting from this physical damage estimation method are then expressed in terms of the probability of a building being in any of these four damage states. (FEMA, 2009a)

7.1.1. Structural Damage:

Slight Structural Damage: Small cracks at corners of door and window openings and wall-ceiling intersections; small cracks in chimneys and veneer.

Moderate Structural Damage: Large cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in wall panels; large cracks in chimneys; toppling of tall masonry chimneys.

Extensive Structural Damage: Large diagonal cracks across shear wall panels or large cracks at joints; permanent lateral movement of floors and roof; toppling of most chimneys; cracks in foundations; splitting of plates and/or slippage of structure over foundations; partial collapse of “room-over-garage” or other “soft-story” configurations; small foundations cracks.

Complete Structural Damage: Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks. (FEMA, 2009a)

Financial losses due to structural, non-structural and total damages are presented in the following sections. Figure 53 shows the financial loss based on the structural damage to residential buildings; Figure 54 shows the financial loss based on the structural damage to commercial buildings and Figure 55 shows the financial loss based on the structural damage to all buildings respectively. It is monitored that the damage is focused in and around the the town centers of Hergamor-Presseger See and Koetschah –Mauthen town centers because of the population the density in these locations and the respectively higher number of buildings and facilities in the town centers. Categories in the maps are presented in a graduated classification from none to complete in five classes as in above sections.

7.1.2. Structural Damage Financial Loss Maps

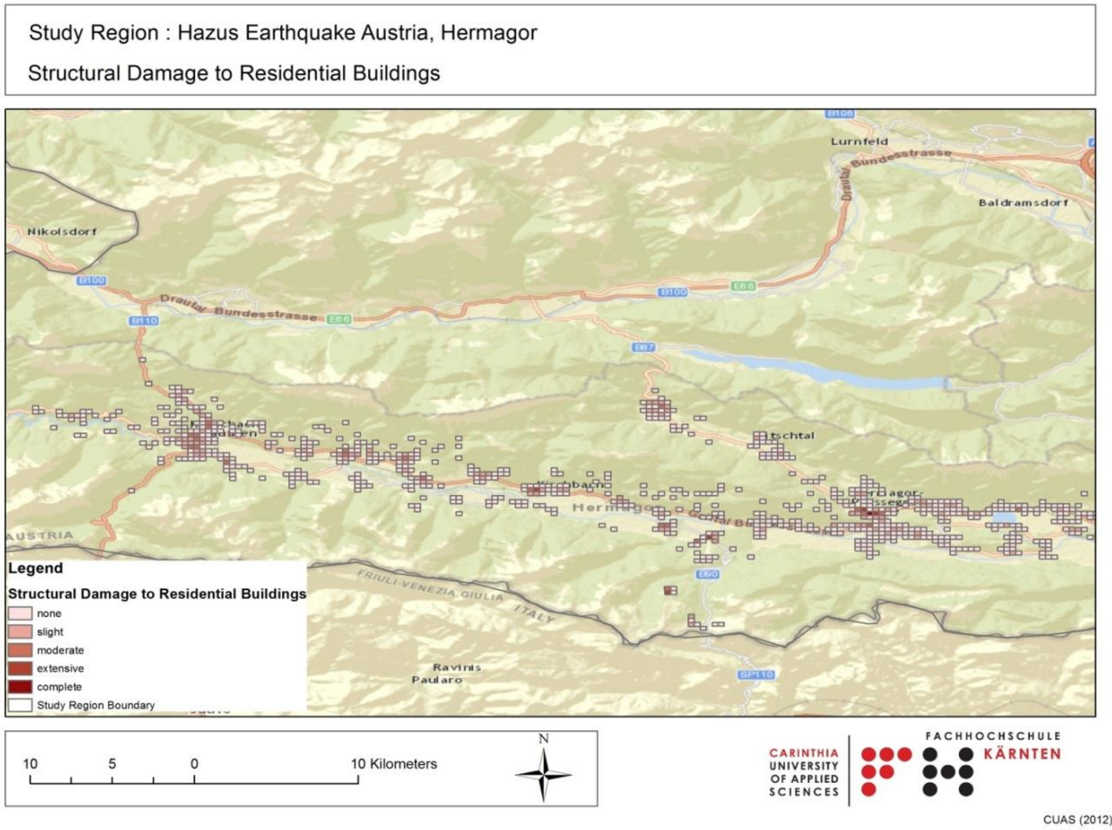

Figure 53: Structural Damage to Residential Buildings

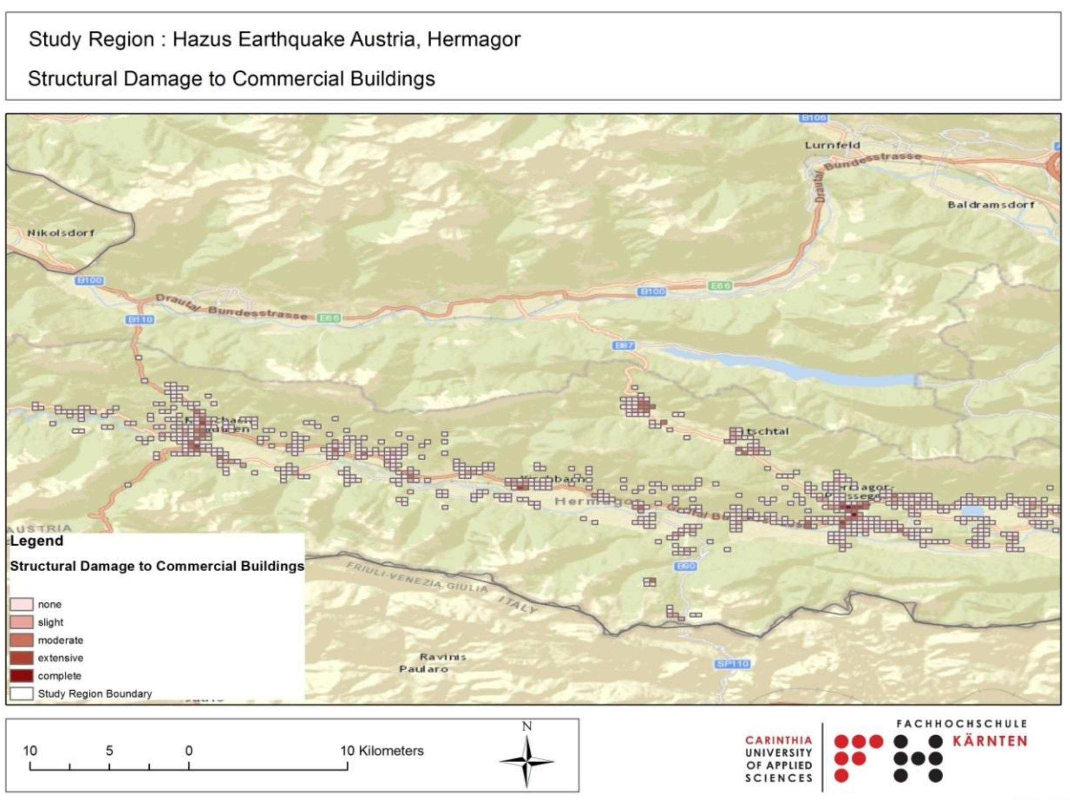

Figure 54: Structural Damage to Commercial Buildings

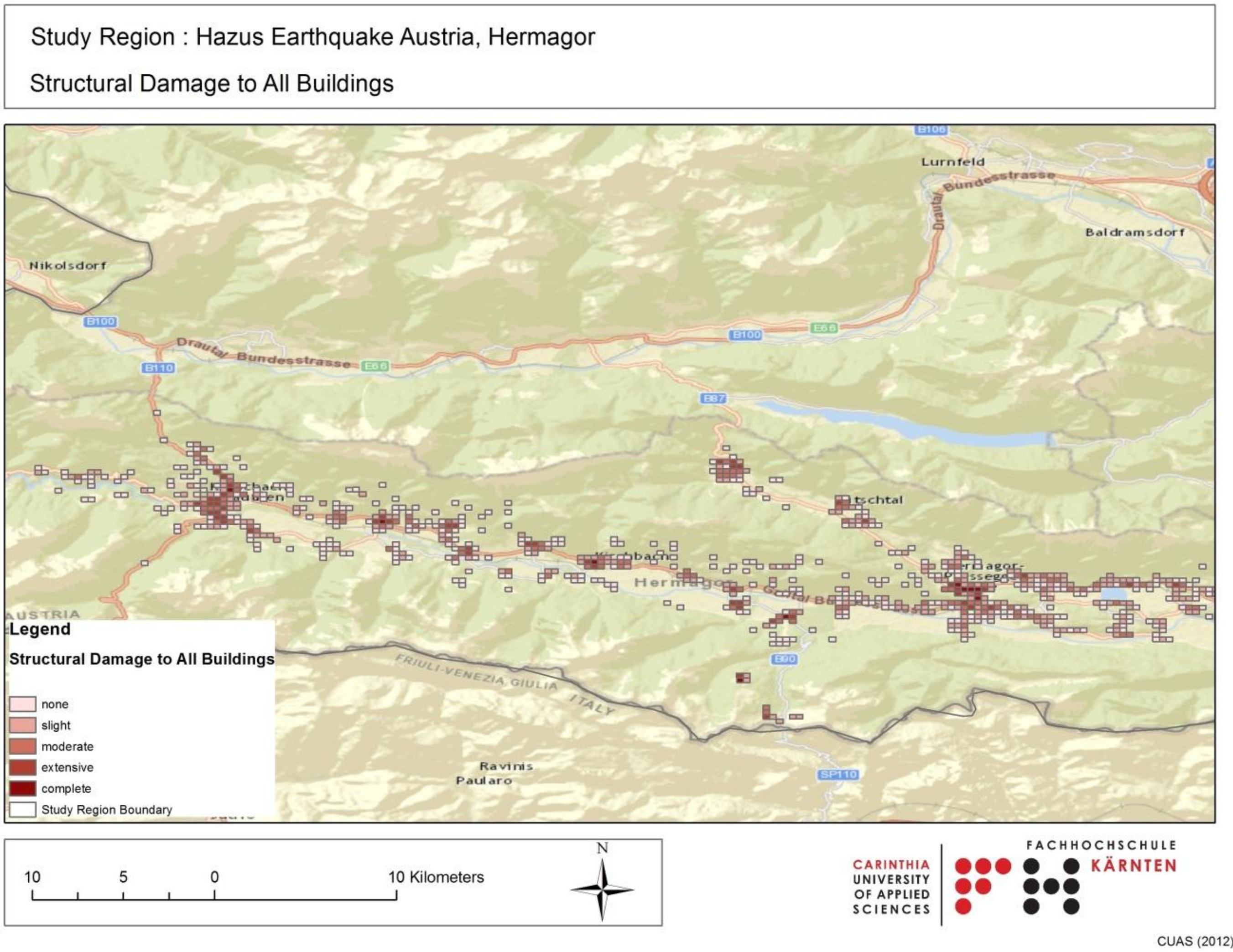

Figure 55: Structural Damage to All Buildings

7.1.3. Nonstructural Damage

Four damage states are used to describe nonstructural damage: Slight, Moderate, Extensive and Complete nonstructural damage. Nonstructural damage is considered to be independent of the structural model building type (i.e. partitions, ceilings, cladding, etc. are assumed to incur the same damage when subjected to the same inter-story drift or floor acceleration whether they are in a steel frame building or in a concrete shear wall building), consequently, building-specific damage state descriptions are not meaningful. Instead, general descriptions of nonstructural damage states are provided for common nonstructural systems.

The type of nonstructural components in a given building is a function of the building occupancy use classification. For example, single-family residences would not have curtain wall panels, suspended ceilings, elevators, etc. while these items would be found in an office building. Hence, the relative values of nonstructural components in relation to the overall building replacement value vary with type of occupancy.

In the following, general descriptions of the four nonstructural damage states are described for common nonstructural building components,

Slight Nonstructural Damage: A few cracks are observed at intersections of walls and ceilings and at corners of door openings.

Moderate Nonstructural Damage: Larger and more extensive cracks requiring repair and repainting; some partitions may require replacement of board or other finishes.

Extensive Nonstructural Damage: Most of the walls and ceilings are cracked and a significant portion may require replacement of finishes; some door frames in the partitions are also damaged and require re-setting.

Complete Nonstructural Damage: Most walls and ceilings finish materials and framing may have to be removed and replaced; damaged studs repaired, and walls to be refinished. Most door frames may also have to be repaired and replaced. (FEMA, 2009a)

Figure 56 shows the financial loss based on the non-structural damage to residential buildings; Figure 57 shows the financial loss based on the non-structural damage to commercial buildings and Figure 58 shows the financial loss based on the non-structural damage to all buildings respectively.

7.1.4. Nonstructural Damage Financial Loss Maps

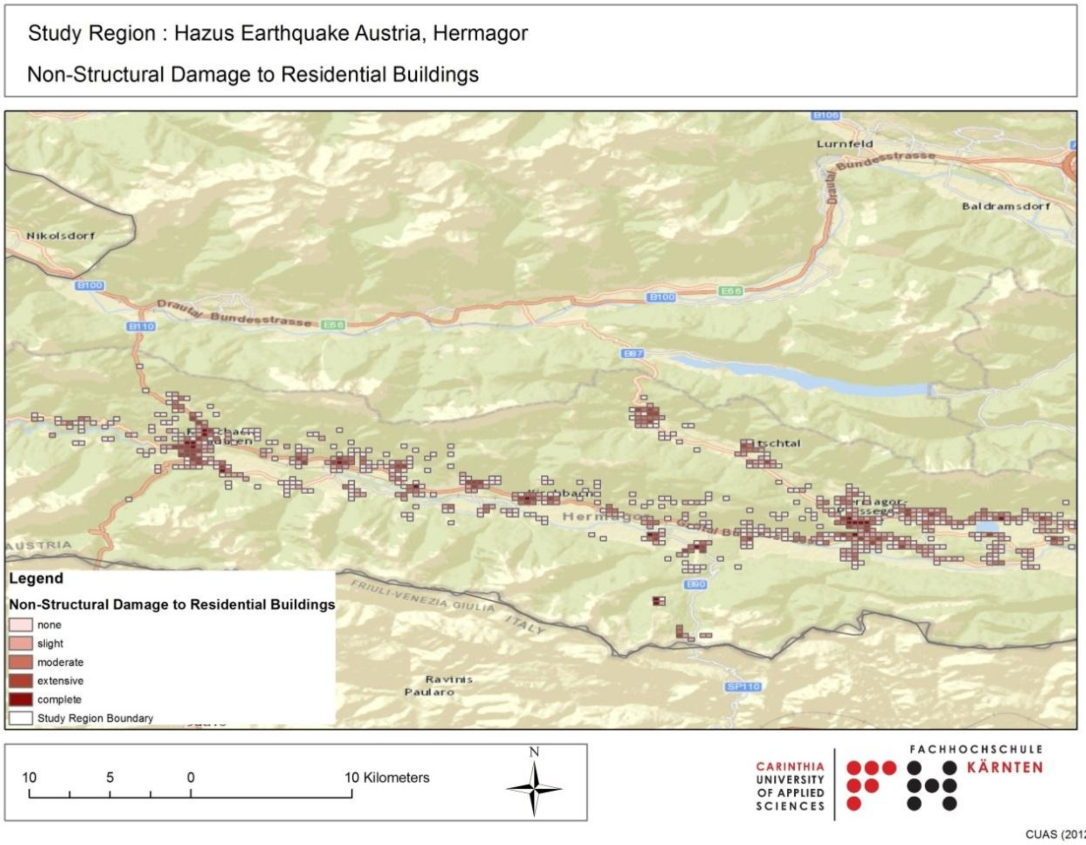

Figure 56: Nonstructural Damage to Residential Buildings

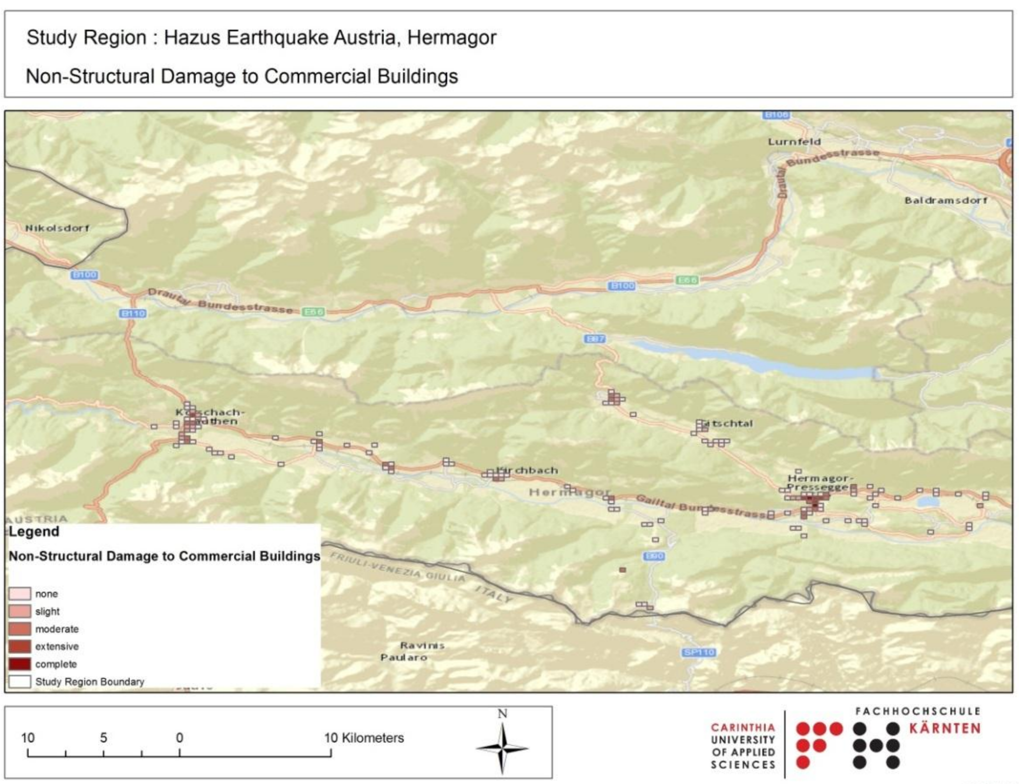

Figure 57: Nonstructural Damage to Commercial Buildings

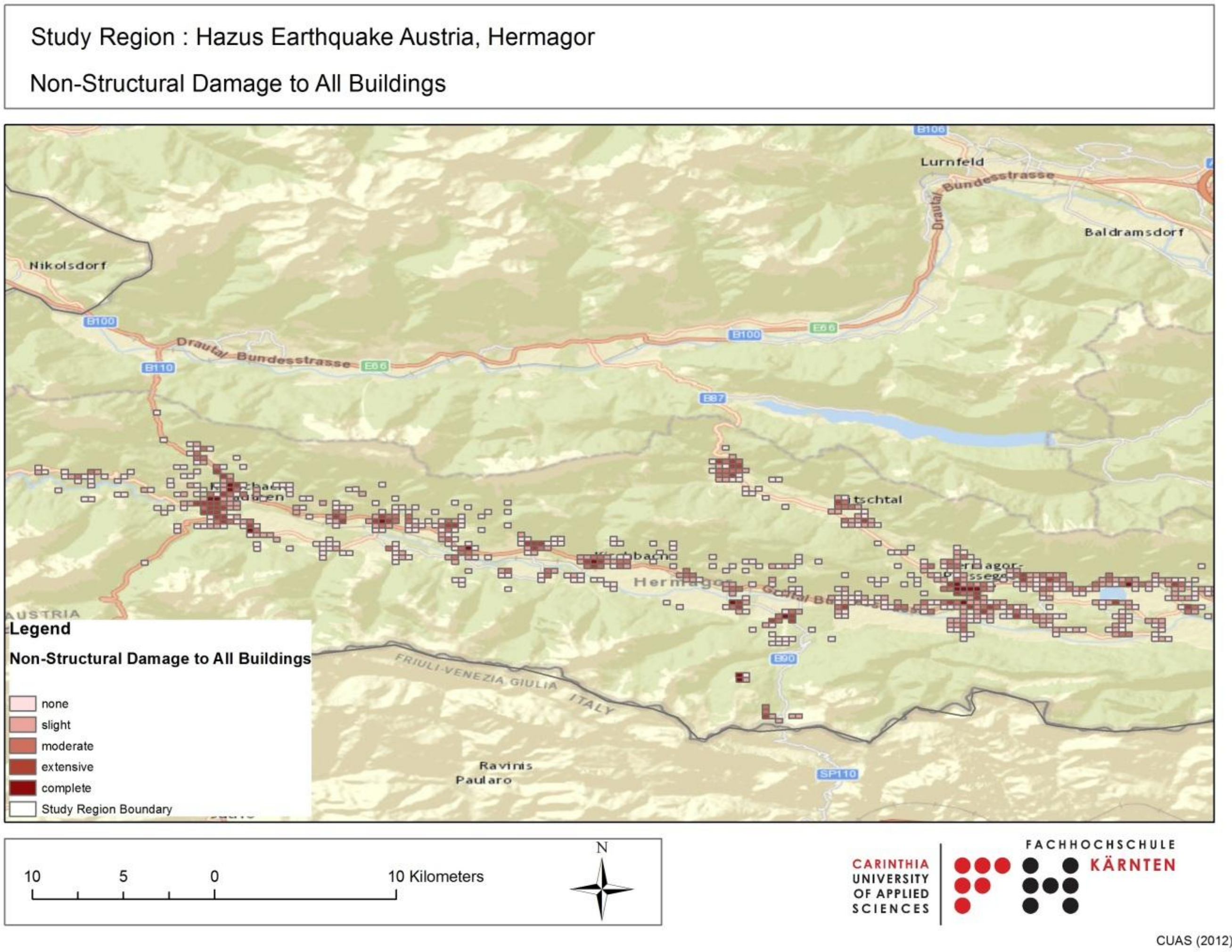

Figure 58: Nonstructural Damage to All Buildings

7.1.5. Total Damage

Hazus-MH estimates that about 737 buildings will be at least slightly damaged, 51 buildings will be at least moderately damaged and 1 building will be at least extensively damaged. Total of the damaged buildings are 789 buildings in the region. Table 7 summarizes the expected damage by general occupancy for the buildings in the region.

Table 7: Expected Building Damage by Occupancy

	Slight	Moderate	Extensive	Complete
Agriculture	0	0	0	0
Commercial	24	5	0	0
Education	0	0	0	0
Government	0	0	0	0
Industrial	0	0	0	0
Other Residential	514	43	1	0
Religion	0	0	0	0
Single Family	199	3	0	0
Total	**737**	**51**	**1**	**0**

7.1.6. Total Damage Financial Loss Maps

Figure 59 shows the financial loss based on the total damage to residential buildings; Figure 60 shows the financial loss based on the total damage to commercial buildings and Figure 61 shows the financial loss based on the total damage to all buildings respectively.

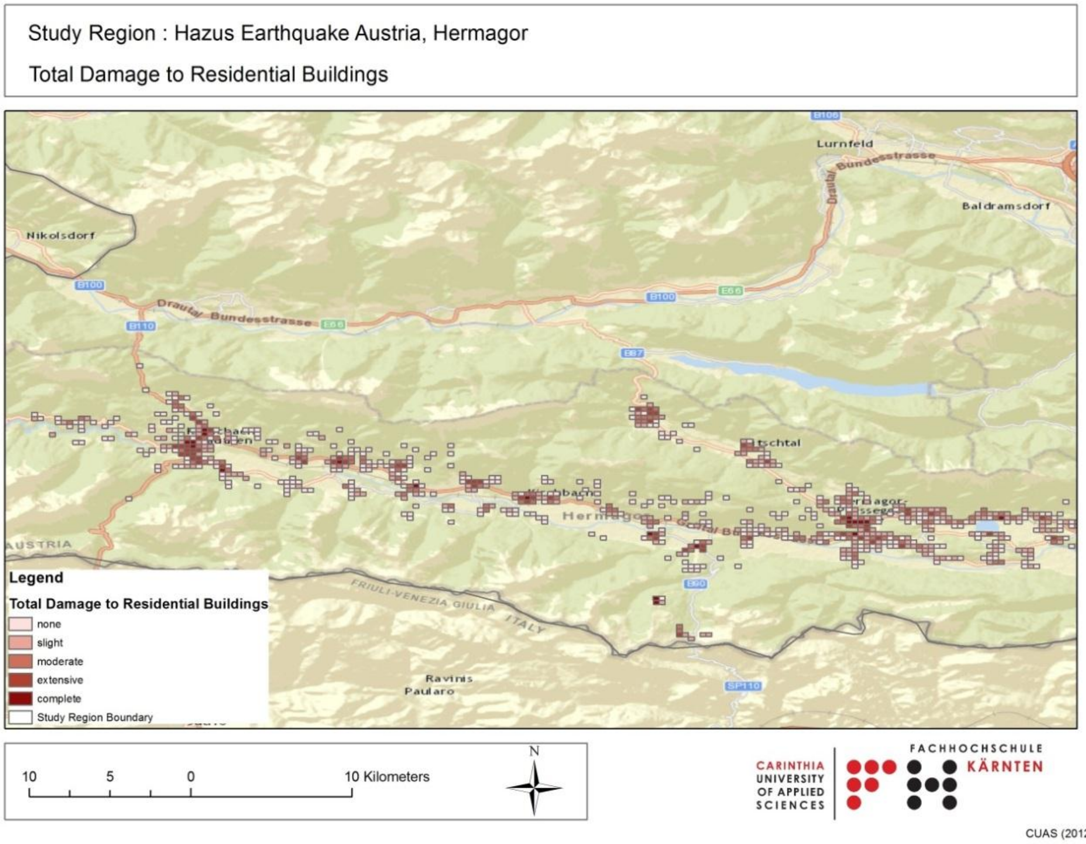

Figure 59: Total Damage to Residential Buildings

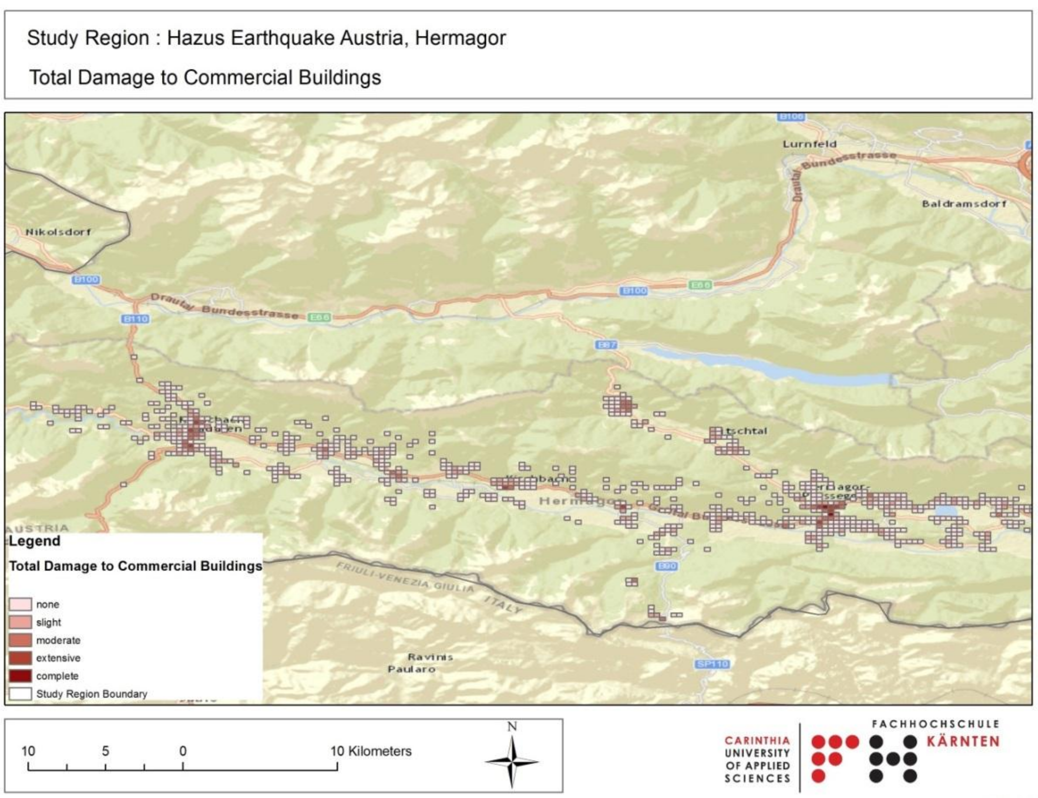

Figure 60: Total Damage to Commercial Buildings

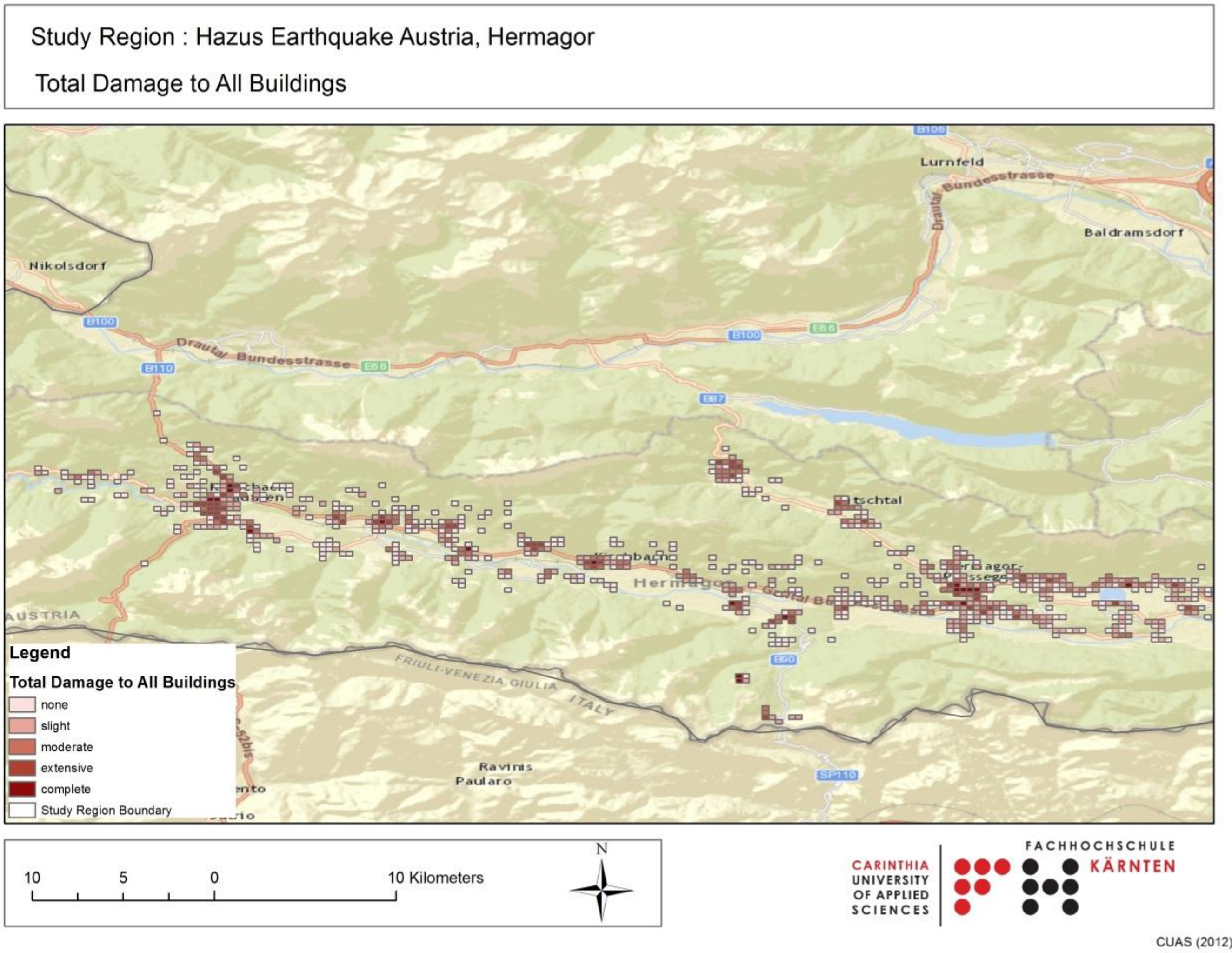

Figure 61: Total Damage to All Buildings

7.1.7. Essential Facilities and Utility System Damage

Before the earthquake, the region had 22 hospitals available for use. On the day of the earthquake, the model estimates that 13 hospitals are at least moderately damaged and 7 are at least extensively damaged and remaining 2 undamaged.

Table 8: Expected Damage to School Facilities

Classification	**Total**	**# Facilities**	
		At Least Moderate Damage > 50%	**At Least Extensive Damage > 50%**
Schools	22	13	7

Before the earthquake, the region had 351 Electrical Power facilities available for use. On the day of the earthquake, the model estimates that 237 facilities are at least moderately damaged and 109 are at least extensively damaged and remaining 5 undamaged.

Table 9: Expected Damage to Electrical Power Facilities

Classification	Total	# Facilities	
		At Least Moderate Damage > 50%	At Least Extensive Damage > 50%
Electrical Power	351	237	109

Table 10 shows that most of the Electrical Power facilities will be out of service on the day of the earthquake and it will take almost 90 days to bring the service back to the previous condition.

Table 10: Expected Electric Power System Performance

	Total # of Households	Number of Households without Service				
		At Day 1	At Day 3	At Day 7	At Day 30	At Day 90
Electric Power	5,930	4,879	3,530	2,185	846	6

7.1.8. Debris Generation

Hazus-MH estimates the amount of debris that will be generated by the earthquake. The model breaks the debris into two general categories: a) Brick/Wood and b) Reinforced Concrete/Steel. This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 0.30 million tons of debris will be generated. Of the total amount, Brick/Wood comprises 64.00% of the total, with the remainder being Reinforced Concrete/Steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 11,960 truckloads (@25 tons/truck) to remove the debris generated by the earthquake (Figure 62).

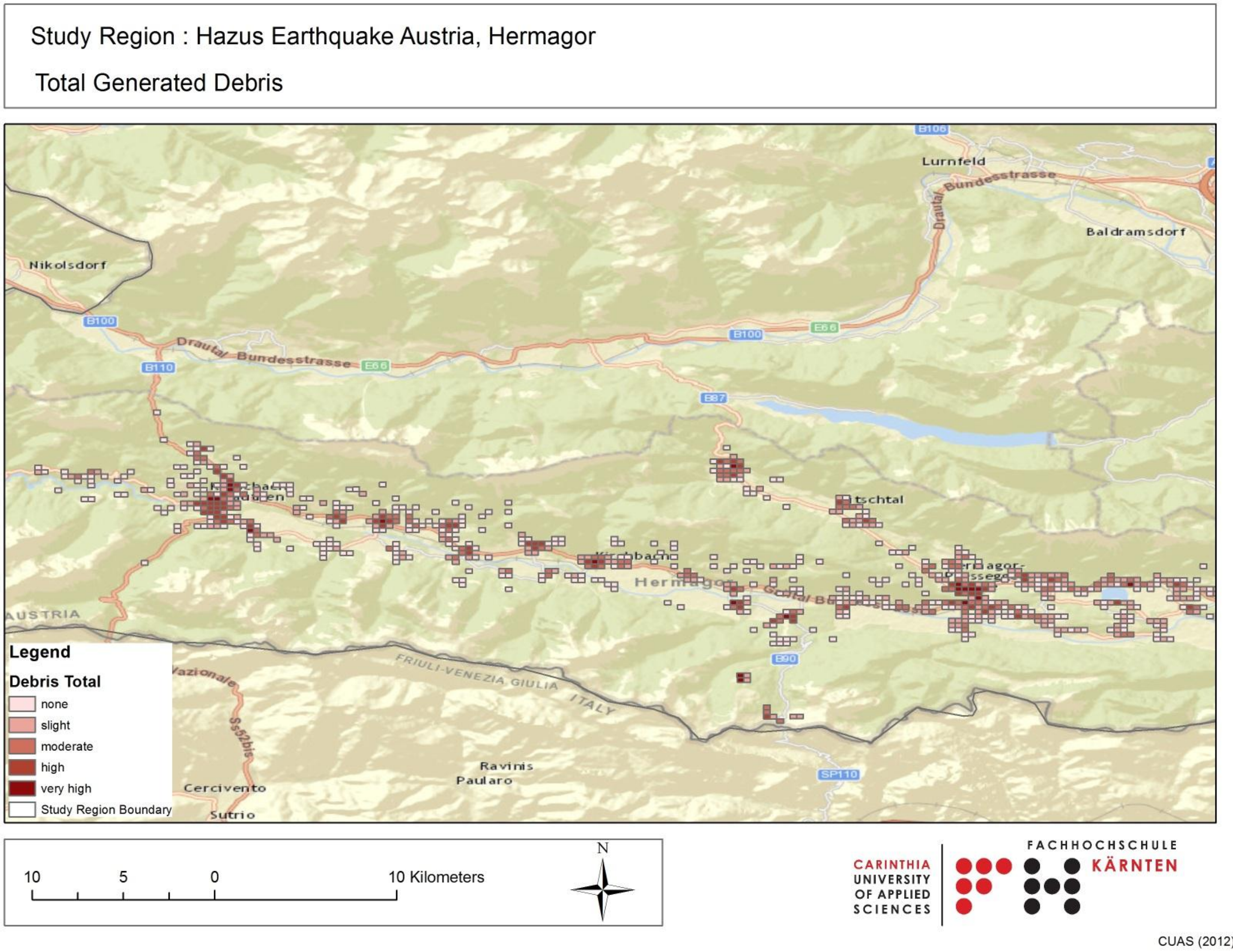

Figure 62: Total Generated Debris

7.1.9. Shelter Requirement

Hazus-MH also estimates the number of households that are expected to be displaced from their homes due to the earthquake and the number of displaced people that will require accommodations in temporary public shelters. Since there is no completely destructed building in the study region the model estimates 0 households to be displaced due to the earthquake but this estimation should also be verified with the local sources and conditions.

8. Discussion

In this section, the discussion of the local proof of concept, the main issues affecting the model results and the limitations of the Earthquake Model is covered.

As presented in the Results Chapter most of the analysis models are ready to be run with the methodology prepared in this international framework study.

However all of the analyses are directly dependent to the quality of the data collected for the region. The data collection, preparation and integration processes are the main issues in the model. The quality of the input data is vital to the analysis to be made and the results produced out these steps. Each step during the data collection and processing should be monitored for data quality.

The model uses many default data and various assumptions are made during the process. The original Hazus-MH structure is produced taking the US environment and building standards into consideration, to reach a regional level framework specific for each country all these default data processes and damage functions should be customized focusing on the local conditions and hazard risks.

General Building Stock Damage Functions

During the testing process many different analysis are run on batch datasets. It is noticed that the effects of the usage of damage functions changes the results of the Earthquake Model for the GBS data. In the default setting the users change the required datasets but use default damage functions, running the analysis and receiving the results. When these damage functions are needed to be changed further geophysical and seismical studies are needed to customize them representing the specific site conditions. After the intermediate steps are fulfilled users can apply these newly acquired damage functions in the analysis and receive more accurate results for the specific study region.

Attenuation Functions

The majority of attenuation functions in Hazus-MH are stochastic relations developed based on the specific regions of the U.S. The way around using the attenuation functions currently available in Hazus-MH for the estimation of strong ground motion is using the user-defined scenario option as explained in the methodology chapter. The development of site specific attenuation functions for the study region of interest should be considered during further development of the methodology.

Soil Types and Classifications

Soil data is important and local data (i.e. NHERP soils maps) are best. However, the Shakemaps used in the methodology are prepared taking the NHERP soil types into consideration internationally where the USGS has modeled soil types based off the DEMs. This simplifies the soil data maps integration into the Hazus-MH Earthquake model and avoids the separate soil map preprocessing requirements.

Technical Issues & Dataset Limitations

Hazus-MH has some technical issues related to the functionality of the damage model. One of these issues can be summarized as the ability to integrate linear datasets for transportation facilities like highway or railroad segments but the inability to generate earthquake assessment results for these facilities. The ability to import high potential loss facilities without damage assessment functionality is also a similar issue. Another related issue is the compulsory importing of the building type even if related data is not available.

These issues can be addressed in future versions of Hazus-MH while the developement processes of core models are continuing.

Projection

Hazus-MH 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 differences between NAD83 and the World Geodetic System 1984 (WGS84) are raised as a question. 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 to one another (Conner 2003). 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).

8.1. Conclusions

After preparing all the processes and the methodology of this study the following outcomes are standing out as a conclusion,

Hazus-MH is a well-studied and documented risk assessment tool that is widely used in many areas of disaster management and mitigation in the United States. With the developed methodology in this master's thesis study Hazus-MH Earthquake Model can be applied in an international framework context taking the explained issues into consideration. With this proposed framework users can perform earthquake damage and loss estimation analysis for general building stock, essential facilities and lifelines in an international perspective. Moreover, the applied method offers an inexpensive way to perform earthquake damage and loss estimation and produce adequate results. With the further development and usage of this tool internationally many limitations and technical issues in the framework can be overcame.

Some of the existing limitations and the data collection and validation requirements may be dissatisfying to some user groups. But it should be taken into consideration that the data quality and the proper data quality control procedures are vital for the analysis model outcomes. The success of Hazus-MH depends on the input data, so these steps leads to the better results.

One of the fields of extension for this study is the European countries which are bind by European standard for seismic actions and rules for buildings and requirements. Most of the countries have geophysical organizations to supply and maintain the hazard data and statistical organizations and governmental offices can provide the necessary inventory data necessary to prepare the required inventory for Hazus-MH. As presented in this study many hazard maps can be produced using Hazus-MH with minimal costs.

9. Future Work

The main focus and the first steps for the future works may be defining the requirements for reaching a wider regional earthquake damage assessment. Each country should be analyzed based on these requirements and the local study region concept presented in this master`s thesis study should be extended to a regional level addressing the study region environment first in the European context and then for a worldwide coverage consecutively.

Another future research topic is the development of study region specific damage functions for earthquake damage assessment analysis. The original damage functions are produced for the US building environment and standards. The next step is to produce new damage functions matching the European standards for seismic related building requirements which would address the European environment in regional level.

Another focus in the future will be cooperation with universities, research institutions and study groups which work on the technical information about earthquake damage estimation in Europe. The model can be further developed with these efforts of cooperation.

One more aspect of a future study is the evaluation of using Volunteered Geographic Information (VGI) data (Goodchild 2007) as an inventory database source. The research on extending the conceptual workflow for collection and usage of VGI datasets as inventory datasets will show if it is possible to link it into the data integration process while meeting data specifications of Hazus-MH.

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11. List of Figures

12. List of Tables

13. Appendices

Appendices provided in this chapter contain geodatabase sections which includes an overview of the database, a main table listing the sub-tables and feature classes, including a brief description of each. For each feature class and table, the following information is documented:

Identification: Name of feature class or table

Type: ESRI's feature class or table type

Purpose: Entity purpose in the aggregation process or/and analysis

Data: Feature classes and tables field definition

Name: Field name. If a field is found in the study region databases, but not in the state database, a value of N/A is included in the column.

Field Type: Contains the field format. If Access field type differs from ESRI field type, Access field type is shown in italics.

Index: Indicates if the field has index. Index properties are provided.

Required: For the aggregation process. Provides an indication of whether a value must be provided other than Null and those specified on Values column.

Values: Identifies valid values for this data element.

Field Description: Provides a human readable description of the field's data element.

13.1. Appendix 1: System Boundary Database Content

The syBoundary.mdb database includes:

Table 11: System Boundary feauture classes

Name	Type	Content
syState	ESRI Feature Class	Worldwide country boundaries,
syCounty	ESRI Feature Class	Administrative boundaries specific to the country,
syTract	ESRI Feature Class	Grid structure layer based on population distribution,

13.1.1. State Boundaries: syState Feature Class

In the international framework structure this feature class contains data related to the country boundaries.

Table 12: State Boundaries Table

Identification:	syState				
Type:	ESRI Polygon Feature Class				
Purpose:	Feature class that plays a crucial role during the aggregation process. It				
Data:					
Feature Class Field Definition					
Name	ESRI Type (Size)	Inde x*	Required*	Values	Description
StateFips	Text(2)	T	T	FIPS state code	Federal Information Processing Standard (FIPS) state code
State	Text(2)	T, U, A	T	USPS State name abbreviation	United States Postal Service (USPS) state abbreviation
StateName	Text(40)	F			State name
Region	Short(2) Integer(2)	F	T	1 = Western United States 2= Central Eastern United States	Region name
NumCounties	Short(2) Integer(2)	F	T		Number of counties in the syCounty feature class belonging to the state record
* T=True; F=False; U=Unique; NU=Non-Unique; A=Ascending; D=Descending; UC=Uppercase; LC=Lowercase					

13.1.2. County Boundaries: syCounty Feature Class

In the international framework structure this feature class contains data related to the administrative structure boundaries.

Table 13: County Boundaries Table

Identification:	syCounty				
Type:	ESRI Polygon Feature Class				
Purpose:	A system boundaries feature class that plays a crucial role during the aggregation process. It belongs to syBoundary.mdb. Provides the definition of county boundaries and the counties available for the region aggregation process.				
Data:					
Feature Class Field Definition					
Name	ESRI Type (Size) Access Type (Size)	Index*	Required *	Values	Description
CountyFips	Text(5)	T, U, A	T	Five-digit FIPS county code	Five-digit FIPS county code. First two digits are the state FIPS; the remaining three digits are the county code.
CountyFips3	Text(3)	T, NU, A	T	Three-digit FIPS county code	Last three digits of the FIPS county code
CountyName	Text(40)	T, NU, A	T		County name
State	Text(2)	T, NU, A	T	USPS state abbreviation	USPS state abbreviation
StateFips	Text(2)	T, NU, A	T	FIPS state code	FIPS state code
NumTracts	Short(2) Integer(2)	F	F		Number of tracts in the syTract feature class belonging to the state record
* T=True; F=False; U=Unique; NU=Non-Unique; A=Ascending; D=Descending; UC=Uppercase; LC=Lowercase					

13.1.3. Census Tract Boundaries: syTract Feature Class

In the international framework structure this feature class contains data related to the population distribution grid.

Table 14: Census Tract Boundaries Table

Identification:		syTract			
Type:		ESRI Polygon Feature Class			
Purpose:		A system boundaries feature class that plays a crucial role during the aggregation process. It belongs to syBoundary.mdb. Provides the definition of census tract boundaries and the census tract available for the region aggregation process.			
Data:					
Feature Class Field Definition					
Name	ESRI Type (Size) Access Type (Size)	Index*	Required*	Values	Description
Tract	Text(1 1)	T, U, A	T	11 digits of the census tract number	11 digits of the census tract number from the 2000 US Census
CountyFips	Text(5)	T, NU, A	T	Five-digit FIPS county code	Five-digit FIPS county code. First two digits are the state FIPS; the remaining three digits are the county code.
Tract6	Text(4 0)	T, NU, A	T	Census tract six-digit number	Census tract six-digit number from the 2000 US Census
TractArea	Float(4) Single(4)	F	F		Census tract area (in km^2)
CenLongit	Double (8) Double (8)	F	F	Longitude decimal degrees	Census tract longitude (centroid)
CenLat	Double (8) Double (8)	F	F	Latitude decimal degrees	Census tract latitude (centroid)
* T=True; F=False; U=Unique; NU=Non-Unique; A=Ascending; D=Descending; UC=Uppercase; LC=Lowercase					

13.2. Appendix 2: Boundaries Database

The Boundaries Database, Boundary.mdb database includes:

Table 15: Boundaries Database feature classes

Name	Type	Content
hzCounty	ESRI Polygon Feature Class	US Census 2000 county boundaries
hzTract	ESRI Polygon Feature Class	US Census 2000 census tract boundaries
hzDemographicsT	ESRI Table	Demographics by census tract
hzBldgCountOccupT	ESRI Table	Building count by occupancy by census tract
hzExposureOccupT	ESRI Table	Building (without content) full replacement value by occupancy by census tract
hzExposureContentOccupT	ESRI Table	Building content replacement value by occupancy by census tract
hzSqFootageOccupT	ESRI Table	Square footage by occupancy by census tract
hzMeansCountyLocationFactor	ESRI Table	Means location factors for residential and non-residential occupancies on a county basis

13.2.1. Demographics by Census Tract: hzDemographicT

In the international framework structure this feature class contains data related to provide housing and population statistics in the administrative boundaries geographical domain for the study region.

Table 16: Demographics by Census Tract Table

Identification:	hzDemographicT				
Type:	ESRI Table				
Purpose:	This table provides housing and population statistics at the census tract level for the study region. It belongs to Boundary.mdb. Data are transferred to the SQL Server database in the Region folder during the process of creating a new study region. Data are subsequently used for Hazus-MH estimation of hazards, damages, and losses, as well as mapping.				
Data:					
Feature Class Field Definition					
Name	ESRI Type (Size) ***Access Type (Size)***	Index*	Required*	Values	Description
CensusTract	Text(11)	T, U, A	T	11 digits of the census tract	11 digits of the census tract number

				number	
Population	Long(4) ***Long Integer(4)***	F	F		Total population
Households	Long(4) ***Long Integer(4)***	F	F		Total households
GroupQuarters	Long(4) ***Long Integer(4)***	F	F		Total group quarters
MaleLess16	Long(4) ***Long Integer(4)***	F	F		Total number of males under 16 years of age
Male16to65	Long(4) ***Long Integer(4)***	F	F		Total number of males aged 16 to 65
MaleOver65	Long(4) ***Long Integer(4)***	F	F		Total number of males over age 65
FemaleLess16	Long(4) ***Long Integer(4)***	F	F		Total number of females under 16 years of age
Female16to65	Long(4) ***Long Integer(4)***	F	F		Total number of females aged 16 to 65
FemaleOver65	Long(4) ***Long Integer(4)***	F	F		Total number of females over age 65
MalePopulation	Long(4)	F	F		Total males
FemalePopulation	Long(4) ***Long Integer(4)***	F	F		Total females
White	Long(4) ***Long Integer(4)***	F	F		Total white population
Black	Long(4) ***Long Integer(4)***	F	F		Total black population
NativeAmerican	Long(4) ***Long Integer(4)***	F	F		Total Native American population
Asian	Long(4) ***Long Integer(4)***	F	F		Total Asian population
Hispanic	Long(4) ***Long Integer(4)***	F	F		Total Hispanic population
PacifiIslander	Long(4) ***Long Integer(4)***	F	F		Total Pacific Islander population
OtherRaceOnly	Long(4) ***Long Integer(4)***	F	F		Total other race population
IncLess10	Long(4) ***Long Integer(4)***	F	F		Total households with less than $10,000 annual income
Inc10to20	Long(4) ***Long Integer(4)***	F	F		Total households with $10,000 to $20,000 annual income
Inc20to30	Long(4) ***Long Integer(4)***	F	F		Total households with $20,000 to $30,000 annual income
Inc30to40	Long(4) ***Long Integer(4)***	F	F		Total households with $30,000 to $40,000 annual income
Inc40to50	Long(4) ***Long Integer(4)***	F	F		Total households with $40,000 to $50,000 annual income
Inc50to60	Long(4) ***Long Integer(4)***	F	F		Total households with $50,000 to $60,000 annual

					income
Inc60to75	Long(4) ***Long Integer(4)***	F	F		Total households with $60,000 to $75,000 annual income
Inc75to100	Long(4)	F	F		Total households with $75,000 to $100,000 annual income
IncOver100	Long(4) ***Long Integer(4)***	F	F		Total households with more than $100,000 annual income
ResidDay	Long(4) ***Long Integer(4)***	F	F		Total daytime population
ResidNight	Long(4) ***Long Integer(4)***	F	F		Total nighttime population
Hotel	Long(4) ***Long Integer(4)***	F	F		Total population in hotels
Visitor	Long(4) ***Long Integer(4)***	F	F		Visitor population
WorkingCom	Long(4) ***Long Integer(4)***	F	F		Population working in commercial occupations
WorkingInd	Long(4) ***Long Integer(4)***	F	F		Population working in industrial occupations
Commuting5PM	Long(4) ***Long Integer(4)***	F	F		Population commuting at 5:00 p.m.
OwnerSingleUnits	Long(4) ***Long Integer(4)***	F	F		Owner-occupied, single-family units
OwnerMultUnits	Long(4) ***Long Integer(4)***	F	F		Owner-occupied, multi-family units
OwnerMultStructs	Long(4) ***Long Integer(4)***	F	F		Owner-occupied, multi-family structures
OnwerMHs	Long(4) ***Long Integer(4)***	F	F		Owner-occupied, manufactured housing
RenterSingleUnits	Long(4) ***Long Integer(4)***	F	F		Renter-occupied single family units
RenterMultUnits	Long(4) ***Long Integer(4)***	F	F		Renter-occupied, multi-family units
RenterMultStructs	Long(4) ***Long Integer(4)***	F	F		Renter-occupied, multi-family structures
RenterMHs	Long(4) ***Long Integer(4)***	F	F		Renter-occupied, manufactured housing
VacantSingleUnits	Long(4) ***Long Integer(4)***	F	F		Vacant single-family units
VacantMultUnits	Long(4)	F	F		Vacant multi-family units
VacantMultStructs	Long(4) ***Long Integer(4)***	F	F		Vacant multi-family structures
VacantMHs	Long(4) ***Long Integer(4)***	F	F		Vacant manufactured housing
BuiltBefore40	Short(2) ***Integer(2)***	F	F		Housing units built before 1940
Built40to49	Short(2) ***Integer(2)***	F	F		Housing units built between 1940 and 1949
Built50to59	Short(2)	F	F		Housing units built

	Integer(2)				between 1950 and 1959
Built60to69	Short(2) ***Integer(2)***	F	F		Housing units built between 1960 and 1969
Built70to79	Short(2) ***Integer(2)***	F	F		Housing units built between 1970 and 1979
Built80to89	Short(2) ***Integer(2)***	F	F		Housing units built between 1980 and 1989
Built90to98	Short(2) ***Integer(2)***	F	F		Housing units built between 1990 and 1998
BuiltAfter98	Short(2) ***Integer(2)***	F	F		Housing units built after 1998
MedianYearBuilt	Short(2) ***Integer(2)***	F	F		Median year housing built
AvgRent	Long(4) ***Long Integer(4)***	F	F		Average cash rent
AvgValue	Long(4) ***Long Integer(4)***	F	F		Average home value
SchoolEnrollmentKto12	Long(4) ***Long Integer(4)***	F	F		School enrollment up to high school
SchoolEnrollmentCollege	Long(4) ***Long Integer(4)***	F	F		College and university enrollment
* T=True; F=False; U=Unique; NU=Non-Unique; A=Ascending; D=Descending; UC=Uppercase; LC=Lowercase					

13.2.2. Building Count by Census Tract: hzBldgCountOccupT

In the international framework structure this feature class contains data related to provide an estimated building count by specific occupancy in the administrative boundaries geographical domain for the study region.

Table 17: Building Count by Census Tract Table

Label	**Occupancy Class**	**Example Descriptions**	**building count value type**
		Residential	
RES1	Single Family Dwelling	House	*Short Integer*
RES2	Mobile Home	Mobile Home	*Short Integer*
RES3	Multi Family Dwelling RES3A Duplex RES3B 3-4 Units RES3C 5-9 Units RES3D 10-19 Units RES3E 20-49 Units RES3F 50+ Units	Apartment/Condominium	*Short Integer*
RES4	Temporary Lodging	Hotel/Motel	*Short Integer*

RES5	Institutional Dormitory	Group Housing (military, college), Jails	*Short Integer*
RES6	Nursing Home		*Short Integer*
Commercial			
COM1	Retail Trade	Store	*Short Integer*
COM2	Wholesale Trade	Warehouse	*Short Integer*
COM3	Personal and Repair Services	Service Station/Shop	*Short Integer*
COM4	Professional/Technical Services	Offices	*Short Integer*
COM5	Banks		*Short Integer*
COM6	Hospital		*Short Integer*
COM7	Medical Office/Clinic		*Short Integer*
COM8	Entertainment & Recreation	Restaurants/Bars	*Short Integer*
COM9	Theaters	Theaters	*Short Integer*
COM10	Parking	Garages	*Short Integer*
Industrial			
IND1	Heavy	Factory	*Short Integer*
IND2	Light	Factory	*Short Integer*
IND3	Food/Drugs/Chemicals	Factory	*Short Integer*
IND4	Metals/Minerals Processing	Factory	*Short Integer*
IND5	High Technology	Factory	*Short Integer*
IND6	Construction	Office	*Short Integer*
Agriculture			
AGR1	Agriculture		*Short Integer*
Religion/Non-Profit			
REL1	Church/Non-Profit		*Short Integer*
Government			
GOV1	General Services	Office	*Short Integer*

GOV2	Emergency Response	Police/Fire Station/EOC	*Short Integer*
Education			
EDU1	Grade Schools		*Short Integer*
EDU2	Colleges/Universities	Does not include group housing	*Short Integer*

13.2.3. Building Replacement Value by Census Tract: hzExposureOccupT

In the international framework structure this feature class contains data related to provide an estimated building (without content) full replacement value by specific occupancy in the administrative boundaries geographical domain for the study region.

Table 18: Building Replacement Value by Census Tract Table

Label	Occupancy Class	Example Descriptions	Building Replacement Value Type
Residential			
RES1	Single Family Dwelling	House	*Long Integer*
RES2	Mobile Home	Mobile Home	*Long Integer*
RES3	Multi Family Dwelling RES3A Duplex RES3B 3-4 Units RES3C 5-9 Units RES3D 10-19 Units RES3E 20-49 Units RES3F 50+ Units	Apartment/Condominium	*Long Integer*
RES4	Temporary Lodging	Hotel/Motel	*Long Integer*
RES5	Institutional Dormitory	Group Housing (military, college), Jails	*Long Integer*
RES6	Nursing Home		*Long Integer*
Commercial			
COM1	Retail Trade	Store	*Long Integer*
COM2	Wholesale Trade	Warehouse	*Long Integer*
COM3	Personal and Repair Services	Service Station/Shop	*Long Integer*
COM4	Professional/Technical Services	Offices	*Long Integer*
COM5	Banks		*Long Integer*
COM6	Hospital		*Long Integer*

COM7	Medical Office/Clinic		*Long Integer*
COM8	Entertainment & Recreation	Restaurants/Bars	*Long Integer*
COM9	Theaters	Theaters	*Long Integer*
COM10	Parking	Garages	*Long Integer*
	Industrial		
IND1	Heavy	Factory	*Long Integer*
IND2	Light	Factory	*Long Integer*
IND3	Food/Drugs/Chemicals	Factory	*Long Integer*
IND4	Metals/Minerals Processing	Factory	*Long Integer*
IND5	High Technology	Factory	*Long Integer*
IND6	Construction	Office	*Long Integer*
	Agriculture		
AGR1	Agriculture		*Long Integer*
	Religion/Non-Profit		
REL1	Church/Non-Profit		*Long Integer*
	Government		
GOV1	General Services	Office	*Long Integer*
GOV2	Emergency Response	Police/Fire Station/EOC	*Long Integer*
	Education		
EDU1	Grade Schools		*Long Integer*
EDU2	Colleges/Universities	Does not include group housing	*Long Integer*

13.2.4. Content Replacement Value by Census Tract: hzExposureContentOccupT

In the international framework structure this feature class contains data related to provide an estimated building content replacement value by specific occupancy in the administrative boundaries geographical domain for the study region.

Table 19: Content Replacement Value by Census Tract Table

Label	Occupancy Class	Example Descriptions	4.3.5. Content Replacement Value Type
Residential			
RES1	Single Family Dwelling	House	*Long Integer*
RES2	Mobile Home	Mobile Home	*Long Integer*
RES3	Multi Family Dwelling RES3A Duplex RES3B 3-4 Units RES3C 5-9 Units RES3D 10-19 Units RES3E 20-49 Units RES3F 50+ Units	Apartment/Condominium	*Long Integer*
RES4	Temporary Lodging	Hotel/Motel	*Long Integer*
RES5	Institutional Dormitory	Group Housing (military, college), Jails	*Long Integer*
RES6	Nursing Home		*Long Integer*
Commercial			
COM1	Retail Trade	Store	*Long Integer*
COM2	Wholesale Trade	Warehouse	*Long Integer*
COM3	Personal and Repair Services	Service Station/Shop	*Long Integer*
COM4	Professional/Technical Services	Offices	*Long Integer*
COM5	Banks		*Long Integer*
COM6	Hospital		*Long Integer*
COM7	Medical Office/Clinic		*Long Integer*
COM8	Entertainment & Recreation	Restaurants/Bars	*Long Integer*
COM9	Theaters	Theaters	*Long Integer*
COM10	Parking	Garages	*Long Integer*
Industrial			

IND1	Heavy	Factory	*Long Integer*
IND2	Light	Factory	*Long Integer*
IND3	Food/Drugs/Chemicals	Factory	*Long Integer*
IND4	Metals/Minerals Processing	Factory	*Long Integer*
IND5	High Technology	Factory	*Long Integer*
IND6	Construction	Office	*Long Integer*
	Agriculture		
AGR1	Agriculture		*Long Integer*
	Religion/Non-Profit		
REL1	Church/Non-Profit		*Long Integer*
	Government		
GOV1	General Services	Office	*Long Integer*
GOV2	Emergency Response	Police/Fire Station/EOC	*Long Integer*
	Education		
EDU1	Grade Schools		*Long Integer*
EDU2	Colleges/Universities	Does not include group housing	*Long Integer*

13.2.5. Square Footage Value by Census Tract: hzSqFootageOccupT

In the international framework structure this feature class contains data related to provide an estimated square footage value by specific occupancy in the administrative boundaries geographical domain for the study region.

Table 20: Square Footage Value by Census Tract Table

Label	Occupancy Class	Example Descriptions	Square Footage Value Type
	Residential		
RES1	Single Family Dwelling	House	*Float*
RES2	Mobile Home	Mobile Home	*Float*
RES3	Multi Family Dwelling RES3A Duplex RES3B 3-4 Units RES3C 5-9 Units RES3D 10-19 Units RES3E 20-49 Units RES3F 50+ Units	Apartment/Condominium	*Float*
RES4	Temporary Lodging	Hotel/Motel	*Float*

RES5	Institutional Dormitory	Group Housing (military, college), Jails	*Float*
RES6	Nursing Home		*Float*
	Commercial		
COM1	Retail Trade	Store	*Float*
COM2	Wholesale Trade	Warehouse	*Float*
COM3	Personal and Repair Services	Service Station/Shop	*Float*
COM4	Professional/Technical Services	Offices	*Float*
COM5	Banks		*Float*
COM6	Hospital		*Float*
COM7	Medical Office/Clinic		*Float*
COM8	Entertainment & Recreation	Restaurants/Bars	*Float*
COM9	Theaters	Theaters	*Float*
COM10	Parking	Garages	*Float*
	Industrial		
IND1	Heavy	Factory	*Float*
IND2	Light	Factory	*Float*
IND3	Food/Drugs/Chemicals	Factory	*Float*
IND4	Metals/Minerals Processing	Factory	*Float*
IND5	High Technology	Factory	*Float*
IND6	Construction	Office	*Float*
	Agriculture		
AGR1	Agriculture		*Float*
	Religion/Non-Profit		
REL1	Church/Non-Profit		*Float*
	Government		
GOV1	General Services	Office	*Float*

GOV2	Emergency Response	Police/Fire Station/EOC	*Float*
Education			
EDU1	Grade Schools		*Float*
EDU2	Colleges/Universities	Does not include group housing	*Float*

13.2.6. County Location Factor: hzMeansCountyLocationFactor

In the international framework structure this feature class contains data related to provide location factor value for residential and non-residential occupancies in the local administrative boundaries geographical domain for the study region.

Table 21: County Location Factor Table

Identification:	hzMeansCountyLocationFactor				
Type:	ESRI table				
Purpose:	The Hazus-MH Means-based location factor at the county level used to "localize" national costs to reflect local conditions.				
Data:					
Feature Class Field Definition					
Name	ESRI Type (Size)	Index *	Require d*	Values	Description
CountyFips	Text(5)	F	T	Five-digit FIPS county code	Five-digit FIPS county code. First two digits are the FIPS state code; the remaining three digits are the county code.
MeansAdjRes	Double	F	F		Means location factors for residential occupancies on a county basis
MeansAdjNon Res	Double	F	F		Means location factors for non-residential occupancies on a county basis
* T=True; F=False; U=Unique; NU=Non-Unique; A=Ascending; D=Descending; UC=Uppercase; LC=Lowercase					

13.3. Appendix 3: Essential Facilities Database

The Essential Facilities Database, EF.mdb is an Access personal geodatabase that contains feature classes for essential facilities with fields that are relevant for all hazards.

The following table shows the structure of the EF.mdb database and descriptions of included feature classes.

Table 22: Essential Facilities Feature Classes

Name	Type	Content
hzCareFlty	ESRI Point Feature	Geometry (point features) and all-hazards information
hzEmergencyCtr	ESRI Point Feature	Geometry (point features) and all-hazards information
hzFireStation	ESRI Point Feature	Geometry (point features) and all-hazards information
hzPoliceStation	ESRI Point Feature	Geometry (point features) and all-hazards information
hzSchool	ESRI Point Feature	Geometry (point features) and all-hazards information

13.4. Appendix 4: Transportation Facilities Database

The Transportation Facilities Database, TRN.mdb is an Access personal geodatabase that contains feature classes for essential facilities with fields that are relevant for all hazards.

The following table shows the structure of the TRN.mdb database and descriptions of included feature classes.

Table 23: Transportation Systems Feature Classes

Name	Type	Content
hzAirportFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information of airports related facilities. Airport transportation systems consist of control towers, runways, terminal buildings, parking structures, and fuel, maintenance, and hangar facilities.
hzBusFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information of bus transportation facilities. Bus transportation systems consist of urban stations, fuel facilities, dispatch facilities, and maintenance facilities.

hzFerryFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information of Ferry facilities. Ferry system consists of waterfront structures, passenger terminals, fuel facilities, dispatch facilities, and maintenance facilities.
hzHighwayBridge	ESRI Point Feature Class	Geometry (point features) and all-hazards information of highway bridges
hzHighwaySegment	ESRI Line Feature Class	Geometry (line features) and all-hazards information highways
hzHighwayTunnel	ESRI Point Feature Class	Geometry (point features) and all-hazards information of highway tunnels
hzLightRailBridge	ESRI Point Feature Class	Geometry (point features) and all-hazards information of light rail bridges
hzLightRailFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information of light rail transportation facilities. Like railways, light rail systems are composed of tracks, bridges, tunnels, and facilities. The major difference between the two is the power supply, with light rail systems operating with DC power substations.
hzLightRailSegment	ESRI Line Feature Class	Geometry (line features) and all-hazards information of light rail tracks
hzLightRailTunnel	ESRI Point Feature Class	Geometry (point features) and all-hazards information of light rail tunnels
hzPortFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information of port and harbor facilities
hzRailFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information of railway transportation facilities
hzRailwayBridge	ESRI Point Feature Class	Geometry (point features) and all-hazards information of railway bridges
hzRailwaySegment	ESRI Line Feature Class	Geometry (line features) and all-hazards information of railway tracks
hzRailwayTunnel	ESRI Point Feature Class	Geometry (point features) and all-hazards information of railway tunnels
hzRunway	ESRI Point Feature Class	Geometry (point features) and all-hazards information of airport runways

13.5. Appendix 5: Utility Systems Database

The Transportation Facilities Database, UTIL.mdb is an Access personal geodatabase that contains feature classes for essential facilities with fields that are relevant for all hazards.

The following table shows the structure of the UTIL.mdb database and descriptions of included feature classes.

Table 24: Utility Systems Feature Classes

Name	Type	Content
hzCommunicationFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information of communication related facilities. A communication facilities system consists of central offices, stations, and transmitters
hzElectricPowerFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information of electric power facilities. An electric power facilities system consists of substations, distribution circuits, generation plants, and transmission towers.
hzNaturalGasFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information of natural gas compressor stations
hzNaturalGasPl	ESRI Line Feature Class	Geometry (line features) and all-hazards information of natural gas pipelines
hzOilFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information for oil system facilities including refineries, pumping plants, and tank farms
hzOilPl	ESRI Line Feature Class	Geometry (line features) and all-hazards information of oil pipelines
hzPotableWaterFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information of potable water facilities including water treatment plants, wells, storage tanks, and pumping stations
hzPotableWaterPl	ESRI Line Feature Class	Geometry (line features) and all-hazards information of potable water pipelines
hzWasteWaterFlty	ESRI Point Feature Class	Geometry (point features) and all-hazards information of wastewater facilities including wastewater treatment plants and lift stations
hzWasteWaterPl	ESRI Line Feature Class	Geometry (line features) and all-hazards information of wastewater pipelines

13.6. Appendix 6: High Potential Loss Facilities Database

High Potential Loss Facilities Database, HPLF.mdb is an Access personal geodatabase that contains feature *classes* for HPLF with fields relevant to all hazards.

The following table shows the structure of the HPLF.mdb database and descriptions of included feature classes.

Table 25: High Potential Loss Facilities Feature Classes

Name	Type	Content
hzDams	ESRI Point Feature Class	Geometry (point features) and all-hazards information of dams structures
hzHazmat	ESRI Point Feature Class	Geometry (point features) and all-hazards information of hazardous material facilities
hzLevees	ESRI Line Feature Class	Geometry (line features) and all-hazards information of levees
hzMilitary	ESRI Point Feature Class	Geometry (point features) and all-hazards information of military facilities
hzNuclearFlty	ESRI Line Feature Class	Geometry (line features) and all-hazards information for nuclear facilities