Evaluation of the HAZUS-MH Loss Estimation Methodology for a Natural Risk Management Case Study in Carinthia, Austria

by

Stefan Kulmesch

Master Thesis

Submitted in partial fulfillment of the requirements of Master in Science of Engineering

Spatial Decision Support Systems: Geographic Information Science and Operations Research

Supervisors:

Dr. Gernot Paulus
Carinthia University of Applied Sciences
International Master Program of Spatial Decision Support Systems and Operations Research

Dr. Michael Leitner
Louisiana State University, Department of Geography and Anthropology

Baton Rouge/Villach, September 2010

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.

Place, Date

Signature

Abstract

In recent years the consequences of inundations for anthropogenic landscapes increased dramatically. Floods have thus become one of the most common geohazards in the European Union (EU), causing 700 fatalities, economical losses of approximately 25 billion Euros and leaving more than 500,000 Europeans homeless since 1998. Natural disasters like the 100 year flood in 2002, which mostly affected the Province of Lower Austria, show that also Austria regularly suffers from such hazards, causing damages of billions of Euros in Austria alone. In order to minimize social, environmental, infrastructural and economic losses within the EU a special directive was developed in 2007 with the goal to identify the damage potential for areas which are at risk to suffer from floods. This thesis investigates flood model provided by the loss estimation tool HAZards United States-Multi Hazards (HAZUS-MH). The goals of this work are on the one hand to find out if it is possible to use this software package with Austrian data. Furthermore a workflow is presented which enables data integration into the HAZUS-MH specific data model. This whole process is tested and evaluated based on a pilot study located in Carinthia, a province of Austria. Moreover requirements for an international version of this software can be derived from this project.

Acknowledgements

First of all I would like to thank my supervisors Dr. Gernot Paulus and Dr. Michael Leitner for their great feedback and inputs for this thesis.

I am especially thankful for the great time at the Louisiana State University. Therefore I want to say a special thank you to Dr. Gernot Paulus and to Dr. Michael Leitner who supported the preparations of this stay.

Additionally I want to thank Kevin Mickey and Jack Schmitz from the Indiana University for their great technical assistance. I would also like to express thanks to Steven Ward for his help.

Special thanks go to my family for their patience and support during my studies and stay in the United States.

Last but not least I also want to thank my friends and colleagues for the great time we shared.

Table of Contents

List of Abbreviations

BMLFUW	Bundesministerium für Land-, Forstwirtschaft, Umwelt und Wasserwirtschaft (Federal Ministry of Agriculture, Forestry, Environment and Water Management)
DEM	Digital Elevation Model
EQRM	Earth Quake Risk Model
EQL	Enhanced Quick Look Tool
ESRI	Environmental Systems Research Institute
EU	European Union
FEMA	Federal Emergency Management Agency
FIT	Flood Information Tool
GBS	General Building Stock
GUI	Graphical User Interface
HAZUS-MH	Hazards United States – Multi Hazard
HORA	Hochwasserrisikozonierung Austria (Flood Risk Zones Austria)
KAGIS	Kärntner Geografische Informationssystem (Carinthian Geographic Information System)
OGC	Open Geospatial Consortium
RMS	Risk Management Solutions
UN/ISDR	United Nations Strategy for Disaster Reduction

1. Introduction

Flood events all over the globe such as in 2005 in New Orleans, or 2010 in Poland and Pakistan show over and over again that these kinds of natural phenomena cannot be prevented. While the severity and frequency of inundations cannot be reduced it is possible to implement strategies in order to mitigate their consequences. Thus monetary and social losses may be diminished to a minimum.

The first task in order to find efficient mitigation strategies is to identify areas which are at risk to suffer from hazards such as floods. Damage potential analysis and loss estimation modeling can contribute to this task as they are specialized in identifying what kinds of risks may occur and where losses might happen.

In this Master Thesis a special loss estimation tool is investigated and evaluated based on results from other studies for a project area located in Austria.

1.1. Motivation

Due to the spatial limitations of settlement areas, anthropogenic landscapes, such as residential, commercial and industrial areas, are expanding and shifting to territories which are at risk from natural hazards, such as flooding. Furthermore, social pressures, like population and economic growth, as well as climate change are contributing to this trend. Thus the damage potential (e.g. the number and value of buildings in an area at risk from being flooded) of these territories are increasing (KEILER, 2004). Although it cannot be proven that the number and the intensity of floods around the globe increased during the twenty-first century, recent flood events (e.g. the flooding in New Orleans in 20005 after Hurricane Katrina) showed the vast damage potential of inundations.

Statistics published by the Dartmouth Flood Observation seem to disprove this tendency at first glance. According to their 18 year long-lasting study, which combines flood damage data from all over the world, the number of floods seem to rise and the damages seem to fluctuate and even decrease from 1998 until 2003. This can be explained by the fact that from 2000 until 2003 the percentage of floods with a recurrence of 20 years was very high and there were only a few severe inundations which have apparently the highest risk potential. Figure 1-1 shows two of the diagrams, published by the DARTMOUTH FLOOD OBSERVATORY (2010).

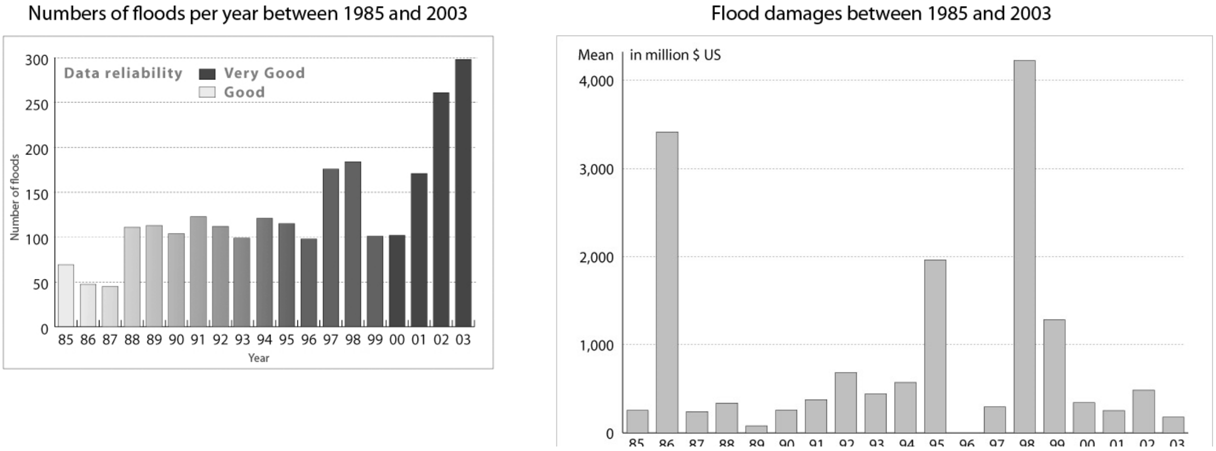


Figure 1-1: **On the left side the number of worldwide inundations per year between 1985 and 2003 is presented. A darker coloring indicates a very good reliability of the used data for this study. On the right side the damages caused by these floods are shown (Source: DARTMOUTH FLOOD OBSERVATORY, 2010)**

According to other ascertainments more than 100 flood events occurred in Europe between 1998 and 2006, causing more than 400 fatalities and damages of more than 27 billion €. Furthermore, more than half a million European citizens had to leave their homes because of inundations during an eight year long time interval (WWF GERMANY, 2007; EUROPEAN UNION, 2007b). One example is the 100-year flood of 2002, which devastated large parts of Central Europe, caused damages between 2 billion and 3 billion € in Austria alone (FUCHS et al., 2003). Also in the Province of Carinthia, which is located in the south of Austria, floods have been occurring often. This is also discussed and illustrated in the so called “Hochwasserchronik” of Carinthia. This report summarizes all inundations in this area between the 792 and 2003. One of the biggest floods in Carinthia occurred in 1965 and 1966, where the river Drau reached two times its all-time high. The highest water level measured was 695cm and large parts of the city of Villach (the second largest city in Carinthia) were flooded (ROHNER et al., 2004). Figure 1-2 illustrates the situation during this inundation.

Figure 1-2: The Ledererergasse in Villach in 1966 during the biggest flood of the 20th century in that area (Source: ROHNER et al., 2004)

Another more recent example described in the report happened in the municipality of Vorderberg in the south-western part of Carinthia. Between 1810 and 2003 an adjacent creek devastated the village six times, the last time being in 2003. The homes of the inhabitants where filled up to 1.5 meters with water and debris (ROHNER et al., 2004).

Figure 1-3: The village of Vorderberg after the inundation in 2003 (ROHNER et al., 2004)

These facts indicate on the one hand that there exists a need for flood prevention and mitigation, but on the other hand side these facts also show that something like perfect flood protection is impossible (EUROPEAN UNION, 2007a).

In order to minimize the adverse consequences of floods, especially for human health and life, the environment, cultural heritage, economic activity, and infrastructure, the European Union (EU) has agreed on the so called EU Flood Directive. It requires EU Member States to identify areas which are subject to flood risk. The Directive comprises of three phases: In the first phase flood risk assessments of the river basins and associated coastal zones have to be undertaken. The second stage obligates Member States to develop flood hazard, as well as, flood risk maps. Based on the outcomes of these maps, flood risk management plans have to be created until 2015 (EUROPEAN UNION, 2007a; EUROPEAN UNION 2007b).

Risk and damage potential analysis can make considerable contributions to this risk identification and risk management process, as they can generate additional information about what might happen. Furthermore, results from these analyses can help answering questions like what kinds and how much damage can occur, or how much and where actions for flood mitigation and prevention are economically reasonable (KULMESCH et al., 2010).

Internationally there exist diverse directives and methods for analyzing the damage potential. In Austria cost-benefit analyses are carried out within the framework of the directives of the Federal Ministry for Agriculture and Forestry (KULMESCH et al., 2010). In contrast to this the software package Hazards United States – Multi Hazard (HAZUS-MH) is used in the United States for estimating losses after natural hazards.

The goal of this Master Thesis is to show how to use HAZUS-MH for damage potential analysis in Austria. Therefore on the one hand the loss estimation methodology provided by the software is compared to other existing methods in the area of flood loss analysis. On the other hand data requirements and data sources are also described. In addition, data are gathered for an Austrian study region and damages for this area are estimated. The results are evaluated with an already existing cost-benefit analysis for the same region, carried out by GUGGENBERGER et al. in 2009.

Thus it is possible to determine the applicability of HAZUS-MH for Austrian flood loss analysis and at the same time, the enforcement of the EU flood directive can be met. Moreover, requirements for an internationally applicable version of HAZUS-MH can be derived from the results of this project. So far such an international version of the software is not available.

1.2. Literature Review

Different scientific approaches for assessing flood related damages already exist. One of these approaches developed by DUTTA et al. (2003) uses a combination of a physically based hydrologic model for flood inundation simulation and a separate loss estimation model. Figure 1-4 gives an overview of this simulation and the assessment tool.

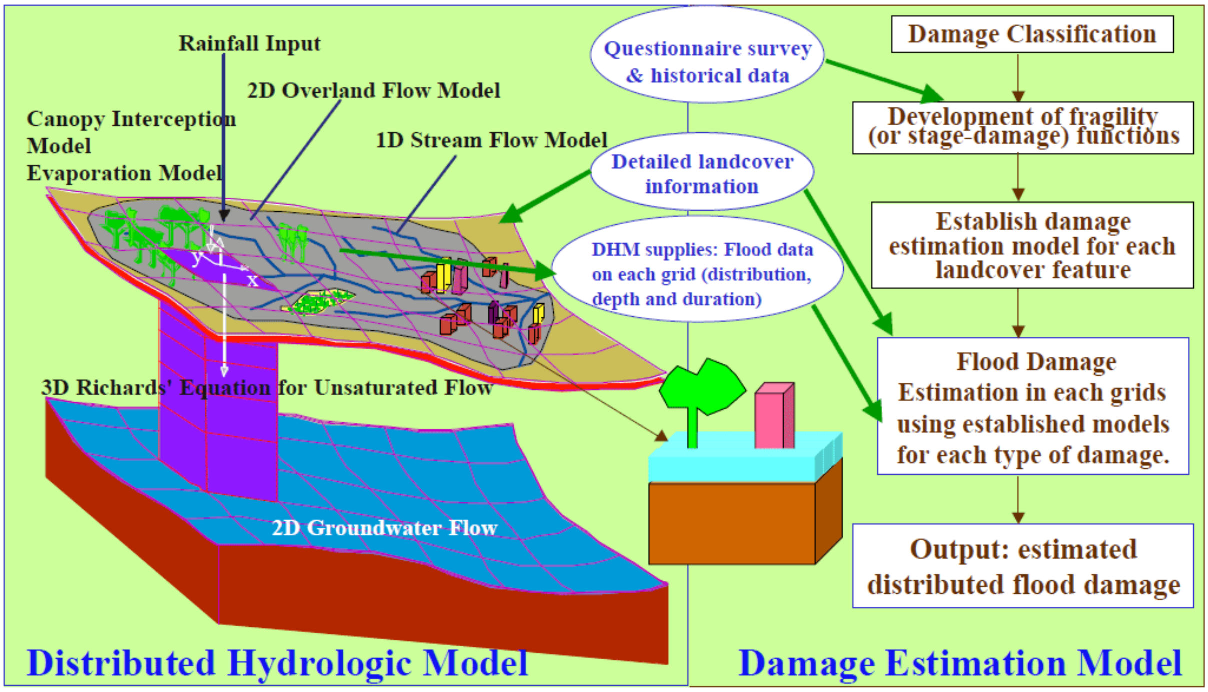


Figure 1-4: An overview of the combined physical hydrologic and the loss estimation model developed by DUTTA et al. (2003).

The hydrological model uses diverse techniques in Flood Modeling such as diffusive wave approximation for open channel simulation and overland flow simulation in order to delineate the flood plain (DUTTA et al., 2000). According to DUTTA et al. (2000) the results of this module show a good agreement with observed flood data. The integrated loss estimation methodology is restricted to primary tangible damages for three major land use classes, namely urban, rural and infrastructure. These classes are further divided into several sub-categories, such as damage to structures, their interior and outside property damage. Furthermore also harmful effects to agricultural products and farms are incorporated in the model. Infrastructural damages include telecommunication, transportation, as well as power supply and other lifelines (DUTTA et al., 2003). However, the scale and level of detail of this methodology only provide rough loss estimation. Although the major landcover classes have been extracted from satellite images with a 20 meter resolution, they cannot provide essential information, such as building count data or detailed information about the building material which are needed for a transparent damage potential analysis.

Another scientific method for assessing flood related damages is proposed by STEINNOCHER et al. (2009). In their paper the authors introduce an approach for analyzing the flood related damages in the area of Bezau in the province of Vorarlberg, Austria. The benchmark for the proposed methodology is a flood event from 2005 which caused damages of about 15 million €. The method differs between two occupancy classes (private and business) and uses four different scenarios in order to reconstruct the damages caused by the inundation. The flood plain is delineated according to geomorphologic conditions as described by surface models, as well as information from aerial images (STEINNOCHER et al., 2009). In order to assess flood-related losses average monetary losses for the buildings have been extracted from the documented damages.

Along with these scientific approaches, there also exist several commercially available software packages. One of these commercial flood risk assessment tools is developed by Risk Management Solutions (RMS). This tool was successfully used in countries like the UK and Belgium. In Germany it was deployed after the 100-year flood in 2002 in order to assess both off and on-flood plain risks. Based on a rainfall event model the corresponding amount of water going into the river network was estimated (RMS, 2010). The calculations also considered the possible effects of flood management structures such as retention dams and polders. The loss estimation model was performed on a variable resolution grid with a cell size of up to 50 meters. Depth-damage functions were then deployed for areas where street level exposure information was available. This kind of model is regarded as too comprehensive, as it mostly focuses on the modeling of the hazard (RMS, 2010).

Another commercially used software package for flood risk analysis is provided by AIR. It comprises different modules ranging from applications for estimating replacement costs, and assessing exposure data, to decision support and risk analysis. Furthermore the AIR methodology can be embedded in existing systems. However, the software system is specialized for insurance related analysis (AIR, 2010).

An alternative to these commercially available services and software packages is HAZUS-MH which is developed and provided by the Federal Emergency Management Agency (FEMA). It is based on scientific assumptions and includes all aspects of risk according to CRICHTON (1999; 2001), as well as FEDESKI & GWILLIAM (2009). Furthermore it has a flexible scale and can thus be used for regional, as well as supra-regional analysis.

1.3. Hypothesis

The goal of this Master Thesis is to evaluate, whether HAZUS-MH can be used for flood loss analysis in Austria. Thus it may be proven that it is possible to adapt and deploy this flood loss estimation methodology for a natural risk management case study in Austria.

Therefore, one of the first steps is to identify the data requirements and data model, which are needed in order to perform the loss estimation methodology within the software package. Based on these requirements different data sources have to be determined. Moreover, a data integration workflow is developed supporting the import of the data, which are acquired from these sources into HAZUS-MH. This dataset is then used in order to carry out the loss estimation methodology within the software. In the next step the results and methodology of this study is evaluated through comparison with the outcomes of an Austrian cost-benefit analysis by GUGGENBERGER et al. for the same area (2009).

The expected results for this Master Thesis are a comprehensive list of data requirements and data sources, as well as a workflow enabling the creation and integration of an Austrian dataset into HAZUS-MH. Furthermore, these findings result in a ready to use sample dataset for a study region in Carinthia, Austria. In addition, a vulnerability and risk assessment analyses are carried out with this dataset. Final results comprise reports, tables, and maps generated with the help of HAZUS-MH. Last but not least, a comparison of the findings produced by the software and a cost-benefit analysis carried out by experts can be identified as a major result of this work.

1.4. Structure of the Thesis

This Master Thesis is structured in nine chapters. In the first section an introduction to the topic as well as motivating factors for this thesis are given. The theoretical background for this report is discussed in chapter two. The theoretical basis includes the different types of loss estimation methodologies in Austria as well as an overview about the software HAZUS-MH. In the third chapter data requirements, as well as data sources are presented. Moreover a pilot study and a workflow for integrating Austrian data into the HAZUS-MH specific data model are discussed in detail. The results of this pilot study are illustrated and discussed in the chapters four and five. The references for this thesis can be found in chapter six. The lists of figures and tables are given in chapter seven and eight. Last but not least the Appendix is located in chapter nine.

2. Theoretical Background

In this section the theoretical basics for this Master Thesis are discussed. This includes first, a discussion of the general terminology in the field of Hazard Geography. Second, existing methodologies, directives, and initiatives for flood hazard analysis in Austria are presented Third, HAZUS-MH, the integrated loss estimation methodology, as well as, the required data are explained in detail. Finally, the whole chapter is summarized.

2.1. Definition of Terms

Authors like BROOKS (2003), KELMAN (2003), PINE (2008), and CUTTER (1996) are describing in detail the discrepancies of defining key terms in the area of Hazard Geography. Therefore the definitions of essential terms used in this Master Thesis are discussed in detail in this section.

Hazard

In general, hazards can be defined as potential harm which threatens the social, economic, and natural capital of a community (PINE, 2008). Furthermore, hazards can be categorized into four different types. These categories comprise natural hazards (floods, hurricanes, earthquakes, etc.), technological hazards (hazardous materials spill, nuclear accident, power outage, etc.), as well as human-induced hazards (terrorist attacks, bombing, mass destruction, etc.), and compounded hazards, which are a combination of different kinds of hazards, such as urban fires after an earthquake (PINE, 2008). In contrast to this, FEMA (1997) is denoting a hazard as an event, or physical condition that has the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural losses, damage to the environment, interruption of businesses, or other types of harms or loss. The BUREAU OF RECLAMATION (2010) is giving a more flood-specific definition. In general it describes a hazard as something that creates the potential for adverse consequences, such as loss of life, property damage, and adverse social and environmental impacts.

Catastrophe

However, disasters are the results of realized hazards (FEMA, 1997). Moreover these non-routine events have to exceed the capacity of the affected area to respond to it, in a way that it is no longer possible to save lives, to preserve property, and to maintain social, ecological, and economic stability (PEARCE, 2000).

Risk

Whilst the formulation for the term “hazard” is in general consistent, the definitions for “risk” vary a lot. This is because these terms are often used interchangeably and inconsistently, as they are used in different fields of expertise, including risk managers, urban planners, and insurance specialists (PINE, 2008). CRICHTON (1999, 2001) describes risk graphically as a triangle consisting of vulnerability, hazard, and exposure as depicted in Figure 2-1. In contrast, FEDESKI AND GWILLIAM (2009) express the term as a function, where risk is the periodic cost of damage caused by the hazard. The parameters of the function are the exposure, representing the extent and value of buildings, which are affected by a hazard, the vulnerability, which describes the susceptibility of these buildings to a hazard, and the characteristics of the hazard itself. These include the probability of the hazard, as well as its spatial extent and severity (FEDESKI AND GWILLIAM, 2007).

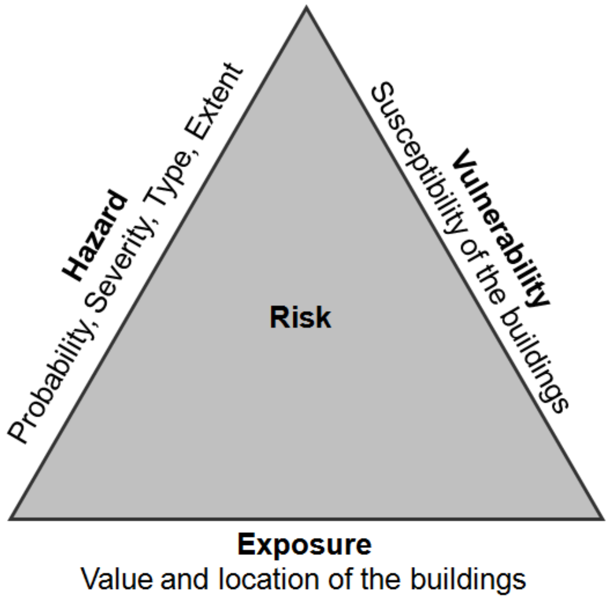


Figure 2-1: The risk triangle by CRICHTON (1999, 2001)

In contrast to this SAYERS et al (2002) and PINE (2008) provide a different definition of risk. Both authors describe it as the product of the likelihood and the consequences of a certain hazard. The consequences are defined as an economic, social, or environmental impact, which can be expressed as a monetary value, by category (high, medium, low) or descriptively (SAYERS et al, 2002). Furthermore, a more flood-specific definition for risk is provided by FEMA, which simply states that risk is the probability of a flood occurring in a certain time interval. Typical time intervals are for example 30-, 100- and 500-year floods (PINE, 2008).

Moreover, the United Nations Strategy for Disaster Reduction (UN/ISDR) (2004) defines risk as the probability of harmful losses resulting from interactions between natural and human-induced hazards and vulnerable conditions. Thus, it can be modeled as the product of hazard (a potential damaging phenomenon) and vulnerability (susceptibility of the elements exposed to a threat).

Another definition of risk is given by GILARDO & GINEVA (1997). The authors describe risk with two independent factors, one being vulnerability and the other being the hazard as shown in Figure 2-2. According to them the vulnerability represents the sensitivity of land use to the flood phenomenon, which depends on the type of land use and the social perception of risk. In contrast to this the second factor, called hazard is independent on the type of land use as it is only affected by the physical parameters of the surface.

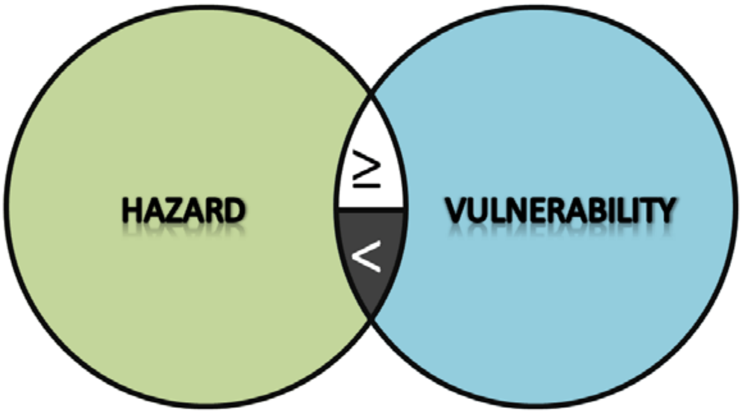


Figure 2-2: Conceptualization of risk by GILARD & GIVONE (1997)

This Master Thesis will follow the definition of CRICHTON (1999; 2001) and FEDESKI & GWILLIAM as it represents best the conceptional model behind HAZUS-MH.

Risk Analysis and Risk Assessment

Risk Analysis is a systematic tool to help to maximize flood protection, while minimizing costs through identification of the negative consequences of a hazard (BUWAL, 1999; KIENHOLZ. et al, 2004). Furthermore it includes determining of probability and severity of certain consequences based on previous incidences, local experience, and best available information (PINE, 2008). In contrast to this KIENHOLZ et al. (2004) define risk assessment and valuation as a decision making process with the goal to evaluate, which losses are acceptable for a community.

The UN/ISDR (2004) describes risk assessment in a different way:

> *"A methodology to determine 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."*

Moreover it includes the identification of the nature, the location, as well as the intensity and probability of a possible threat (UN/ISDR, 2004). The determination of vulnerability and exposure to these threats and the assessment of the capacities to manage hazards are also part of the risk assessment process. Last but not least it has to be determined, what level of risk is acceptable for a community. Figure 2-3 shows the whole risk assessment process proposed by the UN/ISDR (2004).

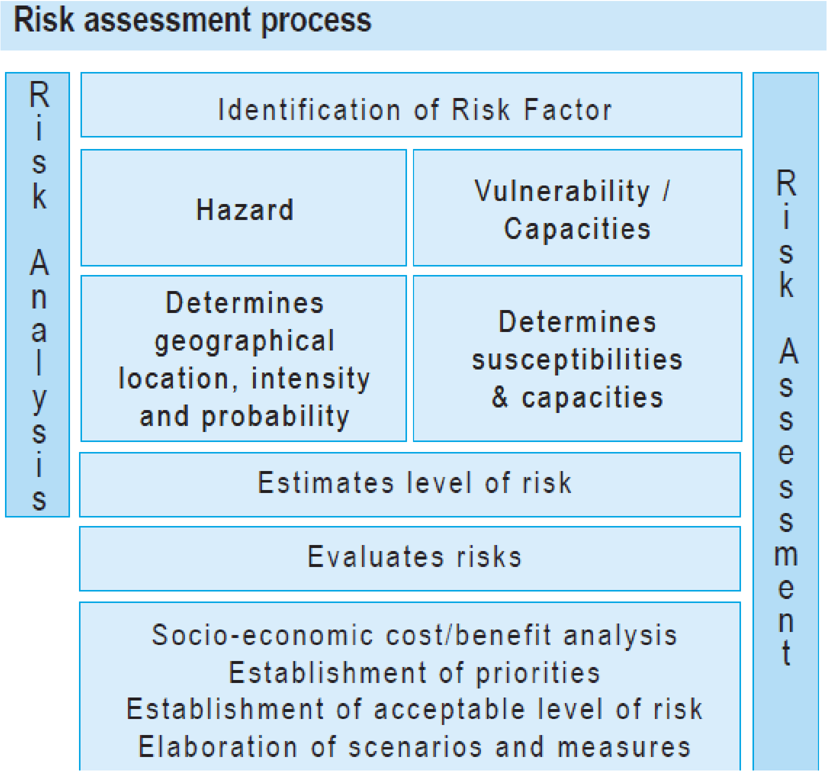


Figure 2-3: The risk assessment process according to the UN/ISDR (2004)

Damage functions

Depth-damage functions are using two types of inputs in order to estimate damages. The first input-parameter is the characteristic of a building. The second input is the flood depth. Using this information a depth-damage function can plot the flood depth versus physical damages in percent for different kinds of occupancies and building types (SCAWTHORN et al., 2006).

Flood depth

The flood depth is defined by FEMA (2009b) as the difference between the flood surface and the ground elevation. Therefore a flood surface grid is created and subtracted from the Digital Elevation Model (DEM). Figure 2-4 illustrates this process graphically.

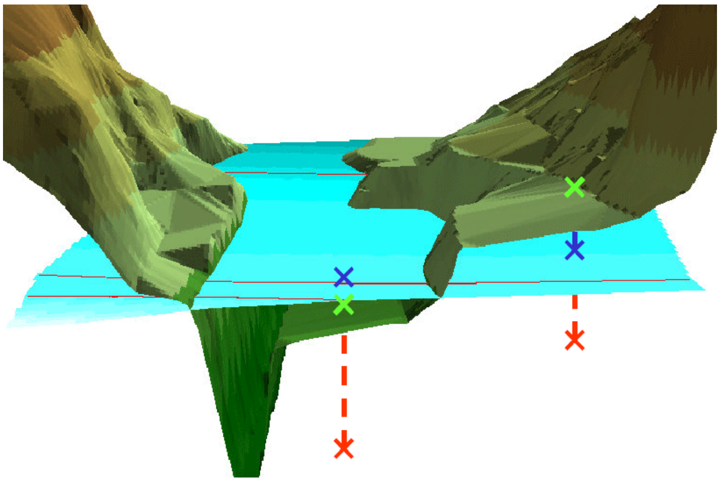


Figure 2-4: Conceptualization of calculating the flood depth (Source: FEMA, 2009b)

Flood damage

In general flood related damages can be classified into tangible and intangible damages. Tangible can be expressed monetarily, whereas intangible cannot (DUTTA et al., 2003). Good examples for intangible damages are casualties and fatalities. Furthermore tangible damages can be divided into direct and indirect damages. Direct damages are mainly caused by direct physical contact of structures with a flood. In contrast to this indirect damages usually are focusing on other consequences, such as business interruptions and the impact on the economy (PRETTENTHALER et al., 2010). This classification of tangible damages can again be sub-divided into primary and secondary damages as shown in Table 2-1.

Table 2-1: Classification of flood damages according to DUTTA et al. (2003).

Tangible Damages			
Direct Damages		Indirect Damages	
Primary	Secondary	Primary	Secondary
Structures, contents and agriculture	Land and environment recovery	Business Interruptions	Business interruptions
Intangible Damages			
Health, psychological damage			

2.2. Flood Hazard Analysis in Austria

In Austria there exist numerous directives, frameworks and regulations as well as procedures, and programs with the goal to analyze flood hazards. These include for example existing flood frequencies and risk zones, the cost-benefit analysis framework, the “Hochwasserrisikozonierung Austria” (Flood Risk Zones Austria) (HORA), as well as the Natural Risk Management Carinthia program and the initiative AdaptAlp. Also for the project “Natural Risk Management in Carinthia” flood hazard analysis is an essential work package. These different approaches are now discussed in detail.

2.2.1. Flood Frequencies and Risk Zones in Austria

Past Austrian flood hazard analysis has mainly focused on 10-, 30-, and 100-year flood events (FABER, 2006). However, these inundation intervals were criticized for being incomplete as they excluded extreme flood scenarios (MERZ, 2006). Therefore, existing directives were adapted in order to support investigations for 30-, 100- and 300-year floods (BMLFUW, 2009).

Furthermore, so-called yellow and red zones are used to map areas which are at risk from flood –related threats. Red zones include all areas, whose usages are either connected with a high threat of being affected by natural hazards, or involved with immense consequences caused by inundations, avalanches, or erosion. This implies a complete ban of building in these areas. In contrast, yellow zones include areas which are impaired by natural hazards. Building projects are only allowed under certain conditions in yellow zones (BMLFUW, 2006a). Furthermore, a residual risk analysis has to be carried out for an inundation interval up to 300 years, which analyzes the consequences after failures of flood protection structures (BMLFUW, 2006a).

2.2.2. Cost-benefit analysis for Flood Management

The most important official procedures for flood loss assessments as well as flood hazard analysis in Austria are included in the so called cost-benefit analysis. The official standardized workflow is described in a special directive and has the goal to increase the transparency and comparability of cost-benefit analysis (BMFLUW, 2009). It is mandatory for diverse flood management related projects and for flood protection activities with a financial effort of more than one million €. Moreover, it should help to implement the EU flood directive and to adapt these procedures to the new framework, including the new inundation interval setup (BMFLUW, 2009). The workflow for cost-benefit analysis contains 15 steps ranging from gathering geodata of the project area to loss assessments and documentation. Table 2-2 shows and explains all these steps in detail.

Table 2-2: The 15 steps of a cost-benefit analysis as proposed in the Austrian directive (Source: BMLFUW, 2009)

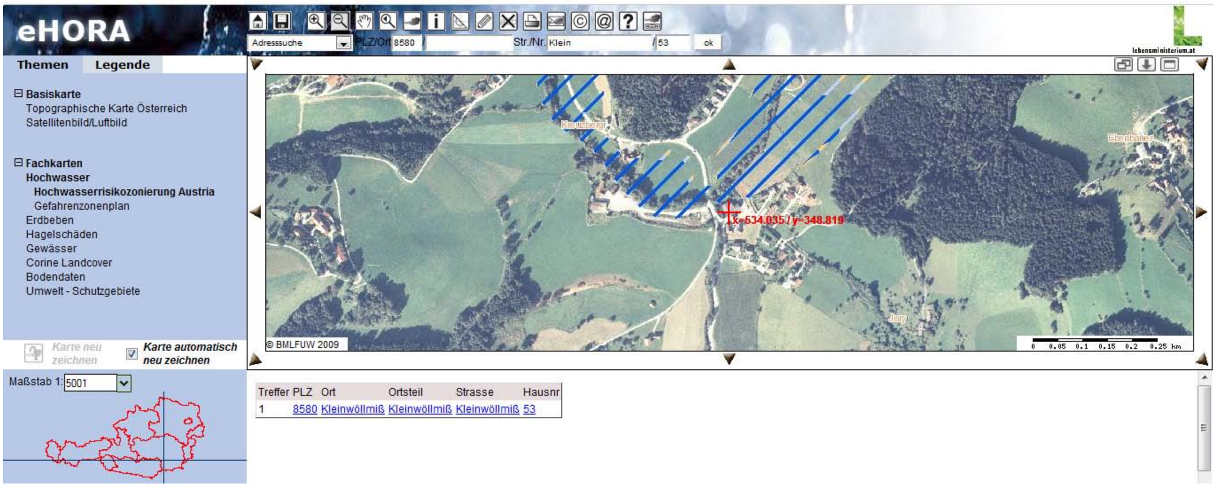
SERVICES		WORK PACKAGE
Required inputs		
Basics of water management	1	Acquiring geodata from project area
	2	Determining characteristics and frequencies of inundations
	3	Processing flood characteristics (determining velocity and depth)
Cost-benefit analysis		
Socio-economic basics	4	Acquiring land usage, population, and employment data
Damage analysis	5	Assessing the vulnerability of the land use classes and monetary damage analysis
Determining the economical efficiency	6	Damage expectations
	7	Estimation of benefits of the project
	8	Estimation of the project costs
	9	Comparison of costs and benefits – carrying out an optional sensitivity analysis

Evaluation and assessment of further consequences	10	Determining the threats to the population
	11	Estimating the effects and benefits which cannot be expressed monetarily
Summary of consequences and benefits	12	Overall assessment
Selecting an alternative	13	Comparison of alternatives and selection of the most efficient solution
Integration into flood management	14	Describing residual risks
Documentation	15	Documentation

One such cost-benefit analysis, using in this framework was carried out in 2009 in the area around the river Glan in the Province of Carinthia, Austria. In this cost-benefit analysis the damage potential of the lower part of this river was analyzed and assessed by hydrologists, consultants and other experts in order to optimize the flood risk management in this area (GUGGENBERGER et al., 2009). The length of the investigated river section was 64 km and the catchment area was 827 km² (GUGGENBERGER et al., 2009). The data for this project were extracted from the “Kärntner Geografische Informationssystem” (Carinthian Geographic Information System) (KAGIS), the largest repository for geodata in the province of Carinthia, as well as from the cadastre from the municipalities involved in the analysis (GUGGENBERGER et al., 2009). The flood frequencies used for this cost-benefit analysis range from 5-year floods to 300-year inundations (GUGGENBERGER et al., 2009). The analysis includes diverse thematic layers such as residential and non-residential buildings (e.g. transformer and pumping stations, as well as storage rooms and agricultural buildings), bridges and roads, as well as different land use classes and tourism-related objects (GUGGENBERGER et al., 2009).

2.2.3. Hochwasserrisikozonierung Austria

Another important initiative in Austria for flood hazard analysis is HORA. HORA is a comprehensive flood simulation tool published by the Bundesministerium für Land-, Forstwirtschaft, Umwelt und Wasserwirtschaft (Federal Ministry of Agriculture, Forestry, Environment and Water Management) (BMLFUW) in 2006. The tool allows users to query the flood risk for certain buildings after entering the address into the system (BMLFUW, 2007). The inundation frequencies included in this analysis are 30-, 100- and 200 years. The goal of this project was to increase the awareness for flood risks in Austria. Nevertheless, the reliability of the analysis tool was discussed and analyzed by ADAMS et al. (2006). The authors claimed that based on the coarse resolution of the DEM, the results of the HORA tool are overestimating the consequences of floods, as small flood protection structures are neglected at this scale (ADAMS et al., 2006). Figure 2-5 shows a sample query with the HORA web tool.



PLZ/Ort 8580

Str./Nr. Klein / 53

☑ Karte automatisch neu zeichnen

Maßstab 1: 5001

Treffer	PLZ	Ort	Ortsteil	Strasse	Hausnr
1	8580	Kleinwöllmiß	Kleinwöllmiß	Kleinwöllmiß	53

Figure 2-5: A sample query provided by the HORA web tool

2.2.4. AdaptAlp

The EU funded project AdaptAlp has the goal to optimize risk management within alpine regions and generate inputs for the EU flood directive (REITERER et al, 2009). Therefore, a dataset should be created and existing risk analysis methodologies should be optimized in order to reduce uncertainties for the prediction of natural hazards affected by the climate change (REITERER et al., 2009). Also the creation of an unambiguous terminology for risk managers is another goal of the project. The results from AdaptAlp should help and support decision makers for a better adaption of the alpine region to the climate change (REITERER et al., 2009).

2.2.5. Natural Risk Management Carinthia

Besides the HORA, there exists a further program in Austria, where the risks of natural hazards are analyzed. It is called “Natural Risk Management Carinthia” and it was launched in 2003 (PAULUS et al, 2005). The goals of this interdisciplinary project were to acquire a comprehensive geodata infrastructure for natural hazards and to create risk maps out of the generated dataset. In addition, processes for risk assessment should be optimized for natural threats, such as avalanches, floods, and debris flow. The authorities involved in this project were coming from different disciplines such as geology, water management, forestry and regional planning. The access to the dataset should be provided through web services proposed by the Open Geospatial Consortium (OGC) 2003 (PAULUS et al., 2005). Figure 2-6 shows the architecture consisting of standardized interfaces which enable data exchange across any administrative borders. Even integrating international datasets, such as from Italy or Slovenia is possible.

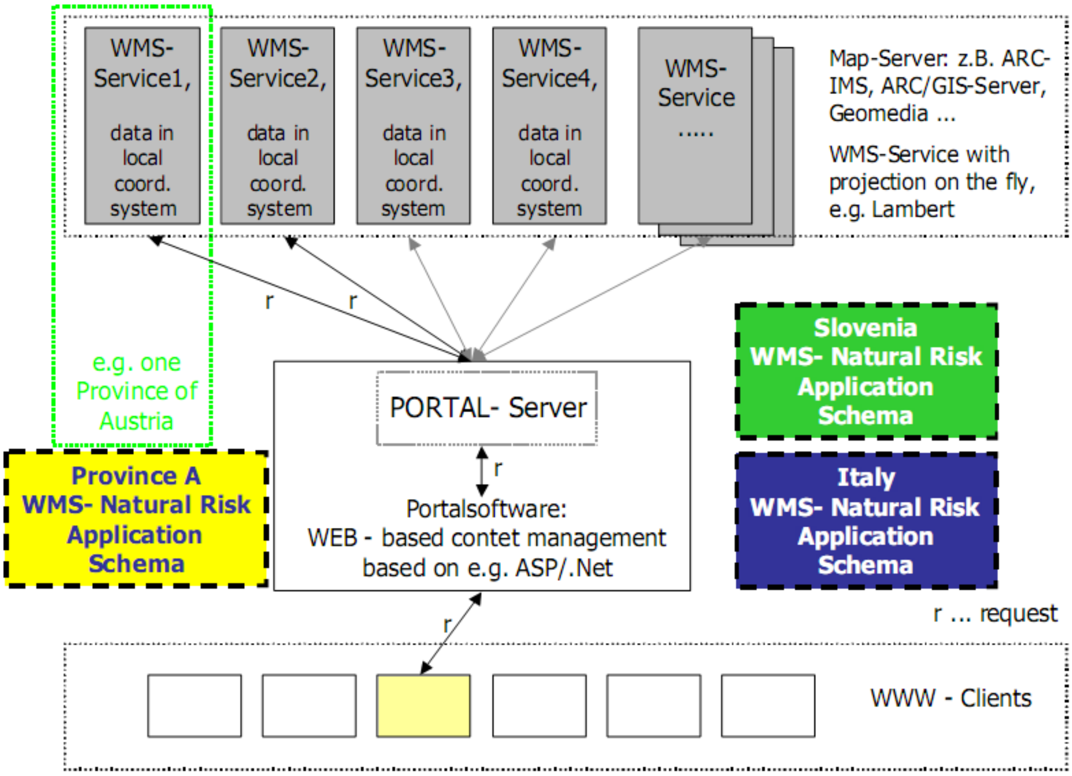


Figure 2-6: The OGC-conform architecture for the project "Natural Risk Management Carinthia" (Source: PAULUS & PIECHL, 2004).

One integral part of the project "Natural Risk Management Carinthia" was the development of an interdisciplinary dataset containing objects which should be protected from natural hazards such as floods, or avalanches (NGK II, 2010). As there exist different definitions for these kinds of objects among the different authorities, one consistent object catalogue was designed which is described in detail by KRAMMER (2009). This catalogue is called "Schutzgüterkatalog" and includes four main categories: Buildings, transportation and infrastructure, supply and disposal, as well as agriculture and timber (NGK II, 2010). These categories are further structured into different classes. The data for the classes are aggregated from already existing data sources, such as e.g. KAGIS and the digital cadastre (KRAMMER, 2009). Table 2-3 shows the object catalogue in detail.

Table 2-3: The object catalogue developed for the project "Natural Risk Management Carinthia" (Source: NGK II, 2010).

Category	Class	Description
1. Buildings	1.1. Buildings with 1 accommodation	Single-family dwellings
	1.2. Buildings with multiple accommodations	Multiple-family dwellings
	1.3. Buildings for residential communities	Residential accommodations
	1.4. Buildings without address point	Garages
	1.5. Industrial buildings / commercial buildings	Offices, retail sales, whole sales

	1.6. Tourism	Hotels, bed and breakfast places
	1.7. Public buildings	Schools, buildings for cultural, social, health care usage
	1.8. Others	Ski lift station, detached house
	1.9. Multiple building usage	Row houses with multiple usage
2. Roads / Infrastructure	2.1. State road (B)	
	2.2. State road (L)	
	2.3. Others	Municipal road, forest road
	2.4. High efficiency track	
	2.5. Light railway	
3. Supply / Disposal	3.1. Power station	
	3.2. Well	
	3.3. Storage Tanks	
	3.4. Water supply	
	3.5. Power line	
	3.6. Power utility	Power poles
	3.7. Clarification plant	
	3.8. Water disposal	
4. Agriculture / Timber	4.1. Forest	
	4.2. Agricultural usage / other usage	Cropland, grassland, alps, etc.

Another essential part of the project “Natural Risk Management Carinthia” was to use the acquired dataset for a risk assessment. Therefore a process was developed which uses the object catalogue in order to estimate damages for a certain scenario within 3 distinct steps (NGK II, 2010).

In the first step the objects which should be protected are automatically extracted from existing data sources for a certain project area. In the second step the hazard is overlaid with the extracted objects from the first step in order to figure out which objects are affected by which natural threat. In the third step the number of affected people and the monetary losses are estimated. For floods the depth of the water is assessed based on the risk zones. For the red zone a water depth of 1.5m and for the yellow zone an inundation depth of 0.2m was determined.

2.3. HAZUS-MH Background

HAZUS-MH is a software package providing a methodology to estimate natural hazards related losses. It is a freely available extension for the software ArcGIS 9.3 from Environmental Systems Research Institute (ESRI). HAZUS-MH is developed and maintained by the FEMA since 1997 (SCAWTHORN et al., 2006a). This governmental organization is responsible for hazard preparation, protection, response, recovery, and mitigation within the United States (FEMA, 2010). It uses HAZUS-MH to quantify the human, property, financial, and social impacts of different kinds of natural hazards, such as hurricanes, earthquakes, floods, and wildfire under existing conditions and given any of numerous possible mitigation measures (SCAWTHORN et al., 2006). This analysis is essential for understanding and communicating existing hazard risks to decision makers, emergency managers, and the public. In addition to the software there is also a ready-to-use dataset available. This dataset includes information about the buildings, demographic composition, and infrastructure for the whole United States. Both the data and the software are available for free.

Until today, HAZUS-MH has been mostly used within the United States. Nevertheless, according to statements of FEMA, there exists considerable interest for international usage of the software package (FEMA, 2010). Furthermore, there exists an international user group, which should provide technical, academic, and strategic support during the implementation of HAZUS-MH related projects. However, international usage of the software package is so far mostly limited to the integrated earthquake module (KULMESCH et al., 2010). For example, this module was used for a loss analysis within the downtown of Ottawa (Canada). For this research an earthquake with a magnitude of 6.5 was simulated with the software (PLOEGER et al., 2009). Furthermore, there exist international alternatives and derivates like HAZTURK from Turkey (URAL, 2006), Selena (Norway) (MOLINA et al., 2009), and the Earth Quake Risk Model (EQRM) (ROBINSON et al., 2006) from Australia, which are all specialized on loss estimation for earthquakes (PORTER et al., 2008). The flood module of HAZUS-MH was so far only used for a project located in Spain (FLETA et al., 2006).

2.4. HAZUS-MH dataset

HAZUS-MH uses two basic analytical processes in order to calculate damages caused by floods (SCAWTHORN et al., 2006a; FEMA, 2009a). In the flood hazard analysis the flood depth for a given location and scenario is estimated. The second process, called loss estimation analysis, uses this information in order to assess damages for the buildings and infrastructure in that area (for details see Section 2.5).

Therefore, two general types of data are needed to carry out this comprehensive loss estimation methodology. These comprise of the so-called inventory data, which includes information about the buildings, people, and infrastructure of the area of interest. In addition, hazard specific data are needed. These two different categories of input data are discussed in detail in the following subchapter.

2.4.1. Inventory Data

The identification and valuation of the property and infrastructure exposed to a hazard, such as floods, is one of the most important requirements for estimating losses. The inventory data contain all information about the buildings, the people living in certain areas, as well as information about infrastructure, like police, emergency and fire stations, transportation and lifeline systems, and other structures (FEMA, 2009a).

In order to keep an overview about this dataset it is structured according to the political division from state, to county, census tract, and census block. In addition to its spatial division, the inventory data are also structured thematically. It includes data about the general building stock. The general building stock includes more than 30 occupancy classes, which group buildings with a similar occupancy, valuation, damage, and loss characteristics into pre-defined classes (FEMA, 2009a). Moreover, the inventory data contain information about how many buildings of a specific type are located in a certain area, their aggregated value, square footage, and what kind of material they are made of, as well as information about the people, who live in a certain area (FEMA, 2009a).

Furthermore, the inventory data include information about so-called Essential Facilities. These facilities provide services to the community and should be functional after a flood. Examples for Essential Facilities are hospitals, care facilities, schools, police-, emergency-, and fire stations. In contrast to the general buildings, the flood damage data for these structures exist on a site-specific basis and are not aggregated. This allows a site-specific damage analysis, as well as an estimation of how long the building would be inoperable (FEMA, 2009a).

Also transportation systems, such as highways and railroads can be added to the inventory dataset. These include bridges for roads and railroads, as well as railroad stations and maintenance facilities. Other transportation systems include airports, bus systems, and ferries (FEMA, 2009a). Another essential part of the inventory data are lifeline systems, such as wastewater systems, potable water systems, as well as electric power-, communication-, oil-, and natural gas systems (FEMA, 2009a). Moreover, data about both, the daytime-dependent location and value of vehicles, in a certain area, as well as hazardous materials and agriculture can be integrated into HAZUS-MH (FEMA, 2009a).

2.4.2. Hazard Specific Data

As has been already mentioned, HAZUS-MH uses the flood hazard analysis and the loss estimation process in order to assess damages caused by inundations. For this process the DEM is an essential part for the hazard specific dataset as it is needed to calculate the flood depth. A DEM describes the ground elevation as an ordered array of numbers, where each pixel represents the spatial distribution of elevations in a landscape (MOORE et al., 1991). Additional data include flood elevations and floodplain boundaries, which are used to describe the outline and characteristics of the floodplain. Figure 2-7 shows a DEM from Carinthia.

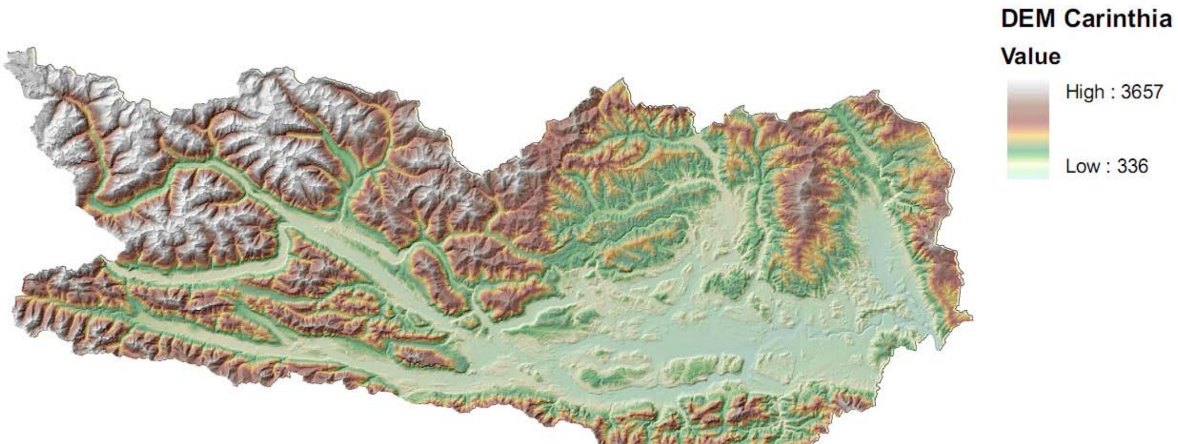


Figure 2-7: A DEM (in meters) combined with the derived hill shade from Carinthia. Lower areas are colored in green, whereas higher areas have a brown and white coloring

Moreover it is also possible to integrate other data, such as riverine discharge values, which describe the amount of water flowing past a given point in a stream. These different sources of information can then be combined and pre-processed within HAZUS-MH.

2.5. HAZUS-MH Loss Estimation Methodology for Floods

According to GROSSI & KUNREUTHER (2005) a catastrophe model consists of four basic components: the hazard, the inventory, the vulnerability, and the loss. First of all the potential risk of a natural hazard has to be characterized. For floods these characteristics might be the frequencies (e.g. a 100-, or 500-year) of certain flood events. In contrast to this a hurricane can be characterized by its path and wind speed, whereas the parameters for an earthquake are the location of the epicenter and the magnitude. Another important parameter for a catastrophe model is the data about the building stock. The information might range from the spatial location of buildings and other structures to the number of stories and the materials they are made of (GROSSI & KUNREUTHER, 2005). Combining the information from the hazard and the inventory enables the calculation of the vulnerability of the buildings and infrastructure. Therefore so-called damage functions are used, which take the characteristics of hazards, as well as the attributes of buildings into consideration in order to estimate the susceptibility (SCAWTHORN et al., 2006b). The quantification of the vulnerability can vary from model to model. It can be represented in a ordinal way (e.g. slight, moderate, extensive damage), as well as quantitatively (e.g. damage in percent). This information can then further be used for assessing both, direct and indirect losses. Direct include all the costs which occur, when repairing, or replacing damaged or destroyed buildings. In contrast, indirect losses include the damage caused by business interruptions and relocation costs (GROSSI & KUNREUTHER, 2005). Figure 2-8 shows the proposed catastrophe model graphically.

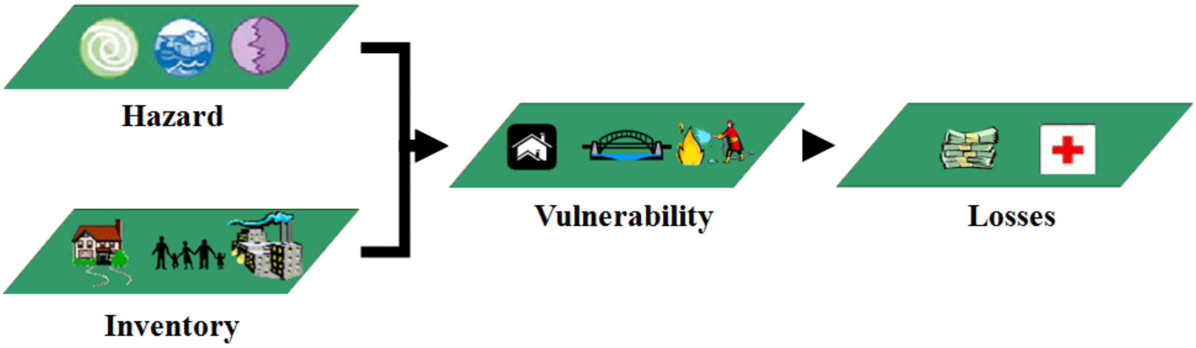


Figure 2-8: The catastrophe model according to GROSSI & KUNREUTHER (2005).

As already stated in Chapter 2.4, HAZUS-MH is implementing this model with two basic analytical processes in order to estimate losses from both, coastal and riverine inundations (SCAWTHORN et al., 2006a; FEMA, 2009a). In the flood hazard analysis phase the characteristics, such as the spatial extent and velocity, of a flood are analyzed. The results of this phase are then combined with the inventory data and damage functions in order to estimate damages, as well as losses caused by the inundation (FEMA, 2009b).

The necessary data for each phase are dependent on the desired level of detail of the analysis. HAZUS-MH provides three different analysis levels, as depicted in Figure 2-9 (FEMA, 2009b).

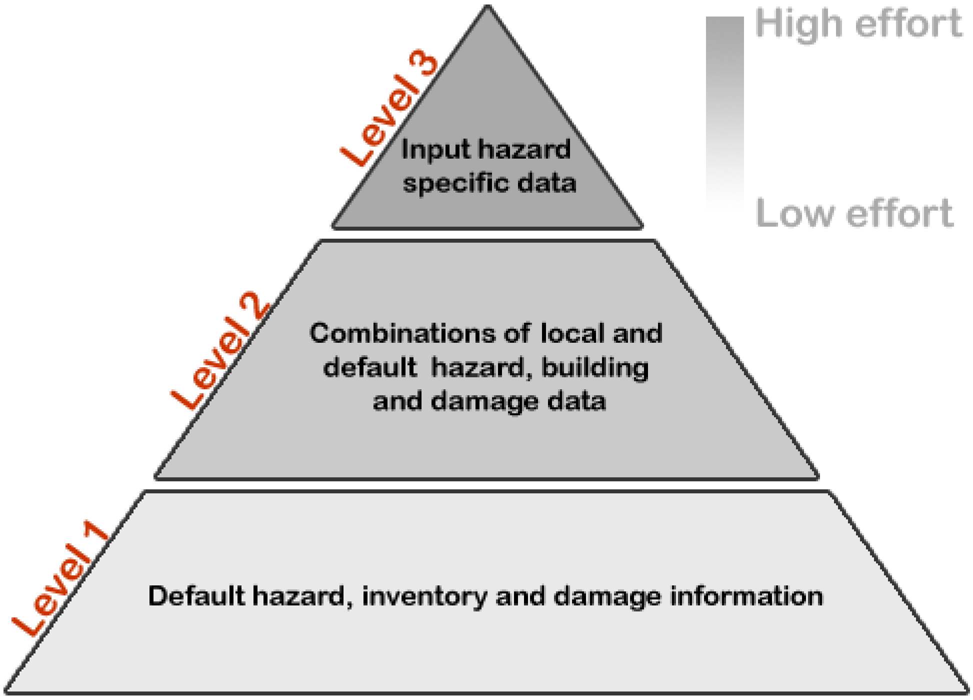


Figure 2-9: **The different levels of detail of the loss estimation methodology provided by HAZUS-MH. The higher the level is, the higher the effort to carry out the analysis. Also the reliability and accuracy of the results increase with the level of analysis (Source: FEMA, 2009b)**

A level 1 analysis uses mainly the default dataset provided by HAZUS-MH. Therefore, it is simple and fast to carry out, as hardly any data need to be collected. Furthermore, the user is not expected to have background knowledge about the software package. Solely a DEM is necessary for the analysis. The rest of the data can be aggregated by HAZUS-MH automatically with the data provided. However, the drawback of a level 1 analysis is that the generated results lack of accuracy and reliability (FEMA, 2009). Furthermore some components within the loss estimation methodology cannot be performed as they would need more detailed information. Nevertheless, this level of detail is enough for a quick assessment of flood related damages (FEMA, 2009b).

A more sophisticated flood damage assessment can be carried out with a level 2 analysis. It requires a more detailed inventory dataset and thus more effort by the user (FEMA, 2009b). Furthermore, the user needs to pre-process the flood hazard data in order to use it for the loss estimation methodology. These efforts are needed to improve the accuracy and reliability of the results generated by the standardized method of HAZUS-MH (FEMA, 2009b). In addition these factors are dependent on the data quality of the user-provided data. Furthermore, all components of the loss estimation methodology can be performed at this level of detail, except the velocity analysis (FEMA, 2009b).

The most effort is required when carrying out a level 3 analysis, as it incorporates results from external engineering and economic studies. Furthermore, methods and tools, which are not provided by HAZUS-MH need to be used for this level of detail, as there is no standardized methodology available. Moreover, technical experts and engineers are required to gather data and perform detailed analyses (FEMA, 2009b). However, it is possible to create the most accurate results with a level 3 analysis.

Despite having different input parameters and processes in the background, all three types of analysis have the same kind of result. The flood hazard analysis results in a so-called flood depth grid. This is a raster file, where each pixel represents the flood depth at a given location. An example of such a flood depth grid is presented in Figure 2-10.

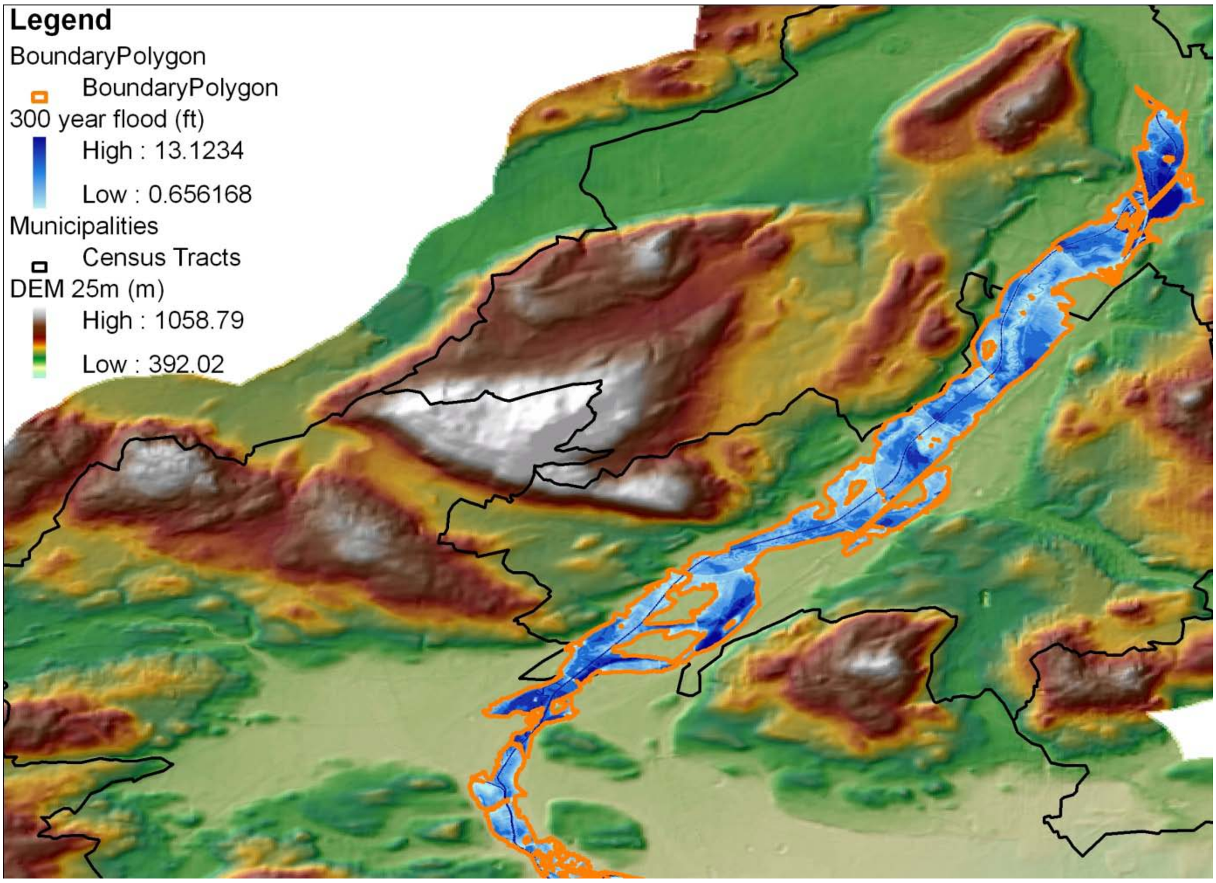


Figure 2-10: A sample graphical overlay of a flood depth grid, the corresponding flood boundary (in orange), and a DEM.

Dependent on the level of analysis the flood depth grid can be calculated in three different ways. For a level 1 analysis it is enough to provide a DEM and use the methodology provided by HAZUS-MH in order to delineate the floodplain (FEMA, 2009b). For a level 2 analysis more information is needed in order to characterize the flood hazard, such as a flood boundary, flood plain cross sections, and discharge values. A flood boundary is a single contiguous polygon describing the spatial extent of an inundation, whereas flood cross sections are line features crossing this polygon, without intersecting each other. Furthermore, these lines are attributed with the flood elevation. These data are then processed with the Flood Information Tool (FIT), a further ArcGIS extension which is explicitly designed to determine the flood hazard in form of a flood depth grid (FEMA, 2009b).

After the hazard has been characterized, the damage module of HAZUS-MH estimates the damage on the building stock as a percent value of replacement costs at the census block level (SCAWTHORN et al., 2006b). Depth-damage functions are used for mapping the depth of an inundation to the caused damages. These estimations are done for each occupancy class at the level of the census block. In the next step the algorithm multiplies the assessed damage in percent with the total or depreciated replacement value (SCAWTHORN et al., 2006b). One feature of the Flood Model of HAZUS-MH is that it provides the capability to model the depreciation of buildings over time based on their age and general condition (e.g. good, average, poor condition). Depreciation functions together with the data allow the estimation of the actual value of the buildings in a certain area (SCAWTHORN et al., 2006b).

For Essential Facilities, like hospitals, schools, fire-, emergency-, and police stations this mapping is applied to each building individually. Therefore, default depth-damage curves are used, which are modifiable within HAZUS-MH (SCAWTHORN et al., 2006b). In contrast, there exists a separate set of damage functions for lifeline systems, as they are either uniquely vulnerable or expensive to repair or to replace (SCAWTHORN et al., 2006b). Through combining the damage with the replacement values, the actual losses can be derived. The entire process including the hazard analysis, the loss estimation methodology and all the input parameters can be seen in Figure 2-11.

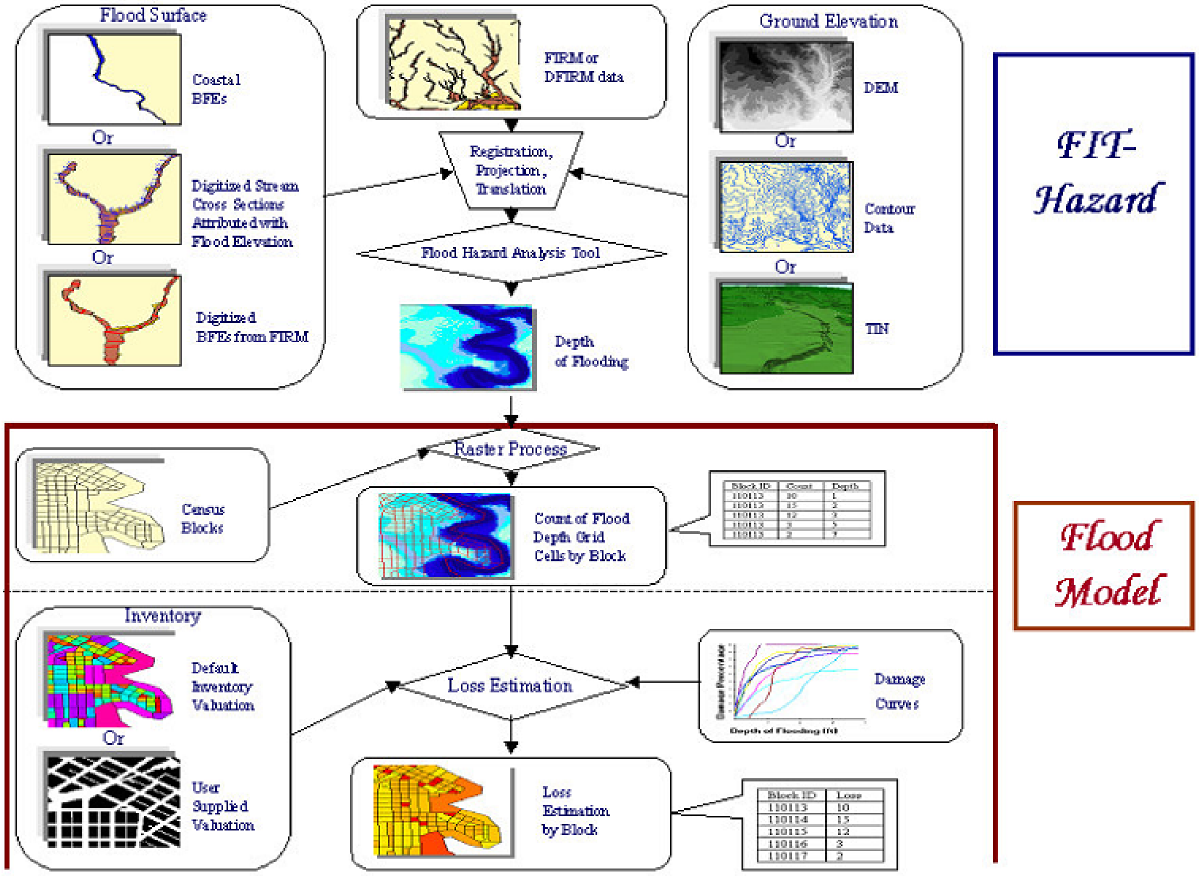


Figure 2-11: Overview of the entire Flood Model of HAZUS-MH, including the hazard analysis (blue) and the damage analysis (red) phases (Source: FEMA, 2009a)

2.6. Summary

This chapter focused on the theoretical basics of this Master Thesis. In addition to the definition of terms, existing methodologies for flood risk analysis in Austria have been discussed. Although numerous procedures, directives, initiatives, and programs do exist, there is no precise standardized method or tool for loss assessment in Austria. Although the directive for cost-benefits analysis provides a framework for such analysis, implementations may still differ as the methodology still offers “room” for misinterpretations. Furthermore, all data collection needs to be done by risk managers, which implies a lot of efforts. Another problem is that for each project area of a cost-benefit analysis all data needs to be acquired from the scratch. In contrast, HAZUS-MH provides a standardized methodology for loss estimations and already offers a standardized dataset (for the United States). It also features the possibility to improve and update the inventory data in order to reduce efforts for the risk manager. Thus, it is possible to distribute the workload for gathering, updating and analyzing the data.

3. Methodology

In this part of the thesis practical aspects of the analysis are presented. First of all the issue for this thesis is explained. Then the project is discussed in detail. Especially the study region and the acquired geodata are examined carefully. Other topics in this chapter include the data requirements and the data model of HAZUS-MH. Moreover, the workflow for integrating Austrian data into the HAZUS-MH system is explained. Last but not least, special tools for HAZUS-MH are presented which are used to integrate data and to model the flood hazard.

3.1. Problem Definition

In the year 2007 the EU agreed on the European Flood Directive which obligates member states to identify flood prone areas. Therefore, flood hazard as well as flood risk maps have to be created. One important analysis for such flood risk maps are loss estimations which assess damages caused by inundations of different severity. The results of these kinds of investigations can be used to evaluate what kind of damages can occur, how many people are affected and maybe most important where damages can happen.

The main goal of this thesis is to find out if HAZUS-MH is usable with Austrian data and, if this is true, how well it can support the implementation of the EU flood directive. Furthermore it should be figured out if the software is applicable for cost-benefit analysis. Throughout these such a cost-benefit analysis experts evaluate whether certain flood protection activities are economically reasonable or not. A second goal is therefore to compare the methodology provided by HAZUS-MH and its results with the conclusions from a cost-benefit analysis carried out by experts.

3.2. Project Area

The boundaries for the project area for this Master Thesis were chosen according to the extent of a cost-benefit analysis carried out in the year 2009. It includes the counties St.Veit an der Glan, as well as the city and surrounding county of Klagenfurt. The municipalities involved in this study are the communities of St. Veit an der Glan, Maria Saal, Klagenfurt and Ebenthal. The focus is on the river Glan which has a length of 63.33 km. The river originates at the Ossiacher Tauern at a height of 667m and contributes to the river Gurk at a height of about 447m. The average slope is about 3.9% and the catchment area is 826.51 km² (GUGGENBERGER et al., 2009). Figure 3-1 shows the entire project area for this Master Thesis.

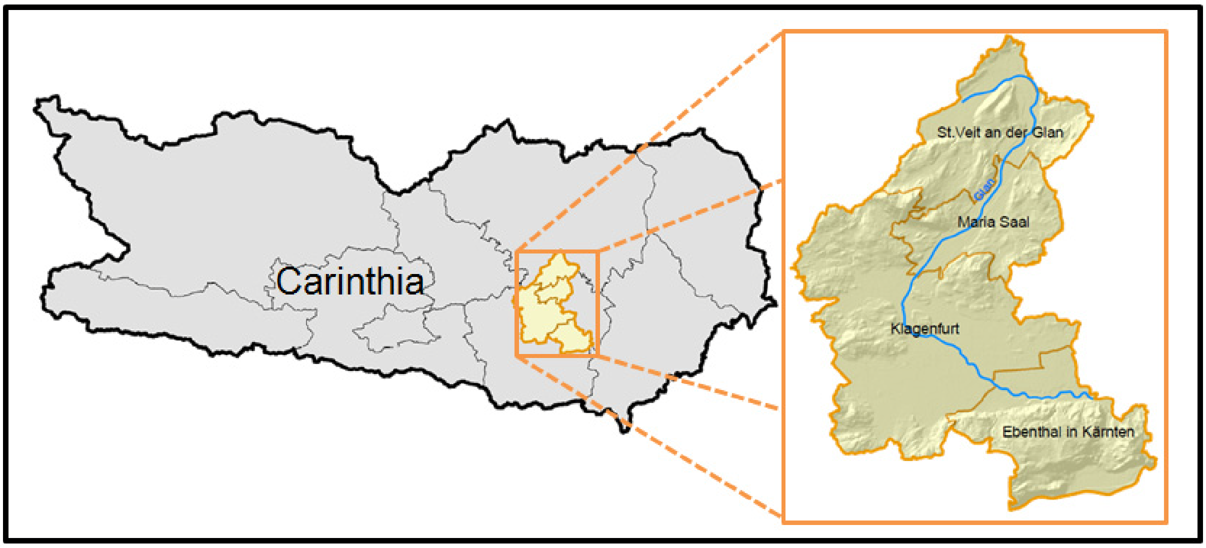


Figure 3-1: The project area for this Master Thesis.

3.3. Geodata

As already mentioned in section 2.4, HAZUS-MH needs two types of data. The inventory data contain information about the buildings, the infrastructure, and the people in the study region, while the hazard specific data describe the characteristics of a flood and the surface of the earth. In this chapter the data sources for these two data sources are analyzed in detail.

3.3.1. Inventory Data

Information from the "Planquadrat" dataset, as well as from the "Schutzgüterkatalog" was used for the inventory data. Furthermore the political boundaries for the province of Carinthia and its counties and municipalities were used.

The building count and the geometries of the polygons from the C-package provided by the "Planquadrat" were used to build the basis for the dataset which was acquired for the flood loss estimation. This dataset was obtained from the Statistik Austria. The "Planquadrat" divides the whole area of Austria into regular cells with resolutions ranging from 125 meters to 10 000 meters (KAMINGER & WONKA, 2004). For these polygons information such as census data and the number of buildings per cell are aggregated (see section 3.4.1 for more information).

Another important data source for the inventory data was the "Schutzgüterkatalog" which was generated for the project Natural Risk Management in Carinthia. It contains objects which are worth to be protected from natural hazards such as floods, debris flows and landslides (NGK II, 2010). The data used for the damage potential analysis for this thesis include the road and rail network, the building footprint polygons, drinking water supply and wastewater disposal, as well as electric power facilities, and fire stations. Table 3-1 gives detailed information about the sources for the inventory dataset.

Table 3-1: Information about the inventory data sources.

Dataset	Data Type	Description	Spatial Reference System	Data capture process / scale
Planquadrat dataset				
Package C	Vector – Polygon	Austria-wide polygon dataset; information is aggregated to regular cells	Bundesmeldenetz	Cell rsolution: 250m
Schutzgüterkatalog:				
Road network	Vector - Polyline	Roads in the project area	Bundesmeldenetz	Acquired from KAGIS
Rail network	Vector - Polyline	Railway system in the project area	Bundesmeldenetz	Acquired from KAGIS
Building footprints	Vector - Polygon	Building footprints of all buildings (residential, commercial, industrial)	Bundesmeldenetz	
Fire stations	Vector - Point	Fire stations in the project area	Bundesmeldenetz	
Drinking water supply	Vector - Point	Drinking water facilities in the project area	Bundesmeldenetz	
Wastewater disposal	Vector - Point	Wastewater disposal facilities in the project area	Bundesmeldenetz	
Electric power facilities	Vector - Point	Electirc power facilities in the project area	Bundesmeldenetz	Acquired from KAGIS

3.3.2. Hazard Specific Data

The data sources for the hazard-specific data comprise of flood boundaries coming from the HORA dataset, the risk zones from Austria, and a 300-year flood boundary, as well as elevation information which are derived from a DEM. Figure 3-2 shows these flood plains and the DEM.

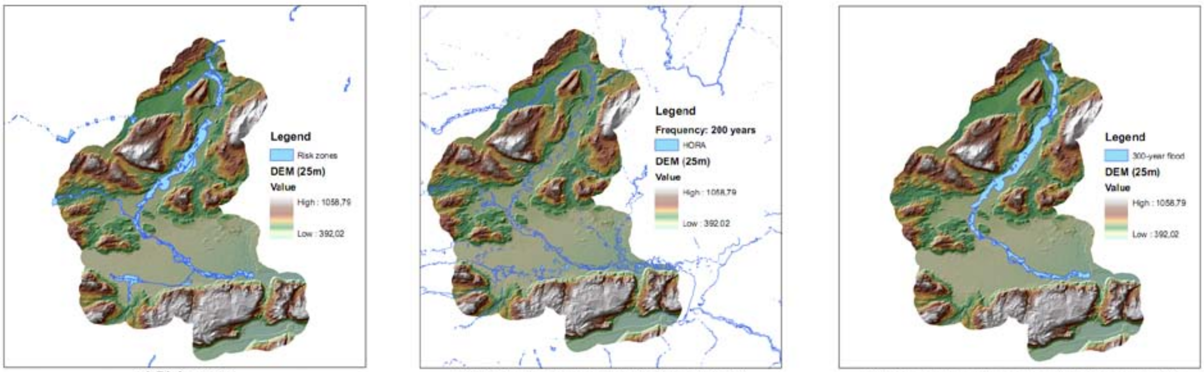


Figure 3-2: The different flood boundaries derived from the risk zones (a), the 200-year flood plain from the HORA-project (b), and a 300-year flood model (c), which was used for a cost-benefit analysis in this area.

The HORA dataset contains flood plains for 30-, 100-, and 200 year inundations for the whole riverine network of Austria. The calculated boundaries include the spatial extent of a flood after the breakdown of dams, levees and similar protective structures (MERZ et al., 2008). The data were collected from 2004 until 2006 during the project “Hochwasserrisikozonierung Austria - HORA” (flood risk zoning Austria) with a scale of 1:500 000. Due to this relative small scale and inconsistencies within the dataset the inundation boundaries can only give an overview about the flood risk in the corresponding areas.

A more promising alternative is offered by the flood risk zones, which are collected according to an Austrian directive. This dataset represents areas at risk from flooding, debris flows, and landslides (BMLUFW, 2006b). The directive distinguishes different kinds of risk zones. The most significant zones are the red and the yellow zone. In the red zone constructing new buildings is prohibited as these areas are under high risk of being affected by floods. In contrast to this the yellow zones comprise areas which are used as drainage for the flood water. The severity of an inundation is assumed to be significantly lower than in the red zone (BMLUFW, 2006b).

For those areas where no data for these risk zones are available the flood plains are determined for relevant frequencies, such as 30-, 100-, and 300-year floods (PIECHL, 2005). These flood plains ignore the risk zones and represent the spatial extent of the inundation for the corresponding frequency. In the analysis discussed in this thesis an inundation boundary for a 300-year flood was used. Table 3-2 gives detailed information about the hazard specific data.

Table 3-2: Information about the hazard specific data used for the loss estimation.

Dataset	Data Type	Description	Spatial Reference System	Data capture process / scale
HORA flood plains	Vector – Polygon	Carinthia-wide flood plain dataset collected for the HORA project	Bundesmeldenetz	Captured at a scale of 1:500 000
Risk zones	Vector – Polygon	Yellow and red risk zones (not available for whole Carinthia)	Bundesmeldenetz	Captured at a scale of 1:1000 to 1 : 5000
Digital Elevation	Raster	Elevation	Gauss Krüger	Resolution: 25m

Model		information of the ground	Transversal Mercator Projection	

3.4. Data Requirements

The data model of HAZUS-MH comprises of a total of 9 databases for structuring all data thematically. The databases include a system specific boundary database (syBoundary.mdb) which is mainly used for selecting a study region from the data repository. This database does not hold any attribute information, which is relevant for the Flood Model but provides a link from the selected project area to the relevant data for the software. In contrast to this the General Building Stock (GBS) database (bndrygbs.mdb) stores aggregated data about the number, square footage, and values of the buildings, as well as data about the people living in this area. There exists an additional database for so-called Essential Facilities (EF.mdb). These facilities include objects such as hospitals, police and fire stations, emergency centers, care facilities, and schools. In contrast to this High Potential Loss Facilities (HPLF.mdb) comprise of features such as dams, levees, military stations, nuclear facilities and hazardous materials. Moreover databases for estimating direct damages to agriculture (flag.mdb) and vehicles (flVeh.mdb) are available. Also transportation systems (TRN.mdb) such as railways, road networks, ferries, and bus systems are included in the data model of HAZUS-MH. Last but not least a database for life line systems (UTIL.mdb) was integrated, which stores information about Potable Water and Wastewater Systems, as well as natural gas and oil facilities and pipes. Table 3-3 gives an overview about the thematic structure of the HAZUS-MH dataset.

Table 3-3: Overview of the HAZUS-MH data model. The “X” indicates that data were collected for the project area in Carinthia.

HAZUS-MH Database	Tables	Data Collected
General Building Stock	Counties	X
	Municipalities	X
	Planquadrate	X
	Building Count	X
	Square Footage	X
	Dollar Exposure	
	Demography	
Essential Facilities	Care Facilities	
	Emergency Centers	
	Fire Stations	X
	Police Stations	
	Schools	
Agriculture	Agriculture Inventory	
High Potential Loss Facilities	Dams	
	Hazardous Materials	
	Levees	
	Military Facilities	
	Nuclear Facilities	
Vehicles	Vehicle Inventory Day	
	Vehicle Inventory Night	

Mapping Schemes	Earthquake Mapping Schemes	
	Flood Mapping Schemes	X
	General Mapping Schemes	X
Transportation	Airports	
	Bus System	
	Ferries	
	Highway Segments	X
	Highway Bridges	
	Highway Tunnels	
	Light rail Facilities	
	Light rail Segments	
	Light rail Tunnels	
	Railway Segments	X
	Railway Tunnels	
	Railway Bridges	
	Ports	
	Runway	
Lifeline System	Communication System	
	Electric Power Facility	X
	Natural Gas Facility	
	Natural Gas Pipes	
	Oil Facility	
	Oil Pipes	
	Potable Water Facilities	X
	Potable Water Pipes	
	Wastewater Facility	X
	Wastewater Pipes	

Furthermore the data have to be spatially structured, as well. For each state within the US there exists an extra dataset containing all information for this state. This state wide dataset is then further divided into smaller units. Thus a regional division is needed in order to aggregate the data to smaller units of analysis. Within the US datasets this hierarchy is built down from states, to counties, to census tracts and census blocks. A similar hierarchy had to be defined for this master project as such a detailed regional separation does not exist in Austria.

The dataset consists of plain tables as well as spatial feature classes. HAZUS-MH supports all common SRS which are provided by ArcGIS 9.3. The only restriction is that the SRS for the feature classes should be consistent among the dataset.

In the following section, the regional divisions, as well as the different aspects of the data model, are now discussed in detail.

3.4.1. Regional Division

As stated in section 2.4.1 HAZUS-MH requires different levels of regional division. In the US there exists a clear partitioning into states, counties, census tracts and census blocks. In Austria such a detailed and consistent separation from a state-level to the level of a census block is not available. Therefore, the common political division in Austria ranging from state, to county, and to municipality was extended in order to fit the requirements by HAZUS-MH.

The missing level of regional division was compensated with the so called “Planquadrat“. This data source is provided by Statistik Austria and uses a grid, which divides the area of

Austria into regular cells. For these cells different kinds of data are available, such as building counts and demographic data. The data are available with a fixed cell size of 125, 250, 500, 1000, 5.000 and 10.000 meters. Thus, it can be used for both regional and supra-regional spatial analysis (KAMINGER & WONKER, 2004).

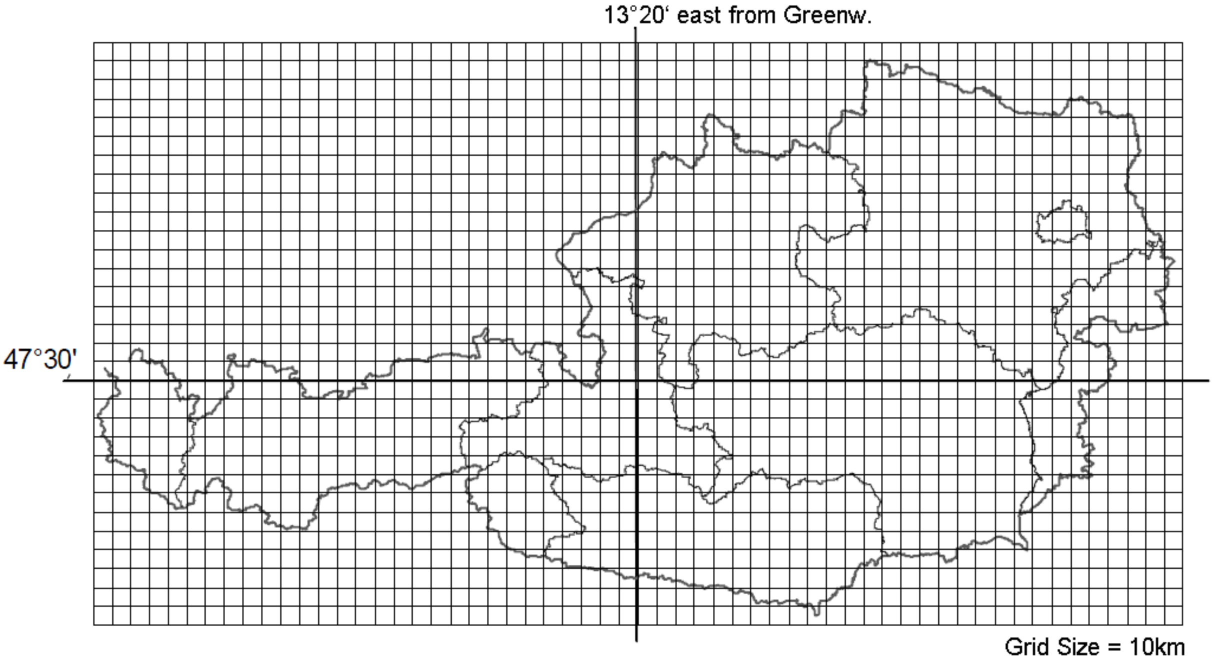


Figure 3-3: The regular grid of the "Planquadrat" with a cell size of 10 kilometers (Source: KAMINGER & WONKER, 2004)

As shown in Figure 3-3 the grid of the "Planquadrat" ignores the borders of states, counties and municipalities. Therefore the cells, as well as the corresponding data have to be processed in order to get a consistent dataset, which is described in section 3.5.

3.4.2. General Building Stock

One of the most important parts of the inventory data is the GBS as it contains essential information about the structures and buildings in the project area, such as building count, the square footage by occupancy, and full replacement values (FEMA, 2009a).

In order to structure the GBS all buildings are classified according to their occupancy. The data model of HAZUS-MH uses 33 classes in order to group buildings with similar valuation, as well as damage and loss characteristics into a set of pre-defined groups for analysis (FEMA, 2009a).

For this Master Thesis 8 out of the 33 occupancy classes were used for the analysis as data were available only for these specific groups. In HAZUS-MH, the classes range from different types of residential and business buildings, to governmental and industrial constructions. Table 3-4 shows all the general occupancy classes provided by the HAZUS-MH model.

Table 3-4: The General Occupancy Classes provided by HAZUS-MH. The „x“ indicates the occupancy class that was used for the analysis in this Master Thesis.

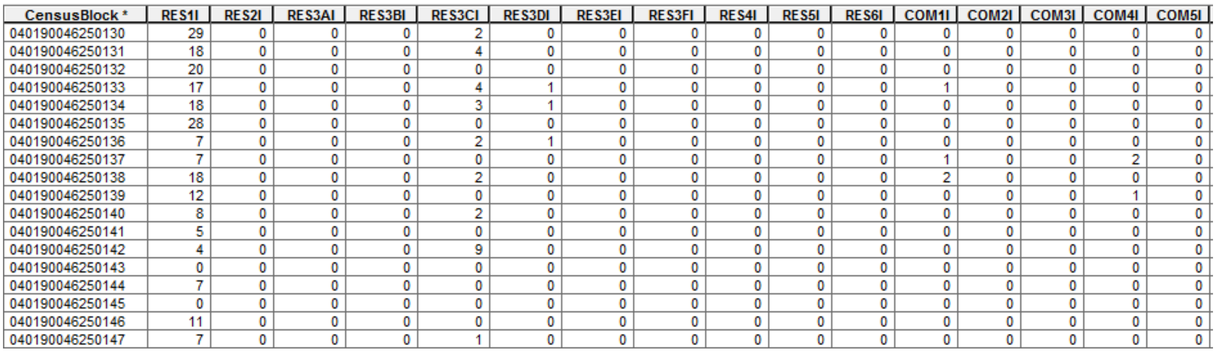
HAZUS-MH label	Definition	Used
Residential		
RES1	Single Family Dwelling	x
RES2	Mobile Homes	
RES3A	Multi Family Dwelling - Duplex	
RES3B	Multi Family Dwelling – 3-4 Units	
RES3C	Multi Family Dwelling – 5-9 Units	x
RES3D	Multi Family Dwelling – 10-19 Units	x
RES3E	Multi Family Dwelling – 20-49 Units	
RES3F	Multi Family Dwelling – 50+ Units	
RES4	Temporary Lodging	
Commercial		
COM1	Retail Trade	x
COM2	Wholesale Trade	
COM3	Personal and Repair Services	
COM4	Business / Professional / Technical Services	x
COM6	Hospital	
COM7	Medical Office / Clinic	
COM8	Entertainment & Recreation	x
COM9	Theaters	
COM10	Parking	
COM11	Retail Trade	
Industrial		
IND1	Heavy	
IND2	Light	x
IND3	Food, Drugs, Chemicals	
IND4	Metals, Minerals Processing	
IND5	High Technology	
IND6	Construction	
Agriculture		
AGR1	Agriculture	
Religion / Non-Profit		
REL1	Church / Membership Organization	
Government		
GOV1	General Services	x
GOV2	Emergency Response	
Education		
EDU1	Schools/Libraries	
EDU2	Colleges/Universities	

For each of the 33 occupancy classes in every “Planquadrat” information about the people, the buildings and their characteristics can be stored in the GBS. The key GBS database tables include the following data (FEMA, 2009a):

- Square footage by occupancy: These data are the estimated floor area by specific occupancy.
- Full Replacement Value by occupancy: These data represent the estimated replacement values by specific occupancy.

- Building Count by occupancy: These data store the information about the number of buildings by specific occupancy.
- General Occupancy Mapping: These data provide a general mapping for the GBS inventory data from the specific occupancy to general building characteristics (e.g. construction material, foundation types, first floor elevations, etc.).
- Demographics: These data provide housing and population statistics for the study region.

From these five key tables only data for the building count and square footage by occupancy were available for the Carinthian study region. The occupancy mapping was taken from an U.S. HAZUS-MH dataset. Figure 3-4 shows parts of the building count table, which was developed for this Master Thesis.



CensusBlock *	RES1I	RES2I	RES3AI	RES3BI	RES3CI	RES3DI	RES3EI	RES3FI	RES4I	RES5I	RES6I	COM1I	COM2I	COM3I	COM4I	COM5I
040190046250130	29	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
040190046250131	18	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
040190046250132	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
040190046250133	17	0	0	0	4	1	0	0	0	0	0	1	0	0	0	0
040190046250134	18	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0
040190046250135	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
040190046250136	7	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0
040190046250137	7	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0
040190046250138	18	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0
040190046250139	12	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
040190046250140	8	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
040190046250141	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
040190046250142	4	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0
040190046250143	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
040190046250144	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
040190046250145	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
040190046250146	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
040190046250147	7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

Figure 3-4: The building count table aggregates the number of structures for each occupancy class in each "Planquadrat"

3.4.3. Essential Facilities

Essential Facilities are objects which offer services to the community and should be functional after a flood (FEMA, 2009a). These kinds of facilities include fire stations, police stations, emergency centers, as well as schools and care facilities. In contrast to the GBS the data of the Essential Facilities are not aggregated. The damages for these kinds of structures are estimated on an individual basis (FEMA, 2009a). They are thus represented as points in the dataset. The purpose for the Essential Facilities module is to assess the monetary losses, as well as investigating the functionality of these critical structures after a flood.

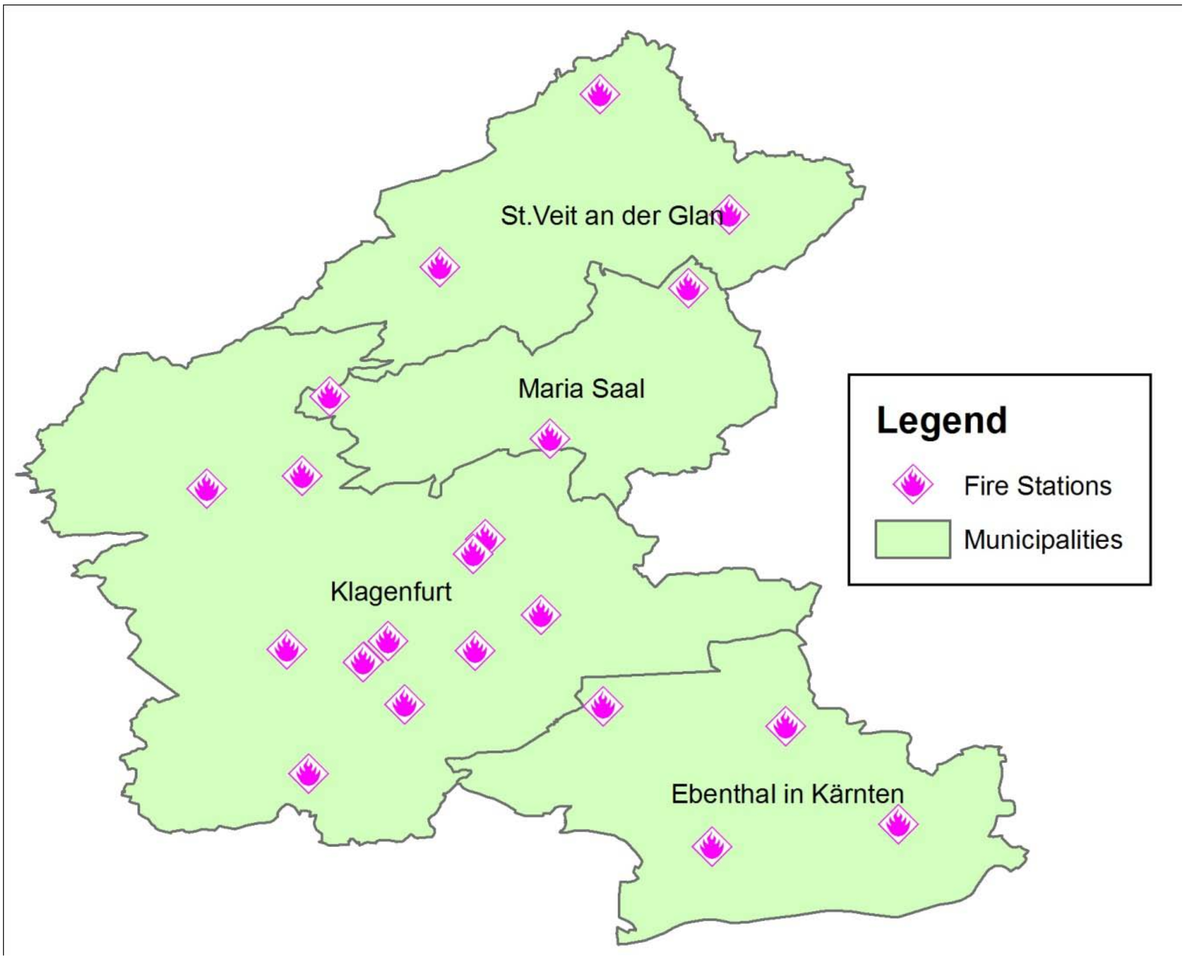


Figure 3-5: **Location of fire stations within the four municipalities of the project area.**

Such critical facilities include objects like police stations, hospitals, emergency centers, fire stations, schools and care facilities. In order to classify the different structures HAZUS-MH provides three general occupation classes (emergency response, medical and schools) and 14 specific occupation classes (FEMA, 2009a). Table 3-5 shows this classification scheme in detail.

Table 3-5: **The general and specific classification for Essential Facilities within HAZUS-MH (Source: FEMA, 2009a).**

HAZUS Label	Occupancy Class	Description
Medical Care Facilities		
MDFLT	Default Hospital	
EFHS	Small hospital	Less than 50 beds
EFHM	Medium hospital	Between 50 an 150 beds
EFHL	Large hospital	More than 150 beds
EFMC	Medical Clinics	Clinics Labs Blood Banks
Emergency response		
FDFLT	Default fire station	
EFFS	Fire station	
PDFLT	Default police station	
EFPS	Police station	
EDFLT	Default Emergency Operation Center	

EFEO	Emergency Operation Center	
Schools		
SDFLT	Default School	
EFS1	Grade Schools Primary/ High Schools	
EFS2	Colleges/Universities	

Furthermore, specific building characteristics can be defined on an individual basis. These include information about whether the building has a basement, its first floor elevation, number of stories, etc. (FEMA, 2009a). However for the study discussed in this Thesis only the fire stations have been used in the loss estimation methodology. 22 of these facilities are located within the project area which are depicted in Figure 3-5.

3.4.4. High Potential Loss Facilities

High Potential Loss Facilities are structures which are likely to cause a vast amount of losses if damaged. Such structures include dams, nuclear power plants, hazardous materials, levees, and military installations (FEMA, 2009a). As these facilities are only supported by the Earthquake Module provided by HAZUS-MH they have been neglected in the analysis for this project, which is focused on the Flood Module.

3.4.5. Transportation

HAZUS-MH also supports the analysis of different transportation system such as highways, railways, light rail, bus, ports, ferries, and airports (FEMA, 2009a). Furthermore, the data model provides the possibility to differentiate between road-segments, bridges, and tunnels for highways, railways, and light rail. Segments are represented as polylines, whereas bridges and tunnels are stored as point feature classes.

However, in the version MR4 the loss estimation methodology can only assess flood-damages caused on bridges. Damages on highway and railway segments, as well as tunnels have been deferred to later versions (FEMA, 2009a). Nevertheless, the data model and classification scheme for transportation systems have already been defined. Information such as the location, the class, and the replacement value have to be integrated into the dataset in order to assess losses and the functionality after a flood (FEMA, 2009a). The classifications for the highway-, railroad-, bus-, and light rail-system can be seen in Table 3-6. The major difference between the railway system and the light rail system is that the light rail system is operated with a DC power supply (FEMA, 2009a).

Table 3-6: The classification scheme for the highway-, railway-, light rail-, and bus-system. The valuation is given in thousand US dollars. The "x" indicates that a feature is supported by HAZUS-MH MR4 (Source: FEMA, 2009a).

HAZUS-label	General Occupancy	Description	HAZUS Valuation	Supported by MR4
Highway System				
HRD1	Highway Roads	Major Roads (1km 4 lanes)	10000	
HRD2	Highway Roads	Urban Roads (1km 2 lanes)	5000	
HTU	Highway Tunnel	Highway Tunnel	20000	

HWBM	Highway Bridge	Major Bridge	20000	x
HWBO	Highway Bridge	Other Bridge (include all wood)	1000	x
HWBCO	Highway Bridge	Other Concrete Bridge	1000	x
HWBCC	Highway Bridge	Continuous Concrete Bridge	5000	x
HWBSO	Highway Bridge	Other Steel Bridge	1000	x
HWBSC	Highway Bridge	Continuous Steel Bridge	5000	x
Railway System				
RTR	Railway Tracks	Railway Tracks (per km)	1500	
RBRU	Railway Bridge	Railway Bridge Unknown	5000	x
RBRC	Railway Bridge	Concrete Railway Bridge	5000	x
RBRS	Railway Bridge	Steel Railway Bridge	5000	x
RBRW	Railway Bridge	Wood Railway Bridge	5000	x
RTU	Railway Tunnel	Railway Tunnel	10000	
RSTS	Railway Urban Station	Steel Railway Urban Station	2000	
RSTC	Railway Urban Station	Concrete Railway Urban Station	2000	
RSTW	Railway Urban Station	Wood Railway Urban Station	2000	
RSTB	Railway Urban Station	Brick Railway Urban Station	2000	
RFF	Railway Fuel Facility	Railway Fuel Facility (Tanks)	3000	
RDF	Railway Dispatch Facility	Railway Dispatch Facility	3000	
RMFS	Railway Maintenance Facility	Steel Railway Maintenance Facility	2800	
RMFC	Railway Maintenance Facility	Concrete Railway Maintenance Facility	2800	
RMFW	Railway Maintenance Facility	Wood Railway Maintenance Facility	2800	
RMFB	Railway Maintenance Facility	Brick Railway Maintenance Facility	2800	
Light Rail System				
LTR	Light Rail Track	Light Rail Track (per km)	1500	
LBRU	Light Rail Bridge	Light Rail Bridge Unknown	5000	x
LBRC	Light Rail Bridge	Concrete Light Rail Bridge	5000	x
LBRS	Light Rail Bridge	Steel Light Rail Bridge	5000	x
LBRW	Light Rail Bridge	Wood Light Rail Bridge	5000	x
LTU	Light Rail Tunnel	Light Rail Tunnel	10000	
LDC	DC Substation	DC Substation	2000	
LDF	Dispatch Facility	Dispatch Facility	3000	
LMFS	Maintenance Facility	Steel Maintenance Facility	2600	
LMFC	Maintenance Facility	Concrete Maintenance Facility	2600	
LMFW	Maintenance Facility	Wood Maintenance Facility	2600	
LMFB	Maintenance Facility	Brick Maintenance Facility	2600	
Bus system				
BPTS	Bus Urban Station	Steel Bus Urban Station	1000	
BPTC	Bus Urban Station	Concrete Bus Urban Station	1000	
BPTB	Bus Urban Station	Brick Bus Urban Station	1000	
BPTW	Bus Urban Station	Wood Bus Urban Station	1000	
BFF	Bus Fuel Facility	Bus Fuel Facility	150	
BDF	Bus Dispatch Facility	Bus Dispatch Facility	1300	
BMFW	Bus Maintenance Facility	Wood Maintenance Facility	1300	
BMFS	Bus Maintenance Facility	Steel Maintenance Facility	1300	
BMFC	Bus Maintenance Facility	Concrete Maintenance Facility	1300	
BMFB	Bus Maintenance Facility	Brick Maintenance Facility	1300	

For the damage potential analysis for this thesis research, the highway- and road-network, as well as the railway-system have been integrated into the HAZUS-MH dataset. As already mentioned the HAZUS-MH version used for the project does not yet support the analysis of these kinds of data. Figure 3-6 shows the road and railway network within the project area.

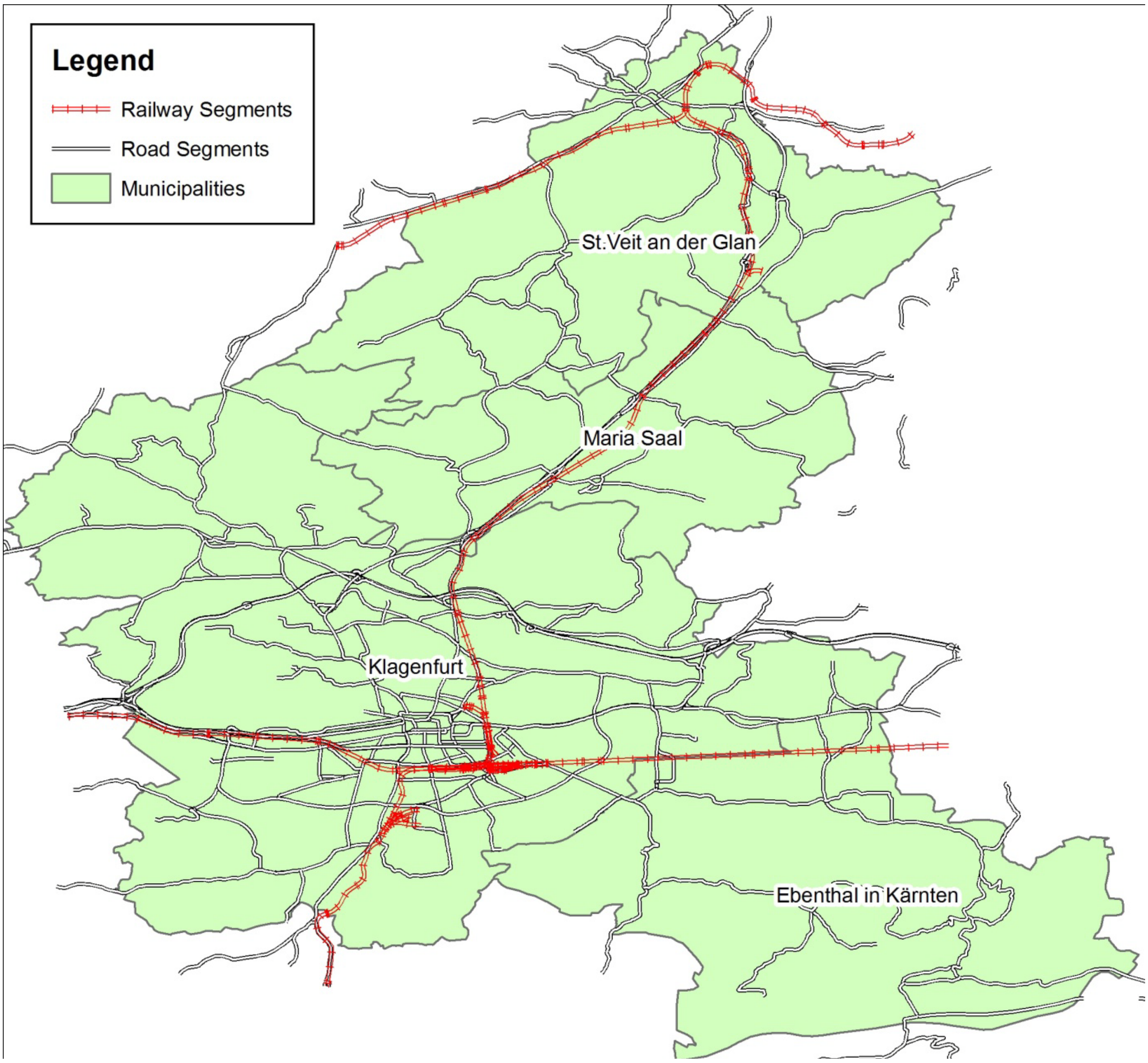


Figure 3-6: **The highway- and road network, as well as the railway system within the project area.**

3.4.6. Lifeline Systems

The HAZUS-MH data model provides the possibility to integrate data about Lifeline Systems such as Potable Water Systems, Wastewater Systems and Electric Power Systems. Others include Communication Facilities (sirens and cell towers), Natural Gas Systems (pipes and facilities), and oil facilities and pipes.

The Potable Water System provided by the HAZUS-MH data model consists of pipelines, water treatment plants, control vaults and control stations, wells, storage tanks, and pumping stations (FEMA, 2009a). The Flood Model will estimate damage, losses, and functionality for selected vulnerable components of the potable water system such as treatment plants, control vaults and control stations, and pumping stations (FEMA, 2009a).

Similar to the Potable Water System the Wastewater System also consists of pipelines, which are stored as polylines. Facilities represented by point features. The Flood Module estimates damages, losses and the functionality on objects like treatment plants, control vaults and stations, and lift stations (FEMA, 2009a). The analysis requires the geographic location, the classification scheme, and the replacement value of the structures.

However, pipelines for water supply and disposal are not supported in the loss estimation methodology in the version MR4. Nevertheless, they can be stored in the dataset in order to use it within one of the next versions of HAZUS-MH.

The Electric Power System provided by HAZUS-MH consists of generating plants, substations, distribution circuits, and transmission towers (FEMA, 2009a). However the loss estimation has not been implemented for Electric Power System facilities in the version MR4. The detailed classification of these Lifeline Systems is explained in Table 3-7.

Table 3-7: The classification scheme of Potable Water Systems, Wastewater Systems and Electric Power Systems. The valuations are given in thousand US dollars. The "x" indicates that the system component is supported in the loss estimation analysis of MR4 (Source: FEMA, 2009a).

HAZUS-label	General Occupancy	Description	HAZUS Valuation	Supported by MR4
Potable Water System				
PWPE	Pipelines	Exposed Transmission Pipeline	1	
PWPB	Pipelines	Buried Transmission Pipeline	1	
PWSP	Pipelines	Pipelines (non-crossing)	1	
PWSO	Water Treatment Plants	Small Water Treatment Plants Open/Gravity	30000	x
PWMO	Water Treatment Plants	Medium Water Treatment Plants Open/Gravity	100000	x
PWLO	Water Treatment Plants	Large Water Treatment Plants Open/Gravity	360000	x
PWSC	Water Treatment Plants	Small Water Treatment Plants Closed/Pressure	30000	x
PWMC	Water Treatment Plants	Medium Water Treatment Closed/Pressure	100000	x
PWLC	Water Treatment Plants	Large Water Treatment Plants Closed/Pressure	360000	x
PPSB	Pumping Plants	Small Pumping Plants - Below	150	x
PPMB	Pumping Plants	Medium Pumping Plants - Below	150	x
PPSA	Pumping Plants	Small Pumping Plants - Above	150	x
PPMA	Pumping Plants	Medium Pumping Plants - Above	150	x
PCVS	Control Vaults	Control Vaults and Stations	50	x
PSTC	Water Storage Tanks	Tanks at Grade concrete	1500	x
PSTS	Water Storage Tanks	Tanks at Grade steel	800	x
PSTC	Water Storage Tanks	Tanks at Grade wood	30	x
PSTE	Water Storage Tanks	Tanks elevated	800	x
PSTB	Water Storage Tanks	Tanks below grade	1500	x
PWE	Wells	Wells	400	x
Wastewater System				
WWPE	Sewers & Interceptors	Exposed Collector River Crossing	1	
WWPB	Sewers & Interceptors	Buried Collector River Crossing	1	
WWP	Sewers & Interceptors	Pipes (non-crossing)	1	
WWTS	Wastewater Treatment Plants	Small Wastewater Treatment Plants	60000	x
WWTM	Wastewater Treatment Plants	Medium Wastewater Treatment Plants	200000	x
WWTL	Wastewater Treatment Plants	Large Wastewater Treatment Plants	720000	x

WWCV	Control Vaults & Stations	Control Vaults & Control Stations	50	x
WLSW	Lift Station	Small Lift Station	300	x
WLMW	Lift Station	Medium Lift Station	1050	x
WLSS	Lift Station	Small Lift Station - Submersible	300	x
WLMS	Lift Station	Med Lift Station - Submersible	1050	x
Electric Power System				
ESSL	Substations	Low Voltage Substation	10000	
ESSM	Substations	Medium Voltage Substation	20000	
ESSH	Substations	High Voltage Substation	50000	
EDCE	Distribution Circuits	Elevated Crossings	3	
EDCB	Distribution Circuits	Buried Crossings	3	
EDC	Distribution Circuits	Distribution Circuits non crossing	3	
EPPS	Generation Plants	Small Generation Plants	100000	
EPPM	Generation Plants	Medium Generation Plants	100000	
EPPL	Generation Plants	Large Generation Plants	500000	

For the loss estimation discussed in this thesis, data for the three Lifeline Systems mentioned above have been collected. The data includes wells, generation plants, water treatment plants, waste water-, water supply-, and electric power facilities. Figure 3-7 shows the spatial distribution of these objects according to the general classification into Waste Water Facilities, Potable Water Facilities and Electric Power Facilities.

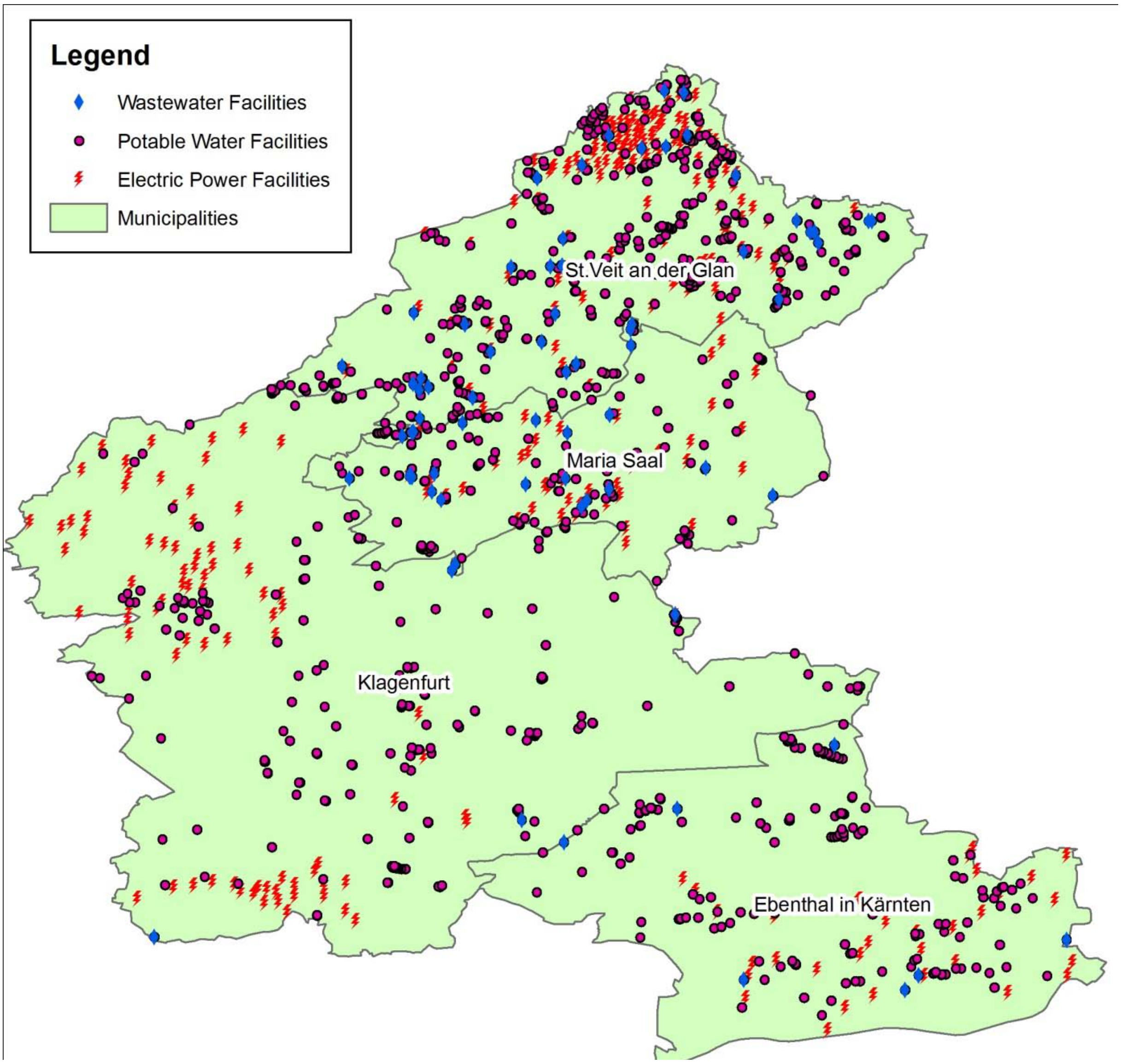
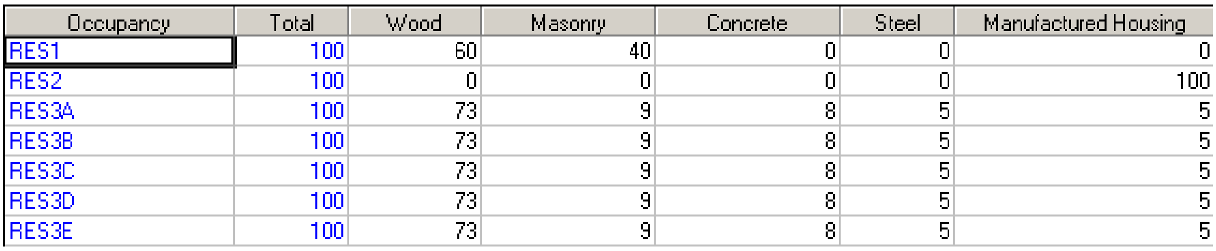


Figure 3-7: Spatial distribution of Waste Water Facilities, Potable Water Facilities and Electric Power Facilities in the project area.

3.4.7. Mapping Schemes

In order to allow the user to define the distribution of general building characteristics HAZUS-MH provides so called Mapping Schemes. There exists a General Occupancy Mapping which is applicable to all kinds of hazards supported by the software, as well as a Flood Specific Occupancy Mapping. The default Mapping Scheme is not editable, but can be duplicated in order to carry out modifications on the parameters (FEMA, 2009b).

There is one General Occupancy Mapping scheme per state and a study region which relates the distribution of the construction material (wood, masonry, concrete, steel and manufactured house) to the GBS of the current scenario (FEMA, 2009b). Figure 3-8 shows parts of the General Occupancy Mapping for the project which was taken from an already existing HAZUS-MH dataset.



Occupancy	Total	Wood	Masonry	Concrete	Steel	Manufactured Housing
RES1	100	60	40	0	0	0
RES2	100	0	0	0	0	100
RES3A	100	73	9	8	5	5
RES3B	100	73	9	8	5	5
RES3C	100	73	9	8	5	5
RES3D	100	73	9	8	5	5
RES3E	100	73	9	8	5	5

Figure 3-8: The General Occupancy Mapping for the Residential Occupancy Class the project area relates the distribution of the building types with the corresponding study region. It was taken from an existing HAZUS-MH dataset from Arizona.

Flood Specific Occupancy Mapping holds hazard specific default parameters which have to be included in the HAZUS-MH model (FEMA, 2009b). These parameters define foremost the different foundation types. The supported types are basement, crawl, fill, pier, pile, slab and solid wall. The definition of these kinds of foundation classes can be viewed in Table 3-8.

Table 3-8: The definition of the different foundation types in HAZUS-MH (Source: FEMA, 2009a).

HAZUS-label	Description
Pile	An open foundation, composed of tall and slender members, embedded deeply into the ground. A pile is a single element, not built-up on site like a pier. For our purposes, cast-in-place columns supported by a deep foundation (pile cap, or mat or raft below the anticipated scour depth) will be classified as a pile foundation. In some pile-supported buildings, shear walls may be used to transfer shear from the upper building to the embedded foundation elements.
Pier	An open foundation (no load-bearing perimeter walls), usually built of masonry units and supported by shallow footings. Piers usually range from approximately 2 ft to 8 ft in height.
Solid Wall	Load-bearing perimeter walls greater than 4 ft in height, usually supported by shallow footings. Floor beams or joists usually rest atop the walls, and may or may not be supported by interior piers or columns.
Basement	Any level or story, which has its floor subgrade on all sides. Usually load bearing, masonry or concrete walls around the perimeter of the building, supported on shallow footings. Floor beams or joists rest atop the walls. Shallow basements with windows slightly above grade are defined as a garden level basement.
Crawl	Usually short (less than 4 ft high), load bearing, masonry or concrete walls around the perimeter of the building footprint, supported on shallow footings. Floor beams or joists rest atop the walls and may also rest on interior piers.
Fill	Soil built up above the natural ground elevation and used to support a slab or shallow footings.
Slab	Concrete slab resting on the ground. It may have its edges thickened or turned down, but does not rely on other walls or footings for support.

Similar to the General Occupancy Mapping, the Flood Specific Occupancy Mapping was also derived from the HAZUS-MH dataset of the US state of Arizona. All Mapping Schemes can be edited either within the software or directly in the database table.

3.4.8. Vehicles

With the loss estimation methodology provided by HAZUS-MH it is also possible to estimate the number and losses of damaged cars. Therefore the vehicle inventory within the study area has to be calculated and allocated to the correct locations dependent on the day or night time. Furthermore the value of these cars has to be estimated and a percent loss damage function has to be applied according to the flood depth. HAZUS-MH separates these tasks into two phases. The first phase called vehicle location estimator is shown in Figure 3-9.

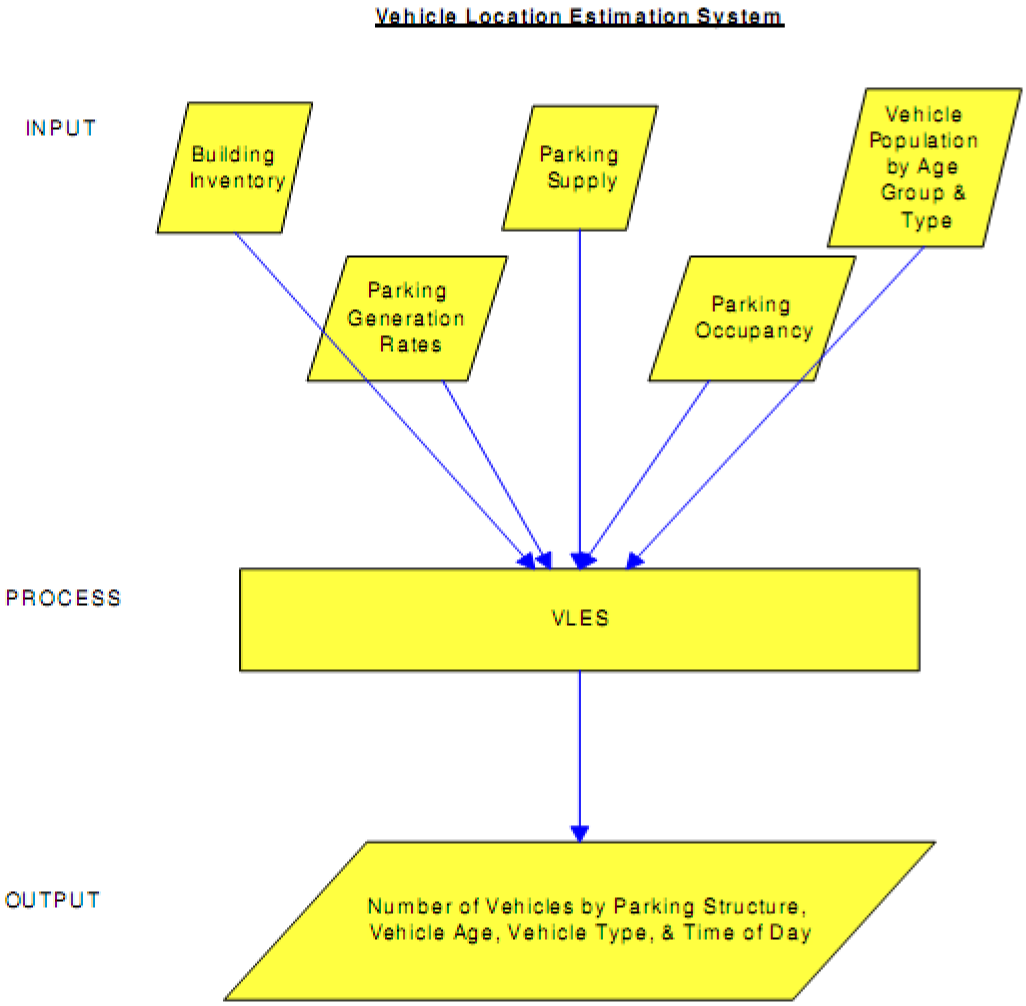


Figure 3-9: The vehicle location estimator takes input parameters such as the location of parking spaces, parking supply parking rates, etc. in order to estimate the number of cars parked at a certain location.

As no data were available for these kind of analysis the vehicle database was not used for this project.

3.4.9. Agriculture

HAZUS-MH also supports the assessment of direct flood damage to agricultural products. A list of supported crops can be seen in Table 3-9

Table 3-9: The types of crops supported by HAZUS-MH.

Crop Type	Crop Type	Crop Type
Alfalfa Hay	Apples	Bahiagrass
Corn	Corn Silage	Corn, Sweet

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

As no data about the agriculture in the project area was available this aspect of the data model was excluded from the analysis.

3.5. Data Processing Workflow

The most important part of the project was to find a way to integrate geodata from Austria into the HAZUS-MH system. Therefore a workflow was created which uses already existing data sources and transforms the information into the software's specific data model. This workflow is made up of four phases as depicted in Figure 3-10. In the first phase the project area and the regional division have to be determined. After that the data need to be acquired and processed so that they are compatible with the data model. In the last step the data need to be integrated into the HAZUS-MH specific system. These four phases are now explained in detail in this section of the thesis.

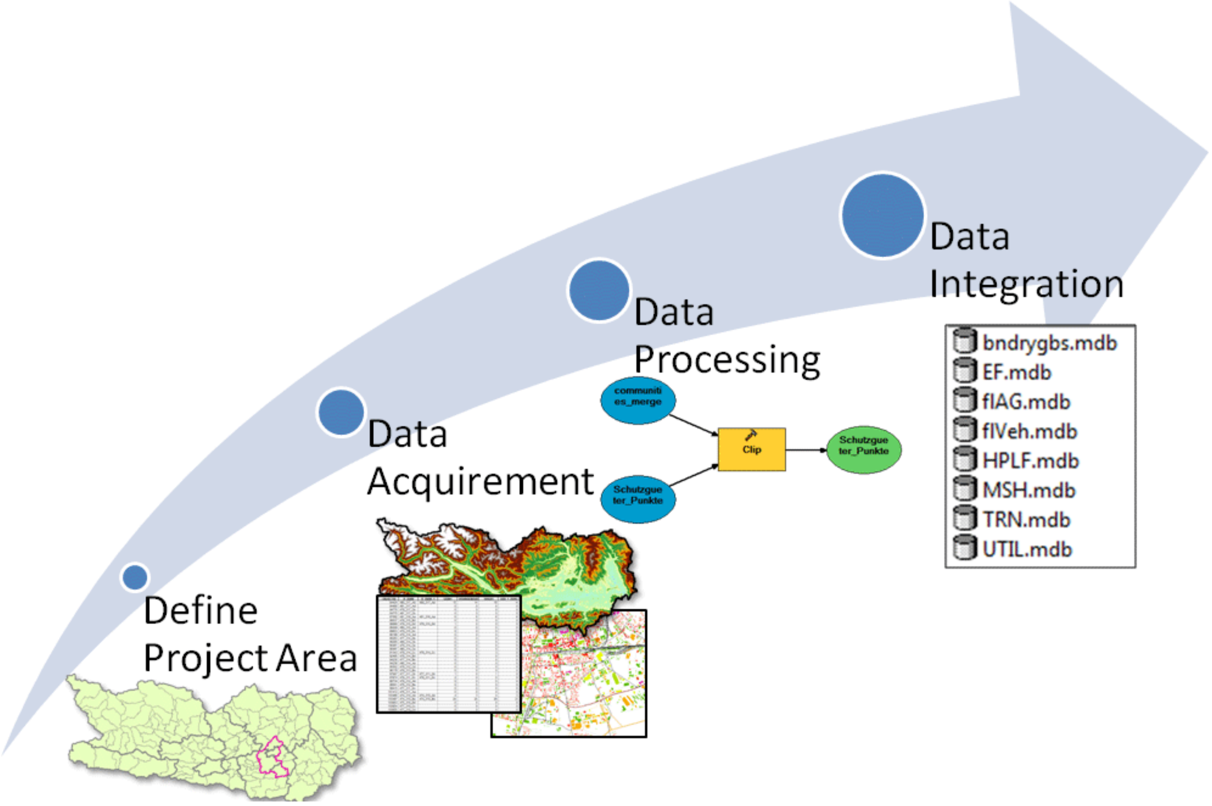
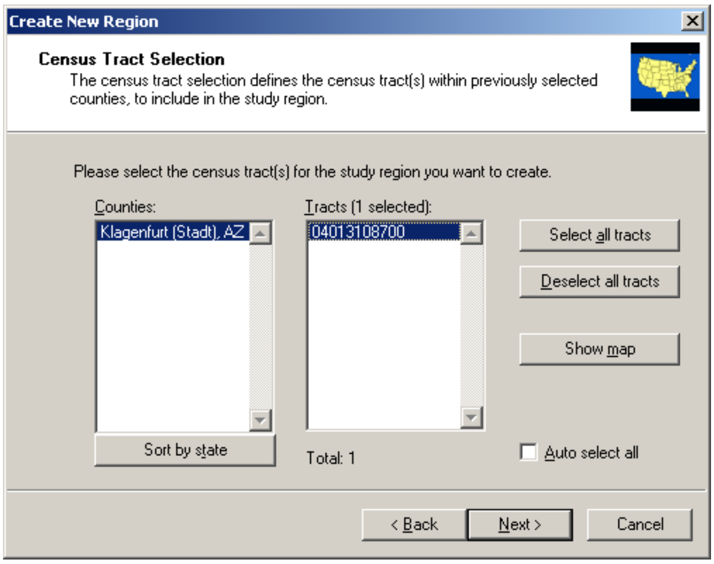


Figure 3-10: Overview of the developed workflow.

3.5.1. Definition of the Project Area

In the first step of the workflow the project area as well as the regional division have to be determined. HAZUS-MH provides the possibility to select project areas from counties down to the smallest unit of analysis. Thus, for example county-wide, as well as regional damage potential analysis are possible. Figure 3-11 illustrates the tool for selecting a study region.



Create New Region

Census Tract Selection

The census tract selection defines the census tract(s) within previously selected counties, to include in the study region.

Please select the census tract(s) for the study region you want to create.

Counties: Klagenfurt (Stadt), AZ

Tracts (1 selected): 04013108700

Total: 1

☐ Auto select all

Figure 3-11: Tool for selecting a project area in HAZUS-MH. It provides the possibility to define a study region ranging from the largest, down to the smallest unit of analysis (e.g. province, county, municipality, Planquadrat).

In order to provide such a flexible selection tool HAZUS-MH needs a consistent regional division. In the US datasets this hierarchy ranges from a state, to counties, to census tracts and census blocks. As the census blocks are the smallest unit of analysis for the flood model of HAZUS-MH, all the data needs to be aggregated based on this level. As already mentioned in section 3.4.1 an adequate regional division for Austria was defined, including the provinces, counties, municipalities, and the Planquadrat.

Another important aspect is to define the thematic scope of the loss estimation. As already shown in section 3.4 HAZUS-MH facilitates the analysis of a large number of different information layers. Acquiring all the data is time-consuming. Therefore it has to be defined in advance what aspects of the data model will be analyzed and what data quality requirements have to be met. For example, it is possible to carry out a quick assessment without customizing the default damage functions of buildings. Considering all these facts in advance helps to save both, time and money.

3.5.2. Data Acquirement

Once the geographical and thematic scope of the analysis is set, the corresponding data has to be selected and acquired. Of course data have to meet the requirements, which were defined in the first phase.

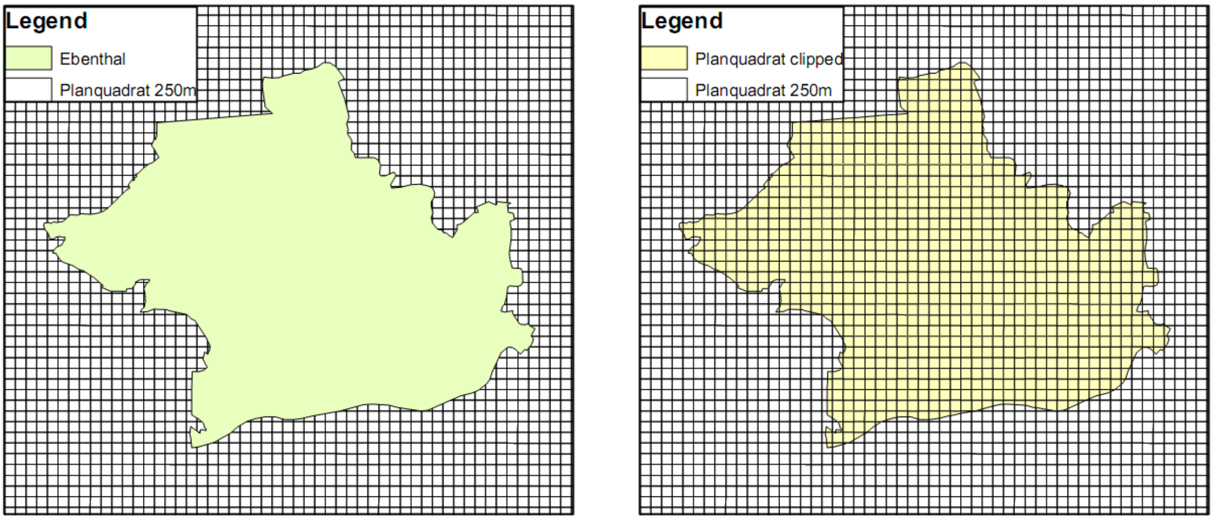
Amongst the different types of geodata such as shape files, raster files, or geo-databases, also other sources of information can be used, like for example tables and reports. The data sources for the analysis presented in this thesis are mostly geodata from shapefiles and tables as discussed in section 3.3.

3.5.3. Data Processing

In order to enable a smooth integration the data derived from the counties and the municipalities, “Planquadrat” dataset and “Schutzgüterkatalog”, as well as from the DEM and flood boundaries need to be processed. The different processing steps for each data source are now explained in detail.

Planquadrat:

As already mentioned in section 3.4.1 the Planquadrat was selected as the smallest unit of analysis. Therefore, all information for the GBS has to be aggregated based on this geodataset. However, as the Planquadrat dataset is dividing Austria into rectangular cells while at the same time ignoring the political borders of counties and municipalities, the geometries have to be adapted to the spatial extent of the communities. This adaptation is necessary to ensure that each cell belongs to only one municipality to guarantee a consistent regional division. Hence, the cells have to be clipped with the border of the communities’ borders. Figure 3-12 displays this process.

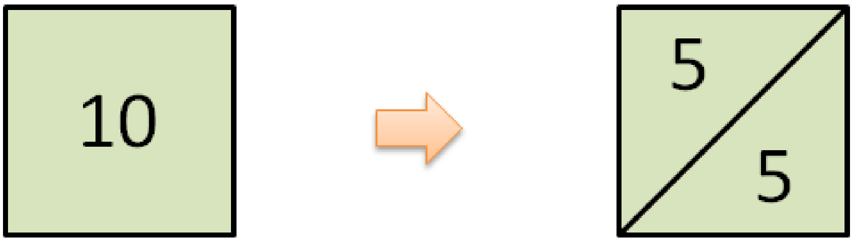


a) The unprocessed Planquadrat dataset and the political

b) the clipped Planquadrat of the municipality of Ebenthal

Figure 3-12: Clipping of the "Planquadrat" for the municipality of Ebenthal. a) Shows the unprocessed "Planquadrat" overlaid by the political border of the community, while b) illustrates the "cookie-cutter"-concept of the clipping tool.

As the clipping tool simply "cuts" the grid of the "Planquadrat" and inherits the attribute values from the clipped cells the data have to be adapted. Thus, the values are adjusted to the size of the clipped cells. So if for example a "Planquadrat" is split into two equal-sized cells, the attribute values are divided so that 50% of the values are allocated to cell each half of the cell as depicted in Figure 3-13. Additionally, integer values have to be rounded.



a) The unclipped cell with a value of 10

b) The 2 equal-sized cells have a value of 5

Figure 3-13: The concept of splitting attribute values after clipping a cell.

After processing, the raw attribute values have to be formatted to a HAZUS-MH compatible system. As the data models between the data source and HAZUS-MH may differ a mapping has to be defined which enables the integration of the information. For the analysis of this Master Thesis such a mapping was set up for the building count between the "Planquadrat" package C and the general occupancy classes. This mapping is depicted in Table 3-10.

Table 3-10: The mapping for the building count between the general occupancy classes of HAZUS-MH and the "Planquadrat".

HAZUS-MH Occupancy Class	Description	Planquadrat Attribute
RES1	Single Family Dwelling	Residential building with 1 or 2 units
RES3C	Multiple Family Dwellings 5-9 units	Residential building with 3 – 10 units

RES3D	Multiple Family Dwellings 10-20 units	Residential building with more than 11 units
COM1	Retail Trade	Commercial Buildings
COM4	Business/Professional/Technical Services	Offices
COM8	Entertainment + Recreation	Hotels
IND2	Light Industry	Garage/Shop, Industry, Depot
GOV1	General Services	Building for culture, free time, education and health care

Moreover, the square footage and the value of the buildings for each occupancy class have to be determined. The square footage was derived from the “Schutzgüterkatalog”. For the monetary value of the buildings no data was available.

Last but not least, the dataset needs to be transformed to a common SRS. As already stated in chapter 3.4 HAZUS-MH supports all common reference systems.

Schutzgüterkatalog:

The “Schutzgüterkatalog” is a collection of several thematic layers, such as a building layer (polygon), road and rail network layers (line), as well as drink water supply facilities and wastewater disposal facilities (point). For the analysis presented in this thesis the building layer was used to derive the constants for the average square footage from the footprint of the buildings for each occupancy class. Then these constant values were multiplied by the building count to calculate the total area for each occupancy class and “Planquadrat” cell. The determined constants for each occupancy class are shown in Table 3-11.

Table 3-11: The average square footage constants for each of the used occupancy class.

Occupancy class	Average square footage
RES1	1001 (93 m^2)
RES3C	3573 (332m^2)
RES3D	3573 (332m^2)
COM1	6458 (600m^2)
COM4	6458 (600m^2)
COM8	13950 (1296m^2)
IND2	31484 (2925m^2)
GOV1	30612 (2844m^2)

The other geodata sources have to be transformed to one common SRS for the entire dataset. Furthermore the sources need to be classified according to their usage. For example a fire station has to be classified as an Essential Facility Fire Station (EFFS). The classes can be found in the tables from sections 3.4.3 to 3.4.9.

DEM:

In order to maximize the efficiency of the flood hazard analysis within HAZUS-MH the DEM should be clipped according to the spatial extent of the study region. Moreover the DEM should also be projected to a common reference system.

Flood Boundaries:

The flood boundary is represented in HAZUS-MH by a single continuous polygon. If more than one polygon exists, then these polygons have to be merged or analyzed separately. As a matter of course this dataset should also be transformed to the common reference system.

3.5.4. Data Integration

In the last step of the workflow the pre-processed data needs to be integrated into the HAZUS-MH specific data model. Therefore an already existing US dataset needs to be duplicated, which is used as a default template for the dataset. First of all the counties and municipalities have to be replaced and renumbered. It is crucial to use the existing numbering scheme, abbreviations, and Mapping Schemes for this data. Next the Census Blocks from the US dataset are replaced by the “Planquadrat” dataset. Again the dataset needs to be renumbered. The identification number for each Census Block is made up of 15 numbers. The first 11 numbers are representing the Census Tract and should be taken from the default template. For the last 4 numbers it is important to form a combination which has not yet been used for the dataset. Otherwise, HAZUS-MH will stop the process for creating a new project area and no information about the “Planquadrat” will be included in the analysis.

Once this is done the table for the square footage and monetary values of the buildings can be added, in addition to the information about Essential Facilities, High Potential Loss Facilities, Transportation Systems, etc. Data, which are not needed can be deleted from the tables in order to save memory.

3.6. Software

Among the loss estimation methodology HAZUS-MH provides different kinds of tools to delineate the flood plain, as well as to import and to export the data. These tools are explained in detail in this sub-chapter.

3.6.1. Flood Modeling Tools

Several possibilities exist to create a Flood Depth Grid for the loss estimation methodology provided by HAZUS-MH. On the one hand it is possible to run an external model in order to generate this kind of raster data. On the other hand the software package offers two tools to create a Flood Depth Grid, namely the FIT and the Enhanced Quick Look Tool (EQL). Both tools need different input parameters and have slightly different processes running in the background.

The FIT is a separate extension for ArcGIS 9.3 and uses a hydrological process in order to process user-supplied flood hazard data into the format required by the HAZUS-MH Flood

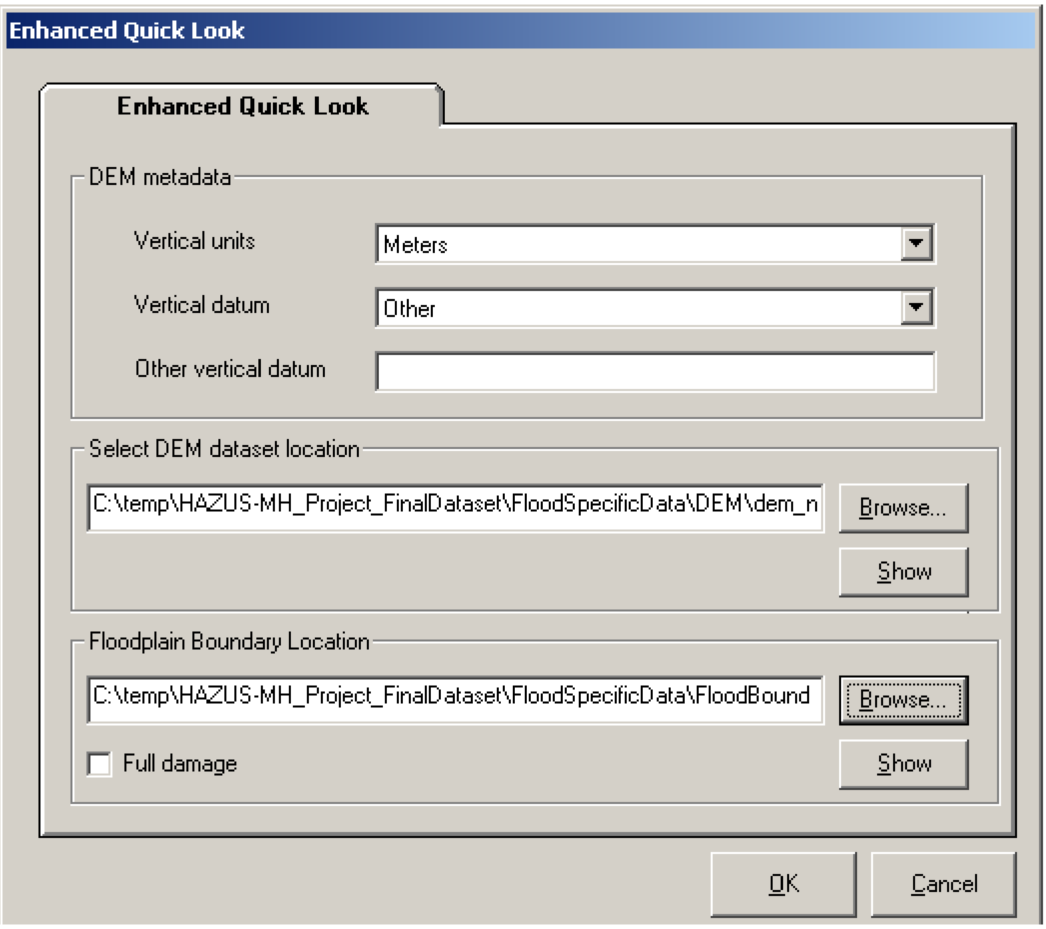
Model (FEMA, 2002). FIT uses three different kinds of spatial data inputs, namely a DEM, flood elevation lines, and a flood plain boundary (FEMA, 2002). The DEM describes the surface of the earth without objects such as buildings or trees. Flood elevation lines are polylines crossing a flood plain and describing its elevation, and optionally the riverine discharge. The third input parameter is the flood surface which has to be provided in the form of a single, continuous polygon. This polygon describes the spatial extend of an inundation. The input parameters are summarized in Table 3-12.

Table 3-12: The input parameters, the spatial data format purpose and format rules for the FIT (Source: FEMA, 2002).

Required Input	Purpose	Spatial Data	Format Rules
DEM	Describes terrain elevations and establishes the cell size of all output grids.	ArcInfo grid	Should represent bald-earth conditions (i.e., no buildings, trees, etc.)
Flood elevation lines	Contain populated fields for flood elevations and discharges (optional) for one or more return periods.	ArcGIS polyline feature class	• Cannot intersect each other • Should intersect the center of the floodplain • No attribute fields named • "Along", "Power", or • "Skew"
Floodplain boundary	Defines the centerline of flow and acts as a guide for determining the floodplain width.	ArcGIS polyline feature class	Represented by a single, continuous polygon feature

First the methodology behind the FIT needs to identify the upper and lower limits of the reach (FEMA, 2002; 2009b). Once these limits have been set by the user the software uses the flood plain boundary in order to generate a smooth center line from the upper to the lower limit. This center line is, among other things, used to identify the relevant cross sections within the flood plain. In the next step, a buffer is set up around this center line which can be increased or decreased by the user until it satisfies the conveyance area of the floodplain of interest (FEMA, 2002; 2009b). This chosen buffer defines the extent to which flood depths are calculated and is referred to as the bounding polygon (FEMA, 2002; 2009b). The flood depth lines do not limit the size of the bounding polygon and they are also extended automatically if needed. Non-Conveyance areas such as tributary streams that retain flood water and are lying outside the bounding polygon can be included in a further process provided by the FIT (FEMA, 2002; 2009b). Additionally, the software uses the flood elevation information from the cross-sections and interpolates the flood depth in between the lines. In the final step, the depth of the flood is subtracted from the DEM in order to calculate the Flood Depth Grid.

In contrast to the FIT, the EQL just needs two input parameters. The first input is a DEM, which again describes the ground elevation in the area of interest. Furthermore the flood boundary is needed to create a Flood Depth Grid (IUPUI, 2010). Figure 3-14 shows the window with the input parameters within HAZUS-MH.



DEM metadata

Vertical units: Meters

Vertical datum: Other

Other vertical datum:

Select DEM dataset location: C:\temp\HAZUS-MH_Project_FinalDataset\FloodSpecificData\DEM\dem_n

Floodplain Boundary Location: C:\temp\HAZUS-MH_Project_FinalDataset\FloodSpecificData\FloodBound

☐ Full damage

Figure 3-14: The EQL window within HAZUS-MH.

In general it can be said that the results from the FIT are better than the ones from the EQL as it includes more input parameters and methodology is more complex.

3.6.2. Comprehensive Data Management System

The CDMS is a freely available software that was developed to assist users in collecting and generating building inventory data for HAZUS-MH (FEMA, 2009a). It works independent from HAZUS-MH and helps to parse user defined data, to analyze, validate, and integrate them into the data structure (ESRI, 2009). The main functions provided by this software are querying and exploring the inventory data, supporting the data transfer (import and export) and the validation of data (ESRI, 2009).

The CDMS supports shapefiles, Microsoft Excel files and Access databases, as well as delimited text files and personal geodatabases (ESRI, 2009). Once a user provides inventory data in the correct format the files are validated by the software. Especially the field structure is reviewed to make sure that it corresponds with the internal structure used by HAZUS-MH (ESRI, 2009). If the validation is successful the data are forwarded to the so called CDMS repository. This is a temporary data-pool, where the user can explore the data before the data import and export. In the final step the data are transferred to the corresponding statewide database (ESRI, 2009). Figure 3-15 shows this process in detail.

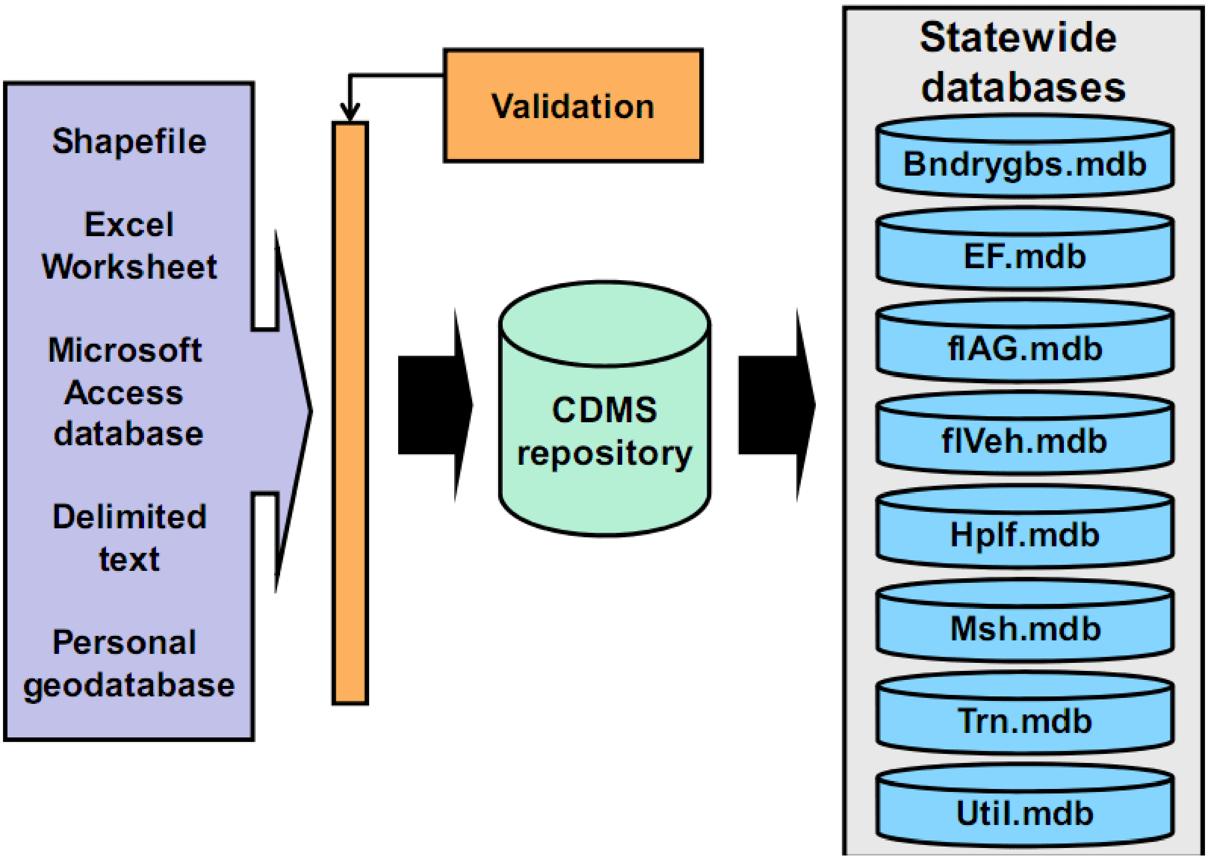


Figure 3-15: The data integration process for the CDMS.

4. Results

In this chapter the different results of the damage potential analysis are discussed. The analysis includes four scenarios. The first scenario uses a 300 year flood boundary, the second the risk zone from the “Gefahrenzonenplan”, and the basis for the third scenario is the HORA boundary for the area of the study region. Furthermore a fourth scenario representing a 300 year inundation was created using a flood depth grid created by hydrologists of the REVITAL GmbH. For each scenario the flood hazard map is given. Furthermore the flood damages for the GBS, the Essential Facilities and the Utility Systems are discussed. The final damage potential maps which depict all these aspects are given in the Appendix (Figure 9-1, Figure 9-2, Figure 9-3, and Figure 9-4).

4.1. Flood Hazard Maps

The flood hazard maps include the flood depth grids of the 300-year flood boundary, the HORA flood plain, the boundaries of the risk zones, as well as the flood depth grid from the external model which was created by hydrologists. Figure 4-1, Figure 4-2 and Figure 4-3 show the different grids which were all created with the EQL tool provided by HAZUS-MH. Figure 4-4 shows the flood depths derived from the data provided by the consultants of the REVITAL GmbH. The units of the DEM and the flood depth grids are meters.

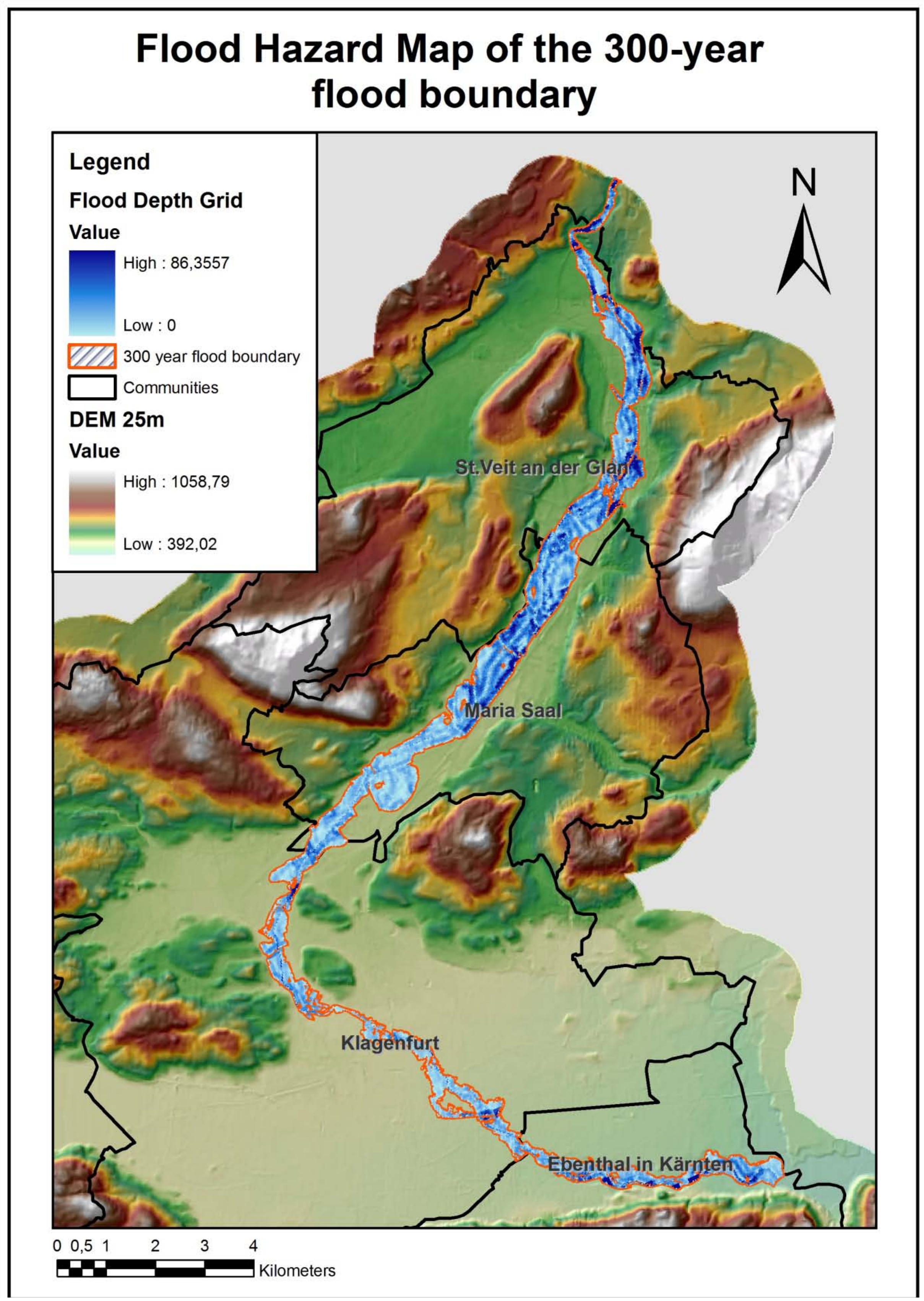


Figure 4-1: The flood hazard map of the 300-year flood boundary.

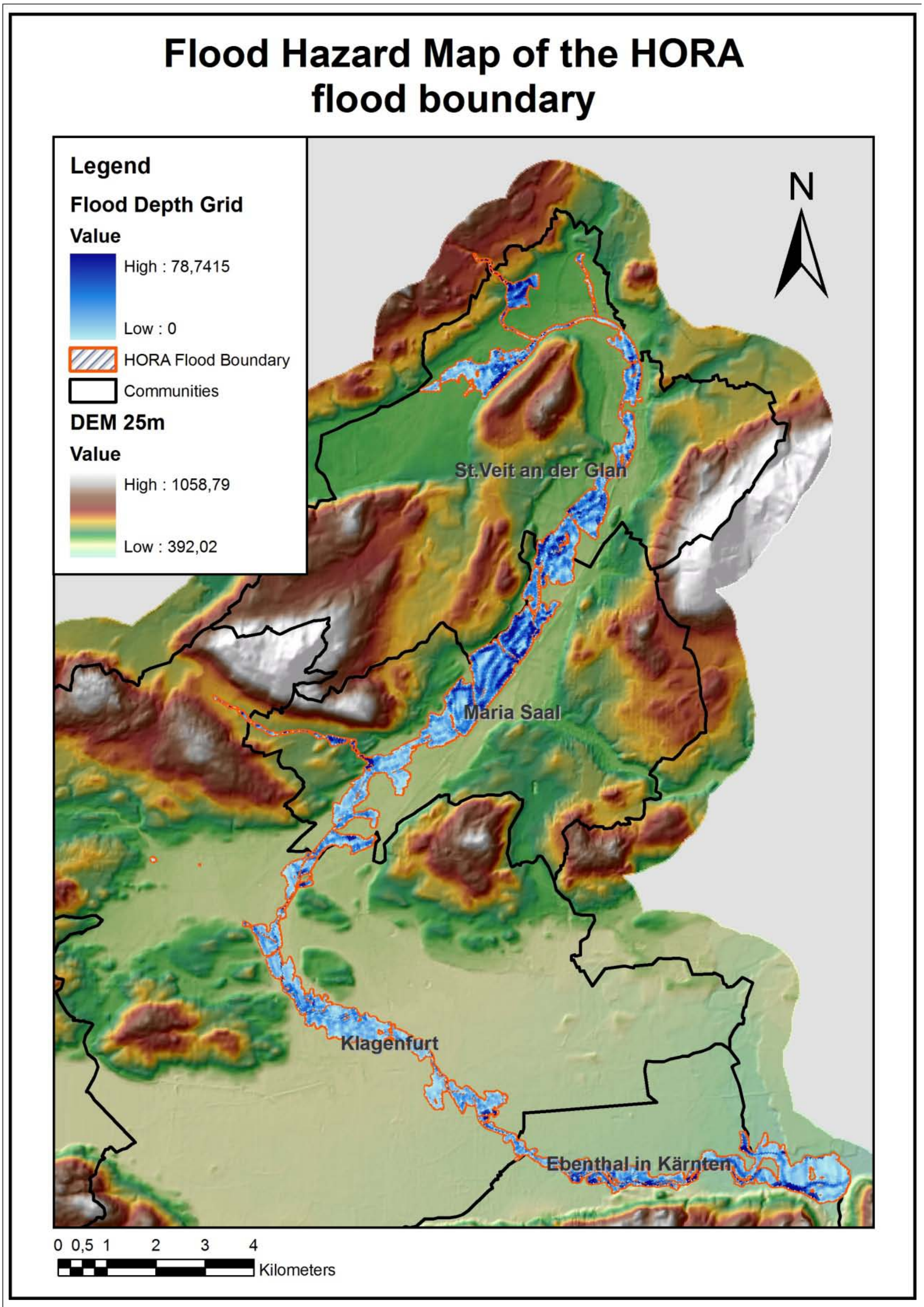


Figure 4-2: The flood hazard map of the HORA flood boundary dataset.

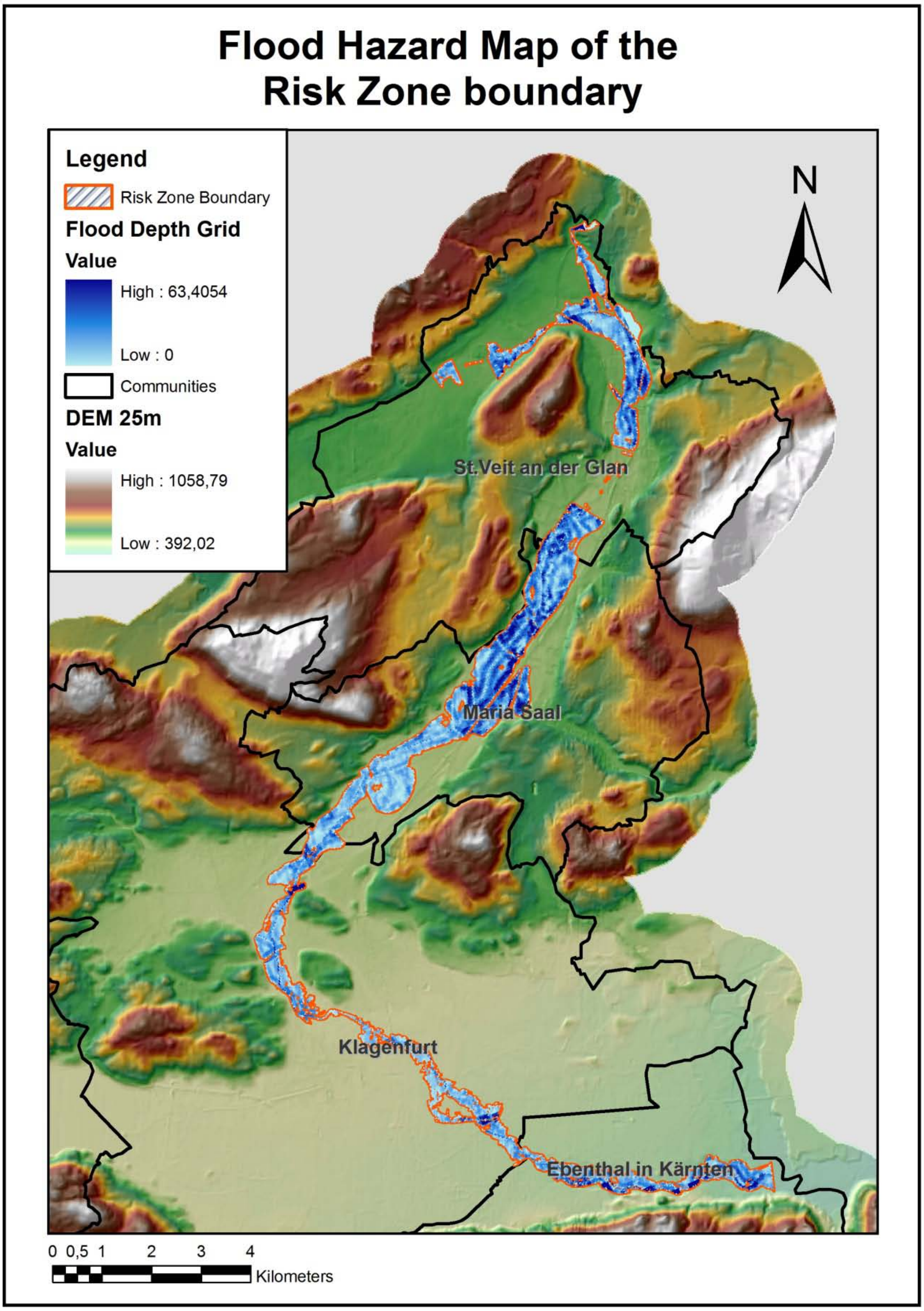


Figure 4-3: The flood hazard map of the Risk Zone dataset.

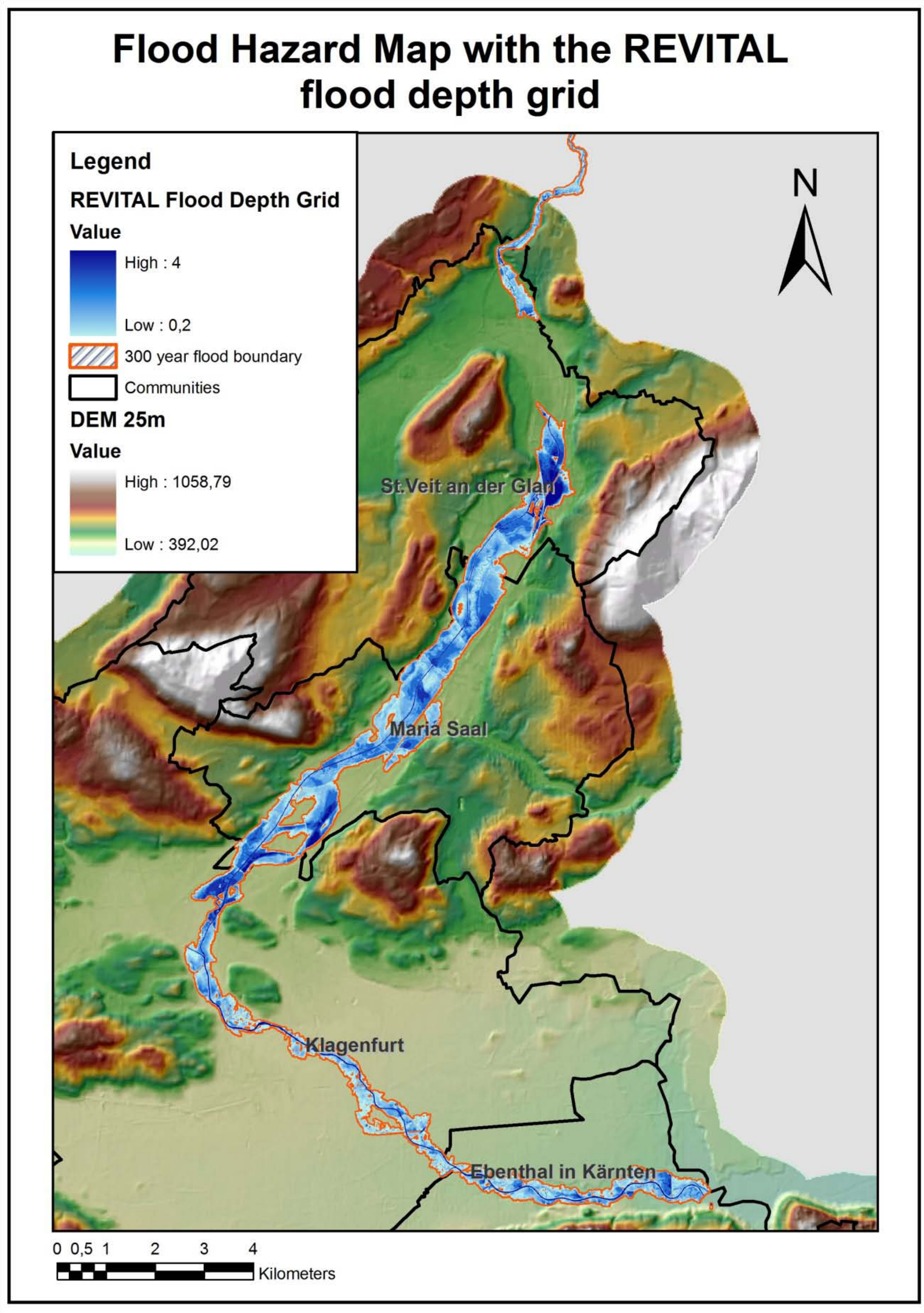


Figure 4-4: The flood hazard map with the flood depth grid created by the REVITAL GmbH.

4.2. General Building Stock Damage

The damage to the GBS can be split up between the number of damaged buildings and the affected square footage by occupancy. The results of the analysis for each scenario are now discussed for these two aspects.

For the 300-year flood scenario the loss estimation of HAZUS-MH computes a total number of 411 damaged buildings. Furthermore about 20 hectares of built-up area are affected by the inundation. When using the HORA flood plains 416 buildings are damaged and about 24 hectares are affected. The damage analysis of the risk zones results in 351 affected buildings and a total of 18 hectares are derogated by the inundation. The biggest damage was estimated with the flood depth grid of the 300 year inundation created by the REVITAL GmbH. The total number of damaged buildings was 587 and the affected built-up area was about 25 hectares. Table 4-1 gives a detailed overview on the results which were produced with the four scenarios.

Table 4-1: Building damage by general occupancy in the different scenarios.

Building damage count by general occupancy

	300-year flood	Risk Zones	HORA scenario	REVITAL 300 year
Residential	406	348	401	567
Commercial	0	0	11	6
Industrial	5	3	3	13
Governmental	0	0	1	1
Total	411	351	416	587

Building damage in thousand square feet by general occupancy

	300-year flood	Risk Zones	HORA scenario	REVITAL 300 year
Residential	925,96	788.25	1025,45	1126,59
Commercial	187,62	179.91	328,53	249,28
Industrial	959,65	902.12	975,20	1171,7
Governmental	115,67	90.12	259,49	169,5
Total	2188,90	1960.43	2588,67	2717,07

4.3. Affected Fire Stations

Among others also Essential Facilities such as fires station were analyzed. For the 300-year, as well as the risk zone scenario one fire station is severely damaged. According to the estimation it will take 720 days until it will reach full functionality again. In contrast to this when the HORA flood plain and the REVITAL flood depth grid are used no fire station is affected.

4.4. Affected Potable Water Facilities

Drinking water supply can be an important aspect when dealing with flood damages. Thus these kinds of facilities have been included in the damage assessment. For the 300-year flood depth grid HAZUS-MH estimates a total number or 63 affected water supply facilities. Most of these facilities are wells and the damages are between 13% and 40%. One well has only minor damages (about 2%). The HORA scenario however results in a total number of 13 affected facilities with damages between 16% and 40%. 3 facilities are damaged up to 40% if the risk zones are used as a basis for the analysis. Analysis using the flood depth grid provided by the REVITAL GmbH show that a total of 56 facilities are damaged. 38 of these water supply facilities only have minor damages (less than 10%). The rest suffers damages up to 40%.

4.5. Affected Wastewater Facilities

Along with water supply also affected wastewater disposal facilities were analyzed. The 300-year flood scenario results in 3 damaged facilities. Damages range between 7% and 40%. Using the flood depth grid produced with the HORA dataset the analysis yields in a total of 5 affected wastewater facilities which have damages between 23% and 40%. The facilities are all located in the south in the municipality of Ebenthal. In contrast to this only 3 wastewater facilities are damaged in the loss estimation for the risk zone scenario. A total of 5 damaged wastewater disposal facilities are computed when the flood depth grid of the 300 year inundation created by the REVIATL GmbH is used for the analysis. The damages range from about 5% to 30%.

5. Discussion

In this section the thesis is summarized and evaluated. The evaluation includes a comparison of results from different tools and scenarios. Last but not least also possible improvements and extensions of this work are discussed.

5.1. Evaluation

The evaluation of the results produced with HAZUS-MH focuses on the number of damaged buildings as no other data, such as population-related information, or a comprehensive monetary assessment of the buildings in the study region was available. The reference data for this evaluation was derived from a cost-benefit analysis carried out by experts in that area and from a tool for damage potential analysis created for a Bachelor Thesis by EBERHARTER (2009). The building counts in the estimation by experts are available for inundation frequencies between 5 and 300 years. For the evaluation only the frequencies between 100 years and 300 years are used. The assessment tool by EBERHARTER (2009) analyzes inundations based on a 100-year flood, the risk zones and the HORA-flood plain dataset. The values for affected buildings are compared in Table 5-1.

Table 5-1: Evaluation of the results (number of affected buildings) of the tool by EBERHARTER (2009), the cost-benefit analysis and HAZUS-MH.

Scenario	Affected Buildings
Eberharter 100 year flood	647
Eberharter risk zones	910
Eberharter HORA	964
Experts 100 year flood	745
Experts 200 year flood	1166
Experts 300-year flood	1325
HAZUS-MH risk zones	351
HAZUS-MH HORA	416
HAZUS-MH 300 year flood boundary	411
HAZUS-MH 300 year flood depth grid	587

The comparison of the results shows that the results produced with HAZUS-MH are underestimating the output of the other tools. This may come from the fact that the other tools do not work based on a flood depth grid. The tool created by EBERHARTER (2009) for example simply defines a constant flood depth for each scenario. Another reason for the underestimation might be that the depth-damage functions for this analysis have been derived from the HAZUS-MH dataset of Arizona. A calibration of this parameter might change the results dramatically. Figure 5-1 shows the comparison of the results graphically.

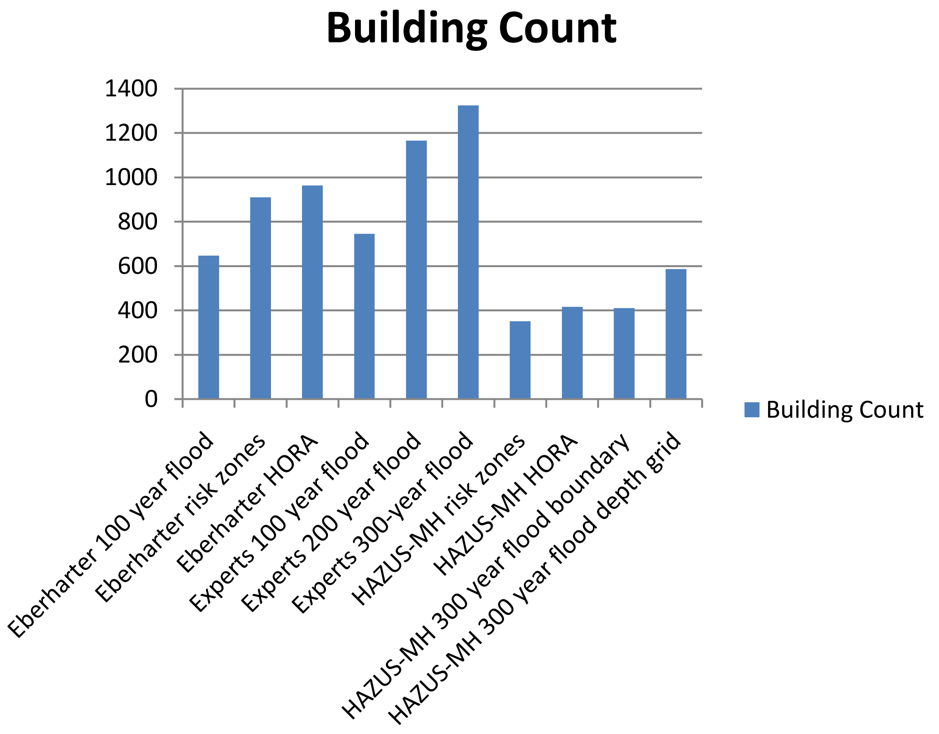


Figure 5-1: Evaluation of the results (number of affected buildings) of the tool by EBERHARTER (2009), the cost-benefit analysis and HAZUS-MH

Another evaluation criterion for this Thesis is to assess how well HAZUS-MH fulfills the EU flood directive framework. This framework comprises 3 phases as stated in section 1.1. Especially the second stage is interesting as it includes the creation of hazard and risk maps. For this phase HAZUS-MH could be useful as it meets nearly all requirements for these kinds of maps. Only debris floods cannot be modeled in HAZUS-MH so far. The software only supports an assessment of the amount of debris produced by a certain flood. Table 5-2 shows in detail how the requirements of flood risk maps are fulfilled by HAZUS-MH.

Table 5-2: Evaluation of the fulfilled criteria for flood risk maps according to the EU flood directive.

Criterion for Flood Risk Maps	Supported by HAZUS-MH
Number of affected inhabitants	X (casualties, displaced population)
Economic Impact	X (direct and indirect economic impact)
Accidental Pollution	X (Hazardous Materials)
Other information (debris floods)	Only the amount of debris can be determined

5.2. Requirements for an Internationally Version of HAZUS-MH

For a smooth and unproblematic international usage of HAZUS-MH several adaptations have to be made. The first important change of the software is to switch to the metric system. Also the currency has to be switched (e.g. from US Dollars to Euros). Both of these modifications have to be done for internal modules (e.g. formulas, data model, etc.), as well as for the output of the loss estimation methodology (tables, reports, and maps).

Furthermore the language settings have to be modified. Thus the phrases displayed on the elements of the Graphical User Interface (GUI), such as buttons, select boxes, windows, labels, etc. have to be translated and different language packages have to be developed for the software.

Similar adaptations are also needed for the reporting module of HAZUS-MH. Among the translation of already existing reports also a new options have to be developed. This new report could for example automatically create risk reports for the flood directive of the EU, or support the framework for cost-benefit analysis in Austria.

Furthermore the regional division should be changed within the software and its data model in order to be more flexible for international usage. The intervals in the data model for demography and the GBS could also be modified as they do not match with the data format in the “Planquadrat” dataset provided by the statistic Austria. This would enable a direct and smooth integration of this information for both, the demographic data and the information about the buildings in the study area.

Last but not least the missing modules, such as highways, pipelines and electrical facilities should be implemented in HAZUS-MH as they are important aspects in damage potential analysis for floods in Austria and the EU.

5.3. Summary

This thesis has shown that it is possible to use the flood model and loss estimation methodology provided by HAZUS-MH with an Austria dataset. It was one of the first successful attempts to use the flood model provided by the software package for an international study region. Furthermore the suitability of the software for flood risk maps for the EU flood directive has been discussed. Therefore first of all a theoretical background has been set up. This theoretical basis includes different loss assessment and damage potential analysis methodologies in Austria, as well as an examination with the software package HAZUS-MH. Moreover the data requirements for the software have been examined and possible data source have been discussed. Using this knowledge a workflow for integrating an Austrian dataset has been designed and implemented for a pilot study. The outcomes have been evaluated with results from a cost–benefit analysis and another project which were both carried out in the same project area. The evaluation showed that the results were underestimating the reference values. The reason for that may be the missing calibration of flood-related parameters for the study region. Nevertheless HAZUS-MH has proven to be a useful tool for damage potential analysis.

5.4. Future work

There exist several possibilities for improvements of the results of the damage potential analysis presented in this thesis. One may be the adaptation of flood damage-related parameters in the model provided by HAZUS-MH. As parameters such as depth-damage functions, distribution of building types (e.g. wood, concrete, manufactured houses, etc.) and foundations were simply adopted from the US dataset of Arizona they need to be modified in order to produce a representative output. Further parameters include restoration functions for Essential Facilities such as Police and Fire Stations, Emergency Centers and Schools. These functions represent the time it takes to restore such a facility after an inundation. Last but not least also the parameters for direct and indirect economical impacts of floods could be changed for a comprehensive analysis.

Another alternative for optimization of the output is to include more data in the analysis. Especially the integration of population-related data, as well as the monetary assessment of the values of the buildings would improve the results dramatically. The integration of Essential Facilities, such as schools, police stations and hospitals, as well as data about agriculture and Hazardous Materials would give the output of the analysis more depth.

Further interesting extensions of this work include also an evaluation of the cost-benefit module provided by HAZUS-MH. The software package provides an extra tool for such kinds of analysis which may be used within cost-benefit analysis in Austria.

Last but not least the whole loss estimation methodology could be evaluated with a real flood scenario in Austria. The estimated damages could be evaluated based on the real inundation damages and possible ways to calibrate the whole model could be figured out in this way.

6. References

AIR (2010), AIR Worldwide: Software Solutions Overview, Retrieved 30. May 2010 from Website: http://www.air-worldwide.com/Software-Solutions-Overview.aspx.

BROOKS, N. (2003), *Vulnerability, risk and adaptation: A conceptual framework*, Working Paper 38, Tyndall Centre, University of East Anglia.

BMLFUW (2006a), *Technische Richtlinien für die Bundeswasserbauverwaltung*, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Sektion Wasser, Vienna.

BMLFUW (2006b), *Richtlinien zur Gefahrenzonenausweisung für die Bundeswasserbauverwaltung*, Wien.

BMLFUW (2007), Lebensministerium.at – Hochwasserrisiko - HORA, Retrieved 11. May 2010 from Website http://www.wassernet.at/article/articleview/47386/1/13523.

BMLFUW (2009), *Kosten-Nutzen-Untersuchungen im Schutzwasserbau*, Richtlinie, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Sektion Wasser, Vienna.

BUWAL (1999), *Risikoanalyse bei gravitativen Naturgefahren*. Methode, Umweltmaterialien 107/I Naturgefahren, Bundesamt für Umwelt, Wald und Landwirtschaft, Bern.

BUREAU OF RECLAMATION (2010), Glossary, Retrieved 28. April 2010 from Website http://www.usbr.gov/library/glossary/#H.

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

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

CUTTER, S. (1996), Vulnerability to environmental hazards, *Progress in Human Geography*, Nr. 20, 4, S. 529-539.

DARTMOUTH FLOOD OBSERVATORY (2010), Flood Archive Atlas, Retrieved 9. April 2010 from Website: http://www.dartmouth.edu/~floods/archiveatlas/index.htm.

DUTTA, D., HERATH, S. & MUSIAKE, K. (2003), A mathematical model for flood loss estimation, *Journal of Hydrology*, Volume 277, Issues 1-2, 1 June 2003, p. 24-49.

DUTTA, D., HERATH, S. & MUSIAKE, K. (2000), Flood inundation simulation in a river basin using a physically based distributed hydrologic model, *Hydrological Processes*, Volume 14, p 497-519.

EUROPEAN UNION (2007a), *Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment of flood risks*, L 288/27, Official Journal of the European Union.

EUROPEAN UNION (2007b), *Environment: European Parliament and Council reach agreement on the new Floods Directive*, IP/07/565, press release, Brussels, Belgium.

FABER, R. (2006), *Flood Risk Analysis: Residual Risks and Uncertainties in an Austrian Context*, Dissertation, University of Natural Resources and Applied Life Sciences, Vienna.

FEDESKI, M., & GWILLIAM, J. (2007), Urban sustainability in the presence of flood and geo-logical hazards: The development of a GIS-based vulnerability and risk assessment methodology, *Landscape and Urban Planning*, Nr. 83, Issue 1, S. 50-61.

FEMA (1997), *Multi Hazard identification and Risk Assessment*, Federal Emergency Management Agency, Washington, D.C.

FEMA (2992), *Flood Information Tool MR3 – User Manual*, Federal Emergency Management Agency, National Institute of Building Sciences, Washington, D.C.

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

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

FEMA (2010), Federal Emergency Management Agency, Retrieved 29. April 2010 from Website: http://www.fema.gov.

FLETA, J., GODE, L., GOMA, J.L., GRACIA, A., GRACIA, J., MARTINEZ, J., MARTURIA, J., PALMA, J.J., PARDO, M., DE PAZ, A.J., SANCHEZ, I. & VERDAGAUER I. (2006), Flooding areas and risk analysis of Catalonia (Inuncat Plan), *5th European Congress on Regional Geoscience Cartography and Information Systems*, Barcelona, Nr. 2, S. 458-460.

FUCHS, H., HABERSACK H., SATTLER, S. & WIND, H. (2003), *Hochwasser 2002: Datenbasis der Schadensbilanz, University of Natural Resources and Applied Life Sciences*, Vienna: Zentrum für Naturgefahren und Risikomanagement-Plattform Hochwasser, BOKU.

GILARD, O. & GIVONE, P. (1997), Flood Risk management: New Concepts and Methods for objective Negotiations, *Destructive Water: Water Caused Natural Disasters, their Abatement and Control (Proceedings of the Conference held in Anaheim, Califormia, June, 1996)*, IAHS, Vol. 239, p. 149-159.

GROSSI, P., & KUNREUTHER, H. (2005), *Catastrophe modeling: A new approach to managing risk*, New York City, NY: Springer Science and Business Media, Inc, p. 26.

GUGGENBERGER, G., JERLICH, K., LUMASEGGER, M., KORBER, S., MICHOR, S. & SACKL, B. (2009), *Kosten-Nutzen-Untersuchung Erläuterungsbericht, Optimierungs-studie Hochwasserschutz Untere Glan*, Ministry for agriculture, forestry and watermanagement, Department 18 of the Carinthian government - watermanagement.

IUPUI (2010), *PDM Project Workflow Flood EQL Analysis*, Polis Center at IUPUI, Indianapolis, Indiana.

KAMINGER, I. & WONKA, E. (2004), Von einer Österreichgliederung nach Gemeinden zu Planquadraten: Statistik Austria erweitert sein regionalstatistisches Angebot, *9th International Symposion on Planning & IT,* p. 549-554.

KEILER, M. (2004), *Determination of Damage Potential for Alpine Risk Assessment*, Dissertation, Universtity of Innsbruck, Faculty of Natural Sciences, Innsbruck.

KELMAN, I. (2003), Defining Risk, *FloodRiskNet Newsletter,* Vol. 2, p. 6-8.

KIENHOLZ, H., KRUMMENACHER, B., KIPFER, A. & PERRET S. (2004), Aspects of Integral Risk Management in Practice – Considerations with Respect to Mountain Hazards in Switzerland, *Österreichische Wasser- und Abfallwirtschaft*, Vol. 56, 3-4, p 43-50.

KRAMMER, D. (2009), *Erstellung eines interdisziplinären Schutzgüterkatalogs und Bewertung am Beispiel des Projekts Naturgefahren Kärnten*, Bachelorarbeit, Course Geoinformation, Carinthia University of Applied Sciences.

KULMESCH, S., LEITNER, M. & PAULUS, G. (2010), Konzeptionelle Überlegungen zur Einsetzbarkeit von HAZUS-MH in Österreich – Eine Fallstudie zur Abschätzung des Schadenspotentials bei Hochwasserfällen in Kärnten, *Angewandte Geoinformatik 2010 Beiträge zum 22. AGIT-Symposium, Salzburg*, p. 872-880.

MERZ, B. (2006), *Hochwasserrisiken: Grenzen und Möglichkeiten der Risikoabschätzung,* Stuttgart, Schweizerbart.

MERZ, R.,BLÖSCHL, G. & HUMER, G. (2008), Hochwasserabflüsse in Österreich – das HORA-Projekt, *Österreichische Wasser- und Abfallwirtschaft*, Vol. 60, 9-10, p 129-138.

MOORE, D., GRAYSON, R.B. & LADSON, A.R. (1991), Digital Terrain Modelling: A Review of Hydrological, Geomorphological, and Biological Applications, *Hydrological Processes,* Vol. 5, p. 3-30.

MOLINA, S., LANG, D.H. & LINDHOLM, C.D. (2009), SELENA – An open-source tool for seismic risk and loss assessment using a logic tree computation procedure, *Computers and Geoscience*s, Vol. 36, Issue 3, p 257-269.

NGK II (2010), *Naturgefahren Kärnten II*, unpublished project report, Amt der Kärntener Landesregierung, Abteilung 20 Landesplanung, Abteilung 18 Wasserwirtschaft, Abteilung 15 GB Geologie & Bodenschutz, Abteilung 10F Forstwesen, Austria.

PAULUS, G., BÄK, R., FLASCHBERGER, G., GRUBER, K., PIECHL, T., SEREINIG, N. & SEYMANN, C. (2005), Interoperability and Geohazards: – A Conceptual Framework for Natural Risk Management in Carinthia, Austria.

PAULUS, G., PIECHL, T. (2004) Interoperability & Risk Management: A Conceptual framework for Natural Risk Management in Carinthia, *Interoperability Workshop AGILE 2004*, April, 28th, 2004, Heraklion, Greece.

PIECHL, T. (2005), Schutzwasserwirtschaft und Raumplanung – ein konfliktträchtiges Spannungsfeld*?, Lebensräume Kärnten Extra*, September 2005, p 10-11.

PINE, J.C. (2008), *Natural Hazards Analysis: Reducing the Impact of Disasters*, CRC Press, p. 1-6.

PIERCE, L. (2000), *An Integrated Approach for Community Hazard, Impact, Risk and Vulnerability Analysis: HIRV*, Doctoral Dissertation, The University of British Columbia.

PLOEGER, S.K., ATKINSON, G.M. & SAMSON, C. (2009), Applying the HAZUS-MH soft-ware tool to assess seismic risk in downtown Ottawa, *Natural Hazards*, Canada, Springer, p 1-20.

PORTER, K., JAISWAL, K.,WALD, D.J., GREENE,M. & COMARTIN, C. (2008), WHEPAGER Project: A new initiative in estimation global building inventory and its seismic vulnerability, *Proceedings of the 14th World Conference on Earthquake Engineering Beijing*, China.

PRETTENTHALER, F., AMRUSCH, P. & HABSBURG-LOTHRINGEN, C. (2010), Estimation of an absolute flood damage curve based on an Austrian case study under a dam breach scenario, *Natural Hazards and Earth System Sciences*, 10, p. 881–894.

ROHNER, K., BERGER, I., STEIGER, H., MOSER, J., PICHLER, F. & SEREINIG, N. (2004), *Hochwasserchronik 792 – 2003*, Department 18 Wasserwirtschaft of the Carinthian Government, Klagenfurt, Austria.

REITERER, A., WÖHRER-ALGE, M. & MAYER, B. (2009), *Climate change and natural hazards – The EU project AdaptAlp*, Journal of Torrent, Avalanche, Landslide, and Rockfall Engineering, Vol. 163, pp. 52-58.

RMS (2010), RMS Catastrophe Models – Germany, Retrieved 30. May 2010 from Website: http://www.rms.com/Catastrophe/Models/Germany.asp#RF.

SAYERS, P.B., GOULDBY, B.P., SIMM, J.D., MEADOWCROFT, I. & HALL, J. (2002), *Risk, Performance and Uncertainty in Flood and Coastal Defence – A Review*, R&D Technical Report FD2302/TR1 (HR Wallingford Report SR587), Crown copyright, London, U.K.

SCAWTHORN, C., FLORES, P., BLAIS, N., SELIGSON, H., TATE, E., CHANG, S., MIFFLIN, E., THOMAS, W., MURPHY, J., JONES, C. & LAWRENCE, M. (2006a), HAZUS-MH Flood Loss Estimation Methodology. I: Overview and Flood Hazard Characterization, *Natural Hazards Rev. **7***, pp. 60-72.

SCAWTHORN, C., FLORES, P., BLAIS, N., SELIGSON, H., TATE, E., CHANG, S., MIFFLIN, E., THOMAS, W., MURPHY, J., JONES, C. & LAWRENCE, M. (2006b), HAZUS-MH Flood Loss Estimation Methodology. II: Overview and Flood Hazard Characterization, *Natural Hazards Rev. **7***, pp. 72-81.

STEINNOCHER, K., AUBRECHT, C., KÖSTL, M.., KNOFLACHER, M. (2009): Flood-related damage cost assessment - Regional projection considering local conditions, *Proceedings of the Third Geoinformatics Forum Salzburg*, Heidelberg, Germany, pp 191-199.

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

URAL, D. (2006), International Disaster Management Cooperation: A Case Study for Turkey and the USA, *The Future of Emergency Management*, Department of Homeland Security, Federal, Emergency Management Institute, USA.

WWF GERMANY (2007), Hochwasser in Deutschland und Europa, Retrieved 8. April 2010 from Website: http://www.wwf.de/fileadmin/fm-wwf/pdf_neu/Hochwasser_in_Deutschland_und_Europa.pdf

7. List of Figures

8. List of Tables

9. Appendix

The Appendix comprises of the final loss estimation maps for each of the four scenarios presented in the thesis. These maps include information about the number of damaged buildings per Planquadrat, as well as the affected fire stations, wastewater facilities and potable water facilities.

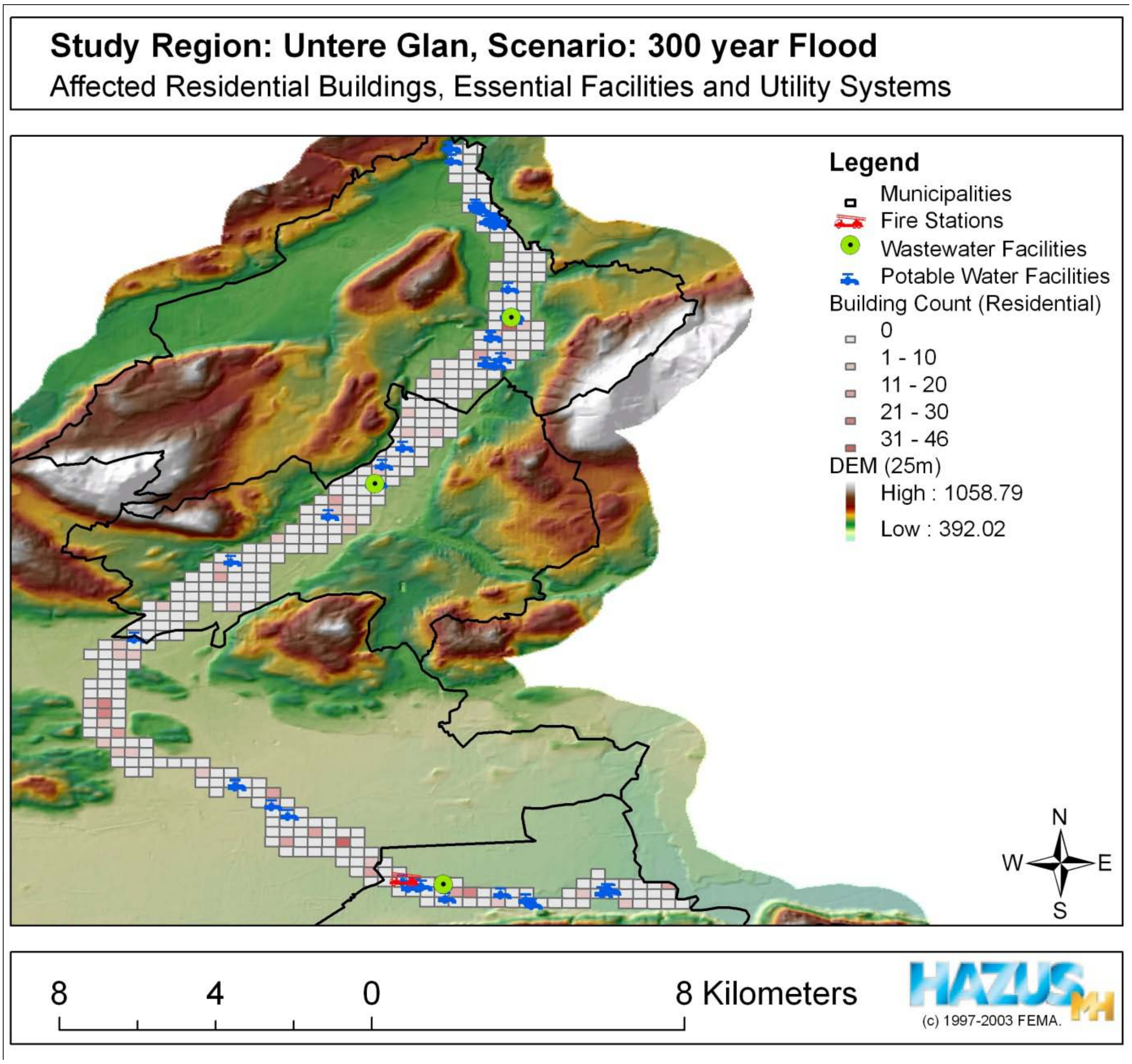


Figure 9-1: **Map showing the affected buildings per "Planquadrat", as well as affected wastewater facilities, fire stations and water supply facilities when the 300 year flood boundary scenario is used.**

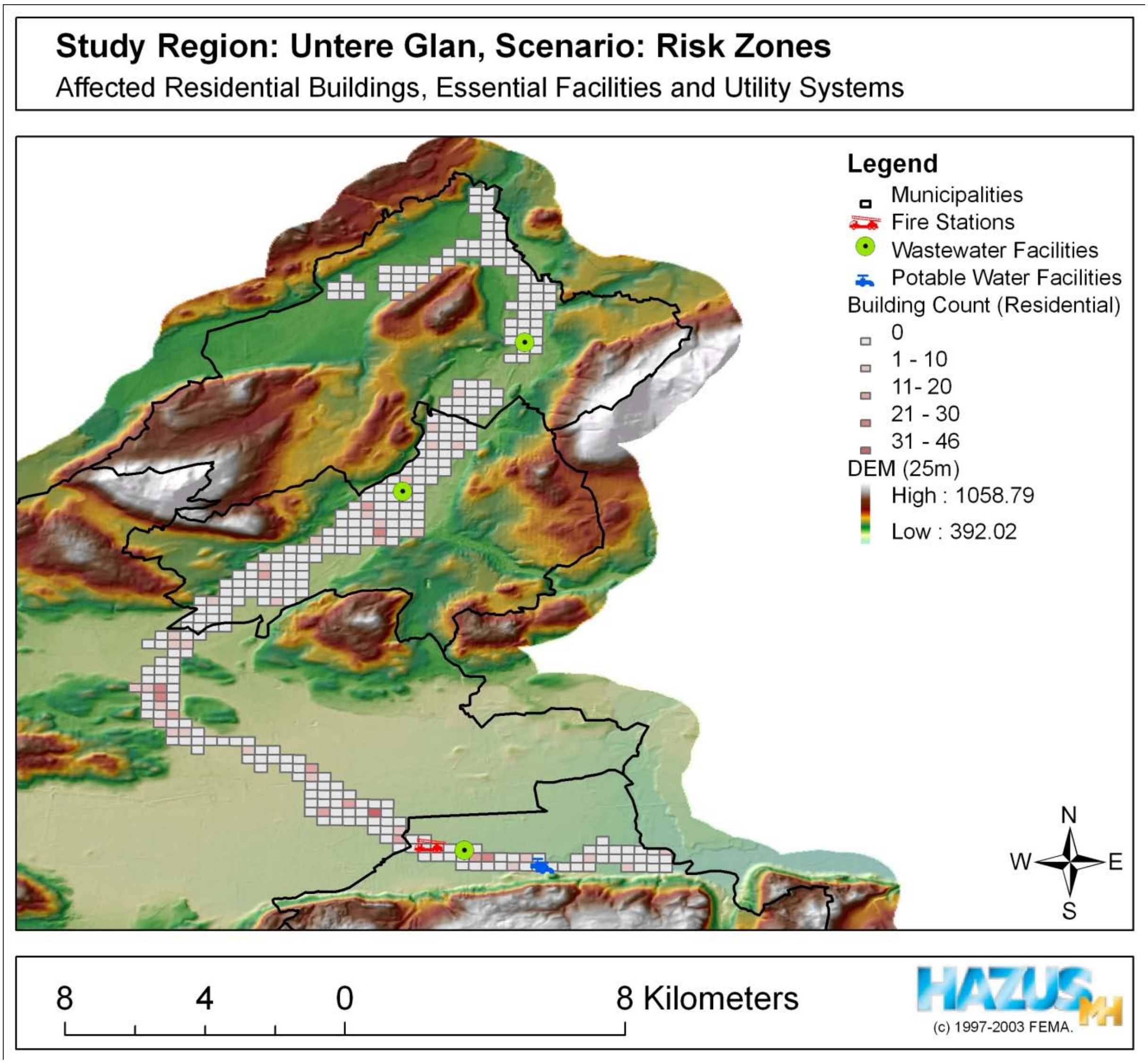


Figure 9-2: Map showing the affected buildings per "Planquadrat", as well as affected wastewater facilities, fire stations and water supply facilities when the Risk Zone scenario is used.

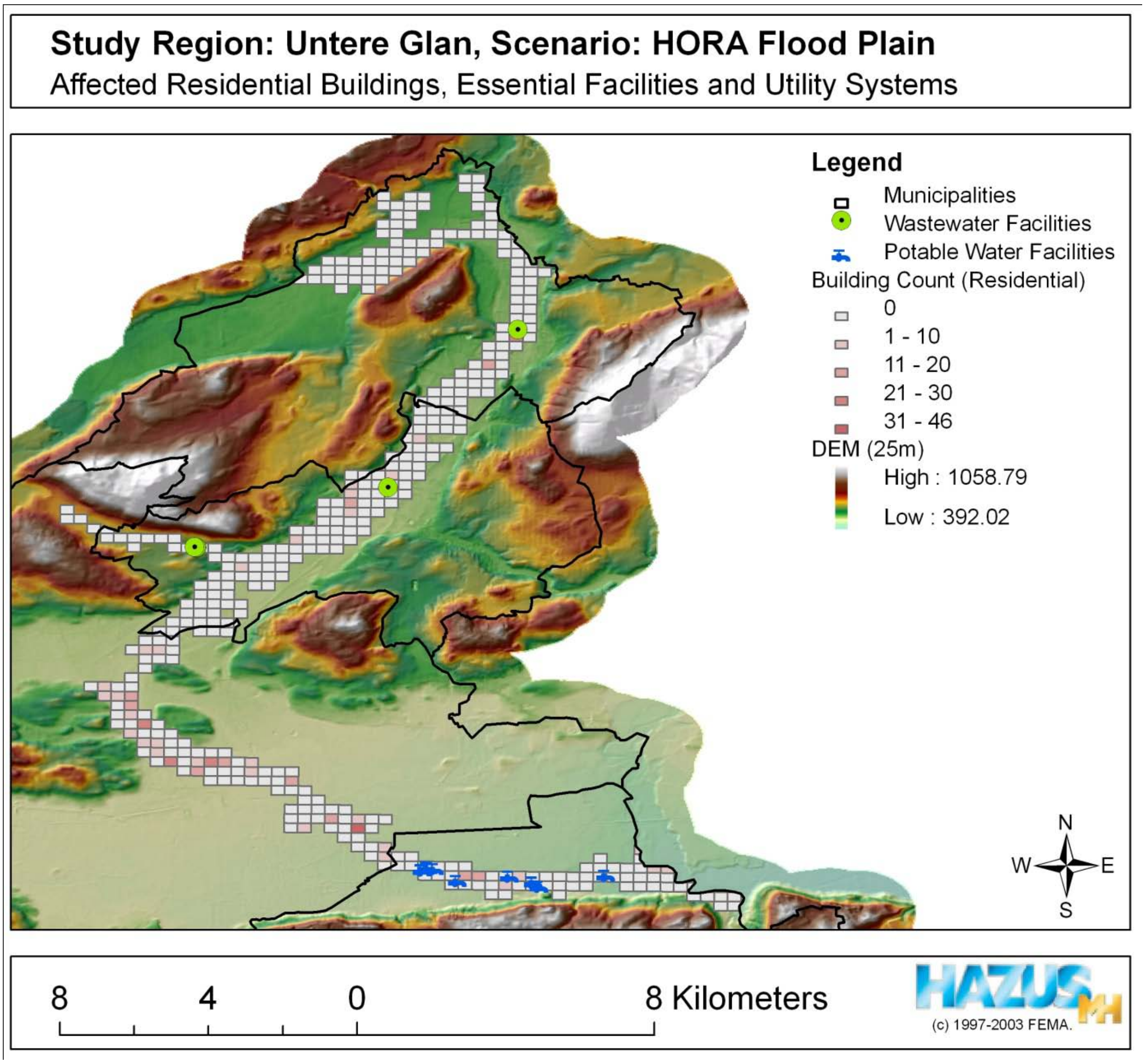


Figure 9-3: Map showing the affected buildings per "Planquadrat", as well as affected wastewater facilities, fire stations and water supply facilities when the HORA flood boundary is used.

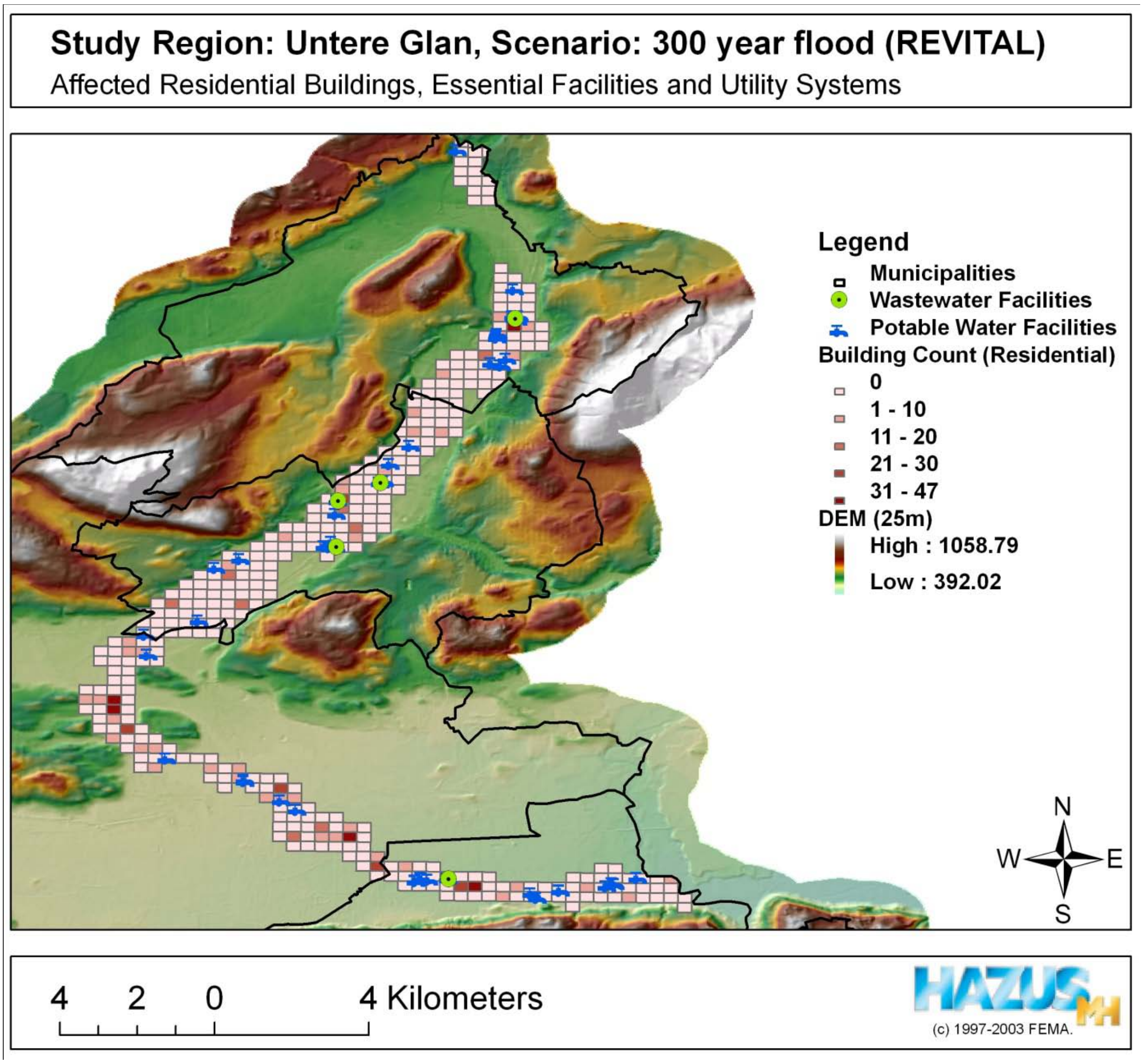


Figure 9-4: **Map showing the affected buildings per "Planquadrat", as well as affected wastewater facilities, fire stations and water supply facilities when the flood depth grid provided by the REVITAL GmbH is used.**