Swedish Civil Contingencies Agency

Research/Study

Data and Methods for Application of HAZUS Flood Model in Sweden

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Summary: HAZUS is a modelling and loss estimation tool developed by the Federal Emergency Management Agency of the United States. The purpose of this study is to investigate data and methods that could be used for application of HAZUS Flood Model in Sweden. To address the aim a literature review approach was applied. The literature review was mainly focused on scientific publications, grey literature, and technical reports.

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1 Introduction

HAZUS is a modelling and loss estimation tool developed by the Federal Emergency Management Agency (FEMA) of the United States. It uses geospatial information, along with information about the built environment and critical infrastructure, to assess the potential impacts of various natural hazards, including floods.

HAZUS Flood Model is used to generate maps of potential flood hazards and to estimate the expected economic and social impacts of these events. It includes models for riverine and coastal floods, and can be used to estimate damages to buildings, infrastructure, and other assets, as well as the number of affected people and the costs of evacuation and recovery.

HAZUS Flood Model provides a standardized, science-based approach to flood hazard assessment. It is designed to be flexible and user-friendly, and can be used to support decision-making at the local, state, and national levels.

HAZUS can be used from a variety of users with a variety of data needs (FEMA, 2022b):

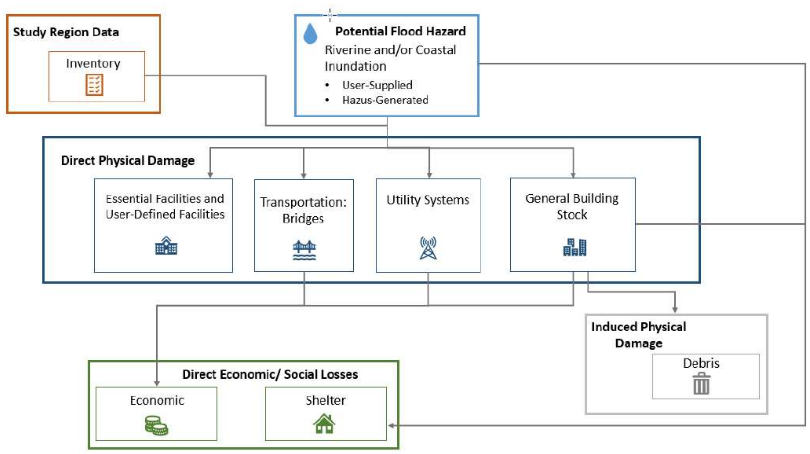
- Local or state government officials that are interested in the costs and benefits of specific mitigation strategies and may want to know the expected losses if mitigation strategies have (or have not) been applied.
- Emergency response experts that are keen on the results of loss studies in planning and performing emergency response exercises. These groups might be interested in the operating capacity of critical infrastructure such as fire stations, emergency operations centers, and police stations.
- Emergency planners that want to know how many temporary shelters will be needed and for how long.
- Utility company representatives and community planners that are eager to know the locations and duration of potential utility outages.
- Federal and state government officials that require an estimate of economic losses (short and/or long term) in order to direct resources toward affected communities. Furthermore, government agencies may use loss studies to obtain quick estimates of impacts in the hours and immediately following a flood event to direct resources to the affected areas.
- Insurance companies that are interested in disaster losses so they can assess vulnerabilities of assets.

1.1 Background

Depending on the level of user expertise, the HAZUS Flood Model is designed to operate with minimal user interface and data (Basic analysis, see Figure 2) to more rigorous analyses requiring pre-processing of higher quality data (Advanced analysis). Users are required to have ESRI's Geographic Information System (GIS) application[1] and the associated extension Spatial Analyst[2] in order to perform flood loss estimations.

HAZUS software uses GIS technologies to perform analyses with inventory data and displaying losses and consequences on tables and maps. Figure 1 displays a graphical representation of the modules composing the HAZUS Flood Model methodology and their interconnection in calculating estimates (FEMA, 2022d).

Figure 1. HAZUS Flood Model methodology schematic. Adapted by FEMA (2022d)



Following the figure, the conceptual relationships and the steps used in HAZUS Flood Model could be summarised as (FEMA, 2022d):

1. In the first step, the user must select an area to be studied. The study region is created based on a watershed, community, census block or track, county, or territory level aggregation of data. The area usually includes a city, a county, or a group of municipalities.

2. In the next step, the user must specify the flood hazard scenario. In developing the flood scenario, the hazard could be specified as riverine, coastal, or a combination of the two.

3. In the third step, the user must integrate local inventory data. These data include essential facilities, utility, and transportation systems, updates to the general building stock characteristics, and/or user-defined facilities.

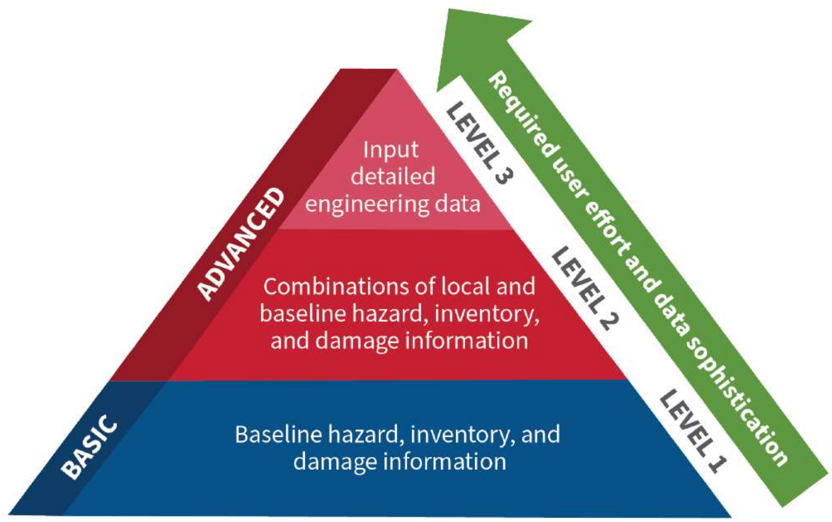
[1] https://www.esri.com/en-us/arcgis/products/index
[2] https://www.esri.com/en-us/arcgis/products/arcgis-spatial-analyst/overview

4. At the final step, the user must compute estimates of direct economic losses and short-term shelter needs.

As an output, a variety of maps can be generated for visualizing the extent of losses. Generated reports provide numeric results that can be examined at the level of census block or track, or aggregated by region of county.

HAZUS Flood Model is designed to permit three levels of analysis (FEMA, 2022d). Figure 2 provides a graphic representation of the different levels of analysis.

Figure 2. Levels of HAZUS flood analysis. Adapted by FEMA (2022d)



Level 1 analysis uses baseline databases pre-developed databases included in the HAZUS Flood Model software and methods on building square footage and values, repair costs and certain basic economic data. Baseline data for transportation and utility systems, and vehicles are also included. The user defines the study region, selects the flood types and scenarios and makes decisions concerning the extent and format of the output. This type of analysis requires minimum effort by the user.

Level 2 analysis is intended to improve the results from Level 1 by considering additional data that are readily available or can easily be converted or computed to meet the methodological requirements. User can pre-process site-specific flood hazard data and facilitate its import into the model for further analysis of damage and loss. It allows the user to create depth grids for various return periods and other parameters. More detailed site-specific data can be employed to replace the default national datasets for buildings and other parts of the inventory.

Level 3 analysis gives freedom to the user and requires extensive efforts in developing information on the flood hazard and the measure of exposure. This type incorporates results from engineering and economic studies carried out using methods and software not included within the methodology. At this level, one or more technical experts are required to acquire data, perform detailed analyses, assess damage/loss, and assist the user in gathering more extensive inventory. The following inventory improvements affect the accuracy of Level 3 analysis results (FEMA, 2012):

- Development of user-supplied depth grids. The use of these products improves the accuracy and performance of HAZUS Flood Model loss analysis and leverages the development and improvements of external flood hazard data and methodologies.
- Use of locally available data or estimates of the buildings footage in different occupancy classes.
- Use of local expertise to modify the mapping scheme databases that determine the percentages of specific building types associated with different occupancy classes.
- Preparation of a detailed inventory of all essential facilities.
- Collection of detailed inventory and cost data to improve the calculation of losses in transportation and utility systems.
- Use of locally available data related to construction costs and/or other economic parameters.

Grahn (2020) has studied the transferability and applicability of HAZUS Flood Model methodology to Sweden and Swedish conditions. By focusing on a case study (Karlstad municipality), Grahn (2020) concluded that HAZUS Flood Model could be implemented as a quantitative risk assessment methods at all levels in Sweden, from local to the national level.

1.2 Aim of the study and methodological approach

The purpose of this study is to investigate data and methods that could be used for application of HAZUS Flood Model in Sweden. The focus is to give an overview of data relating to flood hazard (flood depth grids), exposure data (building-related information), and damage data (stage-damage functions) with respect to residential, commercial properties.

To address this a literature review approach was applied. The literature review was mainly focused on scientific publications, grey literature, and technical reports. Scientific publications refer to the dissemination of research results, findings, and knowledge. Such literature can take various forms including journal articles, conference proceedings, book chapters, and technical reports of a scientific nature. Grey literature refers to literature that is produced outside of the traditional commercial or academic publishing channels. It encompasses a wide range of materials such as reports, working papers, preprints, government documents, theses, and conference papers. Grey literature is often produced by government agencies, non-profit organizations, and other non-academic entities and may not be subject to the same level of peer review or formal publication procedures as traditional academic literature.

The following steps are involved in conducting the literature review for finding data:

- Review HAZUS Flood Model manuals to identify data needs and methodologies.
- Identify relevant sources of information/data: Search for academic literature, government reports, technical reports, and other sources of data.
- Evaluate the sources: Evaluate the quality, reliability, and relevance of the sources found. Consider the credibility of the authors, the data collection method, and the data analysis techniques used.
- Synthesize the information: Organize the information found and synthesize it into databases.
- Assess the data: Assess the availability, quality, and relevance of the data identified and determine if it can be used in HAZUS Flood Model.

Here we have to highlight some criteria that are incorporated in the literature review and data collection. These criteria are:

- The data collected (for use in the Level 3 analysis) must cover the entire Swedish territory. Local or regional data (i.e. local hazard assessments etc.) and sources of information are not included in the analysis
- The data collected must be free of charge and open. Models, information or data from private companies and/or other actors providing proprietary products were not on the focus of the literature review.

2 Data and methods

2.1 Flood hazard data

The HAZUS Flood Model analyses riverine and coastal flood hazards (FEMA, 2012). Flood hazards can be defined as a probabilistic event in terms of the chance that a certain magnitude (area and depth) of flooding is exceeded in any given period or as a specific, deterministic event, such as a historic peak flow or a recent event captured with high water marks. Depth, duration and velocity of water in the flood plain are the primary factor contributing to flood losses.

HAZUS Flood Model allows user to estimate flood losses from depth of flooding (FEMAb). HAZUS Flood Model users in Level 3 analysis can import user supplied data for loss analysis. Importing hazard data into HAZUS Flood Model targeting on improving the accuracy and performance of Level 1 and 2 analyses. Common information, as suggested by HAZUS Flood Model technical manual, that can be used it generate a flood surface including the following:

- High Water Mark (HWM) data
- Base Flood Elevation (BFE) cross sections
- Local hydrology and hydraulics models

Based on the literature review, local hydrology, and hydraulic models are only available for use in the current case study (Sweden).

Dottori et al. (2022) presented a new set of flood hazard maps at 100m resolution, developed as a component of the Copernicus European Flood Awareness System (EFAS). The geographical extent of the new product covers most of geographical Europe.

The input river flow data for the hazard maps are developed by means of the hydrological model LISFLOOD using new calibration and meteorological data (Dottori et al., 2022). The LISFLOOD model is applied to run a hydrological simulation for the period 1990-2016 at 5km grid spacing and at a daily resolution and provided the hydrological input data for the flood simulations. The hydrological input data consisted of daily river flow based on interpolated daily meteorological observations (see Dottori et al. (2022) for a more detailed description).

The inundation simulations are performed using the hydrodynamic model LISFLOOD-FP (Bates et al., 2010; Shaw et al., 2021). Local flood maps are produced for six reference return periods (10, 20, 50, 100, 200 and 500 years). Furthermore, hazard maps are validated using official hazard maps for Norway, Hungary, Italy, Spain and the UK. The new high-resolution database of the river flood hazard maps is available for download at: https://data.jrc.ec.europa.eu/dataset/1d128b6c-a4ee-4858-9e34-6210707f3c81.

In the following figures (3 to 8) the flood hazard maps for Sweden based on the different return periods (10, 20, 50, 100, 200 and 500 years) are presented.

Figure 3. 10 years return period.

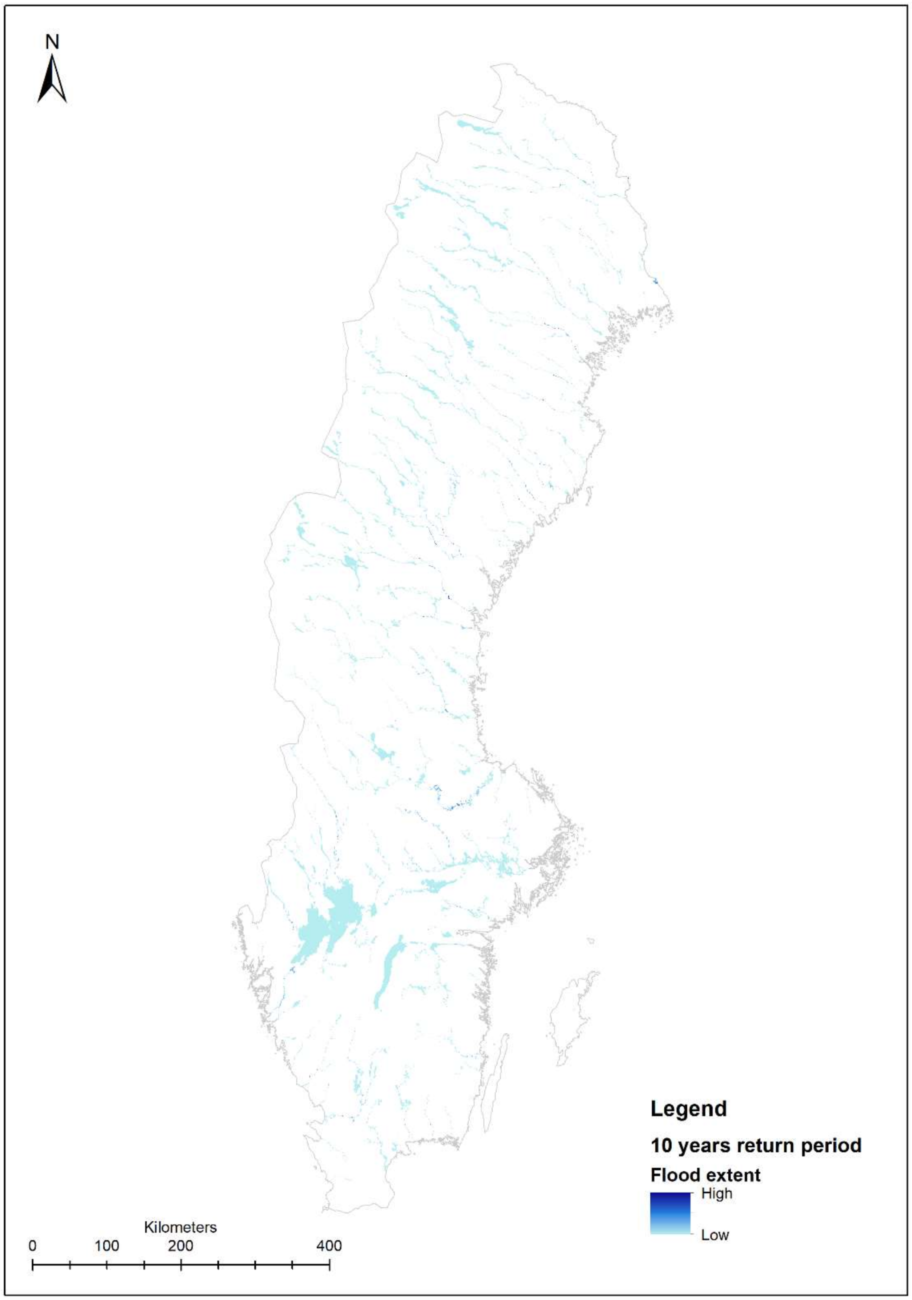


Figure 4. 20 years return period.

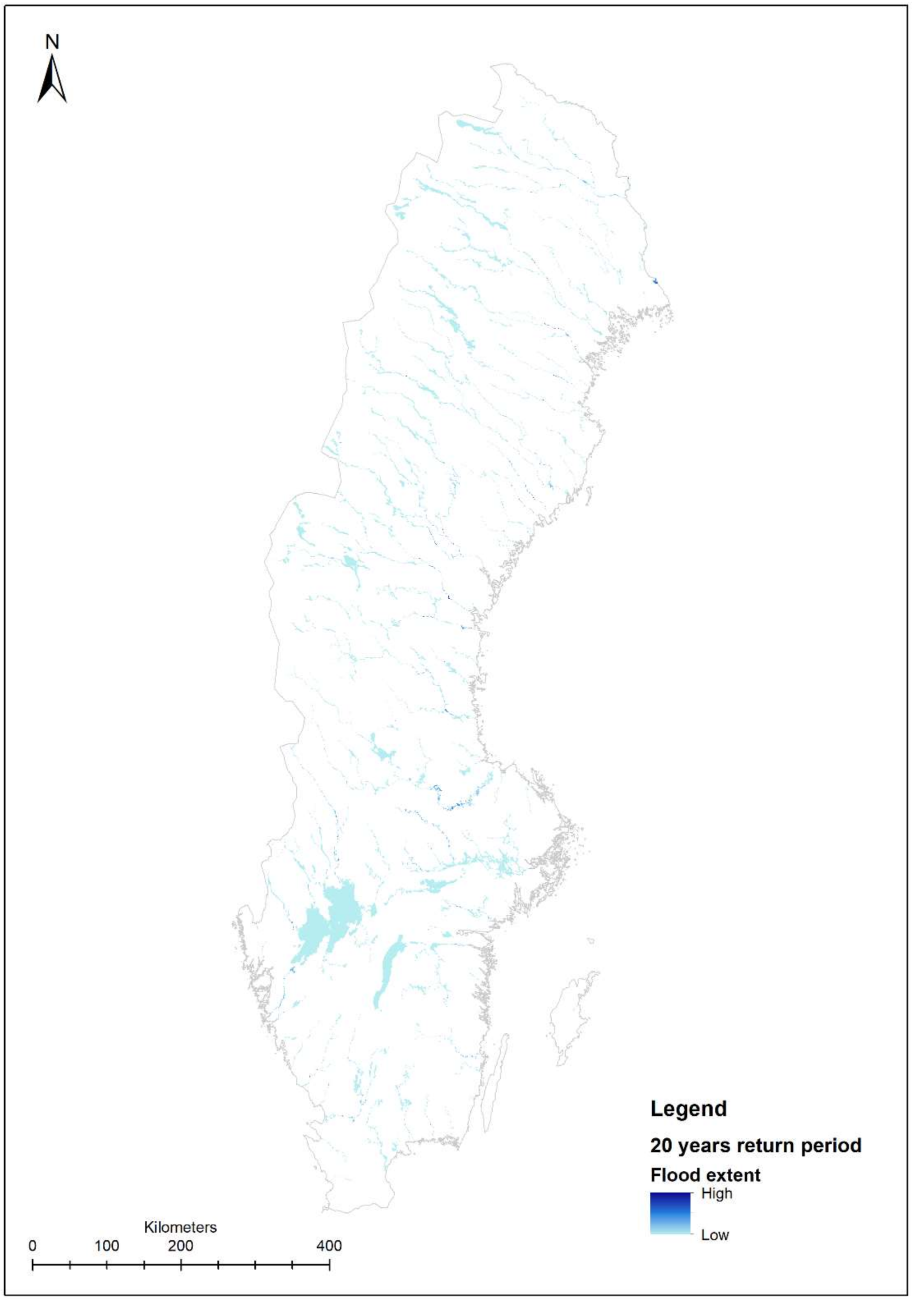


Figure 5. 50 years return period.

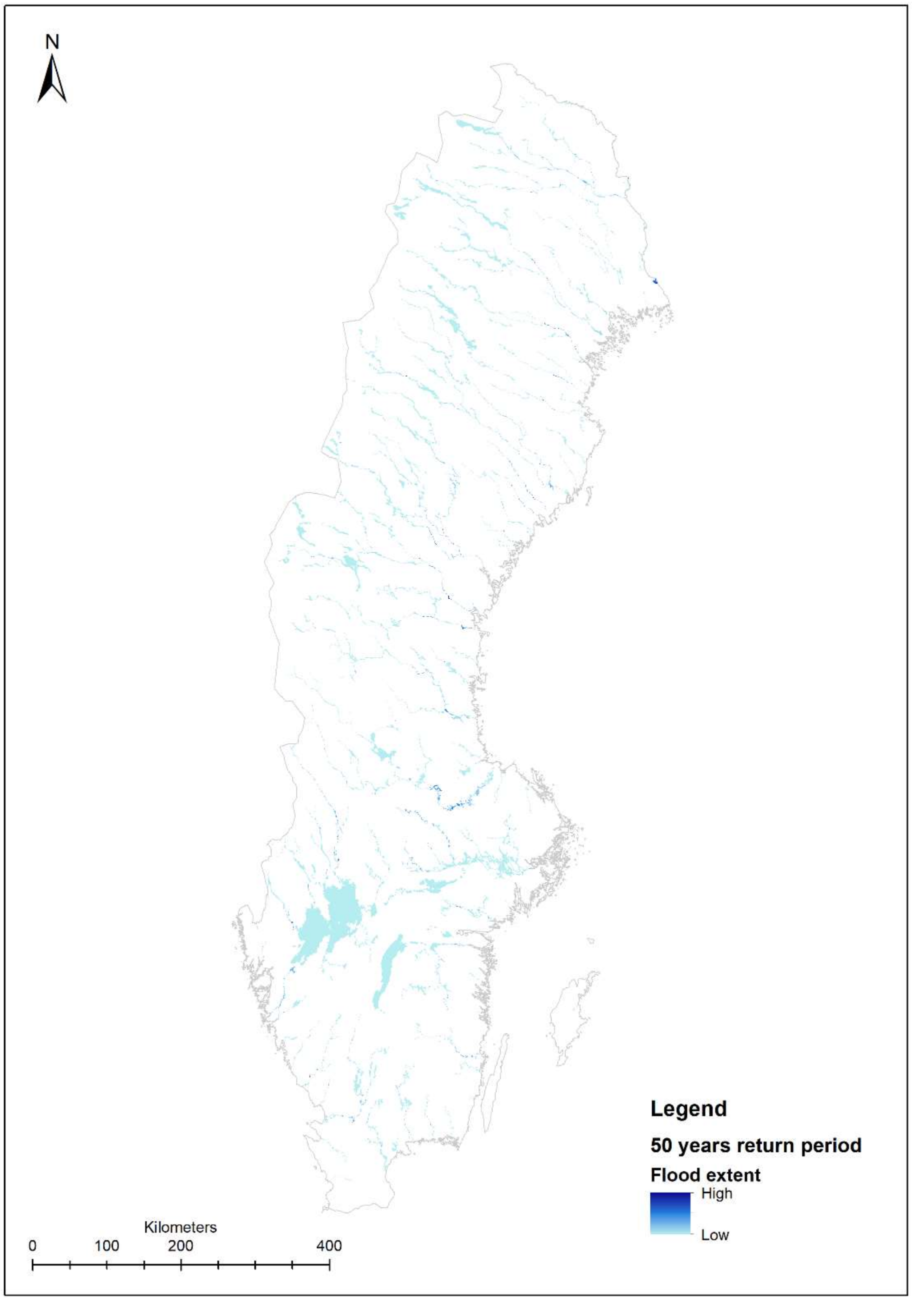


Figure 6. 100 years return period.

Figure 7. 200 years return period.

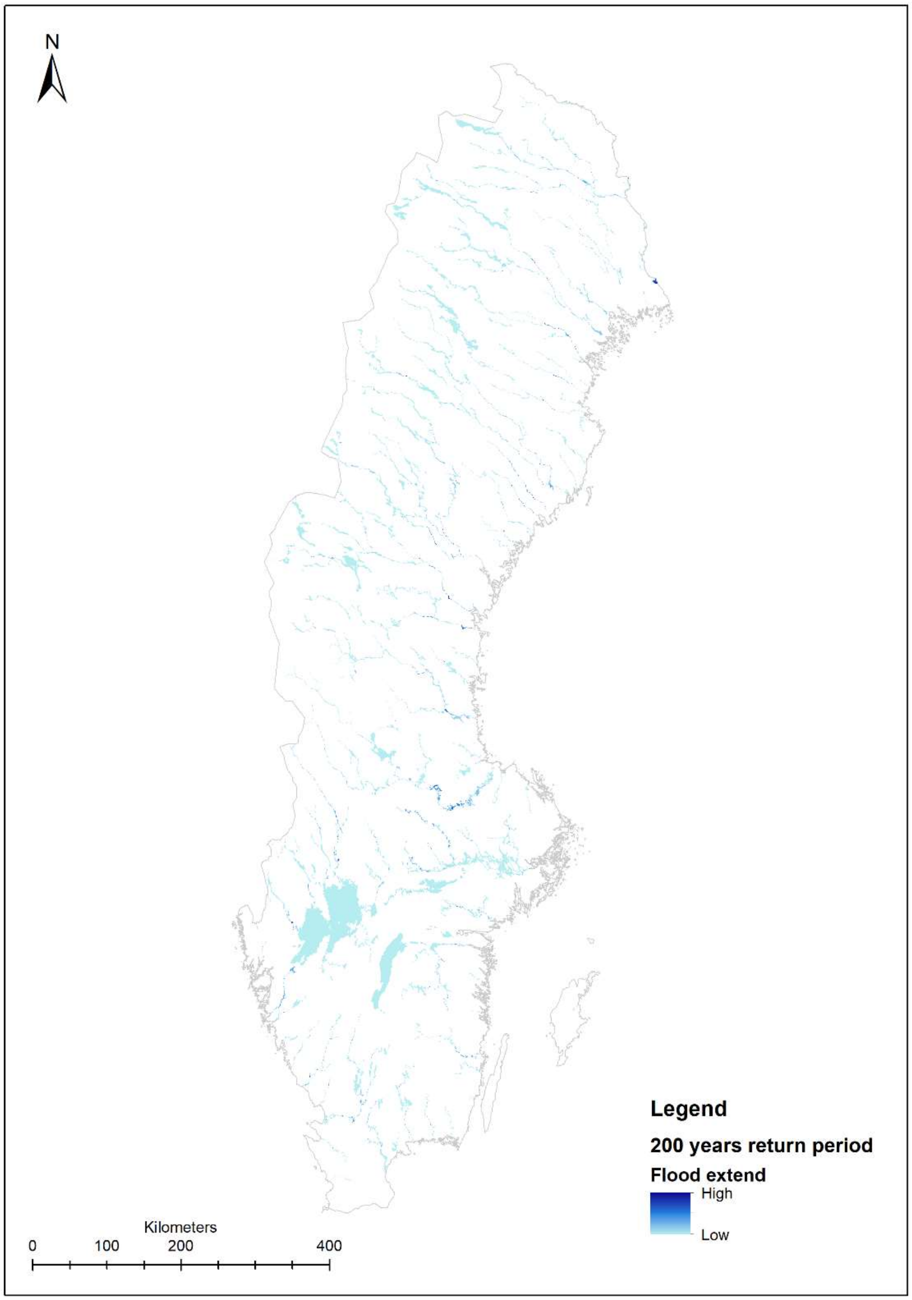
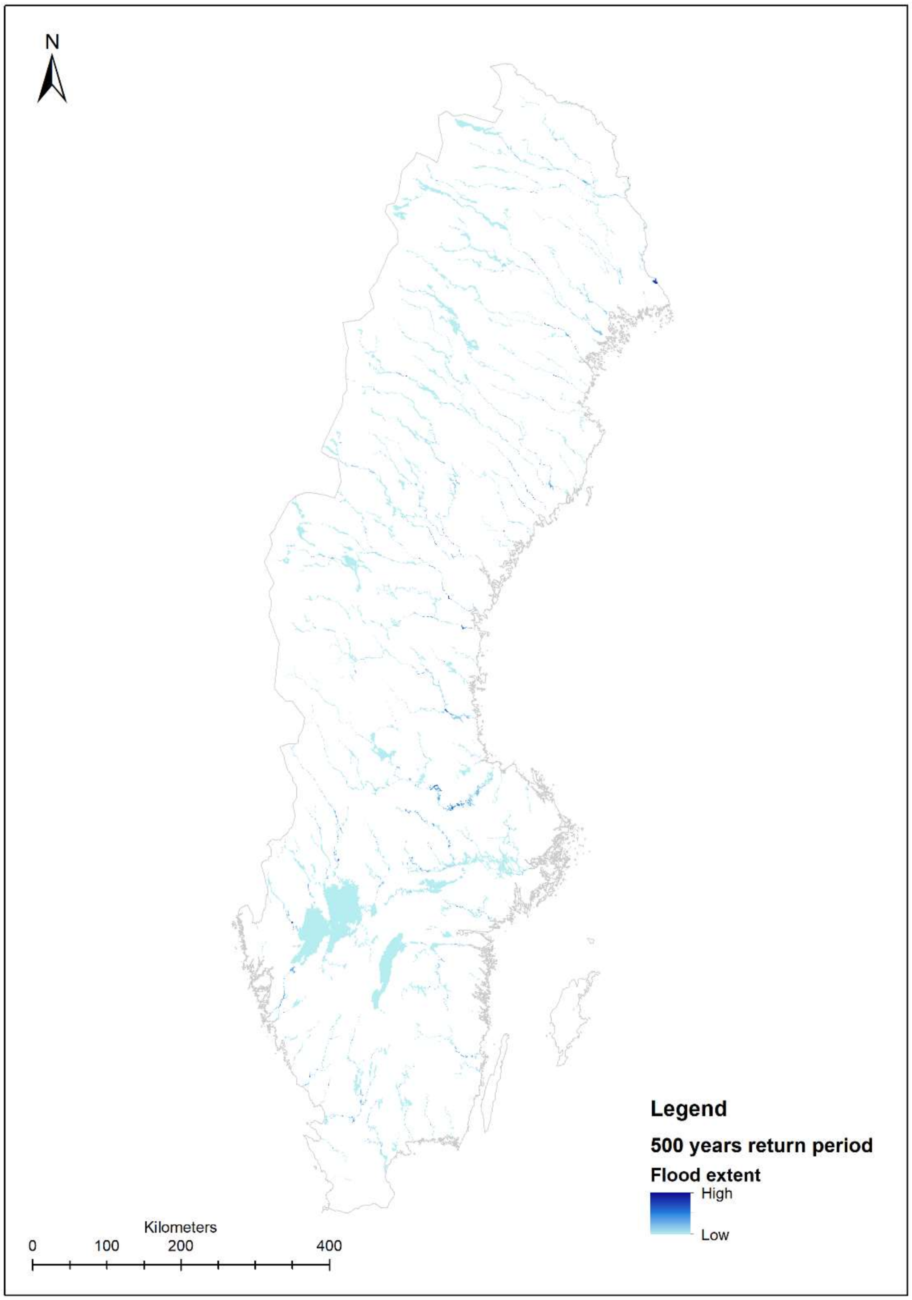


Figure 8. 500 years return period



2.2 Direct damage (depth-damage functions)

The HAZUS Flood Model uses flood depth along with depth-damage functions to compute the possible damage to building and infrastructure (Scawthorn et al., 2006b). Depth-damage functions are plots of flood depth versus percent of damage, developed for different building types and occupancies. The extent and severity of damage to structural components and contents is estimated from the depth of flooding and the application of the assigned depth-damage curve.

The HAZUS Flood Model uses the Federal Insurance Administration's (FIA) depth damage curves and selected curves created by various districts of the U.S. Army Corps of Engineers (USAGE) for estimating damage to the general building stock (Scawthorn et al., 2006a, 2006b).

In Sweden, depth-damage functions are not available. Based on the literature review, depth-damage functions developed by Huizinga at al. (2017) could be used for the implementation of HAZUS Flood Model in Sweden. Huizinga at al. (2017) developed damage curves for each continent and for 214 counties for the following damage categories:

- Residential buildings
- Commerce
- Industry
- Transport
- Infrastructure

In the next sections, the literature review findings on the flood depth-damage curves are presented. The results are shown per damage class. In all figures, the European function is presented as a purple line, as well as the HAZUS Flood Model North America function (red line).

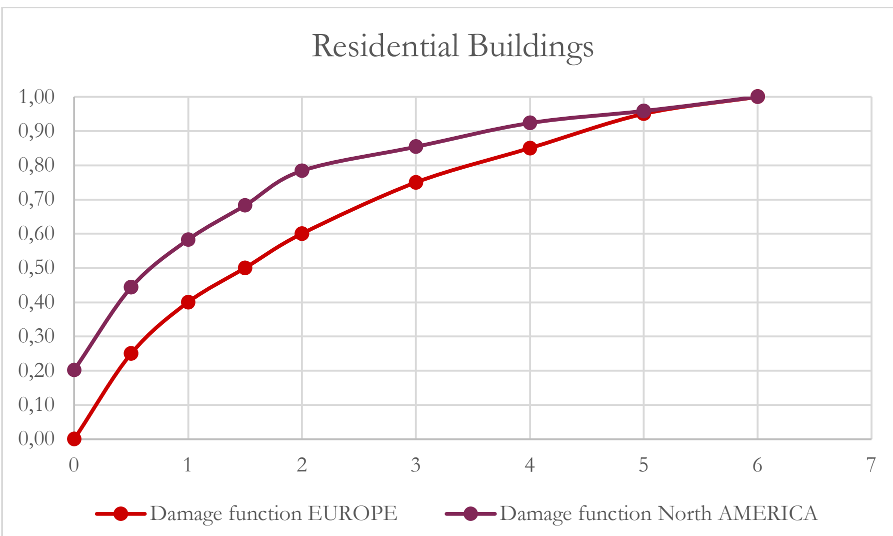
2.2.1 Residential buildings

The residential buildings damage functions including content damage values are presented in Table 1 and are displayed in Figure 9. As we can see the shape of the damage function for Europe and North America is quite similar. The only exception is that the North American function has a positive damage factor at zero flood depth. This is explained by the fact that the North American flood model HAZUS provides data for different house types with –and without basement (Huizinga at al., 2017).

Table 1. Damage function for residential properties

Flood depth, [m]	Damage function	
	EUROPE	North AMERICA
0	0.00	0.20
0.5	0.25	0.44
1	0.40	0.58
1.5	0.50	0.68
2	0.60	0.78
3	0.75	0.85
4	0.85	0.92
5	0.95	0.96
6	1.00	1.00

Figure 9. Damage function for residential properties



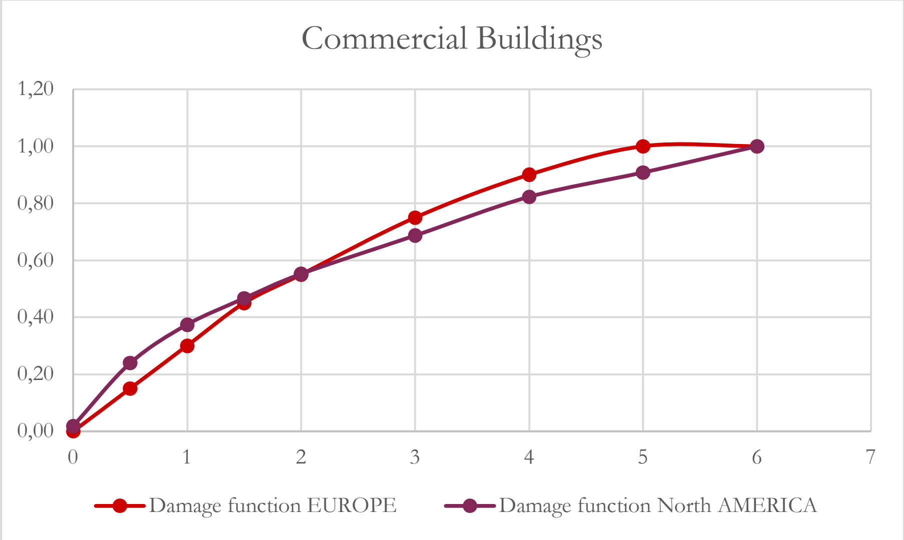
2.2.2 Commercial buildings

The commercial properties damage functions including maximum damage values are presented in table 2 and are displayed in Figure 10. As we can see the shape of the damage function for Europe and North America is quite similar. For smaller process intensities, damage is higher in the US and for bigger process intensities, the damage is higher in Europe.

Table 2. Damage function for commercial properties

Flood depth, [m]	Damage function	
	EUROPE	North AMERICA
0	0.00	0.02
0.5	0.15	0.24
1	0.30	0.37
1.5	0.45	0.47
2	0.55	0.55
3	0.75	0.69
4	0.90	0.82
5	1.00	0.91
6	1.00	1.00

Figure 10. Damage function for commercial properties



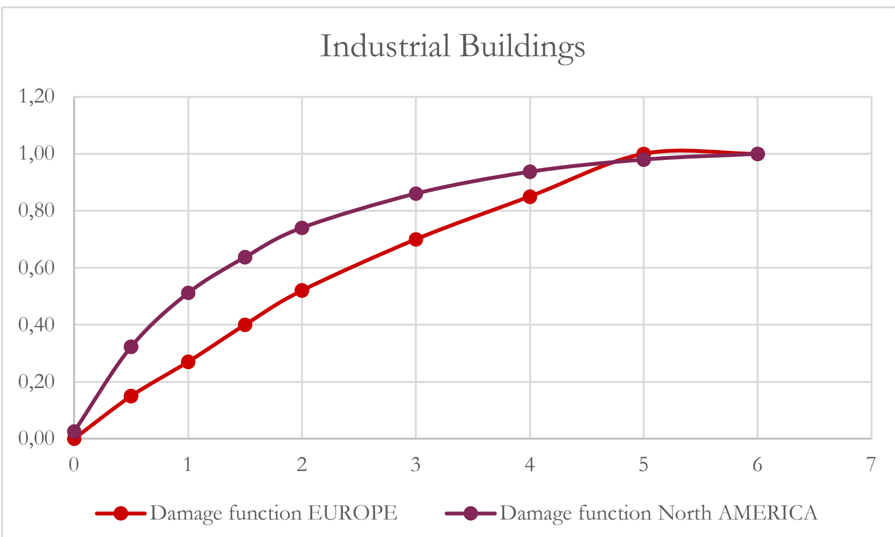
2.2.3 Industrial buildings

The industrial properties damage functions including maximum damage values are presented in Table 3 and is displayed in Figure 11. As we can see, the shape of the damage function for Europe and North America is quite similar but the damage is higher in the North American function.

Table 3. Damage function for industrial properties

Flood depth, [m]	Damage function	
	EUROPE	North AMERICA
0	0.00	0.03
0.5	0.15	0.32
1	0.27	0.51
1.5	0.40	0.64
2	0.52	0.74
3	0.70	0.86
4	0.85	0.94
5	1.00	0.98
6	1.00	1.00

Figure 11. Damage function for industrial properties



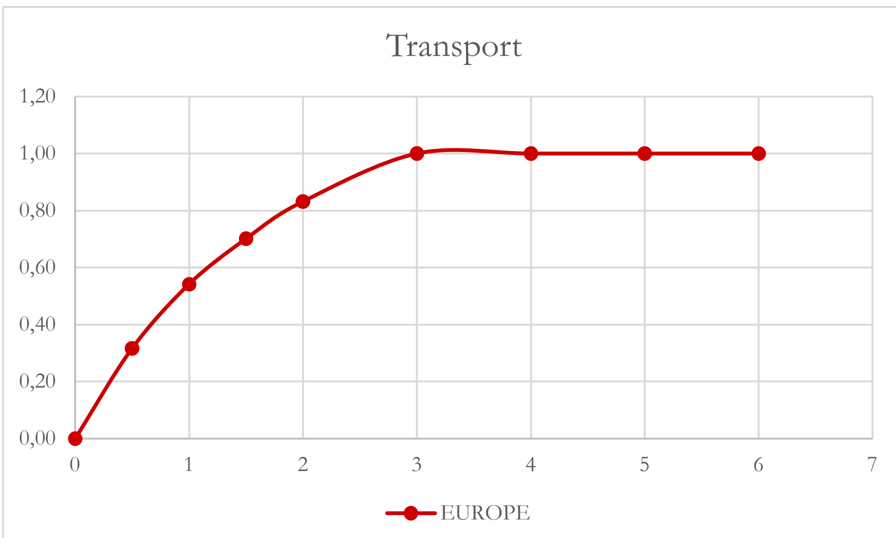
2.2.4 Transport

The transport damage function for Europe is presented in Table 4 and is displayed in Figure 12. For North America, a transport damage function is not available.

Table 4. Damage function for transport

Flood depth, [m]	Damage function	
	EUROPE	North AMERICA
0	0.00	-
0.5	0.32	-
1	0.54	-
1.5	0.70	-
2	0.83	-
3	1.00	-
4	1.00	-
5	1.00	-
6	1.00	-

Figure 12. Damage function for transport



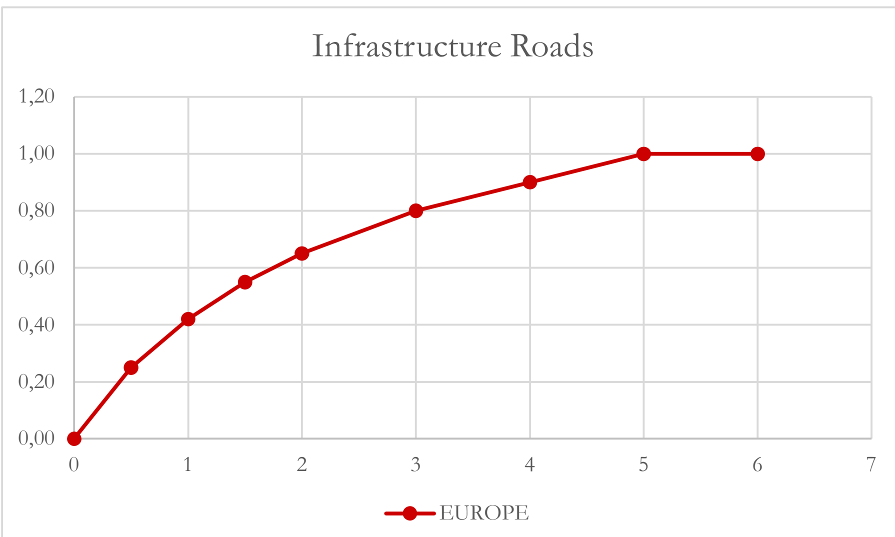
2.2.5 Infrastructure Roads

The infrastructure damage function for Europe is presented in Table 5 and is displayed in Figure 13. For North America a transport damage function is not available.

Table 5. Damage function for road infrastructure

Flood depth, [m]	Damage function	
	EUROPE	North AMERICA
0	0.00	-
0.5	0.25	-
1	0.42	-
1.5	0.55	-
2	0.65	-
3	0.80	-
4	0.90	-
5	1.00	-
6	1.00	-

Figure 13. Damage function for road infrastructure



2.3 Buildings, facilities, and lifeline systems data

Within HAZUS Flood Model, buildings are defined to include both the structural system and architectural, electrical and mechanical, and building finishes. In general, it is expected that the structural components of a building will survive a flood event, but the structural finishes and contents may be severely damaged due to inundation.

Building parameters related to flood damage include:

- Specific occupancy class
- Number of stories
- Foundation type

Facilities that provide services to the community/state are called essential facilities within HAZUS Flood Model. These facilities should be functional following a flood event and include:

- Medical care centers
- Police stations
- Fire stations
- Emergency centers
- Schools

Essential facilities parameters that affect the damage mechanism include location, occupancy class, building type, foundation type, first-floor height above the ground, number of stories, functional depth, flood protection, and building replacement cost (FEMA, 2012; 2022d).

Based on the literature review, Lantmäteriet provides data on administrative units, real properties (i.e. buildings), facilities and lifeline systems.

2.3.1 Real property classification

Lantmäteriets Real Property register[3] contains information on all real property in Sweden. The real property classification corresponds to the boundaries in the Cadastral Index Map (Lantmäteriet, 2019). Lantmäteriet and the municipal authorities in connection with the registration of real property continuously update real property classification in the Cadastral Index Map.

The Property Map's subdivision of real property provides the following data in vector format that can be used in HAZUS Flood Model analyses:

- Administrative classification boundaries

[3] https://www.lantmateriet.se/sv/Fastigheter/Fastighetsinformation/Fastighetsregistret/?

- National: Boundary showing Swedish national boundary to other nations. The boundary also includes county, district and real property boundaries.
- County: Boundary showing county boundary, which is not the national boundary. The county boundary is also the municipal, district and real property boundary.
- Municipality: Boundary showing municipal boundary, which is not a county boundary or national boundary. The municipal boundary also constitutes a district and real property boundary.
- District: Boundary showing a district boundary, which is not a municipal or county boundary or a national boundary. Also constitutes real property boundaries.
- Real properties and joint properties: Boundary for real property, joint property or unofficial parceling area, which is not at the same time a district, precinct district, county or national boundary. When the extent of the real property or joint property area is unclear with respect to water, the boundary is a real property shore instead.

Data is provided in vector format and is available for download in Lantmäteriet's website[4]. In GIS, vector data represents geographic features as points, lines, and polygon shapes, as opposed to raster data which represents features as grids of cells. Vector data are used to store information such as the location of roads, buildings, and other physical features, as well as their attributes such as names, address, and other information. Some common vector formats used in GIS include Shapefile, GeoJSON, and KML.

2.3.2 Real properties

In built-up areas, two different categories related to building occupancy are provided. Build-up areas are presented in four layers with information on buildings and facilities. The extent of land around facilities describes mainly industrial activities or activities related to recreation, sports or culture (Lantmäteriet, 2019).

2.3.2.1 Buildings

The buildings on the Property Map originate from Lantmäteriat's reconstruction and updating of the Basic Geographical Data and partly through collaboration with the municipalities. Information about the building purpose and detailed purposes are provided in the database. Building purpose indicates the purpose that a building is used for. A building may have more than one purposes, such as residential and commercial. In this case, in the database stated the main purpose.

[4] https://www.lantmateriet.se/

Detailed purposes are specified for building s with the building purposes of residential, industrial and public purposes.

In Table 6 the categories (detailed purpose) of the residential buildings are shown.

Table 6. Categories (detailed purpose) of the residential buildings

Code	Purpose of building	Detailed purpose
130	residential	small house, detached
131	residential	small house, chain linked house
132	residential	single family house, terraced houses
133	residential	multi-family houses
135	residential	small house with several apartments
199	residential	unspecified

Similar, for the industrial buildings the different categories are presented in Table 7.

Table 7. Categories (detailed purpose) of the industrial buildings

Code	Purpose of building	Detailed purpose
240	industrial	other manufacturing industry
241	industrial	gas turbine plant
242	industrial	industry hotel
243	industrial	chemical industry
244	industrial	condensing power plant
245	industrial	nuclear power station
246	industrial	food industry
247	industrial	metal or machinery industry
248	industrial	textile industry
249	industrial	wood industry
250	industrial	water power facilities
251	industrial	wind turbine
252	industrial	heat plant
253	industrial	other industrial building
299	industrial	unspecified

2.3.3 Lifeline systems

Following the HAZUS Flood Model manual, facilities are defined as the transportation and utility infrastructure that provides the state with communication, water, power, mobility and other necessities for both continuity of governance and economic health. Based on the literature review, in Sweden, Lantmäteriet provides data on lifeline systems.

2.3.3.1 Facilities

Facility areas data collection and updating are carried out by Lantmäteriet performing photogrammetric measurements in aerial images, as well as through cooperation with municipalities. In Table 8 the different categories (purpose) of facilities are presented. For a more detail description of the categories, please see Lantmäteriet's manual.

Table 8. Categories (detailed purpose) of the public buildings

Code	Purpose of building	Detailed purpose
301	public	public baths
302	public	fire station
303	public	bus station
304	public	distribution building
305	public	animal hospital
306	public	defence building
307	public	healthcare centre
308	public	higher education institution
309	public	ice rink
310	public	railway station
311	public	town hall
312	public	prison
313	public	cultural building
314	public	police station
315	public	sewage treatment plant
316	public	riding stables
317	public	associations
318	public	hospital
319	public	school

320	public	sports hall
321	public	university
322	public	waterworks
324	public	multi arena
399	public	unspecified

2.3.3.2 Transportation

The main responsibility for the transport network objects such as roads, railways etc. is held by the Swedish Transport Administration[5]. Lantmäteriet supplements this work with other road networks and paths. Data and information related to the transportation network is available in the National Road Database NVDB. Within the NVDB the road network is divided into different classes (Table 9).

Table 9. Road network categories

Transport network	Road types
Roads	public road class I, road center line
	public road class I, road center line in underpass
	public road class II, road center line
	public road class II, road center line in underpass
	public road class III, road centre line
	public road class III, road centre line in underpass
	public road, seperated lines, centre line of lane
	public road, seperated lines, centre line of lane, underpass
	road/street
	road/street in underpass/tunnel
	precint road
	poorer quality road
	poorer quality road in underpass
Motorways	motorway, centre line of lanes
	motorway, centre line of lanes, underpass/tunnel

[5] https://bransch.trafikverket.se/en/startpage/

	road under construction
Bridge	opening bridge
Railways	single track railway
	double track railway
	underpass/tunnel for railway
	other railway
	railway under construction
	other railway in tunnel

2.4 Foundation type and number of stories

The first floor elevation is a key parameter for the estimation of flood damage and information is required on foundation types, number of stories and first floor height for the general building stock. Table 9 provides the default elevations for each foundation type (FEMA, 2012) in flood hazard areas.

Table 10. Foundation types as identified by FEMA (2012)

Foundation type	Freeboard above base flood elevation (meters)
Pile	2.4
Pier (or post and beam)	1.8
Solid wall	2.4
Basement (or garden level)	user-specified
Crawlspace	1.2
Fill Slab	0.6
Slab-on-Grade	user-specified

In Sweden, this information is not available in a continuous record or database. However, the HAZUS Flood Model team provided a methodology for the identification and classification of the different foundation types, number of stories and first floor height in the study area.

The information related to the foundation type can be collected using the following methods (adapted by FEMA, 2018):

A. Visual verification using oblique aerial imagery – oblique imagery gives the analyst a side viewing angle of the structure, and the ability to assess whether has a basement (windows shown in the basement below). In Sweden, aerial imagery[6] data are available through Lantmäteriet.

Figure 14. Visual verification using oblique aerial imagery. Photo courtesy of pictometry. (FEMA, 2018)

B. Census block assumptions – census block assumptions can be made using known common practices for an area by occupancy type.

The Number of stories can be derived using the following methods (FEMA, 2018):

A. Google Earth Pro or similar applications. These sources include number of stories, depending on the location.

B. An assumption can be made based on specific occupancy using the following criteria from the HAZUS Flood technical manual. This method is not suggested for Sweden due to the different building types.

C. This attribute can be derived visually using oblique aerial imagery (Figure 9) or Google Street View. In Sweden, aerial imagery [3] data are available through Lantmäteriet.

Figure 15. Number of stories for a single-family dwelling. Picture courtesy of pictometry. (FEMA, 2018)

[6] https://www.lantmateriet.se/en/geodata/geodata-products/product-list/orthophoto/#qry=orthophoto

The first floor height describes the height above ground (not above sea level) of the building first floor. This can be obtained by using one of the following methods (FEMA, 2018):

A. Subtracting the elevation certified by ground surface elevation from high-resolution LiDAR data. In Sweden, LiDAR[7] data is available by Lantmäteriet.

B. Measuring in the field or from orthorectified oblique imagery from the front door threshold to the ground surface.

C. Approximation based on foundation type. The HAZUS Flood technical manual has approximate first floor heights based on different foundation types (Table 10).

2.5 Direct Social Losses

An important factor of any planning scenario is to estimate the number of individuals who will need to be sheltered in the short term (HAZUS Manual 2.1). The HAZUS Flood Model has the ability to determine the number of individuals likely to use government provided short-term shelters based on the number of displaced households as a result of a flood event. To determine the number of households and the corresponding number of individuals will seek help in governmental-provided shelters the methodology based on socio-economic factors (FEMA, 2012).

Those displaced populations using shelters will most likely be individuals with lower incomes and those have limited social networks (friends and family) within the affected area. Consequently, modification factors for flood events are based primarily on income. Age plays a secondary role and represented by younger, less established families and elderly families (FEMA, 2012).

The algorithm uses information from the census databases in the following areas:

- Total number of households in the research area
- Total number of individuals in the research area
- Distribution of households by income in the research area
- Distribution of individuals by age in the research area.

HAZUS Flood Model user can use either the census information or any local or regional data that contains this information. In Sweden, this information is available through the Statistics Sweden (SCB) database[8].

[7] https://www.lantmateriet.se/en/geodata/geodata-products/product-list/laser-data-download-nh/#qry=lidar
[8] https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/

3 Conclusion & recommendations

Since no national platform or tool is available to perform risk assessments in Sweden, Grahn (2020) studied the transferability and applicability of the HAZUS Flood Model methodology - developed by Federal Emergency Management Agency (FEMA) in the United States - to Sweden and Swedish conditions. Following the work done by Grahn (2020), this research study aimed to identify and establish data and practical methodologies required to perform analyses within HAZUS Flood Model.

The accuracy and reliability of risk assessments are greatly influenced by the risk components: hazard, exposure and vulnerability (stage-damage functions). The data availability with respect to the risk parameters in Sweden could be characterised as good. Within this report, data and methods to assess the risk analysis parameters using HAZUS Flood Model presented.

With respect to hazard data, the availability and accuracy is very good in Sweden. MSB provides flood hazard data developed for the European Floods Risk Directive[9] purposes. These data can be assess though a portal free of charge. Furthermore, a dataset developed by Dottori et al. (2021) presented within this report. The dataset covers the entire Swedish territory and the quality check suggested the implementation to HAZUS Flood Model. The dataset[10] is available for download through the Joint Research Centre by the European Commission.

Focusing on exposure data, as described within this study, Lantmäteriet and the Swedish Transport Administration provide different types of exposure data (buildings, facilities, transportation etc.). The quality fits the HAZUS Flood Model requirements and it could be used to update the general building stock and critical facilities within an analysis. The Swedish University of Agricultural Science's portal[11] provides access to the data and good documentation. The data is available for scientific purposes and for use by the governmental authorities.

Concerning stage-damage functions, the data availability is limited in Sweden. Within this report, data by Huizinga et al. (2017) identified as the only dataset available for use in HAZUS Flood Model. The data should be used carefully and additional local knowledge and fieldwork is suggested to limit calculation uncertainties. On the other hand, research projects are working to the direction to produce synthetic damage functions in Sweden (DEPLHI project[12]) and to create a database to systematically collect and analyse damage data (SPARC project[13]).

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[9] https://gisapp.msb.se/apps/oversvamningsportal/avancerade-kartor/oversvamningskartering.html
[10] https://data.jrc.ec.europa.eu/dataset/1d128b6c-a4ee-4858-9e34-6210707f3c81
[11] https://www.slu.se/en/subweb/library/use-the-library/search-and-find/digital-maps/
[12] https://www.kau.se/csr/forskning/forskningsprojekt/utveckling-av-riskbedomningsmetoder-skyfallsskador
[13] https://www.kau.se/en/csr/sparc

Based on the data presented in previous chapters, we conducted some analyses using the Level 3 analysis option. However, we have found that using the HAZUS Flood Model outside of the United States territory is limiting our ability to conduct a thorough analysis. Our experience has highlighted some limitations and problems with using these data, which we will discuss in the following paragraphs.

The Hazard dataset presented in this study was relatively easy to integrate in our analyses. On the other hand, some minor issues must be highlighted. The dataset provided by the European Union via the Joint Research Centre is in the "ETRS_1989_LAEA" projection, which differs from the projection system used in Sweden (SWERF99). As a result, users may require some experience to clip the area of interest and convert the projection system.

The use of stage-damage functions in translating process characteristics to damage requires careful use. The dataset is subject to high levels of uncertainty due to variations in building characteristics and construction techniques. HAZUS Flood Model offers over 22 stage damage functions developed to specific residential buildings based on occupancy class, number of stories, and the presence of basement. However, replacing the original functions with the alternative ones presented in this study drove to uncertain results. Furthermore, we faced difficulties in converting the data from meters to feet and Euros to dollars using different software. Following the above, it is recommended the careful use of this dataset in any future implementation.

Sweden has good availability and quality of real property data, especially with respect to building stock and critical facilities. The HAZUS Flood Model utilizes Comprehensive Data Management System (CDMS) to import and edit user-defined real property data. However, the process of importing and editing this data was complex and required expert knowledge in database management.

When it comes to critical facilities, the data available is of a big amount and of high quality. However, the lack of stage-damage functions for these properties made it impossible to conduct a thorough analysis. On the other hand, while data for stage-damage functions related to transportation networks are available, the HAZUS Flood Model lacks the routines to perform analysis for these properties.

In Level 3 analysis, user experience is crucial, particularly regarding knowledge of Geographic Information Systems and database management. It is worth noting that in the United States, the customary units system is used, and all calculations and methodologies within HAZUS based on US formats and standards. For example, flood depths are measured in feet, and monetary values are expressed in US dollars. Therefore, users must be careful when performing unit conversions and importing data into different applications/methods. A small error can result in incorrect results and misinterpretation.

Moreover, it is critical for the user to have good knowledge of flood processes and risk parameters. HAZUS Flood Model does not address uncertainty and the potential for results' misinterpretation is high. Additionally, HAZUS depends on

Esri's ArcGIS platform, resulting to high costs for licensing. FEMA is currently looking at other options, for example, open-source solutions to enhance flood risk assessment and better serve the community. These options will provide faster scientific integration and will be easier to use (K. Karagiorgos & T. Grahn, personal communication, November 2022).

Following the above, we decided to do not present the results of certain analyses due to the high degree of uncertainty involved. We believe that sharing such information could potentially mislead readers and the decision-making, in case of use, for those involved in flood risk management.

In this vein and based on the data availability, the use of HAZUS Flood Model is possible in Sweden but is not recommended.

On the other hand, the data presented here could form the basis to build a method or a tool, similar to HAZUS, for the Swedish conditions. Similar to Level 1 analysis, this tool/method could provide important information about the areas need more refined flood risk assessments. At regional and local levels, where the primary effects of floods are experienced and where many of the services relevant for flood risk management are situated, decision-makers are heavily dependent on the availability of human and knowledge (Ek et al, 2016). By this tool/method, responsible authorities could identify areas for more detailed flood risk assessments; build new knowledge; and gain valuable support in their work on information, education and training.

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