Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

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Comparing flood cost estimates with varying levels of detail

Master's thesis in Hydropower Development
Supervisor: Knut Alfredsen
Co-supervisor: Bendik Torp Hansen
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Abstract

In this paper, a flood damage estimation method was proposed for the assessment of flood risk in Drammen river basin by using a hydraulic model, GIS and Excel based flood loss estimation model. For the flood damage assessment, hazard characteristics, such as flood depth, flood extent and flood velocity, were computed for the current and future climate scenario using the hydraulic model. In order to visualize flood extent, velocity, depth and their impact, the results of modelling are illustrated in the form of flood inundation maps produced in GIS. Buildings and infrastructures, which are major exposures in flood-prone areas, were taken into account for the flood loss estimation. The flood damage model is formulated based on stage-damage relationships between different flood depths and land use categories. It calculates the economic loss to different land use features based on the simulated flood parameter obtained from the hydraulic model for different repetition interval.

For the case study, the results show that the highest proportion of the total damage in each repetition interval (approximately 90-92%) is expected to occur in buildings. In addition, results showed that the effects of climate change will raise the total damage from floods by 20.26%.

Acknowledgements

First and foremost, I would like to acknowledge and express my special thanks of gratitude to my academic supervisor, Knut Alfredsen for his enthusiastic support and constructive feedback. This accomplishment has been possible because of his valuable guidance through all the stages of writing the thesis. Furthermore, I would like to thank to my co supervisor, Bendik Torp Hansen for his willingness to support.

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I hereby confirm that the works presented in this thesis is my own. All the guidance that are taken from other source are referenced.

August 6, Trondheim

Seble Fissha Hailemariam

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Abbreviations

ARI- Average recurrence interval

DEM - Digital Elevation Model

GIS- Geographic information system

HEC-RAS - Hydrologic Engineering Center's River Analysis System

LiDAR - Light Detection and Ranging

NVE - Norges Vassdrags og Energidirektorat

USACE - United States Army Corps of Engineers

XS - Cross Section

1 INTRODUCTION

Flood has been recognized as the most common and damaging natural disaster in many parts of the world (McGrath et al., 2019). Nowadays, the occurrence of flood is increasing worldwide as a result of extreme rainfall, which is anticipated to occur more frequently as a consequence of the climate change phenomenon(De Silva & Kawasaki, 2018; E. H. Lee & Kim, 2018; J. S. Lee & Choi, 2018). As flood prone areas continue to be developed, the potential damages as a result of floods will continue to rise. furthermore, future climate change may increase flood frequencies and magnitudes, as well as flood damages (Arnell & Gosling, 2016). The pace of urban growth in addition to climate change put the urban water cycle out of balance, which affects surface and subsurface process and further increase flood risk.

Flood losses are responsible for approximately one-third of the economic damages incurred as a result of natural disasters in Europe and are, together with windstorms, the most frequently occurring natural disaster (Munich Re 2005; EEA et al. 2008). The EU Floods Directive (FD, 2007/60/EC) signaled a shift in emphasis from structural defense to a more comprehensive risk management approach, with structural and non-structural interventions having similar importance. The FD requires the identification of areas at risk of flooding and the implementation of flood mitigation measures to moderate flood impacts. Public disaster risk reduction and territorial development policies should be based on reliable, evidence-based risk assessments.

First of all, there are different definition of damages. The concept of direct and indirect loss, and whether the loss is tangible or not define the classes. Direct losses are defined as losses that occur as a consequence of a direct contact with the water, whereas indirect losses only occur as a consequence of the flooding. Direct losses are directly correlated with the duration of the flood, whereas indirect losses can have effects on time scales of months and years (Bruno Merz et al., 2011). Moreover, the losses are divided into tangible and intangible losses. In contrast to intangible losses, tangible losses are losses that can be objectively quantified, i.e., the loss can be accounted for in direct monetary value, which can be determined based on whether or not a market exits for the asset in questions(Hammond et al., 2015). Secondly, various approaches exist regarding the damage appraisal, such as financial and economic valuation based on market values (i.e., based on historical values or replacement values), while variation in the scale of analysis (micro-, meso- or macro-scale) is also found(Messner et al., 2007; Pistrika & Jonkman, 2010).

Thieken et al., 2005) presented the concept of impact and resistance parameters as two sorts of damage influencing factors. The first ones reflect flood event's specific characteristics (such as water depth, flow velocity, etc.), while the second ones represent the properties of the affected assets (such as building type or materials, emergency measures used, etc.). In (B. Merz, Kreibich, et al., 2010) an extensive review of all the damage parameters was carried out. the impact parameter is strongly influenced by several resistance parameters. In a study undertaken after hurricane Katrina(Pistrika & Jonkman, 2010), it was identified that variations in building type implied important changes in the resistance of buildings.

Flood damage assessment consists the evaluation of flood hazard, exposure, and vulnerability (B. Merz, Hall, et al., 2010; Olsen et al., 2015). Flood hazard is the threatening natural event, including its probability of occurrence and magnitude. Exposure represents the capital, humans and ecological assets exposed to the hazard. Vulnerability describes the potential to be damaged or the susceptibility of the receptor to the flood hazard. The evaluation of monetary loss using loss models is a critical component of flood risk analysis and has a direct impact on flood management practice, such as in the cost-benefit analysis of flood management measures or the calculation of insurance premiums (B. Merz, Kreibich, et al., 2010)(B. Merz, Kreibich, et al., 2010).Conventionally, flood damage estimation engages univariable stage-damage functions, which define the relationship between flood parameters and possible damage(Alfieri et al., 2016; Huizinga et al., 2017). (Merz et al. (2010) distinguished two main approaches for development of flood damage functions: (1) empirical approaches, which use flood damage data collected after flood events, and (2) synthetic approaches, which use damage data collected via what-if questions. The choice of the approaches depends on data availability (Messner et al., 2007). Detailed damage models include a number of different stage-damage functions that distinguish between occupancy (e.g., residential, commercial, and industrial), asset type (e.g., building, contents, and equipment), and asset characteristics (e.g., building type, building material, and number of stories). A comparative flood damage model assessment study conducted by (Jongman et al., 2012), examines and contrasts seven distinct damage models developed for various regions in Europe and the United States: FLEMO (Germany), Damage Scanner (Netherlands), the Rhine Atlas (Rhine Basin), the Flemish Model (Belgium), Multi-Coloured Manual (MCM) (United Kingdom), HAZUS-MH (United States), and the JRC (Germany, European Commission/HKV). The fact that five of the seven models are based on aggregated land use data rather than individual objects (HAZUS-HM and MCM) demonstrates that the scale of work is an important consideration when selecting or developing a damage model. In addition, it is worth noting that only two out of the seven models are based on individual objects, demonstrating the difficulty of creating such detailed damage models. While object-based models can account for variations in building density in areas with the same CORINE land use, area-based models can be used to quickly calculate over wider areas. However, HAZUS-MH and MCM, which are object-based models use a large number of object types and corresponding flood damage features. (FLEMO, HAZUS-MH, and the Rhine Atlas models are empirically developed and may be more accurate when applied to similar case studies. The others are mostly synthetic, with the inherent problem of unreliable applicability to a different region or country. An essential improvement in these recent damage models is their GIS-based characteristic. The strong focus on inundation depth as the main determinant for flood damage might be due to limited information about other parameters characterizing the flood, e.g., flow velocity.

This paper aims to improve the current methodologies of building and infrastructure damage estimation in flood risk assessments, as well as to propose and provide an open-access tool to assess microscale flood damages in urban areas. In this research we therefore propose a methodology to estimate the flood damage for present and future climate flood scenarios.

The following are the main research questions addressed:

- How can flood damage analyzed for different flood scenarios?

- What is the increase in cost of floods in the future climate?

The final output of the study is a flood Hazard map, which will help to identify exposed areas of the studied area and to improve land-use management policies along a river course and the flood loss estimation for the current and future climate flood scenarios.

the following states how the paper is organized: The methodology and data used to analyze the flood risk are described in Section 2, which is followed by a presentation of results in section 3, discussion in Section 4 and conclusion in Section 5. In addition, the supplementary document is included.

2 MATERIALS AND METHODOLOGY

Flood impacts may be very diverse depending on the type of damage and the method used to assess them. Therefore, it is important to state the assumptions made, the categories considered, and the approaches used to assess these impacts. To better explain the methodological framework adopted in this work, this section presents and discusses the fundamentals of the applied flood damage estimation method depending on the reviewed literatures presented on the introduction. the approach is composed of three main modules, the hazard, Exposure and the vulnerability module. The bases of these three modules are detailed in Sections 2.1 and 2.2. Section 2.3 introduces the study area and the approach adopted in this research to collect, manage, and explore data.

2.1 Flood Hazard

The flood hazard was determined using the hydrologic–hydraulic method. The assessment process involved the collecting and preparation of geometric data, hydraulic modeling, and the GIS post-processing and mapping.

In the first step, the geometric data has obtained, as the elevation data from Høydedata was collected using red lidar, which does not contain the underwater depth information of the river channel, it was mandatory to integrate the terrain model with the bathymetry data .to do so, 1D geometries were imported and saved in hecras, In the standard Geometry editor, the bank station location in the cross sections was manually edited. When all of the cross sections had been adjusted as desired, the elevation data of the areas in between the cross sections were automatically interpolated and the new geometry layer was exported in a raster format with a cell size of 0. 35m.Finally, the merging of the exported baythemetry data with Høydedata terrain model was done in Ras mapper (detail description is provided in Appendix A). Then, we set up a 2D hydraulic model (HEC-RAS 6 beta) using the combined raster (see Figure 1)as input. unstructured 2D computational mesh using 5 × 5 m (1.73million cells) was built. the underlying 0.35 × 0.35 m terrain was still the computational basis for all simulations of depth, velocity, and inundation. The model domain was comprised of the main Drammenselva River and four major tributaries: Hellfoss, Honselva, Vestfosselva and local field Mjøndalen bru. Further, six bridges; Hokksund bridge, Mjøndalen bridge, bridge on Rv283 at Stensetøya, Landfalløybrua, Øvre Sund bridge and Bybrua were included in the model. Boundary conditions were defined using the information of the hydrological modelling from NVE’s report. in addition, the model domain was extended further down in the Drammen Fjørd to avoid any problem in the boundary definition causing an impact on the results in the study area. The model stability with the 2D approach was significantly higher. Therefore, several sensitivity tests, including time-step, courant numbers, iteration number and theta weight tests, were undertaken in order to probe the model stability with satisfactory results.in the implementation of the model in 2D significant computational resources were used in order to limit this impact.

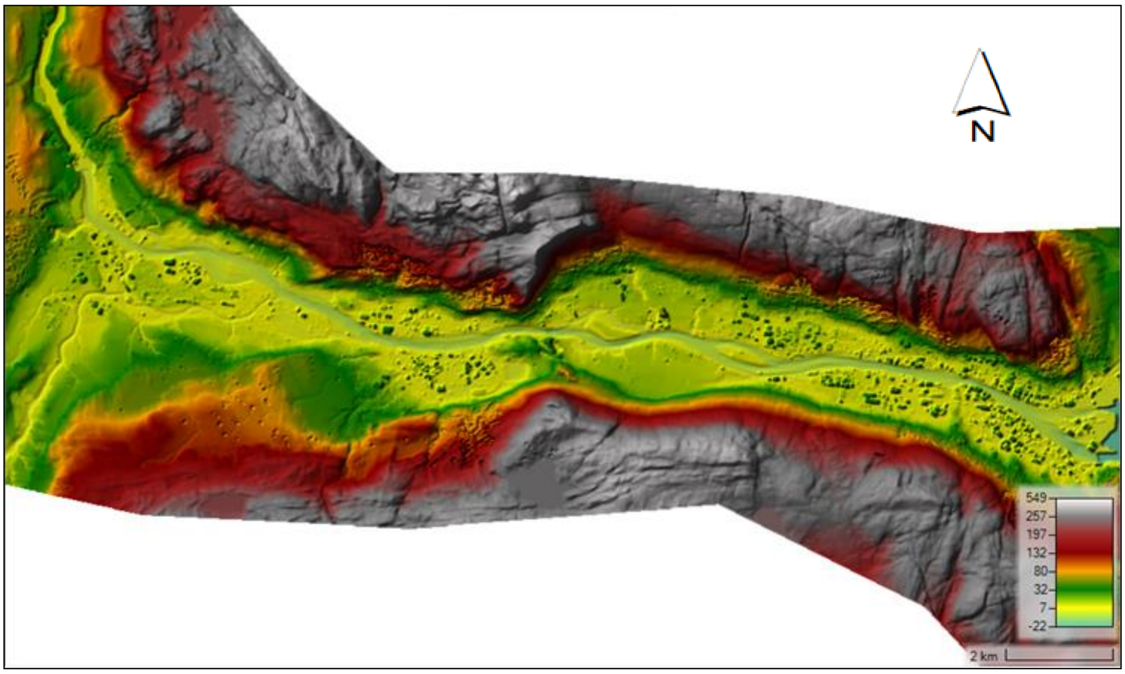


Figure 1 Terrain created by merging 1D geometry and red Lidar data

the bridges on the section between Hellefoss power plant and Drammen harbor are modeled in the 2D model. "Energy equation" method was used to simulate the bridge solution in hydraulics. This method is relatively easy to use and is well suited for the flow situation in the Drammenselva which is subcritical. Appendix B shows in detail how the Mjøndalen bridge is defined in the model. Finally, unsteady flow water surface computation was initiated at the upstream boundary using peak flow for different simulations.

The flood model was calibrated and validated using a 2007 and 2013 flood events respectively. By comparing observed and simulated water surface levels at multiple locations, the model parameters were adjusted. The roughness coefficient was adjusted to fit the simulation results with observations by applying a "trial and error" procedure. For different land use classes, a range of roughness coefficients were tested. built-up areas (0.020) and snaumark (0.027) was assigned to the lowest value of manning roughness coefficients. On the other hand, forests (0.150) and marsh areas (0.3) were assigned to the highest roughness value. the inundation modelling simulation time was 5 h, which accounted for the modelled 5- hours maximum waterflows of 2007 flood, and the output time step was 5 sec.

2.1.1 HEC-RAS Models

HEC-RAS version 6 beta 3, latest version hydraulic modeling software was used in this project, which was developed for the analysis of 1D steady flow and 1D and 2D unsteady flow by the USACE. The 1D model assumes all water flow in a longitudinal direction in terrain represented by a series of cross sections, where it simulates an average velocity and water depth at each cross section. On the contrary, the 2D model simulates the water flow both in longitudinal and lateral directions in terrain represented as a continuous surface of the finite mesh. The finite mesh allows continuous interaction between the main river and floodplain, which enables the 2D model to represent the velocity and water depth variation throughout its floodplain. therefore, the use of the 2D model becomes essential for the accurate estimation of flood depth grid. The 2D model can be expected to work well in the rivers with wide and flat floodplains, where the flow goes out into the overbank area. For a micro scale assessment like this, a highly accurate estimation of flood depth is critical. As a result, 2D approach was required in the model. The output of this model will be in the raster format in the depth grid, which can be imported into GIS for further analysis.

2.2 Flood damage

This impact assessment will consider direct and some indirect tangible damages at a micro-scale level, by using depth damage curves. Flood damage assessment requires the integration of the physical impact results (flood depth) with information on exposure and vulnerability or impact. Direct damage estimates were obtained by intersecting land use data with flood depth data by means of operations within a GIS and extract the exposed objects, then the exposed objects integrated with the corresponding depth-damage functions and unit cost in damage estimation model. This resulted the estimation of damage for each of the return periods considered (100, 200, 500, and 1000 years), which allows evaluating the change in flood damage between current and future climate for the respective return periods.in order to ease the calculation of the final flood damage estimation, an Excel-based toolbox has been used from NVE. This toolbox enables the user to increase the speed of the post processing of data and easing the simulation of several events. The following equation illustrates how the elements in the direct damage model are combined to estimate the total amount of physical damages in a flooded area:

$$D = \sum_{i}^{m} \sum_{r}^{n} \alpha_i \, (h_r) D_{max,i} n_{i,r} \tag{1}$$

$D_{max,i}$ maximum damage for land use category i;

i land use category;

r location in flooded area;

m number of damage categories;

n number of locations in flooded area;

$\alpha_i(h_r)$ stage-damage function for category i as a function of flood characteristics at a particular location r ($0 \leq \alpha_i(h_r) \leq 1$)

$n_{i,r}$ number of objects of damage category i at location r;

2.2.1 Flood cost estimation tool

The tool was developed on behalf of and in cooperation with the Landslide and Watercourse Department in NVE in 2015.The tool was originally cost benefit analysis tool which is built in Excel and uses macros. However, only the flood damage portion of the tool is extracted and used for this study purpose. The tool was made in accordance with the

Directorate for Financial Management's guidelines. Basic information for the tool can be found in the sheets «Municipalities» and «Fixed data». This is static information that should not be changed in daily use. The fixed data sheet is the core of the tool, it contains e.g., all default values, discount rate, expected GDP development and vulnerability factors. Default values are largely based on data from Statistics Norway and are adjusted on the basis of the construction cost index and the consumer price index.

direct and some indirect tangible costs are handled in the damage tool. Therefore, the total flood damage consists the damage of Buildings, agriculture area, infrastructures, and other costs. Other costs include: Fracture cost way, Cleanup and rental cost, and mobilization and other first-line costs.

Fracture cost way: Breakage costs for roads are based on detour costs when closing, based on an estimate of costs per extra km driven.

Clean-up and rental costs: These are costs related to cleaning up in the event of total damage and rental costs in renovation and construction period. No input is required. It is assumed that all homes where there has been water on the ground floor will need renovation or new construction.

Mobilization and other first-line costs: These are societal costs associated with handling the actual incident. Fixed estimate of 5% of material damage.

For this study, the damage of buildings, infrastructures, and other costs excluding fracture cost way (due to unavailability of data) were considered for the damage estimation of the study area.

There are different parameters in the tool that describe a time development. The parameters used in the flood cost estimation tool are Price indices and welfare development. An important point is that present value is used for flood cost estimation, and that future price increases are not taken into account.

Price indices: The tool largely operates with standard prices for replacement values, taken from Statistics Norway surveys and others, as a basis for the utility calculations. If these are fixed in the tool, as time goes on and the price increase becomes significant, the costs will increase while the utility values are fixed. To avoid this, Statistics Norway's construction cost index and consumer price index are used to raise the standard values in the tool. VSL is also adjusted, from 2012 to the current year according to the CPI. This therefore applies from the base year to the current year, not further into the future.

Welfare increase: The value of statistical life is largely based on society's willingness to pay. International surveys There is a clear connection between the level of welfare, expressed by gross national product per capita, and willingness to pay to save lives. In accordance with the Directorate for Financial Management's «Guide to socio-economic analyzes», VSL has therefore been adjusted upwards through the planning horizon in accordance with expected real growth in GDP per capita. In the Government's perspective report from 2013, this is estimated at 1.3% pa for the period 2012-2060. In practice, this comes as a reduction in the discount rate for VSL, so that the present value of life saved in the future falls less with time than material values. (the tool is included in Appendix C)

2.3 Study area and data

2.3.1 Study area

The study was conducted in Drammenselva river, which is located in Buskerud county, southeastern Norway (see Figure 2). DMS latitude longitude coordinates for Drammenselva are Latitude: 59° 43' 59.99" N and Longitude: 10° 13' 60.00" E. Drammenselva is one of the largest rivers in Norway, with a drainage basin of approximatly17,000 square kilometers and a discharge of 300 cubic meters per second. Drammen River is 308 kilometres long which make it, the fifth longest river in Norway. Its course runs 48 km from Tyrifjorden in the north to Drammensfjord in the south, where it crosses through the center of the city of Drammen. The Drammen River gathers inflow from several streams and rivers. The largest include the Simoa River.

The study area stretch starts from approx. 245 meters downstream of the Hellefoss power plant (Hokksund) to the outlet in the sea at Drammen harbor and covers Øvre Eiker, Nedre Eiker and Drammen municipalities.The model area extends over approx. 21 km.

The largest floods in the Drammenselva in recent times occurred during the first 30 years of the 20th century when there were still relatively few regulation reservoirs in the watercourse. Most of them were spring floods that occurred in May and June, some was autumn floods in September. The two largest floods, at the end of June 1927 and in mid-June 1926, had a daily average water flow of 2324 m, and 2197 m 3 /s respectively, which shows that the flood in 1927 is estimated at a 100-year flood, while the flood in 1926 had a recurrence interval of 50-100 years.

In recent years, there have been several floods in the watercourse, such as in 2007 when there was a flood with an interval of approximately 10-20 years. There was also a flood in September 2011 with just over a medium flood and in May 2013 with 5 to 10-year floods.

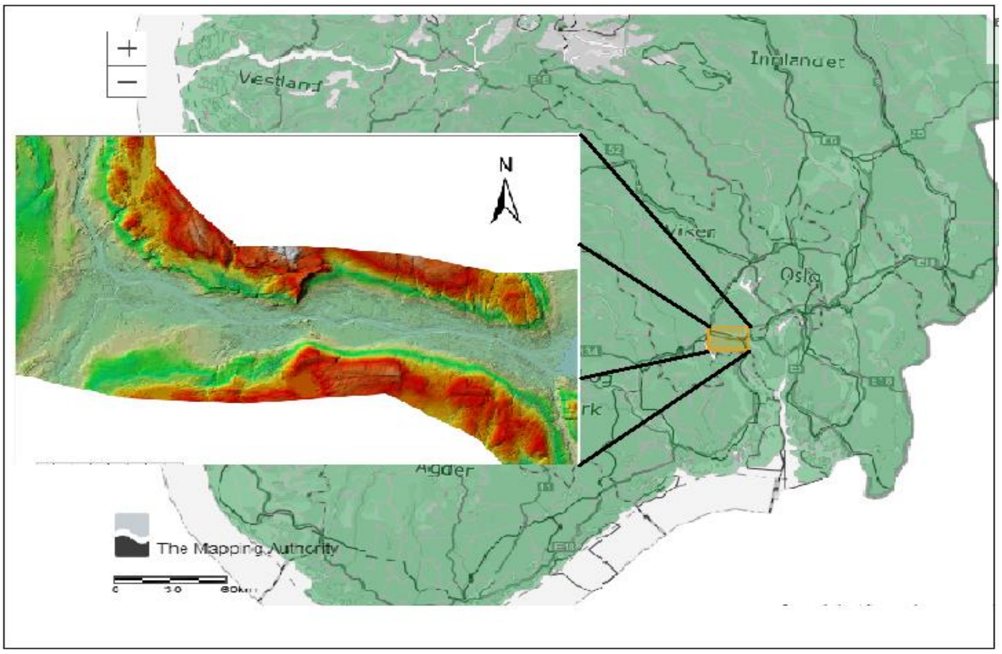


Figure 2 location of the study area Drammenselva

2.3.2 Data

In order to implement the methodology described in Sections 2.1 and 2.2 in the drammen case study, several datasets have been compiled and treated in order to obtain flood damage estimation. The following data was acquired for the implementation of the hydraulic model and damage estimation model in the drammenselva River Basin.

Flood hazard

The DEM represents land elevation data, which are essential for estimating the storage volume of surface flooding. As a result, the output quality is determined by the DEM quality. As the 1m*1m resolution elevation data from Høydedata was collected using red LiDAR, it does not contain the underwater depth information of the river channel. This means that the bathymetric data from the river had to be collected from a different source and merged with the Høydedata elevation model for the floodplains afterwards. For this reason, the river survey of the drammenselva was collected from NVE. from Hellefoss power plant to the port of Drammen, it consists 96 cross-sections in total. The data of cross section survey was received in mike11 format and it was analyzed and processed prior to the inclusion in the hydraulic model. The geometry of the bridges is taken from measurements made by NVE. light openings, height to the lower edge / upper edge of the bridges, pillars to the bridges and width to the bridges have been taken into account. all the properties used in the model for all bridges are provided in Appendix B. Bridge lower edge / upper edge defined horizontally in the model even if some of the bridges have a curved shape.

The detailed methodology of frequency analyses for different ARIs up to 1,000 years for current and future climate were performed earlier (Ejigu et al., 2017). Annual maximum flow values estimated for present and future climates (2100) using frequency analysis for selected ARIs were then used as flood mapping input data in the HEC-RAS model. For the tributaries / local fields, water flow during floods in the Drammenselva is provided. This is less than during floods in the individual local field. For the Extreme water levels at the sea, a 10-year storm surge is used for different repetition intervals as a lower limit condition according to NVE's report. observed sea water levels during 2007 flood at the port of Drammen have been used as the lower limit condition and calculated water flow for the main river and the major tributaries have been used as upper boundary to calibrate the model. The water levels by the flood from 06 July 2007 at 20:06 to 07 July 2007 at 00:22, which was registered at a number of places on the stretch between Hellefoss power plant to the port of Drammen, used in the calibration which corresponds to approx. 10-year flood. In addition, water level measurement made on 24.05.2013 at Mjøndalen bridge was used for the validation. Those all data has been provided from NVE.

Land-use information

Our methodology was based on two main land use elements, namely: buildings and infrastructure. Open-access land-use polygon layer was downloaded from Geonorge.no. A detailed land-use classification has been made using GIS.

Vulnerability factor (Depth damage curves)

Since there were no site-specific curves in the studied area, depth damage curves developed for NVE's cost benefit analysis tool were considered for this study. Such curves are used to obtain costs for a certain water depth relative to the extent flooded. These curves didn't consider flood velocities, however, since the velocity in study area is low, the buildings are less affected by this variable. These curves were created for different types of land-use using what-if analysis and using flood expertise acquired from past flood events. Taking into account the main land uses identified in Norway, 16 different categories of buildings and 7 categories of infrastructures have been defined in the tool. basements are also included in the land-use data sets. Therefore, such as the properties on the ground floor, the basement blocks will have a surface assigned to each land-use class. Consequently, it is related to depth damage curves that do not depend on the ground floor uses. negative depths are used to obtain the damage in the basement. In these approaches, the water fills the basement first, and then it reaches the ground level.

3 RESULTS

implementing the methodology and data presented in Section 2, results presented in the following sections are obtained. Before getting into the integrated risk analysis outputs in Section 3.3 it is worth exploring the Flood hazard model calibration and flood hazard map results, which are define as first-order results.

3.1 Model calibration and validation

Flood model often does not give a satisfactory result in the first run. As a result, flood model has to be calibrated for the desired results. Figure 3 shows the simulated water surface elevation and the water level of surveyed flooded areas. By comparing the simulated results with the survey flood, in general it can be said that the simulated results are close to the actual situation. For the Evaluation Criteria, the statistical indicator coefficient of determination (R^2) was utilized to ensure the agreement between the modeled and observed values (see the scatter plot in the right side in Figure 3). the validation result also shows that There is a good agreement between observed and simulated water levels, see also the last column to the right in Table 1. The agreement between the simulated and observed water levels by the flood in 2007 of the calculated result and existing data from NVE that was simulated using 1D steady flow analysis has been compared. Which is discussed in detail in Appendix D.

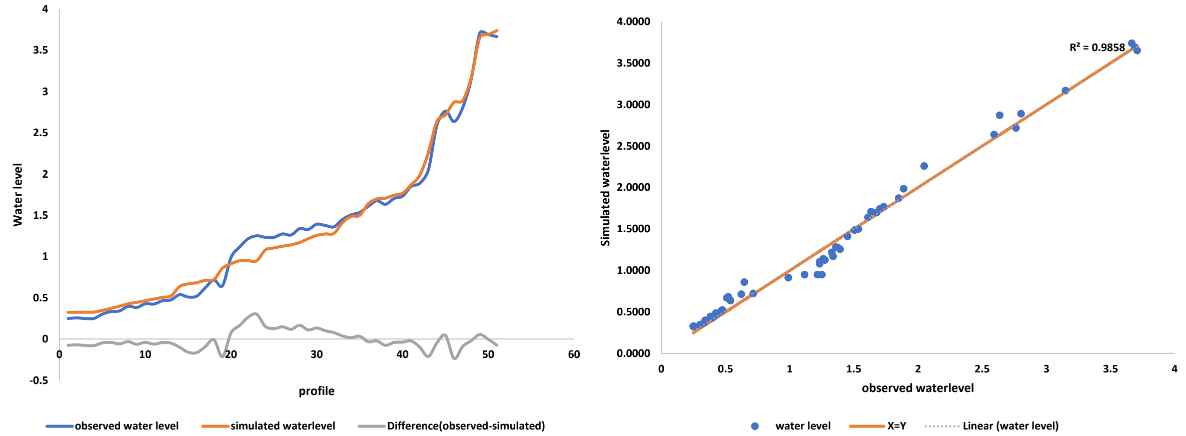


Figure 3 simulated and observed water levels in the Drammenselva by the flood in 2007

Table 1 Simulated and observed water levels for Drammenselva at measuring station Mjøndalen bridge 12,534

Date	observed waterflow at mjøndalen bru	observed water level at mjøndalen bru in NN2000(m)	Simulated waterlevel at mjøndalen bru in NN2000	Difference(obs.- simu.)
24.05.2013	1528.6 m3/s	time: 16:40=2.70m time: 16:50=2.71m	2.751	-0.046

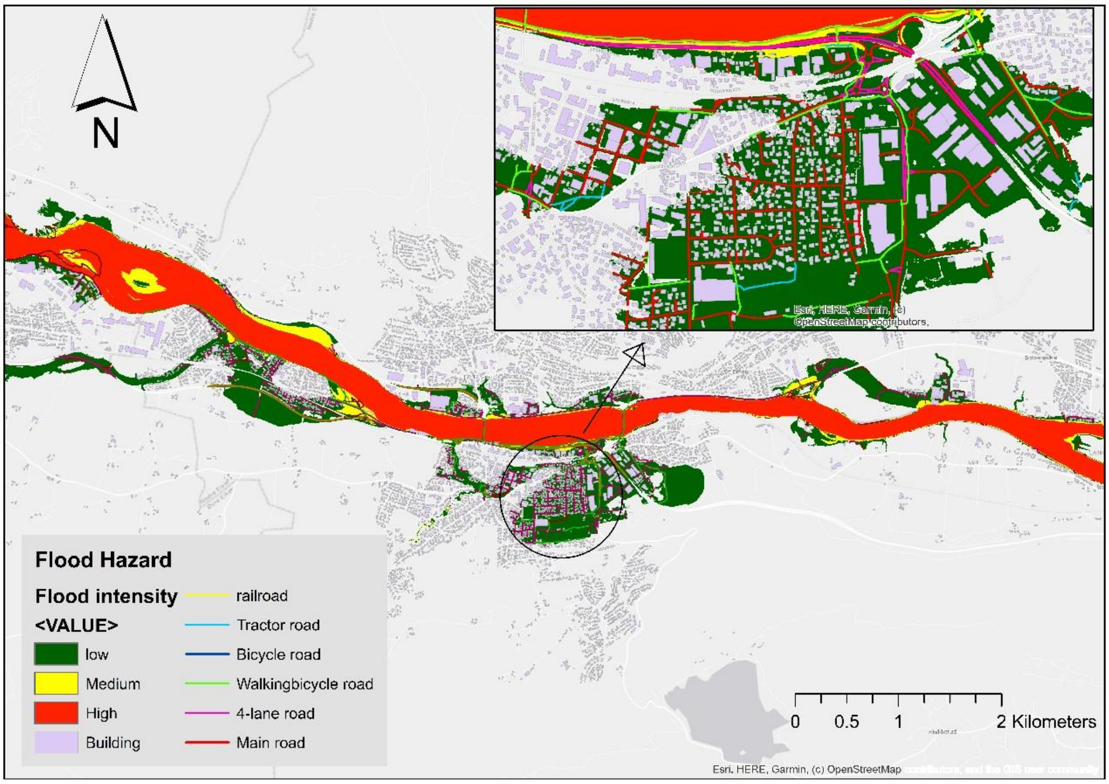
3.2 Flood Hazard Modelling

The flood modelling process described in Section 2.1 allows to obtain a broad set of primary hazard indicators, which alone gives a good insight to the potential magnitude of a flood event in the study area.in this section, it is focused on four hazard indicators: flood intensity, flood extent, velocity, and water depth.

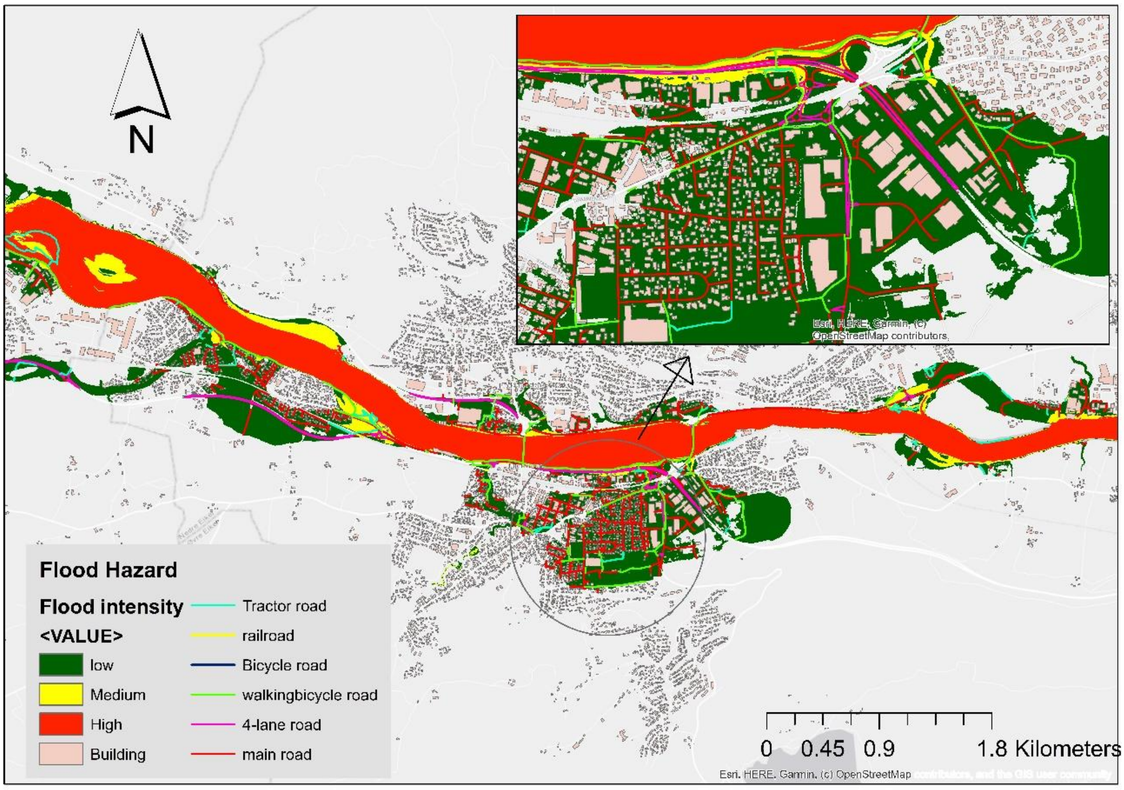
The raster of water depth (d) and flow velocity (v) for each flood scenario (Q100, Q200, Q500, Q1000) were used as input data for the computation of flood intensity (FI) using the equation 2.

$$FI = v * d \qquad (2)$$

The flood intensity for each scenario was used to define the flood hazard in the model area. The flood hazard is assumed to be higher if the flood intensity is higher. Hazard classifications were developed based on the works of (Beffa, 1998). the flood intensity is considered as FI>2 for high hazard, for 0.5 < FI ≤ 2 for medium hazard, and FI < 0.5 for low hazard. Flood hazard maps in Figure 4 show areas with their corresponding hazard categories and flooded buildings and infrastructures for both current and future 200year flood scenario.



(a)



(b)

Figure 4 Flood intensity in the model area for the flood scenario: a, Q200 for current climate b, Q200 for future climate

As for the flood extent, it was found that for the current and future climate 200-year scenario, the study area was significantly affected by the flood. As illustrated in Figure 5, 2399 and 2855 out of the 39000 buildings considered in this analysis are potentially affected by current and future climate 200year flood scenario respectively.

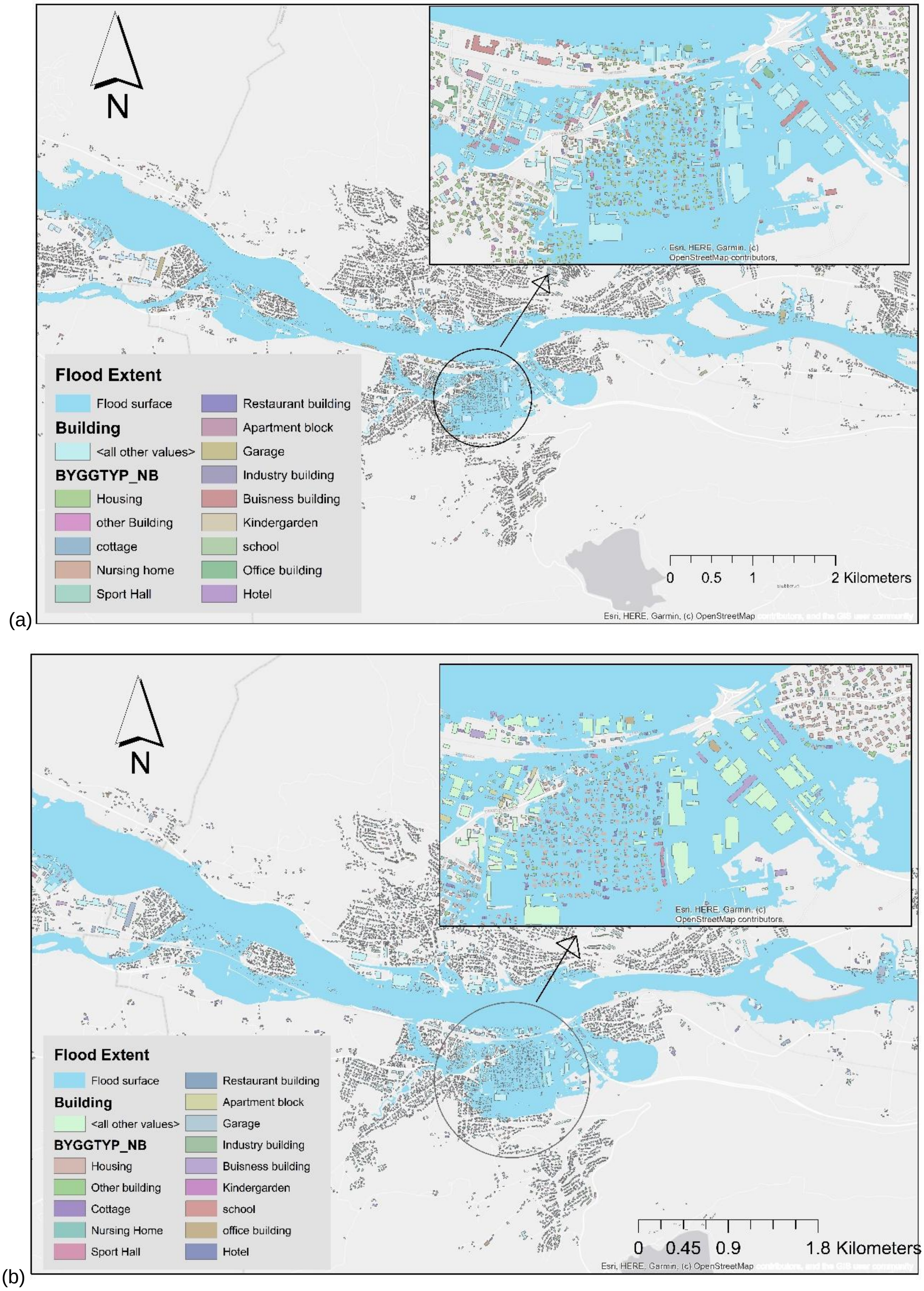
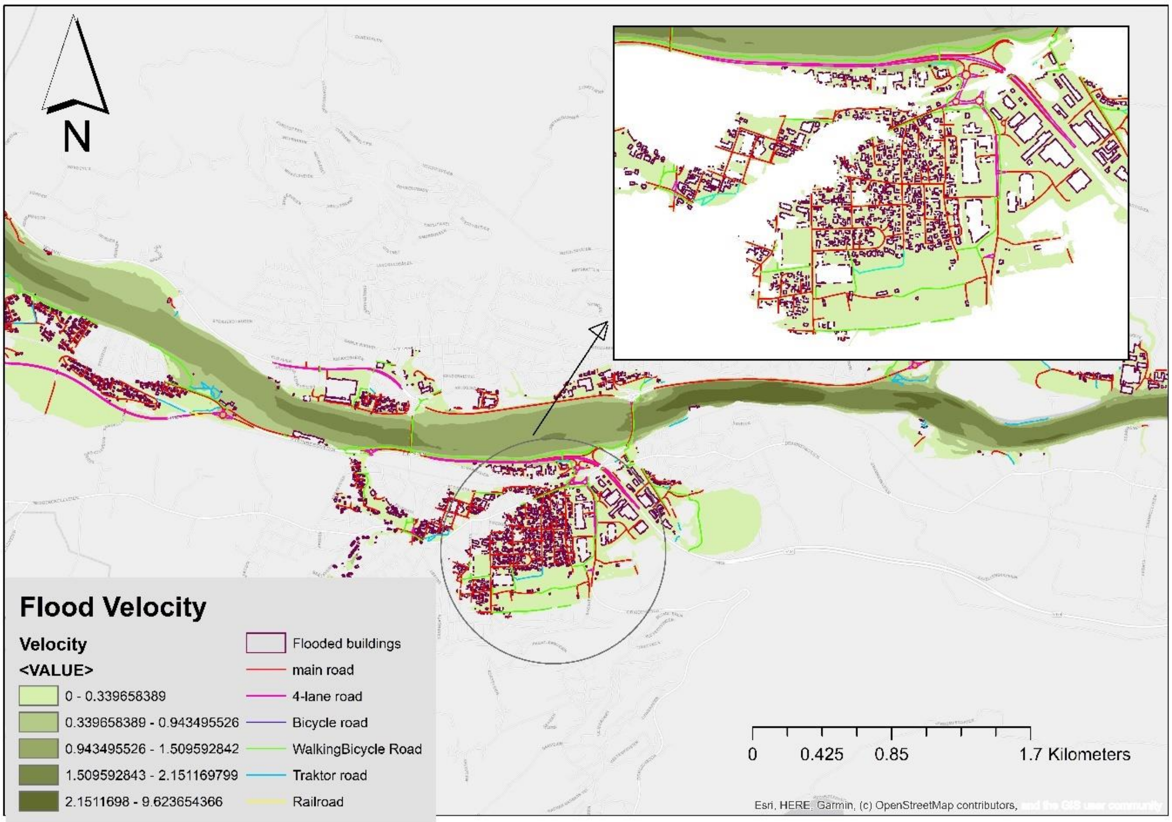


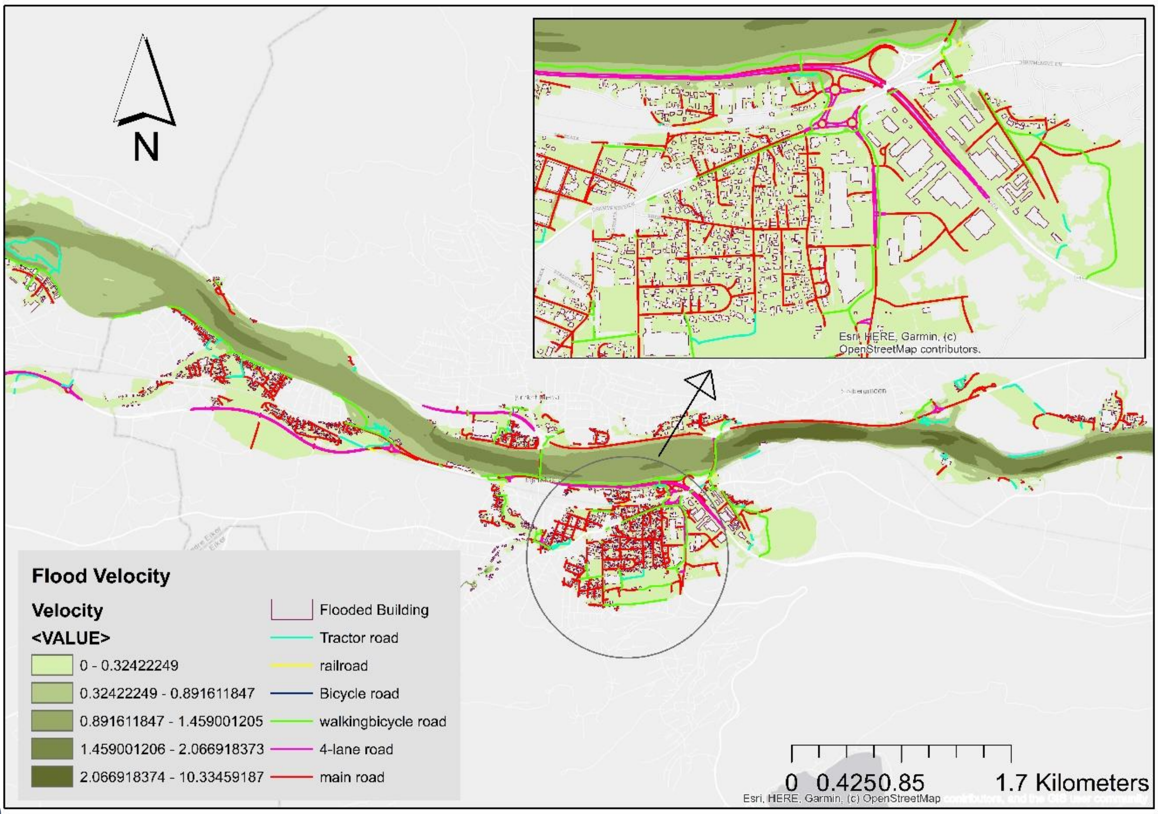
Figure 5 Flood inundation map of a, 200 year flood of current climate scenario b 200 year flood of future senario

In absolute numbers, about 68812.65 m^2 and 81348.32 m^2 of a total of about 6292039 m^2 of built-up area are affected by 200yr flood of the current climate scenario and future climate scenario, which corresponds to about 1.09% and 1.29% respectively.

Concerning the flood velocity, presented in Figure 6, it ranges between 0 m/s and 9.623 m/s for the current climate 200yr flood scenario and between 0 m/s and 10.33 m/s for the future climate flood scenario. The average velocity value at the surface of the 2399 buildings affected by the current climate flood is about 0.256m/s, with a standard deviation value (STD) of 0.0699, being that 25 of these 2399 building are exposed to surface velocities higher than 0.5 m/s. the mean velocity value at the surface of 2855 buildings affected by the future climate flood is 0.257 m/s with a standard deviation value (STD) of 0.13. 27 out of these 2855 buildings are exposed to the surface velocity higher than 0.5 m/s.



(a)



(b)

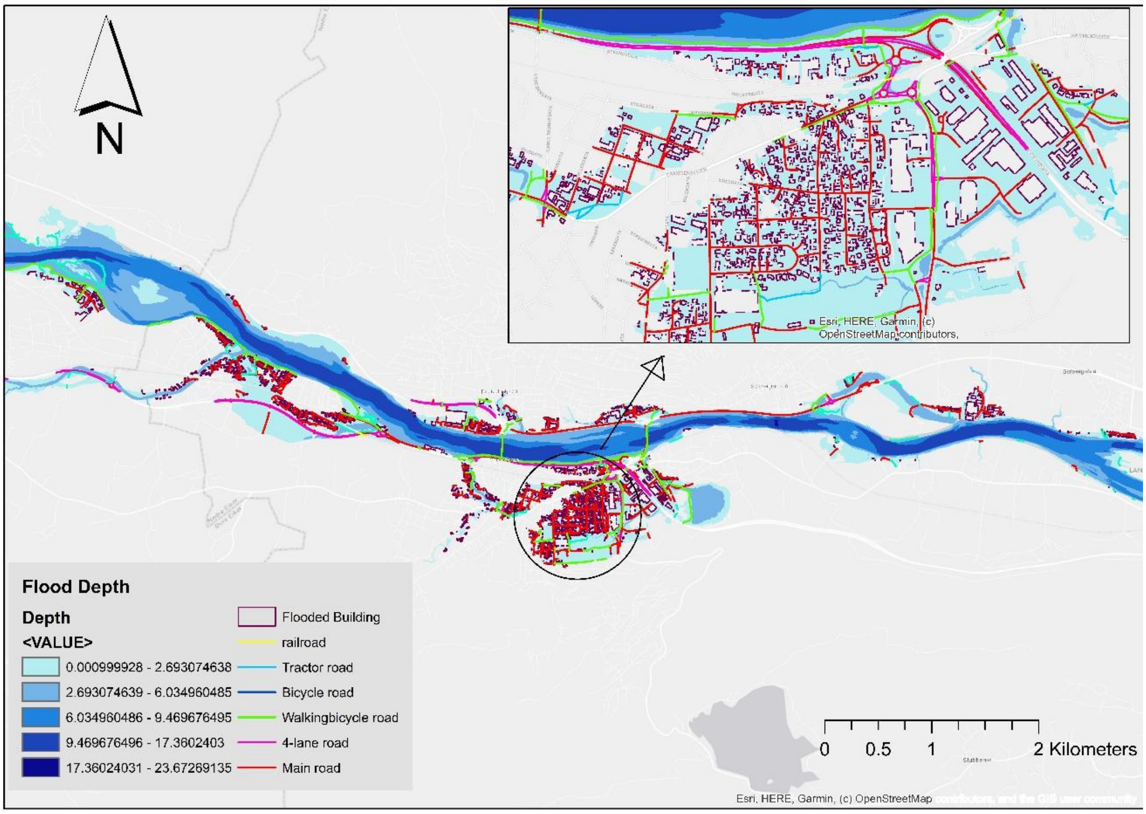
Figure 6 Flood velocities resulted from a, 200yr current climate flood scenario b, 200yr future climate flood scenario

As for the water depth, from the hazard analysis, it was found that for the considered current and future climate scenario of 200year flood, the buildings will expectably be exposed to an average depth of about 0.716m (STD = 1.226) in the current climate flood and 0.698m (STD= 1.10) for the future climate flood. As illustrated in Figure 7, 795 out of the 2399 buildings affected by a water height of more than 0.5 m in the current climate flood ,which is slightly more than 33% and about 1076 out of 2855 buildings affected by water depth more than 0.5 m in the future climate flood, which corresponds to 37.69%, which is a very significant value.

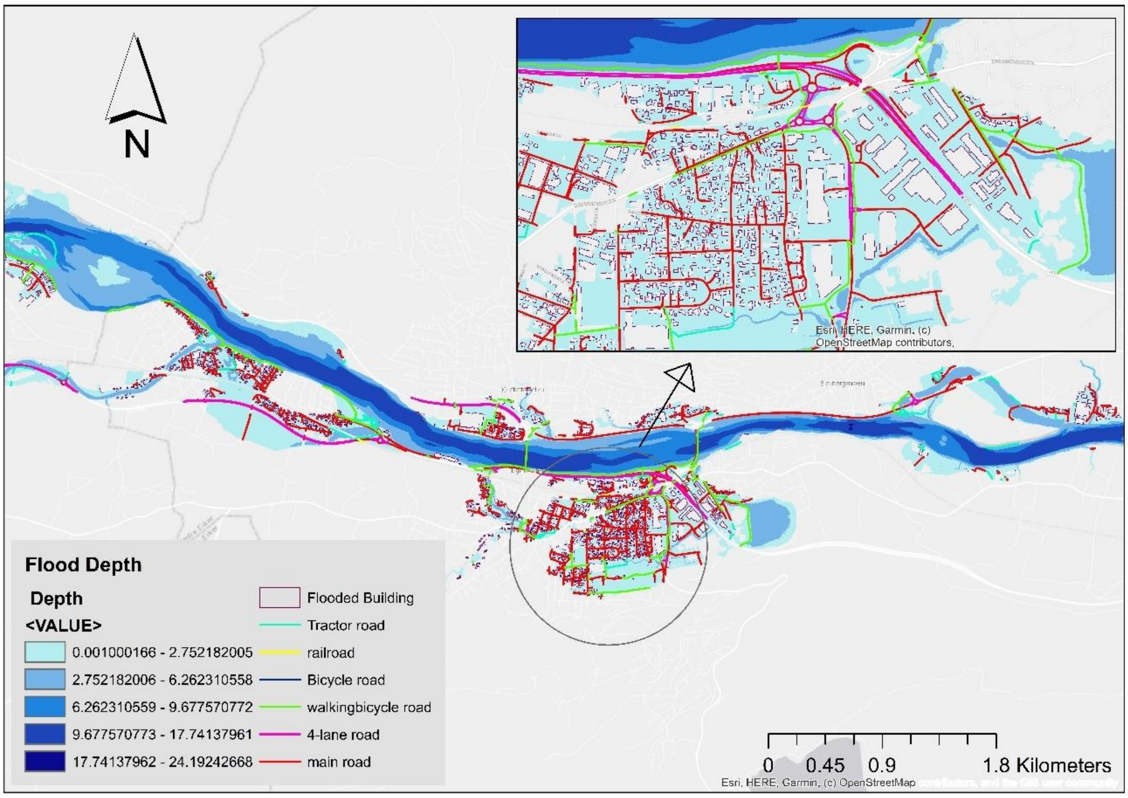
Table 2 summarizes the above-discussed results, presenting the absolute and relative number of potentially affected buildings for different ranges of flood velocity and water depth.

Table 2. Number of affected buildings distributed by ranges of flood velocity and water depth

	Hazard indicator	Range of Values					
		0-0.5	0.5-1	1-1.5	1.5-2	2.0-3	>3
Current Climate	Velocity(m/s)	2374(98.95%)	23(0.96%)	1(0.042%)	0(0%)	1(0.042%)	0(0%)
	Depth(m)	1604(66.86%)	463(19.30%)	162(6.75%)	50(2.08%)	18(0.08%)	102(4.25%)
Future Climate	Velocity(m/s)	2828(99.05%)	25(0.87%)	1(0.03%)	0(0%)	0(0%)	1(0.03%)
	Depth(m)	1779(62.31%)	636(22.28%)	267(9.35%)	55(1.93%)	28(0.98%)	90(3.15%)



(a)



(b)

Figure 7 Water depth resulted from a, 200yr current climate flood scenario b, 200yr future climate flood scenario

As it is presented in the above figures, it was found that about 85657.6 m and 110037.1m length of infrastructures were affected by the considered current and future climate of 200-year flood scenario. To conclude, the comparison between the current and future scenario in 2100 showed that the inundated areas, velocity, and depth increased, as presented in the flood hazard modelling section. Detailed flood hazard maps of different flood scenarios (Q100, Q500, and Q1000) and the affected number of buildings and length of infrastructures for each flood scenario is presented in Appendix F.

3.3 Flood damage

The estimation of expected flood damage over the area covered by the Digital Terrain Model extent was made possible by the development of flood depth maps under specific flood scenarios. For every flood scenario the inundation depth map is integrated with the land use map in ArcMap environment and by applying the damage estimation tool the total expected flood damage is computed in Mill.kr over the land-use categories for which depth damage functions were derived. The estimate of flood damage was determined as the product of damage factor, numbers of affected properties, and unit property values for the respective damage categories Table 3 gives the estimated break-down of damages under every flood scenario for the area under study. It is observed that the cost for flood damage of building (structural plus content) covers about 90 – 92 % of the total cost estimated over all land-use categories under each flood scenario. Furthermore, the damage cost of Table 3 verifies the fact that the smaller the exceedance probability gets, the higher the expected flood damage becomes. The results also show that the impacts of climate change increase the vulnerability of urban areas to flooding and economic damage, which will increase the total damage from floods by 20.26%.

Table 3 Estimates of flood damage cost for building and infrastructure for various ARIs

			Estimated flood damage (Mill.kr)				
	ARI(Years)	Probability	Building	Infrastructure	Cleanup and rent cost	Mobilization and other first-line costs	Total cost
Current climate	100	0.01	592.96	26.41	3.38	30.97	653.72
	200	0.005	715.68	27.86	3.59	37.18	784.31
	500	0.002	869.91	33.42	3.81	45.17	952.31
	1000	0.001	1032.56	37.25	4.09	53.49	1127.40
Future climate	200	0.005	860.75	35.00	2.71	44.79	943.24

Previous flood risk assessment studies found it is difficult to validate flood damage estimates due to the limited and incomplete historical damage data. This study also faced the same challenge. Flood damage estimation was undertaken for buildings and infrastructures. However, verification of the results with actual surveyed data couldn't be due to non-availability of surveyed data.

4 DISCUSSION

Flood cost estimation is a combination of flood hazard, Vulnerability, and exposure. this study shows that damage of flood is mostly affected by hazard component. i.e., flood depth. As for the building damage, the area of housing properties is larger than the other building categories considered. Thus generates a higher number of flood affected properties in each flood scenario.as a result, the total estimated damage (structural plus content) of housing is higher than other building categories. As for 1000 ARI current climate flood scenario, the total estimated damage for housing is approximately 360.58 mill.kr, which is higher than other building categories. The second highly affected Building category is industrial building which estimated approximately 225.75 mill.kr. Moreover, it is observed that the cost for flood damage of building (structural plus content) covers about 90 – 92 % of the total cost estimated over all land-use categories under each flood scenarios.

The effects of varying ARI to flood damage in Table 3 Verifies the fact that as the return period used to estimate that risk increases the flood damage will also increases but as the value of probability increases, the total damage reduces. Moreover, it is noted that at 1000-year current climate flood scenario, the total damage is 1127.40 mill.kr, about 47.74% higher than the damage for 200year flood (784.31 mill.kr) and is approximately 18.38% higher compared to risk at 500-year flood (952.31 mill.kr). this result corroborates the findings of (Oliveri & Santoro, 2000; Velasco et al., 2016; Ward et al., 2011),who found similar trends in their probability–damage relationships, with low probability events contributing to large damage values.

The findings reveal that the impact of climate change on flood risk increases the vulnerability of urban areas to flooding and economic damage. The findings also show that the effects of climate change will raise the total damage from floods by 20.26%. This result is in agreement with findings of (Arnell & Gosling, 2016), who used climate models and socio-economic data to evaluate the future scenario of flood risk.

General limitations

With regard to the results and methods used possible sources of uncertainty and improvements should be considered and discussed. When applying the framework outlined in the methodology section for micro-scale flood damage assessment, it was necessary to adopt the following assumptions, which should be kept in mind when interpreting the results:

- The approach is based on direct and some indirect flood damage caused by different water depths on different land use typologies. Other factors that could lead to an increase in losses, such as flood velocity, building characteristics, sediment content in water, and some indirect economic losses, are not considered in this study.
- Due to the absence of reasonable micro-scale land use change data for the future climate, changes in land use and land cover are not integrated in the economic impact evaluation. hence, only reflect the influence of climate change on flood risk; this may lead to an underestimating of future flood risk.

- It is normally assumed that a damaged object will have the same quality level after a repair as it had before the flood occurred. For some objects, such as buildings, it may happen that the repair leads to an increase in value in relation to the previous condition, due to the fact that the price is independent of the building's condition before the flood occurred. Although this is contrary to the prevailing perception of what damage is, it has not been possible within the framework of this study to exclude compensation that increases the value.
- As for damage estimation applied, all the buildings affected by the flood have a basement, which all of the building categories made from metal and concrete except housing (made of timber) and the assumptions made for the infrastructure data includes that 50% of private roads are made from gravel and 50% made from asphalt, the other road categories like municipality, county and highway roads made from100% of asphalt. those all assumptions may lead to the uncertainty of the estimated flood damage.
- Flood damage may be overestimated if a non-site-specific damage curve is used. These elements should be prioritized in future flood damage works.

5 CONCLUSIONS

In this study, an attempt was made using GIS, hydraulic modeling, and Excel-based damage model to improve the assessment of flood hazard and flood damage cost at local spatial scale. Using geographical information as the fundamental binding element, the modeling approach described in this study allows for the integration of various types of flood risk and flood damage related data.

The flood hazard was calculated using the HEC-RAS 1D- 2D hydraulic model for present and future climatic scenarios, with flood extent, flood intensity, depth, and velocity as outputs. Such outputs, derived from unsteady flow analysis.

In a GIS environment, various data sources related to topography, land use, flood hazard parameters, and other objects were overlaid and analyzed. Finally, The GIS outputs combined with economic parameters (unit cost and stage damage function) based on flood damage model, which provides the expected damage for specified flood scenario.

To conclude, the findings of the study can be useful to help identify and map flood-prone areas at local and regional scales, allowing for the early detection and prioritizing of exposed areas in need of adequate countermeasures. Furthermore, quantifying flood damage can be a useful indicator for raising local decision-makers awareness of the importance of improving efficiency of regional flood risk reduction strategies.

from a methodological standpoint, the use of the research may be seen in the universality of the proposed methods to assess flood hazard and flood risk, which could be applied to other similar flood-prone locations at the local spatial scale. However, more case studies in different regions should be conducted to ensure their general applicability.

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APPENDICES

APPENDIX A: INCLUDING CHANNEL BATHYMETRY IN TO TERRAIN

HEC has provided a way to easily incorporate our cross-section data into the terrain for a single comprehensive terrain model that includes bathymetry. The steps are

- In RAS Mapper, first the geographic projection is selected (Tools…Set Projection for Project…). Then the features of Bank stations were edited manually in the standard geometry editor. then XS (cross section) Interpolation has been done.
  RAS has already created a conceptual interpolated surface from those cross sections. Each pair of cross sections is linearly interpolated. This is very similar to the cross-section interpolation routines in the tool's menu item of the geometry window. Only here, instead of adding interpolated cross sections, we're developing a continuous surface that can be made into a terrain. RAS does all of this for you, all you have to do is enter cross sections into your geometry and check the box that says XS Interpolation Surface.
- From the data file tree on the left, by using right-click button on the name of the geometry the geometry layer was Exported in the Geotiff format for channel only. to create the terrain from XS's,0.35m raster size was used.
- Once we have added the new channel, a new terrain can be created that combines both the original LiDAR-based terrain with the new channel terrain by adding both two files: the original terrain and the new channel terrain. The channel terrain has given a highest priority by moving it to the top of the list using the arrow button on the left. This will ensure that wherever the two terrains overlap, the channel terrain will be used in creating the new single comprehensive terrain. After clicking the Create button, a new terrain is created that combines both the channel bathymetric data (interpolated by cross sections) and the original LiDAR-based terrain.

APPENDIX B: BRIDGE MODELING AND INPUT DATA FOR THE MODELING IN 2D AREA

To model a bridge inside of a 2D Flow Area, the SA/2D Area Conn geometry drawing tool is used. The basic steps followed to add a bridge in to a 2D model are the following:

- First, the centerline of the bridge opening has drawn from left to right looking downstream using the SA/2D Area Conn drawing tool in the Geometric Data editor. then an appropriate mesh (cell size and orientation) with cell size of 3m has included for the bridge, using the structure mesh controls.
- The bridge data has entered (deck and roadway; distance from upstream bridge deck to outside cross section's piers; abutments; bridge modeling approach; Manning's n values for the 1D bridge cross sections; and hydraulic tables controls (HTAB) into the SA/2D Area Conn editor. The bridge data's taken from NVE is presented as follows.

Table 1 Properties of the bridges.

Bridge name	Bridge width	Bridge upper edge /railing	Bridge bottom edge /railing (m)	Bridge distance	Bridge light ipening (m)
Hokksund bridge-RV35	12	8.7	6.4	0.5	186
Mjøndalen bridge	4	7.7	6.5	34.144	219
RV283 bridge at Stensetøya	12	7.3	4.6	23.89	265
Landfalløy bridge	11	4	2.7	36.5	149
Upper sound bridge	23	6.4	4.7	13	148
Bybrua	16	5.3	2.2	18.5	252

- Finally, Pre-process the geometry to create the bridge curves.

The figure below shows how the Mjøndalen bridge is defined in the model.

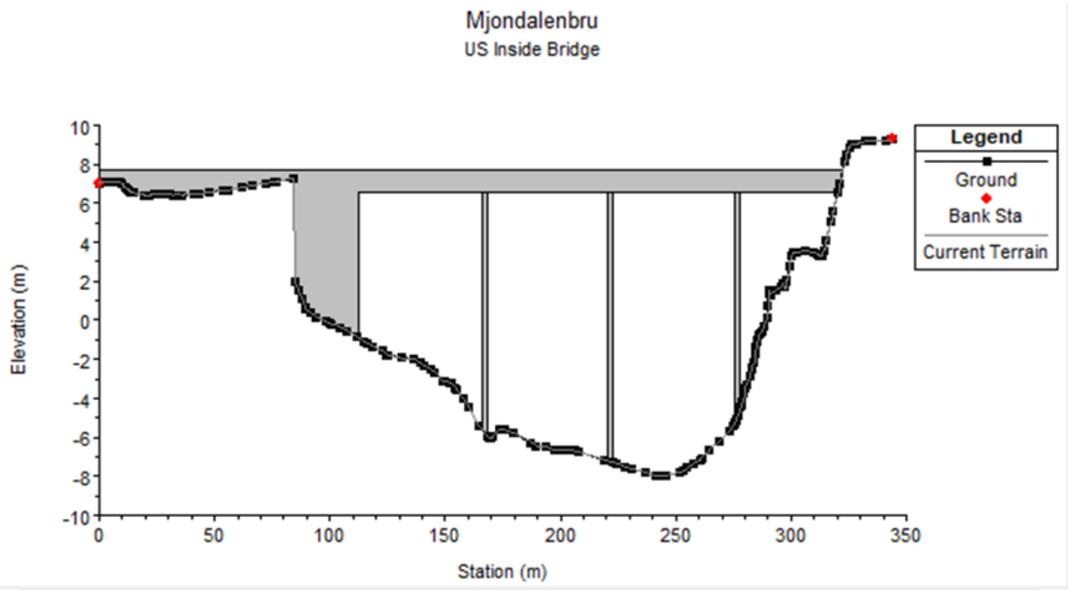


Figure 1 definition of Mjøndalen bridge in the model

APPENDIX C: FLOOD DAMAGE TOOLBOX

Provided as excel sheet.

APPENDIX D: COMPARISON OF CALIBRATION RESULT WITH EXISTING DATA FROM NVE

The agreement between the simulated and observed water levels by the flood in 2007 of the calculated result and existing data from NVE that was simulated using 1D steady flow analysis has been compared. From Figure 2 The agreement between the simulated and observed water levels can be said to be nearly identical with existing data, it has even better agreement with the actual situation than the existing NVE's data in profiles 34-45,50 and 51.

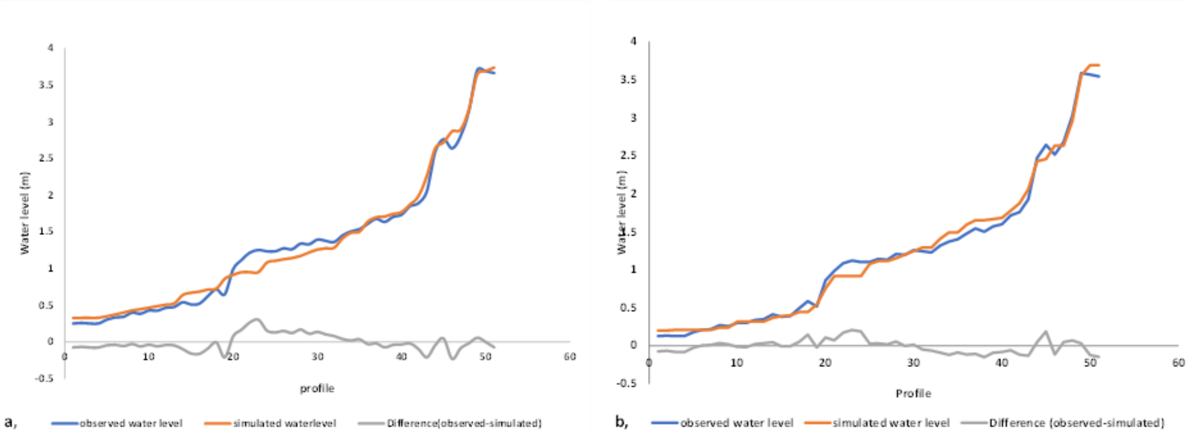


Figure 2 a simulated and observed water levels by the flood in 2007 b, existing data from NVE of simulated and observed water levels by the flood in 2007.

Table 2 2007 flood calibrated simulated result

FID	7/6/2007 20:00	7/6/2007 21:00	7/6/2007 22:00	7/6/2007 23:00	7/7/2007 0:00
1	0.3063238	0.3444487	0.4277042	0.5642581	0.6443691
2	0.3070065	0.3451485	0.4284381	0.5650671	0.6451896
3	0.3074464	0.3456017	0.4289212	0.5656123	0.6457501
4	0.3089285	0.3471165	0.4305067	0.567352	0.6475078
5	0.3298026	0.3668923	0.4479218	0.5820723	0.6605052
6	0.3556577	0.390446	0.4674425	0.5971727	0.6731998
7	0.3825464	0.4160529	0.4906178	0.6180223	0.6924412
8	0.4114946	0.444517	0.5179273	0.6441291	0.7169901
9	0.4291503	0.4617904	0.5344113	0.6599983	0.732048
10	0.4498206	0.4818265	0.5532358	0.6777348	0.7487692
11	0.470209	0.5015988	0.5717982	0.6952344	0.7652499
12	0.4907772	0.5215653	0.5906029	0.7130382	0.7820728
13	0.5090699	0.5393241	0.6072803	0.7287804	0.7969321
14	0.6235508	0.6514238	0.7135902	0.8306287	0.8945234
15	0.6558548	0.682906	0.7434576	0.8592097	0.9217058
16	0.6710411	0.6977266	0.7575727	0.8727898	0.9346637
17	0.7002518	0.7262772	0.7848539	0.8991662	0.9599078
18	0.7108464	0.7366548	0.7947192	0.908656	0.968954
19	0.8487598	0.870918	0.9222017	1.030468	1.0845145
20	0.9030867	0.9237118	0.9719059	1.0768853	1.1282675
21	0.9407591	0.9600925	1.0059808	1.109992	1.1611209
22	0.9407591	0.9600927	1.0059881	1.1103797	1.1623018
23	0.9407591	0.9600927	1.0059881	1.1103797	1.1623018
24	1.0724812	1.0880868	1.1261282	1.2193644	1.261969
25	1.0975935	1.112596	1.149568	1.2415044	1.28306
26	1.1186316	1.1332237	1.169251	1.2603611	1.3010969
27	1.1352382	1.1494848	1.1848218	1.2753255	1.3154285
28	1.1640533	1.1776233	1.2116127	1.3008425	1.3397716
29	1.2113378	1.2239608	1.2564665	1.3446651	1.3820328

30	1.2516644	1.2638413	1.2948889	1.3821955	1.4182147
31	1.2693614	1.2812127	1.3116287	1.3983694	1.4338088
32	1.2761146	1.2878582	1.3180897	1.4049361	1.4403007
33	1.3036515	1.3148724	1.3440419	1.4298106	1.464082
34	1.3853476	1.3950815	1.4213033	1.504674	1.5361743
35	1.3994404	1.4089751	1.4348544	1.5183408	1.5494931
36	1.5554318	1.5620028	1.5817469	1.6582119	1.6836303
37	1.6187887	1.6242659	1.6417608	1.715793	1.7390593
38	1.6296672	1.6349618	1.6520807	1.7257061	1.748612
39	1.6689553	1.6735779	1.6893212	1.7612063	1.7827436
40	1.6961432	1.7003208	1.7151057	1.7859215	1.8065726
41	1.8077216	1.8101609	1.8214134	1.8887832	1.9060277
42	1.4825195	1.4798127	1.8640649	2.0408354	2.0535424
43	2.2217247	2.2186849	2.2188709	2.2765024	2.282892
44	2.6228018	2.6154873	2.606931	2.6562266	2.6537874
45	2.707583	2.6993179	2.6888371	2.7365978	2.7321908
46	2.8662314	2.8566725	2.8433888	2.888191	2.8808732
47	2.8879468	2.8781693	2.8644464	2.9090264	2.9013026
48	3.1760855	3.1638021	3.1451001	3.1860943	3.1747279
49	3.671627	3.6570594	3.633075	3.6656539	3.6572294
50	3.7114606	3.6966863	3.6721611	3.704366	3.6995485
51	3.7591667	3.744205	3.7192569	3.7508104	3.750145

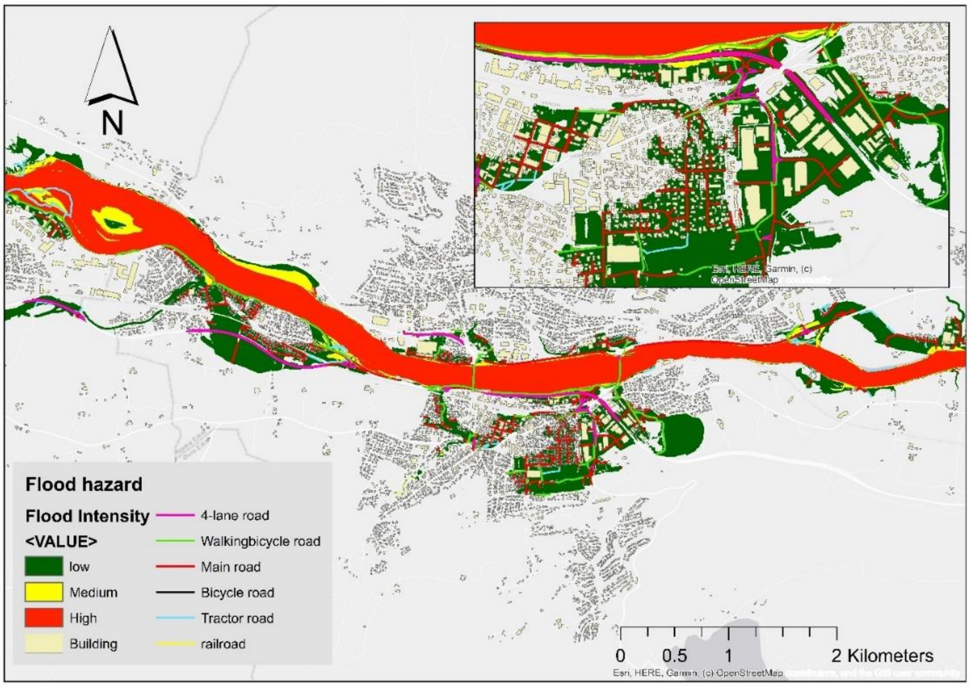
FID	**observed water level**	**simulated water level**	**Difference (observed-simulated)**
1	0.25	0.3254	-0.0754
2	0.257	0.3261	-0.0691
3	0.25	0.3265	-0.0765
4	0.25	0.3280	-0.0780
5	0.303	0.3483	-0.0453
6	0.334	0.3731	-0.0391
7	0.342	0.3993	-0.0573
8	0.398	0.4280	-0.0300
9	0.383	0.4455	-0.0625
10	0.428	0.4658	-0.0378
11	0.425	0.4859	-0.0609
12	0.465	0.5062	-0.0412
13	0.476	0.5242	-0.0482
14	0.539	0.6375	-0.0985
15	0.51	0.6694	-0.1594
16	0.521	0.6844	-0.1634
17	0.623	0.7133	-0.0903
18	0.717	0.7238	-0.0068
19	0.647	0.8598	-0.2128
20	0.99	0.9134	0.0766
21	1.116	0.9504	0.1656
22	1.217	0.9504	0.2666
23	1.252	0.9504	0.3016
24	1.234	1.0803	0.1537
25	1.234	1.1051	0.1289

26	1.275	1.1259	0.1491
27	1.262	1.1424	0.1196
28	1.339	1.1708	0.1682
29	1.329	1.2176	0.1114
30	1.393	1.2578	0.1352
31	1.377	1.2753	0.1017
32	1.361	1.2820	0.0790
33	1.451	1.4126	0.0384
34	1.506	1.4874	0.0186
35	1.536	1.5009	0.0351
36	1.61	1.6412	-0.0312
37	1.677	1.6989	-0.0219
38	1.634	1.7088	-0.0748
39	1.704	1.7444	-0.0404
40	1.733	1.7692	-0.0362
41	1.85	1.8721	-0.0221
42	1.889	1.9861	-0.0971
43	2.049	2.2594	-0.2104
44	2.593	2.6390	-0.0460
45	2.764	2.7192	0.0448
46	2.637	2.8708	-0.2338
47	2.803	2.8916	-0.0886
48	3.15	3.1686	-0.0186
49	3.708	3.6520	0.0560
50	3.69	3.6920	-0.0020
51	3.666	3.7401	-0.0741

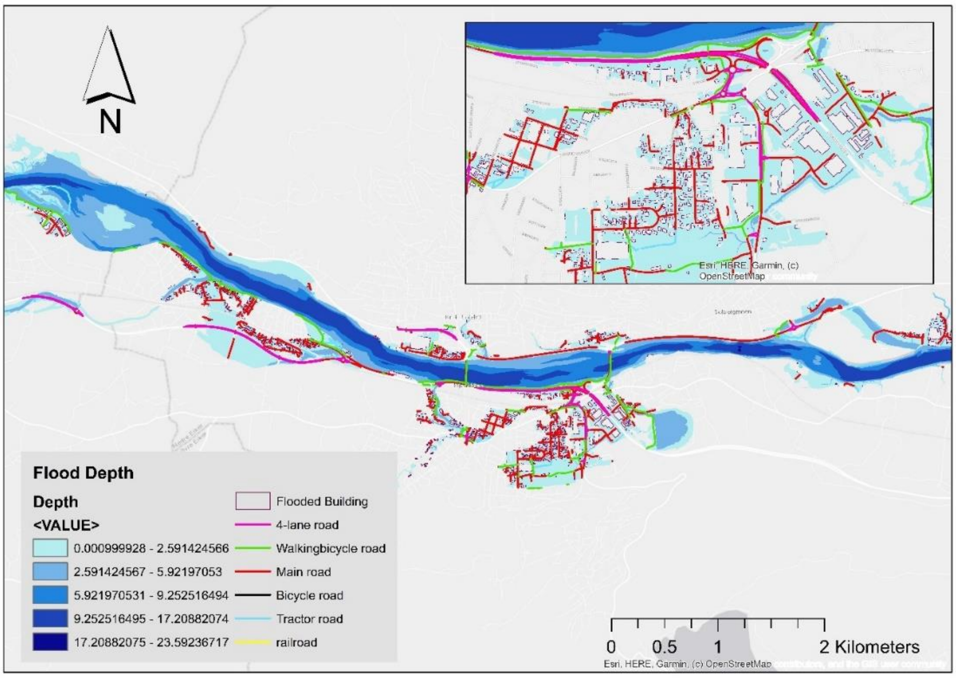
APPENDIX F: FLOOD HAZARD MAPS FOR REPITITION INTERVALS

100 year

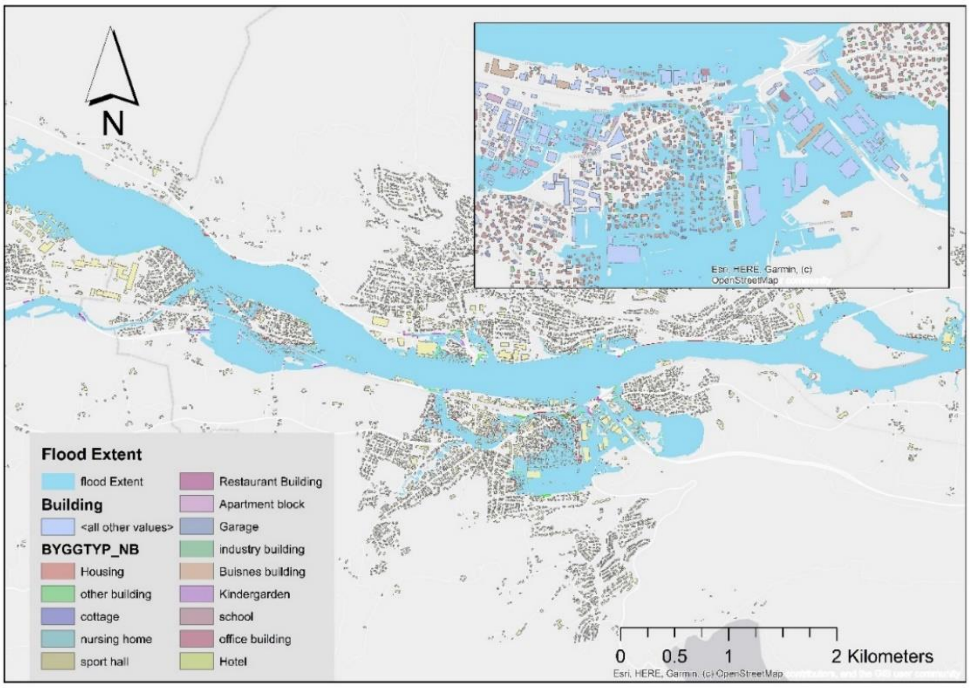
Flood intensity



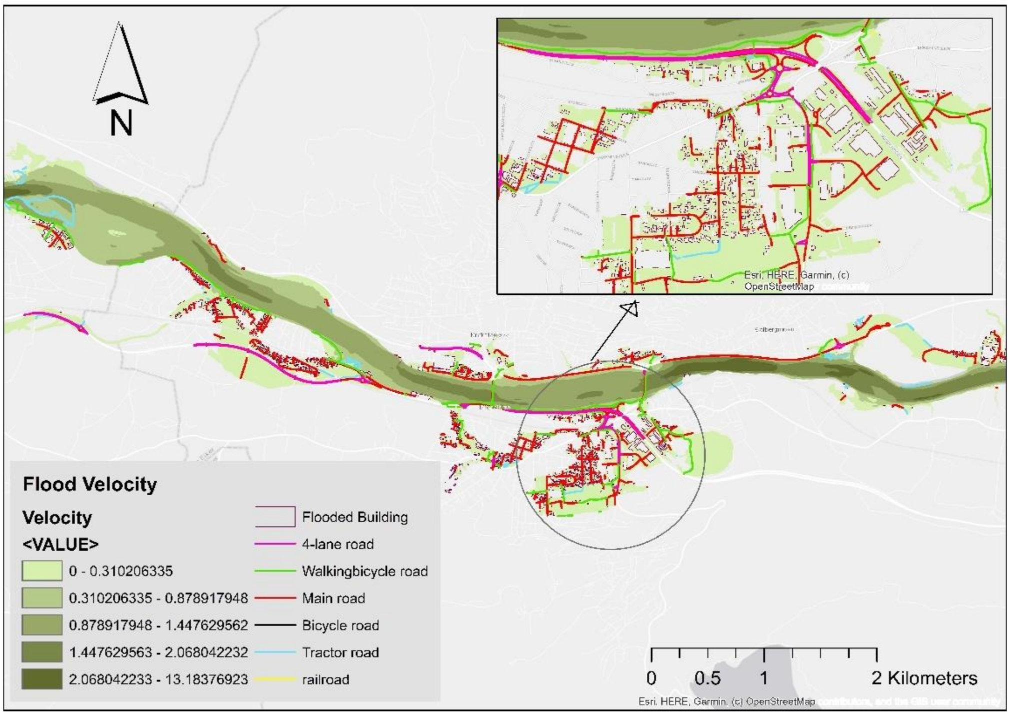
Flood depth



Flood Extent

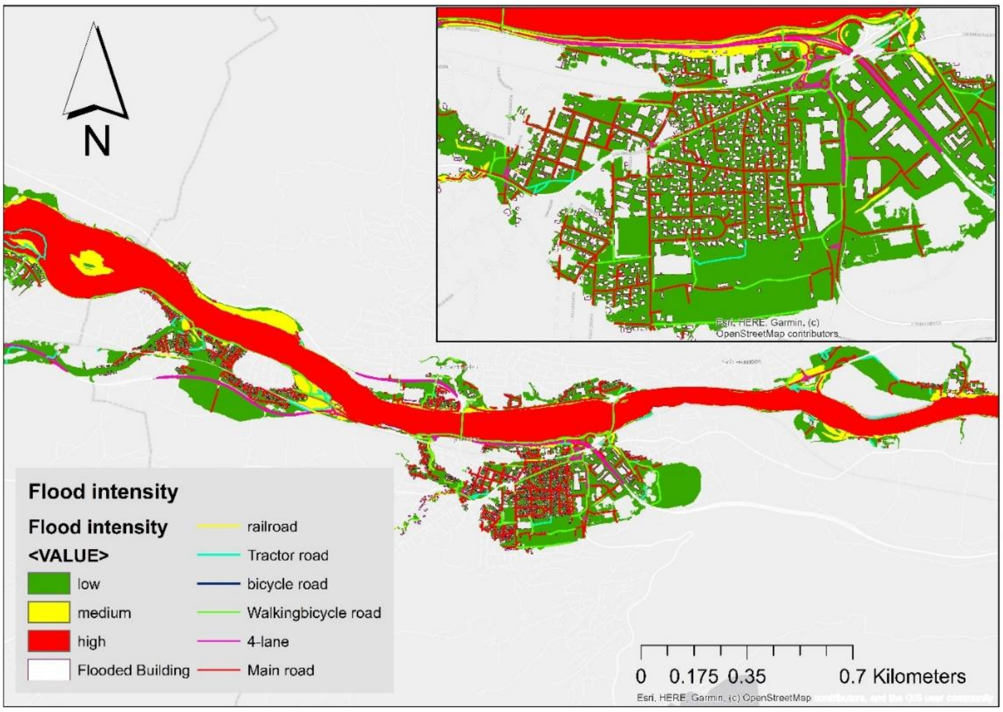


Flood velocity

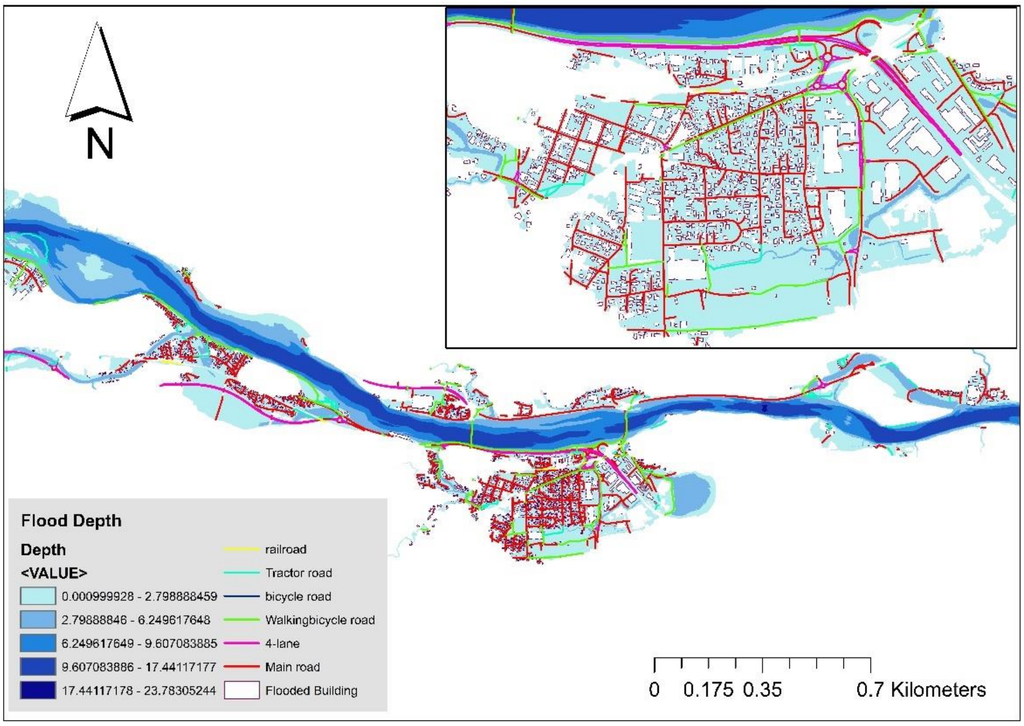


500 year

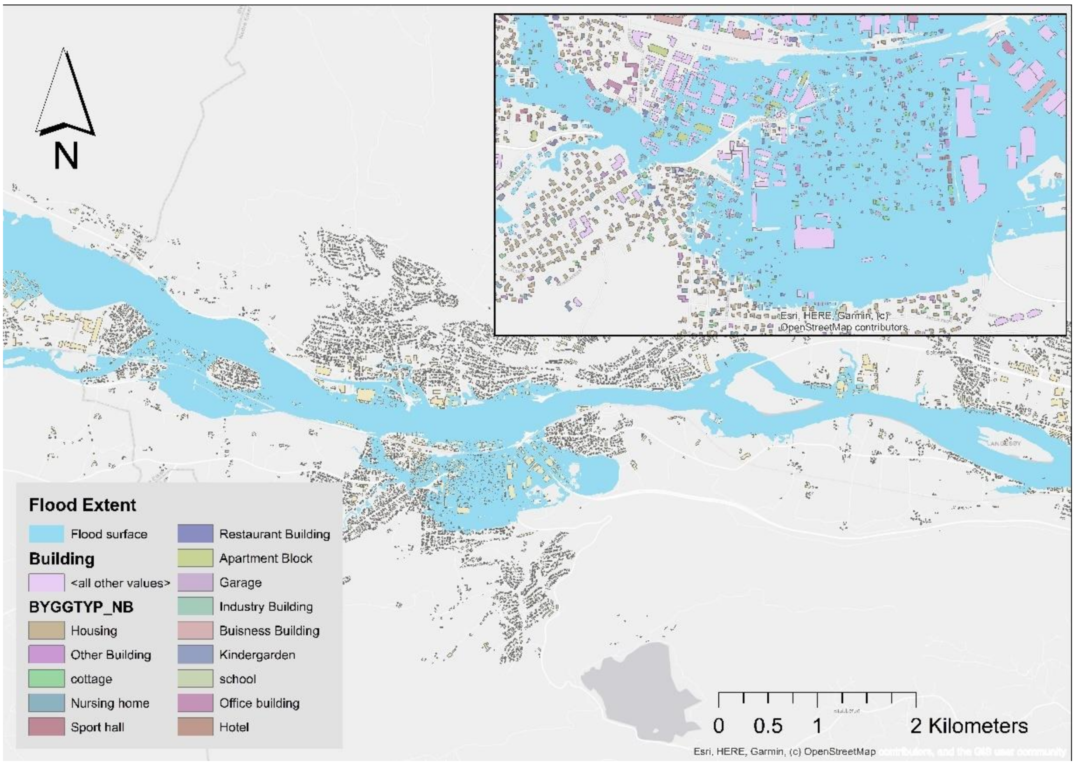
Flood intensity



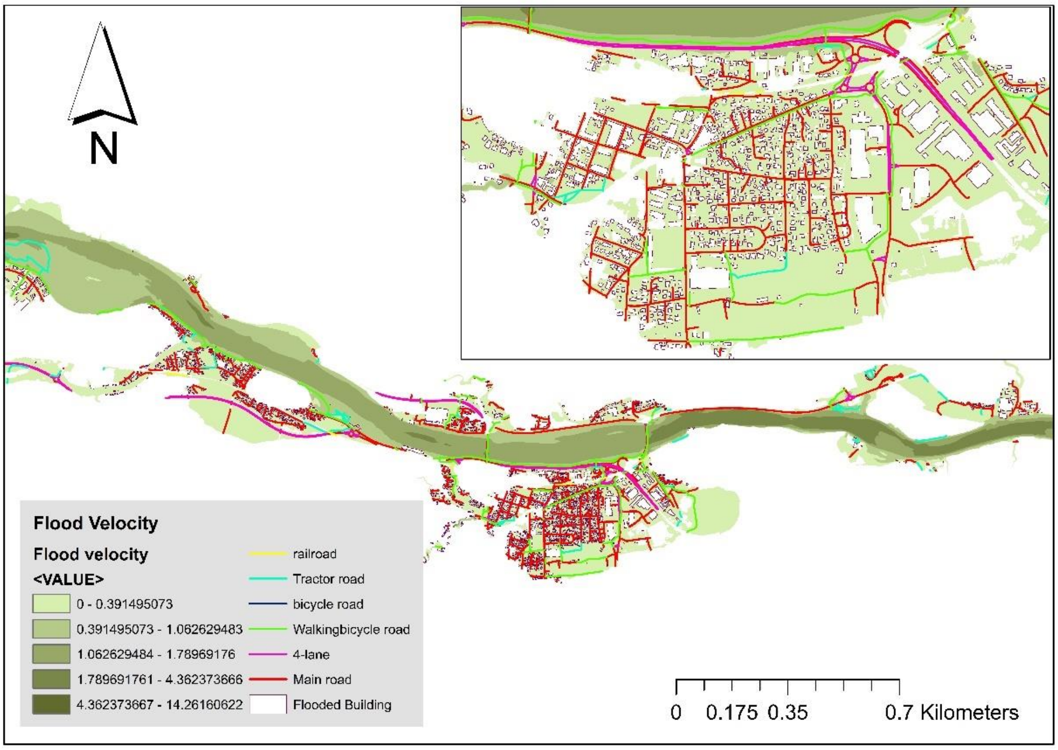
Flood depth



Flood Extent

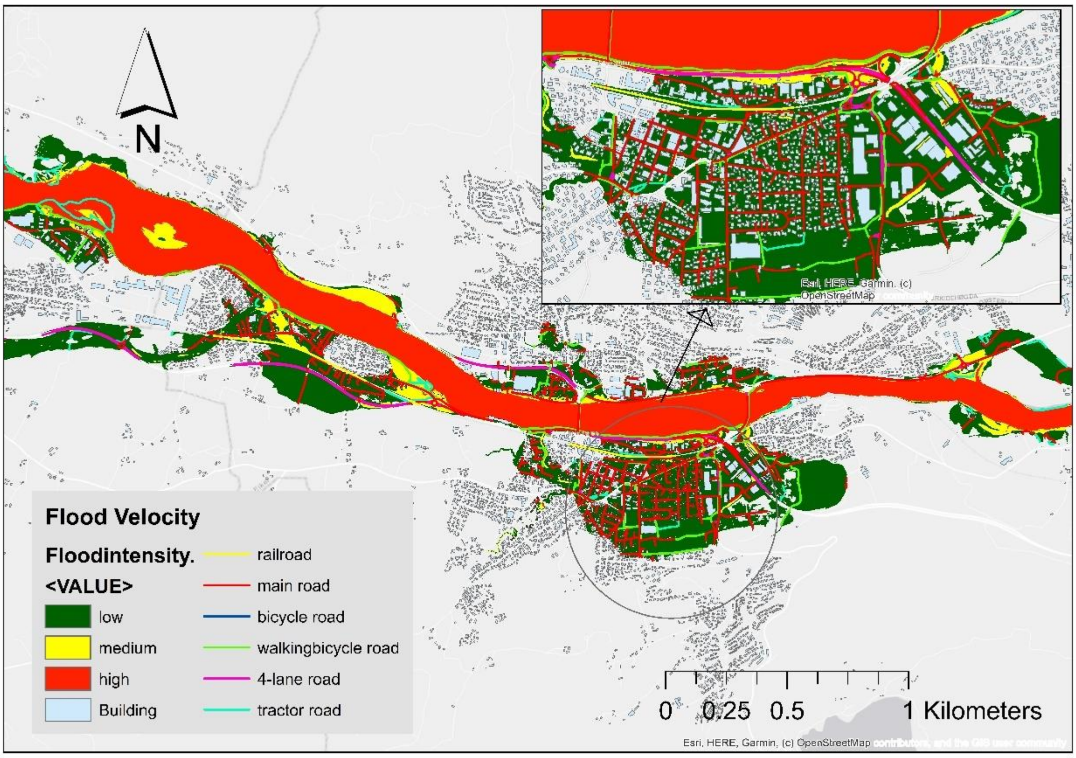


Flood velocity

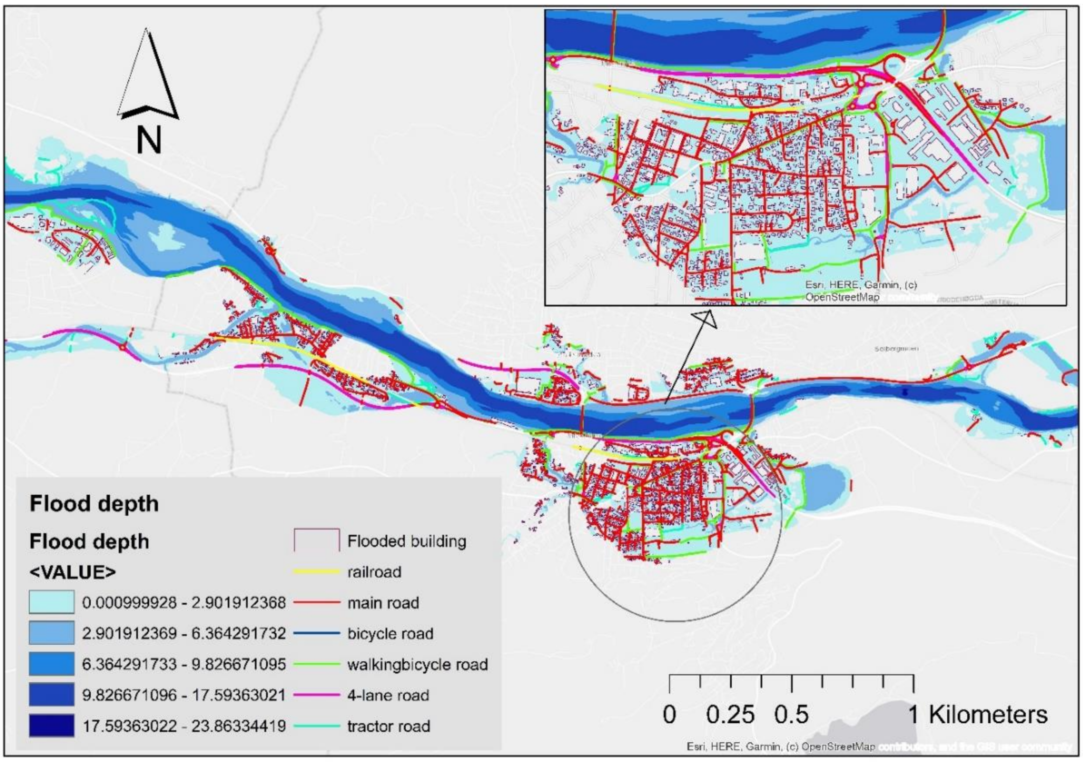


1000 year

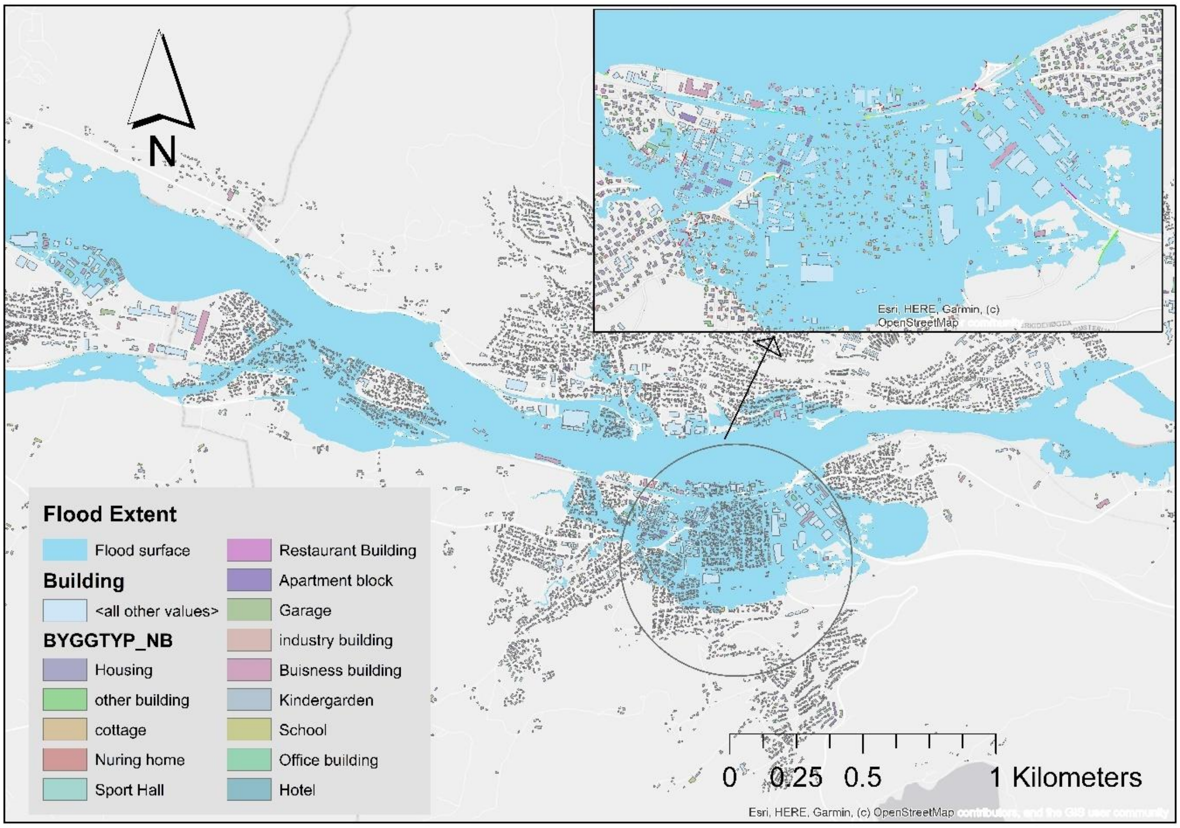
Flood intensity



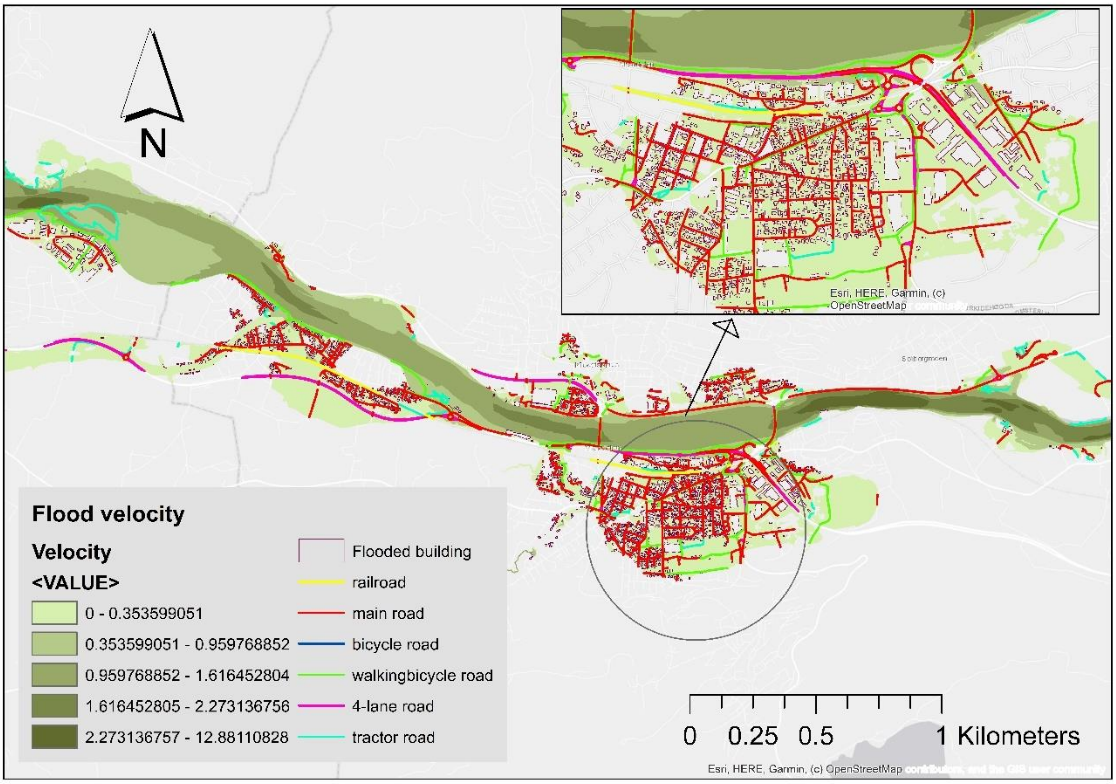
Flood depth



Flood Extent



Flood velocity



The affected number of buildings and length of infrastructures for each flood scenario is provided in excel sheet

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