EVOKED

Enhancing the value of climate data

Deliverable 2.2

Case study site maps of exposure and vulnerability

Work Package 2: Co-develop

Deliverable Work Package Leader:
Kiel University (CAU)

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Summary

A series of exposure and vulnerability maps have been developed and were used in the different case studies of EVOKED for communicating climate information. In this document we provide a brief overview of the role of mapping exposure and vulnerability related to climate hazards and on what types of maps have been used in previous studies for presenting such information. We further outline the methods that were employed in EVOKED for the development of maps that were used to communicate climate information to the local partners of the project and present a series of examples of maps that were produced. Finally, we critically discuss the advantages and limitations involved in the use of these products, assess the potential for further development, and present ideas for future work.

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Review and reference page

1 Introduction

This document describes the development of exposure and vulnerability maps that were used in the different case studies of EVOKED for communicating climate related information. First, we briefly review the current state of research in the mapping of exposure and vulnerability related to climate hazards; and how different products have been used for presenting such information. Then, we outline the methods that were employed in this project for the development of the maps that were used to communicate climate information to the local partners of EVOKED; followed by a series of examples of maps that were produced. Last, we critically discuss the advantages and limitations involved in the use of these products, assess the potential for further development and present ideas for future work.

1.1 Mapping of Exposure and Vulnerability

In climate hazard research, the terms risk, exposure and vulnerability have been defined by several authors (de Moel et al. 2009). The definition of the Intergovernmental Panel on Climate Change (IPCC) is the one most commonly used. It defines risk as a function of a hazard, exposure and vulnerability (Cardona et al. 2012). Hazard is described as a possible future outcome of a human-induced or natural event that might have negative effects on vulnerable or exposed elements. The area where the hazard might occur is the potential hazard area. The inventory of elements in this area (e.g. a potential floodplain) is defined as exposure. Economic resources or population outside the specific hazard areas are not exposed as they do not face direct negative consequences of the hazard event. Vulnerability describes the ability of exposed element to deal with adverse effects induced by a hazard event. Among others, vulnerability depends on preparedness, precautionary measures, insurance, health and financial resources (de Moel et al. 2009). In other words, people living in a potential hazard area can be exposed but not vulnerable to a specific hazard by implementing adaptation measures, such as modifying building structures or implementing effective social support mechanisms. Conversely, being vulnerable to a hazard also assumes being directly or indirectly exposed to a hazard (Cardona et al. 2012; SGI 2018).

In the context of quantifying climate-change related hazards and risks, analyses need to account for future changes in the natural system as well as changes of the socio-economic component. Changes in the natural system can affect the frequency or intensity of hazards, which themselves would lead to changes in exposure even if socio-economic conditions were constant over time. For example, changes in storminess or precipitation could lead to higher water levels and to an extension of the floodplain (Church et al. 2013), which affects more economic resources and population. As socioeconomic conditions are not constant over time and population and the gross domestic product (GDP) are projected to grow at least until 2050 (KC and Lutz 2017; Leimbach et al. 2017), both the inventory of elements in hazard areas increases along with the physical exposure. These changes in the hazard and socio-economic development also need to be accounted for in exposure and vulnerability maps.

Exposure and Vulnerability mapping is a commonly used tool for policy makers for supporting adaptation (Patt et al. 2005; Neset et al. 2016) and land-use planning decisions, while at the same time educating the public about climate change and its interactions with coupled physical/environmental systems and motivating policy responses (Preston et al. 2011). Methods that have been employed in the past mainly involve the following steps (described by de Moel 2009):

First, the magnitude of the hazard is estimated, either as a plausible scenario of a specific magnitude (e.g. 1m of sea-level rise; see Lichter et al. 2011; Neumann et al. 2015) or as the magnitude of an event with a specific return period (e.g. a 200-year river discharge). Then, these values are used to map the exposure, usually by employing a Geographic Information System (GIS) and digital data on elevation; or by modelling the temporal evolution of an event using a physical model (see Kumbier et al. 2018). This process leads to the estimation of the characteristics of the hazard (e.g. flood extent and depth). Finally, further spatial information, such as the distribution of population, assets, infrastructure, land-use, or economic data (Marcy et al. 2011) can be combined within a GIS with the potentially impacted areas to estimate potential exposure and impacts. GIS can also be used to analyse damage exposure based on land use maps and estimates on economic values of different land uses (Ward et al. 2011). Mapping vulnerability builds upon this approach by, for example, using damage curves to quantify the degree to which buildings are effected by hazards (Albano et al. 2017); or by using detailed information on population to identify the number of vulnerable individuals (e.g. people over the age of 80). In the case of damage curves, these show the magnitude of a hazard on the x-axis and the degree to which population or objects are effected on the y-axis. A steep damage curve indicates high vulnerability even for events of smaller magnitudes, while a more gentle damage curve indicates low vulnerability for smaller magnitudes. Risk maps bring together information on the hazard, exposure, and vulnerability and thus define risk zones, which can be used for emergency or spatial planning (de Moel et al. 2009; Albano et al. 2017) as well as for prioritization of measures for risk reduction.

Applications of exposure and vulnerability mapping include:

- the analysis of European climate change vulnerability under the influence of both climate and socio-economic scenarios across multiple sectors by Dunford et al. (2015) who produced mapped outputs for six key ecosystem services for a number of time slices, while allowing for the concepts of capital, coping capacity, and stakeholder-derived scenarios to be included within a quantitative model;
- the work by Preston et al. (2009) who used vulnerability mapping in Sydney, Australia, to help stakeholders visualize climate change impacts on the landscape and to place those impacts in a recognizable local context and illustrate interactions between biophysical and socioeconomic determinants of vulnerability; and
- the vulnerability analysis of ecosystem-service change in Europe (Metzger et al. 2008) where spatial data on parameters such as adaptive capacity, potential impacts, ecosystem service supply, and others were combined to create a vulnerability map for Europe.

A comprehensive systematic review of climate vulnerability mapping applications is provided by de Sherbinin et al. (2019). The authors confirm the usefulness of these maps and emphasise the advantages of further development with the use of scenarios; the importance of validation; and the need to move beyond those maps based on user information.

Further applications involve the extensive development and use of web-based tools. For example, in the context of sea-level rise, the "Sea Level Rise Viewer" (https://coast.noaa.gov/slr/) of the National Oceanic and Atmospheric Administration (NOAA) and the "Mapping Choices" Tool (https://choices.climatecentral.org/) of Climate Central are characteristic examples of tools visualising changes of the potential hazard area. Neset et al. (2016) reviewed and assessed twenty map-based web tools as to how vulnerability and adaptation to climate change are addressed. They conclude that few of these tools can directly help users with concrete climate change adaptation as the information provided cannot directly lead to actual adaptation activities (see also DELTARES, 2019b).

2 Development of Exposure and Vulnerability Maps in EVOKED

In EVOKED, a series of maps have been developed with the purpose of communicating information on vulnerability and exposure to specific climate related hazards to the stakeholders of the four case studies and to support the living-lab process. Depending on stakeholder needs and requirements different methods have been used for developing such maps. In this section we focus on the work that has been carried out conducted for the case study of the City of Flensburg, where substantial needs existed in the process of starting to develop an adaptation strategy to coastal flooding. In addition, information on the maps that were used or developed for the other case studies of Larvik (Norway), Värmland (Sweden), Province of North Brabant (the Netherlands) and Drents Overijselse Delta (the Netherlands) is also presented.

2.1 City of Flensburg

The work for Flensburg has focused on storm-surge flooding as the city frequently experiences coastal flooding. As the frequency and intensity of the flooding will increase in the future due to sea-level rise (SLR) (Church et al., 2013), the City of Flensburg is now starting to discuss potential adaptation strategies to reduce the associated risks. In support of the living lab process taking place in this case study, we have developed a series of exposure and vulnerability maps for different combinations of storm-surge and SLR scenarios. Further, we have conducted model runs assuming adaptation scenarios that involve the implementation of measures (e.g. water detention areas, flood barriers etc.). This work is currently in progress. Additionally, based on discussions with representatives of the City of Flensburg, we conducted a set of detailed simulations for the region Hafen-Ost where property development is planned in the near future.

2.1.1 Methods and Data

The flood hazard, the possible danger of the physical flooding itself (with corresponding probabilities), can be analysed with different metrics, such as flood duration, intensity, extent, and depth (de Moel et al. 2015). Common methods to analyse flooding can be categorized in static models and dynamic models (e.g. reduced complexity models and process-based models). In this study we have employed both a static model (also termed as “bathtub method”) and a process-based dynamic model, namely DELFT3D to calculate flood characteristics under different physical scenarios.

Static inundation model

The static inundation approach reckons that all area hydraulically connected with the sea and below a specific surge height is flooded (Ramirez et al. 2016). It can be performed with low computational cost in GIS (Vousdoukas et al. 2016). The static inundation approach can be used to estimate the residual risk (in the case of e.g. dike failure) and worst-case impacts (Lichter et al. 2011, Hallegatte et al. 2013). The basic dataset required for this approach is a digital elevation model (DEM). We used data from the digital land topographic-cartographic database (Amtliches Topographisch-Kartographisches Informationssystem, ATKIS) of Schleswig-Holstein. The ATKIS has been developed by the land survey departments and the Federal Agency for Cartography and Geodesy and allows the digital organisation and provision of data and maps. It provides two tools, the digital landscape models (Digitale Landschaftmodelle DLM) and the digital topographic maps (Digitale Topographische Karten DTK). Using the DEM all areas below the height of 5m were selected and all the areas not connected to the water excluded. Additionally, water areas were masked out using data from the land topographic database (Amtliche Liegenschaftskataster-Informationssystem, ALKIS) of Schleswig-Holstein Baltic mask. For looking at the exposure and vulnerability of assets we used ALKIS data from 2011. Population density was derived from Census data from 2011, which has a resolution of 100 m (Figure 4). The underlying vertical aerial photography was provided by maps and earth imagery from the Bing search engine and associated online mapping services.

Hydrodynamic modeling with DELFT3D

DELFT3D is a complex process-based model for coastal hydro- and morphodynamics (DELTARES, 2014). Process-based models can be coupled 2- or 3-dimensional models that replicate coastal storm-tide flooding by simulating atmospheric-ocean-land interactions and are able to include winds, waves, currents, tides, and river run-off (Ramirez et al. 2016). We modelled a range of plausible storms based on events that have occurred in the past, also using different sea-level rise scenarios of 0.5m and 1m. We simulated, for present day conditions, a slight storm with a surge of 1m; the Axel storm that hit Flensburg in January 2017 and had a high-water level of 1.78m; and the highest storm recorded in Flensburg that occurred in 1872 and had a high water level of 3.08m. The various combinations are shown in Table 1.

Table 1 Simulated events for the overall model. Storm surge classes adopted from the "Fachplan Küstenschutz Ostseeküste" (LKN.SH 2017).

Scenario	Peak water height [m]
Slight storm surge + 0,5m SLR	1,5
Axel + 0,5m SLR	2,28
Axel + 1m SLR	2,78
Present-day very heavy storm surge + 0,5m SLR	2,75
Present-day very heavy storm surge + 1m SLR	3,25
Storm surge of 1872 + 1m SLR	4,08

For the simulations, we resampled the Bathymetry to the resolution of the (onland) DEM and both rasters were combined into one file. Then we created a roughness profile using Manning's roughness coefficient differentiating between land and water areas (values of 0,035 and 0,025, respectively). We used the water-level time series of the Axel storm to produce the boundary-condition input file in Matlab. As Axel 2017 is the only high-magnitude event with available hydrograph data, the hydrographs for the other scenarios were created by editing the water level values of Axel so that the peak height fits the specific event assuming the same temporal evolution. The basic data employed in the simulations are shown in Table 2.

Table 2 Input datasets, characteristics and sources

Data	Resolution	Reference
Digital elevation model (DEM)	10m / 5m	LVermGeo SH ATKIS
Bathymetry	0.125 arc-minutes	EMODnet
Water levels Axel	Temporal resolution: 1 min	WSA Lübeck 2017
Population density	100m	Census data from 2011
Exposure / Vulnerability	Vector data	ALKIS

Further DELFT3D model parameters such as alpha (reflecting parameter) and smoothing time had to be chosen based on expert judgement, according to which setting appears as most realistic. Therefore, Axel (without SLR) was modelled and the results of different settings were compared to photographs of the flood extent in 2017 in order to calibrate the model. The model was then run with the generated hydrographs. Delft3D produces two output file types: the hydrographs at the observation stations and the floodplain temporal development. The maximum inundation time-step was then identified and was imported as an ArcGIS raster.

Finally, additional simulations were performed assuming the implementation of adaptation measures that were proposed by different stakeholders. These measures included structural protection (e.g. dikes and barriers) as well as accommodation measures (flood storage). This work is ongoing, and results will be available by early 2020. An example with preliminary results is shown in Figure 5.

Nested model for Hafen-Ost

As the hazard in Hafen-Ost was of particular interest, a nested model was set up. Using nesting enables the detailed simulation of flood surge for a smaller area, at a finer resolution (in this case 5m). This would not be possible for the entire study area due to limitations in computational resources and runtime. One-way dynamic nesting is enabled by running the overall model including observation points along the open boundary of the detailed model (DELTARES 2014). The computed water levels at these points can be rewritten as time series and used as boundary conditions for the nested domain. For Hafen-Ost, the following storm events were simulated (Table 3). Results of the nested model for Hafen-Ost can be seen in Figure 6 and Figure 7.

Table 3 Simulated events for the detailed model.

Simulation	Peak height [m]
Axel + 0,5m SLR	2,28
Axel + 1m SLR	2,78
Storm surge of 1872	3,08
Storm surge of 1872 + 1m SLR	4,08

2.2 Värmland Country

Since 2009, the County Administrative Boards in Sweden have been assigned by the central government the responsibility to coordinate the regional work on climate adaptation. They provide support to the municipalities and review their comprehensive and detailed spatial plans. In 2014, the County Administrative Board of Värmland published their action plan for climate adaptation (Länsstyrelsen Värmland 2014). The report describes climate and climate-change scenarios for the county; consequences of climate change; roles and responsibilities for climate adaptation; and what is being done within the climate adaptation work, need for action, and how to proceed. In 2015, the climate change scenarios for Värmland were updated according to the RCP scenarios (Nylén et al. 2015).

2.2.1 Methods for Map Development

The County Administrative Boards in Sweden offer free map services for both the public and professional users. The map services allow direct access to data and map development through a web-based tool (webGIS). Nationwide and regional geodata can be downloaded through a national spatial data catalog. In addition, regional and local geodata can be found at the municipalities. The webGIS tool was therefore employed during the stakeholder meetings at Värmland to visualize information that was required. Examples of maps developed to depict different aspects of exposure related to river flooding are shown in Section 3, Figure 12-14. During the meetings, the usefulness of the webGIS tool in addressing climate information needs of the stakeholders was evaluated. The general response of stakeholders to the different map products is discussed in Section 4. The map service (webGIS) developed by the county administrative board was employed for the generation of maps displaying exposure to river flooding. Example maps are shown in the next section. The webGIS tool can be found at
https://ext-geoportal.lansstyrelsen.se/standard/?appid=ffef1d636c3f4874bca1adb2be062a55
while the national spatial data catalog is available at
https://ext-geodatakatalog.lansstyrelsen.se/GeodataKatalogen/

2.3 The Netherlands

The methods for the development of maps discussed in the previous section were also used for the development of exposure maps for the case studies in the Netherlands. In most cases, events of specific return periods, in some cases including climate scenarios, were employed to develop maps of fluvial inundation exposure; drought due to precipitation shortages; and heat stress indicated via expected temperatures. Resulting maps are shown in the next section.

2.4 Larvik

Maps for Larvik were developed to depict exposure to pluvial flooding, on the basis of the methodological framework described in previous sections. Single events of specific return periods (e.g. 200-year event with a duration of 1 hour) were considered and all areas connected to the lake below the water level induced by the rain were considered as exposed. In a second simulation, based on the soil types a design infiltration rate was assumed to calculate flood exposure. Resulting maps are shown in the next section.

3 Output Maps

The maps that were created using the methods described in Section 2 are presented below for each case study.

3.1 Flensburg

Examples of maps of exposure and vulnerability for the different scenarios described in Section 2 are shown below. These maps were presented during the stakeholder meetings, in combination with quantitative information on exposure (e.g. number of buildings exposed) and on the distribution of values of flood parameters (Figure 1, 2 and 3).

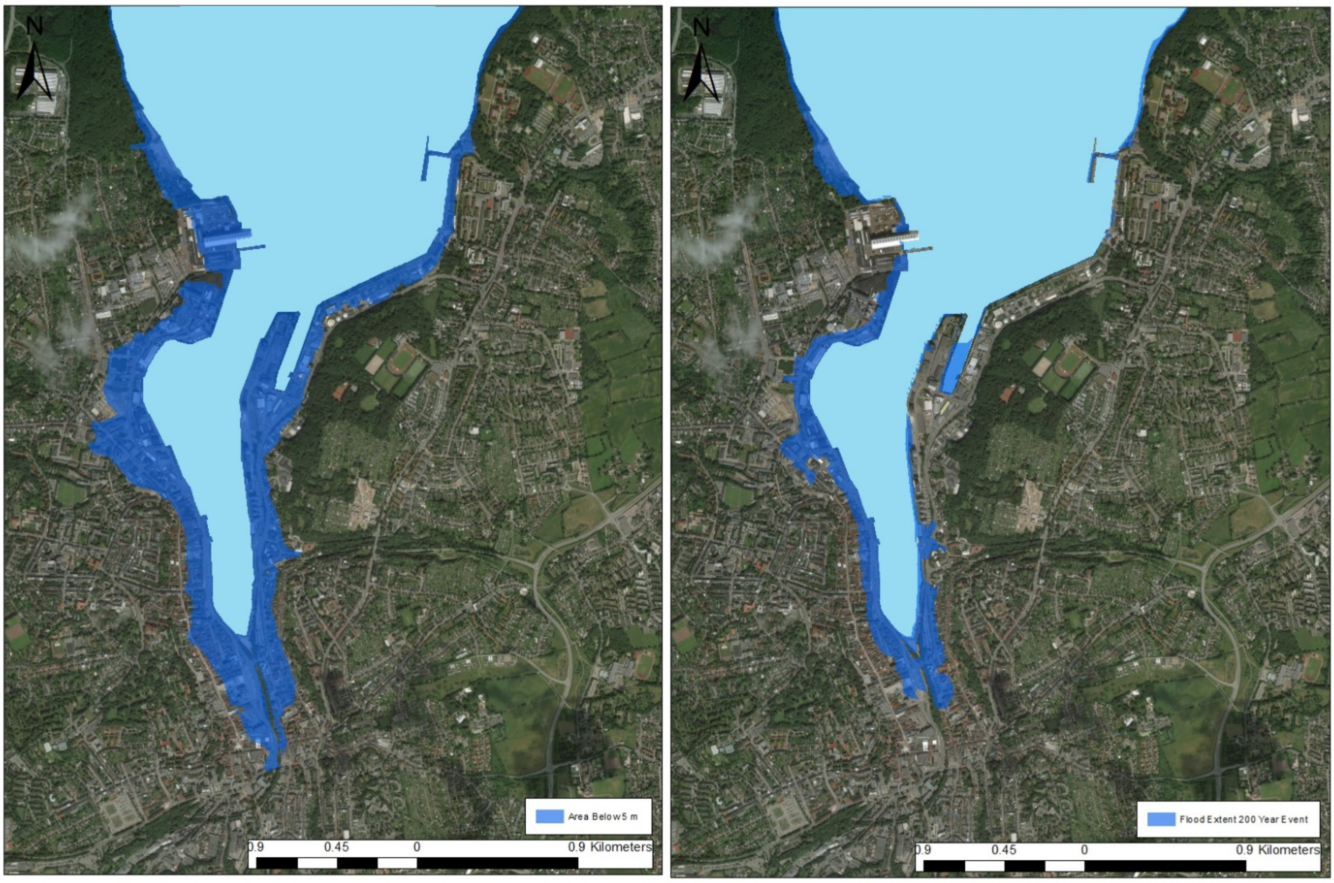


Figure 1 Land area below 5m of elevation (left) and area below the 200-year storm surge height (right) for the City of Flensburg.

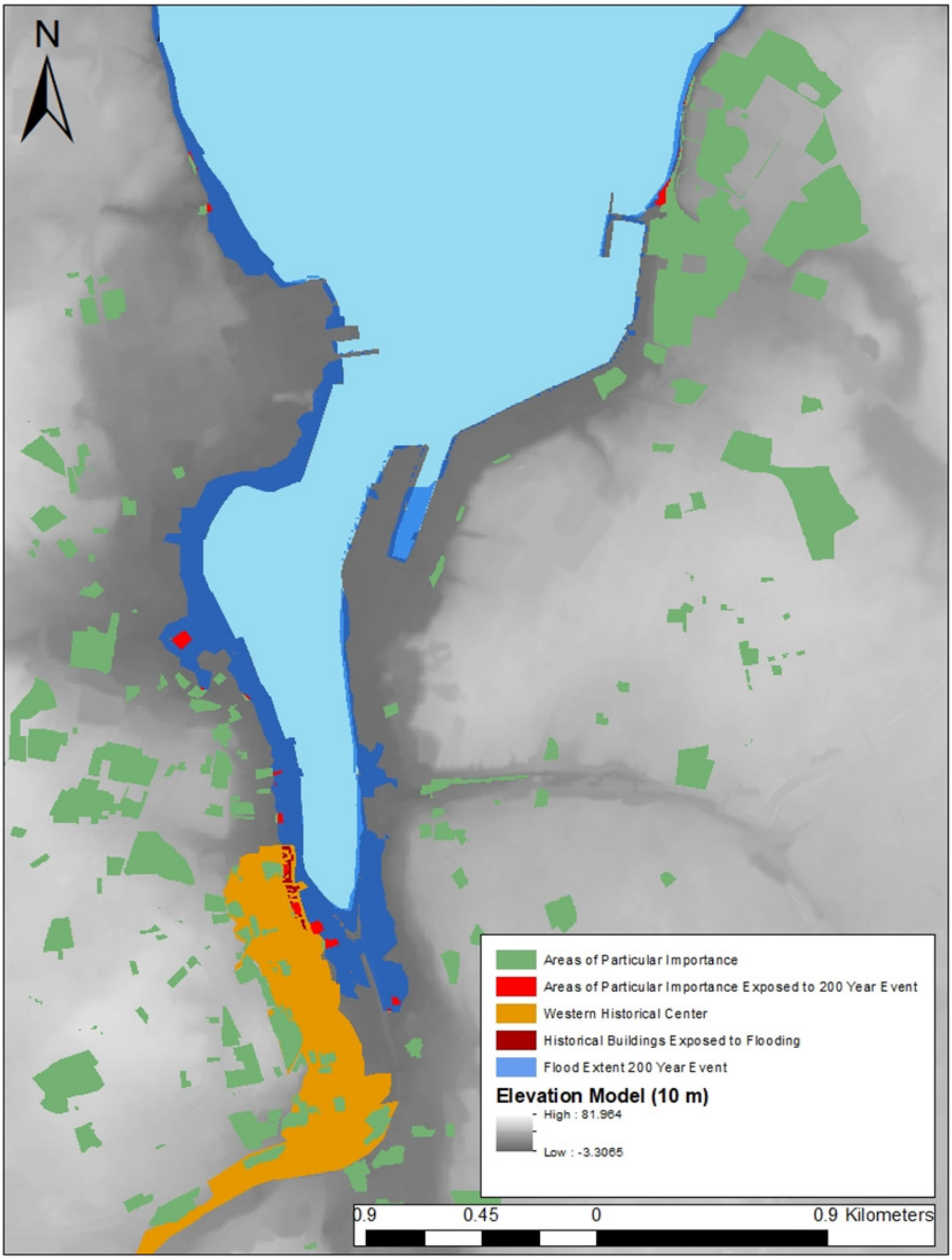


Figure 2: Areas of particular importance (includes the following land uses: administration, education and science, culture, health, social, safety and order) and historical buildings located at elevation equal to or below the 200-year surge level.

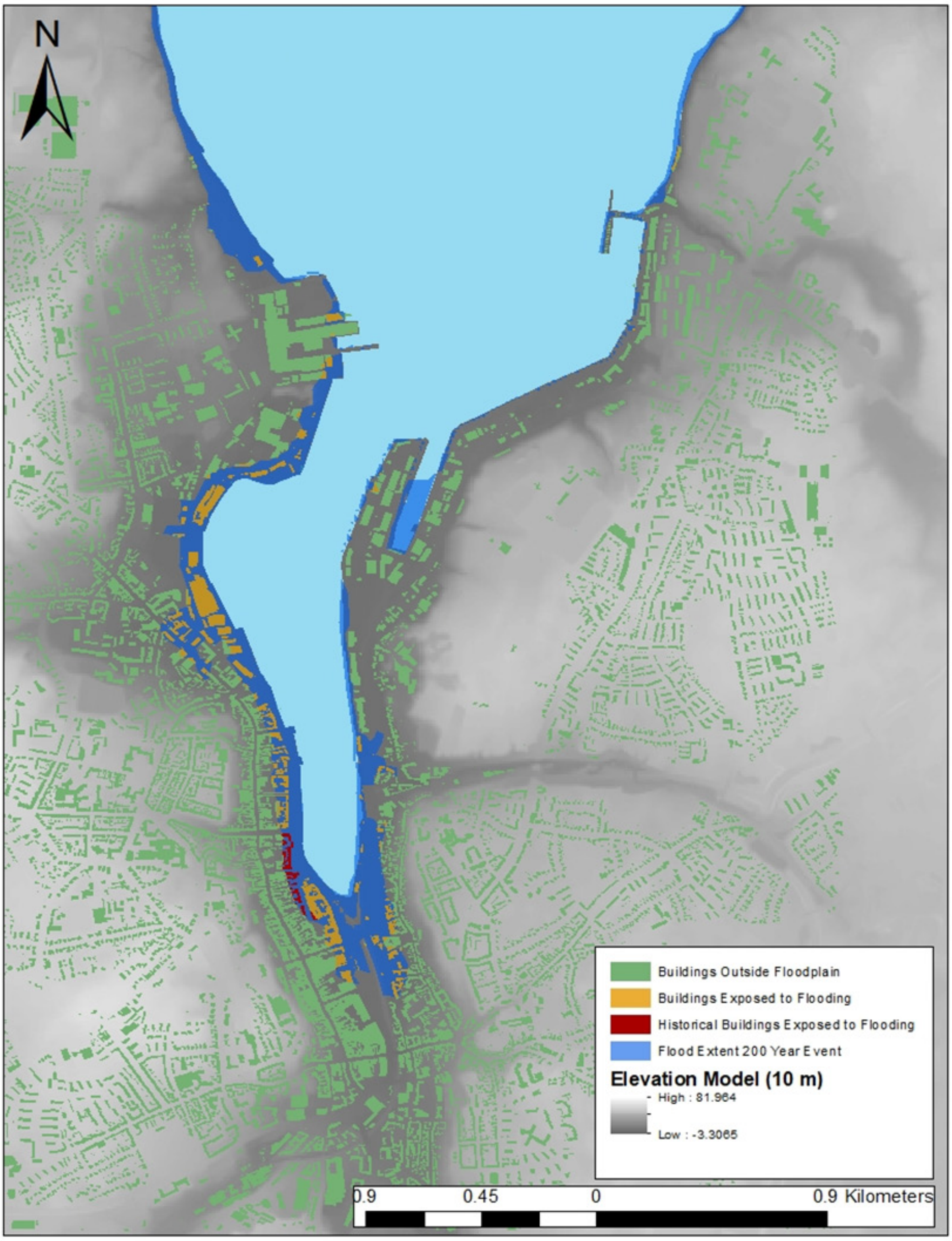


Figure 3: Residential and historical buildings situated at elevations below the 200-year surge level

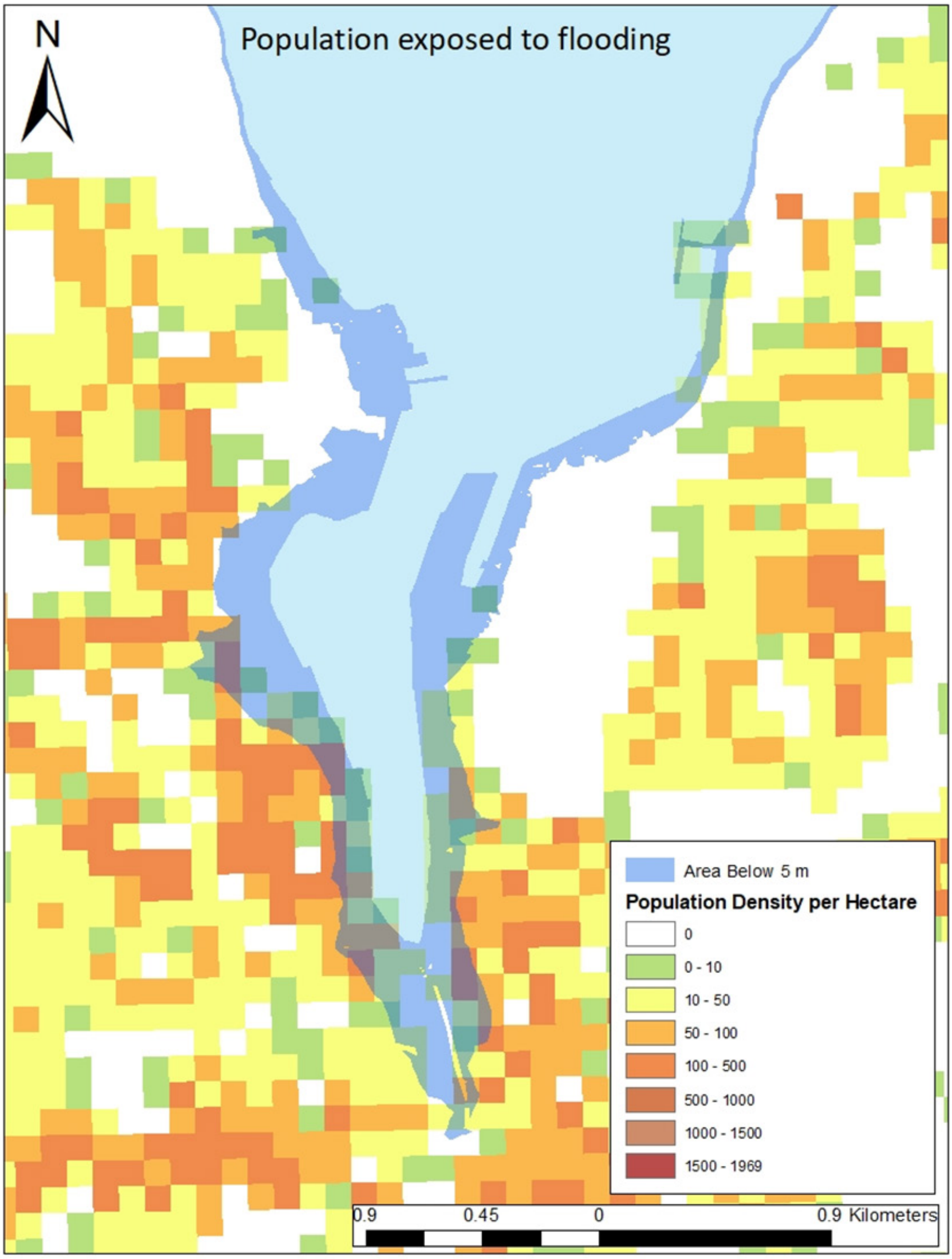
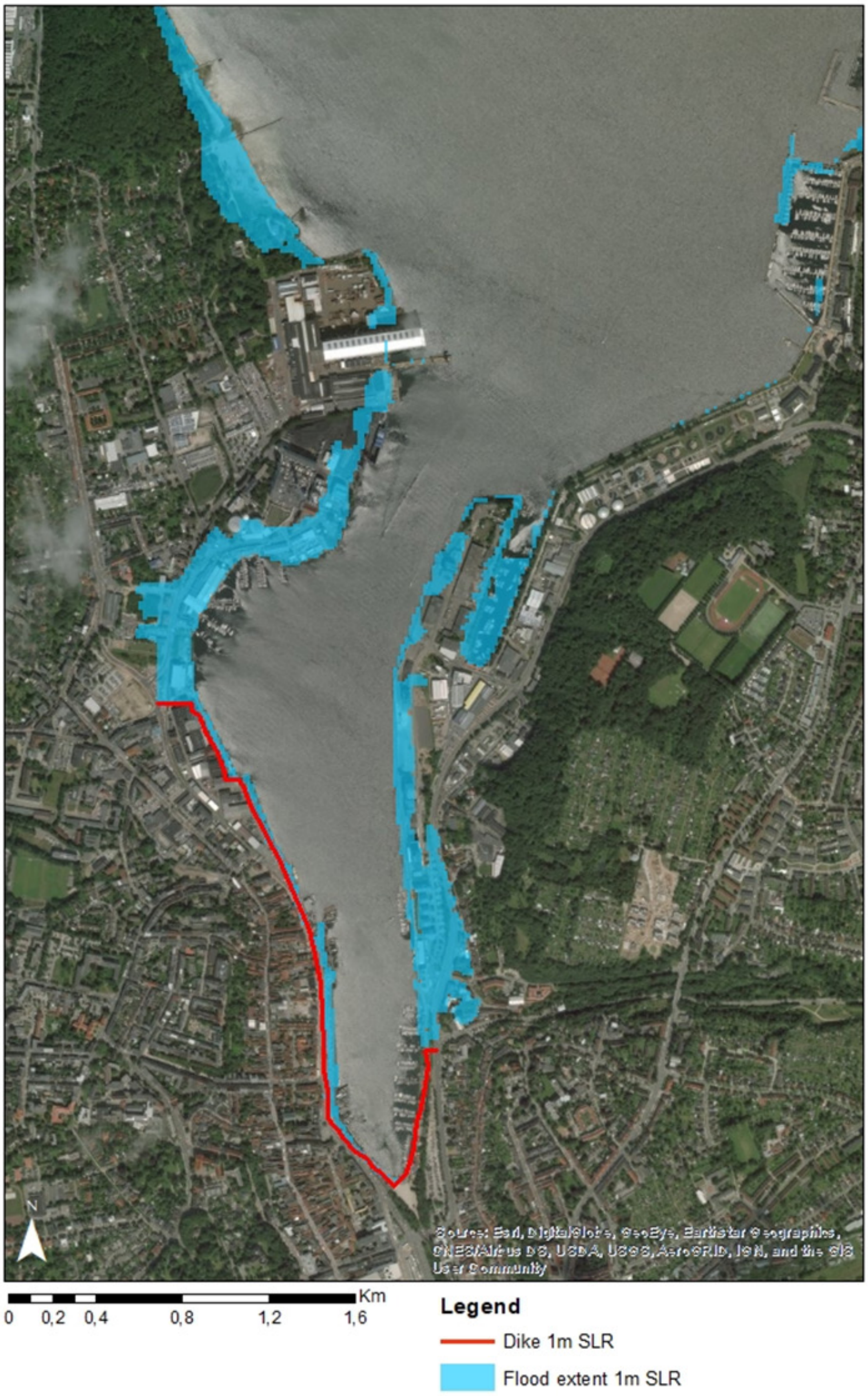


Figure 4: Population density in area below 5m of elevation.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 5: Flood extent in Flensburg based on detailed simulations of the 2017 Axel Storm, assuming a 1-m of SLR and the implementation of a dike protecting parts of the city.

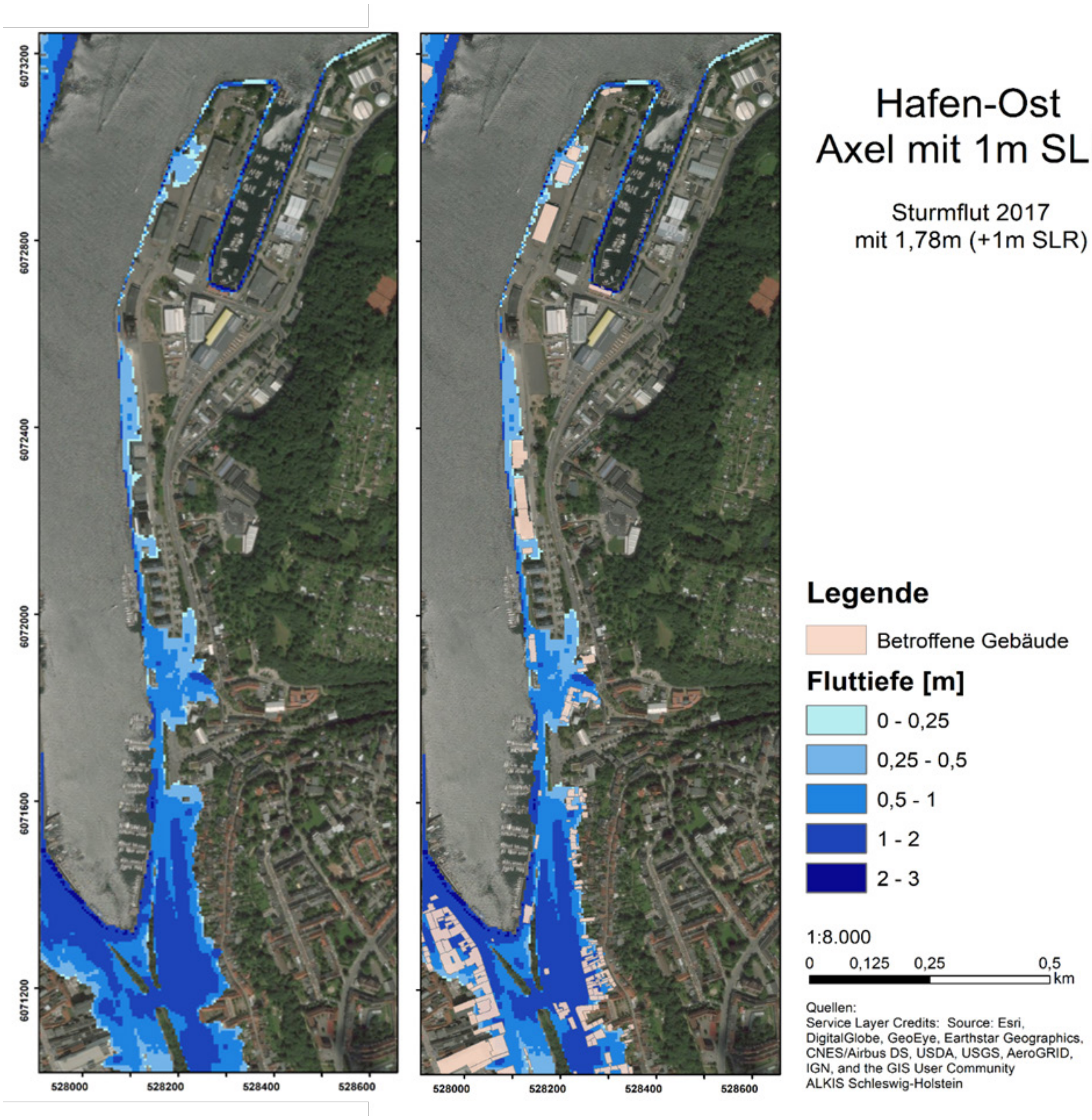


Figure 6: Flood extent and depth (left) and affected buildings (right) based on detailed simulations of the 2017 Axel Storm for the area of Hafen-Ost, assuming a 1-m of SLR.

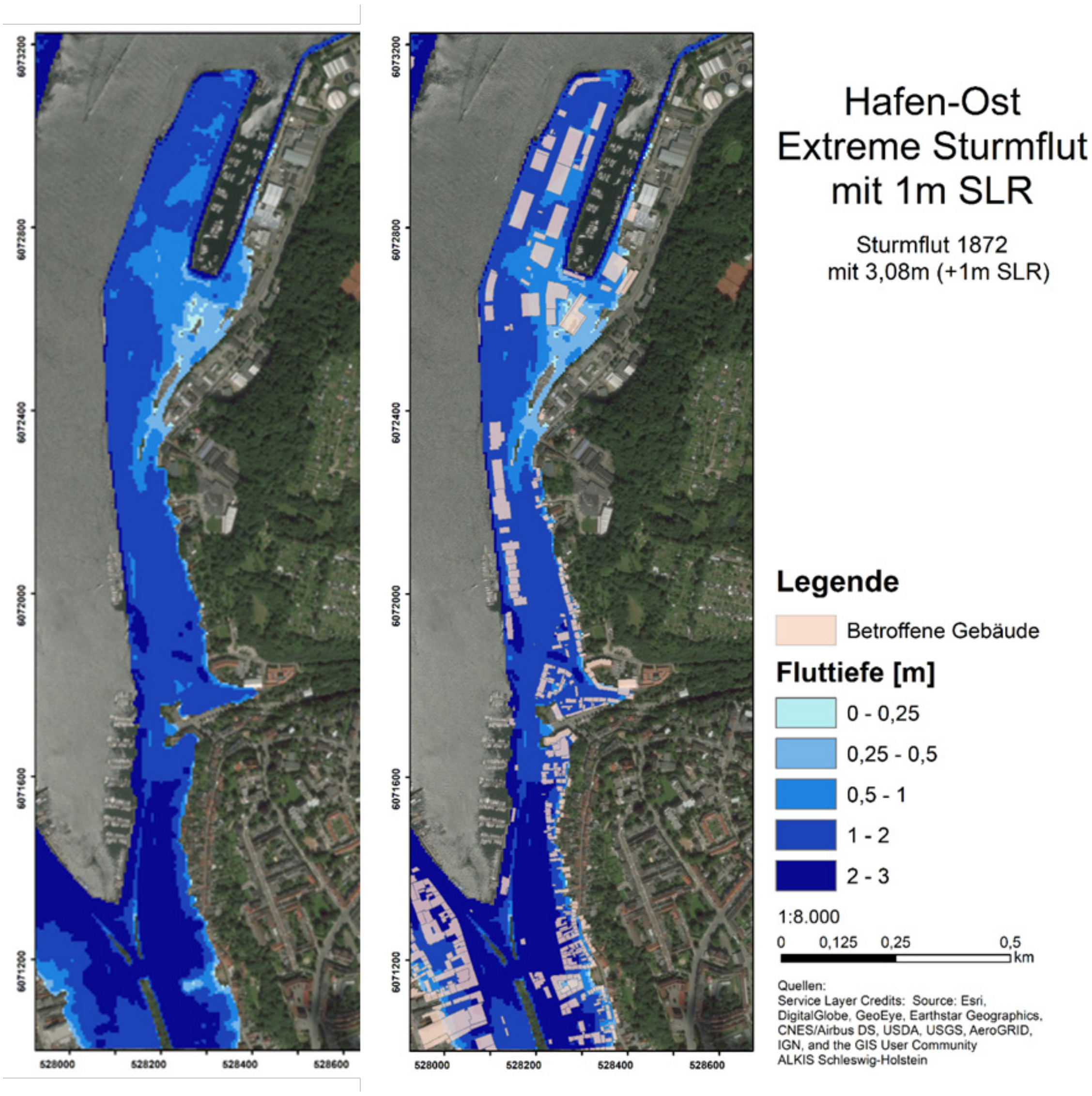


Figure 7: Flood extent and depth (left) and affected buildings (right) based on detailed simulations of the 1872 extreme storm surge for the area of Hafen-Ost, assuming a 1-m of SLR.

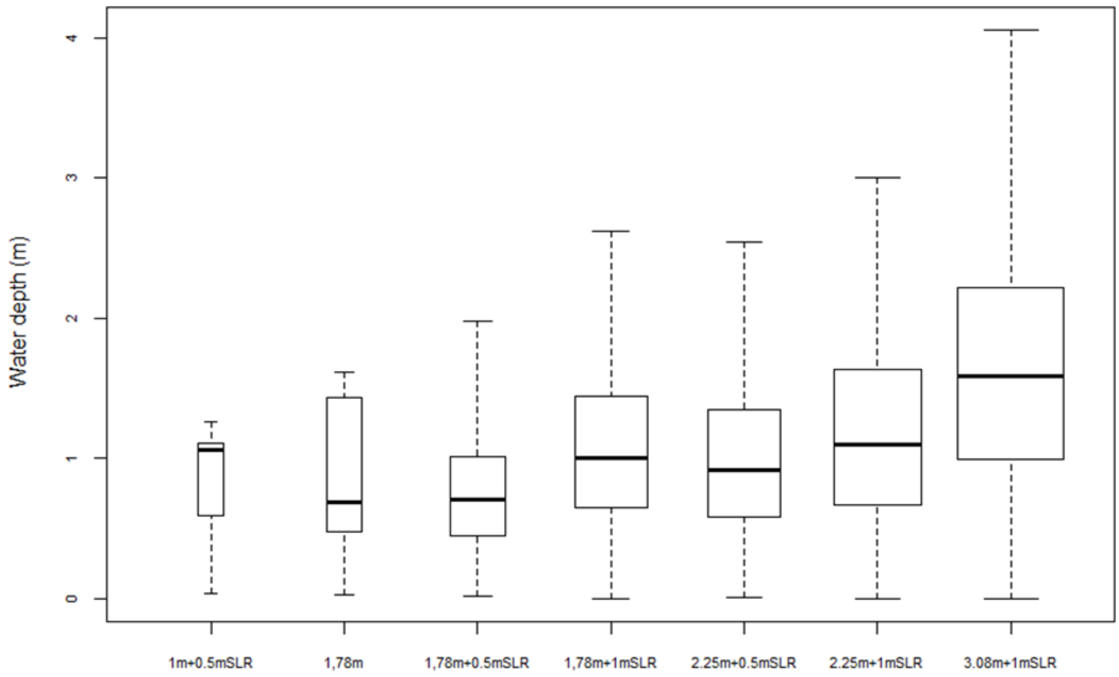
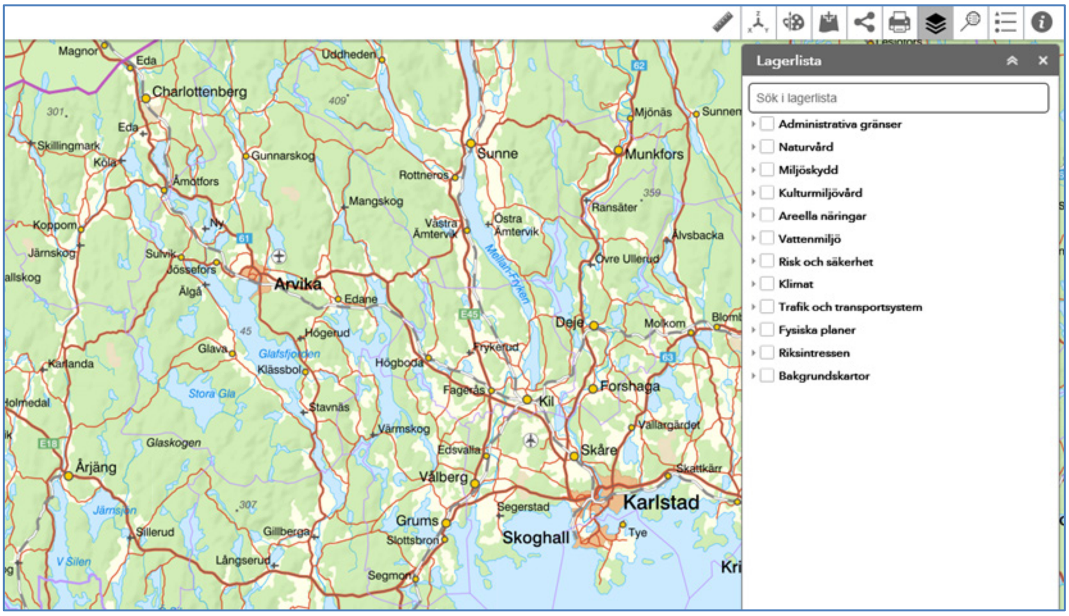


Figure 8: Boxplot of maximum flood depths for the different model runs for the area of Flensburg.

3.2 Värmland Country

Figure 9-14 show examples of maps and data that were extracted from the webGIS tool and provide spatial depictions of parameters related to river flooding:



Lagerlista

Sök i lagerlista

- ☐ Administrativa gränser
- ☐ Naturvård
- ☐ Miljöskydd
- ☐ Kulturmiljövård
- ☐ Areella näringar
- ☐ Vattenmiljö
- ☐ Risk och säkerhet
- ☐ Klimat
- ☐ Trafik och transportsystem
- ☐ Fysiska planer
- ☐ Riksintressen
- ☐ Bakgrundskartor

Figure 9: Planning documents for Värmland County. A list of available geodata layers are visible in the right frame. Each of the 12 layer headings contain additional layers, in a hierarchical system.

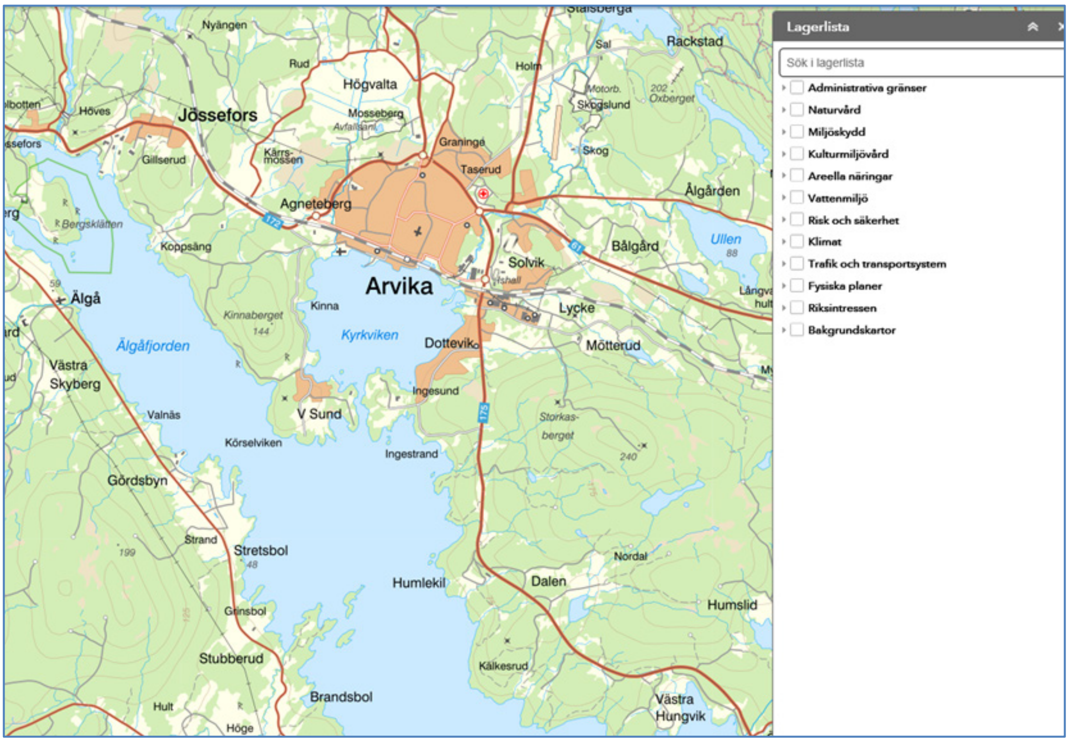


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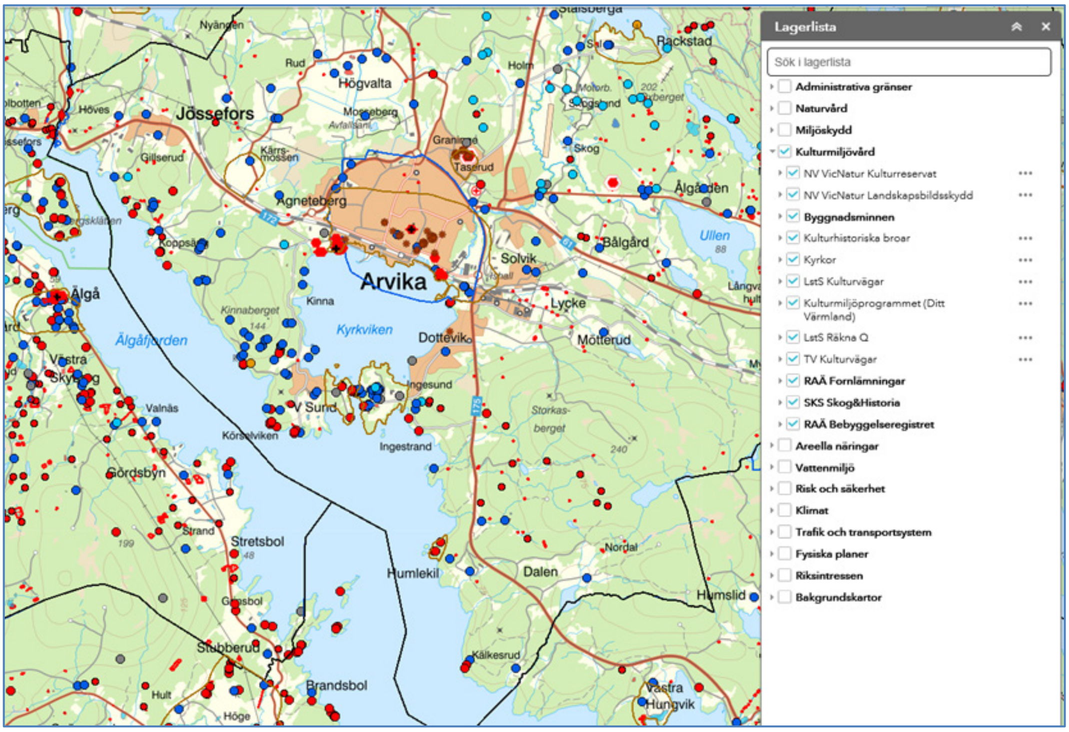
Figure 10: Example for Arvika (topographic background map).



Lagerlista

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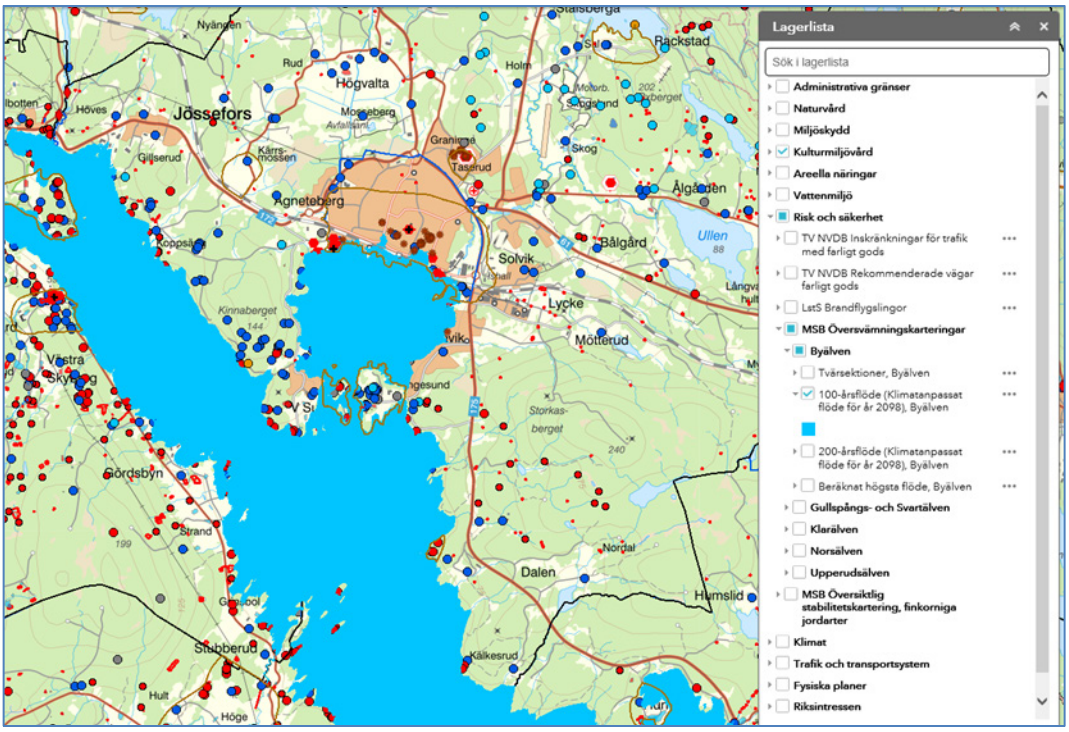
- ☐ **Naturvård**
- ☐ **Miljöskydd**
- ☑ **Kulturmiljövård**
  - ☑ NV VicNatur Kulturreservat
  - ☑ NV VicNatur Landskapsbildsskydd
  - ☑ **Byggnadsminnen**
  - ☑ Kulturhistoriska broar
  - ☑ Kyrkor
  - ☑ LstS Kulturvägar
  - ☑ Kulturmiljöprogrammet (Ditt Värmland)
  - ☑ LstS Räkna Q
  - ☑ TV Kulturvägar
  - ☑ **RAÄ Fornlämningar**
  - ☑ **SKS Skog&Historia**
  - ☑ **RAÄ Bebyggelseregistret**
- ☐ **Areella näringar**
- ☐ **Vattenmiljö**
- ☐ **Risk och säkerhet**
- ☐ **Klimat**
- ☐ **Trafik och transportsystem**
- ☐ **Fysiska planer**
- ☐ **Riksintressen**
- ☐ **Bakgrundskartor**

Figure 11: Example for Arvika. GIS-layers Heritage (Kulturmiljövård).



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- ☑ **Kulturmiljövård**
- ☐ **Areella näringar**
- ☐ **Vattenmiljö**
- ■ **Risk och säkerhet**
  - ☐ TV NVDB Inskränkningar för trafik med farligt gods
  - ☐ TV NVDB Rekommenderade vägar farligt gods
  - ☐ LstS Brandflygslingor
  - ■ **MSB Översvämningskarteringar**
    - ■ **Byälven**
      - ☐ Tvärsektioner, Byälven
      - ☑ 100-årsflöde (Klimatanpassat flöde för år 2098), Byälven
      - ☐ 200-årsflöde (Klimatanpassat flöde för år 2098), Byälven
      - ☐ Beräknat högsta flöde, Byälven
    - ☐ **Gullspångs- och Svartälven**
    - ☐ **Klarälven**
    - ☐ **Norsälven**
    - ☐ **Upperudsälven**
  - ☐ **MSB Översiktlig stabilitetskartering, finkorniga jordarter**
- ☐ **Klimat**
- ☐ **Trafik och transportsystem**
- ☐ **Fysiska planer**
- ☐ **Riksintressen**

Figure 12: Example for Arvika - GIS-layers Heritage and Q100 (water level in the Byälven based on a 100-year water discharge return time flow).

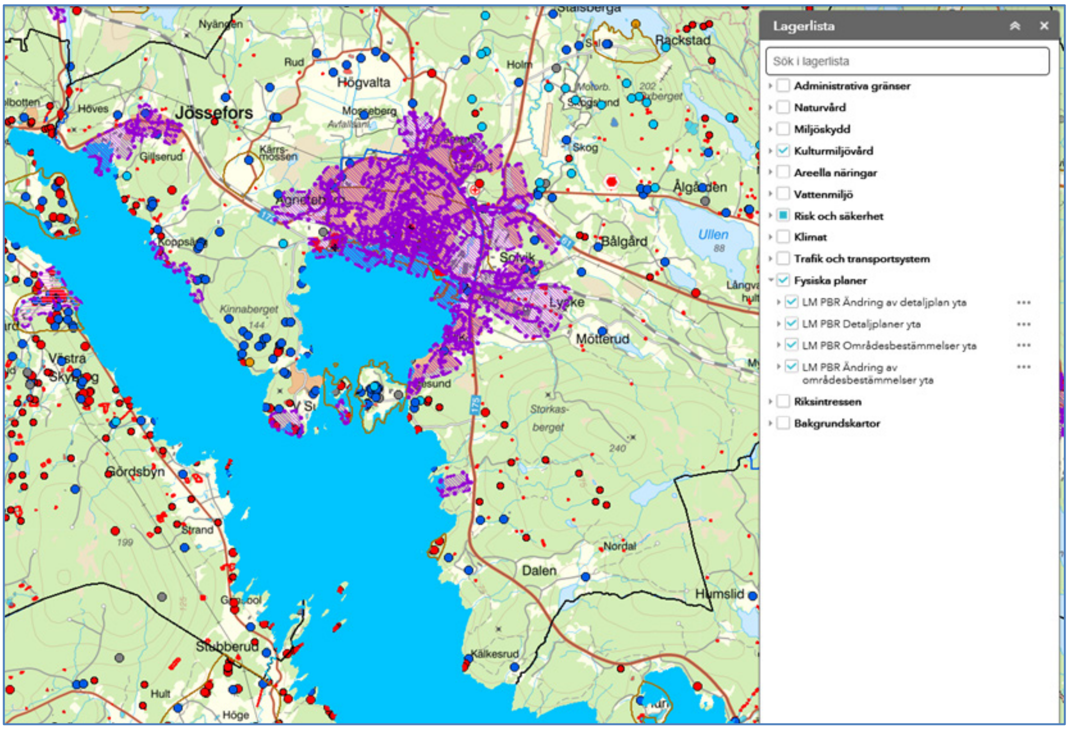


Figure 13: *Example for Arvika. GIS-layers Heritage, Q100 and spatial plans.*

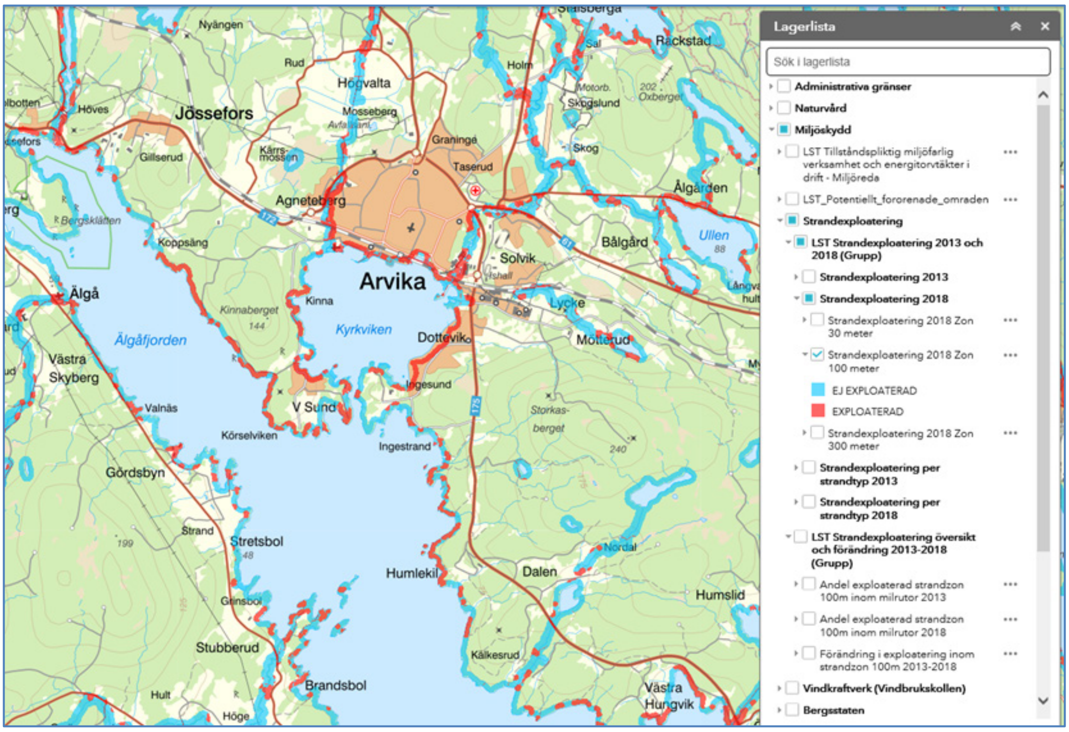


Figure 14: *Example for Arvika. GIS layer Shore exploitation within a 100 meter from the shore. Blue line = not exploited, red line = exploited*

3.3 The Netherlands

A suite of maps was developed in the Netherlands case study. Some examples depicting exposure to heat stress and to fluvial flooding are shown below, Figure 15-17.

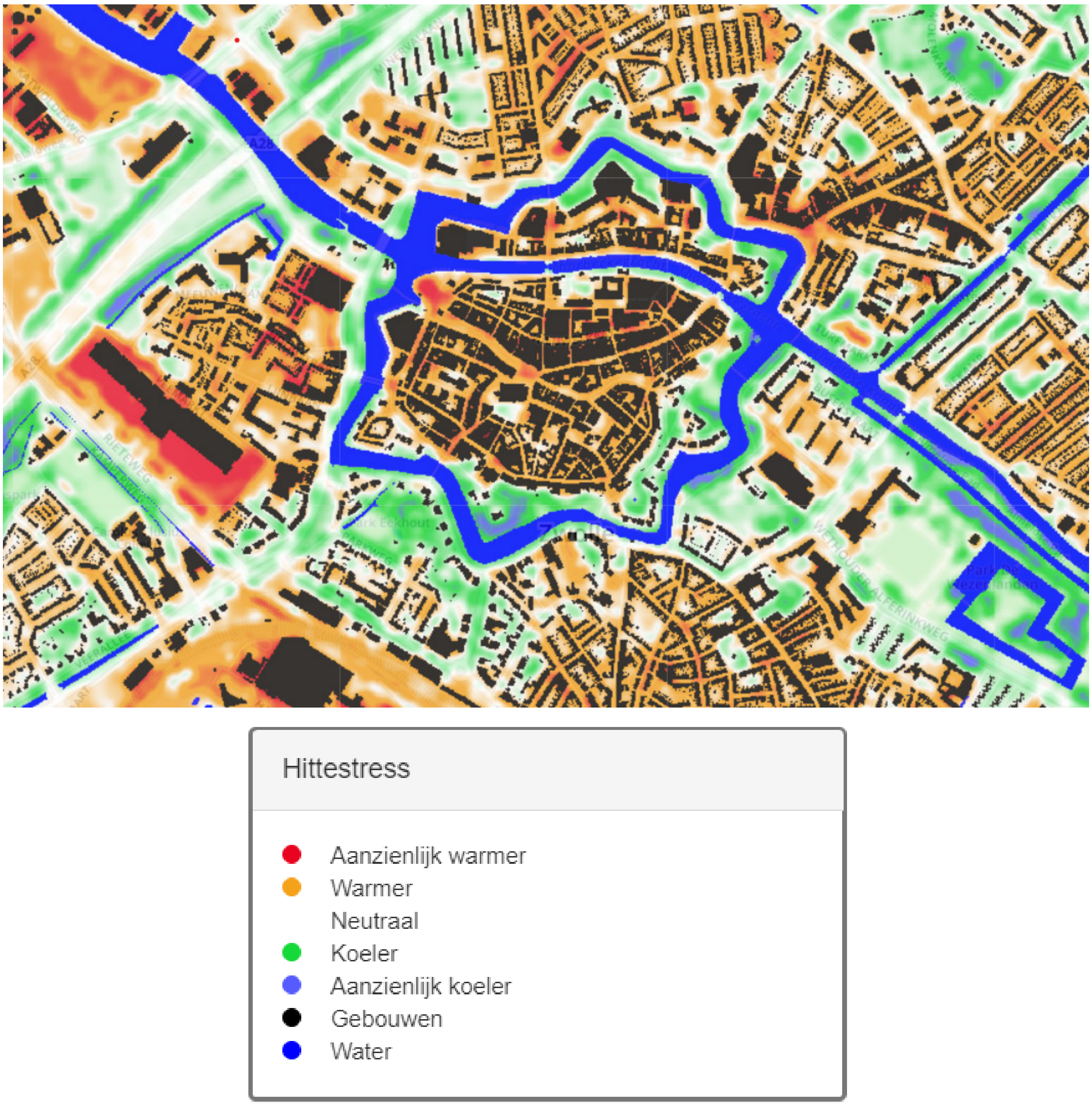
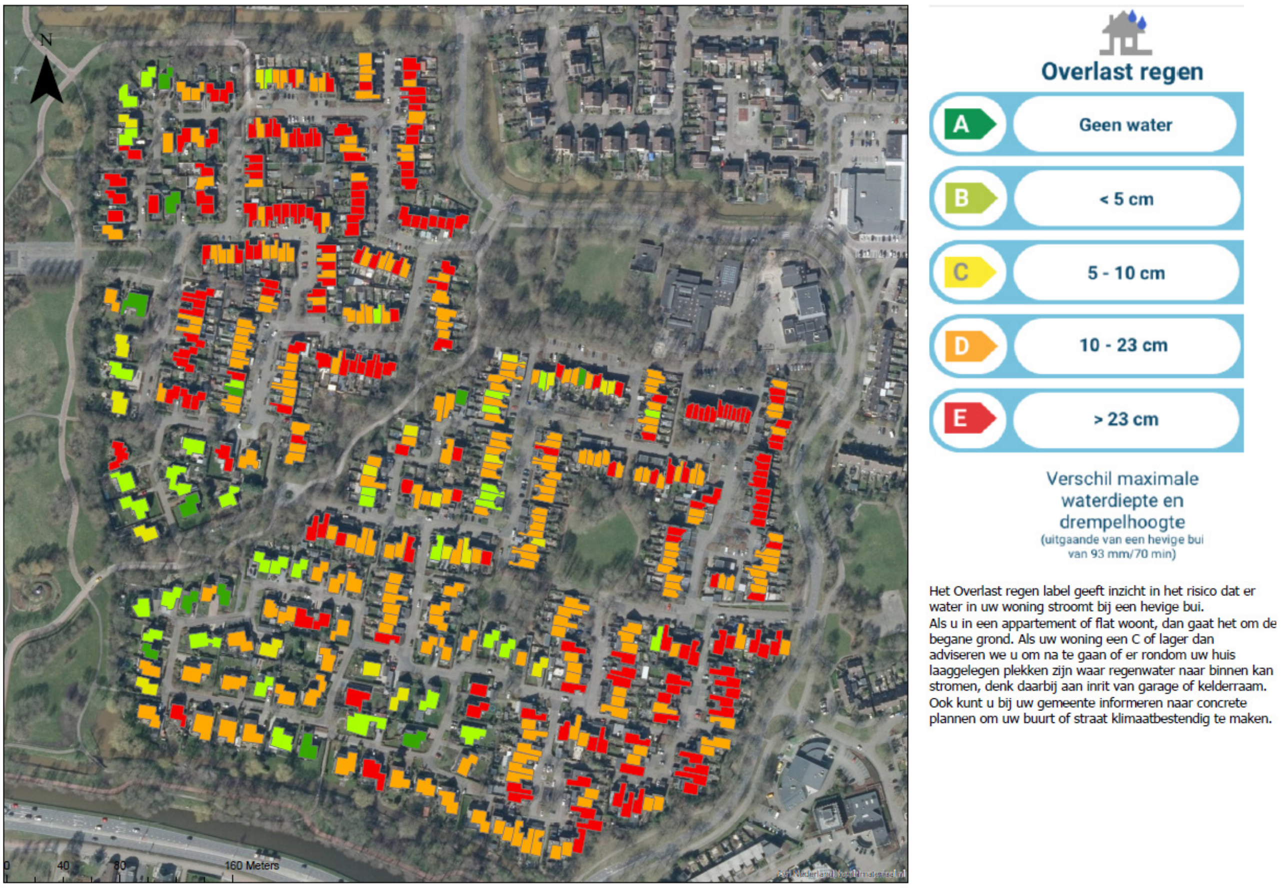


Figure 15 Map of potential exposure to heat stress for the Brabaant region.

Auteur: Gerben Koers
Bronnen: WDOD Klimaateffectatlas; Bluelabel
Datum: 07-07-2019

Figure 16 Map of potential exposure to heat stress, Fluvius region.

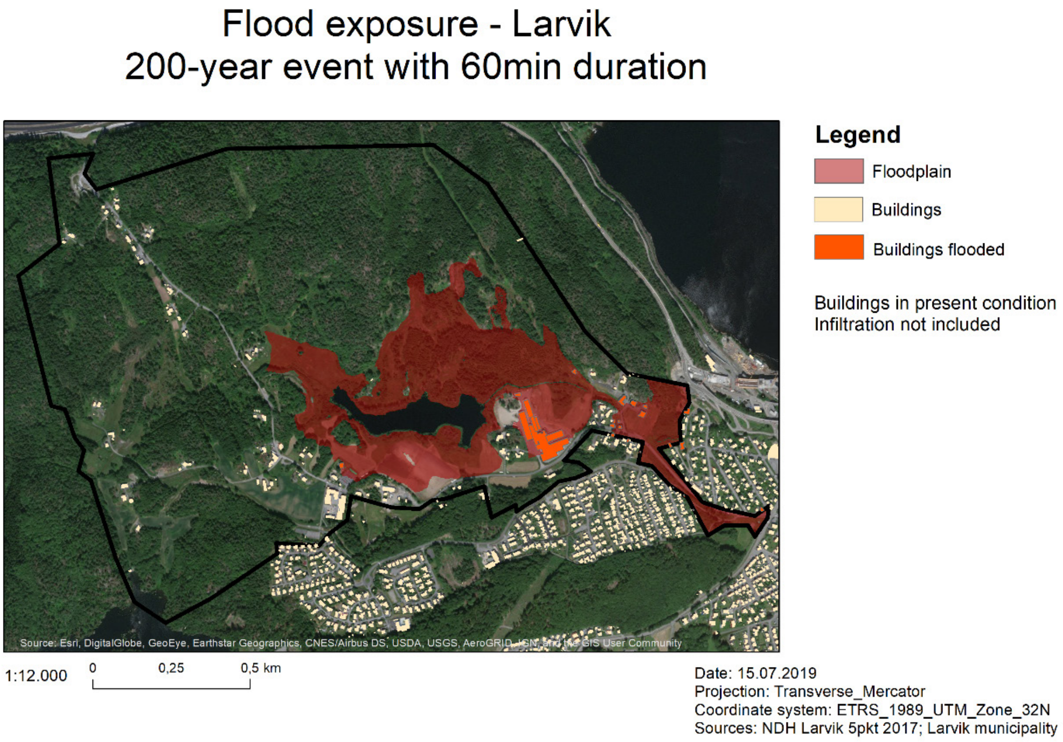


Het Overlast regen label geeft inzicht in het risico dat er water in uw woning stroomt bij een hevige bui.
Als u in een appartement of flat woont, dan gaat het om de begane grond. Als uw woning een C of lager dan adviseren we u om na te gaan of er rondom uw huis laaggelegen plekken zijn waar regenwater naar binnen kan stromen, denk daarbij aan inrit van garage of kelderraam. Ook kunt u bij uw gemeente informeren naar concrete plannen om uw buurt of straat klimaatbestendig te maken.

Figure 17 Map of potential exposure to fluvial flooding based on elevation, Fluvius region.

3.4 Larvik

Exposure to pluvial flooding is depicted in the maps shown in Figure 18-19.



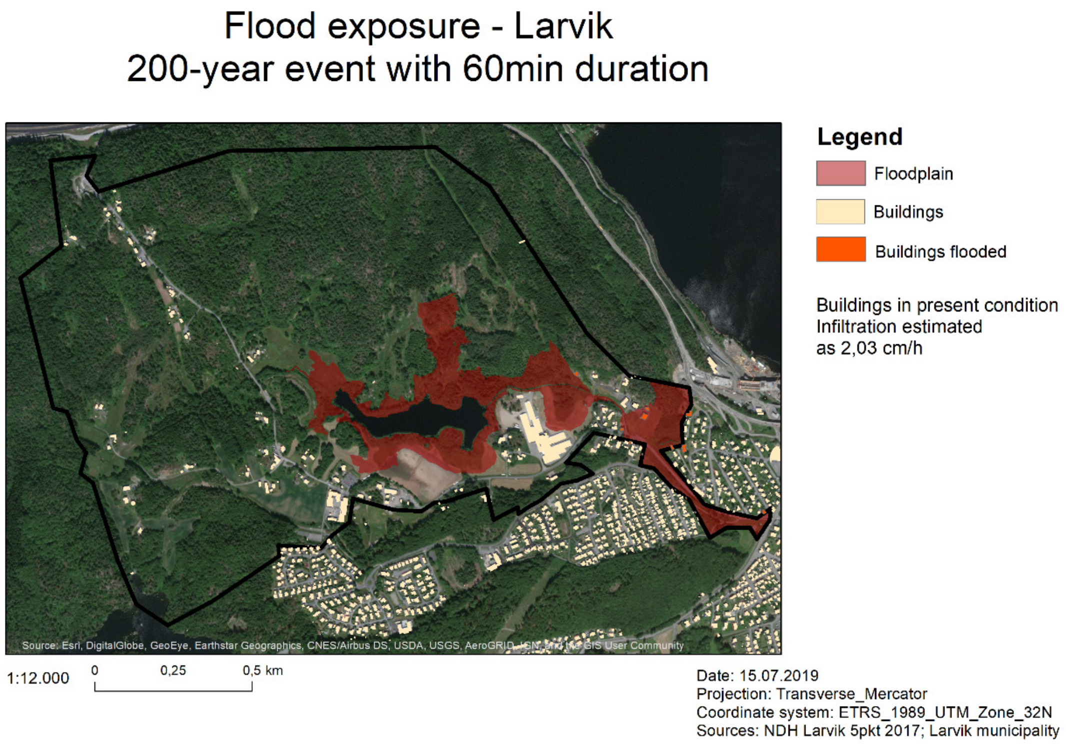
Flood exposure - Larvik
200-year event with 60min duration

Buildings in present condition
Infiltration not included

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Date: 15.07.2019
Projection: Transverse_Mercator
Coordinate system: ETRS_1989_UTM_Zone_32N
Sources: NDH Larvik 5pkt 2017; Larvik municipality

Figure 18 Exposure to pluvial flooding for a 200-year event at Martineåsen, Larvik. Infiltration not considered.



Flood exposure - Larvik
200-year event with 60min duration

Legend

🟥 Floodplain
🟨 Buildings
🟧 Buildings flooded

Buildings in present condition
Infiltration estimated
as 2,03 cm/h

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Date: 15.07.2019
Projection: Transverse_Mercator
Coordinate system: ETRS_1989_UTM_Zone_32N
Sources: NDH Larvik 5pkt 2017; Larvik municipality

Figure 19 Exposure to pluvial flooding for a 200-year event at Martineåsen, Larvik, also accounting for infiltration.

4 Conclusions

Vulnerability and exposure maps constitute a key tool for communicating climate information to stakeholders when developing adaptation strategies to climate change and associated hazards. Such maps have been extensively used so far in EVOKED during the living lab process. These maps are in some case studies regularly updated as their development is based on continuous feedback from stakeholders. In fact, in the various case studies there is a concerted effort to develop climate services that make currently "non-user friendly" climate data more understandable and thus help to bridge the usability gap (DELTARES 2019a, DELTARES 2019b, Kiel University 2019). For example, in a workshop with municipal stakeholders of the Värmland county in early 2019 the specific needs for creating added value of climate data were delineated, with suggestions including:

- Story maps that help with interpreting risk analyses
- Possibilities to create and follow up on local risk and vulnerability analyses
- Planning scenarios
- Analysis (within story maps and other descriptions) of the consequences of hazards, such as flooding and cloudburst, as well as examples of successful adaptation measures elsewhere

EVOKED is currently working on addressing these needs and bridging the usability gap - the results of this work will be reported in the project Deliverable 3.3. So far, stakeholders acknowledge these maps as an important source of information for addressing the issue of adaptation to climate change and related hazards. As an example from the Flensburg case study, stakeholders had the opportunity in the beginning of the project (initial meeting in October 2017) to formulate their needs and wishes regarding the climate services for Flensburg. One of the primary requests was regarding maps which show potential impacts of sea-level rise in the inner city and the old town, as well as in specific parts of the city. In this context climate services that use realistic numbers while at the same time integrating and combining ranges of possible sea-level rise rates and storm-surge heights were requested. The developed maps were then presented in November 2018 to a variety of stakeholders and were subsequently evaluated. The stakeholders emphasized the understandability and the visual mode of the climate services presented in the workshop and particularly, gave positive feedback regarding the benefits of the climate services provided. Table 4 shows the results of the evaluation that took place during the workshop.

Table 4 Results of climate services evaluation for Flensburg.

Items evaluating the climate services (Scale: 1 = strongly disagree to 5 = strongly agree)	N	Mean	Standard deviation
I have basic knowledge about Climate Services (CS)	25	3,44	1,26
The CS promoted in the meeting today are relevant for me	24	3,67	1
The CS promoted in the meeting today are understandable	24	4,08	0,71
This is primarily due to the:			
Visual mode (map, graph, photograph, etc.)	22	4,23	0,75
Spatial scale	21	3,86	0,73
Level of detail	22	3,82	0,73
Textual explanation (title, legend, etc.)	23	3,91	0,85
The CS promoted in the meeting today are useful	24	3,96	1
The CS promoted in the meeting today is advantageous/-beneficial for local climate adaptation	24	4,08	0,93

In the Dutch case studies, most of the attention concentrated on the inundation maps, as they are the most tangible. People appear to better associate with these maps due to personal experience. Effects of drought and heat stress are not so clear as to how these impacts might affect them. Further, a usability gap was identified in that exposure maps do not convey information on vulnerability and on expected damage (e.g. this was pointed out regarding pluvial flooding in the Fluvius region). Thus, the maps only show exposure, but the vulnerability or impact in terms of expected (financial) damage was not incorporated. To address this gap, inundation maps including information on expected damage (impact), and also incorporating information on coping capacity, e.g. to what extent a neighborhood is capable of dealing with impacts (due to e.g. available space or high income), are currently being developed specifically for a local neighborhood in one of the cities within the Fluvius case. Such maps will provide information about the ‘vulnerability’ of neighborhoods and would support a spatially-oriented and area-specific climate policy assessment. Finally, a particularly popular climate service including maps in the case studies, appears to be the story map. Story maps are currently being developed in several of the EVOKED case studies (see Deliverable D2.3).

Finally, we must note that the development of maps of exposure and vulnerability is an ongoing activity that will be carried out throughout the project as it involves stakeholder feedback and continuous development to address the needs of stakeholders regarding climate information. In this context, the present deliverable describes the main methods that have been used in the project and includes examples of products that have been used in the stakeholder meetings. Further work will build on these examples and methods will be expanded to address current usability gaps.

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