UNIVERSITY OF GOTHENBURG
Department of Economy and Society, Human Geography &
Department of Earth Sciences
Geovetarcentrum/Earth Science Centre

Investigating flood risk cost in Kungsbacka using the ICPR FloRiAn GIS-tool

Erika Lindqvist

Degree of Master of Science (120 credits)
With a major in Geography
30 hec

2019
B1053

Abstract

Losses from floods have increased in recent years, worldwide and in Sweden. Understanding the economic and non-monetary cost of being exposed to flood hazard is important from a spatial planning perspective, particularly in urban areas. In order to estimate damage and risk cost of flooding in Kungsbacka – one of the most flood-prone cities in Sweden – the ArcGIS toolbox “ICPR FloRiAn” was used. This model uses data on flood depth, flood probability and vulnerable assets to determine the cost of hazard exposure on the four focal areas or receptors stated in the EU Flood Directive (2007/60/EC): Economic activities, Cultural heritage, Human health and the Environment. The former is assessed in monetary terms, based on the value of land use categories, while the latter three are assessed non-monetarily. The ICPR FloRiAn tools were previously untested in a Swedish context and only sparingly used for local, city-scale assessments. Results showed that risk cost in Kungsbacka is considered low for the non-monetary receptors, although the damage (impact without considering probability of occurrence of floods) was rather high for Environment and Human health. The risk cost on Economic activities is 176 000 SEK/year for the 50-year flood and 226 000 SEK/year for the 100-year flood. Extreme flows such as the ‘Beräknat högsta flöde, BHF’ were problematic to assess. There is potential for FloRiAn to be used in a local context, for comparative studies and scenario modelling of future risk. However, data availability and knowledge on how to assign and interpret non-monetary values and the impact on such values are two key factors that determine success of the outcome. It was concluded that the greatest obstacle for the use of FloRiAn is the lack of data on flood-related damages in Sweden.

Key words: *Flood risk cost, flood risk analysis, risk management, flood, natural hazard, ICPR FloRiAn, GIS*

Contents

List of figures

List of tables

Terminology

BHF

"Beräknat högsta flöde" (calculated highest flow). An extreme flow, which does not have a specified return period (although it can be roughly estimated to occur about once in 10 000 years). The BHF is calculated through hydrological modelling, and takes into account factors that contribute to a high flow, such as snowmelt, precipitation, high water level in lakes, saturated ground etc. (MSB, 2019). According to the Flood Directive, hazard maps shall include areas flooded during extreme flows.

Damage function

Using damage functions is the most common approach to calculating direct damage costs (Meyer et al., 2013). The functions can be used to estimate the sensitivity (damage in monetary terms) of an asset to certain characteristics of a flood, such as water depth or velocity (Grahn, Nyberg & Blumenthal, 2014).

Hazard

Although hazards can be natural or anthropogenic in origin, the term hazard here denotes a natural phenomenon (flood) which can potentially endanger an area (UNISDR, 2017). Hazard should be distinguished from *risk* (see below). For example, hazard maps define the areas affected by flooding whereas risk maps define the risk to assets in the hazard zone, based on their amount or value (people exposed or monetary damage to buildings and infrastructure). Thus, a hazard can expose vulnerabilities to risk (Grahn et al., 2014).

Return period

The return period, or return time, of a flood event is used to measure probability of occurrence. It is the average time between two floods of similar magnitude. It is important to note that this probability is valid for a given year. Thus, the probability for a flood with a return period of 100 years in any given year during that 100-year period is 0.01. The probability of occurrence for a 100-year flood over a period of 100 years, however, is 0.63 (MSB, 2013; Grahn et al., 2014).

Risk

In this thesis, risk is understood as quantitative or probabilistic risk (Grahn, 2017). Flood risk (R) here includes probability of flood hazard (P), exposure to the hazard (E), and vulnerability of assets under exposure (V), usually expressed as:

$$R = P * E * V \qquad (1)$$

Risk cost

Risk cost is used as a statistical monetary measure of risk level, expressed as a yearly cost. It is calculated from the expected economic damage of an event (in this context, a flood event) and the probability of occurrence of the event, and remains the same as long as the probability of occurrence and the consequences are unchanged. Flood risk cost can be used for decisions on where to build and how much investment ought to be put into risk-reducing measures (Karlstads kommun, 2006). The formula from Schmid-Breton, Kutschera & Botterhuis (2018) for calculating risk cost is used in this present study[1]:

$$\text{Flood risk (SEK/year)} = \text{Potential damage (SEK)} * \text{flood probability (1/year)} \qquad (2)$$

Scenario

The term is here used for the development scenarios with different input data:

- Scenario P, which uses present day input data
- Scenario KAL, where an artificial levee has been built in Kolla, southern Kungsbacka
- Scenario RD, where new residential development has taken place

---

[1] This is the formula used for the receptor Economy; the equation is slightly modified for the other receptors for which the damage is not calculated in monetary terms. In Schmid-Breton et al. (2018), the unit of damage and risk cost is Euro, not SEK.

1. Introduction

Floods contribute to about a third of reported material losses from natural disasters over the world, and losses have increased in recent years (Munich RE, 2005). Every year worldwide, 5400 people are killed in floods, but it is very rare that floods have fatal outcome in Sweden (MSB, 2012; Grahn, 2017). The material damages, however, are often substantial, with dwellings and transport systems being the most common receptors to damage that affects economic activities (MSB, 2012). In urban areas the built environment decreases infiltration capacity and the accumulation of valuable infrastructure and assets in such areas can increase vulnerability to floods (Holden, 2012; Grahn, 2017; Morita, 2014). According to Grahn (2017), damage caused by floods has increased in Sweden since the 1980s. Predictions for the end of this century point to a warmer climate due to anthropogenic greenhouse gas emissions, with local effects in south-west Sweden including precipitation events of increased magnitude and frequency (SMHI, 2015). This will have implications for flood risk, underscoring the need for robust spatial planning and integrated flood risk management (Shih & Nicholls, 2007; Busscher, van den Brink & Verweij, 2018).

In 2007, the European Union issued the Flood Directive (2007/60/EC), which regulates mapping and mitigation of flood hazard. The purpose of the legislation is to decrease the adverse effect of flooding on four focal areas: economic activities, cultural heritage, people's health and the environment (Directive 2007/60/EC).

The field of flood risk management has seen a rise in estimations of hazard exposure cost, which influences flood mitigation policy (Grahn, 2017). Risk cost is a term for a monetary measure of risk level which is calculated from the economic consequences of an event and the probability of occurrence of the event. Determining risk cost of an event can be used to evaluate whether an area should be developed with regards to flood risk, or whether measures to reduce flood risk are cost effective (Karlstads kommun, 2006). It has previously been used in a Swedish context to highlight how flood risk can be incorporated into spatial planning (Karlstads kommun, 2006). Several models exist for assessing flood risk, for example HAZUS (US), FLEMO (Germany) and Multi-Coloured Manual (UK), although these are described by Albano, Mancusi, Sole & Adamowski (2017) as being adapted to their specific contexts and lacking in consideration of structural and non-structural measures against floods. There is a growing need for tools estimating outcomes of implementing strategies of risk-mitigation (Albano et al., 2017). The ArcGIS-based tool ICPR FloRiAn, developed for the Rhine catchment, enables calculation of the effectiveness of measures implemented to reduce flood risk (Schmid-Breton et al., 2018). It is built around the focal areas of the Flood Directive and was developed to evaluate the targets of flood risk management plans (ICPR, 2016). While adapted to the countries around the Rhine, ICPR FloRiAn is described as transferrable to other rivers (Schmid-Breton et al., 2018) and has not previously been tested in Sweden.

1.1. Aim

The aim of this study is to investigate the risk cost of a 50-year flood, a 100-year flood and a "worst-case scenario" flood in Kungsbacka, a city that has been identified by the Swedish Civil Contingencies Agency as one of the most flood prone areas in the country (MSB, 2018a). By utilising the recently developed ArcGIS tool "ICPR FloRiAn", the study also aims to identify advantages and barriers to further implementations of the tool in a Swedish context.

1.2. Research questions

a) How does flooding of certain return periods affect the four receptors identified in the Flood Directive in Kungsbacka?
b) How could the economic risk cost change if a strategy for protection is implemented or if the values at risk increased through new residential development in the hazard zone?
c) Which are the principal advantages to the ICPR FloRiAn tool and which are the main impediments against its use in Swedish flood risk planning?

2. Background

This chapter outlines an introduction to flood impacts. Previous research behind risk cost assessments is briefly discussed along with the Swedish context of flood risk management. Lastly, the study area Kungsbacka is presented.

2.1. Flood impacts

Floods can have direct and indirect impacts (Grahn et al., 2014). The direct impacts are the immediate consequences of a flood, such as physical damage to buildings and infrastructure, while indirect impacts are secondary consequences appearing some time after the event, such as production loss or emergency response expenses. The direct and indirect impacts can in turn be divided into tangible and intangible damages. Tangible damage (physical damage to buildings, industry production losses, traffic disruptions etc.) can be measured in monetary terms, something that is significantly more challenging for intangible damage (ecosystem losses, effect on cultural values and health, discomfort etc.). This is why tangible consequences are the focus of the majority of flood damage-related literature (Grahn et al., 2014; Meyer et al., 2013).

Within the field of flood risk management the most common approach to calculate direct flood damage costs, particularly in urban environments, is the use of damage functions (Meyer et al., 2013; Merz, Kreibich, Schwarze & Thieken, 2010). Such functions are used to estimate the damage in monetary terms of an asset to certain characteristics of a flood, such as water depth or velocity (Grahn et al., 2014). The use of damage depth curves, which presents the damage at certain inundation depths, is a common method to assess urban flood damages (Oubennaceur, Chokmani, Nastev, Lhissou & El Alem, 2019). Water depth is considered the most important factor to determine damage on buildings (Grahn et al., 2014, Dottori, Figueiredo, Martina, Molinari & Scorzini, 2016), but other factors are also assumed to affect the level of damage. Examples include characteristics of the flood (impact parameters) such as flow velocity, sediment load, flood duration, or characteristics of the assets and response (resistance parameters) such as building material and age, flood warnings and previous experience (Grahn, 2017; Merz et al., 2010). Damage functions can be created empirically, using data on damage from past floods, or synthetically, evaluating vulnerability of certain objects or land use categories with the help of expert assessments, or by using a combination of both approaches (Merz et al., 2010). The deficit of observations of actual damages from flood events can hinder the creation of reliable damage models and damage functions based on literature may need to be adjusted according to local observed damages (Dottori et al., 2016). Damage functions can be either relative or absolute; the former describing the reduction in value in relative terms, as a percentage, while the latter uses absolute values and connects them to a certain flood depth (or other parameter) (Grahn et al., 2014). Relative damage functions have a greater transferability, both in spatial and temporal terms, since they are not connected to market value changes. However, they do require additional information on the value of assets at risk, which may increase uncertainties (Merz et al., 2010). Modelling flood risk with damage functions requires that the user understands the limitations and the context within which the functions have been developed (Meyer et al., 2014 in Grahn, 2017). Damage functions are usually considered dependent on the geographical context whence it originated (Grahn, 2017).

2.2. Assessing flood damage and risk in Sweden

In Sweden, the Flood Directive is implemented through the decree *Förordning (2009:956) om översvämningsrisker* and the governmental agency direction *Föreskrift (MSBFS 2013:1) om riskhanteringsplaner* (Länsstyrelsen Hallands län, 2015). The management of flood risk in Sweden is based on 6-year cycles, during which flood risk-prone areas are identified, hazard and risk maps produced, and risk management plans with goals and mitigation measures drawn up. The Swedish Civil Contingencies Agency (MSB) is responsible for mapping flood hazard in the country, and the County Administrations are in charge of producing risk maps within hazardous areas as defined by MSB (MSB, 2018b). In 2013, MSB modelled flood risk for a number of cities across Sweden, and in 2018 the models were run again with some improvements (MSB, 2019).

Floods in Sweden most commonly occur along rivers and lakes and are usually caused by periods of prolonged rainfall or snowmelt (MSB, 2012). Riverine floods often evolve gradually, lasting from a couple of days to several weeks. The effects of such a flood can be very localised since the affected area and buildings are the river-adjacent ones. However, areas affected by riverine flooding can be impacted recurrently and frequently, and the potential for substantial losses is high (Munich RE, 2005). In Sweden, flood insurance is included in home insurance, regardless of the risk level (Grahn & Olsson, 2018), and most people are thereby covered by this safety net (Grahn, 2017). Most data on flood damages are also collected by the private insurance sector (Grahn, 2017), meaning that this information in not readily available for the public, or for planners and decision makers. Johansson (2015) raised the issue of scale-dependent capture of experiences from floods; smaller events are more likely to be missed during official statistics collection. The author calls for more proactive collection of data after flood events and proposes that data sources such as the media could be used for information collection on smaller floods, although the reliability could be an issue (Johansson, 2015).

The most substantial analysis of flood risk in Sweden was made for Lake Mälaren as a government commission in 2010. This study combined GIS overlay analysis and interviews to determine which functions were affected by flooding of a 100-year return period and a >10 000-year return period, as well as the scope of damages. It was found that the direct costs were 600 million SEK for the 100-year flood and 1100 million SEK for a >10 000-year flood (Grahn et al., 2014). Another previous study focusing on Karlstad estimated the economic damage from flooding and calculated the annual risk cost for the city (Karlstads kommun, 2006). The study was undertaken within the European project FLOWS (Floodplain Land Use Optimisation Workable Sustainability), the purpose of which was to investigate flood risk mitigation in water-adjacent communities. The risk cost for a 100-year river flow coupled with either a lake water level caused by normal precipitation or a level caused by extreme precipitation was calculated using an equation that considered the probability of flooding and the predicted economic (temporary) damage on buildings and infrastructure, taken from standard values. The study found that the annual risk cost amounted to between 271 000 and 495 000 SEK for the normal precipitation scenario and 135 000-242 000 SEK for the extreme scenario[2], although the authors emphasize that several possible costs have been omitted, for example intangible damages and damage to culturally valuable objects and the environment (Karlstads kommun, 2006).

2.3. Study area

This chapter describes the study area, Kungsbacka, particularly focusing on the flood related characteristics of the place.

2.3.1. Development and risk in Kungsbacka

Kungsbacka is located on the coast in northwestern Halland County (see fig. 1). The municipality has about 80 000 inhabitants, of which 20 000 live in Kungsbacka city (Kungsbacka kommun, n.d.). It is located on a clay floodplain with rocky protrusions (Kungsbacka kommun, 2009a; Kungsbacka kommun, 2018a). Through the Kungsbacka city centre runs the river Kungsbackaån, reaching the sea approximately 2 kilometres downstream. The river is rather shallow and considered to be of high environmental and cultural value (Kungsbacka kommun, 2018a) although it is affected by eutrophication, with surface runoff, agriculture, and private sewage systems being primary sources of nitrogen and phosphorus (Kungsbacka kommun, 2018b). River Kungsbackaån has been investigated as a

---

[2] In 2018 prices, the normal scenario has a risk cost of 313 000-572 000 SEK and the extreme scenario 156 000-280 000 SEK. These numbers were calculated using the Statistics Sweden price recalculator (Statistics Sweden, n.d. a)

potential source of potable water but considered unsuitable due to risk of pollution from the many industries along it (Kungsbacka kommun, 2015). Kungsbacka municipality ranks average when it comes to climate adaptation, according to a 2017 questionnaire study by the Swedish trade organisation for insurance companies and the Swedish Environmental Research Institute, where the municipality placed 103^{rd} out of 202 participating municipalities (IVL, 2017).

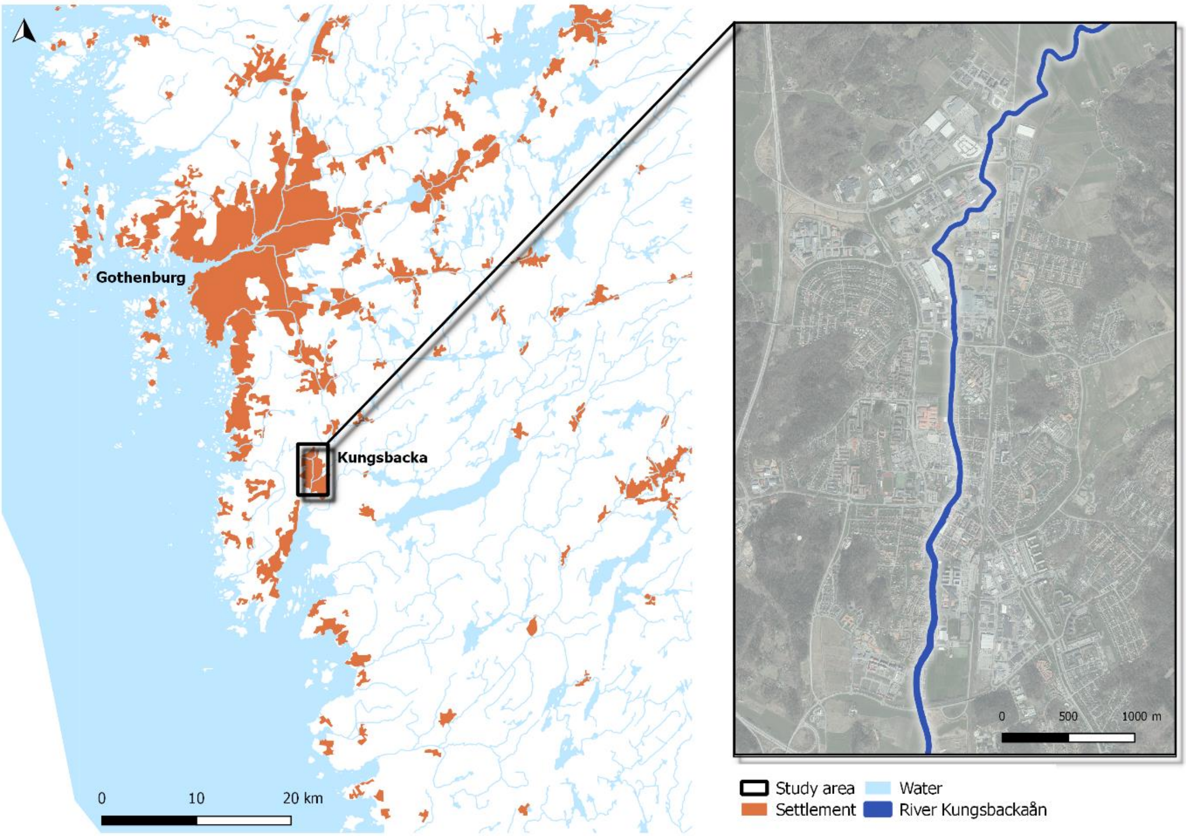


Fig. 1. Overview of the study area, Kungsbacka. Data sources: Lantmäteriet (GSD-Ortofoto, 2016; GSD-Översiktskartan vektor, 2015).

MSB identified the city of Kungsbacka as significantly at risk from flooding in 2011 and again in 2017 (MSB, 2018a). It is one of the 25 areas in Sweden most vulnerable to floods. The city of Kungsbacka is threatened by flooding from two sources, the river Kungsbackaån, and the sea, and the number of residents and employees affected is high. Using modelled flood scenarios from 2013, MSB found that 501 residents and 1409 employees (in total 1910 people) were at risk of being affected by a 100-year flow in the river, whereas 2792 residents and 4813 employees (in total 7605 people) would be affected by the BHF (MSB, 2018a). For the 50-year flow, there is no corresponding information in MSB (2018a). The Halland County Administration has produced a risk management plan for Kungsbackaån. This plan counts only people affected at their place of residence and estimates that only 400 people are affected by the 100-year flow, about 2000 people by the BHF and no people are affected by the 50-year flow (Länsstyrelsen Hallands län, 2015). The purpose of the risk management plan is to create possibilities to mitigate and reduce flood risk, with the implementation of certain measures, which are formulated using the four focal areas from the Flood Directive; people's health, the environment, cultural heritage and economic activities (Länsstyrelsen Hallands län, 2015). Measures to reduce flood risk are classed as preventive (separates flood risk from vulnerable assets), protective (reduces either flood threat, vulnerability or consequences), preparative (early warnings, education, drills, plans) or reconstructive (preparation for reconstruction and capture of experience and lessons learned). Most measures are designed to withstand a 100-year flood. Examples of highly prioritised measures are: inform the public about flood risks, routines and inhabitants' responsibility (focal area: people's health), ensure that measures do not have a detrimental effect on the environment (focal area: environment), evaluate vulnerability of cultural values to climate change (focal area: cultural heritage), identify important transport infrastructure and the need to protect this against floods. Future measures to investigate include long-term, structural protection, such as a barrier towards the sea or diking of the lower stretches of the river (Länsstyrelsen Hallands län, 2015). However, one possible drawback of building structural flood protection is the so-called "levee effect" feedback loop. This means that reinforcing protective barriers encourages development in the flood prone area, which leads to greater need for investment in flood protection (Hino, Field & Mach, 2017; Busscher et al., 2018). Kungsbacka has set a target to produce 300 new housing units per year and the city is planned to grow mostly through the process of densification. The comprehensive plan for Kungsbacka states that the risk level must be within acceptable bounds when new areas are developed. At the same time, access to the river for recreational purposes is important according to the municipality (Kungsbacka kommun, 2009a).

2.3.2. The 2006 flood and flood protection

In December 2006, Kungsbacka was hit by a substantial flood caused by prolonged precipitation in combination with strong southerly winds, which caused seawater to intrude into the river (Länsstyrelsen Hallands län, 2015). No fatalities, severe injuries or evacuations occurred during the event; however, economic activities and services in the city were affected. Several houses and basements were flooded, as were a mall, an industrial area and the building that houses the city archives (Länsstyrelsen Hallands län, 2015). Estimations from the Swedish Meteorological and Hydrological Institute (SMHI) show that the precipitation which preceded the flood event was in the 100-year category for certain areas, while other estimates put the return time of the precipitation event closer to 200 years (Länsstyrelsen Hallands län, 2015; Kungsbacka kommun, 2009b). The geological conditions in Kungsbacka make the city prone to landslides and these stability issues complicate construction of heavy flood barriers (Kungsbacka kommun, 2009a). Since the flood in 2006, however, the city has invested in a couple of protective measures, such as a wall surrounding the mall Kungsmässan and temporary mobile flood barriers (Länsstyrelsen Hallands län, 2015). Kungsbacka also relies on the flood warning system Floodwatch. The system monitors streamflow in Kungsbackaån so that the municipality can assemble the mobile protective barriers in case of high flows that risk causing a flood (A. Noreen, personal communication 2019-02-13). Another result of the 2006 flood is the recommendation in the Kungsbacka comprehensive plan for certain floor heights along different sections of the river

(Länsstyrelsen Hallands län, 2015). In 2014, a protective installation was constructed in Signeskulle (fig. 2), which consists of a steel-clad plastic barrier, concrete plates and a wooden sundeck for recreation (Kungsbacka kommun, 2014). This levee is approximately 600 m long and designed to withstand water levels of up to 3 m above normal height (Kungsbacka kommun, 2014). The project cost 33 million SEK, of which 11.5 million SEK was funded by MSB (A. Noreen, personal communication 2019-02-26). Another artificial levee solution with adjacent pumping station is planned in southern Kungsbacka (Kolla) to protect an area of residential buildings (fig. 2). This levee will be approximately 800 meters long and located along the western riverbank (Kungsbacka kommun, 2018b). The levee will be designed partly as a wall-like structure and grass-covered slope and partly incorporated into a raised path for walking and biking. The aim is to create a new park area along the levee with seating, greenery and meeting places. The projected cost for the Kolla artificial levee is 41.6 million SEK (cost estimation from 2018) (Kungsbacka kommun, 2018b).

Fig. 2. The location of the artificial levees in Kungsbacka. Signeskulle levee was constructed in 2014, while the Kolla levee has yet to be built. Data source: Lantmäteriet (GSD-Ortofoto, 2016).

3. Methodology

The following chapter describes the method that forms the basis of this thesis. It also presents the selection of data and lays out the steps taken to prepare the data for analysis.

3.1. ICPR FloRiAn

Many methods for estimation of flood damages are based on GIS applications. GIS software can be used effectively for risk mapping, overlaying data of flood extent, depth, and velocity with data layers of vulnerable objects such as buildings, roads or valuable nature areas (Grahn et al., 2014). For this present study, the ArcGIS-compatible model "ICPR FloRiAn" (which stands for Flood Risk Analysis) is used to assess flood risk in Kungsbacka. The model, or toolbox, was developed by Schmid-Breton et al. (2018) to be used for evaluating flood risk reduction strategies. The research group behind the toolbox is the ICPR (International Commission for the Protection of the Rhine) and the tool is based on the available data for the Rhine catchment (Schmid-Breton et al., 2018). The model presumes that flood risk can be expressed as the product of probability of an event and the potential damage and is used to investigate the risk to the four receptors *Economy*, *Human health*[3], *Cultural heritage* and the *Environment* (Schmid-Breton et al., 2018). The toolbox is divided into these four categories, each category containing modules for:

1. Damage Assessment – this module uses land use data, flood extent and depth, asset value data and damage functions to calculate the damage to the four receptors. The output from the Damage Assessment tool (the damage to each receptor) is used as input in the Measure Summation and the Risk Assessment modules (Schmid-Breton et al., 2018).
2. Measure Summation – an optional module for calculating the combined effect of different flood-reducing measures on damage or risk. The output is the damage when one or more measures have been implemented and can be run through the Risk Assessment module to get a reduced risk value.
3. Risk Assessment – this module uses damage data from (1.) or damage data with the effect of measures from (2.) and flood probability to determine risk cost (monetary) or risk value (non-monetary).

---

[3] Receptor Human Health will be referred to as 'Inhabitants' in the rest of the text.

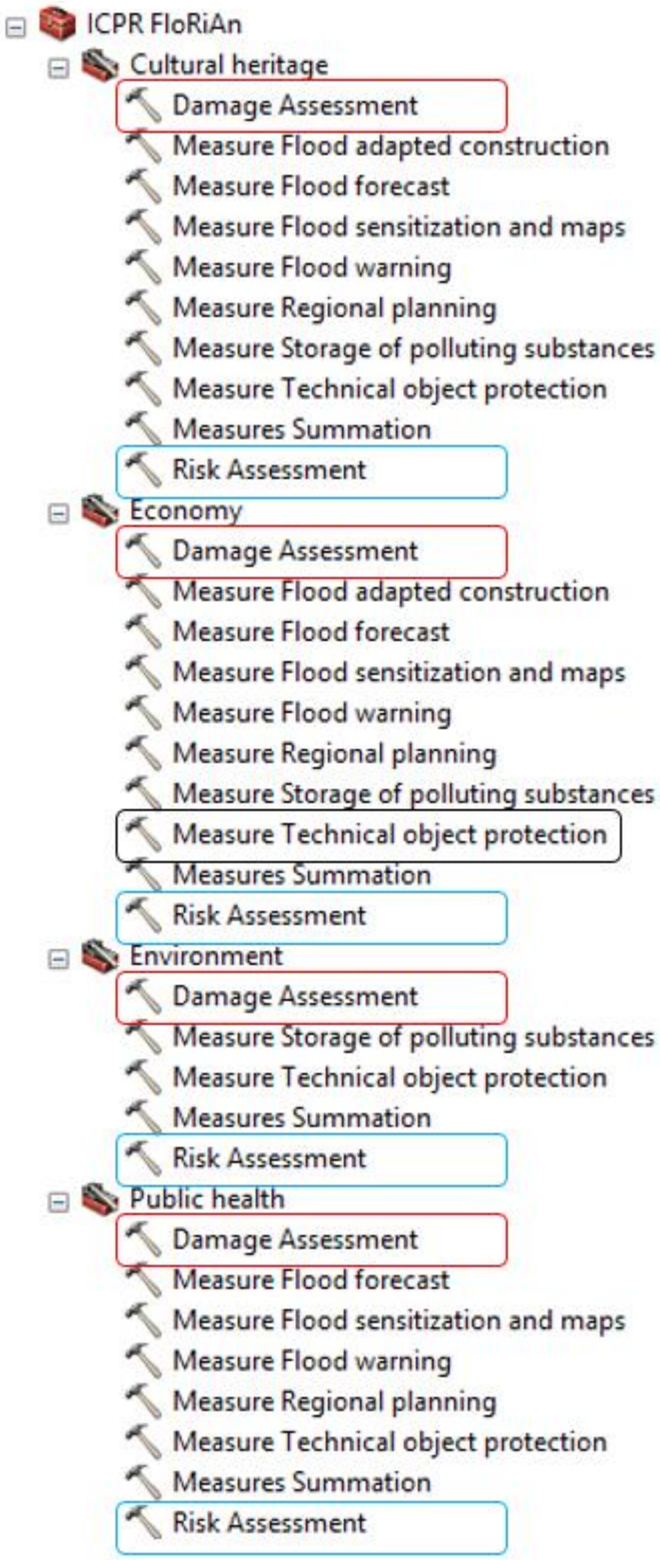


Fig. 3. The layout of the FloRiAn toolbox, which contains one module per receptor. Each module contains tools for Damage Assessment (red), Risk Assessment (blue), and different Measures (the one used in this study marked in black). The marked tools are the ones used in this study.

Fig. 3 shows the layout of the FloRiAn toolbox. The calculations are made at raster cell level (ICPR, 2016) and the output is presented in raster format (damage or risk values) and table format (aggregated statistics of damage and risk). For the receptor Economy the values are monetary (Euros in Schmid-Breton et al. (2018) and SEK in this thesis), while for the other receptors the damage and risk is expressed in non-monetary values. For example, the risk value (output from 3.) for Inhabitants is number of people affected/year, calculated by combining flood depth and inhabited areas (ICPR, 2016). For Culture and Environment the risk value is a classification calculated by combining water depth with vulnerability and significance of culturally and environmentally valuable objects (ICPR, 2016). Some input data are common for analysis of all receptors, such as flood depth, land use and administrative area, while some inputs are specific to each receptor, e.g. asset value, inhabitants, cultural objects, environmental protection areas etc. Further description of input data is found in section 3.2 below. In fig. 4 a flowchart of the FloRiAn analysis for this thesis is shown. Here, input data for each receptor (scenario P) as well as the two scenarios for receptor Economy (KAL and RD) is listed and transferred into the three tools from the FloRiAn toolbox that were used in this study: Damage Assessment, Measure "Technical object protection" and Risk Assessment. The output produced from the former two is used as input in the latter tool to get a value of the risk, with or without measures.

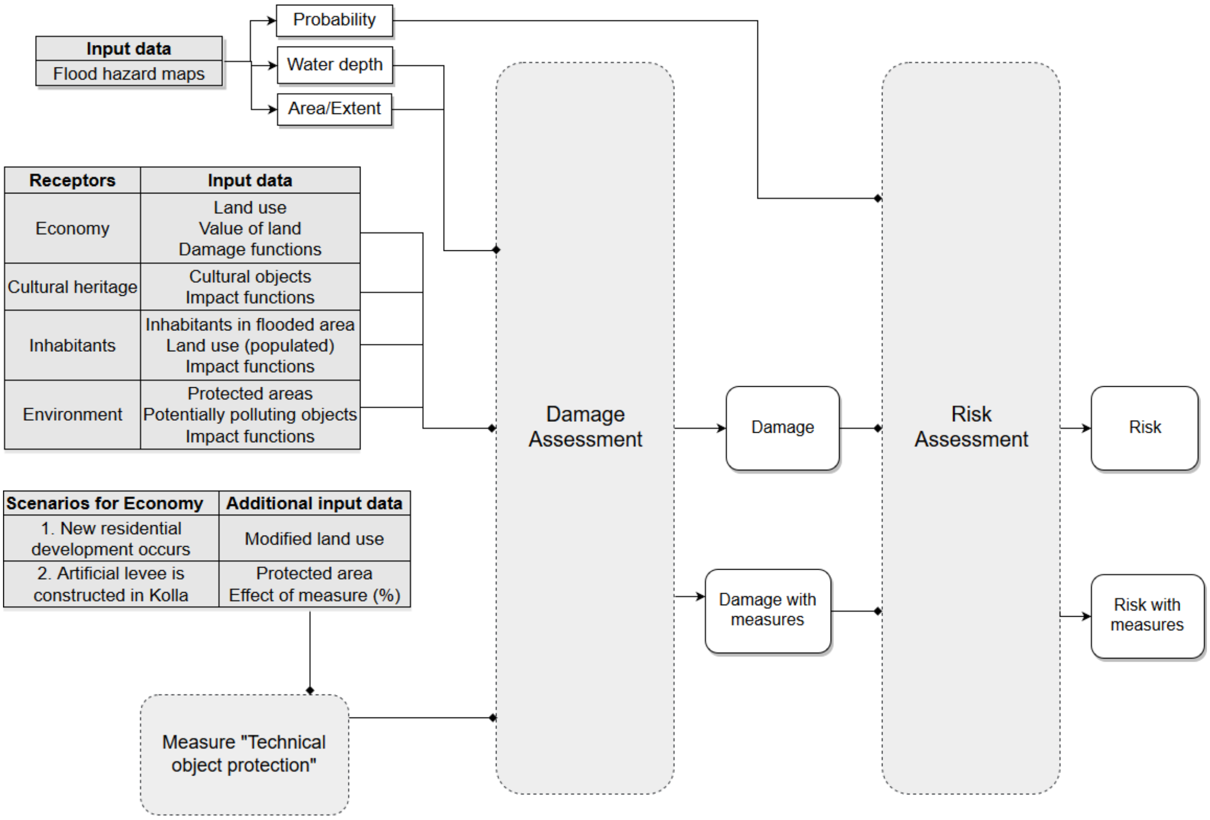


Fig. 4. Adapted from Schmid-Breton et al. (2018). Flow chart of the data processing through FloRiAn. The grey tables contain the input data required for running the scenarios: one with present day input data (P), one where an artificial levee has been built in Kolla (KAL) and one where new residential development has taken place (RD). The grey dashed boxes show the FloRiAn tools used for this study and the white boxes show the output of the tool, which is presented in the Result section below.

3.2. Selection and preparation of data

The necessary input data for FloRiAn are flood rasters (water depth), damage functions and vector and table data with attributes related to the receptors within flood prone areas (land use, number of affected inhabitants, potentially polluting industries, valuable nature areas, cultural heritage objects etc) (Schmid-Breton et al., 2018). The flowchart in fig. 4 presents the data used in the model runs, and another example of datasets can be seen in fig. 5. For a comprehensive table of data, data sources and data preparation, see appendix I.

3.2.1. Administrative area and inhabitants

Kungsbacka was chosen as study area because it is one of the places in Sweden significantly at risk from flooding (MSB, 2018a). Furthermore, the city of Kungsbacka has experienced a 100-year flood in the recent past (2006) (Länsstyrelsen Hallands län, 2015) and is expected to grow through densification of the urban environment, increasing the asset value within the flood risk zone. FloRiAn calculations take place within the boundaries of one or several administrative areas (ICPR, 2016). The extent of the administrative area was taken from the Statistics Sweden database of ‘tätorter’, population clusters of at least 200 inhabitants

(Statistics Sweden, n.d. b). The polygon for Kungsbacka was manually modified to only cover the city and to cover the whole extent of the modelled flood raster, which is necessary for the FloRiAn tools to work (fig. 5).

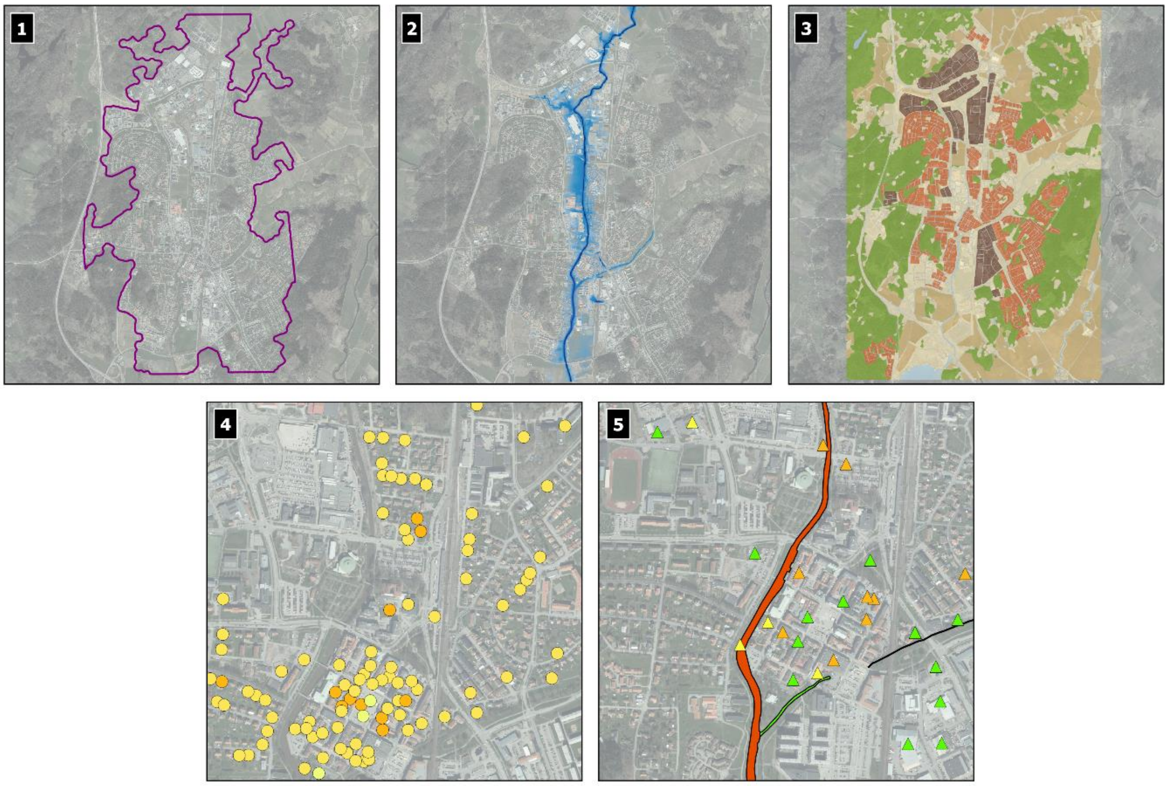


Fig. 5. Example of datasets used in the thesis. 1 = administrative area, 2 = flood raster (100-year flow), 3 = land use raster, 4 = cultural heritage objects, 5 = environmentally vulnerable areas (river) and potentially polluting objects. Data sources: Statistics Sweden, MSB, Halland County Administration.

Data on the number of inhabitants are used to determine the number of people affected by the different flows – e.g. damage on the receptor Inhabitants. For the scale of this study there is no census data with high enough resolution to determine how many people live within the extent of the flood. Since each flow has to have an inhabitant input number > 0 in order for the tool to accept the input, the choice was made to forgo the documentation from MSB (2018a) and the Halland County Administration (Länsstyrelsen Hallands län, 2015) (see section 2.3.1) and calculate the number of inhabitants with GIS for all flows to generate a comparable output. This analysis was made using flood extent for all three flows, a shapefile of buildings with the attribute living area, provided by the municipality, and statistics on average living area per person in Kungsbacka, provided by Statistics Sweden (2019a). This overlay analysis showed that 1156 people are affected by the 50-year flow, 2367 by the 100-year flow and 3241 by the BHF. The number of affected inhabitants is not exact but it should be noted that the information on inhabitants given in both MSB (2018a) and Länsstyrelsen Hallands län (2015) is based on the MSB flood model run from 2013, whereas this present study uses the latest flood data from 2018. Data on the percentage of inhabitants who can be evacuated during a flood event has been set to 0, since such information is not available for the study area. This was done despite the risk management plan (Länsstyrelsen Hallands län, 2015) stating that during the BHF extreme flow evacuation of people will be necessary.

Additional data in tabular form necessary for the analysis have been provided by the ICPR. These are land use categories which are populated (boolean) and the impact categories (ranging from 1 - very small impact - to 5 - very high impact) and their relation to water depth.

3.2.2. Flood data

The FloRiAn tool allows for investigation of several flows at once; a low impact, a medium impact and an extreme impact flow (Schmid-Breton et al., 2018). The low impact event has a higher frequency of occurrence whereas the extreme event occurs very rarely. The return periods investigated in this study are the 50-year flood, the 100-year flood and the BHF, and all flood data were provided by MSB (see fig. 5). These return periods have been chosen because of the recommendation by the Halland County Administration that measures to limit the consequences of a flood focus on the 50-year and 100-year return period flows. However, the consequences of a BHF are also considered relevant, especially from a disaster management perspective (Länsstyrelsen Hallands län, 2015), and therefore this extreme flow, which can be roughly estimated to have a return period of 10 000 years (MSB, 2019) was selected. Another reason for choosing these flows was that the data was readily available (as well as for the 200-year flow). One-dimensional and two-dimensional hydrological models were used by the MSB and its consultants to calculate flood extent, water depth and velocity. The flows with return periods of 50 and 100 years were developed using statistical frequency analysis of measured discharge, although the observations are taken from neighbouring water courses with similar characteristics due to the fact that Kungsbackaån does not have the required measuring stations. The BHF was calculated solely by hydrological modelling since observations of such rare and impactful events are scarce (MSB, 2019). Several authors such as Grahn et al. (2014) and Morita (2014) bring up the importance of considering climate change when modelling flood hazard and flood risk. The 100-year flow is calibrated with a climate effect to reflect a flow with that same return period at the end of this century, whereas the 50-year flow and the BHF are calculated using the climate effect of today (MSB, 2019). The climate effect calibration of the 100-year flow primarily utilised the IPCC emission scenario A1B, which assumes a peak of CO_2 emissions in 2050, and to a lesser degree utilised one scenario with higher emissions (A2) and one with lower emissions (B1) (Andréasson et al., 2011; MSB, 2019).

Apart from the effect of increased precipitation and high water levels in lakes and other water courses, River Kungsbackaån is also affected by the sea level, particularly in the lower stretches of the river. This effect is incorporated in the flood data used in this study. For the 50-year flow the sea level is set to +1 m[4], which is equivalent to present MHW (mean of highest water level for a series of years). For the 100-year flow the sea level is set to +1.8 m, which represents a future MHW and for the BHF the sea level is set to +1.7 m, which is

---

[4] Height reference system RH2000.

equivalent to HHW, the highest measured water level in a series of years, regardless of length of the series (MSB, 2019). Apart from these settings of sea level, other assumptions have also been made in the hydrological modelling. These include that the flood water is free from trees, soil and other debris, that there is not wind or wave effect, and that all bridges, dams and embankments remain intact (MSB, 2019). The flood data used in this study is from 2018 and the difference between this model run and the previous one from 2013 is improvements in the hydrological models and input data, such as elevation and bathymetry. The elevation model used is produced from laser data which includes existing flood protection along the river (MSB, 2019).

The flood data is stored in raster format, with a resolution of 2 m and contains values of depth. The processing of the data before FloRiAn analysis included transforming it to integer and changing the value unit from meters to centimetres.

3.2.3. Land use and asset data

For the analysis, raster data of land use categories is needed. The land use data used in Schmid-Breton et al. (2018) is from the Corine Land Cover database, which covers Europe. Those land use data were substituted in this present study for the vector data of Fastighetskartan, supplied by the Swedish mapping, cadastral and land registration authority (Lantmäteriet). This change was made mainly because of the higher resolution of the Fastighetskartan data. The dataset was divided into six categories: Residential, Industry, Transport, Agriculture, Forest and Other (see fig. 5). Land use categories were chosen because they encompass all land use present in the study area, but also for the reason that they matched the ones used in Schmid-Breton et al. (2018), for which there are available damage functions. After incorporating roads into the dataset, the vector data was transformed to raster format with a resolution of 2 m to match the flood raster data. For the analysis of a future scenario with more residential development the original land use data was manually modified to reflect that future land use (see below, section 3.2.7.).

For the assessment of damage on the receptor Economy, the value of the land (immobile assets) and the inventories that are stored on the land or in buildings (mobile assets) had to be estimated. This proved difficult, and the numbers used should therefore be seen as an indication, or standard value, rather than unequivocal values. For the immobile asset values several sources were used (see table 1). Where a range of values was encountered in these sources a mean of those values was used as the input asset value. To transform the values into today’s (2018 yearly mean) prices, the price recalculator provided by Statistics Sweden was utilised (Statistics Sweden, n.d. a). The value used in the analysis is shown in the fourth column of table 1. For the land use category “6 - Other” no ICPR damage function existed and therefore that category was omitted from the analysis. Thus, the value was set to 0 in table 1. Merz et al. (2010) argues that depreciated values for consumer goods should be used to estimate economic flood damage. This means that the asset is valued at the time of the flood, rather than using the cost of replacement. If replacement values are used the value might be overestimated (Merz et al., 2010). This consideration was incorporated into the analysis since the values used for most land use categories are based on assessed values. The use of depreciated values is likely more important for mobile assets. However, these had to be omitted from analysis since it proved impossible to estimate such values (including inventories of houses, vehicles etc.) accurately within the time frame of this study. The values for one m^2 of agricultural land and forest seem low in comparison to the other land use categories, however, despite extensive research no other reliable data were encountered. The County Administration (Länsstyrelsen Hallands län, 2015) predicts that forest and agricultural land will be affected by a 100-year flood, but with limited negative impact on economic values. During a 50-year flow these land use categories remain undamaged (Länsstyrelsen Hallands län, 2015). Also worth noting is the fact that the land use values in this study are purely economic; the value of the forest as an ecosystem, habitat or recreational area is not included.

Table 1. Immobile asset values used as input in the analysis of damage and risk on receptor Economy. The source of information and indicator used to represent each land use value is presented, along with the value or range of values found in the sources and lastly, the value finally used as input (2018 yearly mean price).

Land use category	**Data source [indicator]**	**SEK/m^2 (year) [chosen value]**	**SEK/m^2 2018 value**
1 - Residential	Statistics Sweden (2019b) [Genomsnittligt taxeringsvärde för småhusfastigheter (mark + byggnader), Kungsbacka]	1000-3000 (2015) [2000]	2096
2 - Industry	Statistics Sweden (2017) [Industri typkod 420-433, genomsnittligt taxerings-/basvärde, Halland]	2677 (2013)	2800
3 – Transport	Karlstads kommun (2006) [Standard value of flood damage cost for road in Karlstad municipality]	500-600 (2006) [550]	636
4 – Agriculture	Statistics Sweden (2019b), Statistics Sweden (2019c) [Genomsnittligt taxeringsvärde per hektar för Åkermark (87% av total jordbruksmark) och betesmark (13% av total jordbruksmark), Halland]	7 (2015)	7
5 – Forest	Statistics Sweden (2019d) [Total skogsmark, Kungsbacka]	5 (2015)	5
6 - Other	-	-	0

3.2.4. Damage functions

Despite the issues with transplanting damage functions to other contexts, this study has had to apply the same functions as Schmid-Breton et al. (2018) for the Kungsbacka analysis (fig. 6). This was necessary due to the lack of comparable information in Swedish flood contexts. All damage functions in the study are based on connecting the water depth to a certain reduction in value, although *Economy* is the only receptor whose value is measured in monetary terms. For the other receptors, the reduction in value is expressed as an “impact value”. These data are stored in .dbf-format. The damage functions from the ICPR were produced using a combined empirical and synthetic approach (Merz et al., 2010). The functions are relative, which means that the reduction in value is expressed as a percentage (here in per mille) rather than an absolute value (Grahn et al., 2014, Merz et al., 2010).

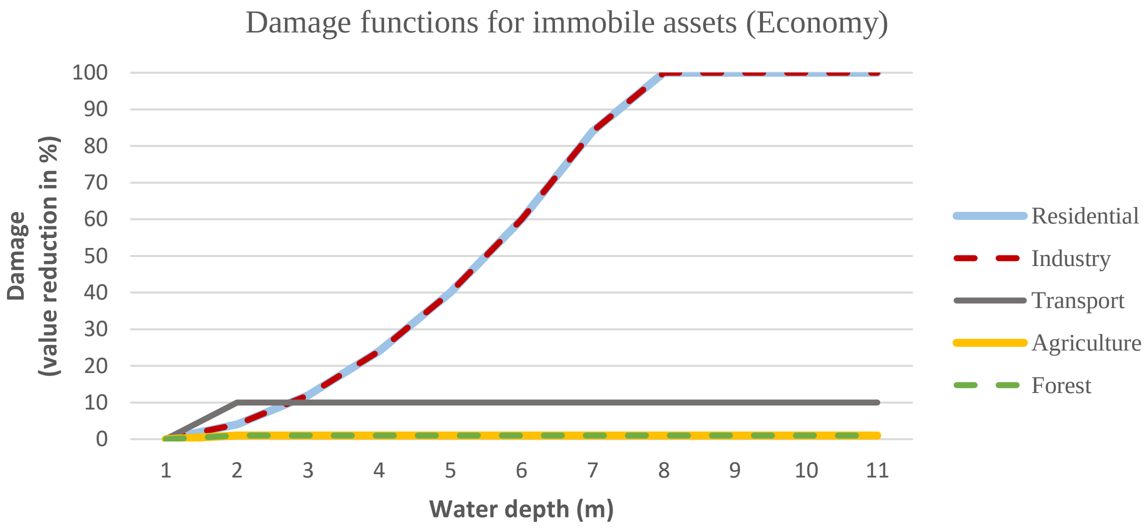
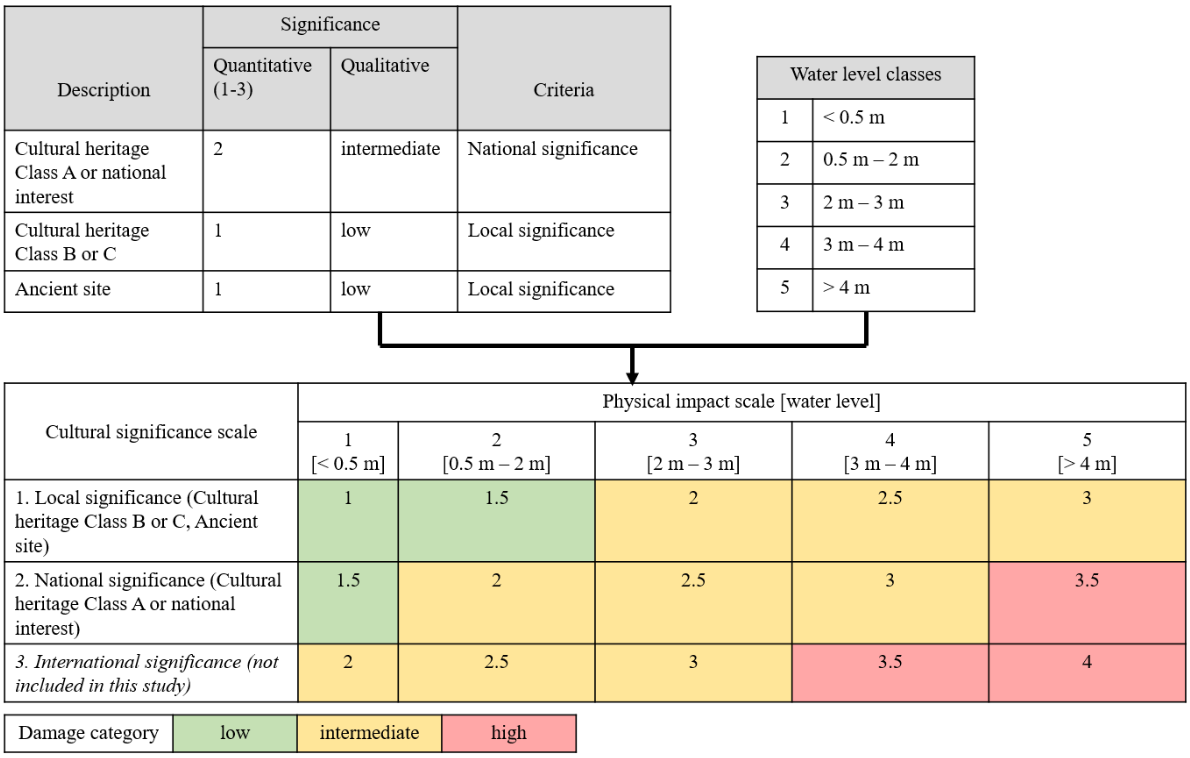


Fig. 6. The damage functions for immobile assets (one function per land use category, except for “Other”), connecting the water depth to a relative reduction in value (percent in the figure, per mille in the data). The functions for Residential and Industry are the same, as are Agriculture and Forest. Figure based on data from ICPR and produced with permission from Schmid-Breton et al. (2018).

3.2.5. Cultural objects

The types of objects serving as an indicator for cultural heritage are slightly modified compared to ICPR (2016) to reflect the available information and the local scale of the analysis. The data used were supplied by the Halland County Administration and consist of vector data for cultural national interests, buildings of three different historical value classes (A, B or C) assigned by the Swedish National Heritage Board (Kulturmiljö Halland, n.d.) and ancient sites. The preparation of the data included transforming it to point data and assigning it significance (international, national or local cultural significance), based on the attribute information (see fig. 5). The single cultural object of national interest received the significance level “national”, as did buildings of the highest class of historical value (A), while buildings of class B and C along with ancient sites received significance level “local”. The reason for putting the latter type of object into the lowest significance category was that there was very sparse information about the exact location and vulnerability of the ancient sites.

Further tabular information needed was taken from ICPR (2016) and modified to suit this study. The tool uses an attribute for “radius”, the buffer distance within which average flood depth is calculated for each cultural object. Radius was set to 1/10 of the ICPR data after using a trial and error approach. In fig. 7, a matrix for assessing cultural damage is shown. Cultural importance and water level are combined to produce the damage value.



Description	Significance		Criteria
	Quantitative (1-3)	Qualitative	
Cultural heritage Class A or national interest	2	intermediate	National significance
Cultural heritage Class B or C	1	low	Local significance
Ancient site	1	low	Local significance

Water level classes	
1	< 0.5 m
2	0.5 m – 2 m
3	2 m – 3 m
4	3 m – 4 m
5	> 4 m

Cultural significance scale	Physical impact scale [water level]				
	1 [< 0.5 m]	2 [0.5 m – 2 m]	3 [2 m – 3 m]	4 [3 m – 4 m]	5 [> 4 m]
1. Local significance (Cultural heritage Class B or C, Ancient site)	1	1.5	2	2.5	3
2. National significance (Cultural heritage Class A or national interest)	1.5	2	2.5	3	3.5
3. International significance (not included in this study)	2	2.5	3	3.5	4

Damage category	low	intermediate	high

Fig. 7. Matrix for the calculation of cultural damage. Modified from ICPR (2016).

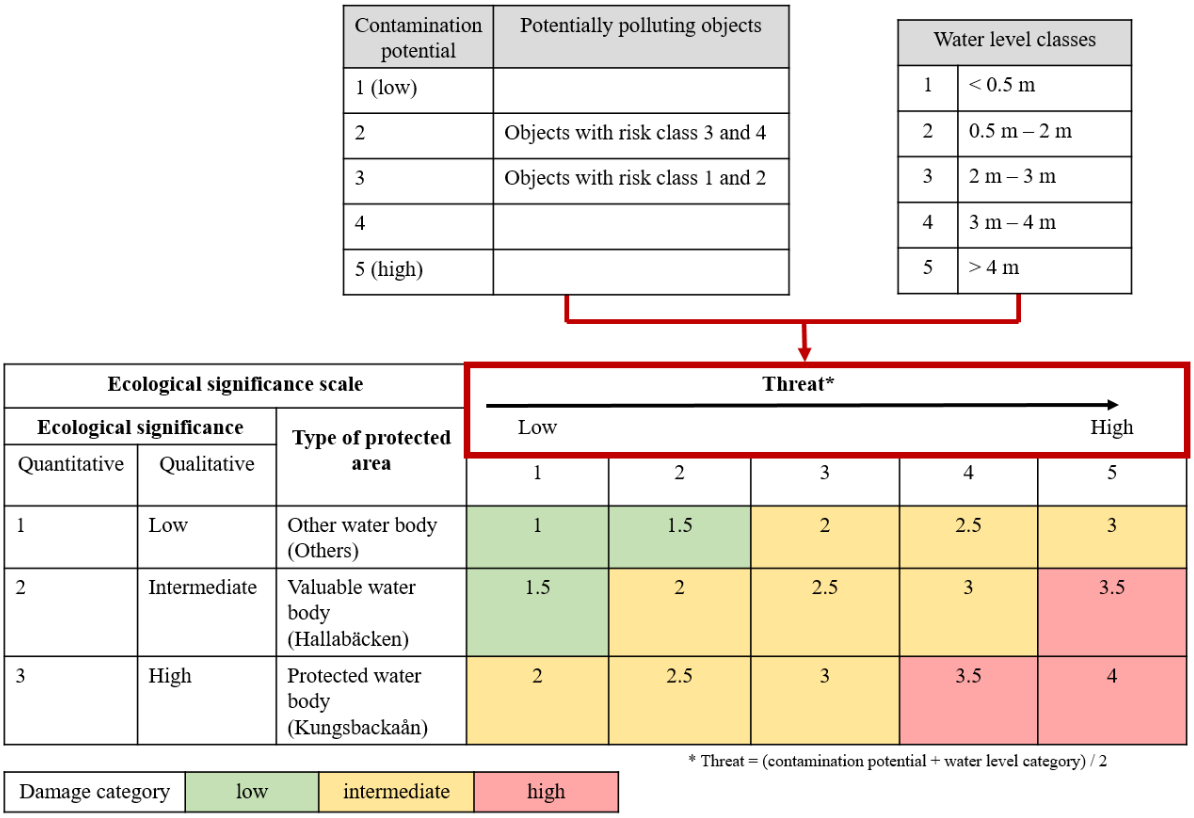
3.2.6. Environmental objects

The environmental impact is defined as the contamination of protected or sensitive areas or water bodies through pollution from industrial objects or areas where contaminated sediments are located, which are impacted by the floodwater (Schmid-Breton et al., 2018). The environmental impact is thus measured as a secondary effect of flooding; the impact of the floodwater itself on environmental values is not included.

The GIS data were downloaded from the County Administration geodata portal. In the ICPR analysis for the Rhine, data for protected areas and water bodies (bird protected areas, flora and fauna habitat, drinking water, Water Framework ecological status, and “other”) are used (ICPR, 2016). Since there are no such protected areas within the present study area the receptor Environment solely consists of water bodies, e.g. Kungsbackaån and tributaries (see fig. 5). To estimate the significance of the waterbodies municipal documentation was used.

During a flood, the risk of polluting substances reaching the river Kungsbackaån is high (Kungsbacka kommun, 2015). Furthermore, Kungsbackaån is classed as particularly valuable by the Swedish National Board of Fisheries (now discontinued) and as valuable by the Swedish Environmental Protection Agency, according to information found in the shapefile attributes. Kungsbackaån is also connected to the bay Kungsbackafjorden, which is protected by Natura 2000 status according to the Birds and Habitats Directives, and classified as a national interest due to its environmental values and a nature reserve. According to municipal planning documents, this connection means that Kungsbackaån ought to be protected against negative impact as the city develops (Kungsbacka kommun, 2009a).

In ICPR (2016) only industrial objects such as IPPC or SEVESO industries were used as potential sources of contamination. In this present study, point data of potentially polluted areas are used in addition to the industry point data (see fig. 5). These data consist of areas (land, sediments, water – below or above ground – and buildings) where contamination is suspected or confirmed (Klimatanpassningsportalen, 2018). This selection of data is considered justifiable since the industry data only contain two industries with potential harmful impact on the environment in the study area, and since the data of potentially polluted areas are intended for purposes such as identification of areas of high risk for pollution during extreme weather or natural hazard events such as flooding (Klimatanpassningsportalen, 2018). The risk of pollution from industries and other installations during flooding is of course connected to the measures these industries take to prevent leakage. The degree to which such preparations are undertaken is not known in this study; rather it is assumed that pollution takes place when environmentally valuable areas are within the impact range of potentially polluting objects that are flooded. The impact range - the distance to which the pollution reaches - was also changed from the ICPR data, since that radius, which is based on theoretical estimations for the Rhine catchment (ICPR, 2016), was considered too large for the smaller study area of Kungsbacka. Impact range is therefore based on the distance to the river mouth from the furthest object (personal communication, G. Göransson, 2019-04-02). This is a distance of 7000 m. It should be noted, however, that there could be some discrepancy between the coordinates of potentially polluted areas and the actual placement and extent of the polluted area. Similarly to the cultural damage assessment, the severity of the impact increases with increasing water depth (ICPR, 2016). The impact is also influenced by the classification of the polluting objects; here the risk classification attribute (1-4, where 1 is very high risk and 4 low risk (SGI, 2018)) already present in the data is used to group the objects. Objects without this risk class value were allocated to the lowest risk class (4). To estimate the toxicity, or the pollution potential, of the objects the risk classification was taken into account; objects with risk class 1-2 were set to toxicity 3 (average) and objects with risk class 3-4 were set to toxicity 2 (low) (personal communication, G. Göransson, 2019-04-02). Fig. 8 shows the method of calculating damage to the environment in a matrix.



Contamination potential	Potentially polluting objects
1 (low)	
2	Objects with risk class 3 and 4
3	Objects with risk class 1 and 2
4	
5 (high)	

Water level classes	
1	< 0.5 m
2	0.5 m – 2 m
3	2 m – 3 m
4	3 m – 4 m
5	> 4 m

Ecological significance scale			**Threat***				
Ecological significance		**Type of protected area**	Low				High
Quantitative	Qualitative		1	2	3	4	5
1	Low	Other water body (Others)	1	1.5	2	2.5	3
2	Intermediate	Valuable water body (Hallabäcken)	1.5	2	2.5	3	3.5
3	High	Protected water body (Kungsbackaån)	2	2.5	3	3.5	4

* Threat = (contamination potential + water level category) / 2

Damage category	low	intermediate	high

Fig. 8. Matrix for the calculation of environmental damage. Modified from ICPR (2016).

3.2.7. *Scenario data*

The following scenarios have been applied to the receptor Economy. The first scenario (RD) considers the evolution of the risk when new residential development occurs; i.e. an accumulation of valuable assets in the hazard zone. The second scenario (KAL) considers the construction of a protective artificial levee, which safeguards a residential area prone to flooding, and the effect of that protective measure on flood risk.

1. New residential development - RD

This scenario was not calculated by running any of the measure modules of the tool; rather, the input data (land use) was changed before a second run of the Damage Assessment and Risk Assessment modules. The land use modification was done according to information in municipal documentation presenting current construction projects (Kungsbacka kommun, 2018c). Only the ones falling within the flood extent were chosen. Approximate borders of the planned development were manually digitized and a new raster of land use produced. It is important to note that the information on current projects was valid in May 2018 and might not represent an accurate view of the municipal plans of today. Therefore, the result should be seen as a scenario, rather than a definite future.

2. Kolla artificial levee - KAL

To investigate a scenario where a protective artificial levee is built in Kolla (residential area in southern Kungsbacka, see fig. 2) the tool “Technical object protection” was used. This tool is meant to represent the protection of areas using mobile systems, or precautionary building/flood-proofing property (ICPR, 2016), but was chosen because the tool more suited to depict a protective levee scenario demanded data in the form of changes in probability of occurrence of the flood, which was not available. Despite the planned levee not being mobile the tool does give an indication of the reduction in risk cost. The artificial levee is meant to withstand a water level of approximately 1-1.5 m above current ground level, depending on the location along the artificial levee (Kungsbacka kommun, 2018b). Therefore, the default tool settings for the effectiveness of the measure are considered adequate. These state that the effectiveness of the protection against a water level of < 0.5 m is 90%, for a water level of 0.5-2.0 m it is 50% and for a water level of > 2.0 m it is 10% (ICPR, 2016). The protective installation is dimensioned to protect against a 200-year flow combined with the highest sea level for the bay Kungsbackafjorden (Kungsbacka kommun, 2018b). The reason for not setting the effectiveness for protection against water levels of < 0.5 m to 100% is that despite most damage being avoided, a small amount of water could seep through or enter buildings through reverse wastewater flow (ICPR, 2016). The effect of the measure is only calculated for the land use categories Residential and Industry - in this case, the protection only covers Residential area. As is the case with the Damage Assessment and Risk Assessment tool runs for the receptor Economy, the mobile assets are not accounted for due to lack of reliable data. The plans to construct an artificial levee in Kolla have not gained legal effect at the time of writing, but the municipality aspires to start construction at the earliest autumn 2019. This result should thus also be regarded as a scenario.

4. Result

This section presents the results of the FloRiAn runs of the Damage Assessment and Risk Assessment. Comparability of outputs varied greatly and therefore some results are presented in maps while others are shown in graphs or tables. The output damage and risk for each receptor (Economy, Culture, Inhabitants and Environment) is shown separately, with the scenario results falling under Economy. Economy is also the only receptor for which the result is given in monetary values.

4.1. Economy

The output from the Damage Assessment run can be seen in table 2. The results show that the damage (SEK) increases with increasing magnitude of flow for all three scenarios; the one with present input data (P), the one where residential development has occurred (RD) and the one where the artificial levee is built (KAL). Scenario P and KAL follow each other closely, with the largest difference occurring for the 100-year flow. For scenario RD, where areas of land use “industrial” and “other” have been developed into residential land use, the values at risk have increased. However, the industrial land is valued slightly higher than residential (table 1) so in some areas the values have decreased. The increase in damage cost between P and RD is largest for the BHF flow and smallest for the 50-year flow.

Table 2. Shows the total economic damage (million SEK) in the flooded area for the three flows and three scenarios: one with present day input data (P), one where an artificial levee has been built in Kolla (KAL) and one where new residential development has taken place (RD). The 100-year flow is adjusted for the predicted climate conditions at the end of the century. The values have been rounded to the first decimal place.

	50-year flow	**100-year flow**	**BHF**
Economic damage for P	8.8	22.6	59.2
Economic damage for KAL	8.7	21.7	59.2
Economic damage for RD	14.8	32.5	76.6

Table 3 shows the risk value (SEK/year) – the output of the Risk Assessment tool run – for the present (P), Kolla artificial levee (KAL) and residential development (RD) scenarios at each flow. Similarly to the Damage Assessment output (table 2), the risk for P and KAL is rather closely matched. As can be seen from table 3 the difference in risk cost between P and KAL is largest for the 100-year flow. The largest difference between scenarios P and RD, however, is for the 50-year flow (table 3). It can also be noted that the risk cost for all three scenarios (P, KAL and RD) to the BHF is very low. This is due to the long return period of this extreme flow. The 100-year flow produces the highest risk cost for all three scenarios.

Table 3. The table shows the total economic risk (SEK/year) in the flooded area for the three flows and three scenarios: one with present day input data (P), one where an artificial levee has been built in Kolla (KAL) and one where new residential development has taken place (RD). The 100-year flow is adjusted for the predicted climate conditions at the end of the century. The values have been rounded to the nearest thousand.

	50-year flow	**100-year flow**	**BHF**
Economic risk for P	176 000	226 000	6000
Economic risk for KAL	174 000	217 000	6000
Economic risk for RD	297 000	325 000	8000

The economic risk (SEK/year) during the three flows (50-year, 100-year and BHF), all for the present (P) scenario, is presented in fig. 9. The maps give an overview of the extent of the flood and the areas where the cost is (comparatively) high and low. It should be noted that the areas exposed to high risk cost are located near the river and that the threatened areas are the same for all the flows, even though the values and extent vary.

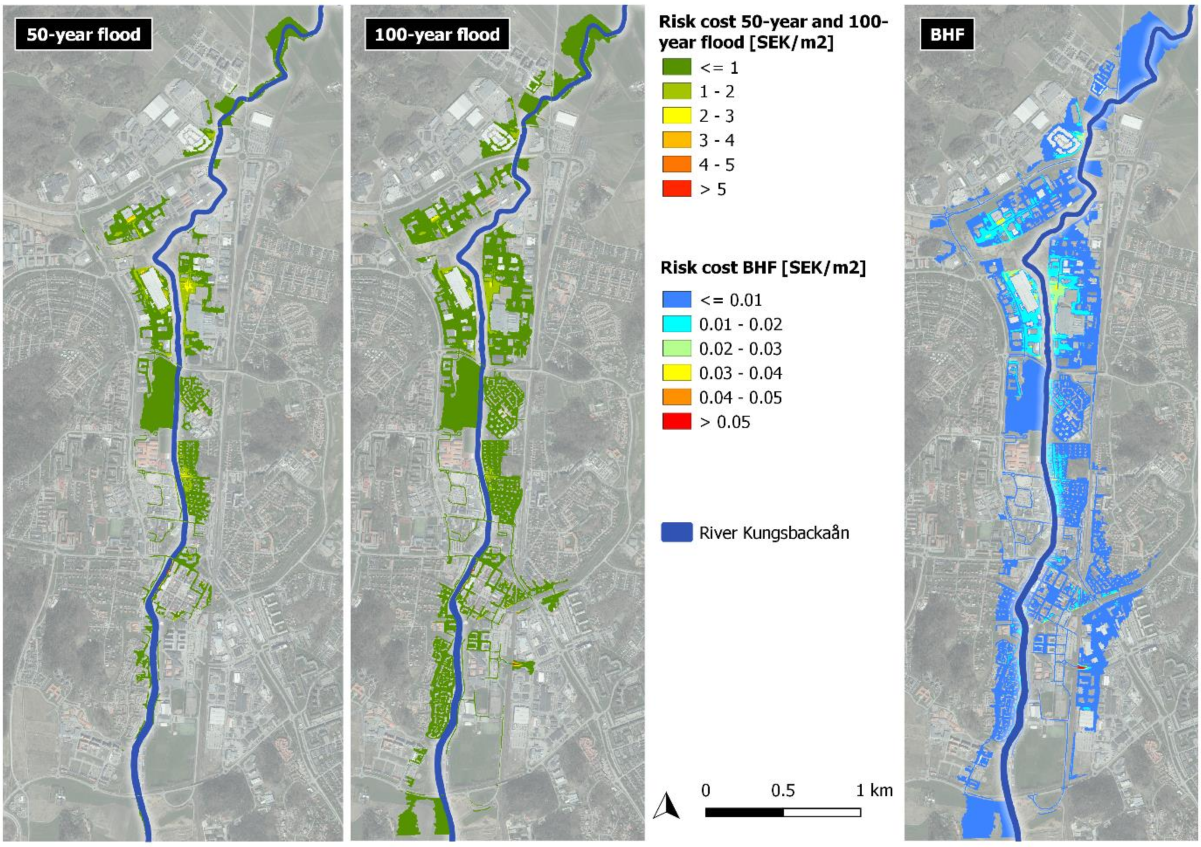


Fig. 9. The map shows an overview of the economic risk cost (SEK/m^2/year) for the three flows. The two flows with higher frequency of occurrence (50-year and 100-year) share a legend, whereas the BHF is shown on a separate colour scale due to its small values – in turn due to a much longer return period. The 100-year flow is adjusted for the predicted climate conditions at the end of the century. The river is also shown for orientation. Data sources: Lantmäteriet (GSD-Ortofoto, 2016), MSB (flood rasters, 2018).

The economic risk cost (SEK/year) for P and RD during the 100-year flow is shown in the middle and right maps of fig. 10. No comparison between P and KAL is shown since the difference in risk cost was too small to distinguish in a map. The increase in risk with residential development can be seen, particularly in the river-adjacent northernmost area of the RD map, but also in the newly built areas to the south that are further from the river.

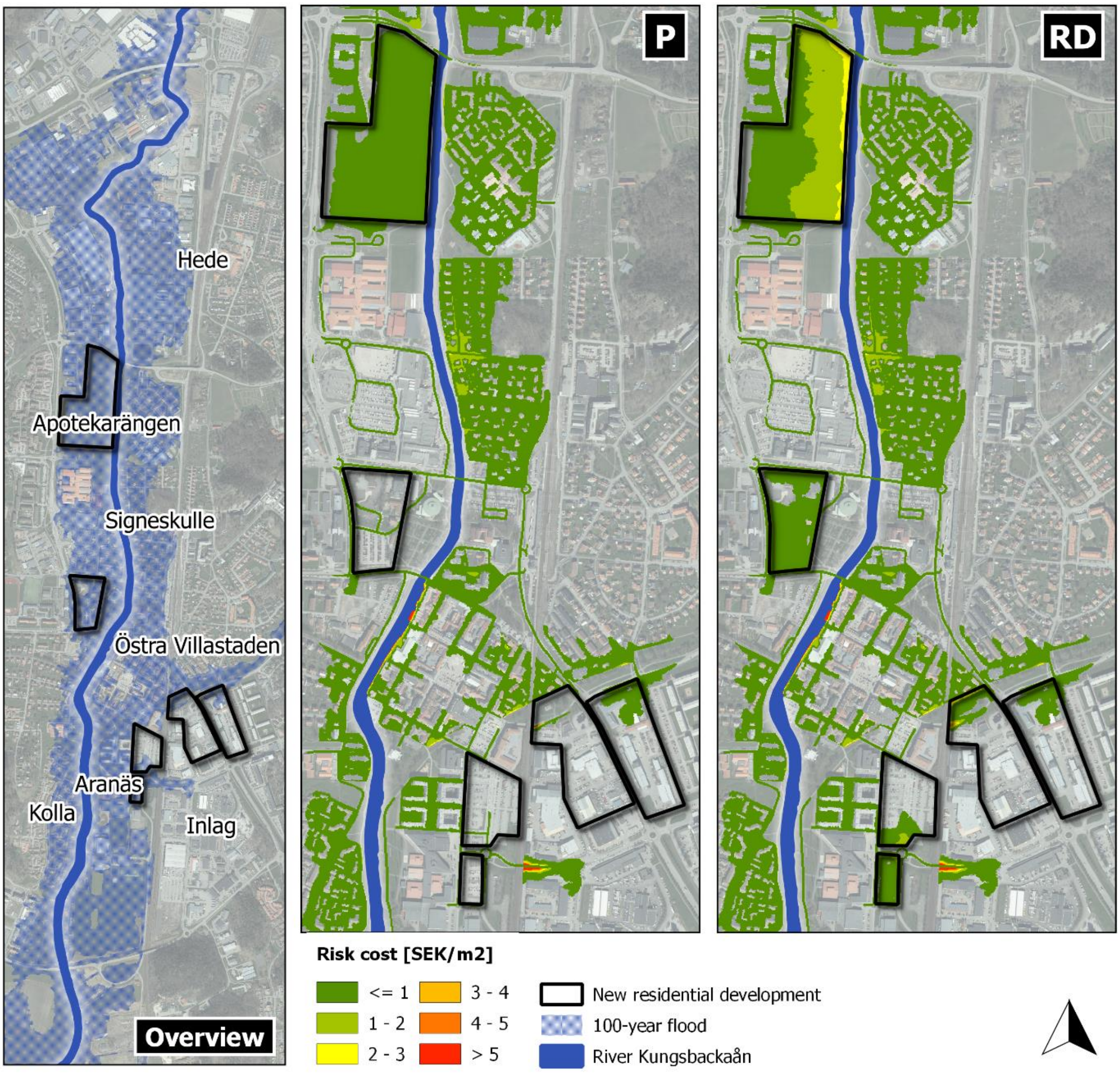


Fig. 10. Overview of areas with new residential development during scenario RD and comparison with scenario P, for the 100-year flow, which is adjusted for the predicted climate conditions at the end of the century. The economic risk cost (SEK/m^2/year) for P and RD are shown in the middle and right maps. Data sources: Lantmäteriet (GSD-Ortofoto, 2016), MSB (flood rasters, 2018).

The maps in fig. 11 show in red the areas of Kungsbacka where the risk cost for the 50-year flood is equal to or more than 3 SEK/m^2/year. The left map shows the northern part of the river and city and the right shows the southern. In total, the flooded area with a risk cost of the aforementioned size amounts to just above 2000 m^2. The cut-off 3 SEK/year was chosen as it is in the middle of the range of values for the 50-year flow (see fig. 9) but another value could just as well have been displayed. This risk cost visualisation was chosen as an example to show where the areas of comparatively high risk cost are located – in built areas close to the river in the north and central parts of Kungsbacka (fig. 11). The same pattern of risk cost can be detected for the 100-year flow (fig. 9), where the areas of higher risk cost are located in the same places, although the total cost is higher for the 100-year flow than the 50-year flow. Furthermore, the land use is shown in fig. 11. The land use where the risk cost is highest predominantly consists of industry or residential.

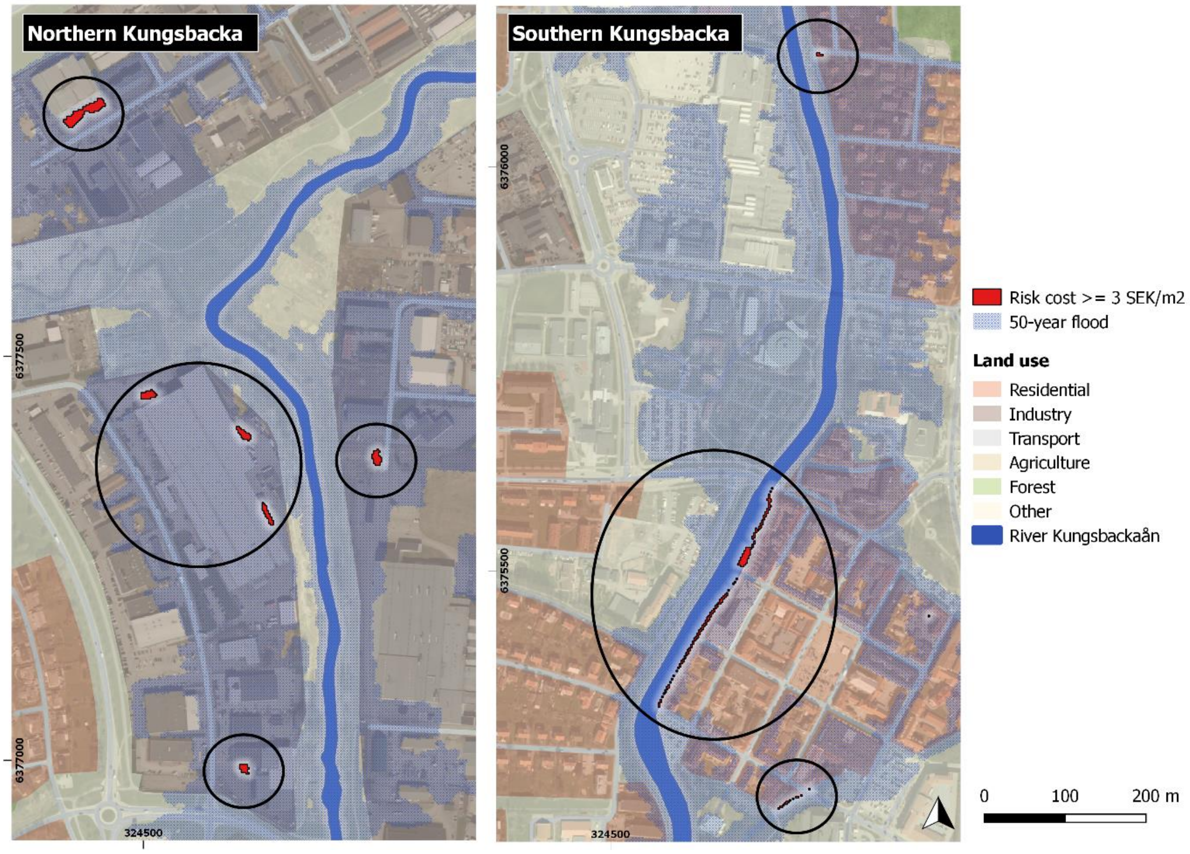


Fig. 11. The map shows the areas of Kungsbacka where the economic risk cost is ≥ 3 SEK/m^2/year for the 50-year flood, scenario P. To the left is the northern stretch of the river and to the right is the southern stretch. The land use is also shown. The sum of all flooded area with a risk cost of 3 SEK/year or more is just over 2000 m^2. Data sources: Lantmäteriet (GSD-Ortofoto, 2016; GSD-Fastighetskartan vektor, 2018), MSB (flood rasters, 2018).

4.2. Culture

For culture, the Damage and Risk Assessment output consists of a raster with one pixel per cultural object containing damage and risk values respectively, and also the summation of the values in a .dbf table. The average damage and risk values for the cultural objects are shown in fig. 12 for the three flows. The solid black line plotted on the left y-axis represents the damage and the dotted black line, plotted on the right y-axis represents the risk. The damage increases with flow magnitude, whereas the risk decreases since the frequency of occurrence also decreases when magnitude increases. Both cultural damage values and cultural risk values fall within the "low" result range on the scale of 0-4, where <1.75 is considered low and >3.25 is considered high (Botterhuis, 2018).

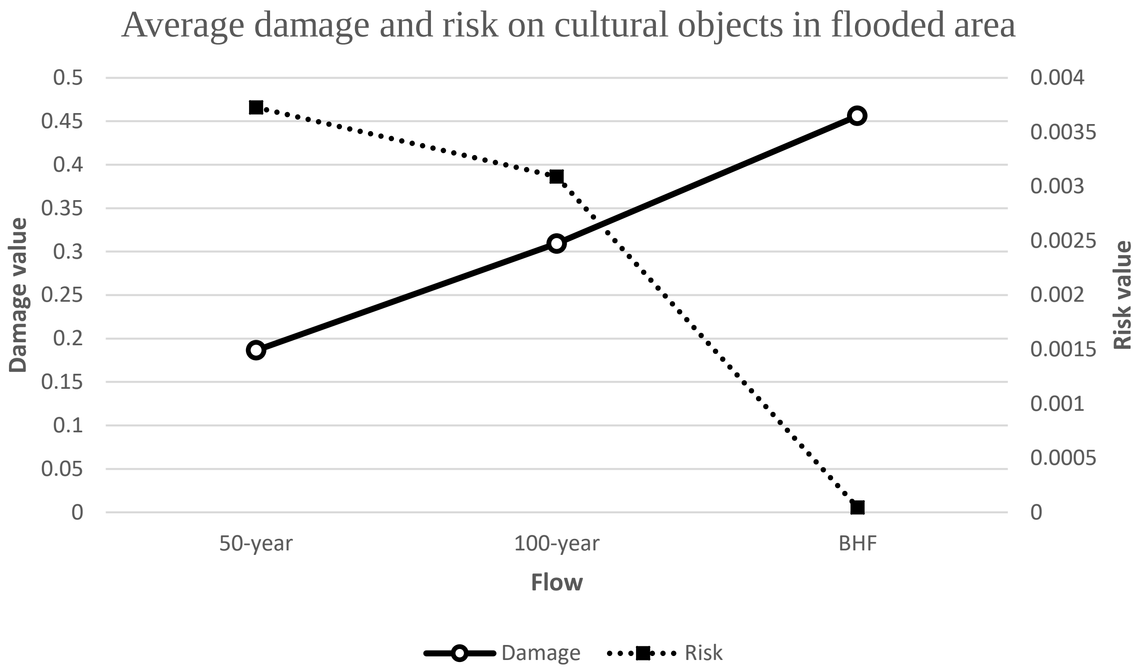


Fig. 12. The figure shows the average damage and risk values for cultural objects in the flooded area for the three flows (50-year, 100-year and BHF). The value is influenced by the cultural significance of the object and the water depth around it. Probability of flooding also affect the risk value. The 100-year flow is adjusted for the predicted climate conditions at the end of the century.

In fig. 13, the risk impact on cultural objects is shown. The objects are divided into three risk classes: low, medium and high, according to Botterhuis (2018), an automatic process in the FloRiAn Risk Assessment tool. The total number of objects for all flows is 228. The number of objects exposed to medium and high risk increases for the 100-year flow and the BHF compared to the 50-year flow.

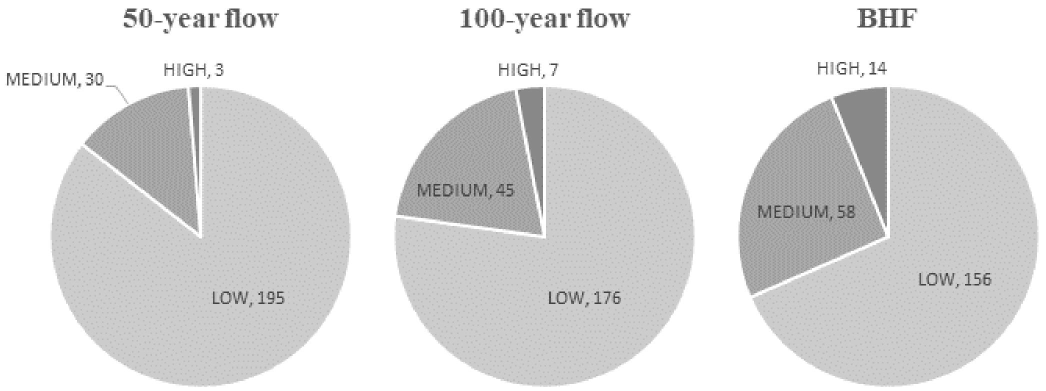


Fig. 13. Number of cultural objects that fall into risk category low, medium and high, for each flow. The risk category allocation is influenced by water depth and cultural significance of objects. The 100-year flow is adjusted for the predicted climate conditions at the end of the century.

4.3. Inhabitants

The damage on the receptor inhabitants is measured in number of people affected, and the risk in number of affected people/year. Unlike damage and risk on culture, which is presented as an average value, the output for inhabitants is a summation of damage and risk. Since no evacuation rate was used, the output values of the Damage Assessment are the same as the input values – number of people within flooded area for each flow. Fig. 14 shows the result of the Damage Assessment and Risk Assessment on receptor Inhabitants. The solid black line plotted on the left y-axis represents the damage and the dotted black line plotted on the right y-axis represents the risk. Here, the difference in risk between the 50-year and 100-year flows is very small; in fact, the risk value for the 100-year flow is slightly higher than for the 50-year flow, a pattern that diverges from the risk on culture and the environment.

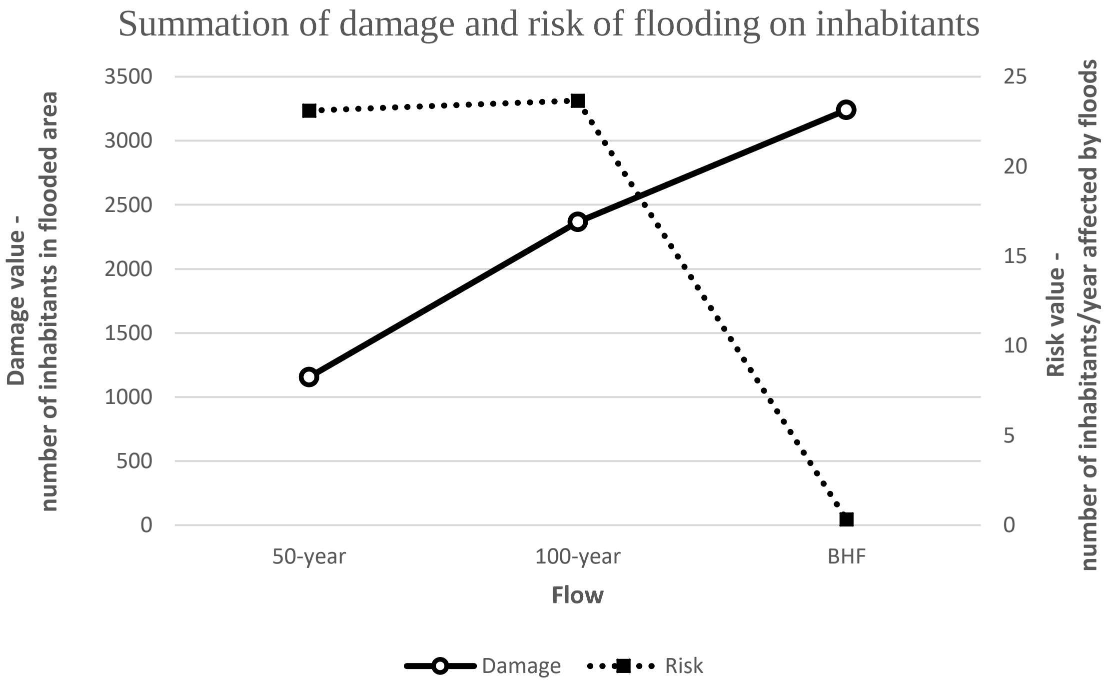


Fig. 14. The figure shows the damage value – the total number of inhabitants affected by floods of three different magnitudes (50-year, 100-year and BHF) as well as the risk value – the number of inhabitants/year affected by the same flows. The damage and risk values are both influenced by water depth and the risk value also by probability of flooding. The 100-year flow is adjusted for the predicted climate conditions at the end of the century.

Fig. 15 shows the division of affected inhabitants into five risk categories. These categories are based on flood depth in inhabited area (Botterhuis, 2018). The shares are shown as percentages to avoid confusion, since the total number of inhabitants affected/year is 23.12 for the 50-year flow, 23.67 for the 100-year flow and 0.32 for the BHF. The share of inhabitants affected by an “average” flood depth (50-150 cm) increases with increasing flow magnitude.

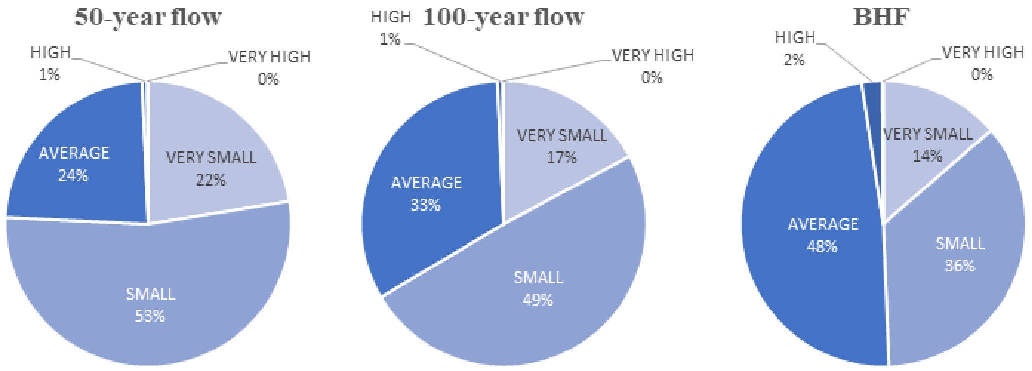


Fig. 15. Share of total affected inhabitants that fall into risk category very small (<10 cm water depth), small (10-50 cm), average (50-150 cm), high (150-300 cm) and very high (>300 cm) for each flow. Risk category allocation is influenced by water depth. The 100-year flow is adjusted for the predicted climate conditions at the end of the century.

4.4. Environment

In fig. 16, the average damage and risk on the environment can be seen. The values are based on the ecological significance of vulnerable environmental areas, the toxicity of the flooded potentially polluting objects and the flood depth. The solid black line plotted on the left y-axis represents the average damage and the dotted black line plotted on the right y-axis represents the average risk. Damage values for the 50-year and 100-year flows are quite similar whereas the risk values differ more. Similarly to the cultural damage and risk, the environmental values fall within a range of 0-4. According to Botterhuis (2018), the environmental damage values all fall within "medium" classification and the environmental risk values fall within "low".

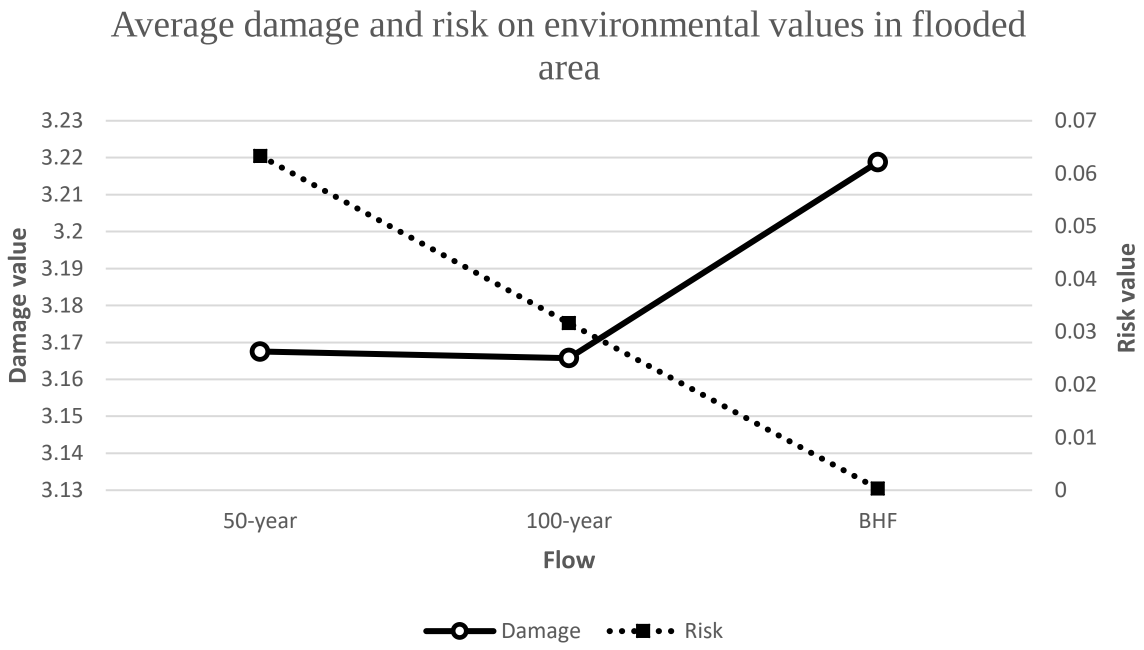


Fig. 16. The figure shows the average damage and risk on the environment within the flood zone. The damage and risk value are influenced by the significance of the ecological areas, the toxicity of the flooded potentially polluting industries and the flood depth. The risk is also influenced by the probability of flooding. The 100-year flow is adjusted for the predicted climate conditions at the end of the century.

The environmentally valuable areas (water bodies) have been divided into risk categories according to Botterhuis (2018) (fig. 17). This allocation is made by the FloRiAn Risk Assessment tool. The area is shown as a percentage per risk category, the total affected area being approximately 88 000 m^2 for the 50-year flow and 93 000 m^2 for the 100-year flow and the BHF. With higher magnitude of the flow, the percentage of area allocated to the highest risk category increases.

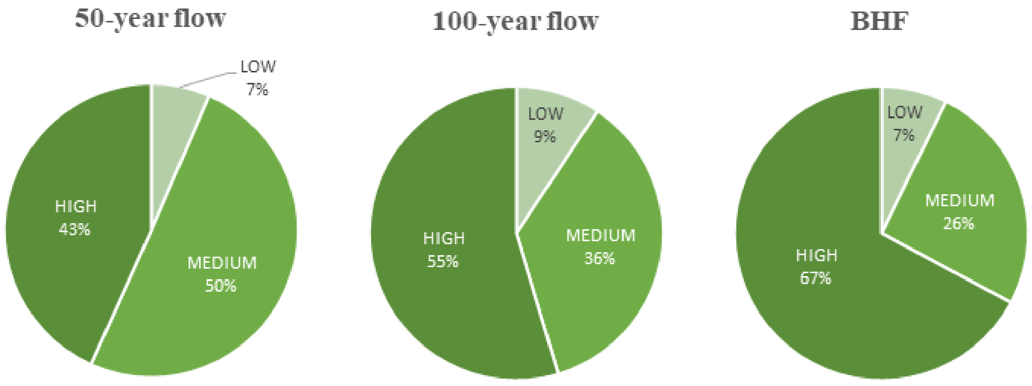


Fig. 17. Percentage of environmentally valuable area that falls within each risk category low, medium and high, for each flow. The risk category allocation is influenced by significance of ecological areas, toxicity of flooded potentially polluting industries and water depth. The 100-year flow is adjusted for the predicted climate conditions at the end of the century.

5. Discussion

5.1. Risk cost of flooding in Kungsbacka

a) How does flooding of certain return periods affect the four receptors identified in the Flood Directive in Kungsbacka?

The large difference in frequency of occurrence between the BHF and the two other flows means that comparison between the flows is difficult. The extremely long return period of the BHF also interferes with the calculations of the annual expected risk cost/damage (not shown in this study for this reason). Therefore, the focus in the following text is on the 50-year and 100-year flows.

Similarly to risk assessments in MSB (2018a) and Länsstyrelsen Hallands län (2015), the risk cost of floods has in this study been divided into impact on four receptors: Economy, Culture, Inhabitants and Environment. According to the investigation made by the MSB (MSB, 2018a), the city of Kungsbacka is exposed to considerable risk of flooding. It was found that only two focal areas (receptors) of the Flood Directive are affected by flooding of a 100-year return period (MSB, 2018a), although it is unclear which focal areas are concerned since the indicators that are listed as affected (potentially polluting industries, radio- and telecommunications towers, railroads, substations and ancient sites, among others) cover all four focal areas. The number of datasets used for each focal area in MSB (2018a) is also greater than in this study, and some data are used for different focal areas than in Schmid-Breton et al. (2018). For instance, flooded roads affect Human health (Inhabitants) rather than Economy in MSB (2018a). This further complicates comparison between the results of MSB (2018a) and the results of this present study, since the input data is a major factor of the resulting flood risk.

From the FloRiAn runs it can be concluded that all four receptors are affected to some degree during a 50-year flood and a 100-year flood. Unfortunately, the FloRiAn tool does not allow for easy comparison and addition of the accumulated risk, rather the receptors are treated as separate. The impact on the cultural heritage and environment are given as a non-monetary risk value. The cultural risk in Kungsbacka is considered low, according to the result from FloRiAn, both counting the average (fig. 12) and the distribution of cultural objects in risk categories (fig. 13). The environmental average risk is likewise low, although the average damage values (where no probability of flooding is considered) fall within the medium category (fig. 16). For both the 50-year flow and the 100-year flow, the amount of environmentally valuable area that falls within the highest risk category is around 50% (fig. 17).

Inhabitants as a receptor is a little different from the other receptors. One of the inputs to the Damage and Risk Assessment is the number of inhabitants affected, which are then distributed on the area marked as inhabited (land use “residential”). Because no evacuation rate was set in this study, the summation of damage on Inhabitants (tabular output) is the same as the input. Furthermore, the raster grid output of damage merely shows the areas with residential land use. When risk (probability of occurrence) is considered the number of inhabitants at risk per year is also difficult to display visually. The number of people is so small (23 inhabitants/year for both the 50-year and 100-year flows) that the distribution into risk categories based on water depth at their location (somewhere within residential areas) seems redundant. Since no inhabitant data was available for all three flows, the use of number of buildings within flooded area as a proxy for inhabitants was considered. However, this was discarded after trial since the number would have been even lower and the connection to the Flood Directive receptor *Human health* weakened. Overall, the risk to inhabitants in Kungsbacka (affected inhabitants/year) should be regarded as low, although the number of people affected by any one flood (the result of the Damage Assessment) is considered high. For instance, the 100-year flow affects 2367 people according to the overlay analysis made in this study. This is significantly higher than findings from MSB (MSB, 2018a), which show that around 800 people are affected at their place of residence during a 100-year flow and 100-year sea level. When adding people affected at their place of work (about 1600), however, the numbers are more similar. Here the definition of "affected" is interesting to consider. Firstly, the spectrum of adverse effects of flooding on people is wide, ranging from social impacts such as discomfort, stress and loss of irreplaceable things to physical health impacts such as drowning (Grahn et al., 2014). Secondly, whether someone is impacted by flooding depends on when the flood occurs. A flood in a residential area during a weekday may not require evacuations of many residents, and if inhabitants are counted as affected at both their place of work and their place of residence the risk may be elevated because of double-counting. It is not possible to cover all these aspects within a quantitative study of this kind, and therefore the risk on "affected" inhabitants is a simplification of a real flood situation.

In order to make assumptions about the result of the non-monetary risks more expert knowledge in the data collection phase is likely required, since the classification of objects into significance and impact categories largely determines the output risk values. The non-monetary risks values would also benefit from comparison with other flood-prone cities for which similar analysis is performed. The result of the Risk Assessment of receptor Economy is perhaps more intuitive, since it is the only module that uses monetary values. To some extent, aspects of the other receptors (Culture, Inhabitants and Environment) are included in the economic analysis since it uses land use data, but to fully incorporate these into the economic analysis the social or environmental values would have to be appraised monetarily. The importance of considering other aspects of flood risk than the economic is recognised by several authors (e.g. Merz et al., 2010; Grahn et al., 2014) and one of the possibilities with FloRiAn is that is enables analysis of several focal areas, all of which are related to EU legislation.

The economic risk for the present scenario (P) is 176 000 SEK/year for the 50-year flow and 226 000 SEK/year for the 100-year flow (table 3). Comparison of this result with studies that have been undertaken with other methods is problematic. However, it is interesting to relate the result to that of the Halland County Administration risk management plan (Länsstyrelsen

Hallands län, 2015). The magnitude of the effects of the 100-year flood is not well known according to the risk management plan, but some functions are affected which are not accounted for in this present study, for example a school and a retirement home. Furthermore, secondary effects such as landslide hazard, power outages and decreased commercial activity are mentioned although the magnitude of these effects are uncertain, and all in all, the scope of the economic consequences is considered to be limited (Länsstyrelsen Hallands län, 2015). Compared to the cost of building flood protection structures, the risk cost according to this present study seems low, but since mobile assets and the effects of decreased accessibility are not included, the actual risk cost would presumably be higher.

Results from the FloRiAn model runs show that economic risk cost is particularly high near the river, in the northern stretches of the watercourse (fig. 11). This is not a surprising result but still relevant, both from a planner’s perspective and the perspective of residents. Risk cost studies can be a useful supplement to material used as decision basis in spatial planning (Karlstads kommun, 2006). The output of FloRiAn is specifically described as useful for cost-benefit analyses, even though the tool itself does not perform such analysis (ICPR, 2016).

5.2. Risk cost after development or protection

b) How could the economic risk cost change if a strategy for protection is implemented or if the values at risk increased through new residential development in the hazard zone?

A natural disaster implies affected humans and assets (Munich RE, 2005); without a receptor to suffer damage, the flood is merely a natural phenomenon. The economic risk cost naturally increases if further value is accumulated in hazardous areas. Residential areas have a higher value in this study than vacant land and although some of the developed areas in scenario RD are located on land previously classed as industrial, which is valued slightly higher than residential, the risk cost increases when residential development occurs in Kungsbacka (table 3). When residential projects are planned, the municipality considers the risk of flooding and in the northernmost planned area of fig. 10 the municipality describes the location as suitable for housing as long as a solution for the flood issues is implemented (Kungsbacka kommun, 2018c). The purpose assigned to flood prone areas determines future risk cost (Karlstads kommun, 2006). One use for the method of economic risk cost is therefore to investigate where certain functions should be located with regards to future flooding (Karlstads kommun, 2006). Grahn (2017) underscored the need for local perspectives on risk changes caused by increases in population and housing stock. The largest difference in risk cost between scenarios P and RD is for the 50-year flow (table 3), showing that added value to land can have large consequences during a flood of small magnitude, which is important from a planning perspective.

In contrast to the comparison between P and RD, the largest difference in risk cost between P and KAL is for the 100-year flow. Thus, the reduction in risk cost is more noticeable in the event of a larger flood, although this does not mean that the levee’s protective capacities are smaller for a 50-year flood. Overall, the effect of the artificial levee in Kolla on the total risk cost is small. The minimal reduction in risk cost is likely because the area protected by the Kolla levee is small in comparison to the entire study area. It can also have been caused by the selection of a tool to represent the effect of the levee that was not entirely suited for that purpose. Nevertheless, the reduction in risk cost for the 100-year flow when the levee is in place is 9000 SEK/year. The reduction in damages when a flood occurs is 100 000 SEK for the 50-year flow and 900 000 SEK for the 100-year flow. This could be cautiously contrasted to the projected cost of building the levee, 41.6 million SEK. However, it is important to remember that no values for inventories and other mobile assets are included in the analysis. Therefore, the estimation of cost-effectiveness is incomplete and this study, like the Karlstad risk cost estimation (Karlstads kommun, 2006) likely underestimates the actual risk cost. Furthermore, the protective effects of the levee extend to all floods of return periods of approximately 1-200 years (Kungsbacka kommun, 2018b) although the effect of the levee is set lower than 100% in the tool, potentially limiting the reduction in risk cost unfairly. Despite these caveats, it could be argued in light of the findings of this study, that rather than building further costly technical protective structures in flood prone areas, those areas are best left undeveloped, or assigned other functions than residential. Hino et al. (2017) describe a flood risk feedback loop of structural flood protection encouraging development behind the barriers, thus producing more value in the hazardous areas, increasing the risk. In the case of Kolla, the area is already developed and relocating the residential functions from the neighbourhood would no doubt prove challenging. Moreover, the accumulation of further residential functions behind a protective structure such as the Kolla levee can increase the effectiveness of the structure in reducing risk cost, provided that it withstands the floods for which it is designed. Nevertheless, spatial planners should carefully consider whether placing valuable functions in flood-prone areas is advisable, particularly since the cost of flood protection and risk-reducing measures are largely borne by the public (Grahn, 2017).

5.3. ICPR FloRiAn in a Swedish context

c) Which are the principal advantages to the ICPR FloRiAn tool and which are the main impediments against its use in Swedish flood risk planning?

5.3.1. Omitted factors

In the analysis, several factors and aspects potentially important to the flood risk calculation have had to be disregarded. Some of these simplifications are discussed here.

Intangible consequences of floods could not be appraised using the FloRiAn toolbox. This is not uncommon to flood risk analysis (Grahn et al., 2014; Meyer et al., 2013). Several tangible consequences are also omitted from the analysis; these are indirect consequences such as economic losses caused by halted industrial production, transport closures, diversions and delays. Furthermore, damage to inventories and other mobile property in private homes, warehouses, shops and public buildings are left out of the risk cost estimation. The risk for the receptor Economy is only based on land use, the value of which, while here based on assessed values collected from reliable sources, in reality may have a subjective element to it. Actors may have different views on which land use is more valuable and which areas to prioritise when protecting against flood. Priorities could vary between residential land, where people live; transportation infrastructure, which is necessary for communications; agricultural land, important for food production and potentially difficult to restore after flooding; or industrial land, which is necessary for generating capital and which could spread pollution if flooded. This may be something to consider in other types of flood risk analyses, but for the purpose of this study, a single land use value per category needed to be set. Land use for transport is represented by roads (features such as railroad, train stations, bike paths etc. not included) and the value is an estimation of cost for repairs, based on the assumption in Karlstads kommun (2006) that the majority of roads can be restored without replacing the road entirely. This decreases the repair cost compared to if roads are completely destroyed and have to be restored at current market price, in line with the recommendation from Merz et al. (2010) to use depreciated values, rather than replacement cost.

The category “Other land use” is not accounted for, the reason being that it does not have a corresponding damage function (ICPR, 2016). Area falling within this category is assumed to be undeveloped and without economically valuable assets, which is a simplification since the area may possess non-monetary values which are reduced during floods. In the Kungsbacka case study, this is not thought to have had a large impact on the result, but if possible in the future, field survey should be undertaken before FloRiAn analysis to ensure that the land use data is correct and updated.

Furthermore, the protective effect of mobile barriers that could be deployed is neglected since there was little information about the capacity and placement of these barriers. However, the effect of permanent levees constructed before 2018 should be accounted for, as the flood datasets are based on recent, laser scanned elevation models where these are included (MSB, 2019).

Other factors than flood depth could influence damage and risk. Grid data of floodwater velocity were available from MSB, but the available damage functions (ICPR, 2016) were adapted to flood depth so it was not possible to accommodate that parameter. Furthermore, even while flooded, Kungsbackaån is a rather slow-flowing river (MSB, 2018c) and velocity might not be a dominant factor in flood damage calculation. Other factors such as flood duration, sediment load, building age would have been interesting to study, although it could be argued that duration is indirectly included in the analysis since a larger water depth in the flooded area (with larger damage impact) likely means that the water is slower to infiltrate into the ground, increasing the flood duration in such places. Floods may also have positive environmental consequences for some areas (MSB, 2018a), but this aspect falls outside the scope of this study.

5.3.2. Scale

The risk cost estimation in this thesis takes place on a microscale level, while the FloRiAn toolbox is primarily developed for regional analyses on a river basin level (ICPR, 2016). While FloRiAn may require assumptions and simplifications best suited to regional scale analyses, the toolbox is adaptable to study areas on a smaller scale, according to Schmid-Breton et al. (2018), and there have been examples of it being used to assess risk on a local city-scale.

The FloRiAn toolbox was developed with the available data in the countries bordering the Rhine in mind (Schmid-Breton et al., 2018). Despite the flood related legislation in these countries and Sweden being similar because of the Flood Directive, Sweden lacks some of the data that are available for the Rhine catchment. The most prominent deficit is the damage functions, which are necessary for the FloRiAn tools to run. Damage functions can be developed either from expert assessments or from statistical analysis of past floods (Merz et al., 2010). The former is time-consuming while the latter is data-intensive, and unfortunately neither method was possible to apply within the time frame of this study. According to findings by Grahn (2017), lack of empirical data in Sweden prohibits the creation of reliable damage functions for residential areas. The data deficit also exists for industrial damage functions in general (Merz et al., 2010). From the research process of this present study it can be concluded that the lack of data extends to the other land use categories as well. Susceptibility and value of assets is rather heterogeneous within the industry sector and more variable than for residential buildings and land use, which is the most common study object within flood risk cost assessments (Merz et al., 2010; Meyer et al., 2013). Merz et al. (2010) therefore warns that transfer of industrial damage functions can have issues. The import of damage functions from other contexts is efficient concerning time, cost and data demand (Grahn, 2017). For this present study, the ICPR damage functions had to be used and that will have affected the result of the risk assessment, despite local asset values being used. Since the ICPR functions are relative, however, they are easier to transfer to other study areas than absolute functions (Merz et al., 2010), and it can be argued that the socio-economic and urban characteristics of the Rhine catchment area and western Sweden are similar enough that the transplant of damage functions is possible.

Regarding flood data, one potential issue is that the 100-year flow is adjusted for the predicted climate conditions at the end of the century, while for instance the economic values of assets are adapted to 2018 price levels. MSB produces climate-adapted flood hazard maps for the 100-year flow and as it is very difficult to estimate future economic fluctuations, this time frame discrepancy was unavoidable. Grahn et al. (2014), for example, write that the effect of future climate change is important to include in risk assessments. Furthermore, the modelled flood data already contain simplifications, which means that the extent and water depth of the flooded area are generalisations. The added effect of future climate on the 100-year flow can therefore be seen as another generalisation when applied to analyses of today's risk cost.

The FloRiAn tools require that three flows of different frequency of occurrence are modelled. The three flows used in this study are the same as the ones in the risk management plan of the Halland County Administration; the two flows for which risk-reducing measures primarily are undertaken (50- and 100-year flows) and the extreme flow (BHF), which is treated as a worst case scenario (Länsstyrelsen Hallands län, 2015). However, the extreme flow used, the BHF, has a very long return period (roughly estimated), and this interferes with the calculation of risk cost, particularly the combined annual expected cost, which considers the annual cost of being exposed to flood risk from all three flows. The miniscule monetary value also causes the intuitive element of the economic risk cost to be slightly diminished, particularly when displayed in maps (see fig. 9). It is valuable to know the consequences for extreme flows, but the recommendation for future analyses with FloRiAn is to use the 200-year flow as the extreme flow in the Risk Assessment and only use the BHF for Damage Assessment tool runs.

It might be relevant to use several administrative areas to analyse flood damage and risk, even though the study area only consists of one city. This could make the effect of smaller local measures and strategies such as the Kolla artificial levee more visible. Here, however, a problem would be that data is not available on that level of detail. In retrospect, more detailed land use data (depicting every building) could also have been used to receive a finer output. However, by using less coarse data, or resolution of data, one runs the risk of misleadingly implying that risk cost values can be predicted very accurately, when they should rather be seen as an indication of the risk.

5.3.3. *Data availability and modification*

One issue with data availability for this present study was that the classes of vulnerable objects had to be slightly changed from the original ICPR data. The change of objects such as vulnerable nature areas and cultural features might have affected the result. Whereas Schmid-Breton et al. (2018) classified cultural and environmental object according to type and assigned a significance to that type, the data collection in this present study has had to start from the significance of objects and steer these objects into matching type categories accordingly. For example, the historic buildings of Kungsbacka were already categorised into three classes depending on cultural importance (Kulturmiljö Halland, n.d.) and assigned to different type categories based on this. Data on environmental areas were handled the same way. The classification of type, significance and radius of cultural and environmental objects are estimations based on attributes already present in the datasets, such as classifications made by authorities, and information found in documentation from municipalities and other agencies. It is important to be critical of the impact this may have had on the result. This means that expert knowledge is collected second-hand, and the recommendation for further applications of this method is that experts within the fields of environmental studies or cultural heritage studies are consulted first-hand when possible. Since the values are non-monetary and the impact functions used does not relate the water depth to value reductions, the effect of the change of input data should be less than for receptor Economy. However, further use of the FloRiAn tools within Sweden might benefit from evaluation of the risk and damage categories; it could be that the intervals for the categories (e.g. what is considered low, medium and high) need to be revised. The overlay analysis of inhabitants within flooded area showed that 1156 people are affected by the 50-year flow, 2367 by the 100-year flow and 3241 by the BHF. Given the development plans of Kungsbacka, a future increase in population within the flood risk zone is expected. This means that risk levels may increase and the overlay analysis of number of inhabitants may have yielded results that are low for estimation of future risk. The number of affected inhabitants is not exact, and for further studies more detailed surveys should be carried out.

5.3.4. Advantages and disadvantages

From the process of conducting this study several advantages and disadvantages with using the ICPR FloRiAn toolset have been identified. Some of these have already been touched upon above.

The main advantages of the model are that it enables a relatively quick estimate of both damage and risk, and furthermore permits estimation of the effect of flood risk-reducing measures. It is relatively easy to handle with some previous GIS knowledge and the connection to EU legislation indicates that comparison of different geographical locations within Europe is possible, provided that the data availability is of similar quality. The tools also allow for investigating scenarios and comparing risk during different time periods, likely suitable for assessing flood risk with the effect of future climate change.

The principal drawback identified in this study is that the tools are rather data-intensive and rigid, both in data format and amount of data required, particularly the tools for appraising the effect of measures. The only flood characteristic to be included in the analysis is depth, which is not unusual for tools estimating flood damages, but somewhat limiting nonetheless. The toolset would preferably be used in consultation with experts on valuation of non-monetary features, or in combination with a more extensive study on these matters. FloRiAn does not produce a single comprehensive risk value, although this could also be seen as an advantage depending on the intended usage of the result. It is also likely better suited to regional analysis of longer stretches of river than Kungsbackaån, as the assessment of risk cost is indicative rather than producing definitive values.

5.4. Future research

The translation of the data requirements from a catchment-scale European context into a local-scale Swedish context has not been without issues. Results from this study highlight the need for a database of features and objects vulnerable to floods, as well as costs of previous floods on different sectors. This would facilitate the development of Swedish damage functions, enabling further and more comparable quantitative risk cost estimations. Another recommendation for future work with the FloRiAn tool is to use a more frequently recurring flow, such as the 200-year flow, as the most extreme flow. This particularly in a planning context, where frequent floods of smaller magnitude might be considered more relevant.

It is important to consider future climate change when modelling flood hazard and flood risk (Grahn et al., 2014). Grahn and Olsson (2018) conclude that predicted increased extreme precipitation events will present a long-term challenge within Swedish flood risk management, while on a shorter time scale the increased need for housing and subsequent accumulation of valuables within urban areas is an issue to consider. Therefore, scenarios for planned increases in development of housing and infrastructure in combination with more frequent high river flows would be a field of study to investigate further.

Meyer et al. (2013) argue that cost assessments need to take indirect and intangible effects of disaster into account to a higher degree. This is a difficult endeavour, as indirect impacts can be far-reaching and complex and intangible impacts are complicated to detect and value (Merz, 2010; Grahn et al., 2014). With the exception of damage and risk on receptor Environment, FloRiAn does not yet lend itself to such analysis. It could, however, be used in combination with other risk estimates to cover more aspects of flood-related impacts.

6. Conclusions

Based on the results of this study, the following conclusions are reached:

- Flood risk cost in Kungsbacka is generally low, particularly risk cost on Culture, Inhabitants and Environment. Risk cost level of Economy is difficult to interpret without comparison with other areas. Since the receptors are analysed separately and several important factor omitted from analysis, it is rather difficult to overview the comprehensive risk cost.
- FloRiAn modelling should not be undertaken for extreme flows such as the BHF, but focus on flows with shorter return periods.
- The analysis of risk to Inhabitants does not add much to the information on flood risk that is already available.
- The analysis of Culture and Environment can be adjusted to Swedish conditions although further study is needed to determine how the categories of risk should be interpreted.
- The analysis of Economy can be adapted to Swedish conditions, but it is data-intensive and potentially problematic because of the lack of local damage functions. Furthermore, the FloRiAn tool is focused on giving an overview of the flood risk situation, rather than a detailed assessment, particularly for Economy. Land use data of every building and its function should potentially be used in future analyses for a more accurate assessment of risk cost, but care must be taken not to present the analysis and resulting risk values as precise.
- The lack of reliable damage functions for Sweden adds an element of uncertainty to risk cost estimations. Swedish flood risk management would benefit from the creation of a database of urban objects and features vulnerable to floods, and the degree to which these are impacted by flood depth and/or other factors. This could be useful for other tools and methods used for estimating quantitative flood risk than FloRiAn.

7. Acknowledgements

Firstly, I would like to thank Björn Holgersson and Mats Ivarsson, who helped me get started on the topic of risk cost assessments, and Adrian Schmid-Breton and colleagues at the ICPR, who provided me with the FloRiAn tool and much assistance during the course of the project. I am grateful to Gunnel Göransson, Per Danielsson and Jim Hedfors at SGI for their knowledge, enthusiasm and support, and to Tonje Grahn, for the information about damage functions. My supervisor, Mats Olvmo, deserves many thanks for reassurance and help throughout the process. The report was much improved by his input. Thank you to the rest of the Geography master students who provided company and encouragement throughout the term and these two years of study.

Secondly, I could not have crossed the finish line without the support of friends, family and especially my amazing partner. Thank you, Jesper, for your unwavering patience, encouragement and love.

And finally, this work is dedicated to Louise – my wonderful friend and fierce supporter – in fond and loving memory.

Thank you.

References

Albano, R., Mancusi, L., Sole, A., & Adamowski, J. (2017). FloodRisk: a collaborative, free and open-source software for flood risk analysis. *Geomatics, Natural Hazards and Risk*, *8*(2), 1812-1832.

Andréasson, J., Bergström, S., Gardelin, M., German, J., Gustavsson, H., Hallberg, K., Rosberg, J. (2011). *Dammsäkerhet. Dimensionerade flöden för dammanläggningar för ett klimat i förändring - metodutveckling och scenarier* (11:25). Stockholm: Elforsk.

Botterhuis, T. (2018). *Instrument to determine flood risk evolution/reduction taking into account the effects of measures and the four risk receptors (protection objectives) of the Floods Directive - GIS-Tool "ICPR FloRiAn (Flood Risk Analysis)" - User guide* (version 1.2). Lelystad: HKV Consultants.

Busscher, T., van den Brink, M., & Verweij, S. (2018). Strategies for integrating water management and spatial planning: Organising for spatial quality in the Dutch "Room for the River" program. *Journal of Flood Risk Management,* e12448.

Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. *Official Journal of the European Union,* L 288/27. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32007L0060&from=EN

Dottori, F., Figueiredo, R., Martina, M. L., Molinari, D., & Scorzini, A. (2016). INSYDE: a synthetic, probabilistic flood damage model based on explicit cost analysis. *Nat. Hazards Earth Syst. Sci., 16,* 2577–2591. doi:10.5194/nhess-16-2577-2016

Grahn, T., Nyberg, L., & Blumenthal, B. (2014). *Analys av översvämningsskador. En kunskapsöversikt.* (2014:1). Karlstad: Centre for Climate and Safety, Karlstad University.

Grahn, T. (2017). *Risk assessment of natural hazards - Data availability and applicability for loss quantification* (Doctoral thesis, 2017:16). Karlstad: Universitetstryckeriet. Retrieved from http://www.diva-portal.org/smash/get/diva2:1089652/FULLTEXT02.pdf

Grahn, T., & Olsson, J. (2018). Insured flood damage in Sweden, 1987–2013. *Journal of Flood Risk Management*, e12465. doi: 10.1111/jfr3.12465

Hino, M., Field, C. B., & Mach, K. J. (2017). Managed retreat as a response to natural hazard risk. *Nature Climate Change*, *7*(5), 364-371.

Holden, J. (Ed.). (2012). *An Introduction to Physical Geography and the Environment.* Harlow: Pearson Education Ltd.

ICPR. (2016). *Tool and Assessment Method for Determining Flood Risk Evolution or Reduction - Technical Report*. Koblenz: ICPR.

IVL. (2017). *Klimatanpassning 2017- så långt har kommunerna kommit*. Stockholm: IVL Svenska Miljöinstitutet.

Johansson, M. (2015). Data sources on small-scale disaster losses and response–A Swedish case study of extreme rainfalls 2000–2012. *International journal of disaster risk reduction, 12*, 93-101.

Karlstads kommun. (2006). *Bedömning av riskkostnad vid översvämning i Karlstads tätort*. Karlstad: SWECO VIAK AB.

Klimatanpassningsportalen. (2018). *LST Potentiellt förorenade områden*. Retrieved 2019-04-01 from http://www.klimatanpassning.se/atgarda/2.3068/lst-potentiellt-fororenade-omraden-1.134735

Kulturmiljö Halland. (n.d.). *Bebyggelseinventeringen i Halland*. Retrieved 2019-05-01 from http://www.kulturmiljohalland.se/bebyggelseinventering.html

Kungsbacka kommun. (2009a). *Fördjupad översiktsplan för Kungsbacka stad*. Kungsbacka: Kungsbacka kommun.

Kungsbacka kommun. (2009b). *Kungsbackaån - översvämningsutredning*. Göteborg: DHI Sverige AB.

Kungsbacka kommun. (2014). *Översvämningsskydd klart.* Retrieved 2019-05-21 from https://www.kungsbacka.se/Archive/Regular-News/2014/9/Oversvamningsskydd-klart/

Kungsbacka kommun. (2015). *Vattenförsörjningsplan för Kungsbacka kommun.* Kungsbacka: Kungsbacka kommun.

Kungsbacka kommun. (2018a). *Detaljplan för översvämningsskydd inom Kolla 1:20 och 1:36 i Kungsbacka.* Kungsbacka: Kungsbacka kommun.

Kungsbacka kommun. (2018b). *Översvämningsskydd och gestaltning av å-rummet, etapp Kolla. Tekniska beskrivning till ansökan om tillstånd för vattenverksamhet*. Kungsbacka: Kungsbacka kommun.

Kungsbacka kommun. (2018c). *Planerat bostadsbyggande 2018-2022 for Kungsbacka kommun*. Kungsbacka: Kungsbacka kommun.

Kungsbacka kommun. (n.d.). *Fakta om kommunen*. Retrieved 2019-02-18 from https://www.kungsbacka.se/Kommun-och-politik/Fakta-om-kommunen/

Länsstyrelsen Hallands län. (2015). *Riskhanteringsplan för översvämningar i Kungsbackaån.* Halmstad: Länsstyrelsen Hallands län.

Merz, B., Kreibich, H., Schwarze, R., & Thieken, A. (2010). Review article "Assessment of economic flood damage". *Natural Hazards and Earth System Sciences*, *10*(8), 1697-1724.

Meyer, V., Becker, N., Markantonis, V., Schwarze, R., Van Den Bergh, J., Bouwer, L., ... & Hallegate, S. (2013). Assessing the costs of natural hazards-state of the art and knowledge gaps. *Natural Hazards and Earth System Sciences, 13*(5), 1351-1373.

Morita, M. (2014). Flood risk impact factor for comparatively evaluating the main causes that contribute to flood risk in urban drainage areas. *Water*, *6*(2), 253-270.

MSB. (2012). *Översvämningar i Sverige 1901-2010*. Karlstad: MSB.

MSB. (2013). *Översvämningskartering utmed Kungsbackaån*. Karlstad: MSB.

MSB. (2018a). *Översyn av områden med betydande översvämningsrisk*. Karlstad: MSB.

MSB. (2018b). *Översvämningsdirektivet*. Retrieved 2019-02-13 from https://www.msb.se/sv/Forebyggande/Naturolyckor/Oversvamning/Oversvamningsdirektivet/

MSB. (2018c). *Översvämningsportalen*. Retrieved 2019-05-09 from https://gisapp.msb.se/Apps/oversvamningsportal/avancerade-kartor/hot-och-riskkartor/kungsbacka/kungsbackaan/hotkartor.html

MSB. (2019). *Översvämningskartering utmed Kungsbackaån*. Karlstad: MSB.

Munich RE. (2005). *Schadenspiegel. Risk factor of water*. Munich: Munich RE.

Oubennaceur, K., Chokmani, K., Nastev, M., Lhissou, R., & El Alem, A. (2019). Flood risk mapping for direct damage to residential buildings in Quebec, Canada. *International Journal of Disaster Risk Reduction*, *33*, 44-54.

Schmid-Breton, A., Kutschera, G., & Botterhuis, T. (2018). A Novel Method for Evaluation of Flood Risk Reduction Strategies: Explanation of ICPR FloRiAn GIS-Tool and Its First Application to the Rhine River Basin. *Geosciences*, *8*(10), 371.

SGI. (2018). *Inventering och riskklassning*. Retrieved 2019-05-06 from http://www.swedgeo.se/sv/vagledning-i-arbetet/fororenade-omraden/fran-inventering-till-atgard/inventering-och-riskklassning/

Shih, S. C., & Nicholls, R. J. (2007). Urban managed realignment: application to the Thames Estuary, London. *Journal of Coastal Research*, 1525-1534.

SMHI. (2015). *Framtidsklimat i Hallands län*. Norrköping: SMHI.

Statistics Sweden. (2017). *Statistikdatabasen. Värderingsenheter (typkod 320, 321, 325, 420-433, 520), genomsnittliga areor och taxerings-/basvärden efter län, slag av enhet och värdeårsklass. År 2000, 2004, 2007, 2010, 2013.* Retrieved 2019-04-04 from http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__BO__BO0601__BO0601D/AlderBasvYta/table/tableViewLayout1/?rxid=6387c4eb-ca03-4c69-aa78-20c88b22d2aa

Statistics Sweden. (2019a). *Statistikdatabasen. Genomsnittlig bostadsarea per person efter region, hushållstyp, boendeform och år.* Retrieved 2019-05-01 from http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__HE__HE0111/HushallT23/table/tableViewLayout1/?rxid=7f0f9914-9abc-4b05-8ed6-6095357dacf3

Statistics Sweden. (2019b). *Land use in Sweden* (seventh edition). Stockholm: Statistics Sweden.

Statistics Sweden. (2019c). *Statistikdatabasen. Genomsnittligt taxeringsvärde per hektar mark efter region och markanvändningsklass. Vart 5:e år 2010 - 2015.* Retrieved 2019-04-04 from http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__MI__MI0803__MI0803D/MarkagandeTaxering/?rxid=9e25940a-d96d-482f-ab96-29d086cc739b#

Statistics Sweden. (2019d). *Statistikdatabasen. Genomsnittligt taxeringsvärde per hektar mark efter region, markanvändningsklass och vart 5:e år.* Retrieved 2019-05-01 from http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__MI__MI0803__MI0803D/MarkagandeTaxering/table/tableViewLayout1/?rxid=b768eea9-bd52-4d3f-b6da-e4ede3757518#

Statistics Sweden. (n.d. a). *Prisomräknaren*. Retrieved 2019-05-01 from https://www.scb.se/hitta-statistik/sverige-i-siffror/prisomraknaren/

Statistics Sweden. (n.d. b). Öppna geodata för tätorter. Retrieved 2019-05-01 from https://www.scb.se/hitta-statistik/regional-statistik-och-kartor/geodata/oppna-geodata/tatorter/

UNISDR. (2017). *Hazard*. Retrieved 2019-02-21 from https://www.preventionweb.net/risk/hazard

Appendices

Appendix I.
Data used for the analysis. Data source and modification of the data is also presented.

Data	Source	Preparation
General input		
Polygon of study area (administrative) Attributes: ID	Statistics Sweden (n.d. b)	The polygon for Kungsbacka was modified to only cover the city and to cover the extent of the modelled flood raster.
Polygon of Kungsbackaån river Attributes: river length (km), probability of occurrence for flow of three return periods (low flow - 50 years, medium flow - 100 years, extreme flow - BHF)	GSD-Fastighetskartan, Lantmäteriet	The main watercourse was digitized manually. Attributes for length calculated and probabilities taken from MSB (2019).
Raster of land use Value: land use categories classified according to Corine land use data	GSD-Fastighetskartan, Lantmäteriet	A polygon layer for land use was merged with a polygon layer of roads. The resulting polygon layer was given attributes according to the classification in ICPR (2016) and rasterized.
Raster of water depth (cm) for 50-year flow	MSB	Data preparation consisted of converting raster from m to cm and changing the grid values to integer.
Raster of water depth (cm) for 100-year flow	MSB	Data preparation consisted of converting raster from m to cm and changing the grid values to integer.
Raster of water depth (cm) for BHF flow	MSB	Data preparation consisted of converting raster from m to cm and changing the grid values to integer.
Economy input		
Table with land use categories Attributes: Corine land use codes and corresponding 6 codes used in FloRiAn analysis.	ICPR	No preparation.
Polygon of study area with asset values of immobile objects (SEK/m^2) Attributes: Values of immobile assets for each land use category (Residential, Industry, Transport, Agriculture, and Forest. The category “Other” was omitted from the analysis) in SEK/m^2	Statistics Sweden (2019b) - [genomsnittligt taxeringsvärde för småhusfastigheter (mark + byggnader), Kungsbacka] Statistics Sweden (2017) - [Industri typkod 420-433, genomsnittligt taxerings-/basvärde, Halland] Statistics Sweden (2019c) - [Genomsnittligt taxeringsvärde per hektar för Åkermark (87% av total jordbruksmark) och betesmark (13% av total jordbruksmark), Halland] Statistics Sweden (2019d) – [Total skogsmark, Kungsbacka] Karlstads kommun (2006)	Searching literature and Statistics Sweden database for approximate values of land per m^2 based on land use category. Recalculating values to 2018 yearly mean price for comparability purposes.
Table with damage functions of immobile objects, per land use category Attributes: Water depth (cm) and corresponding reduction in asset value (in per mille)	ICPR	No preparation

Polygon of study area with asset values of mobile objects (SEK/m^2) Attributes: Values of mobile assets for each land use category (Residential, Industry, Transport, Agriculture, and Forest. The category “Other” was omitted from the analysis) in SEK/m^2	Statistics Sweden (n.d. b)	Value of mobile objects could not be obtained and therefore the values were set to 0, thus being omitted from the analysis. However, the data (.shp and .dbf) still had to be put into the tool.
Table with damage functions of mobile objects, per land use category Attributes: Water depth (cm) and corresponding reduction in asset value (in per mille)	ICPR	No preparation
Cultural input		
Point .shp with location of cultural objects Attributes: ID, type of object (1-3)	Länsstyrelsen Hallands län Swedish National Heritage Board Kulturmiljö Halland	Data was downloaded from the County Administration geodata portal. Changing data to point format, merging the datasets into one .shp, categorising the objects according to information present in the attribute table or found in sources: 1 – Cultural heritage Class A or national interest 2 – Cultural heritage Class B or C 3 – Ancient site
Table with relation between water depth and impact on cultural heritage Attributes: water depth (cm), impact value (1-5)	ICPR	No preparation
Table with relation between cultural object type and cultural importance Attributes: Type of object (1-3), importance (1 or 2), radius in m (buffer distance from object within which average flood depth is extracted)	ICPR	Modified the number of object types and categorized the importance according to sources used for producing the point .shp of cultural objects. Radius was set using a trial and error approach: 1 – Cultural heritage Class A or national interest → national significance (2) and radius 25 m 2 – Cultural heritage Class B or C → local significance (1) and radius 10 m 3 – Ancient site→ local significance (1) and radius 10 m
Table with impact categories based on water level and cultural importance Attributes: impact category (1-4) and corresponding water depth (cm)	ICPR	No preparation
Inhabitants input		
Polygon of study area with the number of inhabitants within flooded area for the three flows. Attributes: Number of people within flooded area for each flow, fraction of inhabitants evacuated (%)	Statistics Sweden (n.d. b) Statistics Sweden (2019a) Kungsbacka kommun	Overlay analysis in ArcMap to receive number of buildings within flooded area, calculations of people per living area unit (m^2). Percentage evacuated was set to 0 for all flows since no such information was found.
Table of land use categories Attributes: Corine land use codes, information about whether populated or not (Boolean)	ICPR	No preparation
Table of impact categories based on water level Attributes: impact category (1-5) and corresponding water depth interval (cm)	ICPR	No preparation
Environment input		
Polygon with location of water-related protected areas	Länsstyrelssen Hallands län Kungsbacka kommun (2009a)	There were no official protected areas of the types described in ICPR (2016) (bird protected areas, flora

Attributes: type of area (1-3)	Kungsbacka kommun (2015)	and fauna habitat, drinking water, Water Framework ecological status) within the study area, so Kungsbackaån river and its tributaries were used instead. Type was assigned based on attribute information already present in the data and classification of significance decided based on information found in municipal documentation.
Table with relation between type of protected area and ecological significance Attributes: Type of area (1-3), ecological significance (1-3; where 1=low, 2=average, 3=high)	ICPR,	Type 1 (Kungsbackaån river) – significance 3 Type 2 (valuable tributary) – significance 2 Type 3 (other small watercourses) – significance 1
Table with impact categories Attributes: Impact categories (1-3)	ICPR	No preparation
Point .shp with location of potentially polluting objects Attributes: ID, type (1-4)	Länsstyrelsen Hallands län Klimatanpassningsportalen (2018)	Data was downloaded from the County Administration geodata portal. The data consists of points for industries and potentially polluted areas. The type was based on the attribute for risk class already present in the data.
Table with relation between object type and toxicity Attributes: type (1-4), toxicity (1-5), radius within which the pollution has an impact (m)	SGI (2018) Kungsbacka kommun (2015) Kungsbacka kommun (2009a)	The toxicity and radius were set after discussion with supervisor.
Table with relation between water depth and impact Attributes: Water depth (cm), impacts (1-5)	ICPR	No preparation
Scenario input		
KAL: Placement of Kolla levee	Kungsbacka kommun (2018b)	Digitised the location of the levee and area protected manually.
RD: Location and extent of planned residential development	Kungsbacka kommun (2018c)	Digitised the location and extent manually and incorporated the new residential areas into the land use raster