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Consequences of a flood in Kristianstad, Sweden

A GIS-based analysis of impacts on important societal functions

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Summary

According to a recent report from the Swedish Civil Contingencies Agency (Herbring and Näslund-Landenmark 2011), the city of Kristianstad is considered as one of the most vulnerable in Sweden regarding consequences of a flood. Being protected by a barrier system, a failure would most likely have serious impact on the city. To quantify the consequences, this study focuses on important societal functions and the impacts of the water to individual objects at different water levels. A disastrous consequence has been defined for 125 important societal objects which relates to a water level where the activities at the object must stop due to security, accessibility or other reasons.

Consequences of a water level at elevations from -2.4 m up to +4.0 m with 0.1 m steps have been investigated and related to characteristic discharge in the river Helge å, as well as characteristic sea water levels in the Baltic Sea. The GIS analyses have been accomplished using Quantum GIS (QGIS) where the flooded areas – including captured flooded areas – have been calculated. The objects chosen are all situated within the +4.0 m flood area and are identified by using the priority classes 0-4 of the Styrel project, a plan that regulates disconnection of electrical power in case of transient power shortage (Gellerbring 2010). The disastrous consequence level equals the highest consequence level (level 5) in a qualitative ranking scale used in the government position "*Konsekvenser av en översvämning i Mälaren*" (MSB 2012).

Two key figures are used to quantify the impacts on the city; the number of affected objects related to number of total objects, and affected objects providing service to a main part of the population related to total number of objects of this category. Four scenarios have been studied that would reflect a 100-year event; three with high discharge in the river Helge å and a barrier failure, a fourth scenario with a heavy rainfall.

A consequence of a west barrier failure is that 16% of the objects with important societal function in Styrel priority class 0-4 would have to close. This includes 27% of the objects providing service to a main part of the population. The figures for a Hammarslund barrier failure is 59% and 45% respectively, and for a simultaneous failure of the two barriers 70% and 58% respectively. A 100-year precipitation would affect 32% of the objects, including 12% of the objects providing service to a main part of the population. The most vulnerable object category at a 100-year event is retirement homes, while freshwater boreholes belong to the least vulnerable. In case of a Hammarslund barrier failure, 25% of the important societal objects would have reached a disastrous consequence at +0.3 m, 50% at +2.1 m and 75% at +3.0 m. In case of a 100-year precipitation, the hospital administration is found to be in special need of protection according to the Styrel priority list.

Keywords: Geography, Geographical Information Systems, Physical Geography, Flood Risk Analysis, Flood Consequences, Hammarslund Barrier Failure, Important Societal Functions, Kristianstad

Preface

This master thesis has been performed in close cooperation with the Rescue Service in Kristianstad. For all help and assistance in different ways to carry out the work, I would like to thank

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Linköping, June 2016

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Abbreviations

MQ	Mean discharge (day mean)
MHQ	Mean high discharge (mean of every year´s maximum day mean discharge)
HQ50	Discharge with a 50 year return period (day mean)
HQ100	Discharge with a 100 year return period (day mean)
HQ200	Discharge with a 200 year return period (day mean)
BHF	‘Beräknat Högsta Flöde’ - highest potential discharge (day mean) in a worst case scenario
MW	Mean sea water level (day mean)
MHW	Mean high sea water level (mean of every year´s maximum day mean sea water level)
HHW	Highest measured or calculated sea water level (day mean)
NNH	New national elevation model
MSB	Swedish Civil Contingencies Agency
DEM	Digital elevation model
NVDB	National road database

1 Introduction

In recent years we have seen an increase in the number of floods around the world. During the period 1998-2002 more than one hundred major floods took place in Europe (Europeiska Gemenskapernas Kommission 2004) and scenarios point towards an increased flood risk. Floods have become the most common kind of natural disaster in Europe. One reason is supposed to be effects of climate change - increase in precipitation and rising sea levels - which also makes floods likely to be worse and more frequent in the future. At the same time there is an increased risk of serious flood consequences since the population and the economic values in risk areas have increased dramatically (Herbring and Näslund-Landenmark 2011). 13 of the world´s 15 largest cities are located in lowland coastal areas (Vattenportalen 2014).

This is the background to the EU Floods Directive 2007/60/EC (Europaparlamentets och Rådets direktiv 2007/60/EG) that was implemented in Swedish legislation in 2009 (SFS 2009:956). The Swedish Civil Contingencies Agency (MSB) is the authority responsible to carry out the work, where the first step is recently concluded by the report ”*Identifiering av områden med betydande översvämningsrisk*” (Herbring and Näslund-Landenmark 2011). As a result of a multi-criteria analysis it presents 18 densely built-up areas in Sweden where the consequences of a flood would be considerable. Note that the study focuses on *the risk of flood consequences, not on the risk of a flood to occur.* In this respect, one of the most vulnerable areas identified is the city of Kristianstad, where about half the population would be found situated within the flooded area in a severe flood situation. As 60% of Kristianstad is built on old lake bed, and actually below sea level, the situation for the city is kind of special. Barriers protect the city from being flooded, and already at normal conditions – mean discharge in Helge å and mean water level in lake Hammarsjön – the consequences of a failure in the Hammarslund barrier would be considerable. In an extreme flood event the consequences of a barrier failure would be even worse. The existence of a barrier may also represent a threat in itself if the city is hit by heavy rainfall – as there is no natural runoff, water will get stuck and has to be pumped out.

The EU Floods Directive stipulates the member countries to start and maintain a work of flood risk management. This work is divided into 6-year cycles and includes identification of areas with high risk of considerable consequences in case of a flood, production of maps showing threats and risk, and establishment of flood risk management plans. An essential part in carrying out the work is *flood risk mapping*, often presented as flooded areas together with water depths and velocity. However, this information is not sufficient to quantify the impact a flood would have on a city since it does not tell anything about land use or specific objects situated in the flooded area. The difference between a water depth of 1 m at the football pitch and at the hospital emergency entrance, is obvious. A quantification of the impacts would help the city calculate the impact cost as well as to take the right measures in minimizing the consequences. So, is there some way to quantify the impacts of a flood?

In a governmental assignment carried out by MSB, "*Konsekvenser av en översvämning i Mälaren*" (MSB 2012), focus is put on impacts on important societal functions to quantify flood consequences around the third largest lake in Sweden. By interviewing owners of important societal objects to identify how they are affected by specific water levels, the study manages to quantify the risk of considerable consequences. An inventory of 236 objects with important societal function showed that about 180 may have serious, very serious or disastrous consequences in case of a flood. 22 of these objects provide service to a main part of the population. The two reports mentioned above, together form the base for this master thesis with respect to study area and method. A conclusion in the study of lake Mälaren is that its methods of analysis may well be used to develop risk and vulnerability analyses in municipalities, county councils and other authorities. This master thesis may be seen as an illustration of that.

In the attempt to visualize risks and determine flood consequences, GIS is a very useful tool in flood risk management. Like the MSB study of lake Mälaren, this study focuses on the impacts different water levels have on objects with important societal function. An inventory of 125 objects in Kristianstad has been made to determine their individual limits; a water level at which the activities will have to shut down. The objects were identified by using the priority classes 0-4 of the Styrel project, a plan that regulates disconnection of electrical power in case of transient power shortage (Gellerbring 2010). An analysis of the number of objects that have reached a disastrous consequence – including the number of objects providing service to a main part of the population – gives a good overview of the vulnerability of the city regarding flood events. With an overlay analysis in a GIS, flooded areas may be calculated and visualized at different water levels, as well as flooded objects, their location and to what degree they are affected. Spatial data used as input in the study is a DEM and the 125 objects in the inventory.

The GIS analysis procedure may briefly be described as follows. With the DEM and a water level, a flooded area is calculated. An overlay between the flooded area and the objects in the inventory will result in a list of flooded objects. Finally, an extraction is made of flooded objects with a level of disastrous consequence equal to, or lower than, the current water level. A calculation of water volumes in case of a Hammarslund barrier failure, and at a heavy rainfall, has also been carried out.

2 Objective

The aim of the study is to quantify the impact a flood would have upon the city of Kristianstad, as well as to analyze its vulnerability. The main questions to be answered are:

- ***In the case of a 100-year event, by way of high discharge in Helge å and barrier failure, or rainfall; What percentage of the important societal functions in Kristianstad would have to close?***
- ***In case of a Hammarslund barrier failure, at what water level would 25%, 50% and 75% - respectively - of the important societal functions reach a disastrous consequence?***
- ***What categories of important societal function are most vulnerable in case of a Hammarslund barrier failure at a 100-year event?***
- ***Are there any specific objects that should be prioritized – according to the Styrel definitions – to prevent serious consequences in case of a 100-year precipitation?***

The GIS-based analysis may as well be seen as a part of the constantly ongoing work of flood risk management in Kristianstad. The GIS tools developed to answer the main questions will provide Kristianstad Rescue Service with a useful instrument for further risk analysis, training, and base for decisions in an emergency flood situation.

The study will contribute to

- improved capacity for rescue service, decision makers and object owners to plan and take preventive measures to eliminate or minimize loss of property, as well as lives and health, in case of a flood
- increase alert and provide a basis for proper actions in an urgent flood situation
- more efficient use of societal resources in a flood situation
- increased consciousness about risks and vulnerability in case of a flood

3 Demarcations

The following demarcations of the study have been made:

- The study does not investigate any risk for a flood to occur, only the risk of severe consequences in case of a flood.
- The analyses focus on consequences of important societal functions as defined by the Styrel priority list, category 0-4.
- The analysis of objects with important societal function is limited to the highest consequence level: 5, disastrous, according to consequence ranking scale used by MSB, (MSB 2012).
- Consequences are studied at elevations from -2.4 m up to +4.0 m.
- The consequences are primarily related to the activity of an object, not to the building/locality that inherits the activity.
- No economic analysis is made.
- The study does not take into consideration dependencies between objects.
- Except for the scenario with heavy rainfall, the consequences are investigated for flooded areas where the surface water has direct contact with the flood source, in the following text referred to as ‘main flooded areas’. Areas not in direct contact with the flood source but with a potential risk to be flooded due to artesian pressure – areas with a ground level lower than the flood water level – are in the following text referred to as ‘captured flooded areas’.
- No hydro-dynamic modelling or run-off routing has been carried out to define flooded areas.
- The analysis of flooded objects in the protected areas (see chapter 4.4 Present situation) is based on a straight water surface. For objects situated outside the protected areas, the water level gradient generated by higher discharge has been taken into account.
- The consequences listed in the study are presented under the conditions that no measures are taken to prevent impacts.

4 Background

4.1 History

To really understand the flood risk situation in Kristianstad of today we have to go back about four hundred years in history. The beginning of the 17th century was a time of battles between the Swedish and the Danish to get hegemony of the region. Skåne, Halland and Blekinge belonged to Denmark and the Danish king Christian IV was looking for a strategic place where to build a new fortress city, easy to defend. His choice was a small peninsula in the Helge å river basin where he founded the city ‘Christianstad’ in 1614. In 1658 the region became Swedish territory, although battles did revive now and then for decades. In the beginning of the19th century Kristianstad lost its importance as a fortress city (Fig. 1).

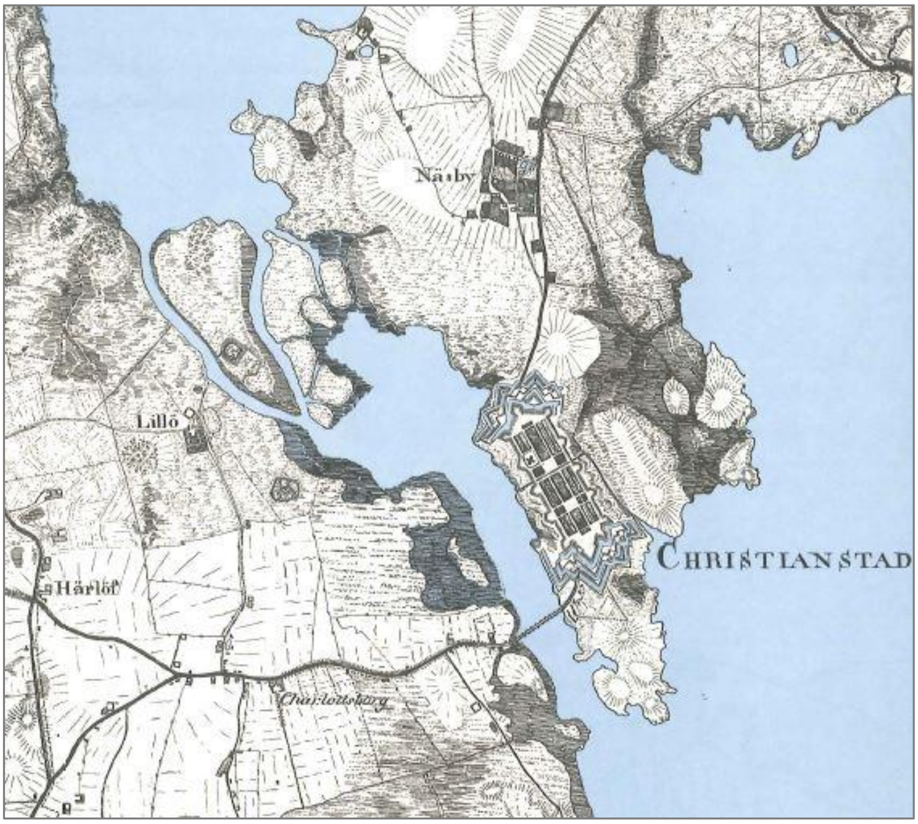

Fig. 1. *Kristianstad at the beginning of the 19th century. From Skånska rekognosceringskartan, published 1812-1820 by Fältmätningsbrigaden. With kind permission from Lennart Dehlin, Lantmäteriet.*

In the second part of the 19th century attempts were made to increase the rural areas and quite a few lakes in the area were lowered. Yet another reason to decrease wetlands was to prevent spreading of malaria. However, the project to get rid of the water in a part of Hammarsjön – the Nosaby bay – was kind of special since the level of the lake bed was lower than the sea level. Thus, a barrier had to be built to the remaining part of the lake and the water was pumped out by an Archimedean screw. The barrier – today named the Hammarslund barrier – took 200 men two years to finalize.

As time went by the city population increased and so the need for more space. The soil in the old lake bed had not been as fertile as expected, and in the beginning of the 20th century the area started to be built-up by housing. A few years later the central sewage plant was built close to the lowest point in the city, and in the 1970's a new regional hospital as well as the Rescue Service was opened. The European highway E22 was also built across the area close to the barrier.

4.2 Hydrology

The area of Helge å drainage basin is 4724 km^2 (SMHI Vattenwebb 2016) and is the largest of the rivers in Skåne. The area covered by lakes is 4.7% and the length of the main stream of the river is about 200 km. Upstream Kristianstad 2/3 of the area is covered by forest. The river starts up in Småland (Fig. 2) and has a fall of 160 meters down to the Torsebro power station 10 km north of Kristianstad, where highest calculated discharge (BHF) is 527 m^3/s. Downstream this point the area consists of pasture and wetlands and the fall to the estuary in the Baltic Sea is quite limited. High discharge in Helge å and simultaneously high sea water level has a significant impact on the water level in lake Hammarsjön, situated just south of Kristianstad. The lake, covering an area of 17 km^2, is very shallow with a mean depth of 0.7 m (VISS Vatteninformationssystem Sverige 2009) which contributes to high deviations in water level. The unit area runoff in Helge å at the inlet of lake Hammarsjön is about 10 l/skm^2, which corresponds to a mean discharge of 40 m^3/s.

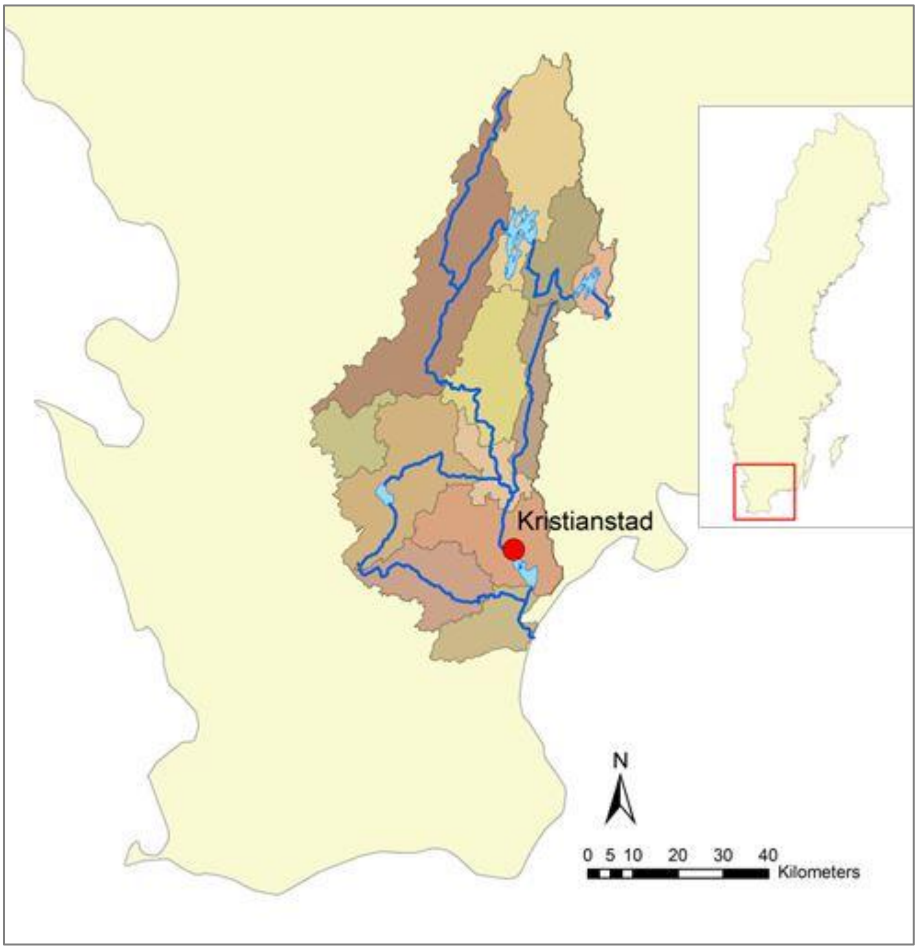

Fig. 2. *Drainage basin of Helge å. Sub-basins according to HBV Sverige.*
Source: SVAR database, SMHI.

4.3 Historical flood events

Historically a number of floods have occurred since measurements started in 1908, in which the water have reached considerable levels, like in 1912 (+2.00 m), 1917 (+2.18 m), 1928 (+2.23 m), 1931 (+2.08 m), 1980 (+2.04 m), 2002 (+2.15 m) and 2007 (+1.96 m, Fig. 3) (Dahlman. *Så skyddas Kristianstad mot översvämningar*.). In 2002 the situation turned out to be urgent since the Hammarslund barrier was close to collapse. To avoid a disaster, major reinforcements were rapidly applied to the barrier. The 2002 event became a healthy wake-up call that proved the need of further actions to be taken to secure the city from being flooded. In spite of all barriers and measures taken, the city was still not safe.

Fig. 3. *Flood in Kristianstad, February 2007. View from northwest. In background center, the city center. In background right, Lake Hammarsjön. With kind permission from Michael Dahlman, C4 Teknik. Photo: Patrik Olofsson /N.*

4.4 Present situation

To prevent the city from being flooded in a situation with high discharge in Helge å and/or high water level in lake Hammarsjön, the municipality is working with identifying the threats, making forecasts and has taken a number of security measures. To a cost of 500 million SEK, a 3.8 m high barrier system is under construction that will protect the city along Helge å and stand a calculated highest discharge (BHF) of 527 m^3/s at Torsebro. The barrier east of Helge å is ready while the barrier west of the river will be finalized in 2025 (C4 Teknik 2016). Total length of the barrier system will be about 11 km. The areas protected by the west barrier and the east barrier respectively are shown in Fig. 4.

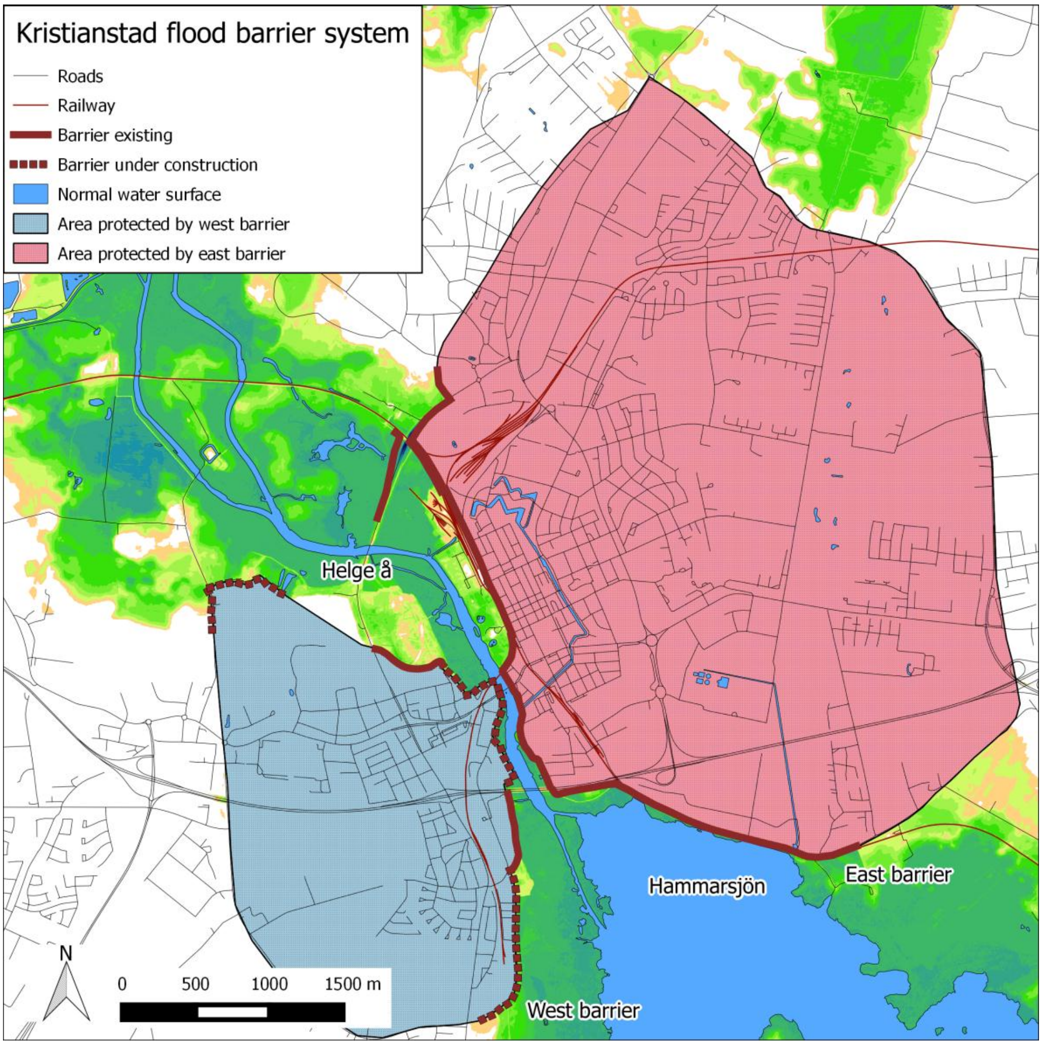

Fig. 4. *Kristianstad flood barrier system.*

In 2007, a flood warning system called Flood Watch (Dahlman. *Flood Watch Kristianstad.*) was established. Twice a day, it gives a 10-day forecast of the expected discharge and water level at different locations in Helge å, close to the city. The forecasts and input data are open to public at http://floodwatch.kristianstad.se.

Although the latest technology was used to reinforce the Hammarslund barrier in 2002, subsidence has been detected, up to 1.0 m in height and 0.2 m sideways. The barrier is therefore subject to careful and continuous measurements (Dahlman 2011). Since 2014 the municipality of Kristianstad is regarded as dam owner according to Swedish legislation. This means that the responsibility for consequences in case of a barrier failure lies upon the municipality head. According to the regulations for dam security (RIDAS), the barriers in Kristianstad are classified to be in category 1A (highest).

5 Risk and consequence

One of the fascinating aspects about risk analysis in a human context is that it combines social and physical science in a sophisticated way. Risk is something more than just a numerical value.

5.1 Defining risk

What is risk? A risk may be defined in a number of ways but generally it can be reduced to the simple formula

Risk = Probability x Consequence

Defining risk this way requires estimating the chance of the event occurring and forecasting what would happen if it does (Molino 2010). Even if this simple product is not sufficient in itself to fully describe the real risk, it gives us a certain hint to understand what it is all about, and at the same time somewhat of the complexity of this matter. However, "intuitively it may be assumed that risks with the same numerical value have equal 'significance', but this is often not the case… low probability/high consequence events are treated very differently to high probability/low consequence events." (Sayers et al. 2002). The way to value the risk seems to be rather subjective.

GJS Wilde´s theory of "risk homeostasis" (Wilde 2014) provides us with ideas which may widen our understanding of risk and risk management. His theory suggests that individuals, as well as whole societies, maintain a specific level of risk irrespective of external influences. An illustration of buying a bigger and more robust car would do as an example; with airbags surrounding me and brand new winter tires I may allow myself to drive faster on an icy road than I would do otherwise. Another closely related example could be when we build barriers along rivers to alter flood hazard parameters under certain circumstances, and then start to build more property in the floodable areas and begin to reduce our preparedness. As long as we start to behave differently and accept to increase our vulnerability, the overall risk has not changed. To really make a change, it is the "target risk, the risk that we are willing to tolerate or accept, that has to be altered" (Kelman 2003).

Some provoking thoughts to our approach to risk and risk management come from Ilan Kelman, former Deputy Director of the Cambridge University Centre for Risk in the Built Environment. Physical scientists seek to measure, quantify and calculate the risk while social scientists try to look at the risk as contextual and kind of a cultural construction. Whatever approach, the act of measuring and trying to understand and manage the risk will change the risk. Risk definition depends on who defines the risk and is a function of culture which can never be proved or disproved. If we communicate flood risk to a community that increases the risk of cardiac arrest, stress-related health effects or crashing property prices – how do we rank these different risks? Maybe we should not study or communicate the risk? However, part of the solution regarding the definition of risk may be formulated by Kelman: "To understand risk, we must understand ourselves."

5.2 Flood risk

Flood risk mapping is a useful – although insufficient - tool in the city planning process. When talking about risks in this context the breadth and complexity of the subject is obvious. The flood risk map tells us something about how hazardous a certain site on a floodplain may be. However, the risk may differ quite a lot depending on the circumstances.

Floods has in recent years come into a more pronounced focus due to a number of extraordinary events where man´s vulnerability in relation to the – often quite unpredictable – power of nature. Only in the period 1998-2002 more than one hundred major floods took place in Europe which has influenced many governments and their view of risk management. As a result of the climate change studies, one reason to the situation is supposed to be effects of global warming which makes floods likely to be worse and more frequent in the future (Herbring and Näslund-Landenmark 2011).

5.3 Flood consequence

While risk = probability x consequence, consequence itself is a function of other factors. The consequences of a flood depend on *the behavior of the floodwaters* and *what they are interacting with*. The consequences of fast flowing floodwaters will be different to the consequences of slow moving floodwaters even if both have the same probability of occurring. The consequences of submerging a building will be different to the consequences of submerging a person even if the probability of each being submerged is the same. Not only the peak water level is important but also the rate of flood rise. It is therefore very hard - not to say impossible - to assign a single risk value to a location based on probability.

Another important factor having influence on the consequence is *vulnerability*. What activities are affected if a certain building is submerged, if roads are flooded, if flood sites are set under water? The vulnerability is closely related to the object owner´s ability to withstand a certain threat, which in turn is related to the level of alert.

5.4 Kristianstad and the flood risk

The flood risk in Kristianstad is multifaceted, much due to the special situation where parts of the city are situated on old lake bed. Even at normal conditions, water has constantly to be pumped out from the area to keep it dry. A heavy rainfall would cause serious consequences, even if a barrier failure of course would turn out to be a worst case scenario, probably taking months to rebuild the barrier. During this period, many people would most likely have to leave the city due to the risk for spreading of diseases by the contaminated flood water. With this as background, five major threats can be identified (Fig. 5):

- The river Helge å that passes through the city. High discharge may be caused by insufficient runoff, heavy and persistent rain, snow melt and/or saturated soil.
- Lake Hammarsjön. Its water level is to a high extent related to the discharge in Helge å as well as the sea water level. As parts of Kristianstad are situated below sea level, the water in the lake is a permanent potential threat.

- Sea water level. Despite a distance of about 20 km to the sea, sea level has a considerable impact on the water level in lake Hammarsjön, as the height of fall is low. Due to climate change the mean sea water level is expected to rise by about one meter to the end of the century. Accordingly, the sea water level with a 100-year return period is expected to vary between +2.15 and +2.60 m (Persson et al. 2012).
- Ground water. As the old lake bed in the Nosaby bay is situated below sea level, this area is set under pressure and groundwater has constantly to be pumped out from the city into lake Hammarsjön.
- Heavy rainfall. High precipitation may cause considerable consequences especially in the Nosaby bay since there is no natural outlet and all water has to be pumped out.

A worst case scenario would probably be in a situation with high discharge in Helge å, high sea water level, heavy rainfall and a barrier failure. However, this study does not focus on any risk for this to occur, it only investigates the consequences of a flood, related to the water level.

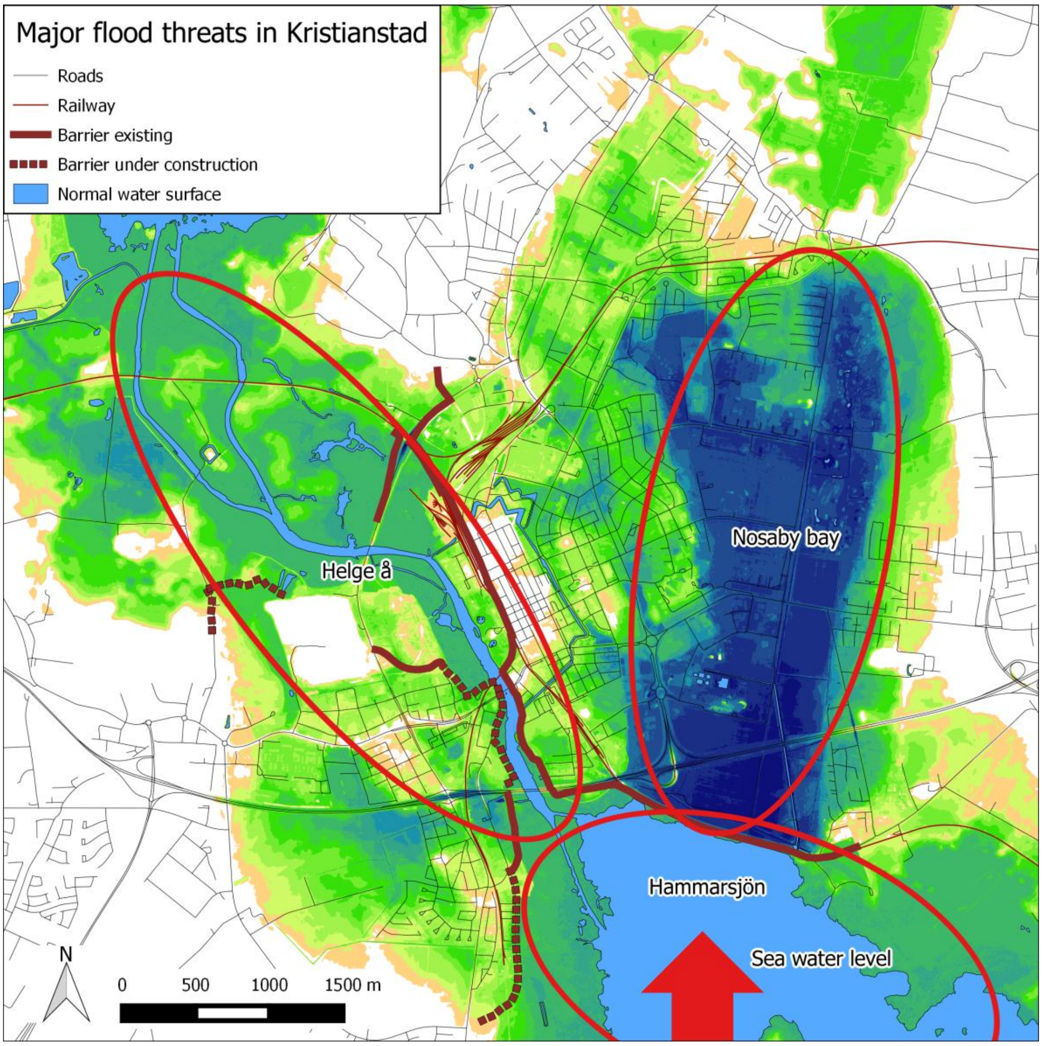

__Fig. 5.__ Major flood threats in Kristianstad: high discharge in Helge å, water level of lake Hammarsjön, ground water pressure in Nosaby bay, high sea water level in the Baltic Sea, heavy rainfall.

6 Data

New National Elevation Model (NNH)

The digital elevation model (DEM) used in the study is derived from the New National Elevation Model (NNH), with a resolution of 2 meters. This high resolution elevation data was produced by Lantmäteriet for the Kristianstad area by airborne scanning in 2010.

National road database (NVDB)

The national road database (NVDB), produced by Trafikverket, is used in the maps.

Objects with important societal function

An inventory was made in which 125 objects with important societal function were listed, see chapter 7 Methodology. Among the objects are 23 nursery schools, 12 comprehensive schools grade 1-5, 9 retirement homes, 8 LSS group homes, 3 communal kitchen, 7 main fuel stations and biogas, 12 freshwater boreholes, 6 high speed internet nodes, 12 daytime medical clinics, 6 supermarkets and 3 major food processors. 33 of the objects are providing service to a main part of the population. This category includes power supply, police, fire station and emergency service center, ambulance, hospital, freshwater boreholes, internet nodes, major food producers, media and dental care.

Coordinate reference system and height system

The coordinate reference system used in the study is SWEREF99 TM and the height system RH2000.

Water level of flooded area

A flood risk mapping along Helge å was made by The Danish Hydraulic Institute (DHI) in 2013 on behalf of The Swedish Civil Contingencies Agency (MSB) (DHI 2013b). The calculation was carried out by one- and two-dimensional hydraulic modeling in MIKE11 and MIKE21. The model input is elevation data, information about structures in the watercourse such as bridges and dams, and boundary conditions like discharge and sea water level. Water levels along the watercourse are interpolated between the calculation cross sections. Finally, the model is calibrated against historical data of discharge and water level. In Kristianstad, four different characteristic discharge - HQ50 and BHF in today´s climate, HQ100 and HQ200 in future climate 2098 - together with sea water level MHW, MHW in future climate and HHW were used as boundary conditions. NNH data from Lantmäteriet was used to describe the topography, while the characteristic discharge and sea water level were provided by Swedish Meteorological and Hydrological Institute (SMHI). The result of the flood risk mapping was presented in maps showing flooded area, water depth and flow velocity. Another model output is water levels along the watercourse, which have been used in the consequence analysis.

Flood caused by heavy rainfall

A model simulation of a flood caused by a 100-year precipitation in Kristianstad has been carried out by DHI in 2013 (DHI 2013a). Two hydraulic models were used, one-dimensional MIKE URBAN describing ditches and channels, and the two-dimensional model MIKE21 for calculation of surface runoff. These models were then linked together in MIKE FLOOD to describe flooded areas of a summer rain with 30 minutes duration of maximum intensity. In the calculation, the stormwater system was assumed to have reached its capacity, as well as the infiltration capacity of the ground soil. The result is most likely an overestimation since the assumed capacity of the stormwater system in all probability is underestimated. The model output is calculated maximum water depths, divided into three categories according to degree of impact; 0.1-0.3 m, 0.3-0.6 m, depths > 0.6 m. Together with data of water depths from this study and the DEM, water levels have been derived and used in the consequence analysis.

Other studies based on laser data in Kristianstad

Another flood risk mapping was made by DHI in 2011, on behalf of Lantmäteriet (DHI 2011). The aim was to compare results from flood risk maps based on elevation data from GSD 50+, in relation to elevation data from the primary map, and NNH. Water levels based on two characteristic discharges were investigated, the 100-year flood (HQ100) and the calculated highest flood (BHF); these are the two scenarios included in the MSB overview flood risk mapping.

7 Methodology

The study focuses on the water *level* rather than the water *depth*, and what impacts different water levels would have upon *objects with important societal function* in case of a flood. In this way, each of these objects is related to individual consequences at different water levels. Every object has its own profile when it comes to how it is affected by a flood; for one object a certain water level may only cause minor damage, for another the same water level may be disastrous. This means that the different object´s *vulnerability* is taken into account. It is also important to find out an object´s *ability to handle and resist a disturbance*, related to a certain consequence or to the object as a whole.

1. Listing objects with important societal function

As the study has its focus on consequences to objects with important societal function, a first step to find these objects was to define some kind of search-criteria. Object sectors were defined with guidance of the Styrel project, a plan that regulates disconnection of electrical power in case of transient power shortage (Gellerbring 2010). Styrel was presented by the Swedish Energy Agency in 2012 and defines 8 categories of electrical power users according to their priority in a shortage situation. To this list, Kristianstad has added yet another sector (numbered 0) that includes power supply (Table 1).

Table 1. *Category 1-8 of electrical power users according to the Styrel definition of their priority in a shortage situation. Category 0 added by Rescue Service in Kristianstad.*

Priority class	Definition of supplier and user category of electric power
0	Objects required for power supply.
1	Users that - already in short-term (hours) - have great importance to secure lives and health.
2	Users that - already in short-term (hours) - have great importance to society´s functionality.
3	Users that - already in long-term (days) - have great importance to secure lives and health.
4	Users that - already in long-term (days) - have great importance to society´s functionality.
5	Users that represent great economic values.
6	Users that have great importance to the environment.
7	Users that have great importance to social and cultural values.
8	Other users.

In the study, the categories with priority 0-4 were used to define sectors of important societal functions. It gave a manageable number of objects to investigate (125), and these categories include the most crucial objects; power supply and objects with great importance to secure lives and health as well as society´s functionality. All objects in the inventory were tagged with data like Styrel priority class, object type, object name, address, coordinates, owner, name of manager as well as operation manager and contact information, if the object is transport dependent or not, water level when object is surrounded by water, and water level when the object is facing a disastrous consequence meaning that the activities at the object must stop.

A major advantage of using the Styrel categories is that it classifies the objects according to their degree of importance to the society. See Table 2 for examples of object types included in these categories. Consequences of a water level at elevations from -2.4 m up to +4.0 m with 0.1 m steps were investigated, and for each priority class, 0-4, an inventory was made to find objects situated within the flood area of the highest water level, +4.0 m.
It should be noted that an important object type is missing; major roads and traffic routes. This type is not included in the evaluation since the study only handles objects as points. Although a road or traffic route may be cut, still parts of it may be used for transports. If included, it should be regarded as a priority class 1 object. Examples of important traffic routes in Kristianstad – and the water level at which they are flooded – are the European highway E22 (-1.7 m), Härlövsängaleden (+2.3 m) and Långebrogatan (+2.0 m).

Table 2. *Examples of object types in different sectors used in the inventory for Kristianstad.*

Priority class	Sector objects
0	Objects of vital importance for power supply
1	Police stations, fire stations, ambulance stations, nursery schools, after-school centres, comprehensive schools grade 1-5, retirement homes, LSS group homes, hospitals
2	Municipality buildings, main fuel stations and biogas, water supply, sewage plants, pump stations, district heating, public transport, school transport, railway station, bus station, mobility service
3	Health centres, daytime medical clinics, pharmacies, security cells (parish houses)
4	Banks, post offices, supermarkets, major food processors, daily and raw product transports, news media, airports

2. Consequence analysis

From start of the thesis project the ambition was to identify all consequence levels for each object by interviewing the object owners. As described in the MSB study “*Konsekvenser av en översvämning i Mälaren”* (MSB 2012), each object was to be classified on a 5-grade scale to indicate the grade of consequence a certain water level would have upon its function, with grades from ‘very limited’ to ‘disastrous’ (Table 3). A questionnaire was sent by mail to about 30 object owners, shortly followed by another, more explanatory. However, when starting the interviews, it soon was clear that only a limited part of the object owners were able to define the different consequence levels for their objects. They had never experienced such an extraordinary flood situation. The project plan was therefore revised to only cover the highest consequence level – disastrous (5).

Table 3. *Consequence levels and their definition according to the MSB study "Konsekvenser av en översvämning i Mälaren" (MSB 2012).*

Consequence level		Definition
1	Very limited	Activities are running as usual.
2	Limited	Activities are basically running as usual with some exceptions. Items worthy to protect are not, or only to a limited extent, affected.
3	Serious	Activities are partly running as usual but items worthy to protect are apparently affected and great reprioritizing has to be accomplished.
4	Very serious	Activities are passably running, or not at all, and items worthy to protect are highly affected. Great reprioritizing has to be accomplished.
5	Disastrous	Activities are not running.

To define the water level corresponding to a disastrous consequence (level 5) for each object, the work was carried out in two steps. First, information about this level was either provided by the object owner or collected by surveying. For some objects surveying was carried out as a complement in addition to information from object owner, in attempt to secure all objects being treated in the same way. However, almost all 125 objects were visited to define a disastrous water level by gps. For a building, a water level corresponding to a disastrous consequence would in most cases be the lowest opening in the building shell that would allow water to enter. Second, all objects were investigated in a GIS using a satellite image to confirm that the defined consequence levels were correct. For some objects the flooded area was not even close and the figures had to be adjusted. A reason for this could be an area of captured water that would have impact on the object. Another thing to be checked was at what water level an object was surrounded by water – if the object was regarded as transport dependent, this would imply a disastrous consequence.

Every object owner was also asked to define the object´s ability to handle and resist a disturbance, estimated on a 4-grade scale, with grades from 'good ability' to 'none or very limited ability', see Table 4. The ability analysis was aimed to show the object´s overall ability to withstand a serious interference. However, since only a few object owners were capable to provide this information, it had to be suspended from the study and may be subject for a more comprehensive analysis in the future. For such a study, it would also be interesting to have the ability defined for each consequence level. The questionnaire sent to object owners is presented in Appendix E.

Table 4. *Levels of ability for an object owner to withstand a flood, according to the MSB study "Konsekvenser av en översvämning i Mälaren" (MSB 2012).*

Ability level		Definition
1	Good	The ability is good.
2	Mainly good	The ability is mainly good but includes some deficits.
3	Insufficient	A certain ability exists, however insufficient.
4	No or very limited ability	There is no, or very insufficient, ability.

3. GIS analysis

As the municipality of Kristianstad recently decided to start using open source GIS software, all GIS analyses in this study were carried out in Quantum GIS (QGIS). In this, a digital elevation model (DEM), roads and railway, existing and planned water barriers, normal water surface, captured flooded areas, a Google satellite image and the 125 important societal objects were visualized. To easier be able to identify each object, an object ID in the form x.y.z was created:

x – Styrel priority class (0-4)
y – object type ID
z – serial number to separate the objects within each object type

Flooded areas for elevations starting from -2.4 m up to +4.0 m with 0.1 m interval, a total of 64 different levels, were calculated by means of the DEM. This range was chosen as the lowest level in Kristianstad is -2.41 m and +4.0 m is the calculated water level upstream the railway bridges at the calculated highest discharge (BHF). The flooded area is retrieved by reclassifying grid values greater or equal to the DEM value, and less or equal to the current water level. By vectorising the new grid values, a polygon of the flooded area is created. In the calculation of impacts, a straight water level was used for the protected areas (see Fig. 4). Since parts of Kristianstad are protected by barriers, the resulting water level in the protected areas will be equal to the location of the barrier failure. 93% of the objects in the inventory are situated within the protected areas, and for the remaining objects calculations have been carried out taking the water level gradient at higher discharge into account. All calculations were performed using 'main flooded areas', where each area has a surface connection to the flood source. As a complement, ‘captured flooded areas’ were calculated and presented as a potential flood risk, where the flooded areas have no surface connection to flood source.

For each elevation and flooded area, an overlay analysis was carried out in order to find the individual impact on the objects. This was done for the Styrel priority classes 0-4 in total, as well as separated. The result of the analysis – regarding the impact on the object as well as its importance to society – was visualized by the four colors presented below. The output of this GIS analysis was an attribute table for each category of affected objects.

Yellow	Object not affected by the flood
Orange	Object within flooded area where water level is below its level of disastrous consequence
Cyan	Object within flooded area where water level has reached or passed its level of disastrous consequence
Purple	Object within flooded area where water level has reached or passed its level of disastrous consequence, providing service to a main part of the population

A specific objective with the GIS analysis and the GIS tools developed was to provide Kristianstad Rescue Service with a useful instrument for further risk analysis, training, and base for adequate decisions in an emergency flood situation. Examples of use is to visualize flooded areas at different water levels, calculate evacuation paths, retrieve lists of affected objects at different water levels ordered by their importance to society´s functionality, get information about flood impacts at specific objects, storage of object data and contact details of object owners.

To handle all required GIS operations, a script was developed to automate the numerous repetitive calculations, as well as to regenerate layers after an object list update. In addition to the analysis of flooded area and impact to flooded objects, another GIS analysis was carried out to estimate water volumes in case of a Hammarslund barrier failure (see chapter 8 Results).

In a flood situation, most objects reach their water level of disastrous consequence (Cyan) immediately when being flooded. Especially if the object is dependent on transports, the activities have to close when access to the object is blocked, although the water still has not entered into the building/localities. However, there are also objects where activities may continue when flood water has reached the building/localities, and even when access has been blocked (for objects not dependent on transports). This motivates a four-grade flood scale.

Flood risk caused by heavy rainfall was evaluated by using a raster of flood depth values made by DHI (DHI 2013a). Water depths greater than 0.1 m were extracted and added to the DEM to get resulting water levels. All objects situated within or close to the flooded area were investigated by a satellite image where the water level was compared to the object´s water level of disastrous consequence. An object was regarded as affected if transport dependent with access roads flooded, or when whole or part of the object was flooded with a water level equal to, or higher, than the water level of disastrous consequence. An analysis of rainwater volume was carried out to investigate the eventual need of increased capacity at pump station Pynten.

For more detailed information about the method used to define disastrous consequence level, see Appendix A.

4. Discharge, water levels and flood scenarios

To get an idea of the magnitude of a certain water level, they are related to specific characteristic discharge in Helge å and sea water level. This is the case for discharge MQ, MHQ, HQ50, HQ100, BHF, future climate HQ100 and HQ200, as well as sea water level MW, MHW, HHW and future climate MHW. Seven combinations of discharge and sea water level - each one corresponding to a certain water level in lake Hammarsjön - have been retrieved from the DHI flood risk mapping (DHI 2013b) and other documents. These water levels are used when describing an east barrier failure (Hammarslund) as well as a simultaneous east and west barrier failure. A list of the water levels together with references is presented in Table 6 and 7. In the same way, five combinations of discharge and sea water level have been retrieved to represent different water levels in Helge å close to Yllan when describing consequences of a west barrier failure. These water levels with references are presented in Table 5.

Four flood scenarios, each one representing a 100-year event in today´s climate, have been chosen to visualize the risk for considerable consequences in Kristianstad in case of a flood. All of them may be regarded as relevant potential threats to the city regarding flood events. Three of the scenarios describe a 100-year flood including a barrier failure, while the fourth scenario reflects a heavy rain with a 100-year precipitation.

- Scenario A - High discharge in Helge å (HQ100), high sea water level (MHW) and a west barrier failure close to Yllan. In this scenario the west barrier is finalized.
- Scenario B - High discharge in Helge å (HQ100), high sea water level (MHW) and a failure of the Hammarslund barrier.
- Scenario C - High discharge in Helge å (HQ100), high sea water level (MHW) and a simultaneous failure of the west barrier and the Hammarslund barrier.
- Scenario D - Heavy rainfall (100-year precipitation).

8 Results

Of the 125 important societal objects in the inventory, 23 are protected by the west barrier and 92 are protected by the east barrier. 10 objects are situated outside these areas and do not have any specific protection. 33 of the objects are providing service to a main part of the population. Due to secrecy regulations, some important societal objects are not presented in the maps. However, they are still included in the data and part of the analysis. In the digital elevation model of the area the pronounced depletion of the Nosaby bay is seen (Fig. 6). The results of scenario A, B and C are based on condition that the west barrier is finalized. Flooded areas presented in the figures are calculated using a straight water surface, generating a certain error in the northern parts of Helge å in the city, at higher discharge. Taking the water level gradient into account, the water level should be higher, and consequently the area wider. This error is taken care of in the analysis results.

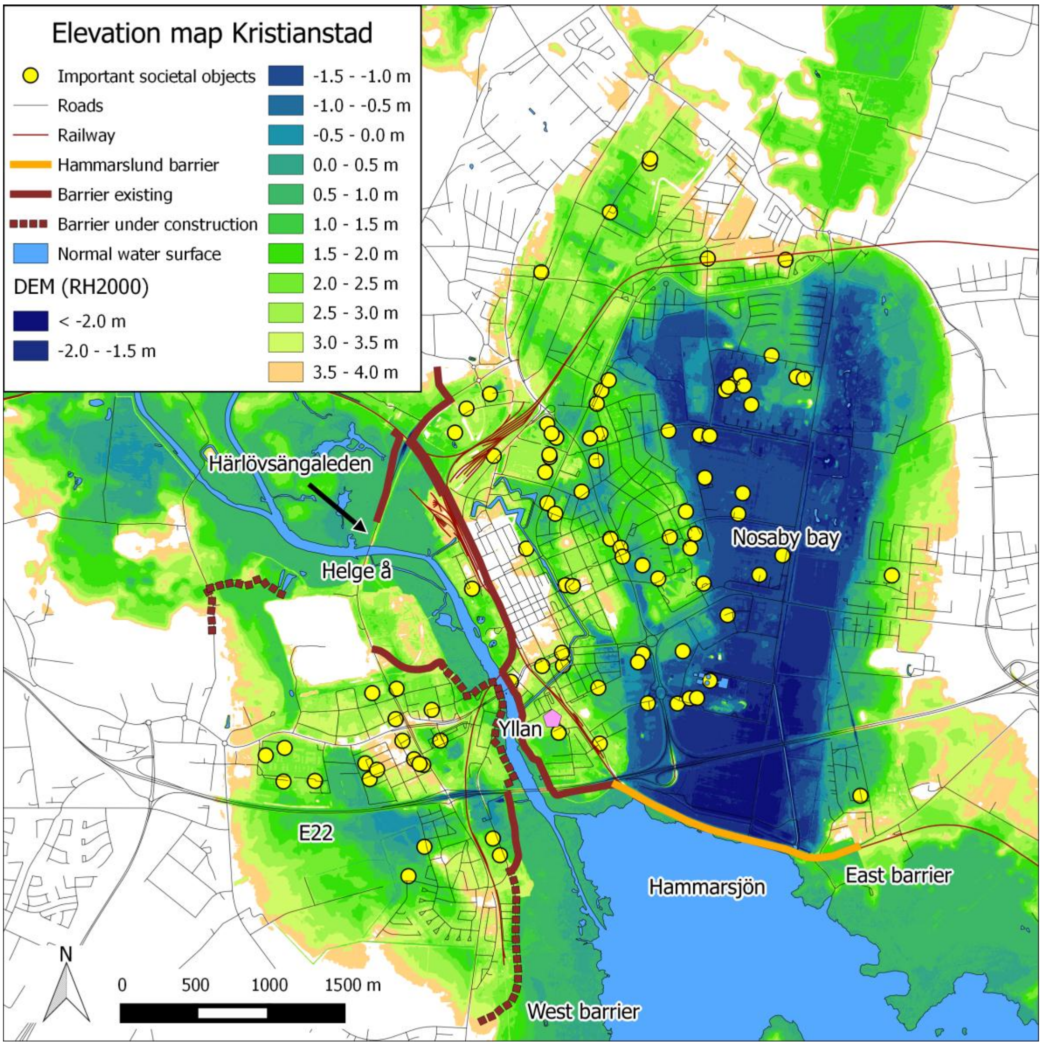

Fig. 6. *Elevation map of Kristianstad. Objects with important societal function according to Styrel priority class 0-4. West and east barrier, including the Hammarslund barrier, lake Hammarsjön and the Nosaby bay. Traffic routes E22 and Härlövsängaleden. Object Yllan as reference point to main part of objects west of Helge å. Source: NNH data, Lantmäteriet 2010. With kind permission from Jan-Olof Pettersson, Stadsbyggnadskontoret Kristianstad. Height system RH2000.*

Scenario A. High discharge in Helge å, high sea water level and a west barrier failure.

In this scenario, the west barrier is finalized (scheduled to 2025) and assumed to have a failure at a location close to Yllan, a few hundred meters north of the inlet of lake Hammarsjön. The number of flooded objects in Styrel priority class 0-4 that have reached a disastrous consequence, as well as resulting water levels in Helge å close to Yllan, is presented in Table 5 and Fig. 7.

Table 5. *Water level in Helge å close to Yllan, Kristianstad, at different characteristic discharge and sea water level. Number of objects with disastrous consequence (Total objects), and objects with disastrous consequence that provide service to main part of the population (Service objects), at a west barrier failure in Kristianstad. * = future climate 2098. All objects from Styrel priority class 0-4. References in //. /1/: DHI 2013b, /2/: DHI 2010. Height system RH2000.*

Characteristic discharge Helge å		Characteristic sea water level		Water level Helge å (Yllan)	Total objects n=125		Service objects n=33	
	m^3/s		m	m		%		%
HQ50	255 /1/	MHW	+0.88 /1/	+2.3 /1/	12	10	4	12
HQ100 (Torsebro)	288 /2/	MHW	+0.88 /1/	+2.5 /2/	20	16	9	27
HQ100*	420 /1/	MHW*	+1.73 /1/	+3.0 /1/	26	21	12	36
HQ200*	458 /1/	MHW*	+1.73 /1/	+3.1 /1/	26	21	12	36
BHF (Torsebro)	527 /1/	HHW	+1.46 /1/	+3.6 /1/	33	26	12	36

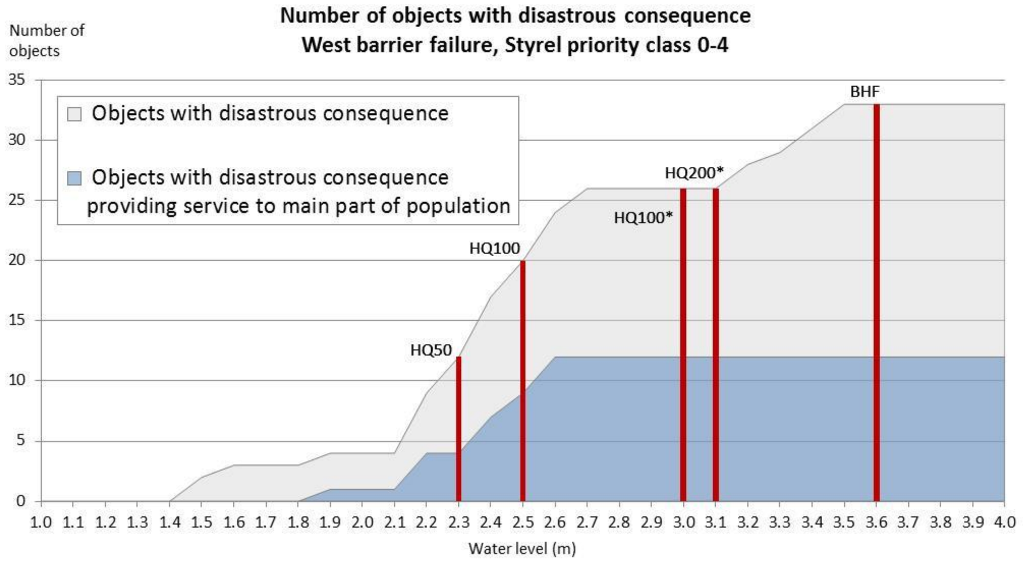

Fig. 7. *Number of objects in Styrel priority class 0-4 with disastrous consequence at a west barrier failure in Kristianstad. Characteristic discharge corresponding to different water levels included as comparison (* = future climate 2098). Height system RH2000.*

The resulting water level in Helge å close to Yllan, caused by a 100-year flood event (HQ100, 288 m^3/s) and mean high sea water level (MHW, +0.88 m), is +2.5 m. In case of a west barrier failure, 16% of the important societal objects in total will reach a disastrous consequence, including 27% of the total objects providing service to a main part of the population. Flooded area and status of the individual objects is presented in Fig 8. For maps showing consequences of other flood events, see Appendix D.

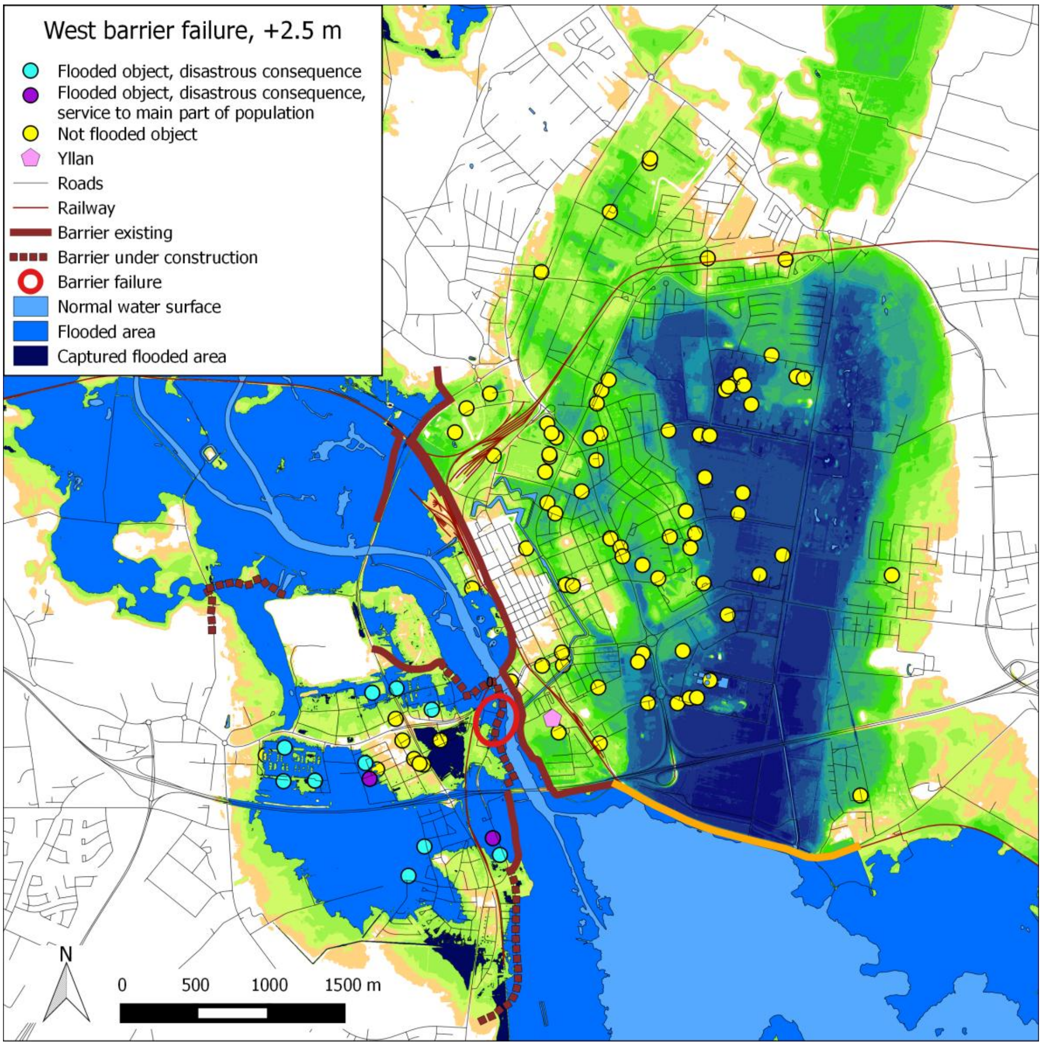

Fig. 8. *Consequences of a 100-year flood event and a west barrier failure in Kristianstad. All objects from Styrel priority class 0-4. Height system RH2000.*

Scenario B. High discharge in Helge å, high sea water level and failure of the Hammarslund barrier.

The Hammarslund barrier is part of the east barrier and is located next to lake Hammarsjön. The number of flooded objects in Styrel priority class 0-4 that have reached a disastrous consequence, as well as resulting water levels in lake Hammarsjön, is presented in Table 6 and Fig. 9. The result is based on condition that the west barrier is finalized (scheduled to 2025).

Table 6. *Water level in lake Hammarsjön at different characteristic discharge in Helge å and sea water level. Number of objects with disastrous consequence (Total objects), and objects with disastrous consequence that provide service to main part of the population (Service objects), at a Hammarslund barrier failure in Kristianstad. * = future climate 2098. All objects from Styrel priority class 0-4. References in //. /1/: DHI 2013b, /2/: DHI 2010, /3/: C4 Teknik 2016, /4/: Kristianstads kommun 2015, /5/: Dahlman. Flood Watch Kristianstad. Height system RH2000.*

Characteristic discharge Helge å		Characteristic sea water level		Water level Hammarsjön	Total objects n=125		Service objects n=33	
	m^3/s		m	m		%		%
MQ	40 /3/	MW	0.0 /3/	+0.3 /4/	31	25	6	18
MHQ	140 /3/	MHW	+0.88 /1/	+1.6 /5/	51	41	9	27
HQ50	255 /1/	MHW	+0.88 /1/	+2.2 /1/	65	52	13	39
HQ100 (Torsebro)	288 /2/	MHW	+0.88 /1/	+2.4 /2/	74	59	15	45
HQ100*	420 /1/	MHW*	+1.73 /1/	+2.9 /1/	92	74	26	79
HQ200*	458 /1/	MHW*	+1.73 /1/	+3.0 /1/	94	75	28	85
BHF (Torsebro)	527 /1/	HHW	+1.46 /1/	+3.5 /1/	100	80	30	91

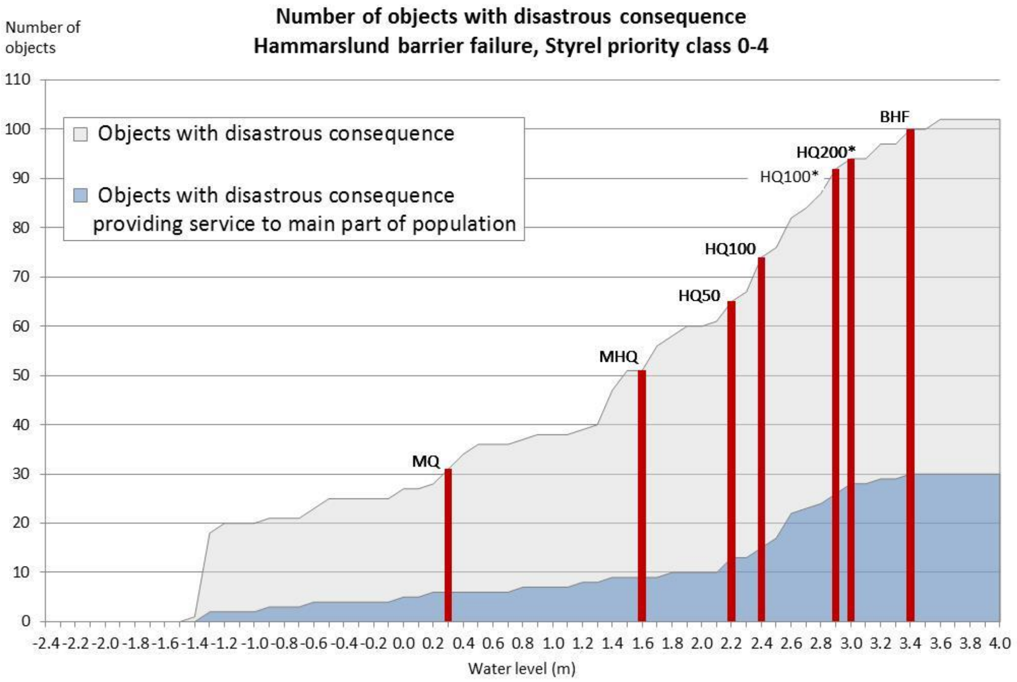

Fig. 9. *Number of objects in Styrel priority class 0-4 with disastrous consequence at a Hammarslund barrier failure in Kristianstad. Characteristic discharge corresponding to different water levels included as comparison (* = future climate 2098). Height system RH2000.*

The resulting water level in lake Hammarsjön, caused by a 100-year flood event (HQ100, 288 m^3/s) and mean high sea water level (MHW, +0.88 m), is +2.4 m. In case of a failure in the Hammarslund barrier, 59% of the important societal objects in total will reach a disastrous consequence, including 45% of the total objects providing service to a main part of the population. At +0.3 m 25% of the objects in the inventory have reached a disastrous consequence, at +2.1 m 50% and at +3.0 m 75% (Fig. 10). Flooded area and status of the individual objects is presented in Fig 11. For maps showing other flood events, see Appendix D.

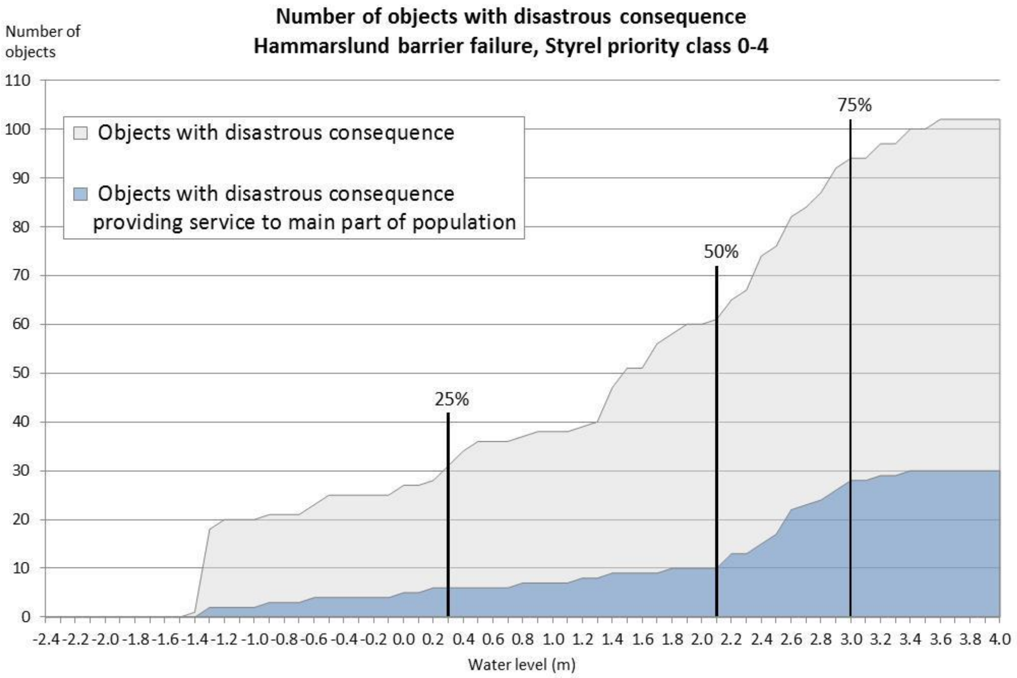

Fig. 10. *Number of objects in Styrel priority class 0-4 with disastrous consequence at 25, 50 and 75 percent of total objects, respectively, at a Hammarslund barrier failure in Kristianstad. Height system RH2000.*

The flood event in 2002, when the water level in lake Hammarsjön reached +2.15 m, is regarded as a flood with a return period of about 15-30 years, according to frequency analysis. In case of a barrier failure, 50% of the total objects with important societal function in Styrel category 0-4 would have been forced to close. 30% of the objects providing service to a main part of the population would have been affected.

The result of a rough estimate is that 5.8 million cubic meters of water would enter into the Nosaby bay in case of a Hammarslund barrier failure at normal water level (+0.3 m) and MQ in Helge å. This equals to half the water volume in lake Hammarsjön. An iterative calculation shows that the water level of the lake then would decrease by about 0.3 meters (on condition that no water is entering the lake). Assuming the same rate of water from lake Hammarsjön going into the Nosaby bay as MQ, the corresponding volume for HQ100 (water level +2.4 m) is 16 million cubic meters. Time for the water level to recover would be about 40 and 16 hours, respectively. However, in reality a continuous discharge from Helge å and a moderate speed of the water outlet at the barrier failure would make a water level decrease in lake Hammarsjön negligible. The estimate does not take into account the capacity of the storm water system.

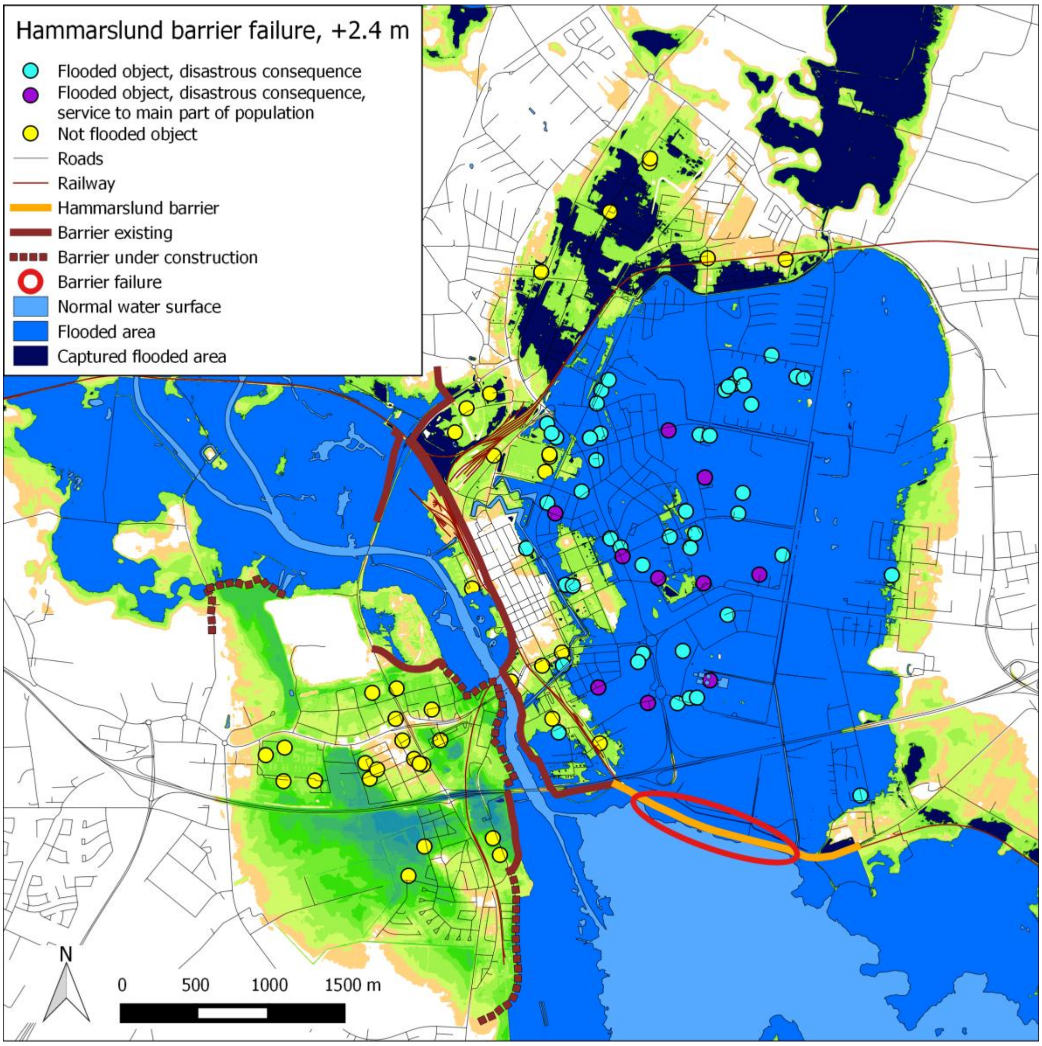

Fig. 11. *Consequences of a 100-year flood event and a Hammarslund barrier failure in Kristianstad. All objects from Styrel priority class 0-4. Height system RH2000.*

The most vulnerable object category at a 100-year flood event and a Hammarslund barrier failure is retirement homes, where 89% of the objects (8 of 9) will have to close (Fig 12). The second most vulnerable category is nursery schools with 74% affected objects. Least vulnerable is freshwater boreholes, 42%.

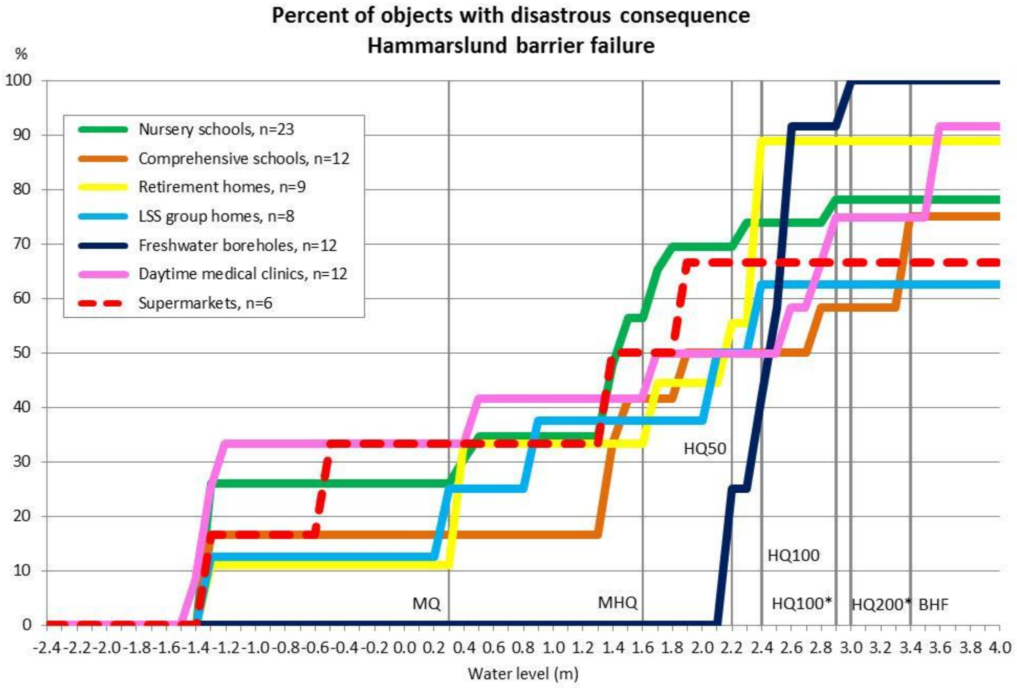

Fig. 12. *Vulnerability of major object categories at a Hammarslund barrier failure in Kristianstad. Percent of total objects in each category (* = future climate 2098). Height system RH2000.*

Scenario C. High discharge in Helge å, high sea water level and a simultaneous Hammarslund and west barrier failure.

The number of flooded objects in priority class 0-4 that have reached a disastrous consequence, as well as resulting water levels in lake Hammarsjön, is presented in Table 7 and Fig. 13. The result is based on condition that the west barrier is finalized (scheduled to 2025). For a more differentiated presentation of the results of the Styrel priority classes and object categories, see Appendix B and C.

Table 7. *Water level in lake Hammarsjön at different characteristic discharge in Helge å and sea water level. Number of objects with disastrous consequence (Total objects), and objects with disastrous consequence that provide service to main part of the population (Service objects), at a simultaneous Hammarslund and west barrier failure in Kristianstad * = future climate 2098. All objects from Styrel priority class 0-4. References in //. /1/: DHI 2013b, /2/: DHI 2010, /3/: C4 Teknik 2016, /4/: Kristianstads kommun 2015, /5/: Dahlman. Flood Watch Kristianstad. Height system RH2000.*

Characteristic discharge Helge å		Characteristic sea water level		Water level Hammarsjön	Total objects n=125		Service objects n=33	
	m^3/s		m	m		%		%
MQ	40 /3/	MW	0.0 /3/	+0.3 /4/	31	25	6	18
MHQ	140 /3/	MHW	+0.88 /1/	+1.6 /5/	53	42	9	27
HQ50	255 /1/	MHW	+0.88 /1/	+2.2 /1/	71	57	14	42
HQ100 (Torsebro)	288 /2/	MHW	+0.88 /1/	+2.4 /2/	88	70	19	58
HQ100*	420 /1/	MHW*	+1.73 /1/	+2.9 /1/	108	86	28	85
HQ200*	458 /1/	MHW*	+1.73 /1/	+3.0 /1/	110	88	31	94
BHF (Torsebro)	527 /1/	HHW	+1.46 /1/	+3.5 /1/	121	97	33	100

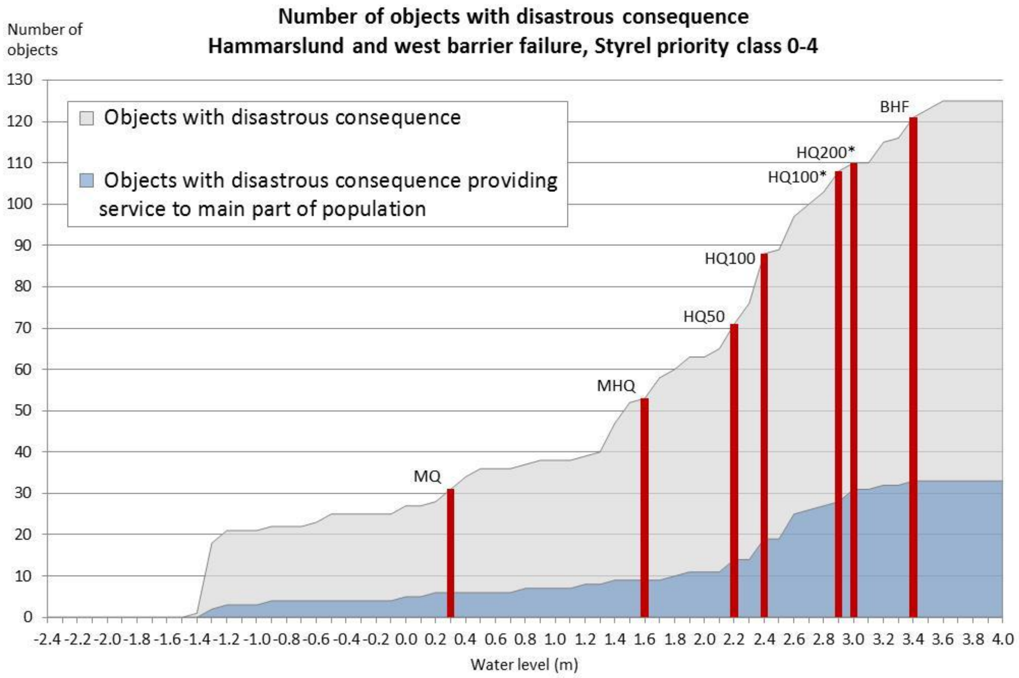

Fig. 13. *Number of objects in Styrel priority class 0-4 with disastrous consequence at a simultaneous Hammarslund and west barrier failure in Kristianstad (* = future climate 2098). Height system RH2000.*

The resulting water level in lake Hammarsjön, caused by a 100-year flood event (HQ100, 288 m^3/s) and mean high sea water level (MHW, +0.88 m), is +2.4 m. In case of a simultaneous failure in the west barrier and the Hammarslund barrier, 70% of the important societal objects in total will reach a disastrous consequence, including 58% of the total objects providing service to a main part of the population. Flooded area and status of the individual objects is presented in Fig. 14. For maps showing other flood events, see Appendix D.

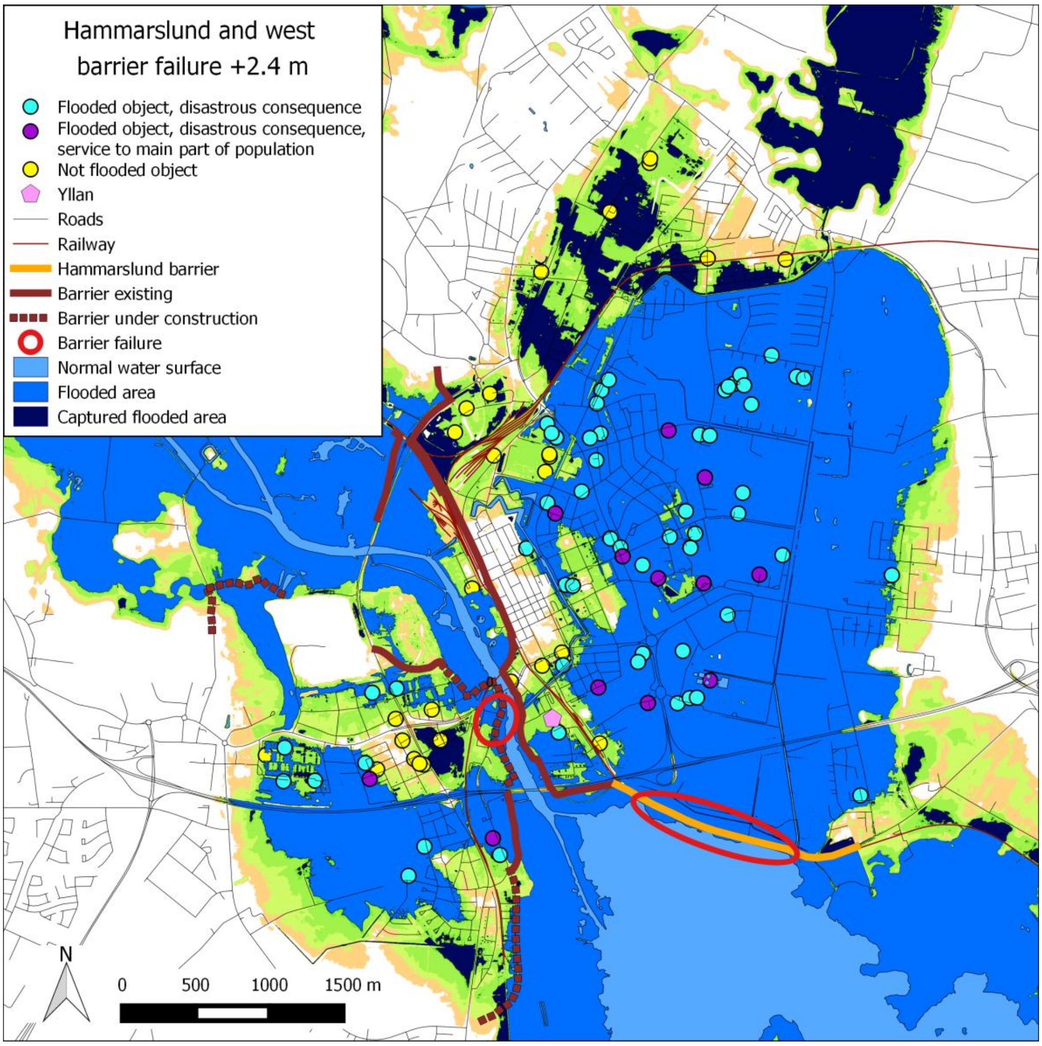

Fig. 14. *Consequences of a 100-year flood event and a simultaneous Hammarslund and west barrier failure in Kristianstad. All objects from Styrel priority class 0-4. Height system RH2000.*

Scenario D - Heavy rainfall

A flood scenario that would likely cause considerable consequences to the city is a heavy rainfall. The reason for this is that the intensity of the precipitation exceeds the ground´s capacity of infiltration and drainage, which will result in a so called ‘pluvial flood’. In recent years occasions of this type have taken place at a number of locations, some of them not far from Kristianstad, like Copenhagen (2011) and Malmö (2014). However, the situation in Kristianstad is kind of special since the precipitation that hits the city inside the east barrier has no natural runoff and has to be pumped out. The possibilities to fully protect the city against a heavy rainfall are limited and focus has to be put on solutions that will minimize the negative consequences.

A model simulation of a flood caused by a 100-year precipitation in today´s climate has been carried out by DHI (DHI 2013a). The output is presented as flooded area and maximum water depths, the result of a summer rain with 30 minutes duration of maximum intensity. Flooded areas and affected objects are presented in Fig. 15. With data of water depths from this study and the DEM, each object has been investigated regarding flooded area and water level related to the object´s disastrous consequence. The results show that

- 40 of the 125 objects (32%) in the inventory are fully or partly flooded and have reached – or are close to reach – a disastrous consequence.
- 4 of the affected objects provide service to a main part of the population which corresponds to 12% of this category.

Roads and main traffic routes are vulnerable in a situation of heavy rain. The European highway E22 is flooded at a 100-year event, especially at the viaducts. The same goes for Härlövsängaleden.

As the area of Nosaby bay is situated below sea level, and the runoff from adjacent areas ends up in the bay, the water needs to be pumped out. A GIS analysis shows that the volume of surface water is about 1.2 million cubic meters. After upgrading water pump station Pynten to a capacity of 13 m^3/s, it would take about 26 hours to lift this water into lake Hammarsjön. Together with two other pumping stations, the total capacity to handle a 100-year precipitation seems to be sufficient.

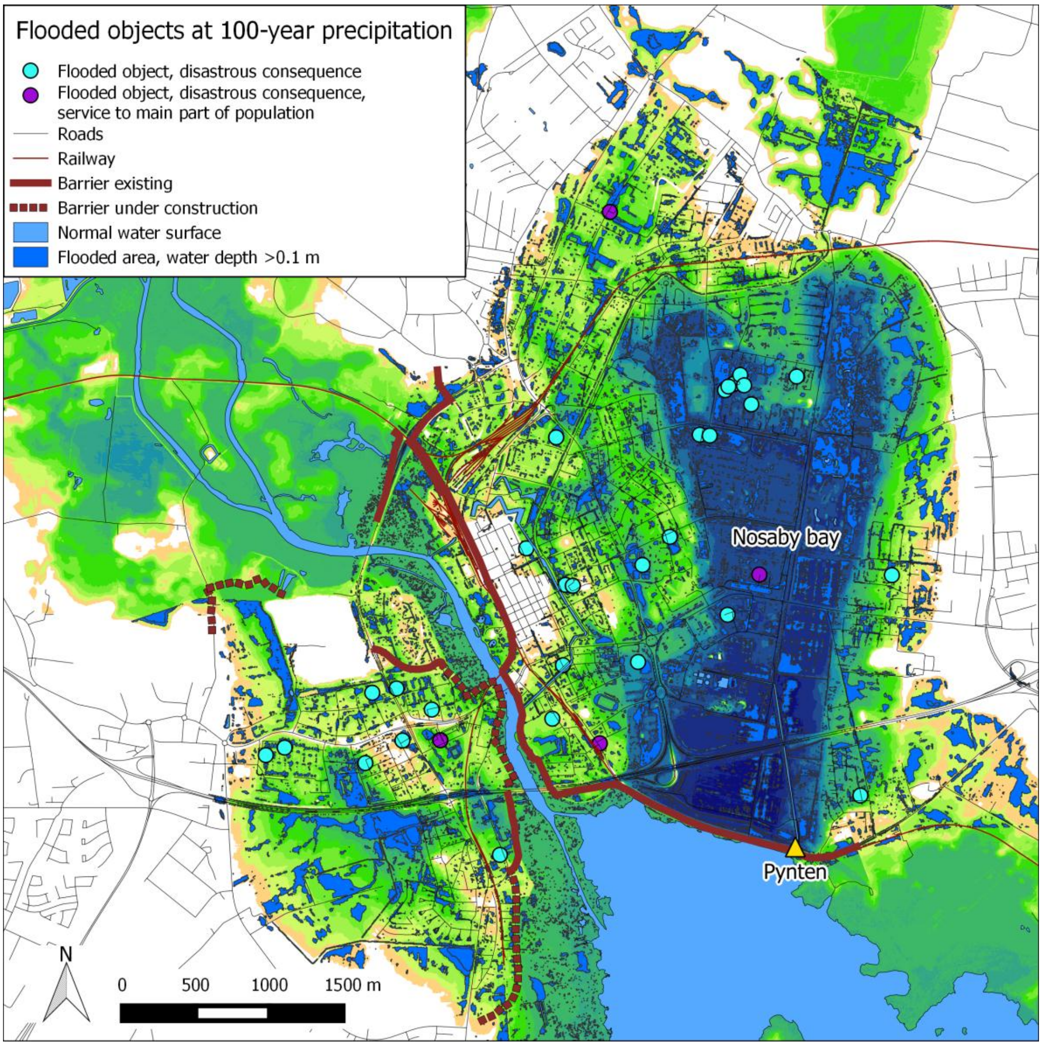

Fig. 15. *Flooded areas and objects at a 100-year precipitation event in Kristianstad. Nosaby bay and water pump station Pynten. All objects from Styrel priority class 0-4.*

Overview of flood scenarios

An overview of the result from the four flood scenarios is presented in Fig. 16.

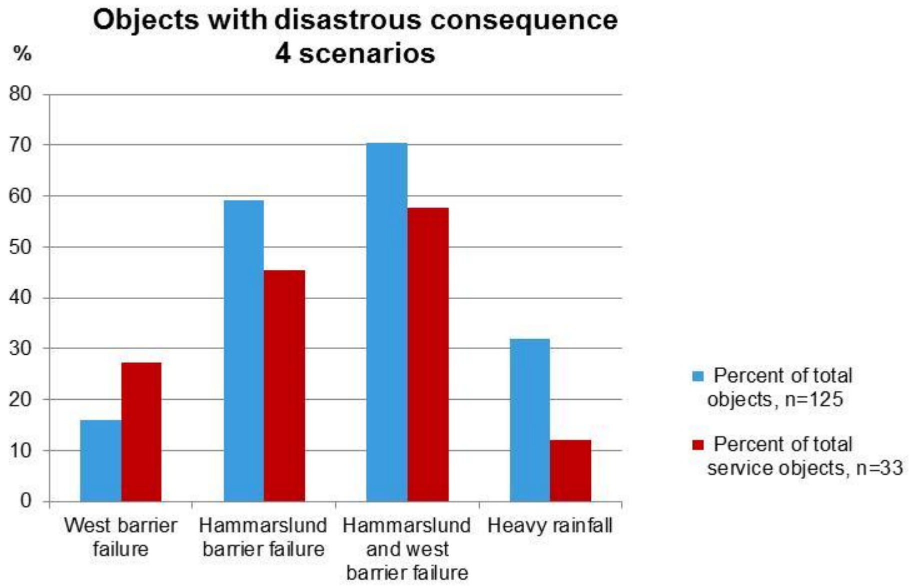

Fig. 16. *Percentage of objects with disastrous consequence at a 100-year event in Kristianstad (discharge in Helge å and precipitation, both with a 100-year return period, respectively). Service objects = objects providing service to a main part of the population.*

9 Discussion

9.1 High resolution elevation data

Before 2009, the elevation data available was GSD 50+ with a resolution of 50 meters in plane and with a standard error of 2.5 meters in height. Based on proposals from the Climate and Vulnerability Investigation (SOU 2007:60), the government has given Lantmäteriet the task to develop a new national elevation model with high and known quality. The work started in 2009 with airborne laser scanning of Sweden and the plan is to produce a nationwide elevation model by 2016-2017 (Lantmäteriet. *Fakta om laserskanning.*). The aim is to get an elevation model with a standard error of height better than 0.5 m for a 2 m grid. In a summary made by Lantmäteriet (Lantmäteriet 2011) it is stated that the height accuracy for open flat well-defined areas is about 0.05 meter. Tests of scanned hard-surface areas have proved them to have an elevation accuracy of +/- 0.03 meter (Lundgren and Owemyr 2010). As this study uses 0.1 m elevation steps in the calculation of flooded areas, it would not have been able to perform without high resolution elevation data.

9.2 Main source of errors

Water levels of lake Hammarsjön and Helge å – corresponding to a discharge of HQ50, HQ100, BHF, future climate HQ100 and HQ200 – are based on hydro-dynamic modelling made by DHI (DHI 2013b). This is assumed to be one of the main source of errors, since the result of the analysis to a high degree is dependent on limitations of the model used, assumptions made, and input data like rawness and boundary conditions. The consequence analysis of a flood caused by a heavy rainfall is also based on data from a DHI study (DHI 2013a), and similarly the result is highly dependent on limitations and assumptions made in the hydro-dynamic modelling. According to the MSB report 'Kartläggning av skyfalls påverkan på samhällsviktig verksamhet' (DHI 2014), there are four main methods in flood risk mapping of a heavy rainfall; GIS analysis of low levels in the flood risk area, two-dimensional hydraulic modelling, combined stormwater model (1D) and model for ground flow path network, combined stormwater model (1D) and surface runoff model (2D). Of the methods listed, the last one is used in the consequence analysis, also regarded as state-of-the-art in pluvial flood mapping.

Another source of error occurs when defining the disastrous water level for each object. A major drawback by defining a disastrous consequence as a visible opening in the building shell, is that it does not take into account the complexity of the stormwater system in a city. A correct output should include a potential influence of this system, where the water is communicating like interconnecting vessels. ‘Captured’ flooded areas may therefore in reality be ‘main’ flooded areas. Buildings with a basement may reach a disastrous consequence if water may enter at the basement floor in case there is no back valve in place. This implies that a disastrous water level in reality is lower for some objects than what is defined in the inventory of the study, and a higher percent of the objects will have to shut down in a flood situation. To improve the reliability of the result, an investigation of all objects with basement should be carried out. The number of objects that may be affected by a captured flooded area with a water level lower than the one used from the main flooded area, is 42 (34%). However, only 18 objects (14%) showed a difference in water level of more than 0.2 m. Still, to include the stormwater system in the calculations would generate a more reliable result, which would require a revision of the object list. This list is also regarded as a dynamic document which will be subject to regular refining. The procedure of defining disastrous water levels in this study is described in Appendix A.

9.3 Object representation and vulnerability

The representation of an object by a point is not quite optimal since an object may cover a relatively large area. The procedure to select the objects affected by a certain water level starts with choosing all objects within a flooded area, and the selected objects are then checked in relation to a disastrous consequence level. This means that it is important that the coordinates representing a building lies within the flooded area at the specific water level. Therefore, some coordinates have been adjusted. All objects were checked according to captured flooded areas as being a potential flood risk.

Some important societal objects, providing service to a main part of the population, are especially vulnerable in case of a Hammarslund barrier failure. Situated in the Nosaby bay they will reach a disastrous consequence at low elevations. This is the case for the Region Skåne Hospital Management which will be surrounded by flood water at -1.3 m. Similarly the Rescue Service will be surrounded by water at -0.9 m. The central sewage plant, serving Kristianstad as well as 18 other locations, is of natural causes located close to the lowest point in the city. It will stop working at -0.6 m when there is no possibility to purify all incoming water; instead it will go directly to lake Hammarjön, via pump station Pynten. The central hospital of Kristianstad, CSK, with 300 beds and workplace for about 2300 employees, will reach a disastrous consequence at 0.0 m. Flood water will then enter a machine room with technical equipment that provides the hospital with electricity, heat, water, steam, breathing air and technical air. Access to the ambulance station will be blocked at +1.2 m.

One of the analysis results is that the most vulnerable object category at a 100-year event and a Hammarslund barrier failure is retirement homes, where 8 of 9 objects will have to close. A relatively rapid evacuation of elderly people, some with significantly reduced mobility, is a quite resource-demanding process. A project of this kind requires an implemented, well-known and practiced plan with the residents involved.

9.4 Study outcome

Consequences of a flood in built-up areas may be presented in a number of different ways. However, if the aim is to be able to quantify the impact, the alternatives are more limited. This study has focused on quantifying the impact to a city by describing the number of objects with important societal function that would reach a disastrous consequence – a water level where the activities must stop. The number of objects with a disastrous consequence is in turn related to characteristic discharge in a passing river, as well as to characteristic sea water levels.

The method may be regarded as relatively simple, naturally having its own drawbacks, some of them mentioned in chapter 9.2. Still the GIS analysis provides useful information about the affected objects – not only how many, but also what objects and where they are located. In the long perspective, it means that decision-makers will have a basis for decision to answer the question if a certain prevention measure is cost effective or not, if a certain object with important societal function should be relocated, or if – and where - infiltration areas should be built according to the risk of flood consequences. In this context, one of the crucial questions to be answered is: What risk are we willing to accept?

One of the by-products of the study is the GIS tool that will provide Kristianstad Rescue Service with an instrument for further risk analysis, training, and base for adequate decisions in an emergency flood situation. This implies an area of application in a short perspective: What important societal objects should be prioritized in an emergency situation of a heavy rainfall or barrier failure?

The study may be seen as a small – however significant - piece in the jigsaw of flood risk management in Kristianstad.

9.5 Future recommendations

This master thesis has presented an alternative approach to analyze consequences of a flood. The method would to advantage be used for studies in other flood risk areas, with more or less advanced modifications. Regarding Kristianstad, further studies to more exactly quantify flood consequences would be of interest. A few examples are listed below.

- A cost analysis in which the value of loss of public service is estimated.
- Investigate the objects´ ability to resist a disturbance in case of a flood.
- Incorporate other consequence levels than the highest – disastrous – or to extend the object inventory to other Styrel priority classes than 0-4.
- Further consequence analyses of floods in a future climate, especially regarding heavy rainfall.
- To build a search engine in QGIS that would allow a quick extraction of affected objects at different water levels.
- Investigate how to decrease vulnerability for retirement homes and secure a rapid and safe evacuation of residents.
- Study flood consequences to objects that will not be protected until the west barrier is finalized in 2025.

10 Conclusions

A 100-year event, by way of high discharge in Helge å and barrier failure, or rainfall, would have consequences as presented in Table 8. For each of the four scenarios, ‘Total’ represents the percentage of the total important societal objects in the inventory that would have to close. Similarly, ‘Service’ represents the percentage of the objects providing service to a main part of the population that would have to close. All objects belong to Styrel priority class 0-4.

Table 8. *Percentage of objects in Kristianstad with important societal function that have reached a disastrous consequence in different scenarios.*

Scenario	Total (%)	Service (%)
West barrier failure	16	27
Hammarslund barrier failure	59	45
Hammarslund and west barrier failure	70	58
Heavy rainfall	32	12

At a Hammarslund barrier failure, the water levels presented in Table 9 represents a situation where 25%, 50% and 75% of the objects – respectively – have reached a disastrous consequence.

Table 9*. Water levels corresponding to percentage of objects in Kristianstad with important societal function that have reached a disastrous consequence. Height system RH2000.*

Objects with disastrous consequence (%)	Water level (m)
25	+0.3
50	+2.1
75	+3.0

Among the main object categories in the inventory, the most vulnerable at a 100-year event and a Hammarslund barrier failure is retirement homes, for which 89% of the objects (8 of 9) would reach a disastrous consequence. The least vulnerable object category is freshwater boreholes.

The objects listed in Table 10 – all providing service to a main part of the population – are found to be in need of increased protection to prevent serious consequences in case of a 100-year precipitation. According to the Styrel definitions of priority classes, the hospital administration should be prioritized to prevent serious consequences.

***Table 10**. Objects in need of increased protection in case of a heavy rainfall in Kristianstad.*

Object	Styrel priority class	Reason
Hospital administration	1	Access blocked
Kristianstad cheese refining	4	Access blocked
Scan	4	Risk for rainwater seepage
Radio Kristianstad	4	Risk for rainwater seepage

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Appendices

Appendix A. Defining water level of disastrous consequence.

Like the MSB study "*Konsekvenser av en översvämning i Mälaren"* (MSB 2012), the aim was to define consequence levels 2-5 (Table 3) for all listed important societal objects. The ability of object owners to withstand a threat of a flood was also subject to investigation. The objects were identified by the following criteria:

- Objects regarded as having an important societal function according to the Styrel priority classes 0-4 (Table 2)
- Objects being situated on a ground level of -2.4 to +4.0 m

A number of 125 important societal objects were identified and listed, as well as object owners and persons responsible for the activities at each object. A letter was sent by mail to ask for the requested data and object owners not responding were contacted by phone or mail. Some of the owners were also physically met at meetings to discuss the analysis task more in detail. Unfortunately, for a great part of the object owners the task to define certain water levels seemed to be quite hard, since no one had experienced such a severe flood situation and the water levels felt kind of hypothetic. To be able to define the levels correctly, the estate manager – who was assumed be the one to know the object best – was the target of the interview. Sometimes the building or locality that inherits a certain activity could not be treated as being one single unit. Even if it is not so common, the activity carried out at an object may not be affected to the same extent as the building itself. Still, the information in the mail sent clearly stated that it was the water levels affecting the *activities* that were of importance, and it was assumed that the estate manager had this in mind when defining the levels.

However, soon it stood clear that the interviews would not be sufficient to gather all the required data for the analysis. A decision was therefore taken to focus on the highest consequence level (5) – disastrous. Compared to consequence level 2-4, this water level is rather easy to define as a level when the activities at an object have to stop. As many of the object owners didn´t know the water level corresponding to a disastrous consequence for their object/objects, the missing data was supplied by surveying and the height measures were carried out by gps. For these objects the lowest level to allow water to pass the building shell was identified.

To define the water levels - corresponding to a disastrous consequence - for objects in which people reside (live, study, work etc), it could be a hint to look at it from the following aspects:

1. The building´s technical function
2. Functions specific for the activity
3. The security for people working or residing in the building

Regarding the building´s technical function, examples of vital functions that are at risk in a flood situation are power and heat supply. Levels of openings in the building shell that may allow the water to get in, like doorstep to power generators, heating or air-conditioning, may be crucial. If such equipment is located in the basement, a water level may be defined by the level of basement stairway, windows or ventilation ducts.

When it comes to functions specific for a certain activity, it may be exemplified by access to computer equipment and servers, archives holding important documents, vehicles in garage, tools storage, fuel, food etc. In case these are located in a basement the risk of disturbance is extra high. Another crucial function is the possibility to reach the building with specific services and products that are required to maintain the activity. What is the highest water level that allows transports to and from the building? The security for people residing in a building may be affected both directly as a physical risk (drowning) and by a decreased access to it as surrounding areas may be flooded. In an emergency situation (fire or accident), crucial water levels may by defined by

- highest water level that allows emergency vehicles access to the building
- highest water level that allows a secure evacuation

The objects were divided into two groups depending on whether the activities are highly dependent on transports to and from the object or not. Most of the objects are dependent on transports, like schools, elderly homes, hospital, grocery stores etc, and – if not reached before – the crucial water level is reached when the object is surrounded by water and no transports are able to reach the object. For the other group, activities are still able to be run although the object is surrounded by water. Examples of objects of this type are high speed internet nodes, fresh water boreholes and power distribution stations. All of the 125 listed objects have been investigated regarding water level surrounding the object as well as to define the highest water level to allow a certain activity. Each object has also been investigated according to the level and area of captured water, although this information is just added as a note in the object list since the calculation of flooded objects is based upon main flooded area only.

Two criteria define the critical water level of an object, of which the lowest level will be decisive:

- Safety. What is the highest water level that allows an evacuation?
- Technical function of the building that inherits a certain activity. What is the highest water level that allows a continued activity?

In reality the two criteria may be mixed when most activities require some kind of transports to and from the object, like people working there, food and other kind of utilities needed for the activities. And when no transports are possible, the activities have to shut down and the people residing have to be evacuated. Although an object is not situated within a flooded area, it could be at risk if it is close to, or surrounded by, a captured flooded area. Another thing worth checking – if it exists - is the level of the basement floor. If this level is lower than the water level of the flooded area, there is a potential risk of the basement being flooded.

The security part put focus on an important question. If the flood water reaches the doorstep or the basement stairway, the building is probably already surrounded by water. This should be the case if the building is flat grounded and not a split level building. According to the possibility of evacuating, the highest consequence level should have been reached before the water has reached the building itself. However, in this study the focus has been on the circumstances that may affect the daily *activity* at an object. It is a fact to keep in mind that there is a certain security risk if an object is surrounded by water, and to take this into account when planning and taking measures in a flood situation. This is also mostly a question to be analyzed for objects where people are living, like old people´s homes, residencies for communities etc.

For many of the objects there is only one consequence level – disastrous. For most small objects the openings in the building are few, and when the water once get access to a building, its function will stop and so the activities running inside it. The most common object is a relatively small object with a basement where facilities crucial for its function are based, like power supply and/or heating. Another common object is one with no basement but with the entrance close to ground level. The activities in these objects have to close when the water level reaches the highest step of the basement stairs, or the entrance level, respectively.

When the water level of a disastrous consequence for all objects had been defined, all transport dependent objects were checked once again according to the possibility of evacuation. Using a satellite image, the highest water level that would still enable a secure evacuation was defined for each object. If required, the water level of the disastrous consequence was updated.

Appendix B. Number of objects with disastrous consequence at a simultaneous Hammarslund and west barrier failure, ordered by Styrel priority class.

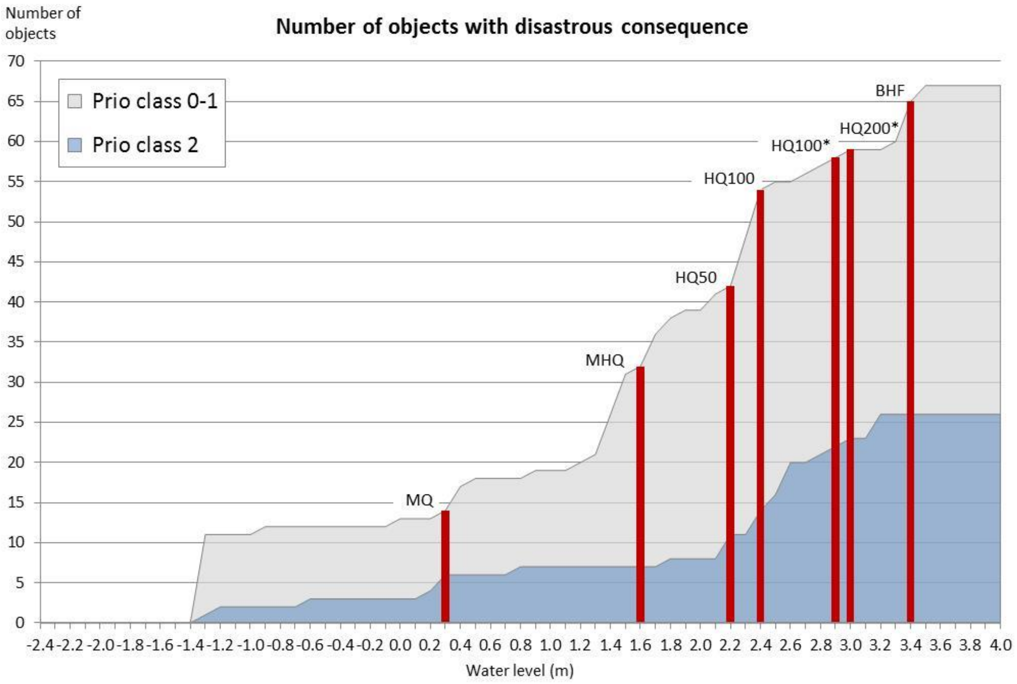

Fig. B.1 *Number of objects in Styrel priority class 0-1 and 2 with a disastrous consequence at a simultaneous Hammarslund and west barrier failure in Kristianstad (* = future climate 2098). Height system RH2000.*

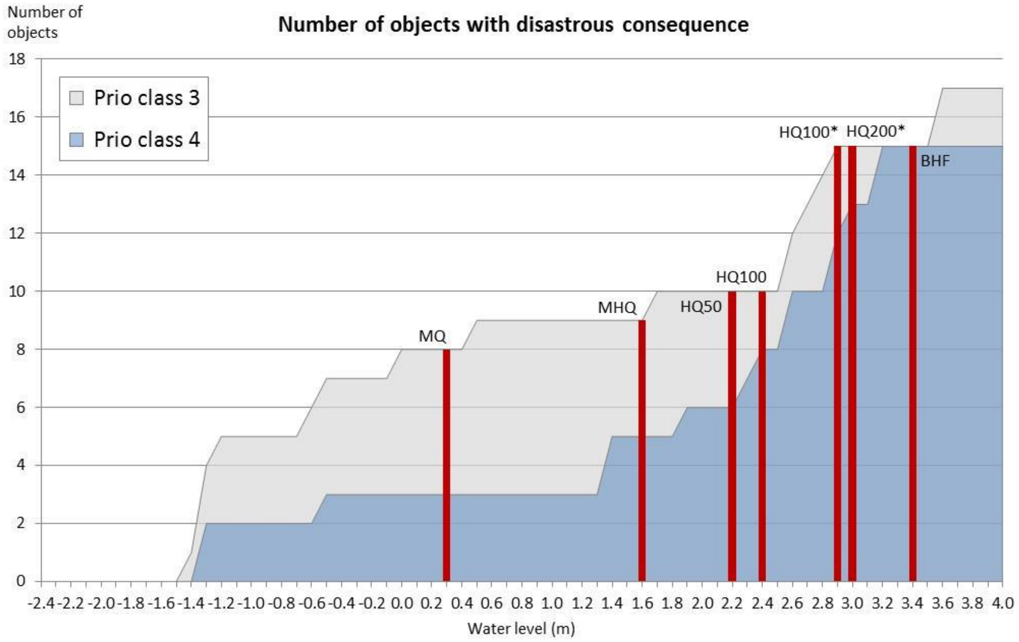

Fig. B.2 *Number of objects in Styrel priority class 3 and 4 with a disastrous consequence at a simultaneous Hammarslund and west barrier failure in Kristianstad (* = future climate 2098). Height system RH2000.*

Appendix C. Number of objects with disastrous consequence at a simultaneous Hammarslund and west barrier failure, ordered by object type.

Looking at the major object types at a Hammarslund and west barrier failure, it is found that the most vulnerable at low water levels are daytime medical clinics and nursery schools, while comprehensive schools, supermarkets, retirement homes and LSS group homes belong to the least vulnerable (Fig. C.1). At high water levels, nursery schools, retirement homes and supermarkets are most vulnerable. The freshwater boreholes are found to be in a special category, not being affected until a medium high water level (+2.2 m). However, as most of the boreholes are situated in the same area, they are affected in a limited water level range. More analyses on the number of objects with disastrous consequence ordered by major object types are presented in Fig. C.2-C.6 below.

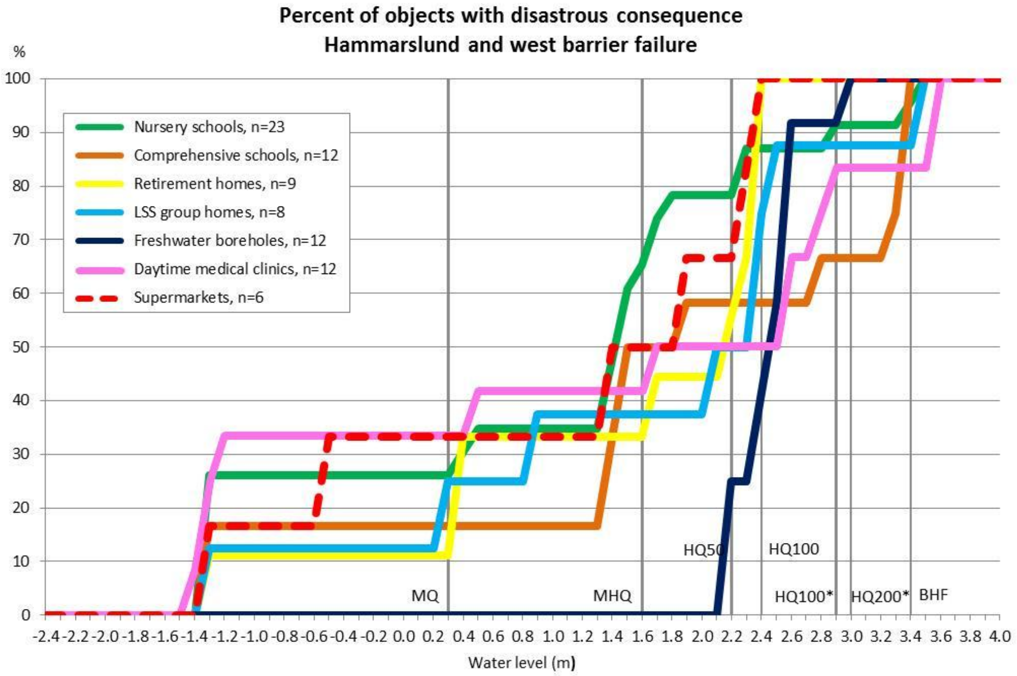

Fig. C.1 *Vulnerability of major object categories at a simultaneous Hammarslund and west barrier failure in Kristianstad. Percent of total objects in each category (* = future climate 2098). Height system RH2000.*

Residents at retirement homes are in special need of protection in a flood situation. A total of about 360 elderly may have to be evacuated from 9 different locations. Worth noting are the leaps in number of residents in need of evacuation at +0.4 m and +2.4 m (Socialstyrelsen 2013) (Fig. C.2).

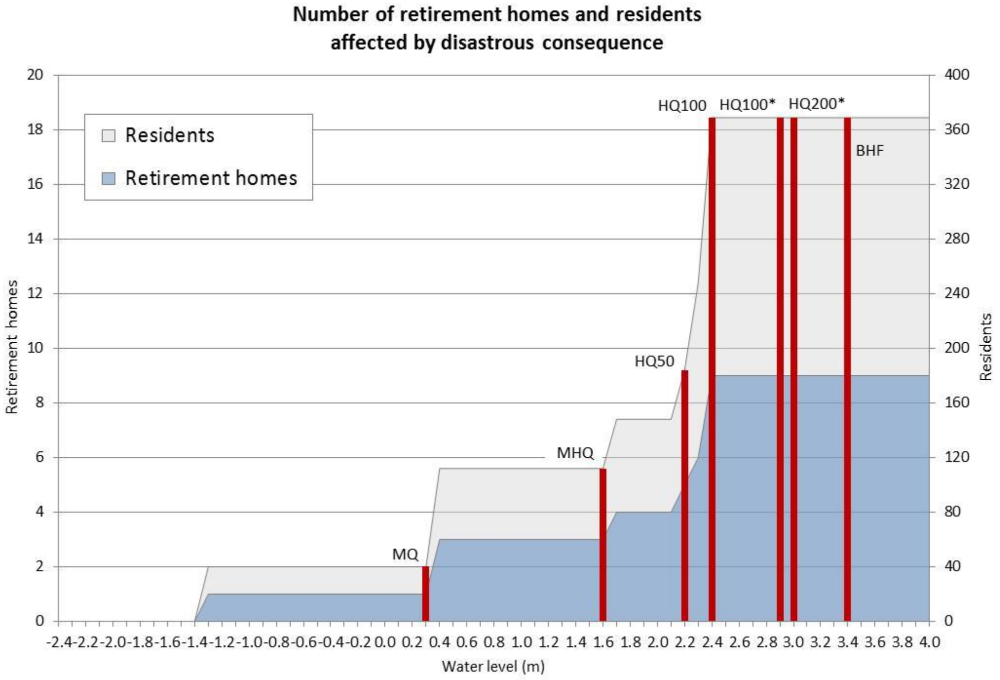

Fig. C.2 *Number of retirement homes and residents related to a disastrous consequence at a simultaneous Hammarslund and west barrier failure in Kristianstad (* = future climate 2098). Height system RH2000.*

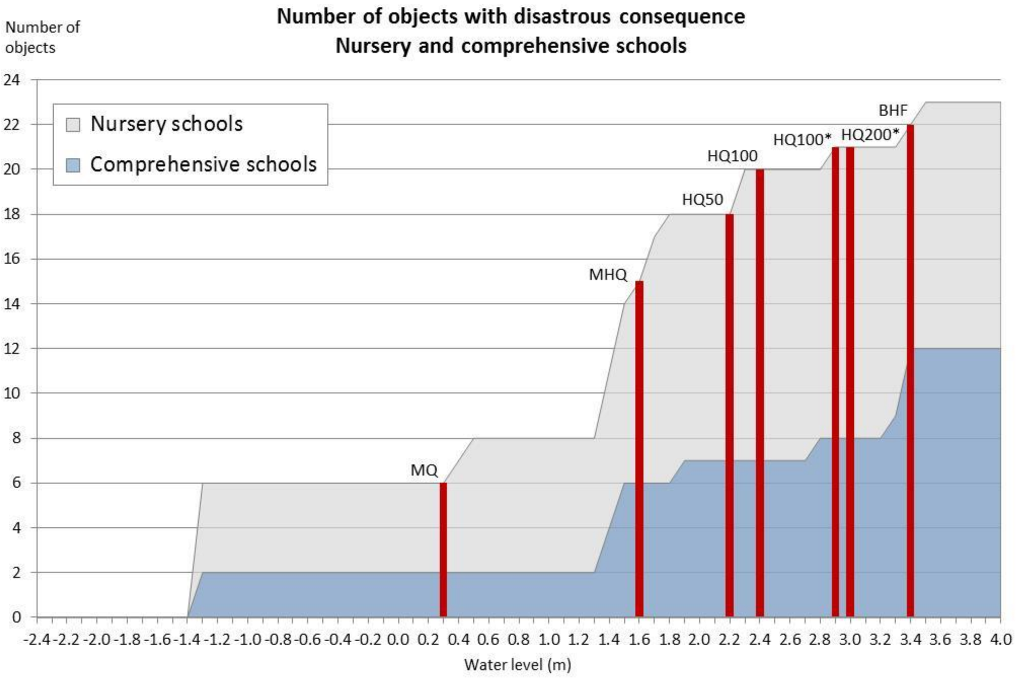

Fig. C.3 *Number of objects with a disastrous consequence at a simultaneous Hammarslund and west barrier failure in Kristianstad; nursery schools and comprehensive schools grade 1-5 (* = future climate 2098). Height system RH2000.*

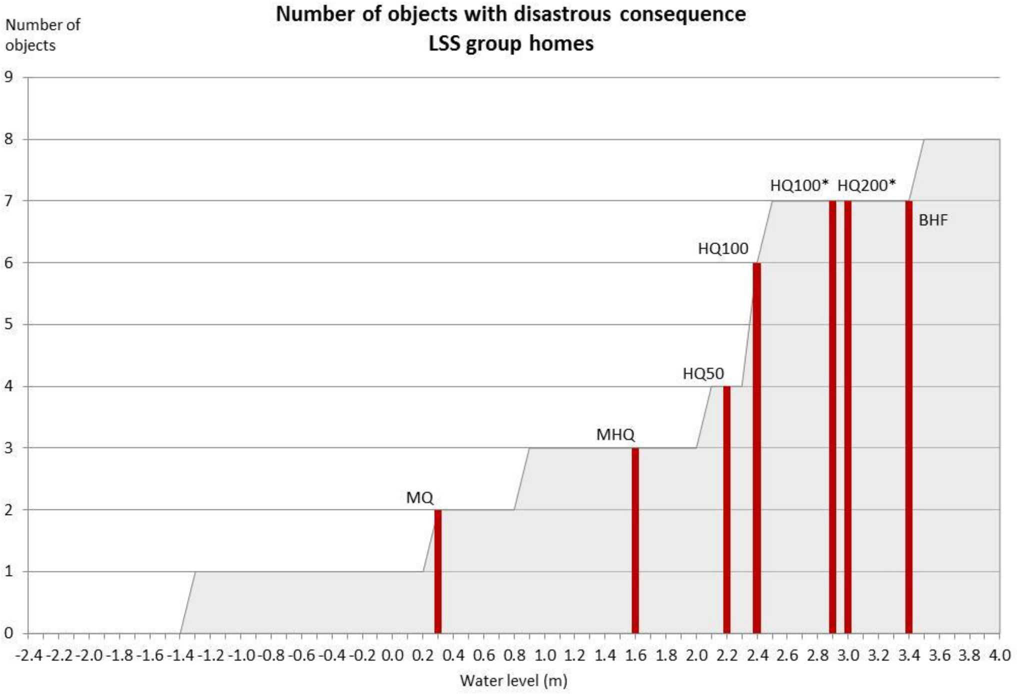

Fig. C.4 *Number of objects with a disastrous consequence at a simultaneous Hammarslund and west barrier failure in Kristianstad; LSS group homes (* = future climate 2098). Height system RH2000.*

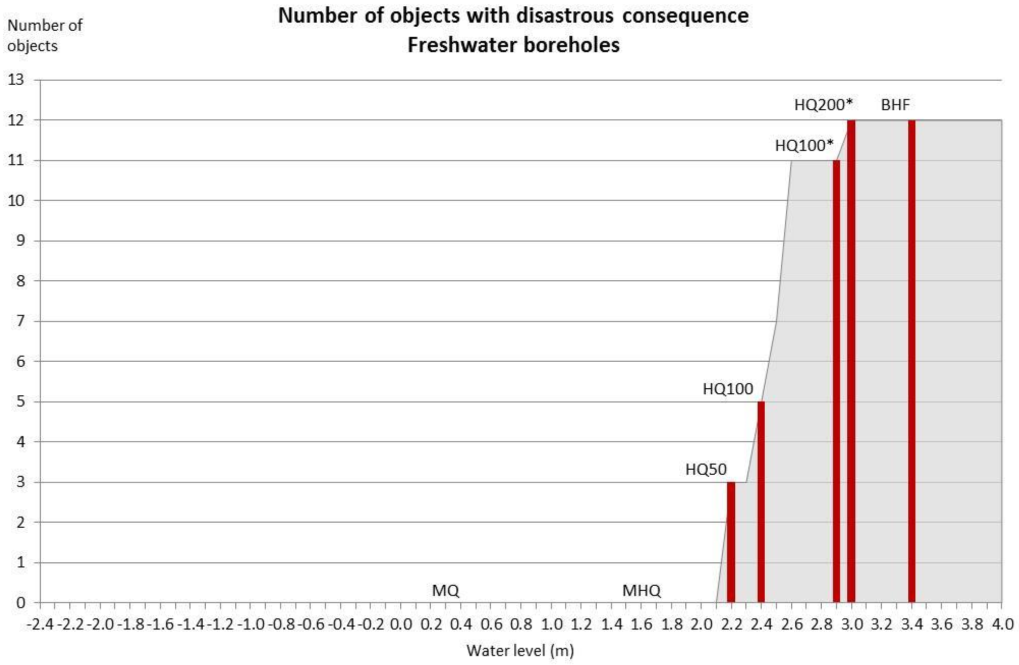

Fig. C.5 *Number of objects with a disastrous consequence at a simultaneous Hammarslund and west barrier failure in Kristianstad; fresh water boreholes (* = future climate 2098). Height system RH2000.*

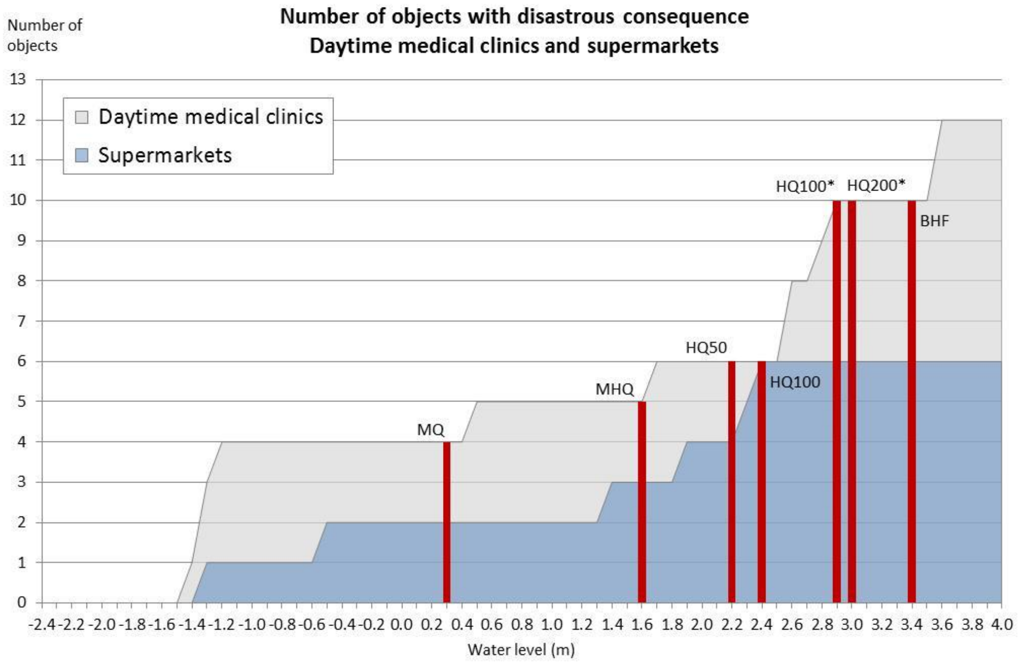

Fig. C.6 *Number of objects with a disastrous consequence at a simultaneous Hammarslund and west barrier failure in Kristianstad; daytime medical clinics and supermarkets (* = future climate 2098). Height system RH2000.*

Appendix D. Additional maps of flooded areas and affected objects at a simultaneous Hammarslund and west barrier failure.

The following maps present flooded areas and flooded objects with important societal function at different water levels in lake Hammarsjön, corresponding to characteristic discharge in Helge å and characteristic sea water level (Table D.1).

Table D.1. *Water level in lake Hammarsjön at different characteristic discharge in Helge å and sea water level. Number of objects with disastrous consequence (Total objects), and objects with disastrous consequence that provide service to main part of the population (Service objects), at a simultaneous Hammarslund and west barrier failure in Kristianstad. * = future climate 2098. All objects from Styrel priority class 0-4. References in //. /1/: DHI 2013b, /2/: DHI 2010, /3/: C4 Teknik 2016, /4/: Kristianstads kommun 2015, /5/: Dahlman. Flood Watch Kristianstad. Height system RH2000.*

Characteristic discharge Helge å		Characteristic sea water level		Water level Hammarsjön	Total objects n=125		Service objects n=33	
	m^3/s		m	m		%		%
MQ	40 /3/	MW	0.0 /3/	+0.3 /4/	31	25	6	18
MHQ	140 /3/	MHW	+0.88 /1/	+1.6 /5/	53	42	9	27
HQ50	255 /1/	MHW	+0.88 /1/	+2.2 /1/	71	57	14	42
HQ100 (Torsebro)	288 /2/	MHW	+0.88 /1/	+2.4 /2/	88	70	19	58
HQ100*	420 /1/	MHW*	+1.73 /1/	+2.9 /1/	108	86	28	85
HQ200*	458 /1/	MHW*	+1.73 /1/	+3.0 /1/	110	88	31	94
BHF (Torsebro)	527 /1/	HHW	+1.46 /1/	+3.5 /1/	121	97	33	100

MQ and MW: +0.3 m

At mean discharge (MQ, 40 m^3/s) and mean sea water level (MW, 0.0 m) 25% (31) of the objects have reached a disastrous consequence. This includes 18% (6) of all objects providing service to a main part of the population. The flooded area equals to a large extent the Nosaby bay (Fig. D.1). Among the objects affected, the Rescue Service, the central hospital (CSK), the hospital management, the central sewage plant, 6 nursery schools, 2 comprehensive schools and 2 supermarkets are found. Residents at one retirement home and two LSS group homes have to be evacuated. The European highway E22 is flooded. One high speed internet node has to shut down.

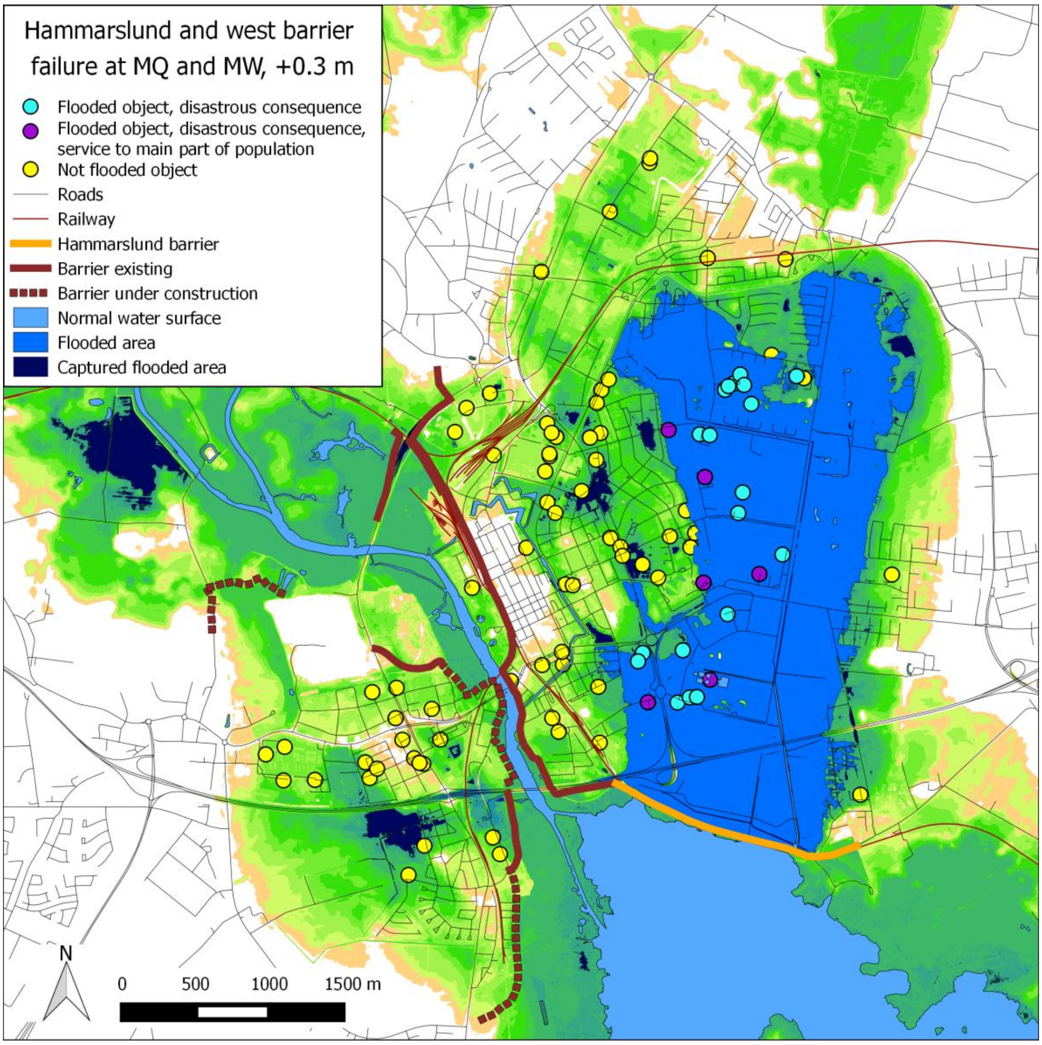

Fig. D.1 *Flooded area and important societal objects at discharge MQ in Helge å and a simultaneous Hammarslund and west barrier failure in Kristianstad. All objects from Styrel priority class 0-4. Height system RH2000.*

MHQ and MHW: +1.6 m

Mean high discharge (MHQ, 140 m^3/s) – mean discharge based on every year´s maximum value – and mean high sea water level (MHW, +0.88 m). At this level 42% (53) of the objects will reach a disastrous consequence level and about 110 elderly people (30%) will be in need of evacuation from 3 retirement homes (Fig. D.2). 27% (9) of the objects providing service to a main part of the population are affected. The ambulance central, 15 nursery schools and 6 comprehensive schools also have to stop activities. 2 (of 6) high speed internet nodes have to shut down.

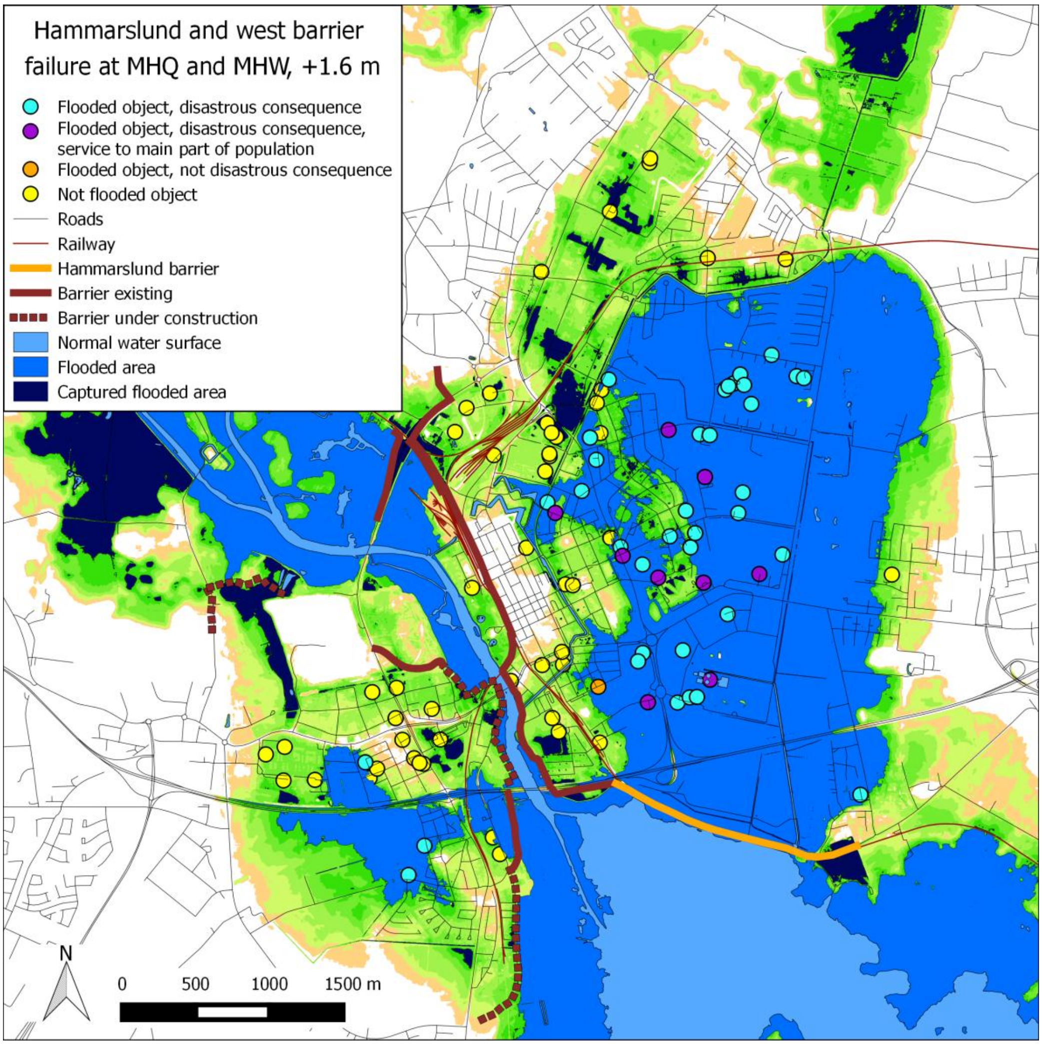

Fig. D.2 *Flooded area and important societal objects at discharge MHQ in Helge å and a simultaneous Hammarslund and west barrier failure in Kristianstad. All objects from Styrel priority class 0-4. Height system RH2000.*

HQ50 and MHW: +2.2 m

Discharge of a 50 year flood event (HQ50, 255 m^3/s) and mean high sea water level (MHW, +0.88 m) will result in a disastrous consequence for 53% (66) of the objects (Fig. D.3). This includes 33% (11) of all objects providing service to a main part of the population. About 180 elderly people (50%) will need to be evacuated from 5 retirement homes. Likewise, residents at 4 LSS group homes have to be evacuated. Access to the Child and Adolescent Psychiatry (BUP) is blocked. 1 (of 12) freshwater borehole is flooded. 3 (of 6) high speed internet nodes has to shut down. 4 supermarkets have to close as well as the traffic route Härlövsängaleden.

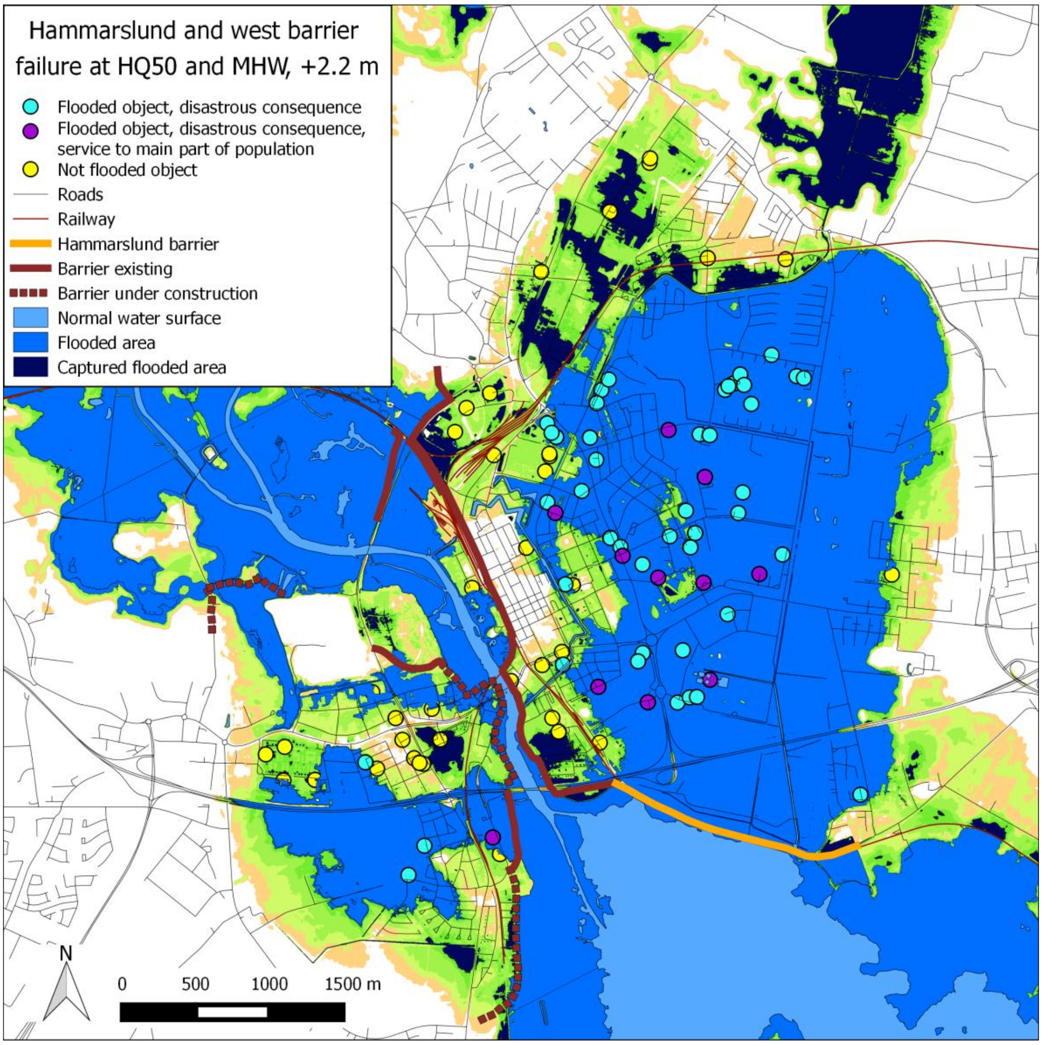

***Fig. D.3** Flooded area and important societal objects at discharge HQ50 in Helge å and a simultaneous Hammarslund and west barrier failure in Kristianstad. All objects from Styrel priority class 0-4. Height system RH2000.*

HQ100 and MHW: +2.4 m

Discharge of a 100 year flood event (HQ100, 288 m^3/s) and mean high sea water level (MHW, +0.88 m) will result in a disastrous consequence for 66% (83) of the objects in the inventory (Fig. D.4). This includes 42% (14) of all objects providing service to a main part of the population. All about 370 elderly people (100%) will need to be evacuated from 9 retirement homes. 6 LSS group homes have to be evacuated. 3 (of 12) freshwater borehole are flooded. 4 (of 6) high speed internet nodes has to shut down as well as all listed supermarkets.

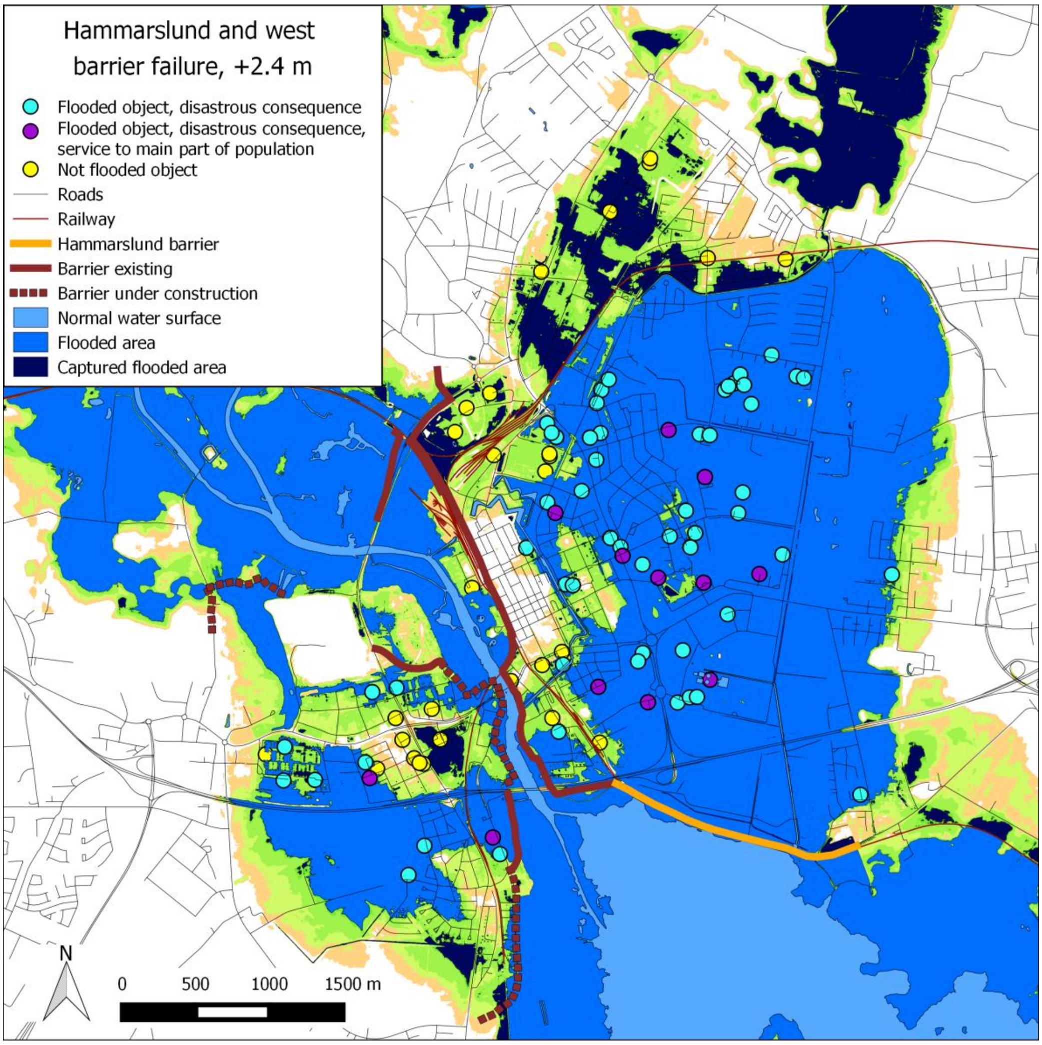

Fig. D.4 *Flooded area and important societal objects at discharge HQ100 in Helge å and a simultaneous Hammarslund and west barrier failure in Kristianstad. All objects from Styrel priority class 0-4. Height system RH2000.*

HQ100 and MHW in a future climate 2098: +2.9 m

Discharge of a 100 year flood event (HQ100, 420 m^3/s) and mean high sea water level in future climate (MHW, +1.73 m). 82% (103) of the objects will reach a disastrous consequence level (Fig. D.5). This includes 73% (24) of the objects providing service to a main part of the population. The power and heat production at Allöverket is surrounded by water. 7 LSS group homes have to be evacuated and 7 (of 12) freshwater boreholes will be flooded. 5 (of 6) high speed internet nodes have to shut down.

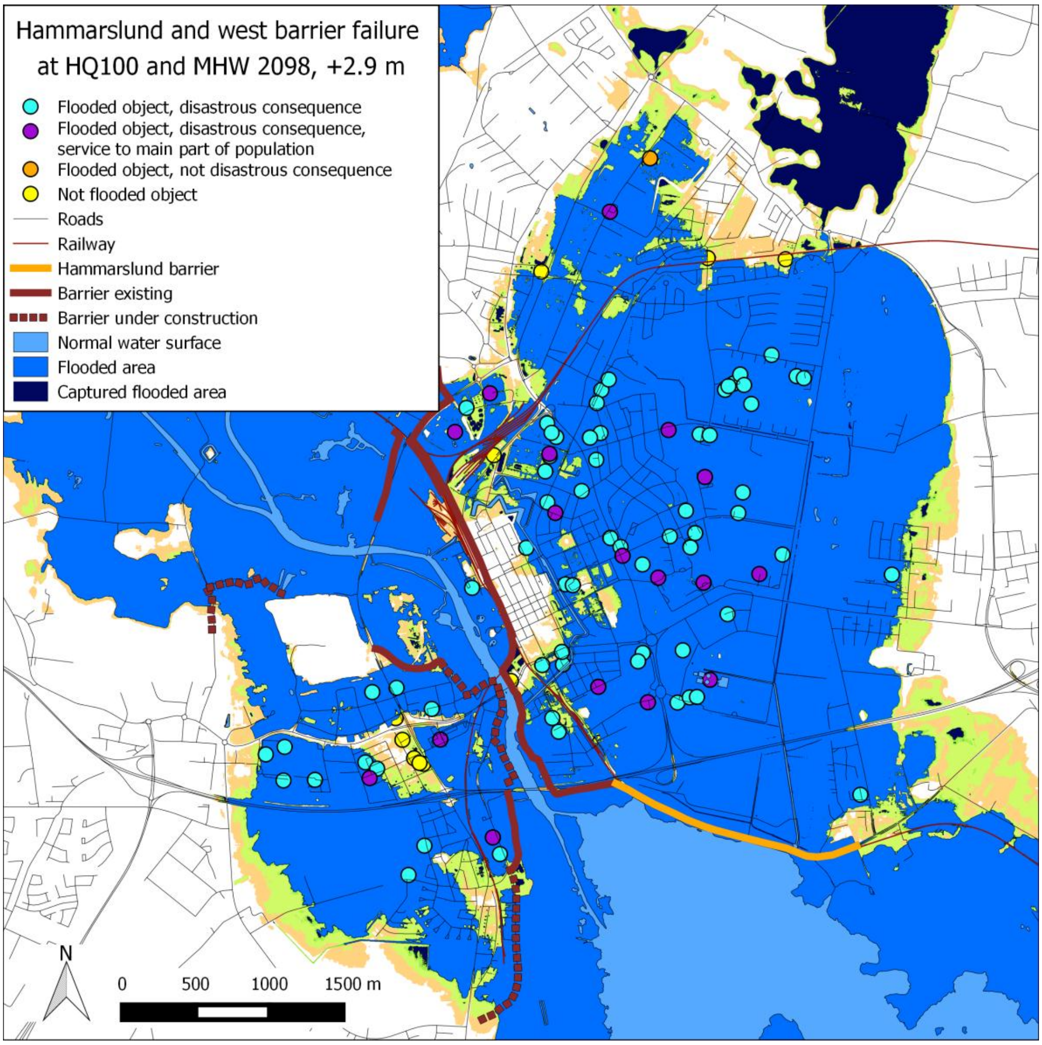

Fig. D.5 *Flooded area and important societal objects at future climate discharge HQ100 in Helge å, at a simultaneous Hammarslund and west barrier failure in Kristianstad. All objects from Styrel priority class 0-4. Height system RH2000.*

HQ200 and MHW in a future climate 2098: +3.0 m

Discharge of a 200 year flood event (HQ200, 458 m^3/s) and mean high sea water level in future climate (MHW, +1.73 m) will result in a disastrous consequence for 86% (108) of the objects in the inventory (Fig. D.6). This includes 88% (29) of all objects providing service to a main part of the population. No major change in consequences compared to HQ100 will be expected except for number of freshwater boreholes affected; 10 (of 12) will be flooded.

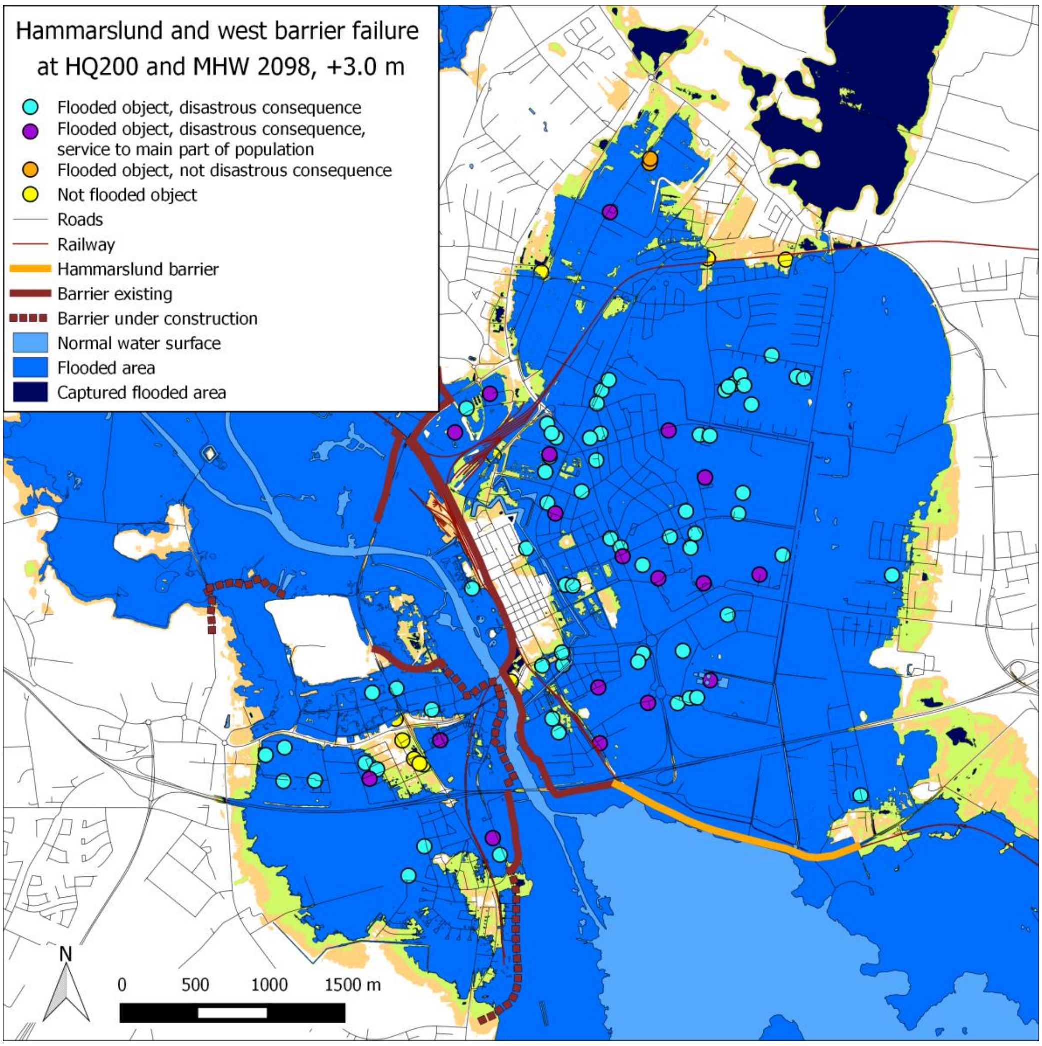

Fig. D.6 *Flooded area and important societal objects at future climate discharge HQ200 in Helge å, at a simultaneous Hammarslund and west barrier failure in Kristianstad. All objects from Styrel priority class 0-4. Height system RH2000.*

BHF and HHW: +3.5 m

Highest calculated discharge (BHF, 527 m^3/s at Torsebro) and highest high sea water level (HHW, +1.46 m). This is the worst case scenario with a disastrous consequence for 97% (121) of the objects (Fig. D.7). All objects (33) providing service to a main part of the population will be flooded, as well as all freshwater boreholes.

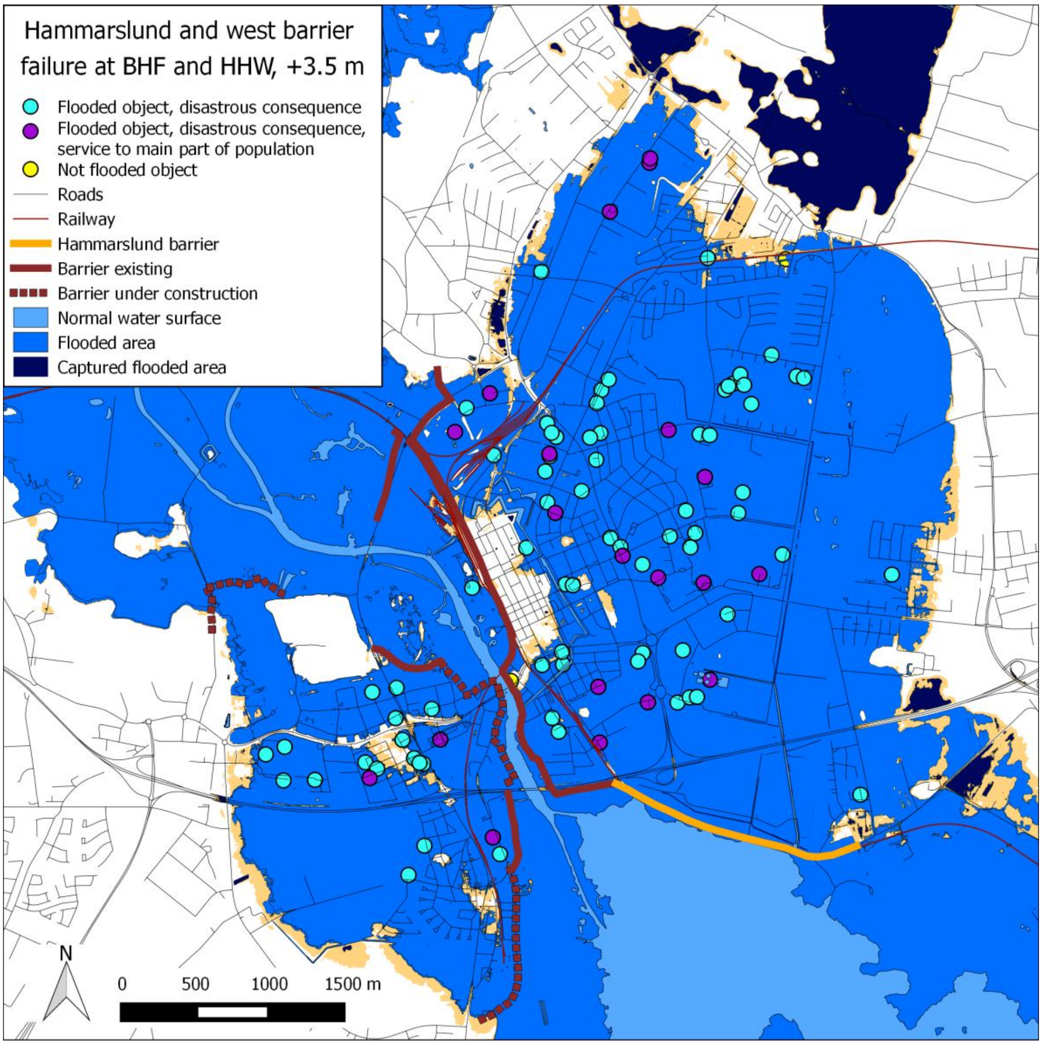

Fig. D.7 *Flooded area and important societal objects at discharge BHF in Helge å and a simultaneous Hammarslund and west barrier failure in Kristianstad. All objects from Styrel priority class 0-4. Height system RH2000.*

Appendix E. Questionnaire sent to objects owners to collect information about water levels corresponding to different consequences.

Information till ägare av objekt med samhällsviktig funktion i Kristianstad

Analys av konsekvenser för samhällsviktiga objekt vid en översvämning i Kristianstad

Som ett led i arbetet med identifiering av risker och förebyggande åtgärder när det gäller översvämningar, genomför nu Räddningstjänsten i Kristianstad en analys av potentiella konsekvenser för objekt med samhällsviktig funktion. Den riktar sig till Dig som är objektägare och som skulle kunna riskera att drabbas av en översvämning i ett scenario med otillräcklig avrinning till följd av ihållande och kraftig nederbörd, alternativt samtidigt högt flöde i Helge å, högt vattenstånd i Hammarsjön och brott på skyddsvall.

Syftet med analysen är att ge Dig som objektägare ökad kunskap om Ditt/Dina objekt, och samtidigt ge Räddningstjänsten i Kristianstad en översikt över potentiella konsekvenser för samhällsviktiga objekt för att på rätt sätt kunna bistå Dig och Din verksamhet i händelse av en översvämning. Målet kan därmed sammanfattas som att:

- Bättre kunna planera och vidta förebyggande åtgärder då det gäller att förhindra eller minimera skador på såväl egendom som människors liv och hälsa vid en eventuell översvämning
- Höja beredskapen och ge underlag för korrekt beslutsfattande i en akut översvämningssituation
- Öka medvetenheten om risker och sårbarhet i samband med en översvämning

Analysmetoden är av en ny typ där konsekvenserna för ett objekt studeras i relation till vattennivån. På så sätt ges möjlighet att analysera konsekvenserna för vilket vattenstånd som helst, i nutida eller framtida klimat. En liknande analys har nyligen genomförts av Myndigheten för Samhällsskydd och Beredskap (MSB) för Mälarområdet (2012). Metoden går ut på att identifiera vilket vattenstånd som motsvarar en given konsekvens enligt nedanstående definitioner.

Konsekvensnivå	Beskrivning av konsekvens
1 - Mycket begränsad	Verksamheten fungerar som vanligt.
2 - Begränsad	Verksamheten fungerar i stor utsträckning som vanligt med vissa undantag. Det som anses skyddsvärt påverkas inte eller mycket lite.
3 - Allvarlig	Verksamheten fungerar delvis men det som är skyddsvärt påverkas uppenbart och omprioriteringar måste göras.
4 - Mycket allvarlig	Verksamheten fungerar hjälpligt eller inte alls och det som är skyddsvärt påverkas betydligt. Stora omprioriteringar måste göras.
5 - Katastrofal	Verksamheten fungerar inte.

Vi ber Dig också att ange vilken förmåga Du anser att Din verksamhet förfogar över när det gäller att motstå en störning som en översvämning innebär.

Förmågenivå	**Beskrivning av förmåga**
1 - God förmåga	Objektägaren har resurser och kapacitet att kunna lösa de uppgifter som är samhällsviktiga vid extraordinära händelser.
2 - I huvudsak god förmåga, men har vissa brister	Samhällsservice åsidosätts i viss mån för att prioritera mer akut verksamhet. Objektägaren har inte tillräckligt med resurser för att lösa sina uppgifter på ett tillfredsställande sätt.
3 - Viss förmåga, men bristfällig	Objektägarens resurser understiger det som behövs för att lösa de uppgifter som är samhällsviktiga vid extraordinära händelser.
4 - Ingen eller mycket bristfällig förmåga	Objektägaren står i det närmaste oförberedd.

Inom kort kommer vi att ta kontakt med Dig för en telefonintervju där Du får möjlighet att förmedla resultatet för Ditt/Dina objekt.

Analysen genomförs i samarbete med Jonas Sjögren som ett examensarbete och den avslutande delen i en masterutbildning i Geografiska Informationssystem (GIS) vid Lunds Universitet. Jonas arbetar vanligen som hydrolog vid SMHI, Norrköping.

Har Du frågor? Kontakta gärna Jonas Sjögren.
Telefon: 0767-202463, 0704-550421
E-post: jonas.sjo@gmail.com

Vi tackar för Din medverkan.
Med vänlig hälsning,
Jonas Sjögren
Peter Zerpe
Säkerhetschef, Räddningstjänsten Kristianstad

Information till ägare av objekt med samhällsviktig funktion i Kristianstad

Kompletterande information till hjälp för att bestämma vilken vattennivå som svarar mot en viss konsekvensnivå i händelse av en omfattande översvämning.

Nedanstående kan anses gälla för de samhällsviktiga objekt i vilka människor vistas (t ex bor, studerar, arbetar etc). För övriga objekt (t ex fördelningsstationer för el, borrhål för färskvatten, bredbandsnoder m m) behöver bedömningen endast ske utifrån objektets verksamhetsspecifika funktion.

För att bedöma hur en översvämning påverkar verksamheten hos ett objekt kan man betrakta det utifrån följande aspekter:

1. Byggnadens funktion
2. Verksamhetsspecifika funktioner
3. Säkerheten för dem som vistas i byggnaden

Med kritisk vattennivå avses i det följande en vattennivå som svarar mot en viss konsekvensnivå. Fastighetsförvaltare/verksamhetsansvarig (eller annan som känner fastigheten/verksamheten bäst) fastställer vilken konsekvensnivå (2, 3, 4 eller 5) som svarar mot respektive kritisk vattennivå.

Ett sätt att börja kan vara att först fastställa den vattennivå som svarar mot den allvarligaste konsekvensnivån (nivå 5, katastrofal), då verksamheten inte fungerar överhuvudtaget och måste ställas in. Utgående från denna vattennivå kan man därefter fortsätta med att fastställa konsekvensnivå 4, 3 och 2. Ett annat angreppssätt kan vara att utgå från en situation då verksamheten fungerar normalt och fastställa den vattennivå som först resulterar i en störning i verksamheten, och därefter fortsätta med övriga. För en del byggnader (främst mindre) kan steget mellan en begränsad konsekvens (nivå 2) och katastrofal konsekvens (nivå 5) vara relativt kort. För större och mer komplexa byggnader kan motsvarande steg vara längre då det finns fler möjligheter att omfördela och anpassa verksamheten vid en störning.
Alla vattennivåer anges med en noggrannhet på decimeternivå.

1. Byggnadens funktion

Vitala byggnadsfunktioner som riskerar att slås ut vid en översvämning är bl a el- och värmeförsörjning. Nivån på öppningar i byggnadsskalet som möjliggör för vattnet att ta sig in, t ex dörrtröskel till elcentral, panncentral, ventilationsanläggning eller annan viktig enhet, kan då vara avgörande. Om dessa funktioner är förlagda till källarplan kan en kritisk vattennivå bestämmas av nivån på t ex källartrappor, källarfönster eller ventilationstrummor.
Om inte vattnet tar sig in via källare kan en kritisk vattennivå för byggnaden som helhet bestämmas av nivån på lägsta dörrtröskel. Om vattnet rinner över tröskeln är förmodligen också byggnaden redan kringränd av vatten (gäller dock främst mindre byggnader; jfr Säkerhet).
Fallet med vatteninträngning via golvbrunnar tas ej med i bedömningen.

2. Verksamhetsspecifika funktioner

Avgörande för verksamheten kan t ex vara tillgång till datorutrustning och servrar, arkiv med viktiga handlingar, fordon i garage, lager för verktyg, bränsle, livsmedel etc. Är dessa belägna i källare är risken för en störning extra stor (jfr Byggnadens funktion).

En annan avgörande funktion är möjligheten att kunna nå byggnaden med specifika varor/tjänster som krävs för att upprätthålla verksamheten. Vilken är den högsta vattennivå som tillåter transporter till/från byggnaden?

3. Säkerheten för dem som vistas i byggnaden

Säkerheten för de personer som vistas i byggnaden kan påverkas, både direkt genom risk för fysisk skada (drunkning) och genom att tillgängligheten till byggnaden minskar då kringliggande mark kan vara översvämmad. I en nödsituation (brand eller olycka) kan kritiska vattennivåer bestämmas av följande:

- Vilken är den högsta vattennivå som tillåter utryckningsfordon att ta sig fram till byggnaden?
- Vilken vattennivå omöjliggör en säker evakuering?

För ytterligare frågor, kontakta gärna Jonas Sjögren.
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