CASCADING EFFECTS OF FLOODS

– An evaluation of the flood risk maps and management plans produced by the County Administrative Boards

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Abstract
Flood is the most common natural disaster globally, affecting human health and assets. The work with the Swedish ordinance of flood risk is connected to the sustainment of vital societal functions. This thesis examines how direct and indirect effects of floods are considered in Swedish legislation and when the County Administrative Boards produce flood risk maps and management plans. Moreover, it identifies potential impediments to use GIS in support of flood risk management and how those barriers could be overcome. The data collection methods used were qualitative content analysis and semi-structured interviews. It was concluded that the County Administrative Boards are aware of the indirect effects of floods on vital societal functions. However, more in-depth analyses of indirect effects to a large extent are lacking. Three main factors limiting the ability of the boards to perform analysis of indirect effects were discovered. These were secrecy legislation, GIS-competence, and communication between people with different fields of expertise. Potential measures to reduce observed challenges include enhancing the security of IT-systems, extracting sensitive information from public documents and collaborative workshops and educations for risk managers and GIS-experts to increase their awareness about each other's terminologies and areas of expertise.

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Summary

Floods are the most frequent type of natural disaster globally, affecting human health and causing material damage. An essential part of the work with the Swedish ordinance of flood risk is connected to upholding vital societal functions during disruptions. This study's objective was to examine how direct and indirect effects from floods are taken into consideration in Swedish legislation and when flood risk maps and management plans are produced by the County Administrative Boards. Additionally, the study identified potential impediments for County Administrative Boards to further use GIS in support of risk management and investigated how those barriers could be overcome. The data collection methods used were qualitative content analysis and semi-structured interviews. It was concluded that the County Administrative Boards are aware of and proposed measures to increase the awareness of the indirect effects of floods on vital societal functions, especially regarding critical infrastructure. This hence suggests that actual/more in-depth analyses of indirect effects to a large extent are lacking.

Three main factors limiting the ability of the County Administrative Boards to perform analysis of indirect effects of floods on vital societal functions were discovered; these were secrecy legislation, GIS-competence, and communication between people with different fields of expertise. To increase the competence related to GIS-analysis methods and to improve the communication between GIS-experts and risk experts, GIS-education was proposed.

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1 Introduction

1.1 Background

According to the World Health Organization (WHO, 2020), floods are the most frequent natural disaster type globally. The Swedish Meteorological and Hydrological Institute, SMHI, defines a flood as an overflow of water, submerging usually dry land (SMHI, 2020). Floods can cause extensive destruction, resulting in loss of life and material damage to personal property and critical public health infrastructure (WHO, 2020). WHO (2020) estimates that between the years 1998-2017, more than 2 billion people were affected by flooding worldwide.

Motivated by several events of damaging floods in Europe between 1998 and 2009, the European Union developed the EU Floods Directive (Directive 2007/60/EC) in 2007. The directive aims to reduce and manage the risk floods pose to human health, the environment, cultural heritage, and economic activity. The EU Floods Directive requires the Member States to estimate whether or not all national watercourses and coastlines are at risk of flooding, to map the extent of the potential floods as well as the material assets and humans at risk in these areas, and lastly to take suitable and coordinated measures to reduce the flood risk (European Commission, 2019).

As a member of the European Union, Sweden implements the EU Flood Directive through an ordinance on flood risks (SFS 2009:956) and regulation on risk management plans (MSBFS 2013:1). The whole process is performed in cycles consisting of three steps, where each step takes two years. Hence one cycle lasts for six years. The first step of the cycle is a national estimation of the risk of floods resulting in identifying geographical areas under the risk of floods. The Swedish Civil Contingencies Agency (Swe. Myndigheten för Samhällsskydd och Beredskap [MSB]) is responsible for this first step. The second step is to develop two kinds of maps for the identified areas. The first type of map is a map of areas threatened by floods developed by MSB. The second type of map are maps of risks related to flooding developed by the local County Administrative Board [CAB]. The third step of the process is for the respective CAB to develop flood risk management plans, containing goals and measures to manage risks posed by floods. In the first cycle, which was conducted between 2010-2015 (MSB, 2020a), 18 areas in Sweden were identified as at risk of flooding (MSB, 2020b). The second cycle started in 2016 (MSB, 2020a) and 25 areas were identified (MSB, 2020b). In the second cycle, besides floods from streams and lakes, coastal floods were included, hence the significant increase of areas at risk of floods (MSB, 2020b).

An essential part of the work with the ordinance of flood risk is connected to upholding vital societal functions during disruptions (MSB, 2011). A vital societal function is an organization, service, or infrastructure that maintains or secure social functions necessary for society's basic needs, values, or security (MSB, 2020c). In the research report *Utvecklad riskhantering för samhällsviktiga verksamheter avseende översvämningsrisker*, the result of a collaboration between MSB and researchers at Lund University, it is concluded that a geographic information system, GIS, is an effective and useful tool to use in risk management, vulnerability analysis and consequence analysis of vital societal functions (Guldåker et al., 2019). In the same report, Guldåker et al. (2019) highlight the importance of taking both direct and indirect effects into account when performing a flood risk analysis. This because the indirect effects can be a large part of the impact of floods. Sometimes even bigger than the direct effects. However, Guldåker et al. lack a comprehensive view of how CABs throughout Sweden are implementing the ordinance of flood risks and how they analyze both direct and indirect consequences of floods

on vital societal functions using GIS. Therefore, this report will evaluate how direct and indirect effects of floods are considered in the flood risk maps and management plans delivered by the CABs. It is believed that this could lead to valuable insights on how the plans can be improved and thereby increase the resilience of our societies towards future floods.

1.2 Aim and Research Questions

The objective of this report is to examine if direct and indirect effects from floods are taken into consideration when the flood risk maps and management plans are produced by the CABs. Further, the thesis aims to investigate how the flood risk management process can be improved from the perspective of potential hinders of using GIS.

Based on the aim of this study, the following research questions will be answered:

- Are direct and indirect effects of floods on vital societal functions
    - requested in the ordinance on flood risks (SFS 2009:956) and/or MSBFS 2013:1 regulation on risk management plans?
    - taken into consideration when the flood risk maps and management plans are produced by the County Administrative Boards?
- In what ways do County Administrative Boards utilize GIS in support of flood risk management?
- What are the potential impediments for County Administrative Boards to use GIS in support of flood risk management and how could those barriers be overcome?

1.3 Delimitations and Limitations

This report only focuses on flood causes mentioned in the Ordinance on Flood Risks (SFS 2009:956) and Regulations on the County Administrative Board's Management Plans of Flood Risks (MSBFS 2013:1). Thereby it does not consider how the CABs are working with cloudbursts (i.e., an extreme amount of precipitation in a short period of time).

Further, this report only considers flood impact on vital societal functions. Hence the work of the CABs within the categories *environment, cultural heritage,* and *economic activity* that are not classified as vital societal functions in by current definition provided by the Swedish Civil Contingencies Agency are not covered by this text. Although it is believed the content of this report could benefit those areas as well.

As the second cycle's flood risk management plans have not been finished yet, a limitation of this report is that only the flood risk management plans from cycle 1 can be analyzed. The risk management plans from the second cycle should be reported to the European Commission in 2021 (MSB, 2020a). Hence, the third delimitation of this study was to use risk maps and management plans from the first cycle.

2 Theoretical Background

In this chapter, a theoretical background of flood risks related to vital societal functions will be given. The chapter is divided into three sections. The first section defines important terms used in this report. The second section gives an overview of Swedish regulations related to flood and vital societal functions. The third section contains a literature selection connecting flood risk, interdependency, vital societal functions, and GIS.

2.1 Definition of important terms

To avoid misunderstandings regarding the terminology used in this report, this section will define and explain important terms.

Flood

When land that is not normally underwater is temporarily covered with water, this includes floods originating from lakes, streams, mountain rapids, and from the sea in coastal areas, but not flooding from sewage systems (SFS 2009:956).

Flood Risk

The combination of the likelihood of flooding and possible adverse effects on human health, the environment, cultural heritage, and economic activity associated with a flood (SFS 2009:956).

Critical Dependencies

Dependencies that are crucial for vital societal functions to be able to function. Such dependencies are characterized by loss or disruption in delivered operations relatively immediately leads to such disabilities that may result in a crisis occurring (MSBFS 2016:7). If two vital societal functions depend on each other, they are interdependent (Rinaldi et al., 2001).

Direct and Indirect Effects

Direct effects/consequences are those arising directly from the flood's impact, including, e.g., affected people, buildings, and impact on infrastructure. Indirect effects/consequences are those secondary, tertiary, etc., effects that arise due to the directly affected systems and infrastructures can no longer uphold their functionality and hence the additional consequences arising in the society due to dependencies (Rinaldi et al., 2001).

Cascading Effects

A cascading effect/failure happens when an interruption in one infrastructure induces the effect/failure of a component in a second infrastructure, which later generates an interruption in the second infrastructure (Rinaldi et al., 2001).

Vital Societal Functions

The term *vital societal function* is here used as a synonym for the Swedish term "Samhällsviktig verksamhet". It can be seen as equivalent to the more prevalent international term "Critical Infrastructure". The current definition by the Swedish Civil Contingencies Agency (MSB, 2020c) is that a vital societal function is an organization, service, or infrastructure that maintains or secure social functions necessary for society's basic needs, values or security. These are functions sustaining the protective values such as human life and health, the functionality of society, democracy, the principle of legal security, human rights and freedoms, environmental and economic values, and national sovereignty (MSB, 2014). These values were derived from goals decided by the Swedish government and the Riksdag

(MSB, 2014). There are several societal important functions within each sector of society. For the energy supply sector, MSB (2019a) mentions the production of electricity, distribution of electricity, production and distribution of district heating, production and distribution of fuels and fuels as vital societal functions.

Societal vital functions are an important base in protecting against accidents, crisis preparedness, and civil defense. Functions identified as essential for society are leading the way for the planning and prioritizing activities before, during, and after a disturbance of society (MSB, 2020c). A disturbance of society can be accidents, crises, or war (MSB, 2019a).

2.2 Swedish Flood and Vital Societal Functions Regulations

As a member of the European Union, Sweden implements the EU Floods Directive through an ordinance on flood risks (SFS 2009:956) and MSBFS 2013:1 regulation on the County Administrative Board's management plans of flood risks. This section will give an overview of the EU Floods Directive, explain what is stated in the Swedish flood regulations as well as mention and describe a selection of the Swedish regulations regarding vital societal functions.

2.2.1 EU Floods Directive

Flood risk management within the European Union is regulated with the Directive 2007/60/EC on the assessment and management of flood risks. The Directive aims to reduce and manage the risks posed by floods on human health, the environment, cultural heritage, and economic activity. It demands the Member States of the European Union to assess whether all national watercourses and coastlines are at risk of floods and map the flood's extent. The map should also include assets and humans at risk in the areas threatened by floods. The EU Floods Directive also states the Member States shall take suitable and coordinated measures to reduce the flood risk and highlight the public's rights to receive this information and to utter their opinion in the planning process (European Commission, 2019). As a Member State, Sweden implements the EU Floods Directive with few alterations.

2.2.2 Ordinance (SFS 2009:956) on Flood Risks

The ordinance aims towards decreasing the adverse consequences of floods on human health, the environment, cultural heritage, and economic activities. It entered legal force in 2009, and the entire process will be repeated in cycles of six years. Figure 1 gives an overview of the different steps that must be conducted according to the ordinance.

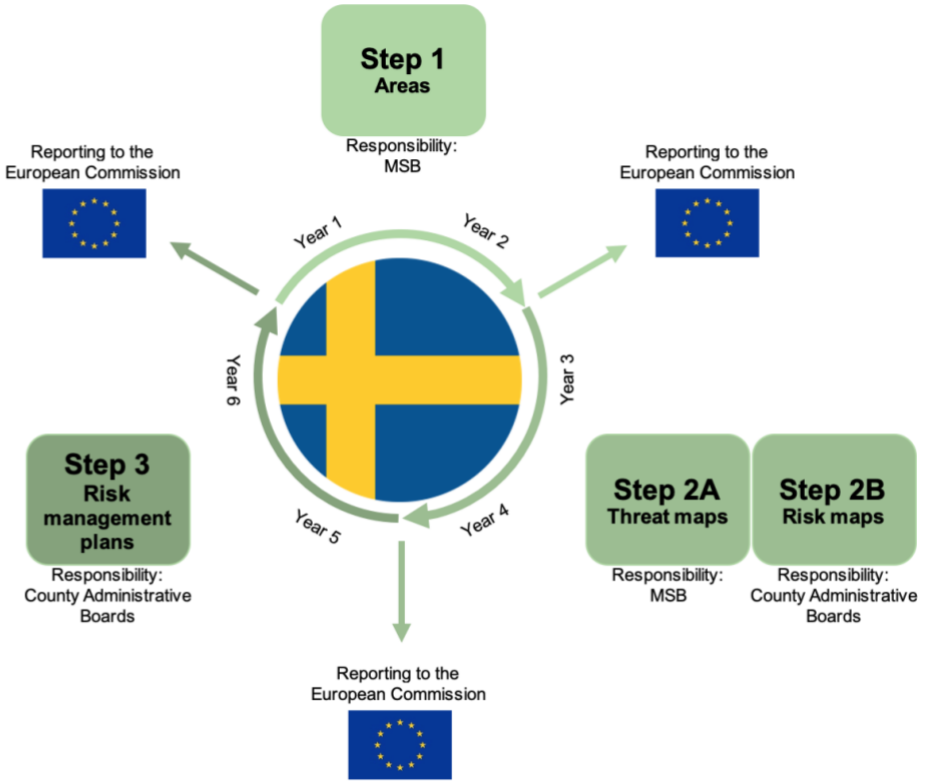

Figure 1 illustrates the three steps of the Swedish ordinance on Flood Risk. Based on figure by MSB (2020a).

The Ordinance (SFS 2009:956) on Flood Risk 4§ states that MSB shall do a preliminary assessment of flood risks for each water district. This assessment shall contain:

1. A map of the water district with lines for catchment areas, sub-catchment areas, and coastal areas, if there are any. Additionally, topography and land use must be shown on the map.
2. A full report on previously occurred floods having a severe negative effect on human health, the environment, cultural heritage, and economic activities, and where there still is a significant risk of future floods. The report shall include a description of the extent of the floods, diversion routes, and an assessment of their adverse impact.
3. A report of previous significant floods where such consequences as described under point 2 could not be ascertained, but which nevertheless were of such a nature, it can be assumed that similar future events will have significant adverse consequences.

If necessary, the assessment shall also include possible adverse impacts of future floods on human health, the environment, cultural heritage, and economic activities. It shall consider, as far as possible, aspects such as topography, watercourse locations and their general hydrological and geomorphological features, the effectiveness of existing human-made infrastructures to prevent floods, population locations, areas of economic activity and long-term development, including the impact of climate change on the occurrence of floods.

6§ states that based on the preliminary assessment of flood risks, MSB shall present the areas for each water district they deem are, or have the potential to be, under substantial risk of flood. 7§ states that MSB shall produce maps of areas threatened by floods for each of these areas, regardless of if the flood risk is considered to be low, average, or high. The maps shall show the distribution of the presumed flood, water depth or water level, and, if appropriate, flow rate or relevant water flow.

Sweden is divided into five water districts. These are based on the borders of the major sea basins and catchment areas. One CAB in each district is assigned to act as water district authority. These coordinate the producing documentation within their water district (Vattenmyndigheterna, 2021). In 8§ of the Ordinance on Flood Risk, it is written that the CABs of Norrbotten, Västernorrland, Västmanland, Kalmar and Västra Götaland County shall proceed by developing maps illustrating flood risks for their respective water district. The maps shall show possible adverse effects of the floods predicted by the Swedish Civil Contingencies Agency. From the maps, it shall be clear

1. how many people that are under risk,
2. what economic activities that are active in the area in risk of flood,
3. which activities that can cause unintended pollution during floods in accordance with ordinance (2004:989) on the review of certain environmentally hazardous activities, and
4. other information that can be useful.

In 12§, it is stated that based on the maps developed by MSB and the CABs, each CAB shall develop a plan for managing the flood risks. The plan shall contain objectives for the flood risk management of the threatened areas. When deciding the objectives, the CABs shall consider the possibility of decreasing adverse consequences of floods on human health, the environment, cultural heritage, and economic activities. The plan shall discuss all aspects of the management of flood risks. Particular emphasis shall be placed on prevention work as well as protection and preparedness, including flood forecasts and early warning systems. The characteristics of the different catchment areas or sub-catchment areas must be taken into account. The plan cannot contain measures that increase the flood risk up- or downstream unless decided upon with neighboring counties and/or countries.

2.2.3 MSBFS 2013:1 Regulations on the County Administrative Board's Management Plans of Flood Risks

The MSBFS 2013:1 Regulations on the County Administrative Board's Management Plans of Flood Risks is a regulation supported by 18§ in the Ordinance (SFS 2009:956) about Flood Risk. The regulation was made by MSB and contains additional regulations regarding the content of the flood risk management plans developed by the CABs in accordance with 12§ in the Ordinance (SFS 2009:956) about Flood Risk.

In 3§ of the MSBFS 2013:1 Regulations on the County Administrative Board's Management Plans of Flood Risks, it is stated that aside from what is required in 12§ of the ordinance (SFS 2009:956) about Flood Risk, the flood risk management plans shall also contain:

1. Conclusions from the preliminary assessment of the flood risks in the form of a general map showing areas there are possible significant flood risks or such can be expected to arise.
2. One or more maps of flood-prone areas and maps of flood risks and the conclusions drawn from the maps.
3. A description of the flood risk management objectives established by 12§ in the Ordinance (SFS 2009:956) about Flood Risk.
4. A summary of measures and priorities aimed at achieving the set objectives.
5. For the risk management plans relating to an international river basin district, the plan shall, where appropriate, include a description of the method for the cost-benefit analysis used to assess measures with cross-border implications.

2.2.4 RVA Regulations

An essential part of the work with the ordinance of flood risk is connected to upholding vital societal functions during disruptions (MSB, 2011). This section will give an overview of the regulations that concern vital societal functions.

According to MSB (2019b), Risk- and Vulnerability Analysis [RVA] is the first step in reducing risks and vulnerabilities and improving society's ability to prevent, resist, and manage crises and extraordinary events. RVAs are performed at national, regional, and municipal levels (MSB, 2019b). It is the Ordinance on (2015:1052) Crisis Preparedness and Measures by the Authorities Responsible for Surveillance in the Event of Heightened Preparedness, 8§ and 16§ that states an RVA should be performed by the CABs to strengthen their crisis preparedness, as well as the preparedness of society. The RVA produced by the CABs is supervised by the Regulations and General Advice on Government Agencies' Risk and Vulnerability Assessments MSBFS 2016:7. In 5§ MSBFS 2016:7, it is stated that when the Boards present their RVA, it shall contain identified vital societal functions within the geographical area of regional importance and their critical dependencies, identified vulnerabilities, and deficits in their crisis management. It also says the RVA shall contain implemented, ongoing, and planned measures since the last reporting. The RVA-report should be reported every second year to MSB and the Government Offices of Sweden (MSB, 2019b). Its content is delimited by the Public Access to Information and Secrecy Act (SFS 2009:400). Besides compiling a regional RVA, the CABs are responsible for supporting actors in the county in their RVA-work (MSB, 2019b).

2.3 Academic Research

There are several academic articles connecting flood risk, interdependency, vital societal functions, and GIS. This section contains a selection of the literature and examples of methods to analyze the indirect effects of floods on societal vital functions using GIS.

2.3.1 Relevance and effect of interdependencies

Various modeling techniques have been used in research and implementation studies to address infrastructure interdependency between the 1980s and 2010 (Satumtira & Dueñas-Osorio, 2010). According to Satumtira & Dueñas-Osorio (2010), mathematical modeling methods in the field can be divided into four categories: agent-based, input-output, network or graph theory, and all other emerging models.

As modern systems are highly connected, Buldyrev et al. (2010) say systems should be modeled as interdependent networks of water supply, transportation, fuel, power stations, etc. A network is a collection of points/vertices/nodes joined together by lines/edges (Newman, 2010). In this report, the points will be referred to as nodes, and the lines will be called edges. According to Rinaldi et al. (2001), *dependency* is a connection between two nodes through which the state of one node influences or is correlated to the other's state. In contrast, interdependency is defined as a bidirectional relationship between two nodes through which each node's state influences or is correlated to the state of each other. Rinaldi et al. (2001) mention several kinds of interdependencies: physical, cyber, geographical, and logical.

Guldåker et al. (2019) state that the negative effects of floods are usually most comprehensive in highly populated areas with interlinked networks of critical infrastructures and vital societal functions. The dependencies between different vital societal functions can result in cascading effects. A flood's consequences may spread to several levels of society, causing local, regional, national, and even global consequences (Guldåker et al., 2019). Buldyrev et al. (2010) explain

that a cascade of failures may happen because a failure of nodes in one network may lead to the failure of dependent nodes in other networks. Therefore, mapping and modeling complex risks allow policymakers to approach hazards, and their economic cascading effects conveyed in a non-linear path (Haraguchi & Kim, 2016).

Networks can be created in GIS-software, such as ArcGIS. There are two types of networks in ArcGIS, geometric networks and network datasets. Geometric networks, such as utility and river networks, only allow travel on edges in one direction at a time, whereas network datasets, such as transportation networks, allow travel on edges in both directions. A network dataset can model multimodal network build of numerous transportation modes as roads, railroads, and waterways. To perform network analysis using ArcGIS, an extension of the software is required (Esri, 2020).

2.3.2 Models and methods for interdependencies

As a tool to model critical infrastructure interdependency, Haraguchi & Kim (2016) used Bayesian networks. A Bayesian network is a graph built of nodes and edges, where the connections between the nodes are characterized by conditional probability distributions derived from Bayes' rule (Koski & Noble, 2009). Nodes were categorized into three layers: hazard, direct effects, and indirect effects (Haraguchi & Kim, 2016). Figure 2 illustrates an example of Bayesian networks for direct and indirect damages in the critical infrastructure system.

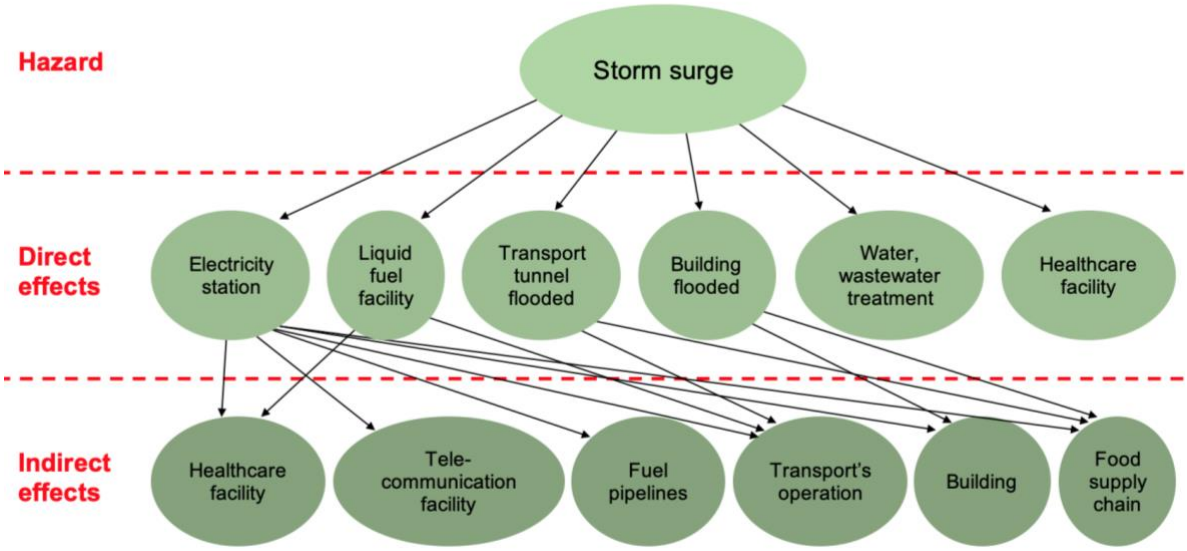

Figure 2: An example of a Bayesian network showing nodes categorized into hazard, direct effects and indirect effects, and the links between these nodes. The ellipses represent nodes and the arrows represent edges. Based on figure by Haraguchi & Kim (2016).

To assess the degree of functional interdependences among the sectors, the study utilizes indirect damages. The idea behind this strategy Haraguchi & Kim (2016, p.137) explain is that "the degree of interdependence between each sector determines indirect damages triggered by a sector". Hence, if indirect damages are calculated for each sector, they can signal the degree of interdependency between each sector and provide a guideline for the estimation. To calculate the direct damages, Haraguchi & Kim (2016) mapped the flooded areas using GIS. They then gathered the actual damages from reports and could thereby estimate the indirect effects.
Haraguchi & Kim (2016) found that the key sector to transmit risk to other sectors was the electricity sector. Nevertheless, "the variance of the direct damage in each sector is relatively

small, while the variance of the indirect damage is large" (Haraguchi & Kim, 2016, p.138). Therefore, Haraguchi & Kim (2016, p.138) conclude that "the degree to which one sector affects other sectors depends on the degree of interdependence among each sector".

Another attempt at mapping indirect effects of floods is presented in the article *Spatial exposure aspects contributing to vulnerability and resilience assessments of urban critical infrastructure in a flood and blackout context.* In the article, Fekete et al. (2017) demonstrate how the interdependency between affected people, critical infrastructure, roads, and civil protection infrastructure during a flood can be analyzed in a spatial clear way. The authors highlight the importance of taking indirect effects into account when performing a flood risk assessment. Fekete et al. (2017, p.157) categorized infrastructure elements into four different categories. Examples from these categories are written in parenthesis.

- *Category A* everyday basic needs supply infrastructure (water, food, energy).
- *Category B* maintenance and service supply for Category A (fire stations).
- *Category C* infrastructure enabling A and B (roads, electricity).
- *Category D* shelters (hospitals, schools)

Further, Fekete et al. (2017) selected components of vulnerability and resilience. The vulnerability factors used by Fekete et al. (2017) were: *exposure* to river flood (such as drowned technical infrastructure or roads flooded to repair damages), *the susceptibility* of critical infrastructure and people (such as of transformer stations or customers and population dependent on electricity) and *capabilities* of critical infrastructure and people (such as coping with energy outage or backup emergency power). The resilience factors were: *stability* (such as buffer and robustness of electricity system or continuation of daily life), *recovery* (such as mean time to repair), and *transformation* (such as resources for flexibility and adaptation or mew measures or resettlement). Additionally, general critical assessment criteria beneficial for GIS assessments were selected as follows: "*Critical amount* (of elements such as number of hospitals flooded). *Critical timing* (of flood phase, arrival times of fire cars, day and night traffic). *Critical quality* (of service offered of emergency supply or modal change from car to boat)" (Fekete et al., 2017, p.156).

According to Fekete et al. (2017), after choosing components of vulnerability and resilience assessments directed towards analyzing exposure to floods, five steps of analysis using GIS can be performed. The five assessment steps proposed by Fekete et al. (2017) were:

1. People at risk: residents and visitors
2. Everyday infrastructure dependencies (electricity, water, food, hospitals, daily emergency management)
3. Backup infrastructure at risk itself (fire brigades, hospitals)
4. Secondary infrastructure that the backup infrastructure is dependent upon itself (roads, electricity)
5. Shelters in operation and at risk (schools, hospitals)

Fekete et al. (2017) say necessary data was obtained by airborne and spaceborne earth observations to apprehend the size of the flood, and demographic data were mixed with place-based information about location and distance of items.

A third group, Guldåker et al. (2019), developed a method for mapping, analyzing, and visualizing direct and indirect effects on vital societal functions that can be applied to floods. The method is presented in the report *Utvecklad riskhantering för samhällsviktiga*

verksamheter avseende översvämningsrisker, (financed by MSB). The method was primarily designed to be used by the CABs and MSB (Guldåker et al., 2019). The method was built on eight steps divided into three different categories. An overview of the method is presented in Figure 3.

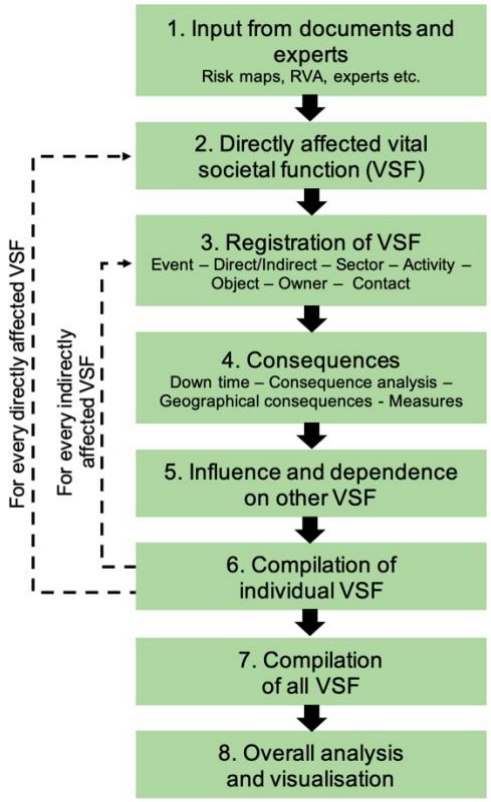

Figure 3: Steps of the method developed by Guldåker et al. Based on figure by Guldåker et al. (2019).

Step 1 consists of gathering information from documents and experts. Step 2-7 involves the consequence analysis of vital societal functions. Step 2-6 is about conducting consequence analysis for separate vital societal functions based on form templates provided by Guldåker et al. Whereas in step 7, the information is aggregated and analyzed using an Excel template (available in Guldåker et al.). At last, in step 8, the data in the excel template is used to perform an overall analysis and visualization of consequences and dependency chains. For the last step, Guldåker et al. (2019) suggest using GIS and dependency chains.

A conclusion drawn by Guldåker et al. (2019) from a case study with the municipality of Värnamo was that there is a demand for method support to analyze direct and indirect consequences from the perspective of different events and scenarios. Another conclusion was that the difficulty of using classified information is a challenge in working preventatively to increase the ability of society to manage disruptions and for more open management, analysis, and visualization of data. A third conclusion made by Guldåker et al. (2019) was that there was a positive attitude towards GIS and clearer visualizations in maps but that there is a risk of misinterpretations of the maps, which can result in faulty decisions and measures.

3 Methodology

Information for section *2.3 Academic Research* was found using Google Scholar and Lund University's database LUBsearch. Terms within the fields of critical infrastructure, GIS, and flood risk management were used.

The overall method of this study is a case study, based on the definition provided by Yin (1989, p.23) where a case study should meet the following criteria: “investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used”. Case studies have a qualitative perspective (Backman, 2008).

In a case study, common techniques for gathering qualitative data are interviews, observations, and document analysis (Höst et al., 2006). In this study, qualitative content analysis and semi-structured interviews were conducted. Content analysis was used for the flood risk management plans as the method is directed towards documentation that has been produced for some other purpose than the current study. The reason semi-structured interviews, rather than a questionnaire, were chosen to gather qualitative data of how the risk maps and management plans can be improved with the support of GIS was because semi-structured interviews are flexible. The flexibility enables alteration of the order and formulation of the prepared questions to suit the interview situation. By using a flexible method, the study could continuously be adapted to changed conditions. Personal interviews also enabled an explanation of the study in person and clarifications of potential misunderstandings. Negative aspects of semi-structured interviews are that they are time-consuming and that the interviewer risk affecting the respondent’s answers. The following sections explain the process of the qualitative content analysis and the semi-structured interviews.

3.1 Qualitative content analysis

To examine how the flood risk maps and management plans take direct and indirect effect into account, a qualitative content analysis was conducted. According to Hsieh et al. (2005, p.1278), "research using qualitative content analysis focuses on the characteristics of language as communication with attention to the content or contextual meaning of the text". The qualitative content analysis used in this report is conventional content analysis, which is usually used in studies that aim to describe a phenomenon (Hsieh et al., 2005). The process of a conventional content analysis follows the general steps of qualitative content analysis (Hsieh et al., 2005). These are: formulating research questions, sampling, coding, and analyzing the coding process results (White et al., 2006). The research question used in this content analysis was the second part of this report's first research question; *Are indirect effects of floods on vital societal functions taken into consideration when the flood risk maps and management plans are produced by the County Administrative Boards?*

The sampling plan was conducted to maximize the geographic diversity of the analysis. This includes CABs with different demographic and financial premises. Both the flood risk maps and management plans are accessible to the public on the Swedish Contingency Agency's web page. Out of 21 Swedish counties, twelve were represented in the flood threat maps produced by MSB from the first cycle in 2011. Flood risk maps and management plans from all threatened counties were used in the content analysis. If a county had more than one area threatened by flood, one of these areas was chosen randomly. In total, twelve flood risk maps and management plans were analyzed. These were the flood risk maps and management plans from the following CABs: Dalarna, Gävleborg, Halland, Jönköping, Norrbotten, Skåne, Stockholm, Uppsala, Värmland, Västerbotten, Västra Götaland, and Örebro.

Regarding the coding, the following coding categories were used:

- Are the words *direct* and/or *indirect* used concerning consequences?
- Are there examples of indirect effects of floods on vital societal functions described in the discussion?
- Are there goals and/or measures focused on preventing floods' indirect effects on vital societal functions?

These coding categories were formed from a process where all flood risk management plans first were read with the research questions in mind to form a general picture of their content. As the reports were read, key phrases and text segments that correspond to the research questions were noted. This process for qualitative coding was suggested by White et al. (2006). Both the words *direct* and *indirect* were counted because using the term *direct* is an indication of awareness that there are both direct and indirect effects.

3.2 Semi-structured interviews

To investigate how the County Administrative Boards utilize GIS in support of flood risk management, what are the potential impediments for further usage of GIS, and how those barriers could be overcome, semi-structured interviews were conducted. These interviews were held with professionals working on developing the flood risk maps and the flood risk management plans. All interviews were held digitally via Skype. An interview invitation was sent to all twelve CABs whose management plan was included in the content analysis. In total, ten different CABs accepted, and interviews with one or two representatives from each Board were conducted. These representatives were selected by sending a request for an interview with staff involved in the making and analyzing flood risk maps and management plans. The interviews lasted between 20-50 minutes. The main questions to the Boards were;

- In your opinion, how does the County Administrative Board take direct and indirect effects of flooding on vital societal functions into account when designing the flood risk maps and the flood risk management plan?
- How and to what extent do you use GIS in connection with the flood risk management process?
- Do you think that the risk management process can be improved based on the use of GIS?

These questions and some related discussion points were sent to the respondents at least one day before the interview. Supplementary questions were asked in between the main questions. Some examples of supplementary questions for the first main question were: In what way? How do you perform the analysis? Do you have a specific method? The interview support for these interviews is inserted in Appendix A.

Further, an eleventh interview was conducted with two representatives from MSB. The MSB interview was based on the results from the content analysis and the interviews with the Boards and lasted for 75 minutes. The interview support for these interviews is found in Appendix B. All interviews were recorded and transcribed. The respondents were able to review and revise the transcripts before their interview was used in the report. Due to their length (approx. 130-140 pages), the transcriptions are not attached in the appendix but can be provided if asked for.

4 Results

This chapter contains an analysis of the requirements in flood laws and regulations and the results of the content analysis of the flood risk management plans and the interviews with the CABs and MSB.

4.1 Requirements in laws and regulations

There is no paragraph in the Ordinance (SFS 2009:956) on Flood Risks or in the Regulations on the County Administrative Board's Management Plans of Flood Risks (MSBFS 2013:1) explicitly saying indirect effects on vital societal functions should be considered. Instead, the ordinance focuses on direct effects, primarily on human health, the environment, cultural heritage, and economic activities. However, it does not say that only direct effects should be considered. It does not mention the terms *direct* and/or *indirect* effects. 8§ can be interpreted as if indirect effects should be considered as they also may lead to possible adverse consequences for the citizens, economic activities, and environmentally hazardous activities. Further, 8§ point four states that the maps shall contain other useful information on what events that can lead to other harmful events may be considered useful information. Also, 12§ of the Ordinance (SFS 2009:956) on Flood Risks stated that the flood risk management plan should discuss all aspects of the management of flood risks. Indirect effects of floods could be included in the term *all*. Further mapping of interdependencies between different stakeholders and considering what indirect effects a potential flood could cause may be considered a part of the prevention work as well as a part of the protection and preparedness work, on which 12§ states a particular emphasis should be placed.

4.2 Content analysis

The content analysis was performed by going through and code flood risk maps and management plans for the first cycle of the flood directive from the CABs of Dalarna, Gävleborg, Halland, Jönköping, Norrbotten, Skåne, Stockholm, Uppsala, Värmland, Västerbotten, Västra Götaland, and Örebro. The results of the analysis will be presented in this section.

4.2.1 Content of flood risk maps

Flood risk maps from the first cycle were either made for the 50-year flow, the 100-year flow, and the calculated highest flow or the 100-year flow, the 200-year flow, and the calculated highest flow. For each flood scenario, the maps showed the area at risk of flood, the people at risk, and specific objects at risk, such as hospitals, distribution buildings, environmentally hazardous activities, roads, nature reserves, drinking water, land type, etc. There was a template for the layout and legends of the flood risk map that has been used by the CABs of Gävleborg, Halland, Jönköping, Skåne, Värmland, Västerbotten, Västra Götaland, and Örebro. As an example, Figure 4 shows the flood risk map for the calculated highest value for Kungsbacka, county of Halland. The risk maps presented by the CABs of Dalarna, Norrbotten, Stockholm, and Uppsala contained the same legends, if relevant, but had individualized layouts.

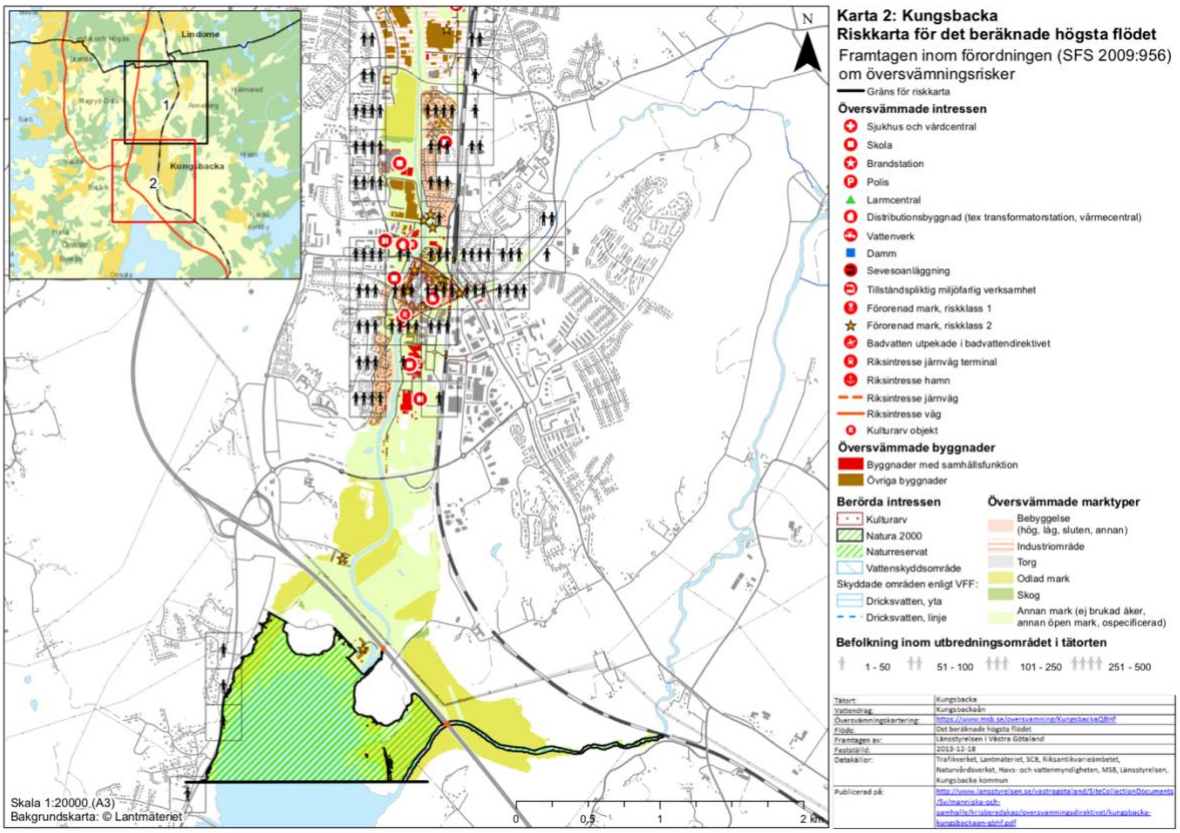

Figure 4: Flood risk map for the calculated highest flow for Kungsbacka, county of Halland. The map contains legends for hospital and health care centers, schools, fire stations police station, alarm center, distribution buildings, waterworks, dams, Seveso facilities, environmentally hazardous activities subject to a permit, contaminated soil risk class 1 and 2, bathing water, national interest railway terminal, harbor, railway and road as well as cultural heritage objects. The map also shows flooded buildings (including buildings with vital societal functions), affected interests (including drinking water supplies), flooded land types, and population within the flooded urban areas.

Figure 5 illustrates an example of a risk map produced by MSB for this second cycle, for the same area as Figure 4. For the second cycle, MSB made the flood risk maps' foundation for the same scenarios as in the first cycle. The maps were standardized and show nighttime population, bathing water, cultural heritage items, environmentally hazardous activities, economic activity items, environment, and people's health. It also illustrates railway and road of national interest, drinking water, affected interests including drinking water supplies and flooded land types. The flood risk map template used in the first cycle was much more detailed than the second cycle maps. Figure 4 shows the type of vital societal function and its position, whereas, in Figure 5, vital societal functions are filtered into general, less detailed categories.

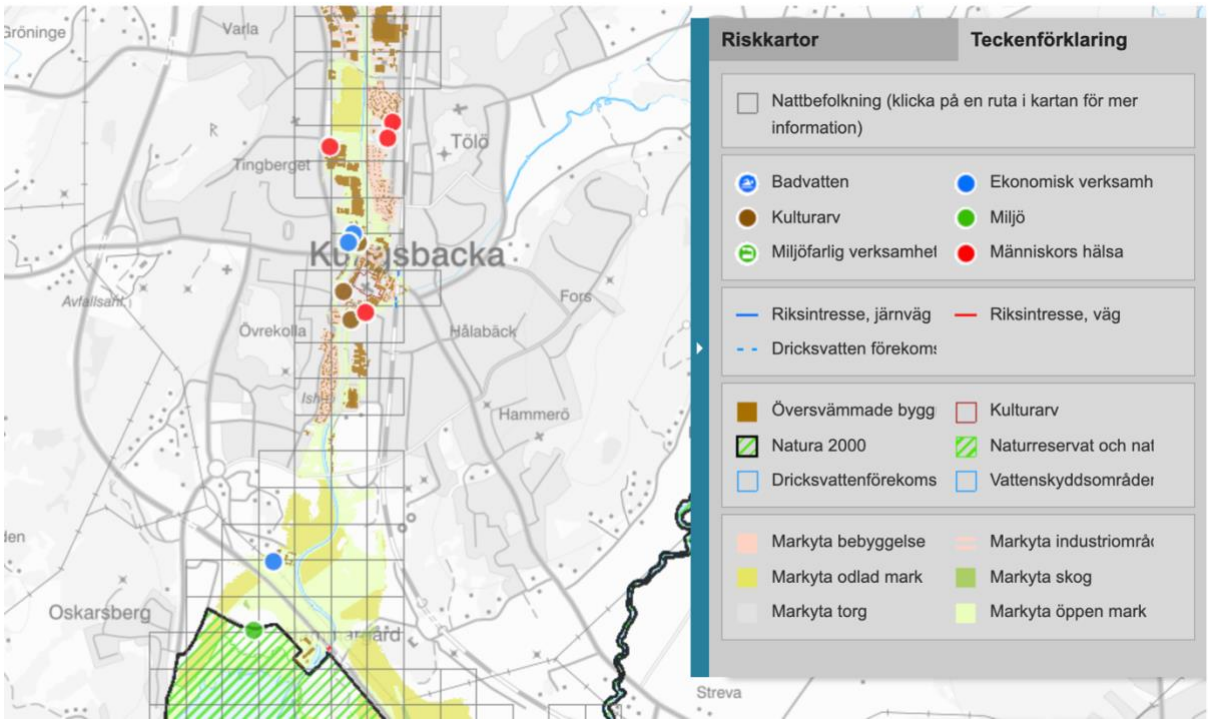

Figure 5:Screenshot of the flood risk map for the highest calculated flow in Kungsbacka, county of Halland. The map is from the second cycle of the ordinance of flood risk and is made by MSB. Source: MSB, n.d.

4.2.2 Content of flood risk management plans

In table 1, the outcome of the coding process is presented. The table shows how many times the words *direct* and/or *indirect* were stated concerning consequences, and examples of how potential indirect effects of floods on vital societal functions are described in the report, and potential goals and measures directed towards the prevention of indirect effects of floods on vital societal functions.

A conclusion drawn from the analysis of the flood risk management plans' content is that the main focus is on the direct effects of floods on human health, the environment, cultural heritage, and economic activity. However, all plans contained examples of how vital societal functions can be affected indirectly by floods, mainly related to critical infrastructures such as traffic, electricity and water supply, and sewage system. This indicates an awareness of indirect effects but also a clear need for conducting more thorough analyses, as vital societal functions are a wider concept that also includes education, elder care, etc. Additionally, many of the plans' measures were directed towards gaining more knowledge regarding the systems of vital societal functions. This to be able to fulfill the goal to uphold vital societal functions during a specific flood scenario.

Table 1: Outcome of the coding process used in the qualitative content analysis of the flood risk management plans provided by the County Administrative Boards. The table shows for what area the risk management plan was written, whether the terms direct and/or indirect are used concerning flood consequences, and examples of indirect effects taken into account in the discussion and the goals and measures respectively. The examples are quotes from the plans that have been translated.

CAB	**Area in risk of flood**	**Word count**	**Description of at least one example of an indirect effect of floods on vital societal functions? Example(s).**	**Goals/measures focused on preventing the indirect effects of floods on vital societal functions. Example(s).**
Dalarna	Falun	Direct: 3 Indirect: 0	"Large parts of the city center of Falun will need to be evacuated, either due to the direct threat from the water or due to the effects of disruptions caused by the water" (p.16). "Major power outages in the central parts of the urban area will occur, which will affect telecommunications, data and other electronic communications" (p.16).	"Water, sewage, electricity, and heat work mainly in areas outside the flood area at a 100-year flow" (p.17).
Gävleborg	Edsbyn	Direct: 0 Indirect: 0	"The Swedish Transport Administration, the County Administrative Board, the rescue service, and the municipality are conducting a review of the affected infrastructure and consequences, which includes contingency planning to ensure the accessibility of the rescue service" (p.14).	“Investigation - functionality of distribution facilities during high flows” (p.10).
Halland	Kungsbacka	Direct: 4 Indirect: 2	"In the work with the risk map, a knowledge gap was identified in terms of consequences for vital societal functions, both for the municipal technical supply and for those owned by private actors. There is good knowledge of which activities may be affected. However, it needs to be clarified in what way society is affected for the municipality and other relevant actors to be able to do adequate planning " (p.25).	"The consequences for identified vital societal functions in the risk area and its impact on society in a 50- and 100-year flow are mapped and documented". Unacceptable downtime from identified vital societal functions in the risk area has been clarified. Critical transport infrastructure has been identified, and the consequences on this together with possible measures to avoid interruptions have been clarified" (p.24).
Jönköping	Jönköping	Direct: 8 Indirect: 3	"The electricity supply and the treatment plant could be affected, which would have consequences for many more than those directly affected by the water level. If the treatment plant's function is affected, it could have major health effects" (p.29).	"The County Administrative Board must have linked the work with the protection of vital societal functions as well as risk and vulnerability assessments to flood risks, by identifying relevant actors and providing them with the current data and a collaboration platform" (p.41).

CAB	Area in risk of flood	Word count	Description of at least one example of an indirect effect of floods on vital societal functions? Example(s).	Goals/measures focused on preventing the indirect effects of floods on vital societal functions. Example(s).
Norrbotten	Haparanda	Direct: 4 Indirect: 0	"Although municipal administration, rescue services, schools, and care are not directly affected by a flood with a return time of 50 years or 100 years, the fact that the waterworks may be affected impact on the ability of the above sectors to operate" (p.13).	"Investigate how the power supply to central functions can be secured" (p.30). "Identify and classify the distribution buildings owned by the City of Haparanda and affected by a calculated highest flow within the risk area regarding function and vulnerability to flooding" (p.30).
Skåne	Kristianstad	Direct: 6 Indirect: 3	"Risk of direct and indirect effects identified as affecting human health, such as the risk of disruption of water supply" (p.7, 11, 14). "Assess the consequences for infrastructure (communications, transport, electricity supply, road/rail, etc.)" (p.8, 11, 15).	“Economic activities contributing to the functioning of society must not be exposed to long-term interruptions in the event of a flood” (p.20).
Stockholm	Stockholm	Direct: 11 Indirect: 0	"[…] a distribution building would be affected by a flood to calculated highest flow. The building class distribution building includes buildings in the distribution network for electricity, telecommunications, broadband, gas, heating, water. Further analysis may be required to see how important the distribution function is for society" (p.47).	"[…] no infrastructure that is important for the functionality of society should have to close in the event of a flood to a 50-year flow" (p.62).
Uppsala	Uppsala	Direct: 6 Indirect: 2	"There is a significant risk that society's ability to maintain the administration, civil protection, policing and other community services will decrease if a flood at the level of the 50-year flow occurs. Some large and small roads are flooded, which could mean a reduced capacity for civil protection. The 50-year flow would also impact society's ability to maintain infrastructure, as communications would be affected largely, particularly train traffic. Reduced accessibility and interruptions in infrastructure entail a risk of affecting human health. As parts of the traffic are affected, traffic accidents can also pose a risk" (p.11).	"Study how a flood affects infrastructure of national interest and what consequences this entails" (p.38). "Study how a flood regardless of return period affects high-priority vital societal functions and what consequences this entails" (p.39).
Värmland	Karlstad	Direct: 12 Indirect: 0	"Examples of functions that fall within the focus area but whose impact cannot be described based on the risk maps are electricity networks, district heating networks, wastewater networks, drinking water networks, telecommunications systems / IT, and waste management. Another example that is of great importance for human health is the possibility of getting around with transport on the road network" (p.18).	"In-depth study of vital societal functions" (p.34).

CAB	Area in risk of flood	Word count	Description of at least one example of an indirect effect of floods on vital societal functions? Example(s).	Goals/measures focused on preventing the indirect effects of floods on vital societal functions. Example(s).
Västerbotten	Vännäsby	Direct: 2 Indirect: 0	"If the water supply were to be affected, however, it would mean that, for example, schools and care would be affected because the operation of the business would be made more difficult" (p.26).	"Critical infrastructure is not affected by unacceptable flood disruptions" (p.32).
Västra Götaland	Göteborg	Direct: 4 Indirect: 1	"In the development of the plan, priority has been given to measures aimed at minimizing risks to human health. These measures apply above all to vital societal functions that can affect human health directly and indirectly. High priority is also given to measures regarding transport infrastructure that affect, e.g., the accessibility of rescue vehicles" (p.37).	"Vital societal functions of significant importance for human health must maintain their basic function at a calculated highest flow" (p.30). "Distribution facilities must maintain their basic function at a calculated highest flow" (p.30).
Örebro	Lindesberg	Direct: 0 Indirect: 2	"The accessibility on the roads will thus be affected, which can cause problems, e.g., emergency services, ambulance, and police to reach people in need. Therefore, there is a great risk that society's ability to maintain administration, healthcare and other community services that are important for human health will decrease in the event of calculated highest flow" (p.12).	"No infrastructure of major importance shall be affected by a flood with a return period of 100 years or more" (p.24). "Investigate the consequences of floods for vital societal functions" (p.24).

4.3 Interviews

Out of the twelve CABs, ten agreed to be interviewed. These were the CABs of Dalarna, Halland, Jönköping, Norrbotten, Skåne, Stockholm, Uppsala, Västerbotten, Västra Götaland and Örebro. The CAB, the respondent's job title, and an assigned ID are presented in table 2. Table 2 also contains the job title and ID of the representatives of MSB.

Table 2: The authority, job title, and the given ID of the respondents that participated in this study.

Authority	**Job title**	**ID**
Board A	Preparedness officer at the unit for civil protection	Respondent A
Board B	Preparedness officer at the unit for preparedness	Respondent B
Board C	C1: Preparedness officer at the unit for preparedness C2: Nature conservation officer at the land unit	Respondent C1 Respondent C2
Board D	Preparedness officer at the unit for civil protection	Respondent D
Board E	E1: Officer at the unit for civil protection and preparedness E2: Water strategist at the unit for community planning	Respondent E1 Respondent E2
Board F	Officer at the unit for climate and risk	Respondent F
Board G	Climate adaptation coordinator at the Planning and Housing Unit	Respondent G
Board H	Preparedness officer at the unit for societal development, civil protection, and preparedness	Respondent H
Board I	I1: Dam safety and river coordinator at the social department I2: GIS specialist at the social department	Respondent I1 Respondent I2
Board J	Water management officer at the water and natural environment unit	Respondent J
MSB	MSB1: Expert in natural disasters at the unit for natural disasters and decision support systems MSB2: Natural disasters officer at the unit for natural disasters and decision support systems	MSB1 MSB2

4.3.1 Major findings from interviews with County Administrative Boards

This section contains the results of the interviews with the Boards that most relate to the research questions of this report.

Design of the flood risk maps and the flood risk management plan

Early in the interview process, it was found that in this second cycle of the flood directive, the Swedish Civil Contingency Agency made the flood risk maps for all areas threatened by floods, not only the threat maps. Thus, the interviews' focus shifted to how the CABs use the risk maps to analyze direct and indirect effects of flooding on vital societal functions and how direct and indirect effects of floods are considered in the flood risk management plan. The overall impression was that the majority of the CABs mainly take direct effects of floods on vital societal functions into consideration by looking at the buildings at risk of flooding during the highest calculated flow. Respondent F commented that MSB also has focused on direct effects in the flood risk maps. Besides these direct effects, some respondents also mentioned they look at roads and other infrastructure related to the traffic to judge accessibility to buildings containing vital societal functions during a potential flood, which is an indirect effect. One of these was Respondent F, who said they note visually apparent indirect effects of floods, such as accessibility issues while screening the flood risk maps. Further, some respondents said they have also started to look at other indirect effects of floods in this cycle (Respondent B, C2), primarily related to energy, and water and sewer supply (Respondent C2). Respondent B and C1 said the main focus in their work in the first cycle had been the direct effects of potential floods. The priority then was to understand the task and develop a foundation (Respondent B).

According to Respondent E2, analyzing the indirect effects of floods might help to decrease the vulnerabilities. The county has hired a consultant to perform a cost-benefit analysis of mainly indirect traffic infrastructure effects. By taking the indirect effects of floods into account, the monetary cost of damages probably would be larger than if only direct effects were considered. According to Respondent E2, this might make it easier to motivate measures.

However, Respondent E2 stated that the purpose of the Swedish flood risk management plans is to avoid floods within the areas threatened by floods and develop measures to prevent unfavorable floods. The focus should be on decreasing vulnerabilities, not to perform an extensive analysis including indirect effects of floods (Respondent E2). Respondent H said that based on the last flood risk management plan's proposed measures, they are not taking the indirect effects of floods on vital societal functions into consideration. However, it is partly discussed in the text, and they are aware of some. In one area at risk of flood, there were no vital societal functions. Respondent A said they did not identify any vital societal functions within the area at risk of flood for any flow scenarios.

GIS-usage in connection with the flood risk management process

Respondent A described the process with the risk maps as follows. First, MSB sends a preliminary map of an area at risk of flood. The CAB then removes or adds items and/or areas depending on estimated relevance. The modified GIS-layer is then sent back to MSB, who in return sends adjusted flows for the areas and the updated number of people at risk etc. When the flood risk maps were sent from MSB to the CABs, they are sent as raster files together with the polygons, lines, and points representing items in the maps (Respondent C2). Also, most of the respondents (e.g., B, C2, E2, F, G, I1 & I2) described a similar strategy of finding relevant objects through an overlay of objects highlighted in their risk and vulnerability assessment and the hazard map. This is then interwoven with the objects from the risk and vulnerability assessment performed by the municipalities. In this step, the direct effects of floods were

observed. Sometimes, indirect effects in the form of roads or other traffic infrastructure were at risk of being flooded, resulting in that buildings containing vital societal functions were cut off. Respondent B mentioned they currently do not have a GIS-method to analyze indirect effects of floods, but that it is something they would like to have. MSB provided the CABs with a guide for the risk maps. Respondent C2, D, F, and I1 all share the opinion that it was a good tool for the analysis process. On the other hand, Respondent A, B, and E2 said the guidelines were not useful for the analysis process. Respondent B thinks it would be good with a section on how to perform the GIS-analysis to create coherency between the CABs.

Some CABs had modified the analysis input to suit them better. Respondent B mentioned they performed further GIS-analysis of the potential water level height during each flood scenario to be better able to judge whether the function of the building would be out of service or not. Another example was in the case of County J, where the entire city was at risk of being flooded for the highest calculated value. Therefore, Respondent J said they use the 1000-year flow as other CABs use the highest calculated flow in their estimations. A third example was Board E. Respondent E1 and E2 believed MSB underestimated the seawater level rise as it is a still water level. Therefore, they have used another model, including wind accumulation and wave rinsing, with those municipalities who agreed to that alternation. Respondent E1 said they appreciate the flexibility of MSB regarding making alterations to fit the county's preconditions better.

To access the input of other actors, the CABs contacted the municipalities and, in some cases, municipal or large private companies working with electricity supply, water supply, and/or housing. In general, these meetings had a "what if"-approach, but most CABs said they did not use a specific analysis method during these meetings other than going through all the objects in the risk maps. Respondent D said they identify direct effects from the risk maps and potential indirect effects from floods via dialog with the municipality. According to Respondent B, these conversations with the municipalities provide the basis of the flood risk management plan's content and measures. Luckily, Respondent D, G, F, I1 all said they have a good dialogue with their municipalities. Additionally, based on the experiences gained from the fires in 2018, Respondent H believes GIS is a good tool for crisis management in general and that it is beneficial to include a GIS-competent person early in a crisis management situation.

GIS-based challenges and proposed measures to improve the analysis of indirect effects

Although no CAB performed a GIS-based analysis of the indirect effects of floods on vital societal functions at the moment, several boards were already considering this approach. Respondent B and J both mentioned that an option could be to perform network analysis using GIS, but neither would feel confident performing such an analysis. To perform a GIS-analysis of both direct and indirect effects of floods on vital societal functions, Respondent B thought there is a lack of knowledge and access to tools required to perform some analysis steps. Respondent B mentioned Spatial Analyst as one of these tools. Respondent E2 did not consider access to GIS-software as a limiting factor, but just as Respondent B, Respondent E2 denoted knowledge as a limiting factor, also time to figure out relevant GIS-analysis. Further, Respondent A said they would like to be more knowledgeable in GIS or even have a GIS-analyst working beside them to better benefit from the functions in the software. Still, having extended access to a GIS-analyst may be difficult, as the GIS-experts' time was listed as one of the biggest limitations (Respondent H and G). Respondent G said they have a small GIS-group of two people and a long queue for them.

To decrease the knowledge gap, Respondent B proposed a workgroup with representatives from different CABs to work with these issues. As is common for smaller CABs, one person

works with the flood directive, and another person works with GIS. Respondent B said that the person working with GIS mainly is responsible for maintaining the GIS-data and not to perform analyses, which means Respondent B has to know the analysis. Another alternative that was presented by Respondent J was to hire a consultant.

However, it was explained that it is sometimes hard to communicate with GIS-experts (Respondent G) and people in general with different backgrounds (Respondent I1). This because people with different backgrounds and expertise have different vocabularies, which can make it hard to understand each other. Still, Respondent H stressed the importance of involving people with varying fields of expertise to identify indirect effects from different perspectives. Another challenge that was brought up related to GIS was faults in input data. For example, surveying data for buildings is not always classified by reality, which, according to Respondent F, takes much additional time. A third challenge when analyzing the indirect effects of floods would be the delimitation of the system, i.e., to know how many steps should be taken into account (Respondents G and H).

To perform an analysis of the indirect effects of floods on vital societal functions, Respondent A deemed it necessary to list regional and local vital societal functions and their critical dependencies. Respondent A said they currently do not have such a list but a project aiming to create a GIS-layer with all vital societal functions. According to Respondent A, this list will take years to develop.

Other proposed measures to improve the analysis of indirect effects

Respondent E2 questioned whether MSB intends for the boards to perform extensive analyses including indirect effects, considering they barely have one full-time position in total working with the task. More respondents experienced a lack of resources. Respondent D requested more staff to enable more time spent on the flood directive, as only a small fraction of the work hours is spent on the flood directive. Respondent E2 believed it is hard to find people within the CAB who have enough knowledge to take on the task. Moreover, when these people are found, Respondent C2 mentioned the importance of a good handover, so knowledge is not lost. The experience of Respondent G was that the flood directive work is bounced around between desks. On the other end, Respondent J mentioned that compared to CABs that handle many municipalities, such as Boards E and F, they could go deeper in their analysis at Board J by talking to other actors besides the municipalities. Regardless, Respondent F said the amount of funding a CAB receives from MSB to work with the flood directive depends on the amount of river and streams at risk of flooding, not how many municipalities are affected.

However, to analyze the indirect effects of floods on vital societal functions, Respondent I1 thought system knowledge and an understanding of the complexity are necessary. There is a need to be able to understand how the data is connected. Respondent I1 also thought there is an over-confidence in the exactness of data and that one needs to consider that the data is derived from estimations. Another difficulty experienced by Respondent C2 is identifying a large number of actors, to figure out how much they know and what measures they are taking. Respondent C1 agreed and added that it requires some imagination to make qualified guesses of what can happen so the right person can be asked. Respondent C2 said there is an issue regarding knowledge detail and questioned whether it is relevant for them to know, for example, where all the power lines are located, especially from a security perspective. Respondent C1 believes such large amounts of data would become unwieldy to handle.

According to Respondent B, a big challenge related to analyzing floods' indirect effects is a knowledge gap in many municipalities. Partly because not all vital societal functions are identified and partly a lack of knowledge regarding the infrastructure networks. Respondent B said that the municipality had identified organizations as vital societal functions in some situations but did not initiate cooperation. Thereby the organization did not know how they could be affected by a flood, what would be needed to restore them, and what kind of measures would be needed to manage potential floods. Another issue brought up by Respondent B was that the municipalities sometimes have difficulties because private actors initially do not want to participate in meetings with the municipality. In these situations, Respondent B said the CAB invites to the municipality's meeting. A similar statement was made by Respondent C2, who mentioned that it is sometimes difficult for organizations to find the time to work with flood measures in addition to their other obligations. It can be a matter of resources at the municipalities as well. Respondent E2 has experienced big differences among the municipalities in access to resources and the progression in their analysis and action work.

4.3.2 Other findings from interviews with County Administrative Boards

This section contains other interesting results from the interviews with the Boards. The findings concern responsibilities, risk and vulnerability assessments, and security.

Responsibility

The responsibility distribution between actors was also brought up during the interviews (Respondent E2, H, I1 & J). Respondent I1 mentioned that although indirect effects of floods will be discovered in conversations with municipalities, the deep analysis will be performed on a local level. The reason for this was explained by Respondent J, who said that analyzing potential indirect effects of floods on vital societal functions was not their responsibility. According to Respondent J, the owner of the item at risk of being flooded is responsible for their property, and they should thereby make their own analysis. The role of the CAB is to coordinate the information (Respondent J) and to lift ideas and thoughts, to make sure the collaboration works, and to formulate measures (Respondent C2). Further, Respondent C2 mentioned that the CABs does not have planning and building rights. It is the municipalities that decide whether an embarkment should be built or not.

Risk and Vulnerability Assessment (RVA)

Additionally, it was mentioned that floods are only one of the many risks the municipalities consider when developing their risk and vulnerability assessment. Respondent B said that the municipalities are very knowledgeable of what vital societal functions there are in the municipality, their networks, and potential indirect effects that can affect the vital societal functions. Both Respondent E1 and H agreed that indirect effects analysis falls under the risk and vulnerability analysis performed by the municipalities and their work with continuity management. Respondent H said the municipalities are responsible for making sure vital societal functions can operate as well as possible during a disruption. However, Respondent H also mentioned that the CAB make a risk and vulnerability assessment for the county. Respondent B concluded that a problem in trying to perform an analysis of indirect effects of floods is that the risk and vulnerability assessment is not yet as developed as they would want. If that work had reached further, there would be a better foundation for the work with the flood directive said Respondent B.

According to Respondent H, MSB does not decide what organizations provide vital societal functions. That is up to the CABs and the municipalities to decide. Nevertheless, Respondent F believes there is a conflict where different actors have different views of what should be

regarded as a vital societal function. Respondent F was also of the opinion that all vital societal functions do not have the same importance for societal functionality and mentioned a project called *Styrel* where CABs and municipalities are prioritizing certain vital societal functions. Additionally, Respondent G said they used to have two categories of vital societal functions, high priority vital societal functions and vital societal functions, but that they now have changed it into one category. However, Respondent G said they are not entirely sure what is included in this category.

Security

Related to aggregated information about vital societal functions, an issue that was mentioned rather frequently (Respondent A, B, C2, E2, F, G, I1) was the matter of security. According to Respondent A ArcGIS, their main GIS-software that is used today, requires an internet connection to access their basic data package and other functions. However, to collect the amount of data required to perform a technical analysis of the indirect effects of floods using GIS, a computer without an internet connection would have to be used for security reasons. Hence the currently used GIS-software stands in the way of analysis of indirect effects of floods. Further, Respondent A says it is not possible to use another software that could work because of the public contract with the supplier of their current GIS-software. However, Respondent A believes a map showing vital societal functions would be easier to absorb than a list. Respondent A wished for flexibility when it comes to what data analysis software is allowed. On the other hand, Respondent C2 pointed out the benefit of having the maps online to easier share its content and communicate it with involved actors, which is also included in the mission. Additionally, Respondent E2 mentioned that flood risk management plans are open documents that should be presented publicly. Therefore, according to E2, many fields in which it could have been interesting to perform GIS-analysis would not be possible to present in a flood risk management plan. To handle the security issue in the publication stage, Respondent C2 proposed two separate flood risk management plans or a restricted appendix.

It was also mentioned that there are some variations in the interpretation of the Security Protection Act (2018:585). Respondent G said that different authorities make different interpretations of the security regulations and find it difficult to know what applies. As an example, Respondent G mentioned maps that are uploaded on the webpage of the Swedish Civil Contingency Agency but that are not allowed to be uploaded by the CAB. Respondent I1 said that last cycle, the flood risk maps and management plans were uploaded online in detail, but this cycle is more restrictive. Respondent I1 believes there will be a balance eventually.

4.3.3 Findings from interview with MSB

MSB made the risk maps this cycle because it was more beneficial from a socio-economic perspective, as they already had the information required for the foundation of the risk maps. However, the Boards did alterations and own the maps. However, having the maps on MSB's webpage facilitated the reporting to the EU (MSB2).

The vision of MSB was that the ordinance of flood risks would naturally integrate with the municipal management plans, RVAs, and crisis preparedness in a mutual system where the work with the ordinance added information regarding flood risks (MSB1). MSB1 said the ordinance of flood risk aims to reduce the consequences of floods. Therefore, both direct and indirect effects of floods should be considered to keep vital societal functions operating as far as possible. According to MSB2, MSB can contribute with the method, foundation, and financing of measures, but they do not have the local knowledge necessary to identify vital societal functions. In the first cycle, the given goal for the CABs was to formulate knowledge

related measures to gain a better understanding of potential physical measures (MSB1). MSB has identified a potential need for further guidance of management of vital societal functions related to floods (MSB2), but in general, MSB2 thinks that the municipalities are knowledgeable in the field. Thereby, GIS will not be used to identify indirect flood risks. Instead, these will be identified by talking to the municipalities.

For the future, MSB intends to introduce network analysis for roads to detect critical and/or inaccessible roads. To provide enough details, these will have to be done on a local level (MSB2). MSB2 acknowledged there are variating levels of GIS-knowledge in the municipalities and CABs. Therefore, MSB2 mentioned they want to provide GIS-tools and methods to perform useful analysis. However, they will not perform the analysis as it demands information they do not have access to because of secrecy reasons. MSB1 mentioned that following the new guidelines for the flood risk management plans published in February 2020, secret information should be written in a secret appendix. Further, it was brought up that MSB is considering introducing variance into the risk maps (MSB2), emphasizing the importance of taking uncertainties and assumptions into account when planning measures. They also said they would want the municipalities to considerer different flood scenarios (MSB1).

MSB1 believes it is a good idea to have a group with members from different Boards to lift ideas and ask questions but pinpoints the importance of a good collaboration with their municipalities and GIS-experts. Perhaps also include the Swedish transport administration, which works a lot with GIS. Concerning finance, MSB1 said the budget for the ordinance of flood risks is bigger than the CABs use annually. MSB2 mentioned that in the flood risk management process, the CABs receives finance, whereas the municipality receives finance related to the measures. However, the CABs can hire the municipalities as consultants during the risk management process (MSB1).

5 Discussion

This chapter will discuss the study's validity and the results of this study in relation to the theory and the research questions.

5.1 Validity of the study

The timing of this project was not ideal. As the second cycle was started in 2016, the flood risk maps for cycle 2 were produced but not the risk management plans. Therefore, the risk maps and management plans from cycle one were analyzed in the content analysis. The difference in time meant that other people were working with the issue in the CABs now compared to 2015, which in term resulted in that the majority of the respondents in this study did not work with the flood risk maps and/or management plans in the first cycle. Instead, the interviewees were focused on the management plans for the second cycle, which created a disjunction between the content analysis and the interviews instead of gaining behind the scene information on cycle 1 as initially intended. However, this is not necessarily a disadvantage as the second cycle's work is based on what was done in the first cycle, which means the interviewees are familiar with the flood risk management plans from the first cycle. In this way, the interviews also indicate in what direction the flood risk management plans are heading.

The content analysis counted how often the words *direct* and *indirect* were mentioned concerning flood consequences in the flood risk management plans. No synonyms to these words were counted, as no corresponding keywords were found in the flood risk management plans' initial screening. Synonyms would have increased the range of the wordcount and perhaps have given a different result. However, this is not considered to decrease the validity of the study as the plans were read thoroughly, and all examples of where direct and indirect effects of floods on vital societal functions were noted. For the study's transparency, it would have been beneficial if all examples of when indirect effects of floods were mentioned would have been presented in Table 1, or if all examples would have been summarized for each plan. However, this was not done because of time pressure.

In this cycle of the flood directive, MSB created the risk maps for all CABs. This was not known before the project started, which resulted in the questions regarding making the flood risk maps using GIS were not as relevant as desired. Hence, questions of how the analysis process of the risk maps was conducted and how GIS was used were asked instead. This shifted the initial focus but instead lead to other interesting findings and is hence in the end, not seen as a weakness. The interviews were conducted with 10 out of the 12 CABs who participated in the flood directive's first cycle. As both small/large Boards, as well as Boards with many/few areas at risk of flood, were included, it is deemed to be a good representation of the Boards. An alternative could have been to also interview Boards that joined in the second cycle, but then it would not be possible to compare their statement to a flood risk management plan as they have not yet been published for the second cycle. Another alternative could have been to expand the interview study to include all five water district authorities, because they are responsible for developing the flood risk maps according to the Ordinance on Flood Risk. Therefore, they should have a valuable insight into the process and limitations of using GIS in support of flood risk management. However, this was thought of late in the work process and therefore was not done due to time constraints. Still, as MSB had made the risk maps, this is not seen as a weakness. Also, two of the five water district authorities (Norrbotten and Västra Götaland) were interviewed. Therefore, the perspective of the water district authorities is at least partly included in the results. Regarding the quality of the conducted interviews, the interviews with the CABs were scheduled for one hour, which was not needed for any of the interviews. Therefore, results were not missed out on because of lack of time. The variance of

the interviews' length was due to several factors; two of these can have been the respondents' chattiness and experience of the role. Further, this study is based on that vital societal functions are important in connection to flood risk management and that GIS is a good tool for visualizing interdependencies. As previously mentioned in personal semi-structured interviews, there is a risk of biasing the respondents. However, the questions were not asked in a leading way, and therefore that risk is seen as small.

5.2 Content of flood risk maps and management plans

The content analysis and the interviews gave a unifying picture that the main focus of the risk maps and management plans are direct effects. However, many of the measures related to vital societal functions brought up in the flood risk management plans were knowledge raising measures, which according to MSB1, was the intention for the first cycle. As the ordinance of flood risk is an iterative process, the plans will be improved each cycle. Mentioned examples of such improvements are that MSB is considering to introduce variance into the risk maps and network analysis of the road network (MSB2). That the potential network analysis will be off roads enhances the conclusion from the content analysis that vital societal functions in the form of critical infrastructure are prioritized. Also, the interviews with the CABs strengthen that standpoint as the examples of Respondent C1 and F of how they work with indirect effects of floods were related to critical infrastructure. On the other hand, MSB2 said indirect floods on vital societal functions would not be identified via GIS-analysis. Therefore it might not be necessary to perform network analysis of other functions than roads besides perhaps other infrastructure.

When comparing the flood risk maps to the five steps of analysis proposed by Fekete et al. (2017), both the maps contain *Step 1* in the form of residents, but visitors are not considered. Further, the map from cycle one contains at least one example from each of the steps. *Step 2* such as hospitals and daycare centers, distribution centers, waterworks, etc.; *Step 3* such as fire stations and hospitals; *Step 4* such as roads; and *Step 5* such as schools and hospitals. As the second cycle map is not as detailed as the map from the first cycle, Steps 2, 3, and 5 cannot be distinguished from the general categories. Step 4 is displayed in the form of roads. However, this does not mean the maps do not contain the information from the missing steps, but they are hidden from the public and probably accessible in a secret appendix. Regardless, the difference in detail illustrates one way of how a more strict view on security, discussed by Respondent I1, was implemented in the second cycle. However, neither of the maps contained information such as electricity network, telecom, district heating, etc., which also are critical infrastructures according to MSB.

5.3 Utilization of GIS in support of flood risk management

According to the literature, it would be possible to perform an analysis of indirect effects of floods on vital societal functions by following the methods provided by Fekete et al. or Guldåker et al. As previously mentioned, the information requested in the analysis method by Fekete et al. probably is available also in the second cycle. Furthermore, the input materials needed for Guldåker et al.'s method should be provided by the RVA and by talking to experts. Both of these researcher groups recommend performing a network analysis using GIS-software to analyze and visualize the data. The respondents also mentioned network analysis as a possible method to analyze the indirect effects of floods on vital societal functions using GIS and by MSB as a tool to use for road network analysis. Network analysis is possible to perform using ArcGIS. However, it is unknown whether the web-based version of ArcGIS used by the CABs has the necessary expansion. If not, acquiring the expansion probably will be possible, as MSB2 said they would provide analysis tools, and MSB1 said the flood risk budget is larger

than what is used annually. The main issue regarding network analysis was related to security, which will be considered later in this discussion.

5.4 Identified issues and challenges

Several factors limiting the possibility of the CABs performing analysis of indirect effects of floods on vital societal functions were discovered. The main factors were secrecy legislation, GIS-competence, and miscommunication between people with different fields of expertise.

Regarding the first issue, there were primarily two problems related to the secrecy legislation. The GIS-software currently used requires internet access to function. However, to be allowed to store large amounts of aggregated data, a computer without an internet connection has to be used. Respondent A knew a software that would fulfill this requirement, but the contract with the current supplier of GIS-software stands in the way. Hence, if it is decided that an analysis of indirect effects of floods on vital societal functions should be developed, either within the frame of the flood directive or the risk and vulnerability assessment, this contract would have to be renegotiated. The other security-related problem was that flood risk management plans are supposed to be public documents. This was highlighted in the EU Floods directive. The proposal made by Respondent C2, to create two separate plans or a secret appendix, would solve that problem. MSB1 said this solution is also stated in the new guidelines for the flood risk management plans published in February this year.

It was questioned whether the CABs must have a high level of insight in the complex system of vital societal functions and if the flood directive's purpose is to perform analysis of indirect effects of floods. Although that is not written in words, the stated aim of the ordinance (SFS 2009:956) on flood risks is to decrease floods' adverse consequences on human health, the environment, cultural heritage, and economic activities. As indirect effects, according to Guldåker et al. (2019), in some cases have been shown to cause more damages than direct consequences during floods, it is believed that indirect effects of floods can be considered adverse consequences. When it comes to how many steps should be considered when analyzing the indirect effects of floods for vital societal functions, that could perhaps be decided from a cost-benefit perspective. It might be secondary, tertiary, or higher orders, depending on what costs are discovered. However, it can also be questioned whether performing an extensive cost-benefit analysis is justified considering the resources demanded to perform such analyses. Additionally, such an analysis would not be possible to perform without having a list of the vital societal functions, their critical dependencies, and the economic consequences of disruptions derived as mentioned as a requirement to perform analysis of indirect effects of floods by Respondent A. However, identification of vital societal functions should already be performed within the scope of RVA and continuity planning, as was mentioned by several respondents. Therefore, analyzing the indirect of floods on vital societal functions should not take much additional time if the functions are already mapped properly. The flood risk assessment should be integrated into the RVA as floods are a hazard that can disrupt vital societal functions.

The second problem mentioned to perform analysis of indirect effects of floods was GIS-competence among CAB staff working with the flood directive. This study confirms the conclusion drawn by Guldåker et al. (2019) that in general, there is a positive attitude towards GIS and clearer visualizations in maps among the CABs and that there is a demand for method support to analyze cascading effects and indirect consequences from the perspective of different events and scenarios. As proposed by many respondents, education would be one way to solve this problem. As proposed by Respondent B, the workgroup with members from

different CABs also seems like a good way to decrease the perceived knowledge gap. Especially as the GIS-experts are in high demand in the CABs, maybe even a representative from MSB knowledgeable in GIS and network analysis could participate in the group to kickstart the work. MSB1 thought it might be better to include the Swedish transport administration, as they are very knowledgeable in GIS related to infrastructure. MSB1 also highlighted the importance of collaborating with the municipality and their GIS-experts.

This leads us to the third problem, which was communication between different fields of expertise. It was an experience shared by both Respondent G and I1 that the GIS-experts have another vocabulary than themselves, resulting in misunderstandings. To increase the word toolbox of both parties, a workshop where risk managers learn more about GIS and GIS-experts learn more about risk management could be an alternative. Another alternative is education in language adaptation based on the recipient, as "if we have no clear indicators for differences in the knowledge and background of the recipient, we use ourselves as the anchor and reference point"(Mustajoki, 2013, p.10). If these solutions would not be enough, GIS-education could provide the risk managers with adequate terminology to communicate with the GIS-experts. Hence, GIS-education would potentially solve two of the identified problems.

Lastly, there was some experienced ambiguity among at least one respondent regarding the definition of a vital societal function. On the 27th of October 2020, MSB published a new definition of vital societal functions. Hopefully, this new definition, which has been used in this report, will clarify this problem.

6 Conclusions

In this chapter the conclusions of this study are presented as well as topics of interest for future studies.

Are direct and indirect effects of floods on vital societal functions requested in the ordinance on flood risks (SFS 2009:956) and/or MSBFS 2013:1 regulation on risk management plans?
Neither the Ordinance (SFS 2009:956) on Flood Risks or the MSBFS 2013:1 Regulations on the County Administrative Board's Management Plans of Flood Risks specifically states that indirect effects of floods on vital societal functions should be considered. However, they do not exclude the possibility of flood risk maps to illustrate indirect effects on vital societal functions.

Are direct and indirect effects of floods on vital societal functions taken into consideration when the flood risk maps and management plans are produced by the County Administrative Boards?
Based on the content of the flood risk management plans published by the County Administrative Boards, the main focus is on direct effects. They had not performed any analyses of the indirect effects of floods, other than road accessibility. Still, there is an awareness of the indirect effects of floods on vital societal functions, and many boards proposed measures to increase that awareness. However, most examples of when vital societal functions were taken into account were critical infrastructures such as roads, electricity, and water supply. This hence suggests that actual/more in-depth analyses of indirect effects to a large extent are lacking. Although neither electricity nor water supply was included in the risk maps due to secrecy legislation and probably lack of knowledge. Regardless, it is recommended that municipalities put effort into including other vital societal functions too.

In what ways do County Administrative Boards utilize GIS in support of flood risk management?
From the interviews, it was found that the County Administrative Boards utilize GIS to perform an overlay analysis of the flood risk map received by MSB with their own layers to detect direct effects of floods and, in some cases, indirect effects such as road accessibility.

What are the potential impediments for County Administrative Boards to use GIS in support of flood risk management and how could those barriers be overcome?
Three main factors limiting the ability of the County Administrative Boards to perform analysis of indirect effects of floods on vital societal functions were discovered; these were secrecy legislation, GIS-competence, and miscommunication between people with different fields of expertise. To safeguard sensitive information, it was proposed to increase the security of IT-systems and extract sensitive information from public documents. To increase the competence related to GIS-analysis methods, it was proposed to gather a workgroup with representatives working with the ordinance of flood risk from different counties to collaborate. To improve the communication between GIS-experts and risk experts, a workshop where GIS-experts learn about risk and risk-experts learn about GIS or communication adaptation education is suggested. Finally, GIS-education was proposed as a solution to the impediments of both GIS-competence and miscommunication.

For future studies, it can be interesting to investigate how the work with the ordinance of flood risk and the risk and vulnerability assessments can be integrated in a good way. It can also be

interesting to examine how to deal with the Public Access to Information and Secrecy Act (SFS 2009:400) concerning an analysis of indirect effects on vital societal functions. A third topic could be whether it should be stated in the Swedish regulations that indirect effects of floods on vital societal functions should be considered. Finally, it would also be interesting to revisit this study when the flood risk management plans from the second cycle are released.

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Appendix A – Interview support, County Administrative Boards

This appendix contains the support used in the interviews with the County Administrative Boards.

Anser du att ni tar hänsyn till indirekta effekter av översvämning på samhällsviktiga verksamheter när ni utformar era riskkartor och riskhanteringsplanen?

- På vilket sätt?
- Hur gör ni analysen?
- Har ni en specifik analysmetod? Systematisk?
- Har ni mycket privata aktörer som liksom tillhandahåller samhällsviktig verksamhet i området som hotas av översvämning? Upplever du att ni får den information om indirekta effekter som ni behöver?
- Hur upplever du att sekretesslagstiftningen påverkar ditt arbete med översvämningsförordningen?

Hur och i vilken utsträckning använder ni GIS i samband med riskhanteringsprocessen krig översvämning?

- Vilken typ av analyser genomför ni?
- Vad har ni för metoder tillgängliga för att utföra analyser av indirekta effekter?
- Vad ser du för svårigheter med att utföra den typen av analyser?
  Motivation? Personal? Analysprogram? Kompetens?
- Vad skulle behövas för att ni skulle kunna utföra analyser av indirekta effekter.

- Känner ni till någon annan analysmetod för att analyser indirekta effekter än den ni använder?
- Tycker du den verkar bättre?
- Varför gör ni inte den? Förutsättningar och hinder.

- Hur upplever du att indirekta effekter av översvämning på samhällsviktig verksamhet fångas upp genom MSBs vägledning för riskkartor?
- Utöver MSBs vägledning för riskkartor, vet du någon analys som ni gör utöver det som står i vägledningen?

Hur anser du att riskhanteringsprocessen kan förbättras utifrån användandet av GIS?

OM JA

- Hur?
- Vilka resurser behövs?
- Vem borde ansvara för vad?

OM NEJ

- Varför då?

Övriga frågor

- Upplever du att det finns något problem med personalomsättning?

Appendix B – Interview support, MSB

This appendix contains the support used in the interviews with MSB.

- Vad har du för vision för översvämningsdirektivet? Tycker du att länsstyrelserna ska ta med indirekta effekter av översvämning på samhällsviktig verksamhet i sina riskhanteringsplaner?

- De indirekta effekter vi ser att länsstyrelserna tar upp är mestadels kopplade till kritisk infrastruktur som vägnät, el och vatten. Det bredare begreppet av samhällsviktig verksamhet tas inte upp i rapporterna. Hur ser du på användandet av begreppet samhällsviktig verksamhet?

- Har du några idéer på hur en hade kunnat ta hänsyn till indirekta effekter av översvämning på samhällsviktig verksamhet med hjälp av GIS?

- Vad ser du för utmaningar kring att ta hänsyn indirekta effekter av översvämning på samhällsviktig verksamhet mha GIS?

- Hur är det tänkt att arbetet med översvämningsdirektivet ska fungera kopplat till ansvarsfördelning? Vad förväntar du dig av länsstyrelserna och vad är deras ansvar? Har kommunerna något ansvar inom översvämningsdirektivet, eller ligger det inom RSA-arbetet?

- Hur ser du på kopplingen mellan översvämningsdirektivet och RSA arbetet?

- Hur ser du på sekretessbehandlingen kopplat till att utreda indirekta effekter?