DEGREE PROJECT

Urban flood risk mitigation

A perspective form urban planning

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Forewords

This master thesis constitutes the end of my studies at Luleå University of Technology and the finish of my master programme in Architectural Engineering with a specialization in urban planning. The work with the thesis started in the autumn of 2021, encompassed 30 credits, was presented in the spring of 2022, and handed in after revisions in the spring of 2023.

As the work concludes I want to thank my supervisor Jing Ma at Luleå University of Technology for all the help she gave me during the process of writing the thesis and preparing the presentation. I also want to thank my examiner Glenn Berggård at Luleå University of Technology for all the support and tips during my work.

Lastly, I want to thank all my friends and family, both in Luleå and in Falun, that helped cheer me on when I needed it as well as made my time studding in Luleå much more fun than I ever imagined it would be.

Andreas Brandow

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Abstract

Due to the global warming and climate change, an increased frequency of high intensity rains and other disasters are expected all around the world (IPCC, 2014). To predict this change in climate the IPCC has created a set of climate scenarios, RCPs, that will try to predict the future climate based on how much we are able to adapt and mitigate the effects we as a species have on the environment (IPCC, 2014).

This master thesis will seek to explore the possibility to use urban planning tools to help mitigate the increased effects and sizes of floods due to the global warming. To achieve this, a case study of Luleå is done, where urban indicators are used to improve the resilience of the city. This is combined with a policy study to see how Luleå compare to other cities in their policies that affect flood protection and mitigation.

To have a strong flood protection system in a city several factors need to be considered. One of the biggest factors is what type of strategy is chosen. One possible strategy is resilience, this combines seeming paradoxes into a working flood protection and mitigation plan. Resilience improves the flood protection and mitigation by combining and improving the robustness, adaptability, and transformability of the city. This is done by, among other things promoting inter disciplinary cooperation, public cooperation and knowledge of flooding, and promoting the use of water in the city as an asset. Blue and green infrastructure could also be implemented into the city as these measures help improve the resilience of a city in many regards. Not just for flood protection, but it can also help mitigate the effects of droughts or heatwaves and improve the general wellbeing of the citizens.

In the policy study it was found that different cities varied in both scale and strategy in their flood protection measures. All the cities that were looked at would also need to increase the scale of their protection and mitigation measures to mitigate the increased size and frequencies that the climate change brings. In Sweden, especially in the northern parts, the increased risk is not as high as in other parts of Europe. This is due to the land rise in Sweden mitigating the sea level rise. In Luleå the sea level and land rise are expected to fully mitigate each other until the year 2100. The policy study also showed that a history of flood related disasters did not necessary guarantee a strong flood protection scheme, but it would increase the probability of one. In the case of Luleå, the city has mostly focused on flood proofing buildings and infrastructure in the high-risk areas or those who are seen as critical to the society.

Based on the analysis of the policies and indicators that were developed for Luleå, the city seems to have good protection from the current risks, such as a 100-year flood, flow, or rain. But the systems in place will most likely need to be expanded and developed further to mitigate the rising risk due to global warming. Some measures that can be implemented are related to the adaptability and transformability, like brochures that teaches the public about flood-protection and what to do and how to act in case of a large flood in the city.

Keywords

Urban indicators, Resilience, Urban flooding, Flood protection and mitigation, Luleå

Table of contents

1. Introduction

1.1 Background

1.1.1 Climate change and increased flooding frequencies

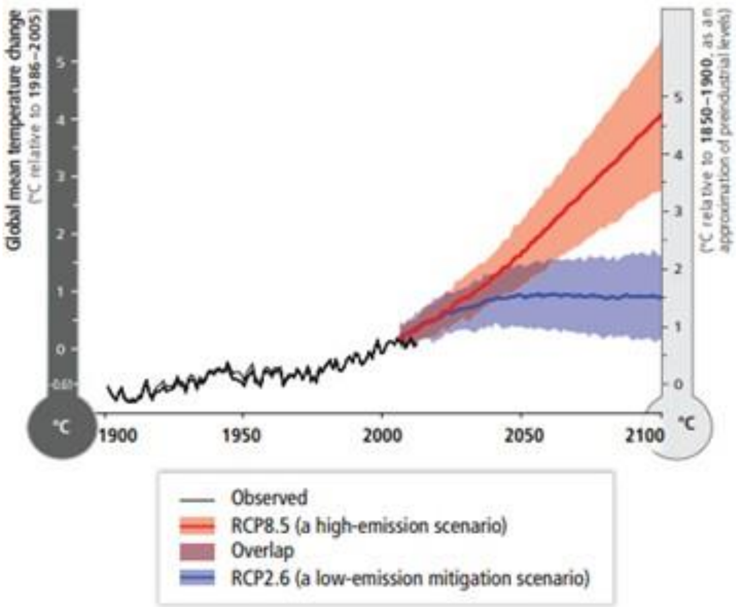


Figure 1: Comparison of the mean temperature change of the RCP8.5 and RCP2.6 scenarios. (IPCC, 2019)

In recent years climate change has had negative effects on the natural and human systems all around the globe, such as increased temperatures, melting of snow and ice caps and increased precipitation. To help mitigate and plan for future risks the IPCC (Intergovernmental Panel on Climate Change) developed climate scenarios in their Fifth assessment report (AR5). Their model, Representative Concentration Pathway (RCP) (IPCC, 2014), has four different scenarios depending on how well we can adapt to the climate change. The harshest scenario is RCP 8.5, and this will occur if we keep increasing our carbon emissions and energy consumption in similar rates as we do today and do nothing to try and change the outcome (IPCC, 2014). The 8.5 scenario is also the commonly used for predictions since it has been seen as the worst-case scenario. While the other three scenarios are RCP 6.0, 4.5 and 2.6. These will occurs depending on how much we do to lower our emissions, our energy consumption and reduce other damaging effects on the climate e.g., deforestation (IPCC, 2014). The number in the naming of the different scenarios is based on the radiative forcing values in the year 2100, the difference in energy we receive from the sun (IPCC, 2014). A positive value indicates that the planet receives that amount of energy (W/m^2) as a surplus from the sun compared to what the planet emits out in space. Figure 1 shows a comparison in the resulting temperatures from the RCP2.6 and 8.5 scenarios.

One of the main effects of climate change is the global warming. With only between 0–1°C of additional warming, coral reefs and arctic ecosystems are at risk, and with higher rises in temperature the risks become greater and will affect more ecosystems around the globe (IPCC, 2014). Further increase in temperature will also lead to a global increase in precipitation and a higher frequency of extreme weather events, such as heat waves, extreme precipitation, and coastal flooding (IPCC, 2014). The global mean sea level will also rise due to the loss of ice sheets and with sustained warming, a complete loss of the Greenland ice sheet could occur over the next millennium, which would lead to about a global mean sea level rise (GMSLR) of 7m (IPCC, 2014). In the RCP 8.5 model the average sea level rise (SLR) would be between 10-20 mm a year in the 21st century and increase to several cm during the 22nd century. Due to the GMSLR and increased frequency of extreme weather events an increase in extreme floodings is also expected (Marsooli, et al., 2019). What previously was a “100-year flooding” would double in frequency in most areas and in some parts on the US-east coast become a yearly occurrence (Marsooli, et al., 2019).

1.1.2 The 100-year floods

The commonly used term 100-year flood originated in the U.S. shortly after their congress passed the National Flood Insurance Act (NFIA) in 1968 (Bell & Tobin, 2007). The passing of the NFIA led to campaigns where flood prone areas all over the nation would be mapped. To do this efficiently, guidelines and policies were created to let multiple different organizations do the work. These policies and guidelines were modelled after a flood with a return period of 100-years, or a yearly chance of one percent (or 26 percent over 30 years), as this was seen as a good balance between the risk and economic incentives of development in the areas affected (Bell & Tobin, 2007). The term 100-year flood was first adopted to help with administration and implementation, but it was later shown that the term worked rather poorly in communicating the risks of flooding and a system more focused on a percent chance would be preferred (Bell & Tobin, 2007).

To this day flood events are still often classified by their expected return period (2, 5, 10, 25, 50 or 100-year flood). But all of them can instead be translated into an annual probability, as seen in Table 1. This is also the preferred way of naming them by many experts as its less misleading and gives the public a clearer picture of the risk (Holmes Jr. & Dinicola, 2010).

Recurrence interval, years	Annual exceedance probability, percent
2	50
5	20
10	10
25	4
50	2
100	1
200	0.5
500	0.2

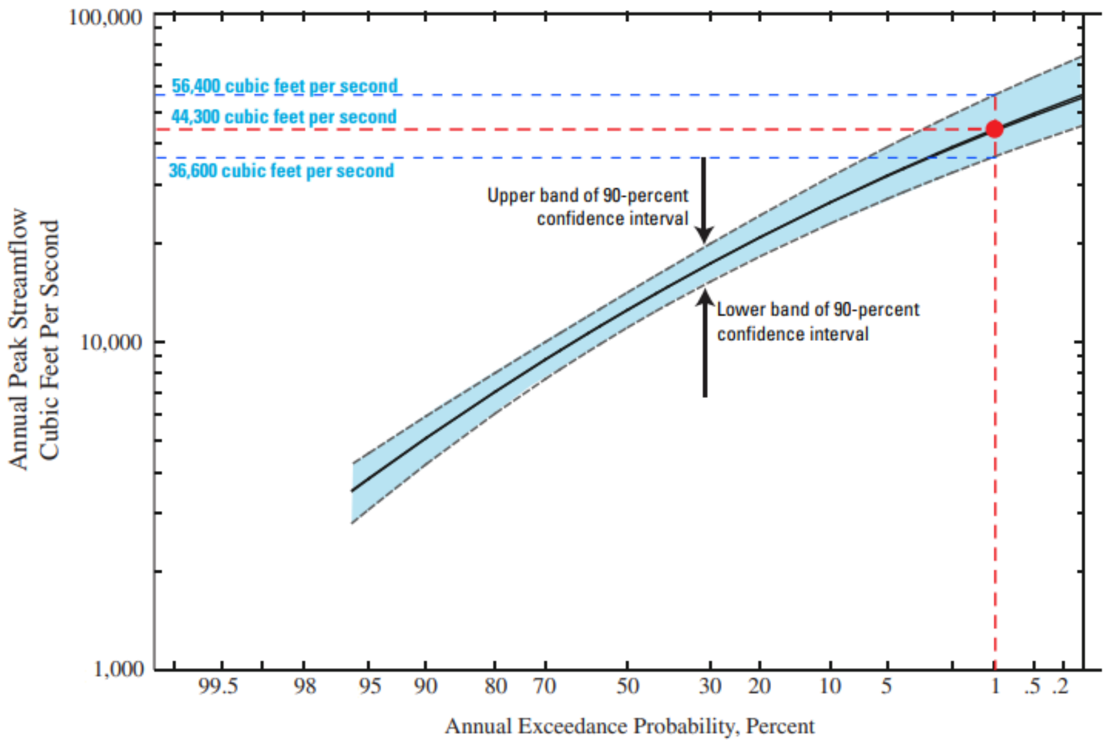


Figure 2: Flows of a river in the U.S. (solid line is expected flow, dashed line is 90-percent confidence interval) (Holmes Jr. & Dinicola, 2010).

The size of a 100-year flood varies from place to place as it is calculated from the past streamflow data for every specific place. But the size corelation between different return times is more universal. As seen in Figure 2, the difference between different return periods is big, a 2-year streamflow (50 percent annual probability) is about 10 000 cubic feet per second in the example while the 100-year streamflow (one percent annual probability) is between 36 600 and 56 400 cubic feet per second, an increase between 3.6 and 5.6 times (Holmes Jr. & Dinicola, 2010).

1.1.3 Effects on the built environment

Flooding can also cause damage to the urban and natural environment. As seen in the autumn of 2021 with large flooding in Gävle, Sweden (SVT Nyhter, 2021a) and in the western parts of Germany (SVT Nyheter, 2021b), where the water caused landslides that destroyed roads, buildings, and a lot of land. Even if the water does not outright destroy a building, it can still cause structural damage, as sustained moisture becomes a breeding ground for mould that could make the building sick (IPCC, 2014). Damage can also be caused by the actual flood; it can cause homelessness as well as force the closing of roads or other important services and infrastructure in the city.

Thus, adaptation to flooding and mitigation to the rising of sea levels are important, since without any intervention, the coastal flood damage is expected to rise by 2-3 times by the year 2100 (IPCC, 2019). Well-designed flood/coastal protection is highly effective in reducing expected damages and can be cost efficient for urban and densely populated regions, but in general unaffordable for more rural and poorer areas (IPCC, 2019).

Experience in the adaptation to flooding is accumulating in both the public and private sectors. Governments at various levels start to develop plans and policies to integrate climate-change considerations into broader development plans (IPCC, 2019). In Europe for example, the adaptation policies have been developed across all levels of government into policies regarding, among other things, environmental protection, land planning and disaster and risk management (IPCC, 2019).

Some cost-effective measures that can be taken to reduce the damages are flood proofing and early warning systems for extreme flooding. But where flood risks are already high and the population size and density are low, or in the aftermath of a disaster, retreat might be the most effective option, though this can be politicly, culturally, and socially challenging to perform (IPCC, 2019).

1.1.4 Climate change and flooding in Sweden and Luleå

The mean temperature in Sweden is rising, for example, in Luleå the temperature rise is measured to +1.3°C since the period 1961-1990 and it is expected to rise even more in the future in line with the rest of the globe (Luleå kommun, 2015). The frequencies of extreme peak flows in the country are also expected to rise, by 2080 it is expected to have increased by 184% (Alfieri, et al., 2015).

In Luleå, the global warming is reducing the snow season to an average of 115 days by 2100 following the RCP 8.5 scenario (Luleå kommun, 2015). This will also cause the vegetation growth period to extend with 59 days to an average of 204 days a year. The precipitation, of which about 30% is snow, is expected to rise with about 30% a year, with a larger increase is during the spring and winter periods where the precipitation is the lowest today (Luleå kommun, 2015). The amount of both longer and shorter extreme events regarding precipitation is also expected to rise.

During the winter, the run-off is minimal causing most of the water to be stored in a snow layer. This leads to the yearly-peak flow, also called the Spring-flow when the snow is melting. Though the yearly peak flow is not expected to rise in Luleå, but the average flow is expected to rise by 20% by 2100 due to the increased precipitation (Luleå kommun, 2015).

The sea level on the other hand is not expected to rise in line with the rest of the globe, this is due to a land rise in Northern Sweden that is expected to negate the rising sea levels until at least year 2100 (Luleå kommun, 2015).

1.2 Purpose

The purpose of this research is to investigate whether urban-planning methods and strategies, especially urban indicators, can be a useful tool to handle the increasing flood risk that is occurring due to the global warming. The flood resilience of Luleå will also be examined in the thesis.

1.3 Scope

This study will evaluate how increased frequencies of 100-year rain and raised sea levels can cause problems, and how urban planning can mitigate them. The study focuses on the climate of Northern-Europe; thus, the research does not consider tropical storms hurricanes and similar events that are not present in the climate of Northern-Europe. However, in the literature study some areas outside of this region are studied to increase the knowledge base of different concepts, though areas outside of Europe has only been used for concepts that are also applicable in Europe.

1.4 Research questions

The research questions are divided into two categories. The first one is the primary research question, to answer the main research question, sub-questions are proposed. The main question of the thesis is:

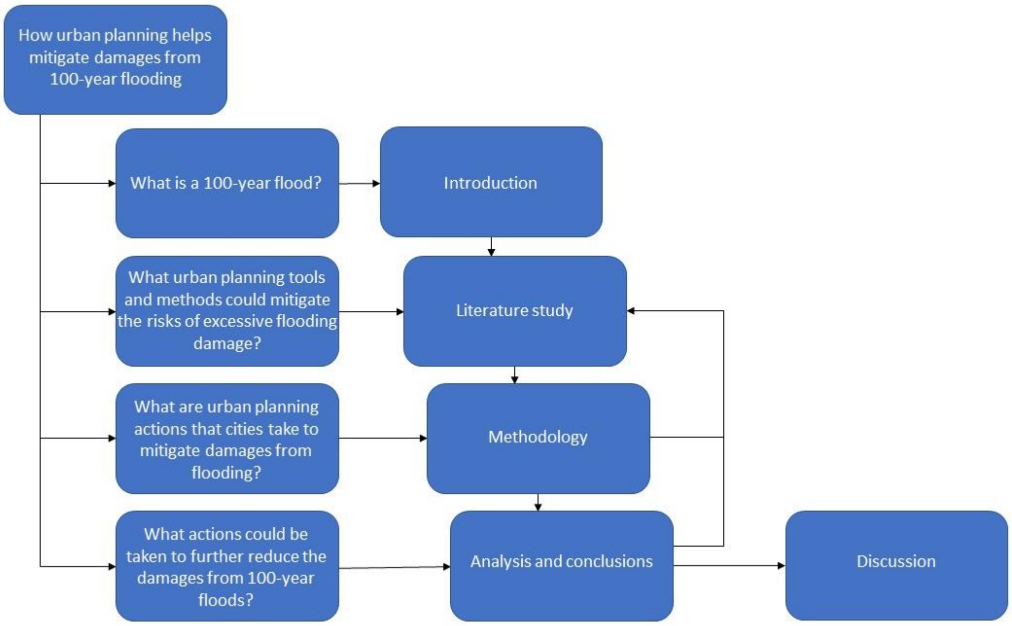
- How urban planning helps mitigate damages from 100-year flooding?

This is followed by the sub questions, with the task to answer the primary question:

- What is a 100-year flood?
- What urban planning tools and methods could mitigate the risks of excessive flooding damage?
    - What is urban resilience?
    - What is blue green infrastructure?
    - What are urban indicators?
- What are urban planning actions that cities take to mitigate damages from flooding?
- What actions could be taken to further reduce the damages from 100-year floods?

1.5 Structure

The structure of the report is based around the research questions, where the sub-questions is supposed to answer the main research question. The sub-questions are answered in the different chapters of the thesis. What question will be answered where is showed in Figure 3. This figure also shows how the different chapters are connected to each other in the thesis, and that an iterative process was used for the literature study.



1.5.1 Summaries of the chapters

1.5.1.1 Introduction

The introduction chapter is introducing the topic, followed by multiple sub chapters where the purpose, scope, research questions, structure and method of the thesis are presented. This chapter provides background information to understand the research topic and parameters of the thesis.

1.5.1.2 Literature Study

The literature study collects information about different studies related with issues of flooding. It discusses and explains various aspects of urban resilience and how to build urban resilience within a city. This is followed by an investigation on blue green infrastructure in an urban environment and the concept Sponge-city that originated in China. The last two parts in the literature study before the summary of the literature findings, is an explanation of urban indicators and how to develop them for a city and then an explanation of the Swedish planning system.

1.5.1.3 Methodology

In the methodology chapter policy studies of three different cities are conducted, two Swedish and one German city. The Swedish cities are Luleå, the case study of this research and Gävle, a city that experienced precipitation related disasters in the past. The city from Germany is Hamburg as it has been seen to have good flood protection.

1.5.1.4 Analysis and conclusion

The analysis part of this chapter is divided in three parts. The first one is a continuation of the policy study. This part consists of analyses of the cities policies presented in the previous chapter and then a comparison of them. The second part is the creation of and evaluation of some urban resilience indicators for Luleå. The third part includes some suggestions for implementations based on the score from the indicators. This is followed by the conclusions of this study, relating to how the research questions are addressed.

1.5.1.5 Discussion

In this chapter, obstacles of undertaking the research have been discussed together with possible errors and limitations. The reliability and validity of the thesis is evaluated and discussed, followed by some propositions of continued work and research in the areas.

1.5.2 Method

1.5.2.1 Choosing the methods

This study investigates Luleå in a case study. This was accompanied with a police study of three different cities, to build contexts for a better understanding of the policies and the evaluation of them. In the case study, urban indicators were chosen as the planning tool. Urban resilience indicators were then developed through the literature study. To evaluate the indicators a spatial analysis of the city and interviews are needed, but due to the time limitation, only the spatial analysis was conducted.

1.5.2.2 Workflow

The workflow to answers the different research questions is an iterative process. It started with the literature study to build a knowledge base as a starting point. Figure 3 shows how the research questions are addressed and answered during the thesis, as well as showing the workflow of the chapters.

1.5.2.3 Information and knowledge gathering

A literature study was conducted to create a knowledge base for the research. The contents of the literature study included flood protection concepts and methods such as urban resilience, sponge-city, and integration of blue-green infrastructure in urban environments. Information about the topics was found by searching on databases, e.g., Google Scholar and Scopus. Articles and papers on the databases were selected based on the phrases used in relevant topics. These topics were narrowed down by adding extra phrases to searches in the titles, abstracts and key words of the articles and papers.

A second round of information gathering was done for the policy study. A thorough search of government websites and documents was conducted to identify as many of the relevant policies and guidelines as possible. These documents were checked to see if they included anything relevant for flood protection or mitigation. The time spent of finding policies and guidelines varied from city to city as different cities had a varying degree of policies and guidelines and different government institutions were responsible.

1.5.2.4 The process of analysing

The analysis part of the thesis is divided in to three main parts. The first one is an analysis and comparison of in the policy study. In this part the policies are first evaluated based on the theory from the literature study, then they are compared between cities.

The second part was the development and evaluation of urban resilience indicators, which has been seen as a suitable urban planning method. The first step was to develop planning goals that the indicators should achieve, these goals were based on the theory from the literature study. After the goals were set, the indicators were developed to address each of the goals for flood protection and mitigation.

The third and last part was suggested implementations in Luleå based on the indicators that scored the lowest on the evaluation. The content of the suggestions was based on the methods and concepts found in the literature study.

1.5.2.5 Reliability and validity

The studies done in the thesis are mostly qualitative as they focus on a lower number of items that are analysed individually. When measuring qualitative and quantitative methods in the academic world reliability and validity are often used. Validity is the measure of the studies ability to analyse and measure what the study sought to research. On the other hand, the reliability is the measurement of the studies ability to be replicated if similar conditions are met (Alvehus, 2013). The reliability and validity will be evaluated at the end of the thesis in the discussion.

1.6 Summary

Due to the global warming and climate change, an increased frequency of high intensity rains and other disasters are expected all around the world (IPCC, 2014). To predict this change in climate the IPCC has created a set of climate scenarios, RCPs, that will predict the future climate based on how much we are able to adapt and mitigate the effects we as a species have on the environment (IPCC, 2014).

A common way to dimension for the disasters relating to floods is to protect from 100-year floods, a flood with a return period of 100 years. The dimensioning of these floods is based on the historic sizes of the floods in the area in question, resulting in difficulties to accurately size what the actual size of the different return periods are. This terminology can be misleading as it makes is sound verry rare, but in fact over a thirty-year time span the probability of a 100-year flood is in the region of 26-percent or a $\frac{1}{4}$ chance. Experts instead prefer the use of yearly percentage chance, thus calling a 100-year flood, a 1-percent flood.

This thesis will seek to explore the possibility to use urban planning tools to help mitigate the increased effects and sizes of floods due to the global warming. To achieve this, a case study of Luleå is done, where urban indicators are used to improve the resilience of the city. This is combined with a policy study to see how Luleå compare to other cities in their policies that affect flood protection and mitigation. But to do be able to do this, a literature study was needed in the beginning. This study was done with an iterative process, where the literature study was started, then as more information was needed, or new concepts discovered it was extended to include those as well.

2 Literature study

2.1 Urban resilience

A general consensus is that the traditional way of flood control measures is not enough as a response to deal with the rising flood risks caused by the change in climate. One way to help mitigate this risk is an increase in the implementation of urban resilience mesures. Traditionaly the concept of resilience has been seen as the oppposite of the resistence concept, the traditional way of flood protection (Restemeyer, et al., 2015). Where resistence would do eveything to withstand a flood, resilience would take the possibility of a flooding into acount during the planing and developing of areas in order to minimize the potential damages of the flood. Though the thought of resilience being the opposite of resistence is outdated and not fully accurate, and resistence should instead be seen as an important part of resilience (Restemeyer, et al., 2015).

Resilience is a combination of three different aspects; *robustness, adaptability and transformability.* Robustnes, or traditionaly known as resistence, is the strength of the city and how good it is to withstand a potential flooding (Restemeyer, et al., 2015). Historicaly it is also the most common method of flood protection. However, as seen many times in the past resistence is not usualy enough for the more extreme weather events, recent examples of ths can be seen in both Gävle and Germany in the fall of 2021. To help mitigate some of the weaknesses in roubustness, adaptability can be implemented as well. As the adaptability of a city is its ability to let the flood pass through the city with out leaving any significant damages in its trail, this is done by planning the city in such a way so a flood would not do any substantial damage to the city or hinder any of the cities vital functions or infrastructure during the flood (Restemeyer, et al., 2015). To achive this, the physical environment needs to be adapted with meassures such as elevating houses on poles, making sure vital services are in areas that are less prone to flooding and even plan for controlled floods of certain areas (Restemeyer, et al., 2015). Though, this will also require a social aspect and an effort from the population to learn how to stay safe during the floods, and how to make sure they and/or their belongings do not get hurt or damaged by the flood. To achive this, flood risk management will have to become a social and cross-diciplineray task that will require planning departments to work with water and risk management departments to plan for and inform the public about how to act during a flood. First when this is done the third part of resilience, transformability, can be implemented. The transformability of a city is the capacity of the city to change and adapt when new information come to light. With recent climate change and flooding disasters this has created a need to stop *"fighting the water"* and start *"living with the water"* instead, this can also be described as an "integrated-adaptive" regime (Pahl-Wostl, 2007). Transformability also implies that in the future when new insights come to light, the city should have the capacity to adapt to find new better and more sutiable ways to handle flood risk and continously develop the flood protection of the city (Restemeyer, et al., 2015).

Resilinece could also be defined as: *"the ability of a system (the city) to adapt and adjust to changing internal or external precesses"* (Voskamp & Van de Ven, 2015) and can be further broken down in to two apects.

- Continous functioning
- Process of adaptation

Continous functioning entails that the city should be able to withstand and recover quick from unplanned events. While the *process of adaptation* aspect dictates that the city always improve and learn from the last flood to have better protection for the futre extreme events (Voskamp & Van de Ven, 2015).

This definition is in-line with the one proposed by Restemeyer, et al. (2015). Since the first aspect of the definition made by Voskamp & Van de Ven (2015), *continues functioning,* consist of *robustness* and *adaptability*, while the seconde, *process of adaptation,* consists of *adaptation* and *transfomability*. With this in mind this chapter will continue to focus on the defenition made by Restemeyer, et al. (2015). In Table 2 the different parts of resilience that Restemeyer, et al. (2015) proposed is broken down into key points in diferent stages to easier understand what the three aspects entails.

Table 2: A strategy-based framework for assessing flood resilience of cities (Restemeyer, et al., 2015).

	Robustness *'Reduce flood probability'*	**Adaptability** *'Reduce consequences of flooding'*	**Transformability** *'Foster societal change'*
Content Measures and policy instruments	- technical measures (e.g. dikes, dams, barriers) - spatial measures (e.g. river widening)	- discourage vulnerable land use in flood-prone areas - flood-proofing existing buildings and infrastructure in flood-prone areas - warning and evacuation schemes - flood insurance / recovery funds	risk communication and awareness raising among: - private stakeholders (e.g. brochures, public campaigns, early education in school) - public stakeholders (e.g. consensus-building, partnership practices, decision support tools)
Context Strategic issues, Institutional structure and legislation	- Water and climate: water as threat - strong public responsibility for water management - collaboration between water management and spatial planning on specific projects	- Land-use and socio-economic changes: need to create synergies - shared legal responsibility public – private - strong collaboration between water management, spatial planning and disaster management on all projects	- societal changes: need to establish water as asset - informal networks fostering a new 'water culture' - new interdisciplinary networks (e.g. 'think tanks') and learning organizations
Process Intellectual capital	- expert knowledge in engineering and planning	- expert knowledge and local knowledge (vulnerability reduction and adaptation options)	- creativity, openness towards new knowledge, learning
Social capital	- good relations among water managers and spatial planners	- good relations among water managers, spatial planners and disaster managers; civil awareness and willingness to invest in flood risk management measures	- mutual trust between public and private stakeholders and social acceptance of new interdisciplinary networks
Political capital	- strong political and financial support for bigger structures (public funds)	- strong political and financial support for adaptation and a risk-based approach	- change agents, leadership; financial support for informal and interdisciplinary networks

2.1.1 Robustness

The robustness of a city is the measure of its ability to withstand a flooding event and prevent any flooding in the city. This is accomplished by implementing different technical and spatial measures (Restemeyer, et al., 2015). Storm surge barieres, dikes and sluices are examples of some technincal messures that would increses the robustenss, while the widening of rivers are a common example of a spatial measures.

When choosing a strategy for water management in a city or area many contextual factors need to be considerd and can play a big role. Economical, populational development, performance and cultural properties is usualy important factors when choosing a strategy (Hutter, 2006). Robustens as a strategy is chosen if the water is seen as a threat in the city. In order to impliment a robustness strategy good relations and collaboration between spaital planners and water managers are needed to make sure projects that increase the robustens of the city is finalised, as almost all of the responsibility for flood protection and mitigation in most cities is on the public sector (Restemeyer, et al., 2015).

2.1.2 Adaptability

The goal with adaptability is to lessen the damages from the flooding when it occurs. This can be done by, for example, floodproof buildings, planning the city to avoid vital functions and infrastructure in the highest risk and most flood prone areas (Restemeyer, et al., 2015). Early warning systems can also be used in combination with evacuation schemes and temporary special measures (such as floodgates) to decrease the effect of the flood. Funds and incurrence focused on flooding and flood damage reimbursement can also help effected citizens and the city in general to recover faster after an extreme event (Restemeyer, et al., 2015).

A more adaptive approach in the strategy is needed when land-use and socio-economic change are major factors to consider (Restemeyer, et al., 2015). Adaptability also needs a stronger collaboration between the planning and water sectors to make sure the city is flood proof. Changes in the law can also be a tool to help promote an adaptability strategy, for example, if flood risk must be considered in the planning phase. Laws can also help dictate if flood protection is purely a public task or if the responsibility should be shared with the private stakeholders, such as, property owners and developers.

2.1.3 Transformability

The transformability of a city is its ability to adapt and promote social change in its population and government in order to increase the flood protection of the city. The only way to properly reduce the flood risk of a city is for the different disciplines such as water management, spatial planning, and disaster management to work closely together (Restemeyer, et al., 2015). The task of flood risk management can not only be a public task and need to be spread between the different disciplines, but it is also required that private stakeholders such as property developers and landlords flood-proof their own buildings. Well informed citizens are also likely to be less affected of a flood (Restemeyer, et al., 2015). Thus, any measure that would raise the public awareness and knowledge of flood protection would be a step in the right direction to increase the transformability of a city. Some examples of such measures are education in schools, public campaigns, and brochures that are handed out to the citizens (Restemeyer, et al., 2015).

In the long term, to be able to raise the transformability of a city the general knowledge and view on water also needs to change. Water needs to be seen as an asset to shape places and identities in a city by building social relations and informal networks around it (Woltjer & Al, 2007). A more strategic tool that can be used to improve the transformability is think tanks, as they could help create new innovative ideas and solutions as well as recognizing changing circumstances to give ample time for the city to adjust to new improved strategies.

2.1.4 Implementations

With resilience requiring a mixture of robusteness, asaptability and transformability as well as a need for both the public- and private stakeholders to take some responsibility to achive success in its implimetation as a wholistic concept. Thus resilience can become complex, difficult, and take a long time to implement in a city. But this is also one of the strengths of the resilience concept, that it combines these concepts and paradoxes into a workning system even though it can be hard to implement.

Since a recilience strategy need more then just a list of messures to impliment, but also needs a change of mindset by the public, and different governmental departements. Achiveing a resilient city and a resilience strategy cannot not be a short term plan. It would need a lot of time and effort to be implimented properly, to be able to change the public thinking of flood protection and help the citizen recognize their role in flood risk manegment. By doing this water can also be removed as a threat to the city, and instead be made into an asset (Restemeyer, et al., 2015).

2.2 Blue-green infrastructure in an urban environment

One traditional way to enhance the resilience of a city is with the use of grey infrastructure – e.g., concrete storage structures, underground drainpipes, and pumping station. These types of structures only have one use, while blue-green structures can make use of natural processes and are self-adapting. They also produce significant co-benefits and can have eco-systems that contribute to an increased resilience of a city. The resilience they contribute is not only in the case of flooding events, but they can also help with droughts and heat stress (Voskamp & Van de Ven, 2015). Thus, it could be beneficial to use them as a part of a resilience strategy no matter the primary risk the city faces.

Depending on the targeted risk, the solution would need to accomplish different results. E.g., A flood would need retention and a slowing down of the runoff while a drought would need previously filed storage for cooling and recharged ground water. Blue-green infrastructure can thus be categorized with the following traits (one single Blue-green measure can have one or more of these traits) (Voskamp & Van de Ven, 2015).

- Storage & harvesting measures: These facilitate water retention in the soil and storage or interception of rainfall.
- Attenuation measures. These measures slow down the runoff during rainfall when its own storage is already full.
- Infiltration measures. These enable the researching of ground water.
- Cooling measures. These measures provide evapotranspiration that enable cooling for the surrounding area.

In the appendices 6.1, Table 7, a table of 31 measures that Voskamp & Van de Ven (2015) categorized according to these traits can be found.

Implementation of new measures in an existing city can be expensive, thus, it can be beneficial to utilizing "windows of opportunity" like when renovations, infill developments or urban renewal projects take place to lower the cost of implementation and to introduce blue-green infrastructure in more areas (Voskamp & Van de Ven, 2015). It is also important to start to think about the implementation in the earlier stages of the planning process, to make sure the plans for the measures will not inflict a need for major change in the projects latter stages, as that would drive up the cost even more (Voskamp & Van de Ven, 2015).

2.2.1 Integrating green-blue infrastructure in urban-planning and -design

When planning to implement different kinds of blue-green infrastructure measures their technical feasibility in the area also need to be assessed, as different kinds of soil, elevation and slope of the terrain, groundwater depth and the climate can affect the performance of the different measures (Voskamp & Van de Ven, 2015). Different soil types, as an example, have different permeability which will affect the infiltration on the site. Classifying soil in an urban environment can unfortunately be quite difficult as they have undergone pollution by humans over an extended period of time (Voskamp & Van de Ven, 2015).

The complexity of the urban site can also vary a lot, depending on the ownership, the ground contamination, land cover characteristics and subsurface infrastructure. With and increased complexity it is harder to implement or retrofit a site with blue-green infrastructure. The main problem with the ownership is that private investor does not see as much of a benefit from the implementation as the municipality does. As the local communities and water boards reap most of the benefits, while the private investor would bear the cost (Voskamp & Van de Ven, 2015). The density of a site will also contribute to the complexity as a lack of space will make implementation harder, but a higher density of people will also put a higher pressure on the available open space and risk more disturbances in the functions of the implemented measures. Subsurface infrastructure, groundwater and soil contamination is also important to consider, as with a lack of space the present subsurface infrastructure will increase the complexity even more during the implementation (Voskamp & Van de Ven, 2015). If there already is pollution present in the area it also has an increased risk of being spread or further affect the groundwater quality (Voskamp & Van de Ven, 2015).

A lack of open green space also has a negative effect on the human health and well-being, this is particularly apparent in developing countries and cities with a high degree of poverty and climate related disruptions (Quyen, et al., 2019). One way to introduce green areas in cities as well as help reducing local flooding is the use of parks. A park can function as recreational areas for both citizens and wildlife while storing water and increase infiltration (Quyen, et al., 2019). This can both mitigate floods and guarantee a water supply for the environment in the vicinity. Implementation of reservoirs and bio swales can also help clean the water before the infiltration process (Quyen, et al., 2019).

But to identify the locations where it is best to implement new blue-green infrastructure and to make it as effective and cost-efficient as possible a thorough knowledge of the spatial properties on multiple scales of the location is needed (Voskamp & Van de Ven, 2015). Having the knowledge of the larger scales also helps in utilizing terrain features in and around the planed sites. As an example, when considering storage and harvesting measures at the lowest scale (buildings and street level). Despite having lower storage capacity, as they are mostly dimensioned for smaller more frequent rains, these can contribute to better stormwater quality (Voskamp & Van de Ven, 2015). The reason for this is that the frequent, lower intensity rainfalls that are combated by these measures, these rains are also the ones that transport most of the pollutants. Then the more intense rain events can be managed on larger scales, e.g., Neighbourhood or city level (Voskamp & Van de Ven, 2015).

2.2.2 Sponge-city

The concept of sponge-city originated from China in 2012 as a government project, this was due to plenty of the cities experiencing regular flooding (Griffiths, et al., 2020). The concept is a about making the city into a sponge by utilizing drainage infrastructure spread throughout the city to absorb as much water as possible. One of the goals with the project was to improve the resilience of the cities and to be able to withstand up to 30 year rainfall events (before they were only able to withstand 1 or 5 year rain events in many of the cities) and take the Chinese cities closer in line with the rest of the large cities in Asia, that in most cases can withstand up to 50 year events (Griffiths, et al., 2020).

To try out the concept the government launched a pilot project with sixteen cities around the country, latter extended to a total of thirty cities. These cities had to adhere to new policies and goals to evaluate the Sponge-City concept. To evaluate the concept seven parameters where measured, these were (Griffiths, et al., 2020):

- Volume control of urban runoff
- Road surface control
- Ecological conservation and eco-system services
- Urban heat island effect and reduction
- Stormwater source control and implementation effectiveness
- Urban water quality
- Groundwater depth and condition

The key policies and guidelines that is relating to this Sponge-City pilot project can be seen summarized by Griffiths, et al. (2020) in the appendices 6.1, Table 8 and 9

One of the pilot cities where the sponge city concept was tried was Ningbo, located on the Chines east coast. Griffiths, et al. (2020) did an in-depth study of this city to illustrate how the guidelines are being implemented locally. When included in the pilot program Ningbo was ranked as of the most vulnerable cities in the world by the OECD (Organisation for Economic Co-operation and Development) (Griffiths, et al., 2020). One of the reasons for its extreme vulnerability is its location, a coastal city surrounded by mountains, it has always been prone to both coastal and pluvial flooding. On top of this, rapid urbanization has decreased the natural sponges (farmland, wetlands, parkland, and lakes) that soaked up much of the runoff in the past. As a result of this the old, and partly obsolete, water drainage systems can no longer manage the runoff from new paved surfaces (Griffiths, et al., 2020). Five areas in the city were chosen by Griffiths, et al., (2020) to illustrate how the guidelines was adapted to fit in a multitude of different environments, areas chosen was located from the city centre to peri-urban areas.

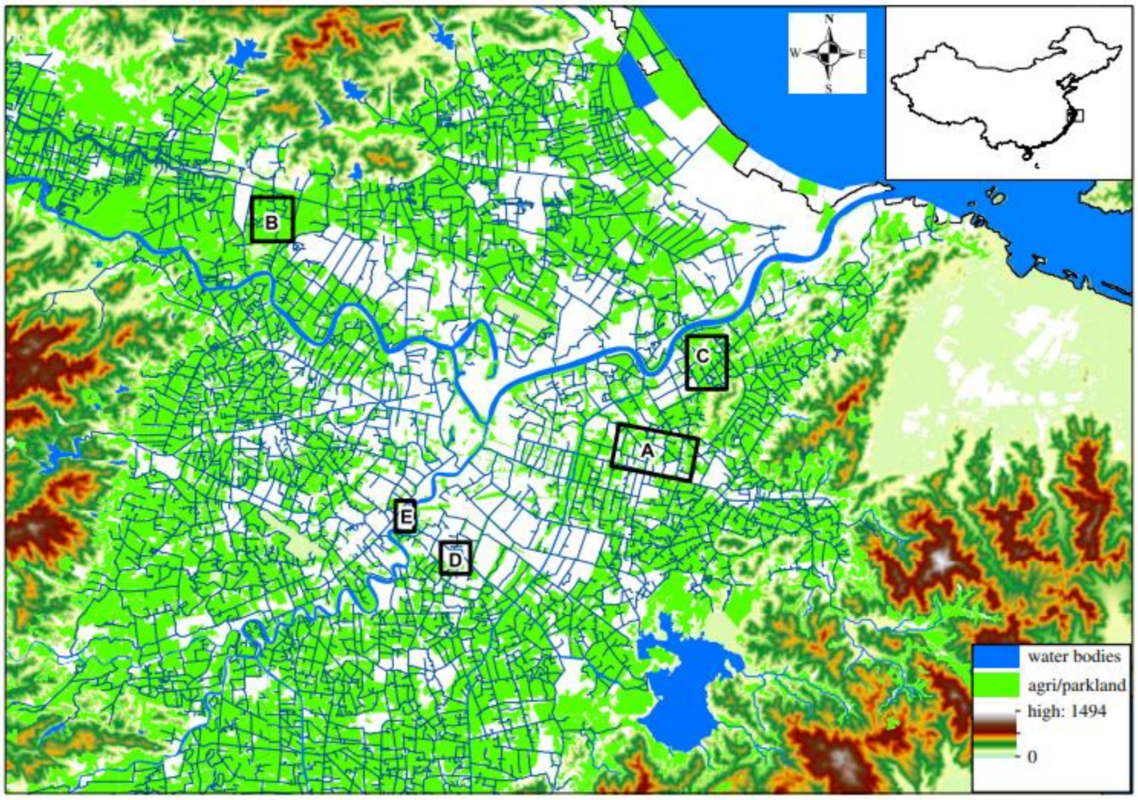


Figure 4: Location of Ningbo and its Sponge city projects discussed by Griffiths, et al., (2020). (A: New east city, B: Ci Cheng, C: Xiaoija, D: Yinzhou, E: Nan Tang Laojie) (Griffiths, et al., 2020).

The five areas chosen by Griffiths, et al., (2020) where: A: New east city, B: Ci Cheng, C: Xiaojia, D: Yinzhou, and E: Nan Tang. In Figure 4 a map of the region with the locations marked can be seen. The following parts are summaries of Griffiths, et al., (2020) explanations of the areas:

(A): The new East-city is the highest profile new development in the city of Ningbo. It consists of 205 acres and includes a range of urban parks, natural landscape of topography, hydrology, and vegetation. The key features in this area are an 'Eco-corridor' that consist of ponds, wet-lands, and other land-based measures to improve the infiltration. Another of the key features is installations in the canal system that help reduce the flow speed to promote settlement and aeration of transported particles and sediment. The last key piece in the sponge-city concept is a 2803m² lagoon that functions as storage capacity for run off during flood events.

(B): The Cicheng new district is unique area since it had started compatible development (a range of rainwater storage and infiltration measures) as early as 2004, long before Ningbo became a pilot city in the Sponge-City project.

(C): In the Xiaojia river district the development is, in general, like the one in Cicheng. The main difference is that in Xiaojia the development uses existing water ways as a foundation to guide all the future development (ecological, social, economic, and touristic). This project integrates urban design and planning with water management to create a green corridor that will expanded around the whole city.

(D): Yinzhou central river demonstrates an alternative approach to an urban waterfront compared to the rest of China. Yinzhou faces problems with its flood control due to minimal land availability. It combats this with innovative projects like one that transformed an urban concrete channel to an urban garden landscape. Another problem was a perceived barrier between land and water, the riverbanks was also hard to alter since the drainage capacity of the channels could not be reduced. Their solution to this was lowering the riverbanks anyway and instead implementing a number of outer measures in the proximity to achieve the same drainage capacity.

(E): Nan Tang Lao Jie, or Nan Tang old street is the last area Griffiths, et al., (2020) discuses. This area is also different from the rest, as it is not really included in the concept of Sponge-City. But they chose to include and highlight it anyway because of its modern use of concepts of sustainable urban development with an integrated, aesthetical, and functional riverside design. This has both increased the flood resilience in the area and created a high commercial value.

Luo, et al., (2021) created a framewotk for assseing the compatability of the Sponge-city concept to a city or other geographical areas. This was done by combing a few different methods (among them, but not limited to, GIS and Soil Conservation Service models) to get a wholistic view of the properties of the area. This study was done as a case study over the Shenzhen metropolitan area in the south-easat parts of China. With this combination of models that covered everithing from georgaphical feturese to social and economical aspects ten feterures was chosesn as the drivers to locate a sustainable location for the construction and investemnt of Sponge-City. The ten feturese where devided in three different categorys, namely: Risk of enviorment, Voulnrability of hazard-bearing body and Rain-flood resilience of sponge city. In Table 3 Luo, et al., (2021) comprised the ten featsures and distributed a (+) or (-) to show the preferable value (eg. Increse (+) in 'elevation' yields lower flood risk and so does a decrease (-) in 'risk of rainstorms').

Target Layer	Rule Layer	Child Rule Layer	Index Attribute
Land stability of sponge city	Risk of environment	Elevation	+
		Slope	−
		Risk of rainstorm	−
	Vulnerability of hazard-bearing body	Spatial characteristic of residential area	+
		Density of service industry	+
		Spatial characteristic of population	+
	Rain–flood resilience of sponge city	Road accessibility	+
		Perfection of infrastructure	+
		Vegetation coverage	+
		Utilization of existing areas	−

Based on these ten fetures Luo, et al., (2020) evaluated the region and maped and analyzed the whole region. From the results of theese analyses Luo, et al., (2020) created classes from I-VI to differentiate the suitability of implementation of the sponge city concept. The geography of the regions encompasing the different classes varry a lot. Class I and II are mainly distributed in diffrnt areas along the rivers in the region, while class III are located in the more rural areas in the North, west and east. The largest area is covered by class IV and is filling the areas inbetween the other classes. The last two classes, V and VI, are located in and around the most urban areas of the regions with class VI being in most of the city centres.

In Table 4 Luo, et al., (2020) sumrised what implemenetations are sugested for the different suitability classes and Figure 5 shows the classes maped in the region of Shenzhen.

Table 4: Suitability construction evaluation and construction measures of sponge city (Luo, et al., 2021).

Suitability Classification	Class No.	Construction Measures
Relatively suitable for construction	IV, V	Should make full use of the natural ecological sponges in the area. The sponge facilities with strong infiltration capacity, such as sunken green space and biological retention, are considered in particular—select facilities to play the role of infiltration and self-purification of water, including infiltration ponds and wells. Through infiltration, emission reduction, and storage utilization, more runoff will be intercepted.
Generally suitable for construction	VI	Strengthen the construction of artificial sponges. Select the type of LID facilities with small infiltration volume and slow penetration rate, and arrange them in combination with urban gray rainwater facilities, sponge city transmission, and regulation facilities. Construct rainwater storage sponge city facility types, such as rainwater tanks and reservoirs. When necessary, plan the land receding to a certain distance from both sides of the river and set a safe distance for rainwater flooding.
Less suitable for construction	I, II	Combined with urban drainage facilities, alleviate the waterlogging in urban river channels. Strengthen the construction of flood control projects and transmission facilities, such as planting grass ditches along the river for out-of-area transmission of rain floods.
Not suitable for construction	III	Strictly protect the ecological sponge, maintain its sedimentation function and hydrological, ecological processes, and perform isolation and ecological buffering on the edge of the construction land.

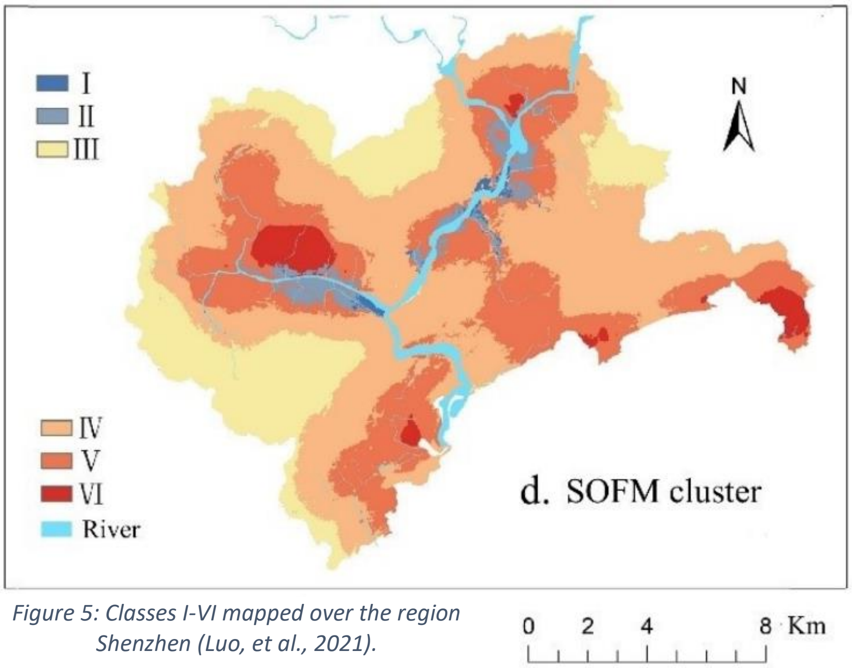


Figure 5: Classes I-VI mapped over the region Shenzhen (Luo, et al., 2021).

The implementation of the Sponge-city concept has had a fair number of problems and difficulties. One of the bigger problems seen with the concept was that implementing it all around the country would be expensive, as the estimated cost of implementation would be approximately US$ 0.14 million/km² (Griffiths, et al., 2020). In order to mitigate the cost of funding, public support and funding from the private sector would be needed. But many of the pilot cities (19 out of 30) has experienced flooding since 2014 resulting in people losing faith in the project, even though the reason of the floodings often were related to old drainage infrastructure not included in the Sponge-city concept (Griffiths, et al., 2020). Due to this the larger flood events will keep being seen as a flaw of the concept until the drainage infrastructure is properly modernized and integrated into the larger flood control systems. One last difficulty with the concept is finding suitable land for implementation, as, slopes, different types of soil, current infrastructure, social demography, et al. have huge impacts on how effective implementing different measure are.

Even though the Sponge-city concept brings some new problems and difficulties with its implementation, it is almost impossible to avoid any problems with new development. So, the best course of action is usually to be aware of the usual problems with the chosen concept and mitigate them as good as possible. Luo, et al., (2020) gave four examples of measure that could help mitigate some of the problems with Sponge-city and, especially for land with low suitability:

1. Urban planners and managers should plan and incorporate disaster prevention and mitigation consciousness into urban planning and construction risk aversion.
2. The municipal department should strengthen the construction of drainage systems following the danger of waterlogging.
3. Focus on the flood-affected areas (Around rivers and other high-risk areas) and prepare for hazard prevention.
4. The metrological department shall timely forecast and warn of heavy rain hazards and establish monitoring, warning, and emergency response to heavy urban rain and waterlogging.

2.3 Urban planning indicators and urban resilience

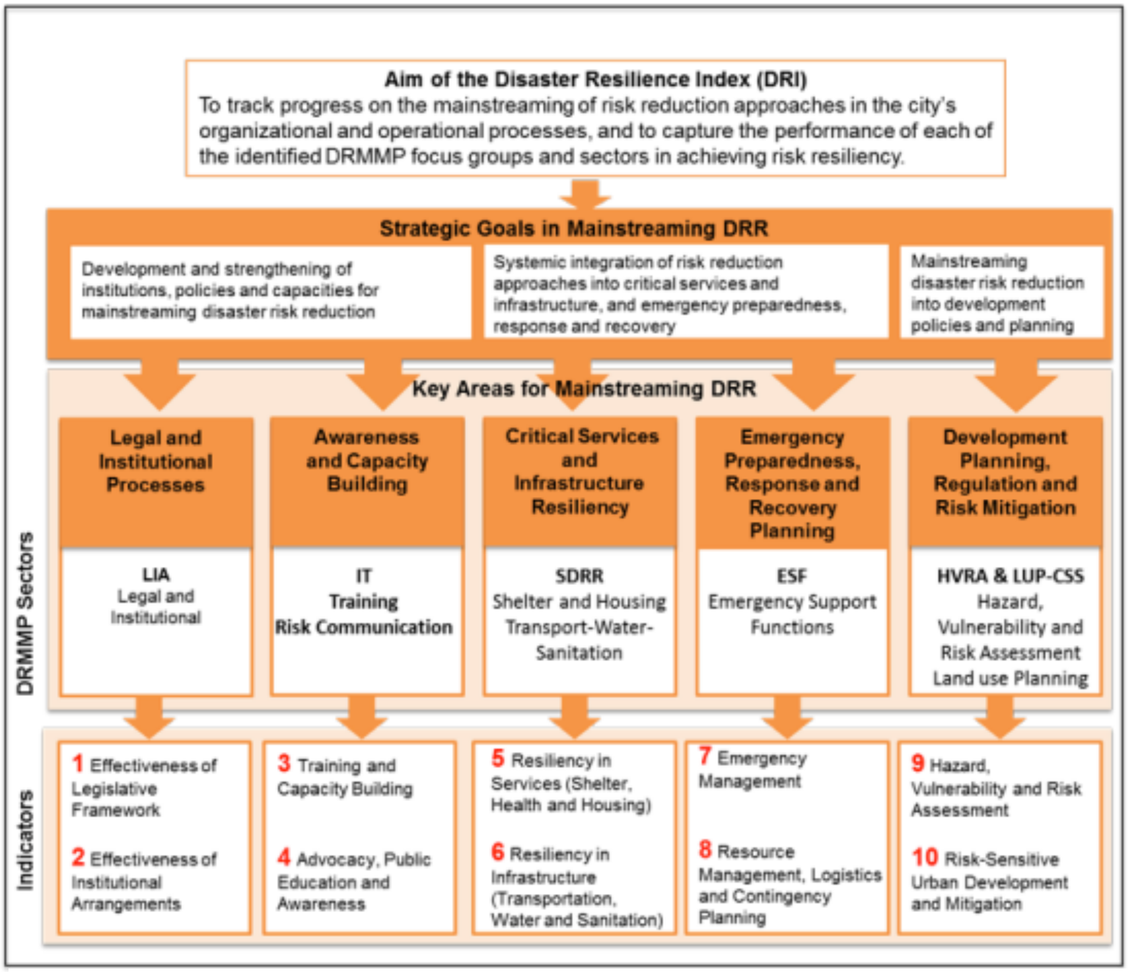
In urban planning indicators is a verry useful tool to help monitor progress and see if changes contribute towards a set goal. An indicator can monitor a single variable, like a cars fuel efficiency (kilometres per litre) or something more complex like the European Green City Index, where thirty different variables, weighted differently are combined into a single value (Weber, 2015). Using indicators in urban planning can bring a lot of benefits, for example, it can help planners define smart, measurable goals; give a structure to monitoring, evaluation and revision of policies to fine tune them and help them reach their goals; it can also help involve stakeholders in the processes as it gives them tangible material to comment on and help them visualize the progress (Weber, 2015).

Most articles and papers that discusses indicators regarding flooding and flood protection are in the view of water management and not urban planning, thus not in the focus of the research in this thesis. Khazai, et al., (2015) also states that pre-determined indicator systems can't capture the local processes and key dimensions within a city that are needed for the planning process. Due to this Khazai, et al., (2015) developed a framework for the developing of a custom indicator system that would fit the specific city for which it was developed.

Because of this, new indicators will be developed for the case study of Luleå. In most cases when developing new indicators expert opinions in the different fields are used to evaluate the indicators (Munier, 2011). A method for the development of the indicators from *"A guide to measuring urban risk resilience"* by Khazai, et al., (2015) was used. To start the development of the indicators the dimensions and goals fist need to be identified. According to Khazai, et al., (2015) there are six key dimensions for urban resilience connected to risk management. They first identified five key dimensions for urban resilience regarding disaster risk management. These five are: (1) Legal and institutional arrangements,

Figure 6: Key dimensions of urban resilience (Khazai, et al., 2015).

(2) Critical service and public infrastructural resiliency, (3) Emergency preparedness, response, and recovery, (4) Planning, regulation, and mainstreaming risk management, and (5) Awareness and advocacy. Another dimension was later added, "Social capacity", this represents social ties, integration, and participation of different areas in the city (Khazai, et al., 2015). The key dimensions and what is essential for them are illustrated in Figure 6.



Based on the five first key dimensions ten baseline indicators was developed to be further specified for the specific cities they are being applied to. These ten indicators, and what key dimensions they belong to can be seen in Figure 7. In the appendices 6.1, Table 10 and 11 the characteristics of the indicators and key dimensions are presented. Based on these characteristics the indicators for the case study will be developed.

This method also included a self-assessment tool with five levels of integration (further explanation in appendicitis 6.1, Table 12):

1. Little to no awareness.
2. Awareness of needs.
3. Engagement, and commitment.
4. Policy engagement and solution development.
5. Full integration.

In Figure 8 a visualization of the self-assessment system is showed, where a higher level of integration is closer to the bullseye. The green colour shows a high level of integration, the yellows shows that the institution is in a transition period and the red means next to no integration and commitment in those areas (Khazai, et al., 2015).

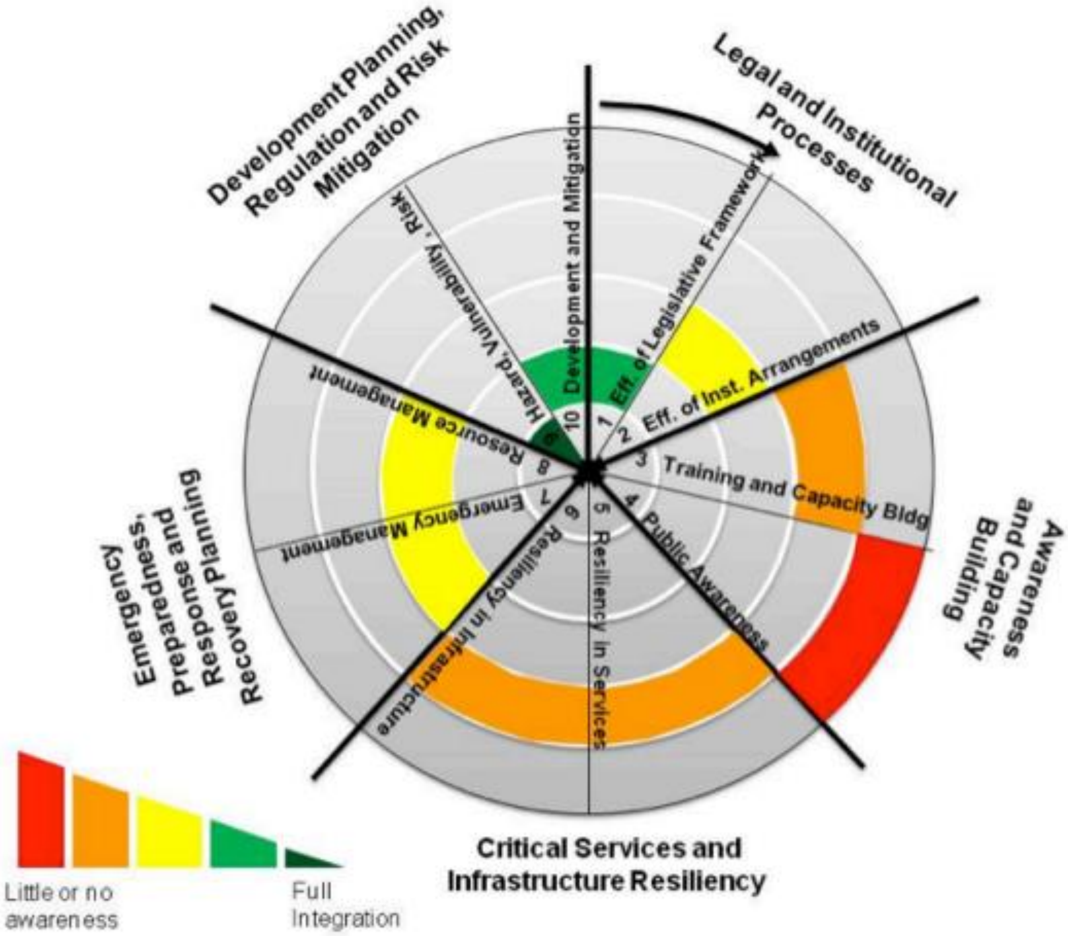


Figure 8: Schematic representation of the mainstreaming scale presented as an example. Goal is full integration (direction towards the "bulls-eye", represented by dark green). The chart should be read clockwise, where each of the ten indicators is represented by a pie (Khazai, et al., 2015). Definition of the levels are found in the appendices, Table 12.

2.3.1 Process of developing indicators

For the process of developing the indicators based on their system, Khazai, et al., (2015) also propose the following five-step guide, where different people and groups are consulted to make sure the indicators are as suitable as possible for the city in question.

2.3.1.1 Step 1: Stakeholder identification

The first step is to identify a "Focus Group" (FG) consisting of the different key stakeholders in the city. The key stakeholders are the ones connected to the key dimensions mentioned earlier in the chapter. From this FG a "Core Group" (CG) is then identified, consisting of the FG leaders from the different sectors. Thus, ensuring that both the FG and CG has adequate knowledge in all affected sectors that are important for the indicators.

2.3.1.2 Step 2: Stakeholder consultation

The CG will focus on building context around the key dimensions to make them more applicable to the city in question. This will be done by structured interviews with the FG and engagement with other local stakeholders to develop specific monitoring and valuation indicators.

2.3.1.3 Step 3: Initial indicator development

Based on the interviews in step 2 an initial set of indicators are developed by the CG. These are also based on the key dimensions and "base" indicators earlier discussed. The indicators should include guiding questions and expected outcomes according to the context of the city.

2.3.1.4 Step 4: Validation of the indicators in workshops

The indicators should now be validated by parts of, or the whole FG (depending on size) in an interactive workshop setting. The goal with this is to improve and refine the indicators presented by the CG. This will also serve a few other purposes; (1) to identify the current level of understanding within the FG, (2) getting to know the political landscape and possible challenges due to it, and finally (3) familiarize possible facilitators with a background understanding to ensure that future management have the knowledge needed.

2.3.1.5 Step 5: Participatory evaluation of the indicators

The last step in the process is a final workshop where the whole FG should be present. They are then voting on the current level of integration of the indicators and discussing them. By first doing the votes, and then the discussions, an opportunity to provide and utilize conditions to identify, and then focus the discussions on the key issues, while not imposing pre-existent ideas and concepts become possible.

2.4 Flood protection in the Swedish planning system

2.4.1 The Swedish planning system

The planning in Sweden according to *Plan- och Bygglagen (PBL)* consists of regional plans, comprehensive plan, area regulations and zonal plans (Boverket, 2022a). When explaining these different parts *Boverket* was used as the source as they are the Swedish institution that handles urban planning, -development, construction, and housing. Specifically, the source for the following three paragraphs was their webpage "*Så planeras Sverige"* (Boverket, 2022a).

On the national scale the actual planning is minimal, their role is instead to create a framework for the planning conducted on lower levels in the government by designating national interests and legislation. The responsibility to monitor the national interests is with the different county administrative boards in the nation. They also have the ability and mandate to intervene in the municipal planning within the county in situations where a national interest is included or affected. The only planning that the government are decision makers for is the sea. This is done be three maritime spatial plans that that the sea and water authority is responsible for and managing.

One step down on the regional level, regional plans are primary tool of planning, these plans are not mandatory, as of the writing of this thesis Skåne and Stockholm has the only two active regional plans. The regional plans are managed by the county administrative boards and gives a basis for the handling of ground, water, buildings, and built-up areas that have importance for the whole region. These plans are however not binding, but rather meant to be guiding for the municipal planning.

The comprehensive plans, area regulations and zoning plans are all managed by the municipalities, it is also only the municipalities that has the mandate to accept a plan or decide when planning should begin in an area. The comprehensive plan is the broadest plane that's managed by the municipality, the plans cover and gives a broad overview of the whole municipality. In the plan broad strategies for the land and water use, how the built environment should be used as well as how to accommodate for the national interests and regional goals are presented. The area regulations are supposed to aid the comprehensive plan and further specify and regulate the same areas, but in a little more detail in the different areas and districts of the municipality. The final and smallest scale plan is the zoning plan, this is the legally binding plan that regulates down to single blocks or plots and what can be done on them. This type of plan can regulate things like where new development within a plot can take place, how tall or how many stories are allowed on the buildings and if piping can be laid through the surrounding plots. The zoning plan is not only regulating where and what can be built but can also regulate how buildings should look to fit in with the style and aesthetic of the area. The zoning plan also regulates what areas of the municipality is public or private areas, as well as how public and water areas should be used and developed. The zoning plan is, as mentioned earlier, the legally binding planning documents and because of this it also the zoning plans that gives the basis and criteria for the building permits that is be needed for new development.

2.4.2 Division of responsibilities in case of flooding

According to the Swedish planning system and laws every individual has the responsibility to protect their own property in case of an emergency such as flooding. The necessary protection can usually be achieved with traditional methods such as floodproofing of building, the economic aspect is usually covered by the different insurances that the individual has acquired or in some cases a national fund (Ek, et al., 2016).

On a larger scale, and especially for public or public-utility areas and buildings the primary responsibility for the emergency preparedness and response is with the municipalities (Boverket, 2022a). The municipalities are tasked with creating plans, strategies, and guidelines for flood mitigation and management. Boverket (2022b) suggests that this planning is done in conjunction with the development of the comprehensive plans to integrate them in the work as soon as possible to aid the implementation of these plans and strategies. In the comprehensive plan the climate-based risks in the municipality should be evaluated and how to handle them to negate or mitigate their effects (Ek, et al., 2016). The municipalities can also use the zoning plans to regulate the implementation of flood protection measures, this can be especially useful in more vulnerable or high-risk areas, where such measures can become a requirement for building permits to be granted (Ek, et al., 2016).

The county administrative boards primary task and responsibilities in the regards of flood safety is to aid the municipalities with reports on different topics relevant in the county (Boverket, 2022c). The flood risk in and around lakes, rivers, and the coastline in the county are examples of what these reports can inquire about. However, if the county administrative boards deem the zoning plans developed by the municipality to be inadequate for the risks in an area the county administrative board have the responsibility and mandate to revoke the zoning plan in that area (Ek, et al., 2016).

2.5 Literature summary

In order to have a strong flood protection in a city several factors need to be considered. One of the biggest factors is what type of strategy, one strategy is resilience, this strategy combines seeming paradoxes into a working flood protection and mitigation strategy. Resilience as a concept or strategy combines and seeks to improve the robustness, adaptability, and transformability of the city. This is done by, among other things promoting inter disciplinary cooperation, public cooperation and knowledge of flooding as well as promoting the use of water in the city as an asset. Blue and green infrastructure should also be implemented into the city as these measures help improve the resilience of a city in many regards, and not just for flood protection. Blue and green infrastructure can also help mitigate the effects of droughts or heatwaves and improve the wellbeing of the citizens. This can be done in many different ways, one example of this is the Sponge-City framework developed in China to increase the resilience of the Chinese cities and increase the flood resistance to similar levels of other large cities in Asia. The concept is based around making the city into a sponge and then safely releasing the water in a controlled manner to avoid unwanted flooding.

After the implementation of a strategy, and the different measures and concepts are done, everything needs to be evaluated and measured to make sure they achieve what they were supposed to. One way to do this is with the use of urban indicators. To make sure these indicators measure the right things in a way that fits the city, they usually need to be developed individually for each city as all cities have different conditions and characteristics. To do this a method and framework developed by Khazai, et al., (2015) was evaluated and used to latter develop a fitting set of indicators for the case study of Luleå.

To properly evaluate the different flood protection measures in Luleå some knowledge of the Swedish planning system was needed. The system has three main layers starting with the national government drafting legislation and national interests that that then the lower levels of government will follow and work towards. The next step is the regional governments that aid the municipalities in their work and in some cases drafts a regional plan. The final part is the municipal government that also carry the largest responsibility. They draft the comprehensive plan to cover the whole area, and the zoning plans that have the final say in what and where projects can be built in the municipality.

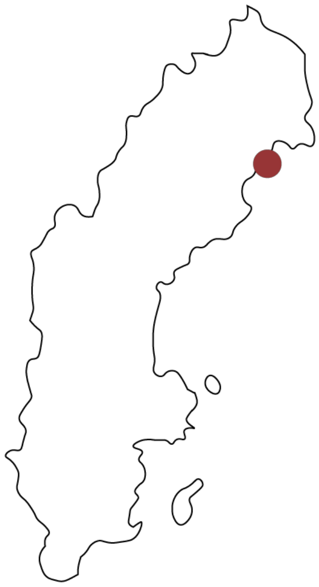
3 Methodology

The methodology of this thesis consists of a policy study of three different cities in Northern-Europe. The policies that will be looked at are the ones that manages and discusses risk management, flooding, and risk mitigation in the cities. The first city chosen was Luleå, the reasoning for this was that the central parts of Luleå is surrounded by water and thus could experience flooding from many directions. The author of the thesis is also studying in the city and thus have some familiarity with the city. The two other cities choses where Gävle, Sweden and Hamburg, Germany. Gävle was chosen due its history with precipitation related disaster, the recent flooding in the autumn of 2021, and a snowstorm in 1998, and both ravaged the city. Hamburg on the other hand was chosen as it is seen as a city with verry good flood protection. This is in large parts due to its history of floodings, and especially the horrific flooding in 1962 were 340 people died (Mauch, 2012).

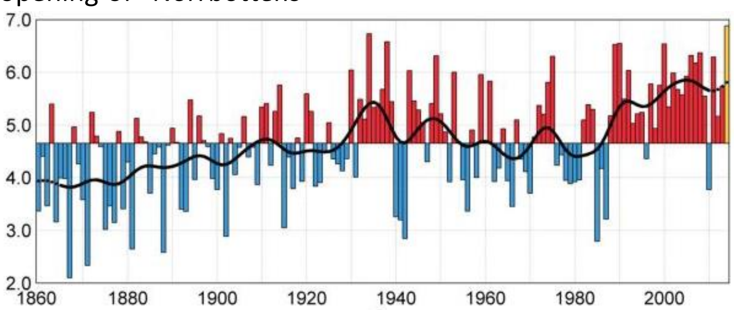
3.1 Luleå

3.1.1 Introduction

Luleå is a city located on the east coast of Northern Sweden, about 100 km south of the polar circle. The municipality has approximately 80 000 inhabitants (SCB, 2021a), with about 50 000 of them living in the urban areas (SCB, 2021b). Figure 9 show Luleå marked on the map of Sweden.



Luleå, in its courent location was founded in 1649 when, in an order from king Gustav II Adolf, a city plan was established. The grid plan, with some minor changes, is still preserved to this day (Ahlberg, 2005). During the early life of the city the growth was verry slow. But the growth speed of the city incresased in the late 1800s when Malmbanan*,* a train track between the large iron mine in Kiruna and Luleå was completed. The next growth spurt of the city came in the 1940s and 50s with the opening of "*Norrbottens Järnverk AB*", NJA. NJA was incorpirated with two other swedish iron-works in the 1970s to creat "*Svenskt Stål Aktie Bolag",* SSAB, with this coincided the last big push in population of the city and it has stayed relativiley stagnent since, slowley growing towards 50 000 inhabitants.



Due to the location of Luleå, it has a sub-arctic climate with temperatures that can vary from below -30°C in the winter to above +30°C in the summer. This means it has a unique climate with temperatures that can differ with more 60°C within a year. However, the local mean temperature in Luleå is +4°C which is a slightly milder climate then other parts of Norther Sweden, this is because of its location on the coast. In Figure 10 the mean yearly mean temperature from 1860 to 2010 can be seen. However, the mean temperature is still lower than the national average (Luleå kommun, 2015). The yearly precipitation is usually between 525mm - 675mm, of which 35-40% is snow, with the largest yearly snow depth at around 70cm along the coast (Luleå kommun, 2015). During the Winter, the runoff from the precipitation is minimal and it is usually stored in the ice and snow cap, remaining until the spring floods where the yearly peak flow will usually occur. This will also lead to the highest flood risk of the year, but extreme events can occur at any time of the year and cause a flood or other disasters (Luleå kommun, 2015).

Historically Luleå and its sourounding areas have enduered regular floodings from both rivers (Luleälven and Råneälven) and due to melting snow. However, this havent led to any major loss of human life, as most of damage comes in the form damages to houses and infrastructure during the larger floods. For example the spring flood in 1995 and the extreme precipitation in the summer of 1993, where in both cases the resault was, among other things, flooding of Luleälven and water damage on buildings close to it (MSB, 2012).

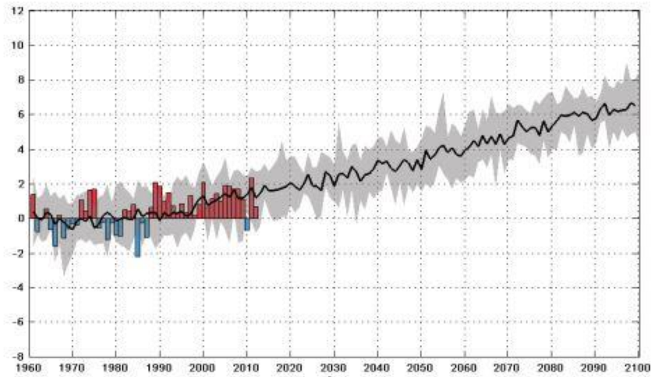
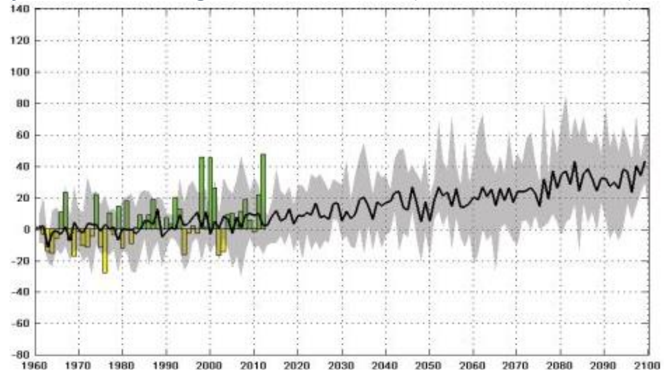


Figure 11: Expected mean temperature rise on the Northern coast of Sweden according to RCP 8.5 scenario (Luleå kommun, 2015).



In case of a flood in Luleå today, the municipality has conducted a study to loacate what areas of the city would have the highest riskt of flooding. The resault of the study was in a decision that the area effected if the water level rise with +2.5 meters is appropriate for the flood protection of the regular buldings and infrastructure (areas are showed in Figure 14 and can be compared with Figure 15 that shows the same map with +0m). As this is seen as the areas that run the highest risk of flooding in most cases. The city center will be mostly safe in this case as showed by the map, and only the coastal parts of the peninsula will see any significant flooding. The largest risk is North and east of the city center where a low density residaental and a industrial area will see a more significant amount of flooding. This industiral area is also the only area where the flooding will penetrate further inland and not only affect the imidiet vicinity of the coast. Due to being almost enteriely suronded by water, Luleå will, in genral, have an easier time to deal with floods relating to extreame precipitation compared to many other citises. This is because the short distance to open water decrese the area of runoff sectors and thus also reducing the peakflows (Luleå kommun, 2019).

The future climate of Luleå, if the RCP 8.5 climate model is used for the predication, will change drastically. The mean temperature will rise to about +7°C (seen in Figure 11), the number of heavy rainfalls will increase (both long and short) and so will the average yearly precipitation (Luleå kommun, 2015). The yearly precipitation is expected to increase with 30% (seen in Figure 12), with a big part of the increase coming during the winter and spring months. The mean sea level however will remain, this is due to the land rise in Northern Sweden negating the effect until at least the year 2100 (Luleå kommun, 2015). In Figure 13 the expected water level rise on the Swedish coast is shown, in Luleå it Is expected to be 0m until 2100 as the rising water is countered by the land rise.

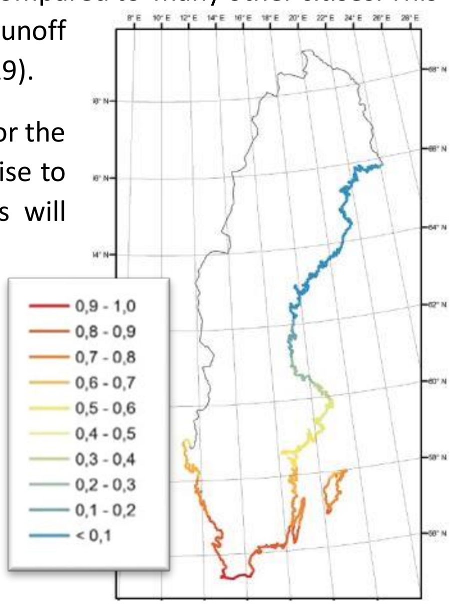


Figure 13: Expected water level rise (m) in Sweden until 2100 (Luleå kommun, 2021b)

Figure 14: Flood map of Luleå at sea level of +2.5m compared to regular levels (MSB, 2019).

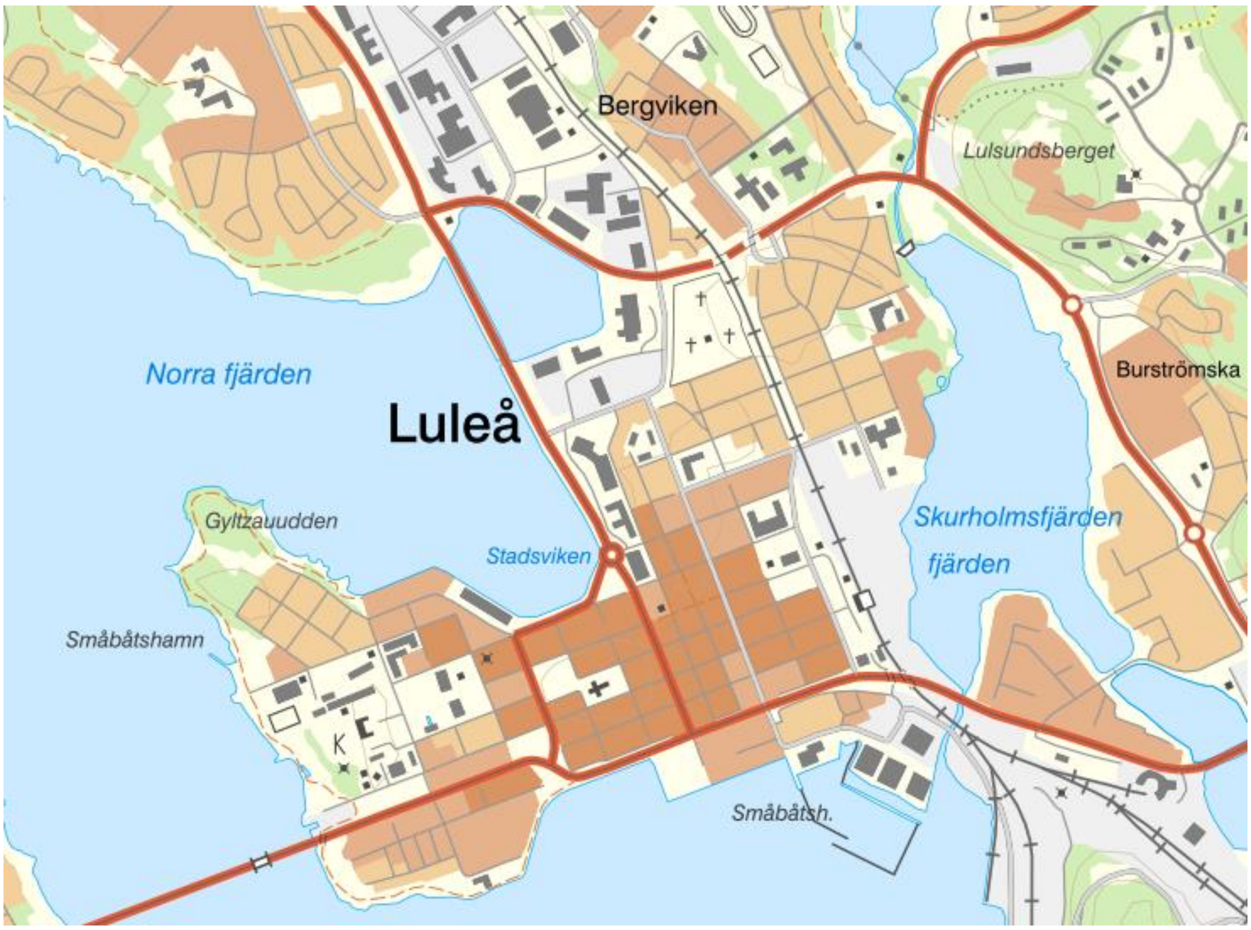


Figure 15: Flood map of Luleå at regular sea level. (MSB, 2019)

3.1.2 Guidelines

The main policy of Luleå regarding flooding is *“Riktlinjer för klimatanpassning, Luleå kommun”* (Luleå kommun, 2015), this document outlines what measures should be taken where, depending on the location and functions of buildings and accordingly protect against flooding.

The first and largest measure is floodproofing. All buildings that would be flooded at a sea level rise of +2.5m should be floodproofed, this corresponds to the areas flooded in Figure 14. However, if the area is located close to Luleälven the floodproofing should extend to buildings that would be flooded at a +3.0m rise instead, an increase of an additional +0.5m floodproofing, this is because of the increased flood risk around the river. Buildings and infrastructure considered to be critical for the city, according to MSB (2021) critical services as in the Swedish planning system are (translated into English):

> Buildings and infrastructure with operations or services that maintain or secure the societal functions that are necessary for the basic needs, values, and security of the society. (MSB, 2021)

Thus buildings such as police and fire station, hospitals, schools, and evacuation routes, should also have an extra level floodproofing, increasing it with an additional +0.5m, resulting in them being flood proofed for +3.0m in the city and +3.5m around Luleälven. In other areas of Luleå municipality, not close to the sea, the floodproofing should be at least +0.5m above the highest measured water level in the nearby body of water. The final guideline regarding flooding from this document is that the stormwater management capacity should in general be increased and designed to slow down the runoff to ease the stress of the other stormwater management systems.

The guidelines also mention other important aspects in urban planning with a changing climate in mind. Two examples of this are that drinking water and sewage pipes should be secured for increased volumes and that the outdoor areas should be designed to offer shading and cool places in case of heat waves (Luleå kommun, 2015). One example proposed to secure the production of drinking water are more and better hygiene filters in the facilities and to secure the sewage network it needs to be continuously upgraded. An example given to improve on the shading and cooling of public places is to integrate a water management strategy, for an example store the stormwater and later use it to cool public areas like squares, parks, and playgrounds with ponds or fountains.

Luleå municipality also released another document, *“Omvärldsrapport November 2021”* (Luleå kommun, 2021c), where they discuss their goals from *“Agenda 2050”* (Luleå kommun, 2021a). On the topics of nature, they outline, among other things, a need to consider the nature more in urban planning to make sure green structures in the city is not replaced with other types of development. In the same topic they also outline the importance of preserving the ecosystems in the nature (both on land and in the water). In he “*VA-plan 2030*” (Luleå kommun, 2018) this is further discussed with measures and plans to secure a sustainable utilization of the ecosystems as well as secure high-quality water (drinking, ground, and surface) when providing their services. The perseveration of the ecosystems is further discussed in “*Grönplan Luleå*” (Luleå kommun, 2020) this document also presents plan on increasing green infrastructure in and around the city. When talking about the climate an increased need for quick responses measures was highlighted and more cooperation between different actors. This was to help mitigate increasing costs relating to, and frequency of extreme weather events due to the changing climate (Luleå kommun, 2021c).

Luleå also suffers the risk of having a different type of flooding, upstream in Luleälven there are dams, in case of these dams bursting a severe flood of big parts of Luleå is expected, a sea level rise of 7-8 meters North of Luleå city centre and 5-6m around central peninsula is expected (Luleå kommun, 2012). The municipality of Luleå together with the municipality of Boden, the county administrative board and Vattenfall (Energy company that operates the dams) has produced a brochure named *"Om dammen brister" (If the dam bursts)* where they present what you as a citizen should do in case the dam burst, as well as planed routes and destinations for evacuation depending on where in Luleå you are residing (evacuation routes and destinations are shown in Figure 16). Even if these plans are specifically made for if the dam bursts, the plans could also be used in case of a severe flood, that the other flood protections of Luleå cannot withstand and are not affecting the destination cities.


Utrymning av Luleå

Bergnäset utrymmer via väg 94 till Arvidsjaur

Bergviken utrymmer via väg 94 till Arjeplog

Porsön, Björkskatan och Bensbyn utrymmer via E4 till Piteå

Centrum, Östermalm, Lulsundet, Gammelstad, Sunderbyn, Rutvik och Persön utrymmer via E4 till Skellefteå

Hertsön, Lerbäcken, Kvarnbäcken, Örnäset, Skurholmen, Malmudden, Svartöstan, Lövskatan, Kronan, Bälinge, Avan samt övriga berörda byar utrymmer via E4 till Umeå/Vännäs

Mjölkudden, Notviken och Karlsvik utrymmer via E4 mot Skellefteå, därefter vägarna 95, 370 och 365 till Lycksele

Har du vänner i andra orter kan du utrymma dit. Sörbyarna och byar omkring Råneå har sannolikt elektricitet och behöver inte utrymma.

Figure 16: Locations for evacuation if the dam bursts depending on where in Luleå a citizen resides (Luleå kommun, 2012)

There is also a nationwide brochure sent out to all households in Sweden, named "*Om krisen eller kriget kommer*" (*If the crisis or the war arrives*) that informs the reader what do in case of a crises or war, among other things it also suggests getting informed on what types of disasters are of the highest risk where you are located and how to act if they would occur. The brochure also contains a checklist of items and types of food that is recommended to have in your house in case of an emergency as seen in Figure 17 (MSB, 2018).


Tips för din hemberedskap

Förutsättningar och behov ser olika ut, exempelvis om du bor på landsbygd eller i tätort, i hus eller lägenhet. Här får du allmänna tips för din hemberedskap. Använd det som passar just dig och dina nära. Gå gärna ihop om vissa saker och låna av varandra.

Mat

Det är viktigt att ha extra mat hemma som ger tillräckligt med energi. Använd hållbar mat som kan tillagas snabbt, kräver liten mängd vatten eller som kan ätas utan tillagning.

- ☐ potatis, kål, morötter, ägg
- ☐ bröd med lång hållbarhet, till exempel tortilla, hårt bröd, kex, skorpor
- ☐ mjukost, messmör och andra pålägg på tub
- ☐ havredryck, sojadryck, tormjölkspulver
- ☐ matolja, hårdost
- ☐ snabbpasta, ris, gryn, potatismospulver
- ☐ färdigkokta linser, bönor, grönsaker, hummus på burk
- ☐ krossade tomater att till exempel koka pasta i
- ☐ konserver med köttfärssås, makrill, sardiner, ravioli, laxbullar, kokt kött, soppor
- ☐ fruktkräm, sylt, marmelad
- ☐ färdig blåbärs- och nyponsoppa, juice eller annan dryck som håller i rumstemperatur
- ☐ kaffe, te, choklad, energibars, honung, mandlar, nötter, nötsmör, frön.

Vatten

Rent dricksvatten är livsnödvändigt. Räkna med minst tre liter per vuxen och dygn. Om du är osäker på kvaliteten behöver du kunna koka vattnet.

Om toaletten inte fungerar kan du ta kraftiga plastpåsar eller plastsäckar och placera i toalettstolen. En god handhygien är viktig för att undvika smittor.

- ☐ flaskor
- ☐ hinkar med lock
- ☐ PET-flaskor att frysa vatten i (fyll inte ända upp, då spricker flaskan)
- ☐ mineralvatten
- ☐ dunkar, gärna med tappkran, att hämta vatten i. Du kan också ha ett par rena dunkar fyllda med vatten i reserv. De ska stå mörkt och svalt.

Lär dig mer om hemberedskap på dinsäkerhet.se

Värme

Om elen försvinner under en kall årstid kommer bostaden snabbt att bli utkyld. Samlas i ett rum, häng filtar för fönstren, täck golvet med mattor och bygg en koja under ett bord för att hålla värmen. Tänk på brandfaran. Släck alla ljus och alternativa värmare innan ni somnar. Vädra regelbundet för att få in syre.

- ☐ ullplagg
- ☐ varma och oömma ytterkläder
- ☐ mössor, vantar, halsdukar
- ☐ filtar
- ☐ liggunderlag
- ☐ sovsäckar
- ☐ stearinljus
- ☐ värmeljus
- ☐ tändstickor eller braständare
- ☐ alternativ värmekälla, till exempel gasolvärmare, fotogendrivna element.

Övrigt

- ☐ spritkök och bränsle
- ☐ ficklampa, pannlampa
- ☐ batterier

Kommunikation

Vid en allvarlig händelse behöver du kunna ta emot viktig information från myndigheterna, framför allt via Sveriges Radio P4. Du behöver också kunna följa mediernas rapportering, ha kontakt med anhöriga och vänner och i akuta fall kunna nå räddningstjänst, sjukvård eller polis.

- ☐ radio som drivs med batteri, solceller eller vev
- ☐ bilradio
- ☐ papperslista med viktiga telefonnummer
- ☐ extrabatteri/power bank till bland annat mobiltelefon
- ☐ laddare till mobiltelefonen att använda i bilen.

- ☐ kontanter i mindre valörer
- ☐ husapotek och extra mediciner
- ☐ våtservetter
- ☐ handsprit
- ☐ blöjor och mensskydd
- ☐ utskrifter på papper av exempelvis försäkringsbrev, bankuppgifter, registreringsbevis
- ☐ drivmedel i tanken.

10

11

3.1.3 Conclusions about the city

The flood protection and policies of Luleå focus on protecting buildings and infrastructure in risk zones and/or of critical importance. In later years they have started to work on more programs that inform and incorporate the public in and about flooding risks and protection. The future climate change could increase the size of possible disasters like floods or heavy rains that in turn can cause a flood. This will most likely lead to a need to increase the scale of the flood protection in place today, but not in the same rate as in the southern part of Sweden and down in Europe since the land rise is negating the rising sea level that can magnify the threat to other cities around southern Sweden, and especially in Europe.

3.2 Gävle

3.2.1 Introduction

Gävle is a city located in the middle of the Swedish east coast, approximately 170 km North of the capital Stockholm. The city of Gävle has about 77 500 inhabitants (SCB, 2021b) and the municipality has about 103 000 people living in it (SCB, 2021a). The location of Gävle on a maps of Sweden can be seen in Figure 18

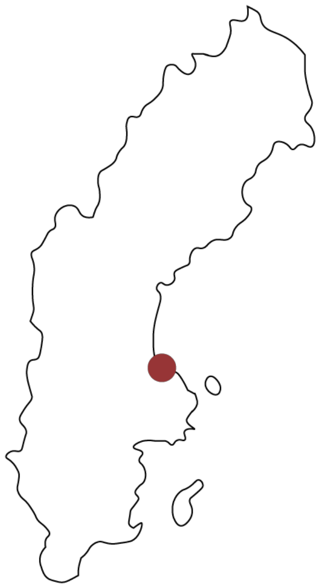
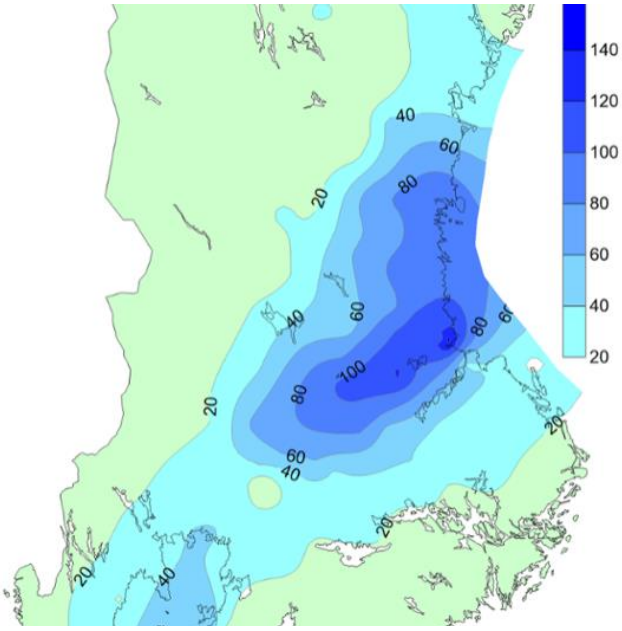


Figure 18: Location of Gävle in the central parts of Sweden

Gävle is an old city, earning its town privilege as early as 1446, the town was a staple port and functioned as both a fishing and shipping port for the region of Bergslagen. Bergslagen is an area inland of Gävle containing multiple mines, among them Falu Koppargruva, one of the largest copper mines in the world at the time. The city was thriving and even competing in trade with the capital until 1636 when the Bothnian trade embargo forced cities in Norrland to not send any ships south of the capital, thus forcing all the trade from the North, including Gävle, to go through the capital. This act was repealed about 40 years later and the trade in Gävle started to thrive once again. In the late 19th-century Gävle started to focus more on implementing and growing new industries rather than rely on the old trade and fishing industries. One of the largest growing industries was the paper industry where Korsnäs sågverks AB was the largest actor, operating a lot of different industries relating to the production of paper such as sawmills. This also coincided with a population boom that then slowly grew during the 20th century until it stagnated in the 21st century just shy of the population Gävle have today.

In Gästrikland, the province where Gävle is located, the lowest monthly mean temperature during the winter is in January and it varies between -7°C in the Northwest and -4°C on the coast in the eastern parts near Gävle. In the summer, the highest monthly mean temperature is about 15°C during the month of July over almost the whole province (SMHI, 2022). The yearly mean precipitation in the province varies from just under 600mm around Storsjön and on the coast to slightly over 700mm in the North-eastern parts (SMHI, 2022).

Due to the location of Gävle it has on multiple occasions experienced extreme weather events, both heavy rains to large snowstorms. One of the reasons for this is when the Bothnian Sea is not covered with an ice cap during the winter and there are North-eastern winds, moist air is transported and converted to snow and rain which can strike Gävle with almost surgical precision (SMHI, 2022). This happened in 1998 when Gävle experienced one of the worst snowfalls Sweden has ever seen, forcing the roads of central Gävle to be closed from private use for almost one whole week while the snow was taken care of. Two pictures of this can be seen in Figure 19 and 20.



Another extreme, and more recent weather event endured by Gävle was the 2021 rainfall where parts of Dalarna and most of Gästrikland endured over 100mm of rain with in 24h (Figure 21), where the highest peaks located around Gävle had 161mm rain within the 24h period (SMHI, 2021). In Figure 22 a picture of the flooding in Gävle is shown. The rain lasted a few days, and the peak was on 18th of August. The residual flows in the surrounding rivers increased drastically. At a power station in Gavleån the flow was measured to be the highest summer-flow (Figure 23) since measurements had started in 1905, though not as high as the highest spring-flows that had been measured. At a measuring station south of Borlänge in Dalarna the water level was measured to be 170cm over the regular measurements, this was also the highest since measurements started. The flows in the same river were measured to be 19 m^3/s, which equated to a return period of about 50 years.

Figure 22: Flooding in part of Gävle (17-8-2021) (SMHI, 2021).

In the future, the climate in the region will change, and how much depends on how well we will adapt in the use of fossil fuels and greenhouse gas emission. SMHI (Sveriges meteorologiska och hydrologiska institut), the Swedish state agency tasked with predicting weather and climate in and around Sweden, published a report in 2015 where they predicted the future state of the climate in the region of Gävleborg according to the RCP scenarios explained earlier in this thesis. All the numbers and data in the following section will be taken from that SMHI report (SMHI, 2015).

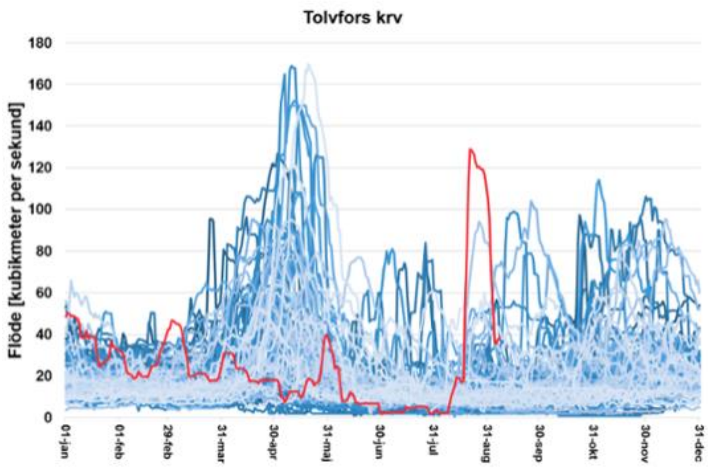


Figure 23: Peak flows in Gävleån, each line is for a different year, the red line is the flow of 2020. (SMHI, 2021)

The yearly mean temperature is expected to rise in line with most other parts of the country, with a rise in the yearly mean temperature of about 3°C following RCP4.5 and 5°C following the RCP8.5. With smaller rises of the temperature in the summer and larger rises in the winter. This will also lead to a prolonged vegetation period of about 1-2 months in the RCP8.5 scenario. The average yearly precipitation will increase with 20-30%, the largest increase would be during the winter. Though, some of the western part of the province will have an increase of precipitation of up to 50%. The daily peak precipitation is also expected to rise by 15-20% depending on the RCP scenario. The yearly flow in the rivers is expected to rise by about 10%, though it will be more spread out as the spring-flows (usually the yearly peak) is expected to come earlier and decrease a little in size, while the flows of the other seasons will increase. Lastly the magnitude of 10- and 100-year flows will increase, this will lead to what is toady perceived as a 10- or 100-year flow will increase in frequency.

3.2.2 Policies

The county administrative board of Gävleborg has done a thorough background work utilizing the SMHI report that is predicting the future climate of the province to determine what climate adaptation is needed (SMHI, 2015). They have published reports and brochures that will help all the municipalities and people living in Gävleborg to get educated and prepare for the future climate in the province.

Though only a few policies from the municipality of Gävle in regards to flooding and stormwater management was found. The first one was *"Dagvattenpolicy för Gävle Kommun" (Stormwater policy for Gävle municipality)*, that states that all new construction and renovation of buildings or infrastructure should be dimensioned to withstand a 100-year flow unless it's economically or for other reasons not feasible (Gävle kommun, 2018). The second notable mentioning was from the comprehensive plan of Gävle (Gävle kommun, 2018). This plan discus stormwater management and flooding in two separate places. First was the stormwater management which was verry lacking and mostly stated that it was important and that it was regulated by the Stormwater policy, that as already stated was lacking. Latter on in the comprehensive plan fluvial flooding is discussed. This part is a little better but still not verry comprehensive. They give overarching directives on what type of development should be located in what areas depending on risk of a 100-year flood. Where important infrastructure should be located in low-risk areas, and almost no new development should be located in high-risk areas (Gävle kommun, 2009). In Figure 24 a rise of +2.5m of the sea level is shown (Figure 25 shows the same are but without flooding for comparison), and this can flood a considerable part of the city, and roughly correlates with the size of a 100-year fluvial flood, though it could be even larger.

Another tool that can be used help with knowing what areas are in risk of flooding Is "*Översvämningsportalen"* by MSB (Myndigheten för samhällsskydd och beredskap), this tool provides information for what areas, over the whole country, that are in risk of flooding in the case of 100- and 200-year flows, or a sea level rise. With the possibility to generate flood maps of a sea level rise from 0.0-5.0m with 0.5m intervals (MSB, 2019). Though this does not seem to have been used to prepare any measures in the areas most affected by the municipality of Gävle.

3.2.3 Conclusions about the city

The background work and information created for the whole province of Gävleborg is thorough and well made, though as mentioned earlier there are very few policies and measures that manage flooding and flood protection, and the existing once should be further developed by the municipality. This is also highlighted in an interview made to the newspaper *Gefle Dagblad* by Christoffer Carstens, unit manager at the county administrative board of Gävleborg, where he says that they (the county administrative board) wished that the municipality would have allocated more resources to flood protection and prevention earlier to prevent new floodings in the future (Forsmark, 2021).

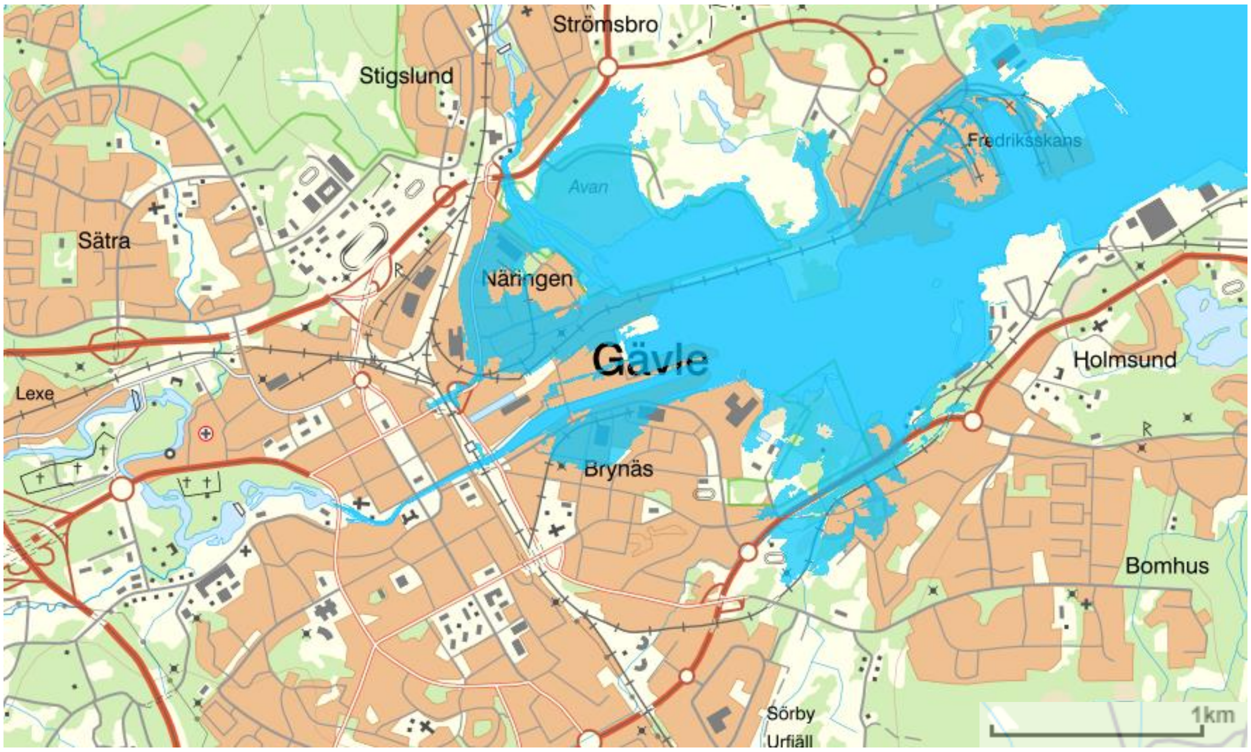


Figure 24: Flood map of Gävle at a sea level rise of +2.5m. (MSB, 2019)

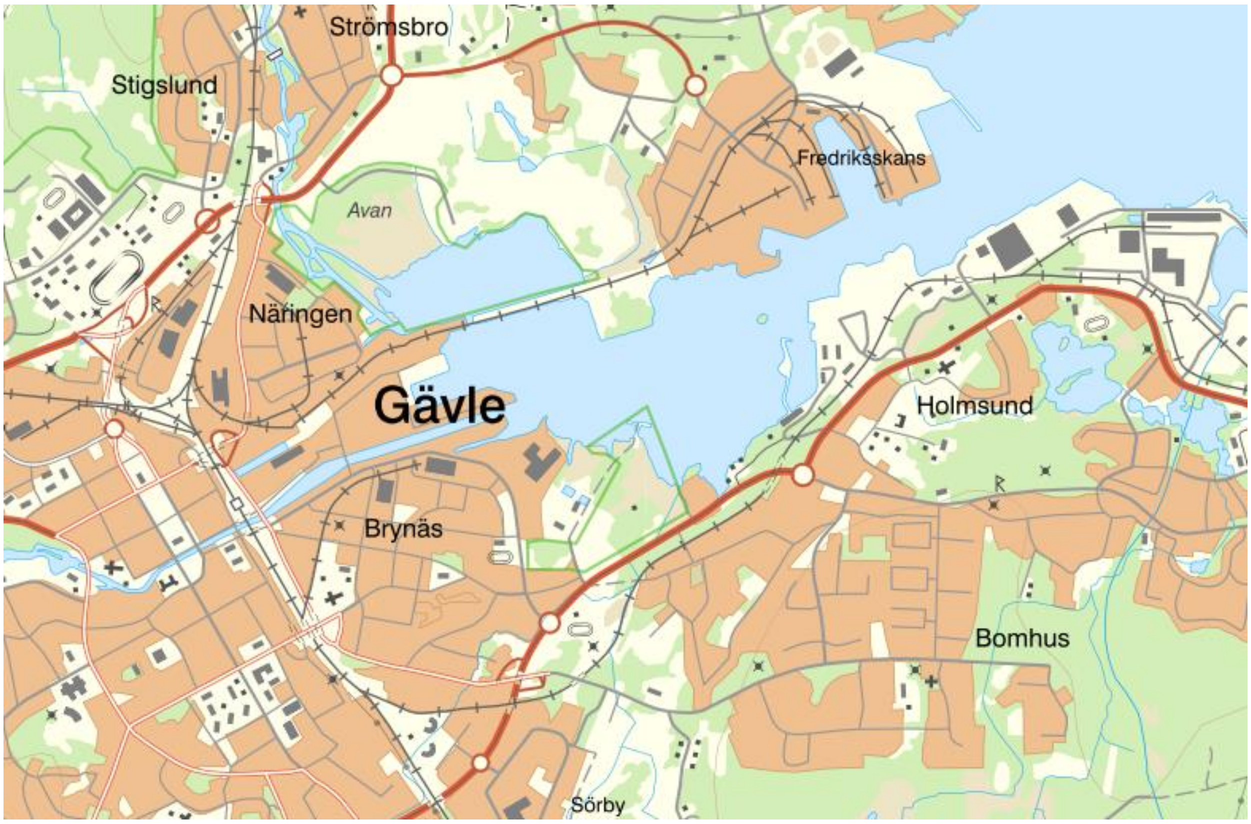


Figure 25: Flood map of Gävle at a regular sea level. (MSB, 2019)

3.3 Hamburg

3.3.1 Introduction

Hamburg is Germanys second largest city and located in the Northern parts of the country. It has approximately 1.85 million inhabitants in the city, and 3 million if suburbs are included. Hamburg is an economic and cultural powerhouse in both Europe and Germany, this is partially due to its location on the river *Elbe* and having one of the largest container ports in all of Europe. The location of Hamburg is shown on a map of Germany in Figure 26.

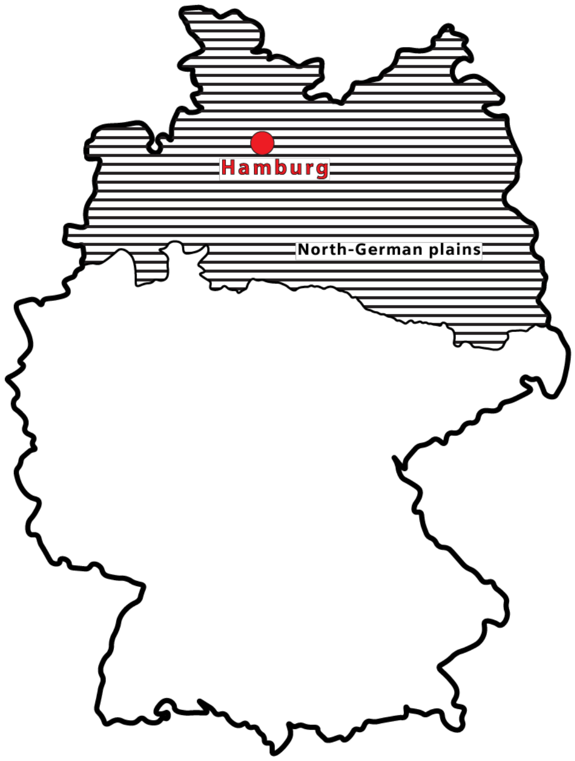


Figure 26: Location of Hamburg in the North of Germany and the North-German plains.

Hamburg, like many cities around Europe is incredibly old, the name comes from the first permanent building, a castle commissioned by Charlamagne 808 AD as a defence against the Slavic incursions from the east. During its history, the city has been ravaged multiple times, starting in the medieval era when the city was raided multiple times by Vikings, Poles, and Danes (WTCF, 2014). During this time, the city also burnt down several times and the black death wiped out about 60% of the inhabitants. In the 12th century Hamburg became a Free Imperial City within the Holy Roman Empire, this helped the city grow its influence in the trade around Elbe, the North- and Baltic Sea, resulting in it becoming one major ports in Northern Europe (WTCF, 2014). Hamburg joined the North German Confederation in the late 19th century and quadrupled in size during the same time period to approximately 800 thousand inhabitants. This large population boom was partially due to the cities growing Atlantic trade that also helped its harbour to grow to the second largest in Europe. During the second world war the city was, once again, destroyed. This time by allied bombing raids that ravaged the city and killed thousands.

The city has also experienced natural disasters in later years, where a notable example is a flooding in 1962 where 315 people drowned in Hamburg, and another 35 in other parts of Northern Germany (Mauch, 2012). That year, in early February a storm front swept over the North German coastline pushing enormous amounts of water, a flood wave of 5.7m over the sea level (Mauch, 2012), into the outlet of the river Elbe. This overwhelmed the flood defences of Hamburg, which was the most effected city by the disaster, and flooded almost one-fifth of the municipal area. A picture of the flood can be seen in Figure 27. The aftermath of this flood disaster led to an increased support for more costal protection and disaster preparedness. This led to construction of further flood defences and increased strength of current installations. Similar strength floods have occurred since, in 1976, 1981 and 2007, but none of them caused damages comparable the ones in 1962 (Mauch, 2012), proving that the new and improved measures worked.

The climate of Germany is, in general, milder than that of Sweden. The mean temperature in the Northern parts of Germany is around 0°C with the decreasing the further east its measured (Britanica, 2021). Due to the location of Hamburg on the coast, winds from the North Sea provide moderately warm summers, mild winters, and a generally high humidity. On the North German Plains, where Hamburg is located, the yearly precipitation fluctuates between 500 to 750 mm and increasing even more when moving south in the country (Britanica, 2021).

In the future the mean temperatures of all of Germany is expected to rise with about 1.6 to 3.8°C, where Hamburg is located on the Northern coast, is expected to be closer to the 1.6°C mark. The average cold spell on the other hand is expected to increase by 5°C in most of western Europe which will have a higher impact on the climate in general (ClimateChangePost, 2021). The yearly precipitation in the country will see a slight increase (less than 10%), though the precipitation during the different seasons will change more. During the summer, the precipitation will decrease but events of precipitation extremes (heavy rainfalls and droughts) will increase (ClimateChangePost, 2021). During the winter, the precipitation is increasing, resulting in the total yearly precipitation slightly higher on average in the future.

3.3.2 Policy and protection

The flood protection policies of Hamburg-Mitte, the area of central Hamburg located around the river Elbe and including the port, Hafen-City and all the islands in the river, is regulated by the Hamburg Port Authority (HPA). The HPA explains in detail on their website what to do in various kinds of scenarios depending on the scale of the flooding (Hamburg Port Authority, 2022). They provide maps for what areas would be flooded depending on the scale of the flood (Figure 28), as well as evacuation routes for the different scenarios (Figure 29). In case of an evacuation a warning siren will sound, and

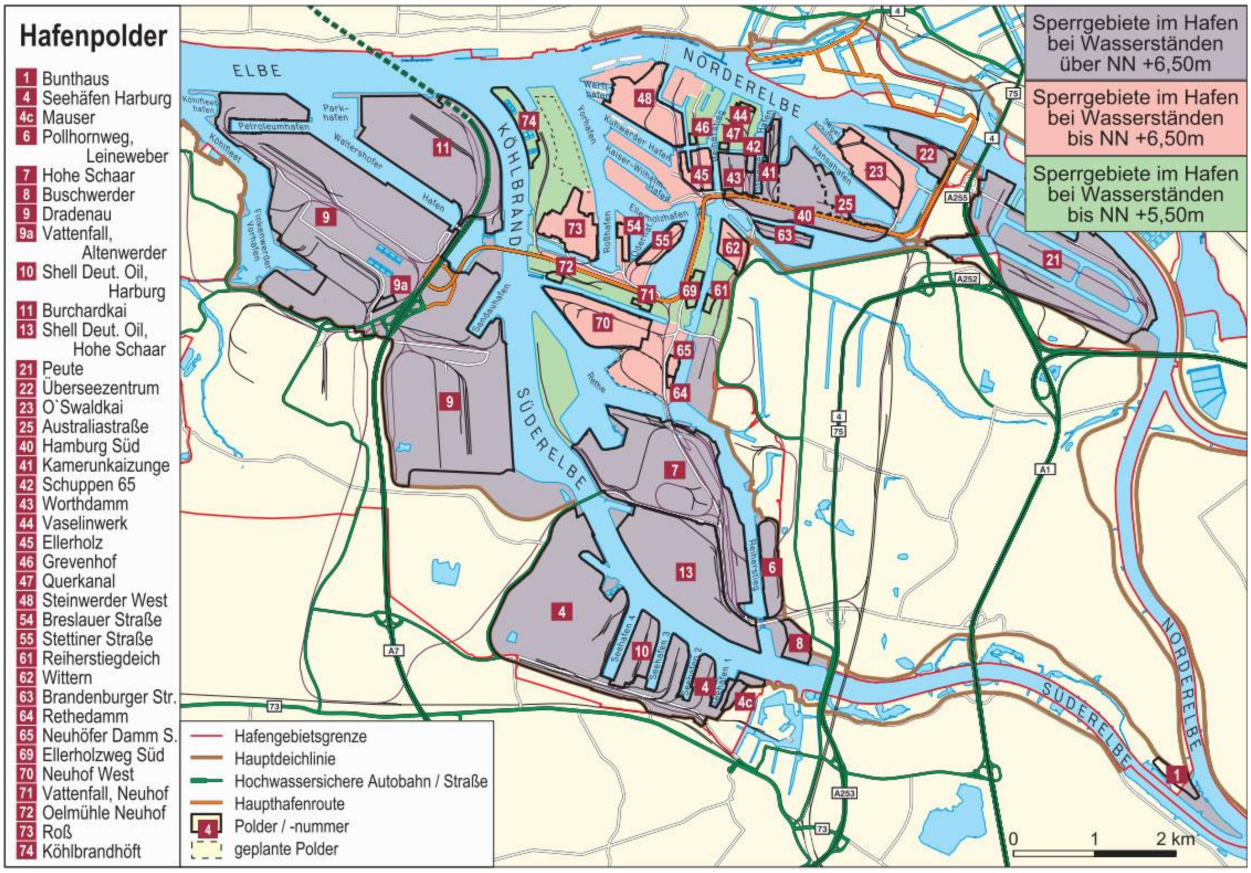


Figure 28: Map showing what polders are flooded at various levels of flooding; Green: Less den +5.50m increase in water levels; Red: Less then +6.50m increase in water level; Grey: Over +6.50m increase in water level. (Hamburg Port Authority, 2022)

information will be transmitted on the radio, residents and employees that work in the area will then use their own vehicles to evacuate during normal hours, but in busy hours compulsory traffic will be used with some extra roads closed off as recuse and defence vehicles are using the same roads.

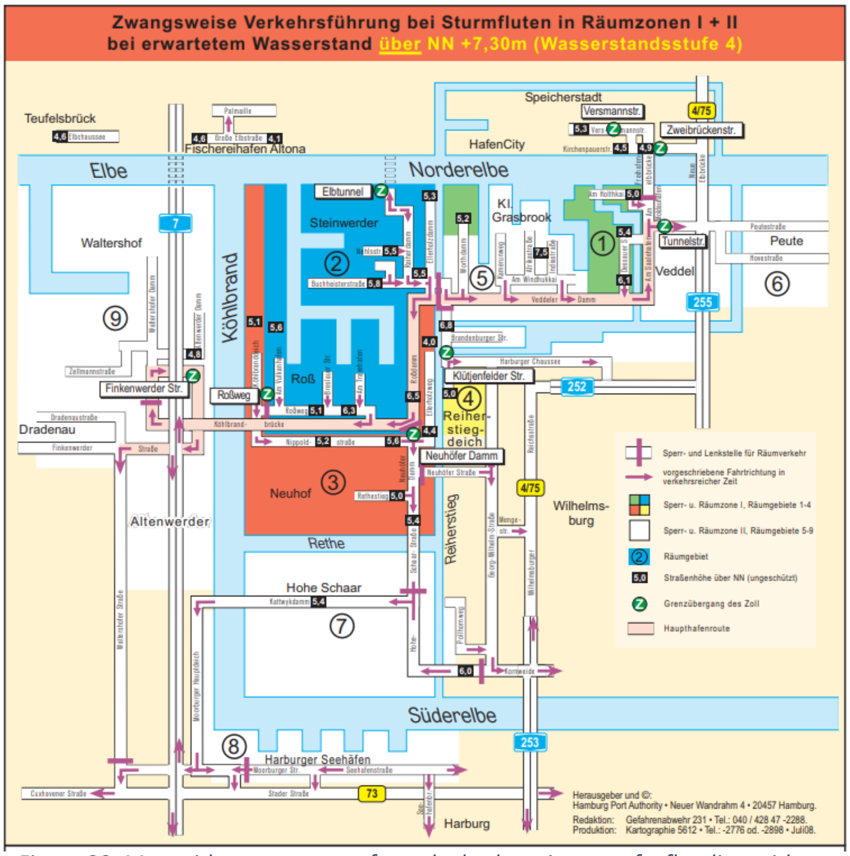


Figure 29: Map with escape routes from the harbour in case of a flooding with an increased in water level of over +7.30m. (Hamburg Port Authority, 2022)

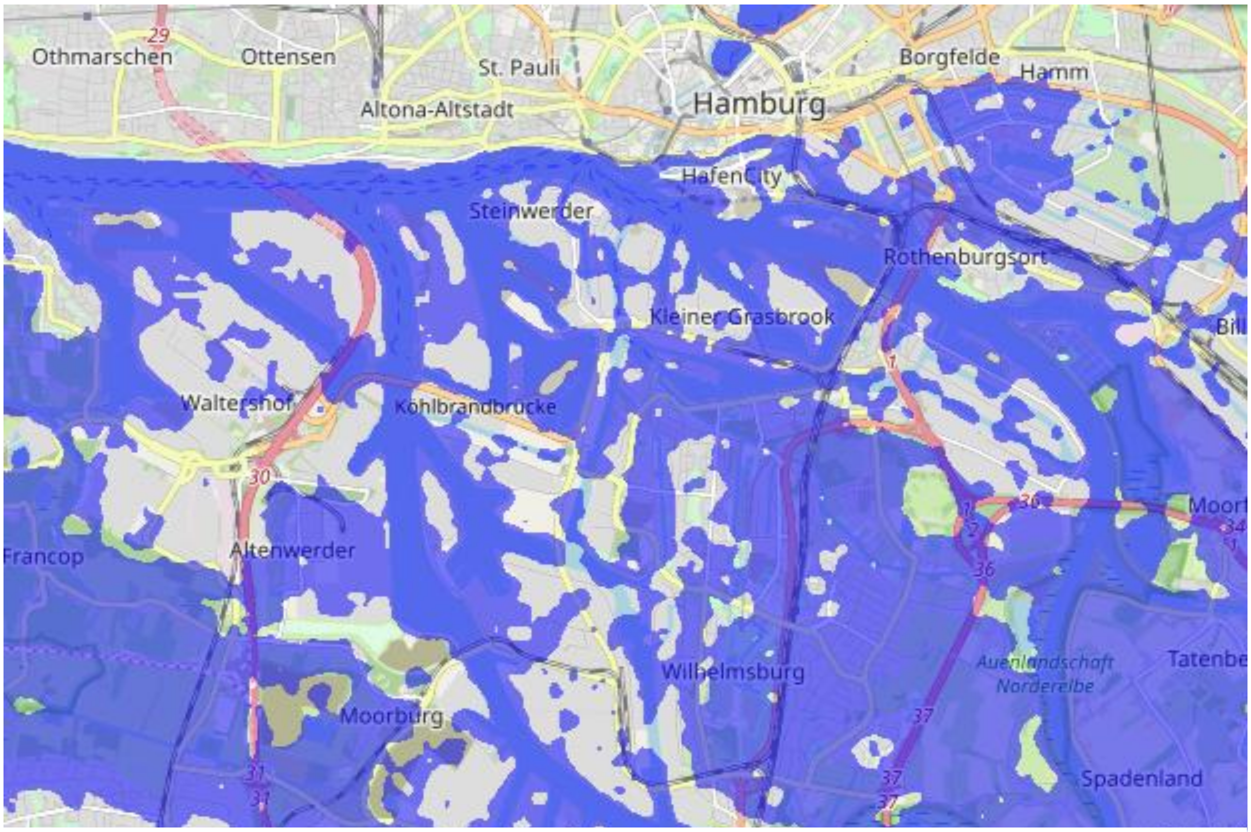
The actual flood protection for the most parts of Hamburg is dike lines. These are regularly maintained and updated to increase the height of the dike walls. Leaflets are handed out to residents on a yearly basis regarding flood safety and evacuation protocols. The brochure includes important telephone numbers, advice in case of a storm surge, as well as an evacuation map indicating routes and safe areas in the city (Restemeyer, et al., 2015). As seen in Figure 30 the main parts of the city would not get flooded since they are protected by the dikes and most of the flooding occur around the river islands that are a part of the port areas (this can be compared with Figure 31, the same map with a sea level change of 0m).

Hamburg has a well developed drainage system that covers all the central parts as shown in Figure 32. The systems that cover the inner city are bit outdated (from the 1980s) but still shows exempler resuslts in comparions to other part of germany. However theeses systems are still being improved and upggraded through different plans and project in order to ensure a continuation of the good results (Bertram, et al., 2015).

A couple years back there was a discussion of integrating new flood protection measures in Hamburg. These new measures were leaning more towards resilience and "*living with the water*". An example of *"living with the water"* can be seen in Figure 33 where the water was disposed of overnight. The concepts were a "dike park" and a "compartment system". The compartment system was constructed by dike rings instead of the one dike line that is the norm. The plan was that the more vulnerable an area would be, the less likely it would be to flood, this would also create a smoother transition between water and land.

But in the end the idea was scraped, a researcher involved in the project explained:

> Back then, the idea was considered to be inadequate … Many people did not understand that the goal was to lower the flood risk and offer chances for urban planning at the same time … that they would still be protected – but according to the concept of resilience, not resistance. Most people still associate flood protection with huge walls. However, smooth transitions between water and city are better since they also improve the risk awareness among the population. (Restemeyer, et al., 2015)



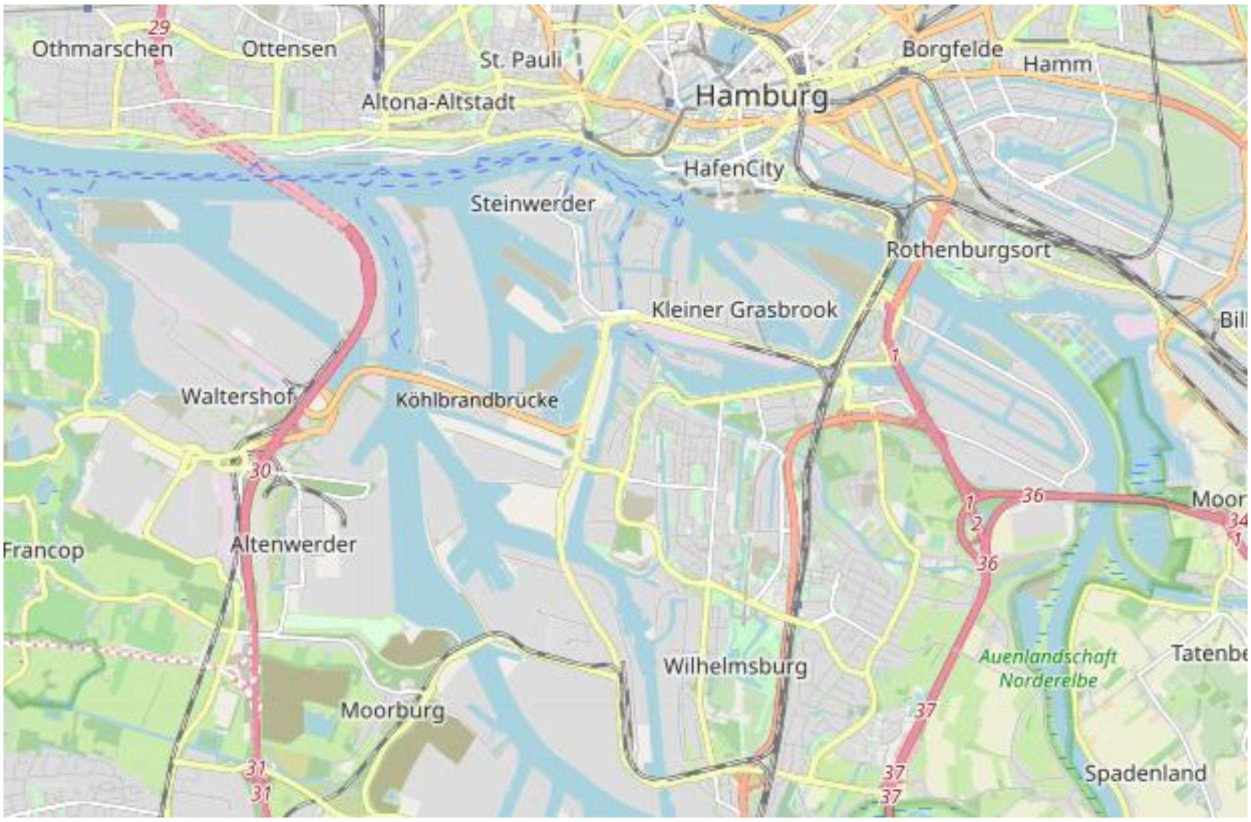
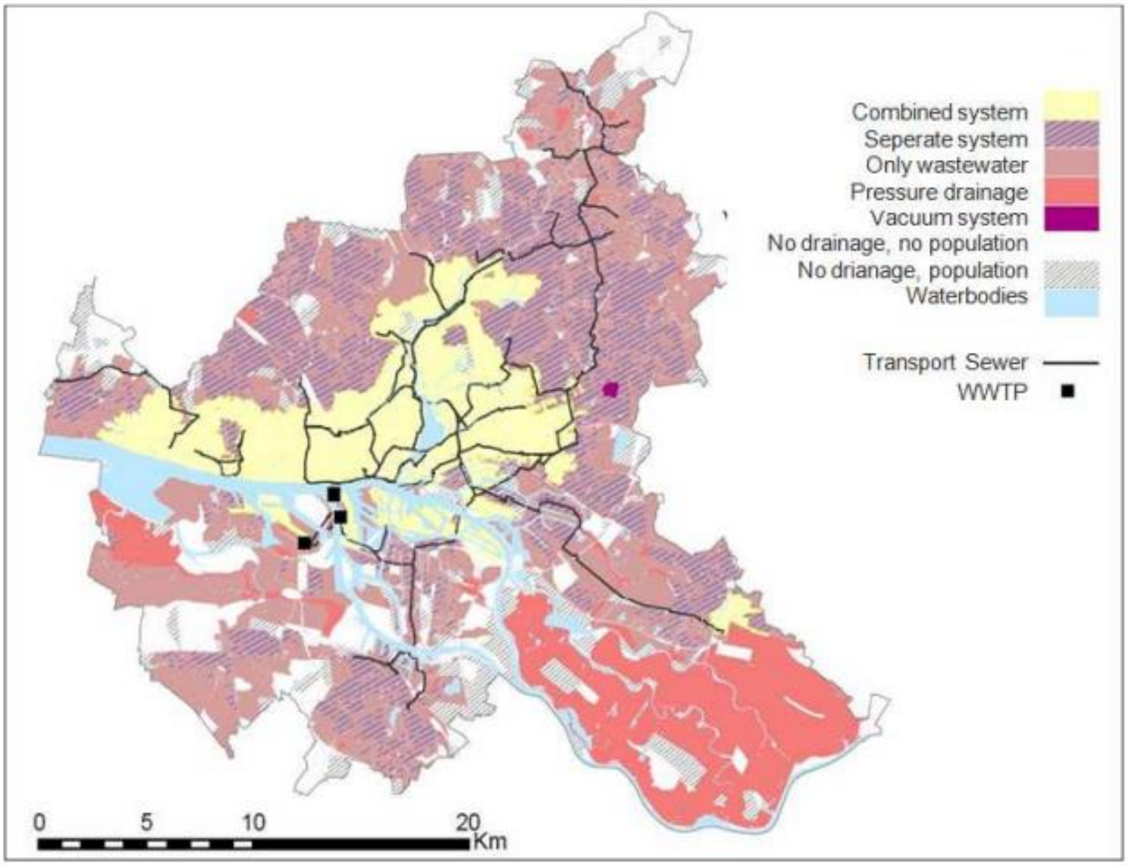


Figure 31: Flood map of Hamburg at a regular sea level. (FloodMap.net, 2020)



The dike park would use the existing dike lines, but integrate them with public space, the thinking was that the investments into dike walls then would be multi purposed and create more open space for the public within the city. This project has been partly tested when a piece of a dike line was equipped with a staircase during renovation to make the waterfront more accessible. Though this project was not seen as that successful as it increased cost and additional work for maintenance, safety, and future upgrades to the dike for what was perceived as little benefit (Restemeyer, et al., 2015).

A notable exception to the use of dikes in Hamburg is the HafenCity on the North bank of the river Elbe. The reason for this is that during the reunion of Germany in 1989 the importance of Hamburg and its location increased, and the development project of HafenCity became seen as important to strengthen Hamburg as a harbour city. The location of HafenCity is outside of the main dike lines of Hamburg which prompted a need for legal change, both in the zoning of the area and the laws that prevented citizens from living outside the dike lines. But this also meant that new flood protection

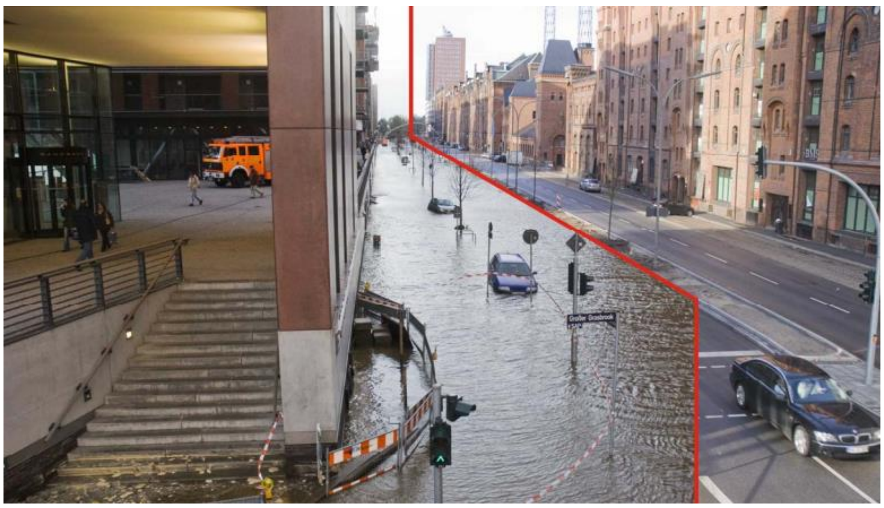


Figure 33: Example of living with the water. Left: storm surge 11-9-2007 in the afternoon. Right: Same area in the morning after, 12-9-2007 (Kluge, 2012).

was needed, two options were presented, one where the dike lines would be extended to cover HafenCity as well. This meant that almost 5km of dike lines would be needed to be constructed before the development started which would have delayed the project (Restemeyer, et al., 2015). Or a "dwelling mound solution", this solution meant that bridges and streets would be elevated to a flood proof level (7.5m above sea level) and building would have a dwelling mound in the form of a basement. In case of a storm surge all windows and doors to the dwellings would be covered by flood gates that are temporarily installed. This strategy also made it possible to start the development step-by-step as streets and bridges used for evacuation were finishing construction. This way of implementing flood protection was seen as very innovative, as they transformed a concept previously used only in harbour areas into a residential one. In the harbour areas it is a widespread practice that the owners are the ones that finance the flood protection and a are responsible for or the designation of someone who is installing the flood gates, and this is true in HafenCity as well. But to make private stakeholders pay for flood protection is not an easy task, as its often seen as the responsibility of the city or state. But in the case of HafenCity the private stakeholders thought it was worth it due to the location on the riverbank (Restemeyer, et al., 2015). However, private stakeholder does not always need to take the whole bill of the protection measures as the HPA also makes it possible to request extra funds for improving private flood protection facilities all around Hamburg (Hamburg Port Authority, 2022).

3.3.3 Conclusions about the city

The flood policies of Hamburg seem through, robust, and well-funded. This results in lower risk for larger damages and a lower effect in case of a disasters. This is also shown in the fact that disasters of comparable size as the catastrophic one in 1962 has happened since, but with minimal to no damage to the citizens, buildings, and infrastructure of Hamburg. The changing climate will force the city to keep improving its defences, as it has already done over the past decades. Though, the city might need to increase the rate and/or scale of the improvements compared to what has been done prior. This will increase the cost as well, but this does not seem to be a problem as the politicians and citizens of the city seem willing to spend and focus on flood protection due to past incidents, like the horrific flood in 1962.

3.4 Policy summary

The policies and strategies in different cities vary, both in scale and strategy. All cities will also need to increase the scale of their flood protection and prevention measures due to the global climate change, the scale of the increase will vary though, because in certain areas land rise will mitigate some, but not all, of the increased risks that come with climate change. Having a history of disasters does not guarantee that the city will have adequate protection for the future, even though it makes it more likely, especially if the disaster led to loos of life like it did in Hamburg 1962. The cities in Sweden focus mostly on floodproofing, as this is the requirements that the government has signed into laws, while Hamburg instead mostly rely on upgrading and extending their dike lines, and only seem to consider the use of other methods on areas not protected by these dike lines.

4 Analysis and conclusions

4.1 Analysis and comparison of policies

4.1.1 Luleå

From a resilience perspective the flood protection policy of Luleå seems to be mostly focused on mix of robustness and adaptability, as seems to be the norm in Sweden. But they seem to have started incorporating other parts of resilience strategy as well, like increasing quick response measures and interdisciplinary cooperation (adaptability and transformability). Most of the vital infrastructure and services within the city centre are also located outside of the most dangerous areas. This however was most likely not done with resilience as the main goal, but non the less it is within the resilience strategy framework. *"Omvärldsrapport November 2021"* and *"Agenda 2050"* exemplifies this common mindset in the plan to make sure to preserve and expand green and permeable areas to help ease water-lodging. In planning the city, Luleå municipality seem to have had a focus on a robustness mindset in the past (water seen as a threat and a strong focus on public responsibility in flood protection), but in newer policies, like the *"Omvärldsrapport, November 2021",* a more wholistic resilience mindset seem present, with actions that trend towards using water as an asset in the city. It is also in this policy where they propose most of the other adaptability and transformability measures Luleå have (quick response measures and more interdisciplinary cooperation).

In order to evaluate if Luleå would fit in to a sponge-city framework the seven parameters that Griffiths, et al. (2020) used to evaluate the concept will be compared with the different flood protection measures of the city. Most of the parameters from Griffiths, et al. (2020) (*Volume control of urban runoff, Road surface control, Urban heat island effect and reduction, Stormwater source control and implementation effectiveness* and *Groundwater depth and condition*) are regulated and monitored in the *"Riktlinjer för klimatanpassning, Luleå kommun"*. Examples of some of these measures are the floodproofing of buildings and infrastructure (*Volume control of urban runoff* and *Road surface control*). *Urban water quality* is discussed in the "*Omvärldsrapport, November 2021"* and then further evaluated in *"VA-plan 2030"*. The last parameter, *Ecological conservation and eco-system services,* is first outlined in the "*Omvärldsrapport, November 2021"* and then further evaluated in "*VA-plan 2030*" and even further in *"Grönplan Luleå",* this last document also shows plans to further increase green areas in and around the city that would lead to an increased storage and infiltration capacity, one of the main goals of the Sponge-city concept. These last two parameters are both well developed in their respective guidelines and can both be considered to comply with the framework. Thus, Luleå should be considered to fit in to a sponge-city framework.

4.1.2 Gävle

The policies of Gävle are verry weak, but the whole province has had thorough background work done and analysis made by the county administrative board that covers the future climate and the major flood risks. This however is not utilized by the municipality, and the only policies found that managed any kind of protection or similar in regard to flooding was the stormwater management policy that suggests that, if possible, new and renovations of buildings and infrastructure should be flood proofed for 100-year flood, an adaptability measure, and the comprehensive plan that also added that important infrastructure should be located in low-risk areas for 100-year fluvial floods, also an adaptability measure. They also seem to have a mindset of water as a threat (robustness) as many cities do and are not trying to use the water as an asset. As a result of the flooding in the autumn of 2021 the county administrative board also seem to put pressure on the municipality to improve the flood protection of the city, what kind of strategy they want implemented is however uncertain. When comparing it to the parameters from Griffiths, et al. (2020) Gävle once again seem week with only two documents that applies to the sponge-city concept and framework.

4.1.3 Hamburg

Hamburg seems to have two distinct and different strategies for their defence of floodings. The first one is a very robustness heavy, which protects the main parts of the city located North of the river Elbe where the main population centres are located. This defence is focused on the use of dike lines that are improved periodically to stay ahead of the current risks the city face. The other strategy mostly covers the port area, HafenCity and the river islands, the parts of the city that are located outside of the dike likes. Here they have adopted a more wholistic resilience strategy where they have implemented all parts of the framework. These areas have technical measures like dams and barriers (robustness) but are also floodproofing for the more extreme events (adaptability). They see the water as an asset and plan these parts of the city to let the water in instead of forcing it to stay out, they are *"living with the water"* (transformability). These areas also have plenty of different soft measure to help protect themself, some examples are evacuation schemes (adaptability), flooding broachers (transformability) and a shared responsibility for the flood protection (adaptability).

The approach of Hamburg seems to differ in both goals and execution to the sponge-city concept. As the main goal of the flood protection in Hamburg is to mitigate and protect against storm surges from the river Elbe, and thus warranting a heavy focus on robustness measures like the dike lines. Inside the dike lines however a well encompassing network of rainwater disposal measures exists. These robustness measures, while still apart of the framework, only makes up a small part. However, when Hamburg-Mitte is examined, measures covering the other parts of the sponge-city framework can be found such as the dwelling-mounds and accompanying measure in HafenCity. This results that when Hamburg as a whole is compared to the sponge city framework put forward by Griffiths, et al. (2020) fulfils most of the parameters and thus has good compatibility with the framework.

Overall, Hamburg has two verry different, but stable strategies that work well for the areas they are designed to protect. This requires a strong political and public will to focus on the flood protection to the extent that Hamburg does. One big contributing factor to the level of commitment that Hamburg have to their flood protection program is the horrendous flood of 1962, where over 300 people lost their lives. After that event, the municipality and public have worked hard to prevent anything similar ever happening again, and thus implementing these, well thought out, strategies they have in place. Since the flooding in 1962, floods that where of a bigger scale have occurred on several occasions but none of them have even come close to the same disastrous outcome due to the flood protection the city have implemented.

4.1.4 Comparison

The cities examined all had slightly different approaches to their policies, while most still having some sort of robustness and adaptability in their mindset or strategy (dike lines and huge political capital for Hamburg, and water is at least partially seen as a threat in Gävle and Luleå and a focus on public flood protection, for robustness both the Swedish cities have flood protection in building and Hamburg have, among other things, some flood proofing and evacuation schemes). But in contrast to Hamburg, both the Swedish cities of Luleå and Gävle have a bigger focus on floodproofing, an adaptability measure instead of the robustness (dike lines) that most of Hamburg relies on for their main defence. Both Hamburg and Luleå also have some sort of implementation or mindset linked to the other parts of the resilience framework of varying size. In the case of Hamburg their adaptability and transformability come from their attitude of *"living with the water"* and shared responsibility of flood protection, this is especially true in the port areas and HafenCity where the reliance of robustness is minimal, and there is a huge focus of a wholistic resilience strategy, compared to the rest of the city. Luleå has a robustness thinking in their way of managing the responsibility of flood protection, by splitting all, or almost all, of the responsibility on the different municipal agencies. Their transformability is implemented more recently, when they started to focus more on interdisciplinary cooperation and utilize the water as an asset in the planning of the city.

As mentioned earlier, both Swedish cities in this study relies on flood proofing their buildings and infrastructure. Though, Luleå seem to have done a more thorough study do conduct what areas are in the risk zone (set at a sea level of +2.5m over regular levels), Gävle on the on the other hand, have only a policy that buildings and infrastructure should be protected form 100-year flows, but does not seem to have any clear maps of how much flood proofing this would require in different areas. Moreover, if a flood map with the same water levels as the on for Luleå (Figure 14) is applied on Gävle, like in Figure 24, a much larger area is flooded. Using strategies like the dike lines in Hamburg could be a good option for them.

When the cities are compared to the sponge-city framework Luleå and Hamburg performed well and seemed to fulfil the requirements, while Gävle was lacking here as well. Luleå seemed to be the best fitting of the cities, this however could be because when looking at inner parts Hamburg the focus was at the storm surge protection around Elbe as this was the largest threat and biggest focus of the city and this part of the flood protection strategy only fulfilled a small part of the framework but in conjunction with the strategies in Hamburg-Mitte an acceptable level of the framework was still achieved.

4.2 Urban flood risk mitigation Indicators for Luleå

The development of urban indicators is a time-consuming iterative task that includes a multitude of different people and experts from different disciplines. This is needed to make sure they are correctly validated and measure the right things. In this paper there have not been enough time and access to the necessary people to accomplish this. However, an attempt to develop indicators was done anyway. The development of the indicators was thus based on the knowledge acquired during the research and utilizing the framework put forward by Khazai, et al., (2015).

The first step was to pinpoint what the indicators should achieve, to do this urban resilience goals was developed that were connected to the key dimensions and base indicators developed by Khazai, et al., (2015). The 9 goals and to what key dimension(s) and base indicator(s) they connect to can be seen in Table 5 (the key dimensions and base indictors found in the appendices in Table 10 and 11.)

Table 5: Urban resilience goals and what key dimensions and indicators they are connected to.

Nr:	Goals	Key dimensions	Base indicators
1	Policies and Procedures for flood protection and risk mitigation	(1)	(1)
2	Cross disciplinary cooperation on flood-risk and mitigation	(1)	(2)
3	Integration of public flood-protection responsibility	(1)	(2)
4	Increased professional knowledge and awareness of flood risk and protection	(2) and (5)	(3) and (9)
5	Increased public knowledge and awareness of flood risk and protection	(2)	(4)
6	Buildings and infrastructure of critical importance for the community is safe from flooding	(3) and (5)	(5), (6) and (10)
7	Resilience and preparedness of critical services in case of disaster	(4)	(7) and (8)
8	Increased risk identification, forecasting and response planning	(5)	(9)
9	Increased urban resilience in high-risk areas	(5)	(10)

Based on the goals the indicators were then developed, the indicators and corresponding goals can be seen in Table 6. To make sure that all the key dimensions that Khazai, et al., (2015) presented were covered all the indicators was connected to the base indicators as well as the goals. This was done because some of the goals cover multiple key dimensions and base indicators, and the base indicators was divided by Khazai, et al., (2015) in such a way to make sure that coverage of the base indicators would ensure coverage of the key dimensions. The method of measuring the indicators were based on common urban planning tools in the industry, and then decided on depending on what would fit the best to the specific indicator.

Table 6: The indicators for Luleå, how they are measured and connect to the base indicators.

Nr:	Indicator:	Measured by:	Goal:	Base indicator
1	Are there adequate flood protection policies in place?	Policy study of relevant policies and documents.	(1)	(1)
2	Perceived feeling of cooperation between different disciplines	Survey about the perceived cooperation between different disciplines.	(2)	(1)
3	Public share of flood protection and mitigation.	Survey to water managers about the division of responsibility in flood protection and mitigation	(3)	(2)
4	Professional knowledge of flood protection, risk, and awareness in different disciplines.	Survey to professionals in different disciplines in relation to flood risk, awareness, and protection.	(4)	(3) and (9)
5	Public knowledge and awareness of flood risk and protection.	Public survey about flood risk, awareness, and protection.	(5)	(4)
6	Location and flood protection of critical buildings in relation to flood prone areas.	Analysis of the city and the location and protection of important buildings, followed by analysis of location in case of new vital development.	(6)	(5), (6) and (10)
7	Location and flood protection of critical infrastructure in relation to flood prone areas.	Analysis of the city and the location and protection of important infrastructure, followed by analysis of location in case of new vital development.	(6)	(5), (6) and (10)
8	Preparedness of critical services in case of a disaster.	Survey to critical services about their preparedness in case of a disaster.	(7)	(7) and (8)
9	Forecasting, risk identification and disaster plans for different disciplines.	Survey to relevant disciplines about their forecasting, response plans for possible disaster and risk identification.	(8)	(9)
10	Higher level of urban resilience in high-risk areas.	Analysis of the cities high-risk areas and if there are extra measures applied there.	(9)	(10)

In this stage of the process the indicators are supposed to go out on consultation with a focus group consisting of the stakeholders in the city. This could not be done as previously stated, and instead an attempt to verify their validity was made by carefully going through the indicators with the knowledge collected from the literature study in mind.

4.2.1 Measuring the indicators

To see how Luleå would perform according to the urban resilience indicators presented they also need to be measured. The indicators will be measured according to the suggested method in Table 6. However, only a sample of the indicators will be measured, the indicators chosen were those not requiring interviews. The indicators that will be excluded from measuring are numbers: 2, 3, 4, 5, 8 and 9. The four remaining indicators to be measured in this report are:

1. Are there adequate flood protection policies in place.
6. Location and flood protection of critical buildings in relation to flood prone areas.
7. Location and flood protection of critical infrastructure in relation to flood prone areas.
10. Higher level of urban resilience in high-risk areas.

4.2.1.1 Are there adequate flood protection policies in place?

When looking at the policies from Luleå to determine the scoring according to the indicator, a level of 3 seems appropriate. The reasoning behind this is that most of the policies in place seem solid and cover most of the necessary parts, especially for the protection of the buildings and infrastructure. However, they focus mostly on the preparation for, and prevention of, the floods and seem to be missing another part that should be included in the polices, that being something regarding the response to the disaster, like the evacuation plans found in Hamburg or the evacuation plan from *"Om dammen brister"*.

4.2.1.2 Location and flood protection of critical buildings in relation to flood prone areas.

The definition to critical buildings and infrastructure by MSB (2021), found earlier in the report:

> Buildings and infrastructure with operations or services that maintain or secure the societal functions that are necessary for the basic needs, values, and security of the society. (MSB, 2021)

With the definition of critical buildings and infrastructure in mind, the first step to scoring this indicator was looking at the policies again. The goal was to find out what they said about critical and important buildings in relation to flooding. This was found in *"Riktlinjer för klimatanpassning i Luleå kommun"* (Luleå kommun, 2015), this policy states that all critical buildings and infrastructure should have an extra flood protection of +0.5m.

The next step was to locate what building where considered to be critical and were in the city they are located. Followed by looking in to if they had the extra protection and if they are located in a high-risk area. This was done by first analysing maps of the city and using prior knowledge from literature of what types of buildings is considered important.

When the map in Figure 34 is compared to the flood map of Luleå presented in an earlier chapter (Figure 14) it can be seen that none of the buildings that are considered critical are located within the flood area. This will in combination with the polices extra measures (+0.5m extra flood proofing) for critical buildings result in the 5th, and highest level of integration on this indicator.

Figure 34: Critical infrastructure and services in Luleå.

4.2.1.3 Location and flood protection of critical infrastructure in relation to flood prone areas.

For the scoring of this indicator the same method was used as the last indicator. The policy (*"Riktlinjer för klimatanpassning i Luleå kommun"* (Luleå kommun, 2015)) used in the previous indicator also applies here, as that policy is relating to both critical infrastructure and buildings.

In contrast to the critical buildings, it is hard to fully remove all of the critical infrastructure from the high-risk areas as Luleå is on a peninsula and bridges and roads (see Figure 34) close to water are needed to connect the inner city to other parts of Luleå. However, most of the infrastructure are still safe from flooding, as the water levels of +2.5m would not reach the roads or the bridges. One exception to this is Bodenvägen North of the city. As this road can risk flooding as seen in the flood map (Figure 14) and results in a decrease in the result on this indicator. The final level here will thus be 4, as there are still other good connections that are safe, and the policies are as good as they were for the critical buildings.

4.2.1.4 Higher level of urban resilience in high-risk areas

The first step was to identify the high-risk areas. Based on *"Riktlinjer för klimatanpassning i Luleå kommun"* (Luleå kommun, 2015) the high-risk areas where set to be the areas flooded in a water level rise of +2.5m. In these areas, as previously mentioned in the policy study, all buildings are supposed to be flood proofed up to at least +2.5m and critical buildings and infrastructure up to at least +3.0m. The actuality of this was examined by looking at the planning documents accompanying the zoning plans in these areas. The result of this was mixed, as some of the zoning plans are verry old (some om them from 1968) and thus not having these requirements in them as they were implemented much later. But all the newer planning documents seemed to contain a section which dictated that building in the area was not a problem as long as flood proofing of the buildings and infrastructure was done. Example from the zoning plan for Malmudden translated to English:

> The zoning area is located in connection to Skurholmsfjärden. Luleå kommuns riktlinjer för klimatanpassning (2015) states that the highest water level by the year 2100 is expected to be +1.9m. Land facilities, Buildings and other infrastructure should be designed in such a way that they are safe for flooding up to +2.5m. (Luleå kommun, 2016)

The next step taken was analysing the risk areas an looking for blue-green infrastructure or other resilience measures in the areas.

After the examination of the zoning plans and analyse of resilience measure in the risk areas, a reasonable score for the indicator seems to be level 3, since many of the older the zoning documents are not up to date and would need revisions for a higher score to be achieved.

4.2.2 Result of the indicators

After the evaluation of the indicators Luleå seem to be in a decent state for flood protection, as it achieved the score of 3 or better in all the examined indicators. This also indicates that urban indicators could be a useful tool in urban flood risk mitigation. However, this is not conclusive as the rest of the indicators would need to be examined to get a wholistic view of the actual flood protection and the viability of indicators as tool in flood protection and mitigation. In Figure 35 below the results of the evaluation is presented, all indicators are visible, but only the measured ones are scored.

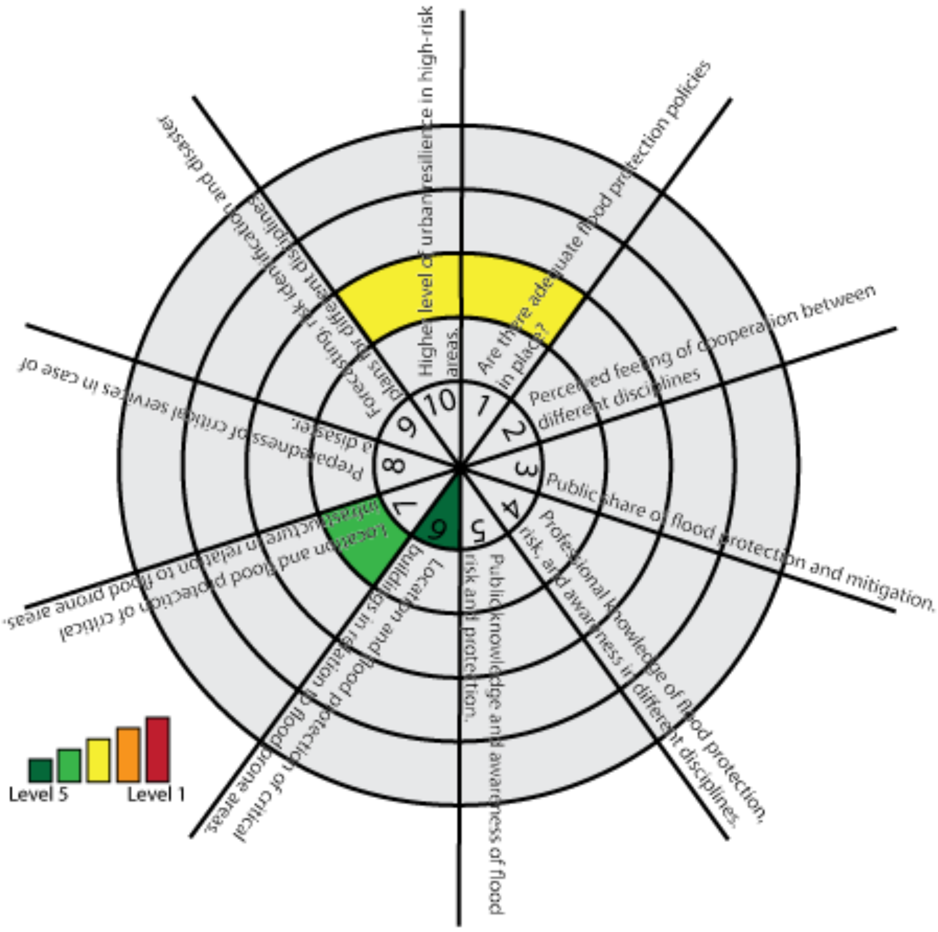


Figure 35: The indicators from Table 6 and their scoring.

4.3 Implementations

Based on the indicators that have been measured some suggestions of improvements or implementations for the indicators that scored the lowest are suggested.

The first suggestion from indicator 1, that scored a 3, is implementing more of a resilience strategy spanning more and new policies are suggested. Luleå seems to have a good start to this, but it is not complete and if a resilience strategy is the end goal more work has to be done. To accomplish this, the adaptability and transformability need to be developed further. One way to do this is increasing the knowledge of the citizens and private stakeholders, this can be done by creating something like "*Om dammen brister*", "*Om krisen eller kriget kommer*" found in Luleå and Sweden, or the "Storm surge information for public" found in Hamburg, but more focused on Luleå and recommending more local actions and evacuation plans depending on the disaster. Something like this can also be combined with the already existing "*Om dammen brsiter*" brochure.

The second indicator that scored a 3 is the other area were a suggestion will be provided. This indicator was the last one evaluated, indicator 10. The biggest flaw found on this indicator was that many of the zoning documents were verry old and would need a revision in order to accommodate and make sure all the high-risk areas and buildings with in them are protected in some way from the possible flooding. The suggestion is therefore to revise the oldest zoning plans for the high-risk areas to make sure they are up to date with the more modern ones. This does not mean that all the zoning documents need to be changed but at least that they should be examined so that glaring risks are mitigated in them.

These proposed improvements would improve the overall flood resilience of the city, and in doing so they would also reinforce Luleå in the parameters for the sponge-city framework. Especially the second measure would benefit the *"Volume control of urban runoff"* and *"Road surface control"* parameters. However, the first measure could also improve softer values that as a whole would improve the overall effectiveness of the sponge-city concept as it can increase the effectiveness of other stormwater control measures and thus aiding in the *"Stormwater source control and implementation effectiveness"* parameter.

4.4 Conclusions

Based on the analysis of the policies and indicators developed, Luleå have good protection for the current risks it can face like 100-year floods, flows and rains. But the systems would need to be expanded and developed further to mitigate the rising risk and scale of the risks due to global warming. The suggested implementations will help to achieve this and improve the current system, but other aspects of the flood protection will need improvements as well.

Urban planning as a tool in flood risk protection and mitigation also seem to work well. But using only planning methods and nothing else would, in most cases, not be sufficient. Since the planning methods can only be used in some parts of a resilience framework and not constitute the whole thing. An example of this is the indicators that was the method examined in this report, these types of indicators can be very useful in the planning and evaluation of a city but can lack in concrete measures to implement. As a whole, urban planning methods are a good tool but can lack in implementing measures at later stages in the planning process of the city. Another problem with using most urban planning tools to implement robustness measures is that they in some many cases would only point out that a robustness measure would be needed but not always make sure that the right option is chosen in the right place. Thus, cooperation between the planners and other disciplines involved, like water managers, are verry important to create a resilient city, and no single discipline can reach as good of a result as multiple disciplines working together in an effective way can do.

5 Discussion

5.1 Choice of the methods

The decision to do an iterative literature study was based on not knowing exactly what literature would be need for the studies in the thesis. This ability to repeatedly go back and extend the literature study with new information and knowledge for the rest of the thesis was helpful for the analyses and evaluations done in the thesis. Because of this the choice to do an iterative study was considered a good one.

The policy study was more structured and mostly linearly done city by city, but not a hundred percent, this was also beneficial and seen as a good choice. This was due to the risk of missing relevant policies and documents during the first cities, and if policies or guidelines were found in new documents or places for the later cities, similar documents and places could be searched for the previous cities if it had not already been found and or searched.

The case study as a method to evaluate the planning methods was a decision that was made early on. This was done as it was seen as an effective way to evaluate a planning method in a realistic way due to the ability to theoretically apply it in a physical place. The decision to do the case study in Luleå was also decided on early, the main reason for this was that the author was studying and living in the city and thus rather familiar with it. This was also helpful later as during the different studies in regard to the city of Luleå the author already had a decent amount of prior knowledge about the city, and a better knowledge of where to locate the rest of the necessary information and sources.

An interview study was at first dismissed as a method for the project as it was not seen as necessary to find answers to the research questions. However, later during the work of the thesis it was realized that interviews would have helped increase the reliability in the development and evaluation of the indicators and thus revealing more of its ability to help mitigate urban flooding. Though at that time it was concluded that the time to properly conduct and analyse the interviews was lacking, thus it was instead proposed as future work of the study.

5.2 Reliability and validity of the thesis

The concept of reliability and validity was previously explained in chapter *1.5.2.5 Reliability and validity*, this thesis will now be evaluated based on those principles.

For the literature study both the reliability and the validity of the study is considered high, as the goal of this study was to build a knowledge base that the rest of the thesis could use. This was accomplished and a similar result should be achievable if done in similar conditions, as many of the articles are cited plenty of time, meaning they are used by others and thus should have a high reliability, in turn giving this study a high reliability.

The validity of the policy study was high as the goal was to see what policies the different cities had and how they compared, and this is what the study accomplished. The reliability for this study is also on the higher end, the reason it might not be as high as the previous one is that in some cases verry few policies were found and there is a risk some polices were missed even though a thorough search for them was done. Though, even If some policies were missed and this could partly change the outcome, it would not make any drastic changes as comparison of methods and types of policies were some of the main goals in this study.

For the indicators in the case study the validity is high, as it is a good way to measure the intended goal, use of urban planning methods in flood mitigation. On the other hand, the reliability can be seen to be a little dwindling. This is due to not all the indicators being measured, and if they all had been measured the end result could have been different (either better or worse).

5.3 Limitation

The biggest limitation in the thesis was, as previously mentioned, the lack of the interviews, this however was found out to late to correct in the end. Another limitation or a possible error is the use of flood maps. Since according to Joy Lim (2018) flood maps usually have a crisp boarder that can create a false sense of security in areas that are located close to the boarder, but not within the flood zone. The reason for the inaccuracy is the difficulty to predict the actual size of floodings that they supposedly show, instead she suggests replacing the crisp boarder with uncertain zones to indicate that there might be a risk, but it is not as certain as in other more flood prone areas. This also leads in to a third uncertainty in the thesis, which is the dimensioning of 1-percent or 100-year floods, flows, and rains. Usually the size of the 1-percent floods, flows, and rains are dimensioned based on history, though this method is usually not that accurate and this is especially true due to the increased intensity and frequency due to global warming. The problem with this is that many cities use these 1-percent floods, flows, and rains as a measurement for dimensioning, resulting in cities that on paper seem to have good protection might in fact not have enough protection for the floods in the future.

5.4 Future work

Based on this work some future work in the field is suggested. The primary one it the continued evaluation of the indicators that was developed in the thesis. But also, further examining and development of the indicators them self, as they also could use some expert opinions from the applicable fields to be optimized for the city. Moreover, more research in the use of urban planning tools for flood mitigation is suggested as most of the reports and articles found during the research that focused on flood mitigation were geared towards water managers and water management rather than urban planning.

6 Appendices

6.1 Literature study

Table 7: Overview of 31 blue-green measures and their typology (Voskamp & Van de Ven, 2015).

Blue-green measure	Description of the measure	Storage & harvesting	Attenuation	Infiltration	Cooling
Adding grass/herbs in streetscape	Replacing paved surfaces by grass or herbs, e.g. as tree pit.	0	+	+	+
Adding shrubbery in streetscape	Replacing paved surfaces by planting shrubs, like hedges on parking lots.	0	+	+	+
Adding trees in streetscape	Planting trees e.g. in streets or at squares.	0	+	0	+
Artificial urban wetland	Urban area used as wetland.	+	0	0	+
Bioswales	Vegetated ditch for stormwater storage, drainage and infiltration. Storage is provided above grounds, while an infiltration/drainpipe is situated subsurface to provide drainage and infiltration.	+	+	+	+
Cooling with water elements	Use of fountains as cooling elements; uchimizu practices.	0	0	0	+
Deep groundwater infiltration	Infiltration of water in aquifers.	0	0	+	0
Ditch or infiltration-strip	Dry small-scale channel with aboveground storage, used for infiltration.	0	+	+	+
Extensive green roof	Roof covered with soil and plants.	0	+	0	+
Green facades	Facades of buildings covered with plants.	0	0	0	+
Green shores and riverbanks	Vegetated banks for canals, rivers and coastal areas.	0	+	+	+
Helophyte filter	Zone of reeds for natural water purification.	+	0	0	+
Increase area of surface water	Increasing the area of surface water increases its overall storage capacity. In canals and rivers, it also increases the discharge capacity, such that locally, more rainfall runoff can be discharged.	+	0	0	+
Infiltration and Transport-sewer	Porous stormwater sewer pipes from which stormwater can both infiltrate into the soil and be discharged and groundwater can be drained.	0	0	+	0
Infiltration boxes	Crates that are installed subsurface, for instance under sport fields and playgrounds. These boxes can store stormwater for a short period of time, subsequently water leaves the crates by the sides and infiltrates.	0	0	+	+
Infiltration field	Area of sufficient size and porosity used to infiltrate stormwater (from roofs and paved surfaces) directly on meadows and green areas.	0	0	+	+
Infiltration trench	A lowered area filled with gravel or similar material, often applied next to an impervious surface (e.g. road, building) to allow stormwater infiltration.	+	+	+	+
Intensive green roof	Roof covered with thick layer of soil with plants and possibly small trees.	+	+	0	+
Lowering embankments	Realizing seasonal storage by creating extra storage height for surface water.	+	0	0	+
Park or urban forest	Area of open green space or collection of trees in a city, used for recreation.	0	+	+	+
Porous pavement	Pavements that allow rainfall runoff to (quickly) infiltrate into the soil. Two types exist: pavement systems where water passes around the pavement elements (e.g. bricks) and pavements where water passes through it.	0	0	+	0
Private green garden	Greening the garden or street side.	0	+	+	+
Rainwater retention pond	A pond that buffers and infiltrates rainwater. If it has a more natural design, including vegetation, also purification can take place.	+	+	0	+
Rainwater storage below buildings	An underground reservoir that is used to store water below a building, e.g. incorporated in a parking garage.	+	0	0	0
Rainwater tank	A storage tank that is used to store water in. Most often these are used to store rainfall runoff from especially roofs and are located on private property and the water is stored for reuse.	+	0	0	0
Specific seasonal storage facility	Storage reservoirs with a multifunctional character used to compensate summer shortages.	+	0	0	0
Swale	A moist, low-lying area or strip of land. When such a depression is planted, it is often designated 'rain garden'.	0	+	+	+
Systems for rainwater harvesting	System to harvest and reuse rain water within a building, including a rainfall collection point, a storage reservoir, pumps.	+	0	0	0
Urban agriculture	Growing fruit and/or vegetables within a city.	0	+	+	+
Water roof	Roofs to store water on and slowly discharge, or evaporate (two types: permanently wet and temporarily wet).	0	+	0	+
Water squares	Square having an area depression to store water in, during rainfall events. After the event the water is slowly discharged to the groundwater, surface water and/or the sewer system.	0	+	0	0

[a] '+' and '0' reflect: a measure *can* respectively *cannot* be typified as such.

Table 8: National planning and policy relevant to implementation of Sponge City guidelines (Griffiths, et al., 2020).

national policy	aims	source (in Chinese)
The Communist Party of China's State Council policy on urban drainage storm water drainage facility construction notice (April 2013)	— transform water drainage and sewage control systems (by 2023) — promote sustainable drainage construction methods — permeable surfaces area ratio minimum of 40% in new developments — convert impermeable surfaces to permeable surfaces, to store rainwater and reduce hydrograph peak	The State Council of the Peoples' Republic of China (2013) The Communist Party of China's State Council policy on urban drainage stormwater drainage facility construction notice. Notice No. 23 of the State Council (http://www.gov.cn/zhengce/content/2013-04/01/content_5066.htm)
The Communist Party of China's State Council policy on promoting the Sponge City-building guidance and aims (October 2015)	— increase implementation of Sponge City approach — rehabilitate urban water ecology — conserve urban water resources — increase storm water drainage capacity — increase public investment in drainage projects — promote human development in harmony with nature — reduce impact of urban development on ecology — infiltrate 70% of rainfall within the development areas — by 2020, 20% of urban areas should achieve the above objectives — by 2030, 80% of urban areas should achieve the above objectives	The State Council of the Peoples' Republic of China (2015) The Communist Party of China's State Council policy on promoting the Sponge City-building guidance and Aims. Notice 75 of the State Council (http://www.gov.cn/zhengce/content/2015-10/16/content_10228.htm)
The Communist Party of China's State Council on further strengthening the urban planning and construction management (February 2016)	— draft Sponge City construction guidance — use natural landscape: topography, wetlands, farmlands, woodlands, grasslands, and existing rivers and lakes — develop synergistic eco-spaces to promote water conservation; recycling; flood and water-logging resilience — encourage households to install rainwater collection devices — significantly reduce in urban impermeable surfaces	The State Council of the Peoples' Republic of China (2016) The Communist Party of China's State Council on further strengthening the urban planning and construction management. 6 February 2016 (http://www.gov.cn/zhengce/2016-02/21/content_5044367.htm)

Table 9: National standards for prevention of waterlogging (Griffiths, et al., 2020).

national standards	specification	source/citation (in Chinese)
Outdoor drainage design code (GB50014-2016)	— guidance on rainwater harvesting, transportation, storage, discharge, processing and utilization of natural and artificial facilities, and related management measures — medium-sized cities and small urban water-logging prevention schemes to design for return periods of 10–20 years — no more than 15 cm of runoff depth on road surfaces — engineering and non-engineering measures — used to prepare for and respond to urban water-logging — post-development conditions not to exceed original runoff	Ministry of housing and urban rural development of the People's Republic of China (2016). Code for design of outdoor wastewater engineering (GB 50014-2006), 2016 edition. China Planning Press, Beijing, China.
Sponge City construction technology guide—Low-impact development storm water systems construction	— volume runoff objectives: total annual runoff rate to be limited to 15–20% annual runoff control of 80–85% of incident rainfall — peak runoff objectives: city storm sewer and pumping stations to be designed with respect to outdoor drainage design code (GB50014-2016) — stream pollution control targets: classification system for runoff pollutant and to control the frequency and total amount of combined sewer overflow	Ministry of Housing and Urban-Rural Development (2014). The construction guideline of Sponge City in China. Ministry of Housing and Urban-Rural Development, China Planning Press, Beijing, China.
The city flood control engineering design code (GBT50805-2012)	— relates to flood control, including storm surge, flood tide and related impacts — flood control and engineering design standards — river flood engineering for 200-year events — urban flood design for 20-year events	Ministry of housing and urban rural development of the People's Republic of China (2012). 'Code for design of urban flood control project (GB/T 50805-2012)', 2012 edition, China Planning Press, Beijing, China.

Table 10: Characteristics of the 6 key dimensions and 10 indicators for urban risk resilience (1 of 2) (Khazai, et al., 2015).

SECTORS	INDICATORS	CHARACTERISTICS
LEGAL AND INSTITUTIONAL	Indicator 1: Effectiveness of Legislative Framework	• Laws, acts and regulations • DRR Policies • Compliance and Accountability • Resource mobilization and allocations (financial, human)
	Indicator 2: Effectiveness of Institutional Arrangements	• Organizational structures that define roles and responsibilities • Review, update, enforcement, monitoring and reporting process • Partnerships with civil society and communities
AWARENESS AND CAPACITY BUILDING	Indicator 3: Training and Capacity Building	• Institutional commitment to training and capacity building with dedicated resources and evaluations • Knowledge Management, Research and Development
	Indicator 4: Advocacy, Communication, Education and Public Awareness	• Commitment to advocacy and public awareness and education programs that engage all relevant audiences and stakeholders including civil society and community organizations • Commitment to participatory processes and community involvement • Research facilitation, Use of Information, Information Technology and Communication (ITC) to disseminate information • Pro-active and constructive Media relations

SECTORS	INDICATORS	CHARACTERISTICS
CRITICAL SERVICES, INFRASTRUCTURE RESILIENCY	Indicator 5: Resiliency of Critical Services	• Inclusive, participatory and transparent slum rehabilitation policies and programs • Protection of living (i.e. shelter) and livelihood conditions (i.e. access to and availability critical services including opportunities for livelihood) against disasters • Resiliency of health services to deliver services during a disaster
	Indicator 6: Resiliency of Infrastructure	• Resiliency of water, sewer and storm drain systems • Resiliency of transportation systems • Contingency for delivery of essential services
CRITICAL SERVICES, INFRASTRUCTURE RESILIENCY	Indicator 7: Emergency Management	• Functioning EOP with Basic Plan and ESF system • Year-round Response Planning and functioning SOP's • Drills and Simulation involving relevant stakeholders including civil society and communities • Preparedness programs for first responders and leaders and representatives of communities at risk
	Indicator 8: Resource Management, Logistics and Contingency Planning	• Self analysis of resource management and logistics • Contingency planning for key institutions for pre-defined scenario analysis and planning parameters • Ability to manage delivery of resources to most vulnerable populations
DEVELOPMENT PLANNING, REGULATION AND RISK MITIGATION	Indicator 9: Hazard, Vulnerability and Risk Assessment	• Awareness of hazards and vulnerabilities (natural and man-made) • Risk Identification and Assessment, Vulnerability and Capacity Analysis, • Impact Assessments (loss analysis) by relevant sectors and segments of populations at risk • Use of forecasting and early warning in preparedness and response planning
	Indicator 10: Risk-Sensitive Urban Development	• Risk-Sensitive Land use planning and urban re-development, • Enforcements of codes and standards, particularly in slum upgrading programs; quality control norms in construction • Reinforcing and retrofitting of critical assets and infrastructure

Table 12: Definition of target levels for resilience in Figure 8 (Khazai, et al., 2015)

LEVEL 1	'Little or no awareness' Level 1 represents little or no awareness and understanding of mainstreaming. There is no institutional policy or process for incorporating risk reduction within the functions and operations of the organization. Further, in some cases there is an adverse attitude and adverse institutional culture towards adopting measures to reduce risk. As a result, significant resistance is expected from any risk reduction initiative resulting in greater vulnerability and higher losses in the future.
LEVEL 2	'Awareness of needs' Level 2 refers to an early stage of awareness. The organization has a growing level of awareness, and there is support for disaster reduction among the policy makers. The institution may have activities and dedicated efforts for preparedness but these are simply limited to response. However, support is limited and does not necessarily carry through all levels of the organization; resistance to change is expected at various levels where business as usual is judged sufficient. In general, the institution has no established policy, guidelines or system for mainstreaming, and action will be needed at the highest level to establish such policies and systems. This level is expected not to result in risk reduction in the long term. Vulnerability is expected to increase.
LEVEL 3	"Engagement and Commitment". Level 3 refers to a high level of engagement and commitment to DRR by the institutions. However, the policies and systems have not been fully established yet. The institution may not have a deep understanding of the mainstreaming process and requirements and still has limited capacity, but overall it is willing to make the investments and has already taken some action; commitment for change, and in particular to shift from response only to mainstreaming DRR. There maybe "pockets of resistance" but these are expected to be overcome with time.
LEVEL 4	'Policy Engagement and Solution Development' Level 4 refers to an intermediate stage in mainstreaming, where there is already an established policy for mainstreaming, an overall institutional process/system, and identifiable actions that render the system sustainable and irreversible. In general DRR is seen as an asset by policy makers who are willing to invest in it. The organization is engaged into planning and control processes to address the requirements of integrating risk reduction into its planning and development processes, and in building resiliency in the core services. Processes of coordination and regular drills and exercises have been put in place.
LEVEL 5	'Full integration' Level 5 refers to a situation where risk reduction is fully absorbed into planning and development processes as well as core services. The organization places high importance on reducing disaster risks in a sustainable program of action at multiple levels and within multiple sectors, and there is a comprehensive demonstration of practice. Level 5 describes a situation where disaster risk reduction is 'institutionalized'. However, this is not to suggest that an optimum level of attainment has occurred: there is still a need for further progress. The process of mainstreaming should be viewed as open-ended: while organizations should aim to achieve Level 5, they should also aim to make continuous improvements to their approach.

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