Resilient Waterfronts: Climate Adaptation Strategies for Sweden’s Changing Landscapes
A Deep Dive into Gothenburg and the Göta River

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Abstract

Climate change poses growing challenges for many waterfronts in Sweden, especially in low-lying regions with unstable soil types, such as Gothenburg. With increased rainfall intensity, rising sea levels and more frequent flooding events, traditional grey infrastructure flood protection strategies are proving insufficient and environmentally unsustainable. This thesis explores how Nature-based Solutions (NbS) can enhance climate resilience in the waterfront regions of Gothenburg and the Göta River providing multifunctional, adaptive and environmentally sustainable alternatives to conventional grey infrastructure. The study aims to identify suitable NbS strategies for local application and needs, advocate for their integration into municipal and regional planning frameworks and evaluate the local spatial and land use conditions necessary for their success.

A multi-method approach was utilized, combining critical discourse analysis of planning documents, spatial GIS analysis using the program SCALGO Live and a case study of the Gothenburg and Göta River regions. Through this combination of approaches, institutional discourses, the theory behind the most commonly used NbS systems and their potential for real-world implementation were examined.

Findings reveal that while there is awareness of flood risks in municipal planning, current frameworks still prioritize grey infrastructure solutions. NbS such as wetland restoration, living shorelines and reinforced riverbanks are acknowledged but lack systematic integration and clear implementation strategies. Various areas were identified as highly suitable for implementing a wide range of NbS strategies.

***Keywords**:* Climate adaptation, Nature-based Solutions, Flood resilience, Flood risks, Gothenburg, Göta River, Urban planning, Regional planning

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Abbreviations

Abbreviation	Description
SLU	Swedish University of Agricultural Sciences
NbS	Nature-based Solutions
IPCC	The Intergovernmental Panel on Climate Change
MSB	Swedish Civil Contingencies Agency
SMHI	The Swedish Meteorological and Hydrological Institute
SGI	The Swedish Geotechnical Institute

1. Introduction

The increasing frequency and intensity of unpredictable weather. driven by climate change, is causing serious challenges for landscapes and communities in waterfront areas. Flooding, storms and escalating erosion threaten infrastructure, ecosystems and neighbourhoods in waterfront regions. Sweden contains numerous inland watercourses such as lakes, rivers, creeks as well as an extensive coastline. The counrty is vulnerable to climate and infrastructural related risks that could temporarily or permanently increase the amount of water found in the landscape. Rising sea levels pose a substantial threat to many coastal cities, for example, Gothenburg, Malmö and Helsingborg (MSB, 2018). Coastal cities in the south of Sweden are especially vulnerable due to the lack of postglacial rebound that affects the northern and middle parts of Sweden (Lantmäteriet, 2025). While cities like Stockholm and Sundsvall are coastal and at risk of flooding due to sea level rise, the postglacial rebound raises the land by 6–10 mm annually, effectively offsetting the average sea level rise of approximately 3.7 mm per year (see Figure 1; SMHI, n.d.). In the southern region of Sweden, the postglacial rebound is negligible.

Intensified extreme weather events are increasingly affecting inland watercourses, impacting large river systems that carry significant volumes of water. This results in increased flow speeds and water volumes, which have the potential to cause substantial damage to habitats and infrastructure (Göteborgs stad, 2019). Gothenburg is a specifically interesting area with a large population and large-scale significant infrastructure. In addition, it is located in close proximity to the Skagerrak and Kattegat, an extension of the North Sea, making the region vulnerable to sea level rise. Further, one of Sweden's largest rivers, the Göta River, flows through the city.

The known risks for flooding is further problematized with evident gaps in current urban and regional planning, especially in the integration of long-term, resilient and sustainable climate adaptation strategies. Grey infrastructure solutions, also referred to as hard surfaces or hard-engineered systems, such as concrete walls, dams and piped drainage, remain the favoured strategy for combating flooding, leaving limited spatial and regulatory room for sustainable and multifunctional systems. This study is therefore necessary to critically analyse how flood resilience can be strengthened on Gothenburg's and the Göta River's waterfronts though more resilient, sustainable and adaptive approaches.

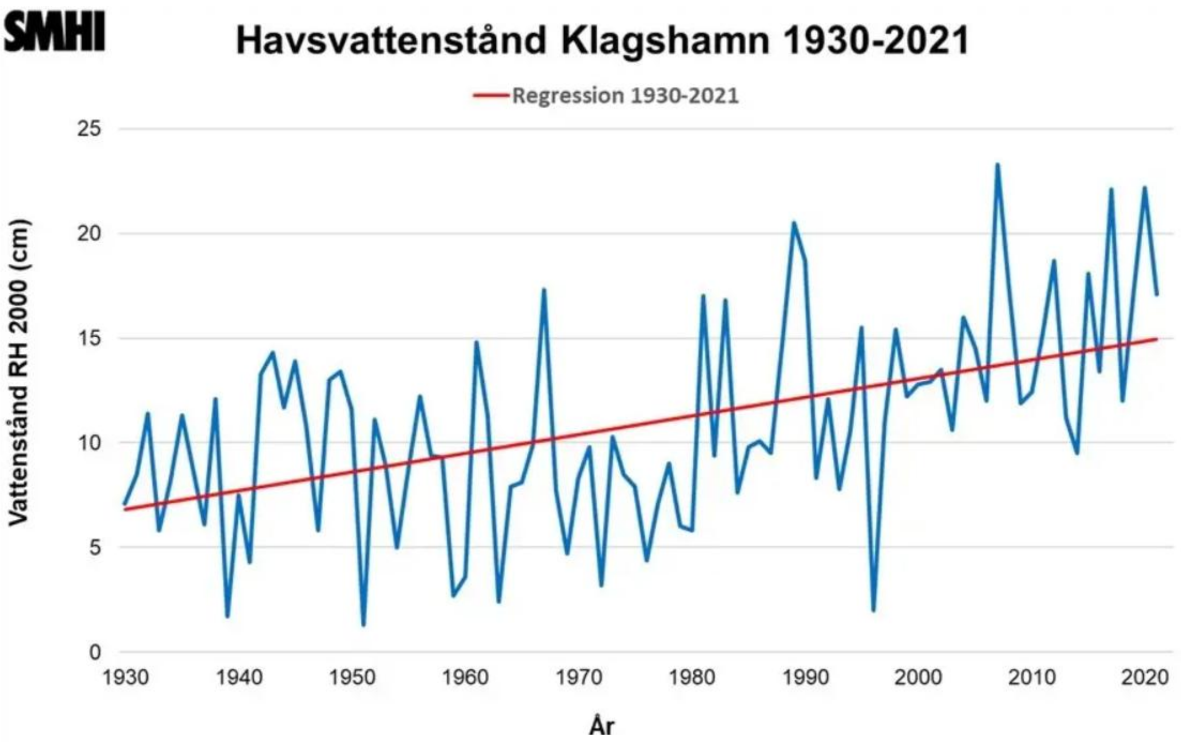

Figure 1. Sea level Klagshamn 1930-2021. SMHI https://www.smhi.se/kunskapsbanken/klimat/vattenstand-och-klimat/framtida-vattenstand-langs-kusten. The figure shows the regression from 1930-2021 of sea level according to RH 2000. Clearly indicating sea level rise in the last century.

1.1 Problem Statement

The region of Gothenburg is especially vulnerable to rising sea levels and more frequent extreme rainfall caused by climate change, due to a combination of geographical, geological and weather patterns in the area. Collectively, this is leading to increased flooding, shoreline erosion and erosion on riverbanks. This poses significant risk to urban and rural land alongside ecosystems and communities living along the waterfronts. These risks are exacerbated by urban and rural expansion proposed by Göteborgs stad (2019) into vulnerable areas. Together with outdated drainage systems, large areas are increasingly at risk.

Nature-based solutions (NbS) are an alternative to hard-engineered systems, presenting a sustainable and cost-effective alternative by utilizing and enhancing natural systems to mitigate flooding and erosion. NbS systems, such as restored wetlands, living shorelines, reinforced riverbanks and floodplains reconnection. have shown promise in other waterfront regions. However, in the context of Gothenburg the implementation through urban and regional planning are insufficiently studied resulting in a knowledge gap.

1.2 Research Aims and Goals

Given the environmental and infrastructural challenges found in the Gothenburg region, there is a growing need for flood adaptation strategies that are both ecological and practical. This thesis aims to explore how flooding risks and waterfront vulnerabilities can be mitigated through climate adaptation strategies, utilizing NbS. The study investigates the effectiveness, long-term sustainability and economic feasibility of NbS in comparison to conventional hard-engineered methods. By focusing on planning practices and the spatial situation specific to the Gothenburg region, the study aims to assess the practicality of integrating NbS into urban and regional planning.

This topic is particularly relevant to the west coast of Sweden but could additionally be relevant to other parts of the country and abroad. Regions that experience similar weather patterns, as well as similarities on water in the landscape could potentially gain knowledge from this study. The thesis aims to gather and deepen the knowledge of climate adaptation frameworks and sustainable design principles in landscapes that contain water, infrastructure and communities, evaluating risks and potential solutions.

1.3 Research Purpose

The purpose of this study is to provide a comprehensive understanding of NbS for decision-makers, urban planners and stakeholders to showcase its usefulness in reducing flood risks and enhancing the climate resilience in Gothenburg and the Göta River. NbS would preserve and enhance the ecological and social value of the region by increasing habitable landscapes for animals and plants, in addition to providing more recreational opportunities for humans. The focus will be on analysing previously completed projects, assessing site-specific conditions that will provide practical insights on the most effective, sustainable and affordable NbS strategies for the region. Ultimately, the findings in the study aim to contribute to a more ecologically friendly approach in flood management policies, promoting sustainability, adaptability and resilience.

1.4 Research Questions

To achieve the previously explained aims, the thesis will be exploring the following questions:

1. **How are climate-related hazards, such as flooding, extreme rainfalls and rising sea levels caused by climate change, projected to affect waterfront regions in Gothenburg, including ecosystems, infrastructure and communities?**
2. **What Nature-based Solution strategies are most suitable for implementation to enhance the resilience in Gothenburg's waterfronts?**
3. **To what extent are current regulation frameworks, municipal and regional planning in Gothenburg supporting and incorporating NbS for climate adaptation?**

2. Water, Climate and Planning: Foundations for Flood Adaptation

In the following chapter theory concerning climate change, causation for increased flood risks, water in urban planning and the historical role of water in the Swedish planning context are presented.

2.1 Climate Change

The Intergovernmental Panel on Climate Change (IPCC), composed of climate scientists from the United Nations, has constructed a comprehensive report summarizing the current state of accumulated knowledge on climate change (IPCC, 2021). The primary conclusion of the report is that human activities largely affect climate systems, supported by a wide range of observations from diverse climate regions all across the globe. Furthermore, the IPCC emphasizes that human activity is causing severe and often irreversible damage to natural environments and ecosystems, strongly highlighting the urgency of transitioning to a low-emission society and reducing greenhouse gas emissions.

The report states that climate change is clearly intensifying hydrological processes, particularly through rising sea levels and the increased intensity and frequency of extreme rainfall events (IPCC, 2021). Global sea levels are driven by two factors, both connected to increased global temperatures. Firstly, thermal expansion increases water volume without added mass. Secondly, melting of much land- and sea-based ice coverage adds additional freshwater mass into the oceans, directly increasing sea levels as described in the report (IPCC, 2021). In regions such as Gothenburg, sea level rise of +2.5 to +2.9 meters is predicted during the 21st century as seen in Figures 2 and 3 (Göteborgs Stad, 2019). The figures demonstrate how water is projected to enter the city centre and eventually harming residences and infrastructure.

The Gothenburg area is expected to experience higher intensity and frequency of extreme rainfall events, caused by rising atmospheric temperatures that allow the air to hold more water vapor and increase its moisture capacity per degree Celsius (IPCC, 2014), leading to rainfall events tending to be more intense.

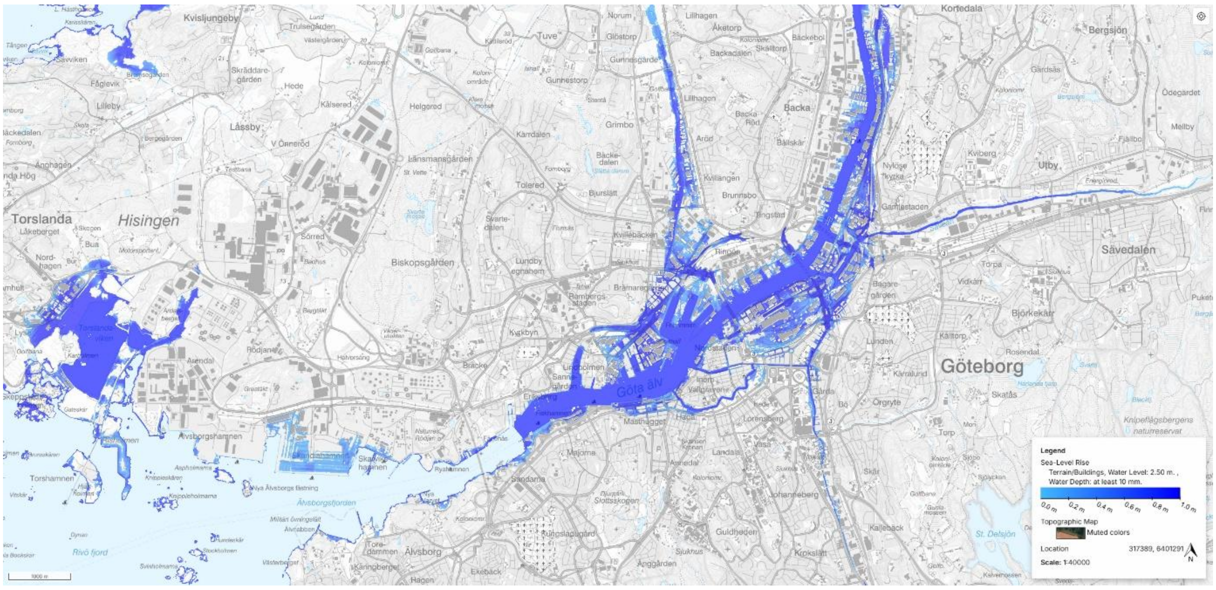

Figure 2. 2,5m sea level rise in Gothenburg. © SCALGO Live https://scalgo.com/live/ Visibly showcasing the city's future challenges with flooding in the inner city.

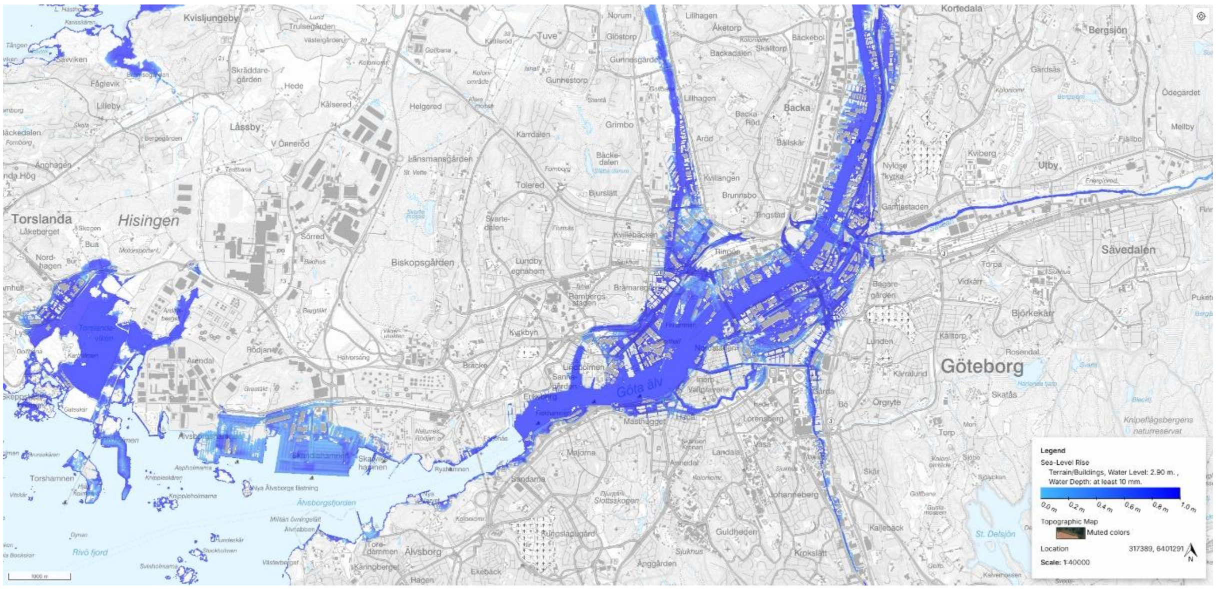

Figure 3. 2,9m sea level rise. © SCALGO Live https://scalgo.com/live/. Visibly showcasing the city's future challenges with flooding in the inner city.

2.2 Shocks and Stresses

Two key concepts contribute to flooding and destruction of land, habitats and humans: shocks and stresses (IPCC, 2014). Shocks refer to extreme events that can appear suddenly and cause immediate disruptions. For the context of floodings, the shock events are usually short, high-intensity events that can easily overwhelm natural systems and infrastructure. In this category, extreme rainfall events, such as, 100-year or 500-year rainfall events, strong storms and dam failure are included (IPCC, 2014). Events that may seem unpredictable and have the capability for large and rapid destruction. Stresses refer to long-term pressures that under long periods of time gradually lessens ecosystems´ and habitats´ ability to effectively manage water and its ability to withstand floods. The most evident example is rising sea levels that gradually encroach coastal areas, increasing the permanent sea level, as well as increasing potential flooded areas.

2.2.1 Planning for Rising Sea Levels

Since the dawn of mankind, people have settled near inland watercourses and coastal regions, due to its essential role in human lives. As well as its critical geographical role in trade, transportation and industrialisation (Mithen, 2003). Therefore, it is no surprise that cities such as Stockholm, Malmö, and Gothenburg have become the country's largest urban centres, containing the most populations of humans in the nation. Historically, communities living near coastal regions adapted their way of life after the natural water fluctuations. However, as the population has grown, urbanization and waterfront developments have become more and more intensive (LIFECOASTadapt, 2018). Resulting in many housing developments and industrial expansions into flood-prone areas, increasing risks for many inhabitants as sea levels are rising.

In response to the growing recognition that rising sea levels present a major challenge. Planning around the coastal regions has in the latest decades become stricter with legislation that limits expansion into regions near waterfront. Built and legislated by the Shoreline Protection Act (Regeringen, 1998) that restricts the implementation of housing in a proximity of 100m to the shoreline. However, the act has seen its fair share of criticism. For example, private individuals most often get denied getting a permit near the waterfront, while larger infrastructure projects may get a permit. With the explanation that it serves the public interest, even though larger infrastructure projects can be more disruptive to nature. Additionally, it is the local municipalities responsibility to enforce and implement the act. However, the interpretation of the law varies depending on the municipality and the politicians in office (Arvidsson & Johansson, 2024). This leads to a system that can be dissimilar throughout the country.

Further, while the Shoreline Protection Act (Regeringen, 1998) aims to protect nature, it often fails to efficiently support modern climate adaptation strategies effectively, such as, NbS like floodable parks or coastal wetlands that are supposed to help the coastal landscapes (Christian et al., 2019). A solution for rising sea levels can be the implementation of NbS on the coastline.

2.2.2 Planning for Intensive Rains

Intensive rainfall, defined as short duration events with high-volume precipitation, is expected to increase in the Gothenburg region (SMHI, 2023). A key concept to make urban areas less prone to flooding is to increase permeable surfaces as much as possible. Urban centres traditionally are characterized by hard surfaces such as pavements and roads. These surfaces are mostly impermeable and rely on engineered systems to carry out the water. Heavy rainfall events often exceed the capacity of both the sewage systems and surface runoff in hard surface design. This leads to overwhelmed drainage systems, flooded residents and could potentially cause damage to infrastructure. The challenge is not only the volume of water coming from these events, but also the short time period it releases in, which is hindering the effectiveness of urban drainage systems, even at modest rainfall (Arvidsson & Johansson, 2024).

To combat the increased number of intensive rains, urban planning must shift focus towards decentralized and adaptive stormwater management (Albert et al., 2019). Nature offers an ideal model for handling heavy rainfall. By mimicking natural hydrological processes, a number of ecologically engineered systems can be made (UNESCO, 2018). By increasing permeable surfaces, water can be slowed, captured and infiltrated, delaying peak discharge and reducing runoff.

2.2.3 Planning for Collapse of Water Infrastructure

Water infrastructure is particularly vulnerable to a range of natural hazards and extreme weather events. In the Göta River region, for example, heavy rainfall, rapid snowmelt, storm surges and landslides can individually or collectively threaten critical infrastructure in the river system such as dams, reservoirs and water distribution systems. If critical water infrastructure are damaged, they can result in even more severe flooding and structural damage (Länsstyrelsen, 2024).

In the event of a hydroelectric plant collapse, large volumes of water could be released downstream into the specific watercourse, which would be destructive for many cities and settlements situated along the river. With infrastructure such as hydroelectric plants, this proximity to essential water sources also increases the risk of severe flooding, if these structures were to burst. Therefore, much planning is required for the security of these systems. As well as the development of settlements downstream. Thus, collaborative preparation planning for the major watercourses in Sweden have been developed with actors including, counties, municipalities, water plant owners and Svenska kraftnät. From Sweden's 30 rivers classified as major waterways, 20 of these are included in this collaboration (Svk, 2023).

2.3 The Historical Role of Water in Swedish Planning

Historically, urban planning and infrastructural development in Sweden has been proactive in integrating water management and climate adaptation. The first *Water Act* was implemented in 1941 to combat water pollution (Nilsson. K, 2016). Previously there was no law regulating the wastewater that got accumulated, hence, a large number of wastewaters were thrown out in the streets or in nearby watercourses. Resulting in significant public health issues and the rapid spread of disease.

The first regulation explicitly created for protection of important nature was the *Act for Nature* adopted in 1964 and implemented in 1966 (Naturvårdslag, 1964). In the act, it was stated that nature is a national asset, and it should be cared for and protected. The Right of Public Access (*Allemansrätten*), first formally introduced in this act marked a significant milestone in recognizing the value of human interaction with nature and the principle of non-exploitation of sensitive natural environments (Naturvårdsverket, n.d.). While not a statutory law, it is protected in the constitution and grants public access to private land for recreation and nature appreciation (Naturvårdsverket, n.d.). The act was repealed in 1999, when the Environmental Code replaced it. Which is, until this day, one of the highest protectional frameworks found in Sweden.

For regulations regarding physical planning, the *Economising of Land and Water* act was introduced in 1972 (Regeringen), with the intention of protecting and preserving valuable nature from destruction caused by exploitation and constructions mainly connected to infrastructural activities (Nilsson, 2016). By providing a framework for national planning, a holistic nature conservation and resource utilization were possible. The act was divided into five key components: firstly, a goal of constructing a comprehensive assessment of the land and water resources in Sweden. By identifying existing land and water use and environmental vulnerabilities. Secondly, following the identification of land and water resources, planning for balancing economic development and environmental protection (Nilsson, 2016). Strategies for ensuring water supply and control of pollution in freshwater sources. As well as recognition of the importance of Sweden's coastline for biodiversity and regulation of development causing environmental damage.

The intersection between urban planning and water management has, as explained in this chapter, been a central part of Sweden's development. This was particularly important in combating the public health crisis in early 20th century, when efforts were made to protect and control urban watercourses to prevent diseases and improve sanitation. The *Water Act* of 1941 laid the foundation for how planners worked with water management (Nilsson, 2016). As Nilson explains, planners were increasingly tasked with integrating hydrological systems into urban environment, ensuring access to clean water, separating sewage and stormwater systems and implementing flooding control measures. During this period, significant investments were made in grey infrastructure, much of which we still use today, including dams, drainage systems and constructed riverbanks. That heavily increased technical approach in urban water management models. Although these grey solutions were innovative and effective at the time, they are increasingly seen as outdated in light of rising water levels and intensifying flow velocities (SMHI, n.d.). This highlights the need to shift toward long-term, adaptation strategies that integrate ecological considerations.

3. Planning Frameworks and Nature-based Solutions for Flood Resilience

This chapter explores how municipalities in Sweden engage with climate adaptation strategies, focusing on the governance structures, coordination and responsibilities. It further reviews multiple NbS strategies applicable to the Gothenburg context. Together, these sections provide a theoretical foundation that the case study then develop further.

3.1 Municipal Responsibilities and Institutional Conditions for Adaptation

In Sweden, climate adaptation responsibilities are primarily assigned to municipal and city levels (Glaas et al., 2010). However, it is just in the recent decade that the Swedish municipalities have started to translate the adaptive measures into planning practices and strategies. However, as municipalities are now responsible for the central position in adapting to future sea level rise and flooding from increased rainfalls. Planning is increasingly dependent on strategic coordination across sectors and municipalities to integrate large-scale flood mitigation strategies such as NbS. Without strategic coordination, urban planners are expected to balance technical, ecological and social considerations. The ability of municipalities to implement transformative adaptation is constrained by entrenched governance structures and sectoral divides. As Becker (2021) argue, integrating climate adaptation strategies into urban planning requires deliberate shifts in institutional processes, including co-production of knowledge, cross-sectoral collaboration and adaptive policy learning. Yet such integration remains limited, particularly in Swedish contexts where policy instruments are often technocratic rather than systemic. Becker (2021) continues by stating that the largest gaps exist between actors assessing the flooding risks and the actors implementing them. With the fact that different municipalities have widely different prerequisites in terms of budget, size and staff etc. the work with resilience against increased hazards such as floods are dissimilar (Glaas et al., 2010). Therefore, it is critical to carefully review the municipality or city in question to understand how they work with implementing adaptive measures for increased water in the urban context, which will be investigated in this thesis.

3.2 Regional Planning and the Role of Planners

Although Sweden has implemented the EU Floods Directive through the national regulation (SFS 2009:956), the majority of the flood risk assessments remain uneven. Arvidsson and Johansson (2024) explain that, although flood risk mapping is relatively well developed, consequence assessments especially that of indirect impacts such as infrastructure interdependencies remain poorly integrated and methodologically inconsistent into appropriate scale.

Regions and regional planning have for a long time been viewed as an appropriate sub-national divide in many of the EU countries (Haughton & Counsell, 2004) The purpose for this sub-national divide is to comprehensively enable planning practices in an appropriate scale. Further, it eases with regional policies and favours coordination with sectors and stakeholders. However, In Sweden regional planning has traditionally had a weak impact on policy making. This has resulted in a number of reform proposals that question the role of the region. The institutional arrangements differ a lot in Sweden, with only 3 of the 21 regions using statutory planning, whilst the remaining 18 regions are practicing different forms of non-statutory regional planning (Bergkvist Andersson & Schmitt, 2024). Statutory planning provides a legal binding guidance for municipal planning that adopts a regional planning framework. Aimed at coordinating housing, transport and other interests on a regional scale, applied by Stockholm County. The non-statutory approach is not legally binding across the whole region and promotes the idea of strategic coordination across municipalities and flexibility. Adapted by regions such as Västra Götaland, Skåne and many others.

Statutory planning offers a clear alignment and formal guidance and strong integration with national, county and municipal levels. However, they offer less adaptability than the non-statutory approach. Nevertheless, the non-statutory method heavily relies on partnerships and extensive collaboration to effectively plan for larger projects over a greater area (Bergkvist Andersson & Schmitt, 2024).

As previously explained, the modern planning practice in Sweden are largely local and municipalities rely on regional flood risk plans produced by County Administrative Boards and often in collaboration with MSB, yet Arvidsson and Johansson (2024) highlight that these plans often lack standardized methods for evaluating societal consequences, leaving municipalities with limited usable data for implementation This highlights the need for spatial planners to operate within a clear framework to compensate for the absence of standardized systems. In the study *Exploring Local Spatial Planning as Practices of Process Design in the Stockholm Region, Sweden* (Högström et al., 2023), key points of planning inquiry and process trajectory that planners can employ to effectively go from ideas to concrete actions were discussed. This planning model is highly relevant to the thesis as it provides a structural framework for analysing how planners in the municipality of Gothenburg can translate NbS ideas into concrete planning practices, which is the central focus for the discourse analysis and case study.

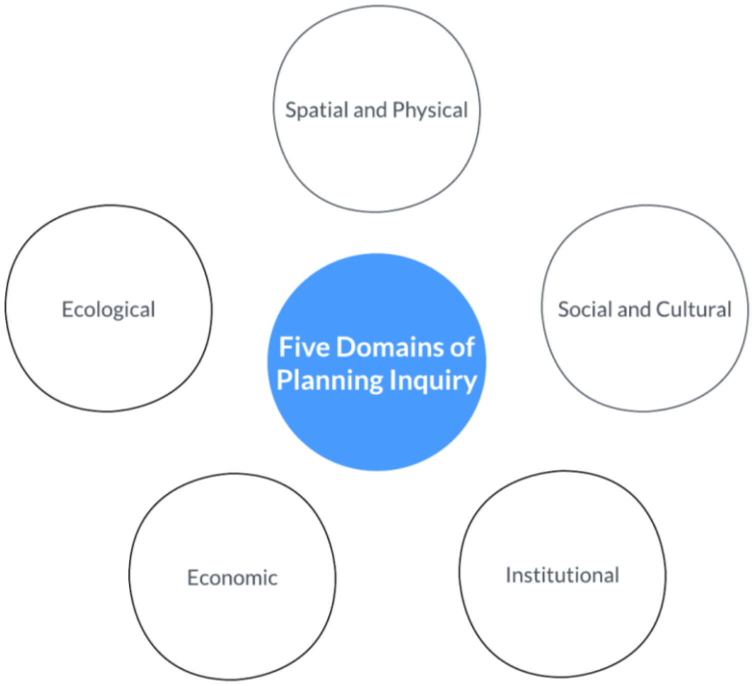

Figure 4. Five Domains of Planning Inquiry (Illustration: Martin Enderskog)

Spatial and Physical: When examining a proposed planning area, the physical characteristics and spatial arrangement of the site needs to be understood.
Social and Cultural: Planners need to understand the social dynamics, local community needs and cultural and historical values.
Institutional: Planners need a good understanding of the governance structures, including policies and regulatory frameworks.
Economic: Assessing the economic activities, resources, funding and development potential.
Ecological: Profoundly consider the environmental aspects that a potential project would result in, including, biodiversity and sustainability.

Contextualization

The initial phase in the planning process involves a comprehensive exploration of the context of the planning project, utilizing the five domains of inquiry (Högström et al., 2023). Planners then gather crucial information about spatial, cultural, institutional, economic and ecological properties of the proposed site. A holistic approach and understanding of the factors at play are fundamental for urban planning and decision-making. However, as noted by Becker (2021), even if planning frameworks are well-defined, local implementation often suffers due to weak institutional linkages between actors. This is further explained by Arvidsson and Johansson (2024) who emphasize that Swedish municipalities often struggle to align cross-sectoral planning with national adaptation goals due to fragmentation in responsibilities.

Concretization

Continuing, the insights gathered from the contextualization phase, planners then enter to the so-called concretization phase where goals, strategies and actions are being planned based on the information from the contextualization (Högström et al., 2023). The main purpose of the phase is to translate the contextual knowledge into planning practices, ensuring that the practical planning aligns with the identified needs and potential. However, according to Becker (2021) this translation of contextual knowledge in climate adaptation strategies such as NbS often requires institutional learning and the undoing of isolated sectoral work.

Implementation, Monitoring and Reflection

Once actions are defined, planners and other stakeholders continue with implementation. Planners need to ensure that the interventions are executed as intended. By monitoring projects during and after implementation, planners can assess their effectiveness and functionality, generating valuable lessons to inform future planning processes. (Högström et al., 2023). However, Arvidsson and Johansson (2024) highlight that in Sweden, mechanisms for evaluating indirect outcomes such as high volumes of rain or infrastructure failure, are underdeveloped, posing a challenge for reflective planning proces.ses and adaptive learning.

3.3 Nature-based Solutions Theory

NbS are defined by the International Union for Conservation of Nature (IUCN) as methods to protect, sustainably manage and restore natural ecosystems to address societal challenges in effective and adaptable ways (IUCN, 2020). This is to support biodiversity benefits and human well-being. NbS is further an umbrella term for a range of strategies used to combat environmental hazards and pollutants found in urban and rural areas (Kabisch et al., 2016).

In this chapter, the most commonly utilized NbS strategies for combating floodings will be presented. However, only strategies applicable in the Swedish context will be discussed. The suitability of different NbS is largely determined by regional climatic conditions. For instance, mangrove forests are highly effective in mitigating flooding caused by strong winds and large wave action in tropical coastal regions (Menéndez et al., 2020). However, it is a solution that cannot be implemented in a Swedish context because of the Sweden's cold climate. Therefore, alternative NbS strategies will be assessed and reviewed. Cost estimates for several NbS strategies have been included, building on previous research to present their plausibility and comparing them to traditional hard-engineered solutions.

Living Shorelines

The ocean and the shoreline are regions that are especially vulnerable to damage caused by climate change. Numerous solutions have been theorized and tested to prevent the sea from closing in and flood nearby settlements and urban regions. However, many of these solutions mainly handle the problem by constructing high concrete walls to keep the water out. Theoretically, it is the easiest way of handling the problem (Hardaway, 2019). However, it doesn't mean that it is the best way of managing the issue. By constructing large, hardened walls, many ecosystems would be damaged, as large unnatural barriers are introduced in the environment. Moreover, the human connection to nature would be lost, recreational purposes for human activity and the interactions with plant and animal species greatly damaged.

The term living shorelines is a term developed in the 1970s (Hardaway, 2019). However, limited implementation in large-scale context has been constructed on shorelines ever since. To successfully revitalize shorelines, native vegetation is crucial, to stabilize the soil and prevent landslides. Native plants and shrubs' root systems penetrate the soil deeper and are more robust compared to invasive species, which is important due to shoreline soil types often being unstable due to fine substrates (Hardaway, 2019). Increasing erosion resilience and infiltration, crucial aspects in flood mitigation management.

Implementation of living shorelines is expected to cost ranging from €130-€600 per meter, which is cheaper than the price of grey stabilization systems per meter being €350-€3250 (Restore America's Estuaries, 2021). The study analysed 6 case studies in USA that utilizes living shorelines as climate adaptive measure. While traditionally implemented in rural settings, new ideas are emerging that explore their application in more urban contexts, especially in urban settings consisted of extensive shorelines. Gothenburg is therefore an appropriate area.

Seagrass Restoration

Seagrass plays a major role in reducing wave energy, as well as, improving water quality and providing animal habitat for marine life (Forrester, J et al., 2024). Promoting native plants is fundamental for the systems and wildlife. Zostera Marina (Eelgrass) is a species native to the Gothenburg region and grows in shallow and sandy seafloors. Its importance extends beyond providing habitats, its purpose also includes binding and stabilizing sediments on the seabed. Essential for preventing erosion and protecting from waves (Forrester, J et al., 2024). Eelgrass can effectively reduce the erosion rate of seabed by 25-50% (Meysick, 2022). In the study *ZORRO - Interdisciplinary research about management and restoration of eelgrass in Sweden* (University of Gothenburg, 2024) small-scale pilot projects have been successful in the Gothenburg region, showing promise for implementation in large-scale. Additionally, the study *Seagrass Restoration in Sweden: A Pilot Study* (Moksnes, P.-O, 2016 the study made the estimation of the cost for Zotera marina plantation at approximately €120 000-250 000 per hectare (Moksnes, 2016) in a Swedish context.

Oyster Reefs Restoration

The west coast of Sweden offers a different marine biology and conditions, compared to other coastal regions in Sweden (SLU Artdatabanken, 2025). Being situated in the transition zone between Kattegat and Skagerrak. A proximity to the North Sea results in salty waters and a diverse ecosystem of species living in and around the water content. Oysters (Ostrea edulis) and other shellfish and species native to the coastal regions of Gothenburg, being dependent on salty waters to create their shells. They are essential to support many marine species such as fish, shrimps and crabs. Vital for water quality, acting as natural water filtration systems. One oyster can filter as much as 50 Liters of water each day, removing many pollutants and excessive nutrients (SLU Artdatabanken, 2025). Furthermore, oyster reefs can combat coastal regions from rising sea levels in multiple ways (Morris et al., 2018). They reduce wave energy by acting as natural breakwaters to absorb the energy provided by the waves. Additionally, with higher sea levels and stronger wave action, erosion tends to increase and follow the pattern. Oyster reefs help stabilize sediments, preventing shoreline to wash awa, trapping sediments and gradually increasing oyster reef height over time, constructing an artificial barrier consisting of natural obstacles for wave control. Oyster reefs are comparable to the cost of traditional constructed sea walls and in the study estimation on €250 000 per hectare have been calculated for Reville Bay in Ireland (Hynes et al., 2022), demonstrating effectiveness against coastal flooding, biodiversity enhancement and cost-efficient.

Reinforced Riverbanks and Buffer Zones

Reinforced riverbanks and implementing buffer zones are vital strategies for mitigate flood and erosion risks, particularly in regions with sensitive geological and hydrological conditions (Ström et al. 2012). In Sweden, many rivers such as the Göta River passes though densely populated and industrial areas, increasing the vulnerabilities of these landscapes during extreme rainfall events and floodings (SGI, 2012).

Several geological factors intensify these risks since much of Sweden’s terrain consists of post-glacial clay soils, which are highly sensitive to water saturation. These soils, particularly common in regions like Gothenburg become unstable when overloaded with water, raising the risk of landslides and increased flooding impacts (Strudley et al., 2020). The effects of isostatic rebound that has uplifted the terrain following the latest Ice Age, have also contributed to irregular soil profiles that further complicate drainage and runoff management (SGI, 2012). Given these challenges, managing Sweden’s risks for landslides and floodings are a combination of sustainable flood control measures, responsible urban planning, and NbS strategies to mitigate risks associated with climate change and extreme weather events must be taken into account.

Reinforcing riverbanks and implementing buffer zones using native vegetation along riverbanks is therefore a vital strategy for flood mitigation and erosion (Ström et al. 2012). In the context of southwestern Sweden, several native species are particularly effective at stabilizing soils such as, Salix spp, Alnus glutinosa and Populus tremula (SLU Artdatabanken, 2025). Beyond erosion control, these plants could also help with flood resilience by slowing down water flows and absorbing excessive water, filtration of nutrients and pollutants would improve water quality, as well as providing key habitats for many animal species, including insects, birds and aquatic species. The cost of reinforced riverbanks approximately varies from €200-€350 per linear meter as calculated in the *Riverbank Restoration Guide* (Rexine, 2010). A study conducted in Mississippi, USA, heavily incorporating native species and stones to reinforce the riverbanks.

Ultimately, reinforcing riverbanks and establishing vegetated buffer zones are not only flood management tools but critical elements in multifunctional landscapes. Although traditionally utilized in rural areas, potential for integration in urban and regional planning can reduce flooding risks in vulnerable cities like Gothenburg while simultaneously providing ecosystem services.

Reconnecting Floodplains

For many decades and centuries structured and engineered streams have replaced many natural rivers and streams in the landscape (Brown et al., 2018). Many of them have in the process become thinner, straighter and stripped from much of its natural elements and biodiversity. Replaced with artificial embankments, these changes to natural waterways make rivers and streams more vulnerable to extreme rainfalls and sea level rise. Furthermore, straightened rivers increase water velocity, greatly reducing the time for natural infiltration leading to more surface runoff. High water velocity increases bank erosion along the rivers, allowing for large amounts of sediment transportation to end up in unwanted areas and could clog up important infrastructures, leading to further damage (Brown et al., 2018).

To combat anthropocentric structured rivers, NbS strategies such as re-meandering watercourses and revitalizing floodplains have started to gain traction and recognition. Remeandering watercourses is a process of restoring channelized and straightened rivers back to its former natural meandering and winding form (Albert et al., 2019). With the introduction of a more meandering watercourse many functions and advantages could be brought back to its original purpose. Water flows would be reduced leading to more time for infiltration and decreased risks for floodings. With lessened water velocity and larger diversity of habitat, many important species of plants, animals, fish and amphibians would be attracted to the area. Improving biodiversity and water quality in the region.

Within the surrounding landscape of rivers are floodplains that serve as natural buffers against floodings. As acknowledged by research (Brown et al., 2018) floodplains in Europe looked vastly different before humans started farming the lands. The rivers did not have the high floodplains it is today. They were instead either heavily brained or had interconnected streams that linked wetlands and forests. However, when humans started cultivating near watercourses, large amounts of sediments started to accumulate, causing rivers to carve deeper channels and disconnecting former floodable regions. Floodplains is an umbrella term for habitats and landscapes such as wetlands, forest and agricultural fields that can contain a large number of runoff water to prevent flooding. During the Anthropocene age many of these floodplains have been cut off by embankments. The consequences of this disconnection can be severe, most often during heavy rainfalls when the river capacity is pushed to its extent.

An ecological solution for flooding issues is to revitalize these floodplains. By removing structural impermeable embankments would help floodwaters to spread to nearby floodplains (Albert et al., 2019). Furthermore, many floodplains have been raised due to land use changes and artificial development. Methods of restoration include landscaping and planting techniques to achieve a connection to lost floodplains. The price for reconnecting floodplains challenging to quantify, largely depending on if ownership of the land has to be purchased. However, it is viewed as one of the most cost-effective solutions for mitigating floods. An estimation made by the European Environment Agency (2017) approximates a construction and rehabilitation cost of roughly €360 000 per hectare

Wetland Restoration

Wetlands are systems that provide multifunctionality in nature and support the hydrological fluctuations while improving water quality. While wetlands are mostly natural, constructed wetlands can be implemented to support the hydrological processes, enhance biodiversity and resilience. Beyond providing benefits to natural systems, wetlands have been shown to be as effective at retaining floodings with short return periods (Ferreira et al., 2023). For extreme floodings (100 years return time) specific locations inside vital catchment areas can have substantial value in catching and retaining water. Large wetlands positioned low in the catchment area can effectively store additional volumes of water rather than wetlands existing further up in the catchment area on higher elevations (Ferreira et al., 2023). Demonstrating that wetlands situated further down in the catchment area, in this case around the Gothenburg region, shows the most promise as a flood mitigation strategy.

Natural wetlands are however largely threatened by climate drivers, resulting in many wetlands needing restoration efforts. Both for current climate conditions and the more extreme conditions projected in the future. Recent estimates have shown a global loss of 21% since the 18th century (Fluet-Chouinard et al., 2023) and in Sweden the number is a staggering 25% in just the latest century according to Naturvårdverket (n.d). Showcasing the importance for restoration projects, to help recover their natural hydrological properties. Natural and constructed wetlands have seen interest due to their low operating and maintenance actions when established, being self-sufficient. In a study made by Javaheri and Babbar-Sebens (2014), the effects of wetlands in the USA were researched. With simulative flows, they reported that wetlands are able to reduce peak flows by 42% and flood areas up to 55%. Restorative wetlands cost approximately €10,000–€20,000 per hectare (Kraufvelin et al., 2021) in the context of the weather patterns found in the Gothenburg region. It may sound high to investors, but with the huge benefits it contributes to, it can be argued to be very reasonable.

Reforestation and afforestation

By identifying low-altitude regions and creating periodical connections to the river during high water-flow times, large amounts of water could be stored in multi-purposed unutilized land during the time. For example, agricultural land or forested land could be used to temporarily store water. However, standing water for a longer period of time could damage this land (Iles & Gleason, 2008), harming the land and the landowner. If agricultural land were to be flooded in prolonged times, could nutrient-rich topsoil be washed away reducing the fertility of the land and harming crop or vegetation growth when planting season is in time.

If crops or vegetation is present, many species are extremely valuable for oxygen deprivation which occurs when they are submerged under water during prolonged periods (Iles & Gleason, 2008). Likewise, issues could affect forested areas as well. Root suffocation is a major concern for many tree species as they rely on oxygen in the soil which prolonged floodings could waterlog the soil and cause rot in the root system, leading to threat to the survival of many trees (Iles & Gleason, 2008). Further, seedlings and young saplings are especially valuable to floodings due to their root system being not that developed and could easily be eradicated both from the force of the flowing water, as well as, from suffocation due to oxygen deprivation in the roots.

However, reforestation and afforestation can still be a valuable NbS strategy. By strategically planting flood-tolerant species in riparian zones and along floodplains to stabilize soils, slow down water flows and help with groundwater absorption. Showcasing its potentials for multifunctional flood management. Furthermore, it is also the most cost-effective alternative, with the price of reforestation being around €700 per hectare in the Swedish context, as indicated by the Swedish Forest Agency (2023).

Urban Green Infrastructure

Flood resilience has in the latest decade embarked in an urban approach. Referring to the ability for urban social and ecological systems to sustain their functionality and structural properties during flooding events (Lee, 2021). Infrastructure in the urban context serves several functions that are of desire. Through conserving and improving water quality, air quality and biodiversity. Furthermore, mitigating heat island effects and controlling stormwater runoff.

Green Infrastructure systems have been developed to help solve these issues (European Commission, 2012; Kabisch et al., 2016).

Stormwater parks are large-scale, multifunctional green spaces that combine the use for stormwater detention and retention, with important habitats for many species, as well as recreational areas with green space for humans. With its wide functionality as hydrological, ecological and recreational, these systems have seen a high interest in urban planning (Fletcher et al., 2015). However, these systems require large areas in urban regions to effectively capture stormwater runoff.

In contrast, green roofs are roof systems that store rainfall and can be designed in a large variety of scales (Green Roof Organisation, 2021). By being able to retain water in the substrate, green roofs reduce the rate and volume of stormwater runoff that enters the urban drainage systems. Reducing peak runoff during heavy rainfall events and delaying the runoff discharge (Berndtsson, 2010). Furthermore, green roofs offer additional benefits such as, supporting biodiverse habitats, mitigation of urban heat island effects and working as thermal insulation.

Summary

The literature reviewed, highlights that there is a growing consensus on the ecological, social and economic value that NbS strategies have for urban flood resilience. While various NbS strategies reviewed in the chapter have demonstrated significant potential in mitigating flood risks, their application and integration into the urban and regional planning in the Gothenburg region are in need of further exploration. In urban contexts in Sweden, planning frameworks have yet to adapt to multifunctional and cross-sectoral work that the nature of NbS often require, in addition to long-term coordination across municipal land and landowners (Glaas et al., 2010). Particularly for regions working under non-statutory planning models, with Gothenburg and Västra Götaland poses as an example. The gaps in planning models born from the absence of a binding framework emphasizes the need to further investigate how local planning processes can be altered to effectively support implementation of NbS strategies. To understand how these NbS strategies can be effectively implemented, the following chapters will focus on a case study of Gothenburg´s waterfront, examining how current spatial planning practices, legal tools and discourse shape the possibilities for resilient, nature-based adaptation. This transition from theory to practice is essential in identifying realistic pathways for mainstreaming NbS into Swedish urban planning.

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4. Methodology

To investigate climate adaptations for flood-prone waterfront areas in the Gothenburg region, this study employs a multi-method approach, integrating qualitative and quantitative research methods. These include a discourse analysis, a detailed case study and GIS-based spatial analysis. This approach provides a comprehensive view of theoretical frameworks, institutional practices and site-specific physical vulnerabilities. The research further engages local planning efforts to examine how NbS are or could be incorporated into spatial planning for flood resilience.

The research addressed questions related to the effectiveness, cost-efficiency and implementation of NbS, comparing them to traditional grey solutions. The discourse analysis draws on theoretical perspectives from climate adaptation, resilience and ecological restoration, which guide the case study's methodology. This ensures that the analysis is grounded in academic research and real-world application, while also establishing a basis for examining planning documents and practices.

4.1 Discourse Analysis

A critical discourse analysis was conducted to examine how resilience, risk and responsibility are framed in regional and municipal planning. Policy and planning documents were collected from the municipality of Gothenburg, Västra Götaland County and national authorities such as MSB and SMHI. Search terms used included "flood risks", "Nature-based Solutions", "climate adaptations", "high water" and "comprehensive plan". Documents were then selected that included policy plans, strategy documents and site-specific reports. The focus was on NbS' ability to provide climate resilience and how these solutions can be incorporated into urban planning and risk reduction strategies to bridge the gaps between theoretical research, policy implementation and real-world applications.

Furthermore, this approach enabled examination of the institutional narratives, language and frameworks that shape understanding of policy issues. The discourse analysis was guided by a critical lens, focusing on governance structures and power relations embedded in the planning discourse. By reviewing comprehensive planning documents and technical solutions, the study aimed to uncover how municipalities evaluate risk, responsibility and resilience in the context of sea-level rise and the increasing severity of rainfall events driven by climate change.

4.2 Site-specific Methodology

This thesis employed a detailed case study, as defined by Yin (2003), focusing on the Gothenburg region, specifically its waterfront along the Göta River and the shoreline toward the ocean.

It examines how NbS could address flood risks, coastal and riverbank erosion. By analysing flood-prone areas within the case study region, key locations where NbS could have the greatest impact are identified. Furthermore, by reviewing existing adaptation efforts implemented by the county and municipality of Gothenburg, the effectiveness and suitability of these measures for flood protection can be evaluated in comparison to NbS approaches. This evaluation includes consideration of the environmental, economic and social implications of NbS relative to traditional flood defence strategies based on hard-engineering practices.

GIS Analysis: Geospatial tools include SCALGO Live, interactive maps from the counties and municipalities in question were used to analyse and visualize the physical risks and vulnerabilities of the case studies waterfront sites. Such as, mapping rising sea levels and mapping floods from heavy rainfalls.

Interview: To complement the document analysis, semi-structured interviews were conducted with a Gothenburg planning official from the municipality of Gothenburg. This exchange provided valuable context on how the planning strategies are being integrated into ongoing municipal planning efforts. The interview contributed to the empirical understanding of how the municipality is working with the High-water Protection program.

4.3 Materials and Limitations

Materials used in this thesis include research articles, climate adaptation guidelines, maps and governmental reports*: Kunskapsunderlag för samordnad hantering av höga flöden och dammhaveri i södra Sverige* (Länsstyrelserna i Hallands, Västra Götalands, Jönköpings, Kronobergs, Skåne, Kalmar och Blekinge län, 2024), *Tematiskt tillägg till Översiktsplanen – Översvämningsriske*r (Göteborg stad, 2019), *Projektplan – Högt vatten* (Göteborg stad, n.d.), H*ögvattenskyddsprogrammet* (Göteborg stad, 2022). Data on climate statistics, historical weather events, water levels and erosion patterns were reviewed and cited from local agencies and scientific databases. Illustrations were created using Adobe Illustrator and Adobe Photoshop.

Limitations of the methodology include its regional focus on southwestern Sweden. Other parts of the world, with different climates and weather patterns, may have more extensive research and case studies available. Additionally, regions with warmer climates might offer more applicable insights for climate adaptation, potentially enabling more effective solutions.

Data availability poses another concern as the GIS analysis relies heavily on accessible spatial data, weather event records and geological information for the study area. Additionally, limited access to county and municipal planning documents may further constrain the research. It further relies on previous material that dates back a few years. Although the material is not outdated, changes in climate tend to accelerate quickly. Therefore, it is possible that material has lost relevance in certain areas because more recent climate changes have resulted in new challenges and perspectives. While this is a weakness, it could potentially also be viewed as a possibility, as this study can provide more accurate knowledge while building on previous work.

5. Case study – Gothenburg and The Göta River

The city of Gothenburg is vulnerable due to its geographical position on the west coast of Sweden, situated between the North Sea and the Göta River, which runs through the entire city (Göteborg Stad, 2019). Additionally, central Gothenburg is a spot where several watercourses converge into the Göta River, creating complex hydrological dynamics and increasing the city's exposure to high water levels. The area has been identified as being at risk of coastal flooding, river flooding and landslides. Such events could have catastrophic consequences for residents and critical societal functions. Without any adequate adaptation measures being implemented, large portions of the city will be flooded in the following decades, resulting in extensive social, economic and ecological disruption (Göteborg stad, 2022).

The Göta River contains the largest catchment area in Sweden at a staggering 50 000 km^2 with the source being found in Härjedalän, see figure 5. It dewaters the largest lake in Sweden, Vänern (SGI, 2012). In addition, the river passes through multiple important urban areas such as Vänersborg, Trollhättan and Gothenburg which together are inhabited by approximately 700 000 people (Göteborg stad, 2019).

Figure 5 Catchment area for the Göta River expanding over 50 000 km^2 accounting for 10% of Sweden's total land area. © Göta älvs vattenvårdsförbund [*https://www.gotaalvvvf.org/faktaomgotaalv.4.101b298612d0e33932680001774.ht*](https://www.gotaalvvvf.org/faktaomgotaalv.4.101b298612d0e33932680001774.ht)

The Göta River is sensitive to heavy rainfall due to a combination of geographical, geological, hydrological and infrastructural factors. The city of Gothenburg is prone to flooding from heavy rainfall events, see figure 6, 7 and 8. Accumulated in low-lying locations including road networks and many buildings.

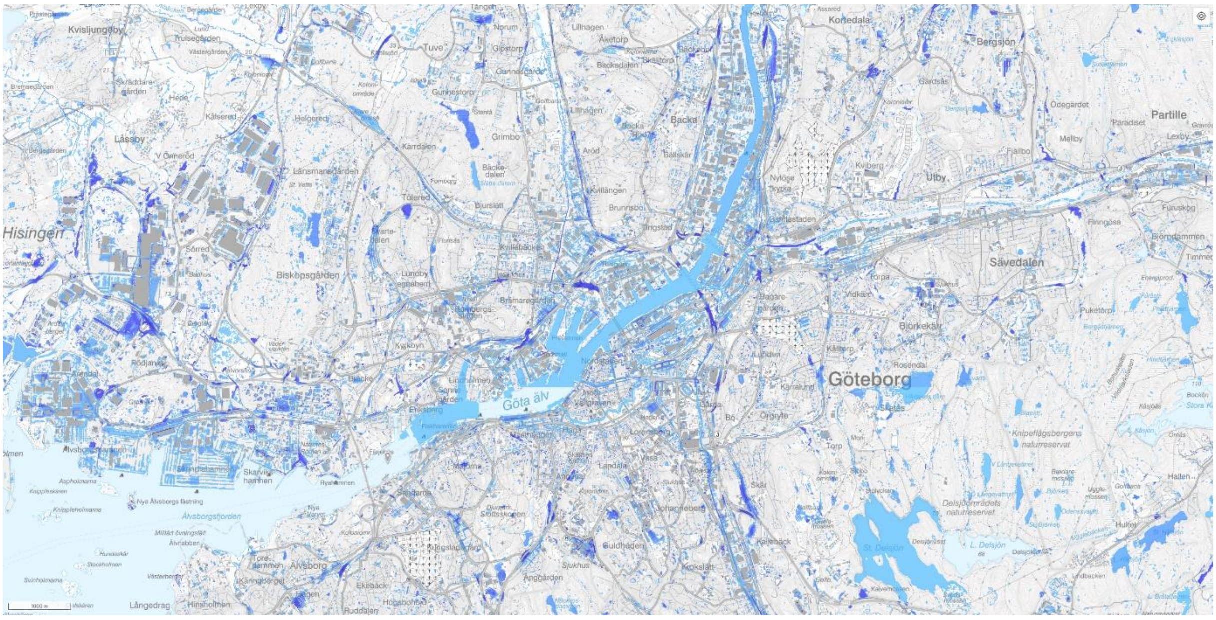

Figure 7. 100-year rainfall event projected over the Gothenburg region. Showing accumulation of water depth > 10cm standing water, in light blue to dark blue gradient. © SCALGO Live https://scalgo.com/live/.

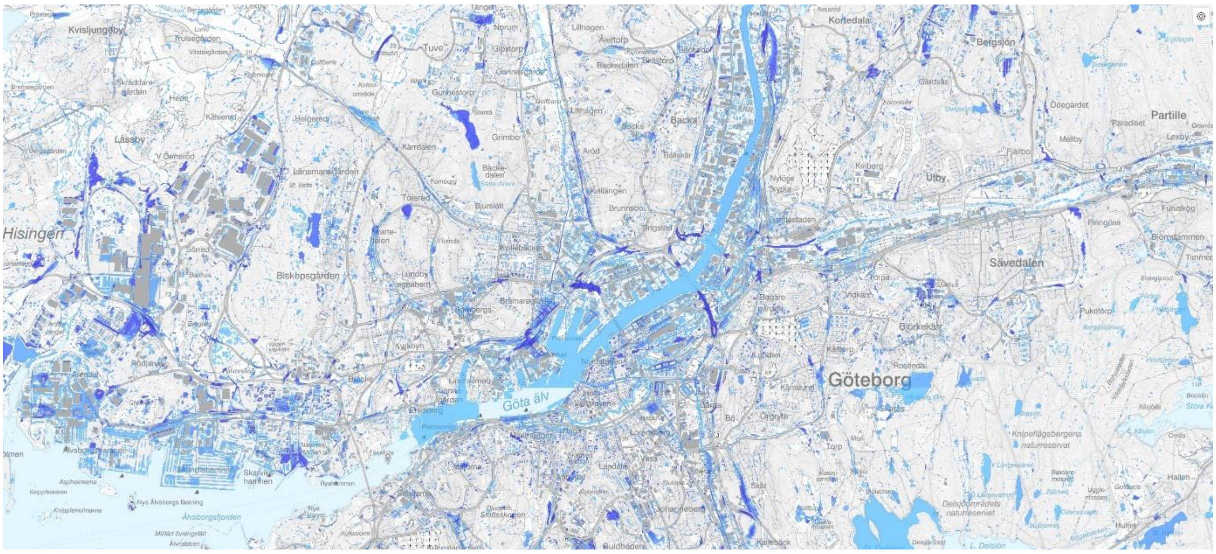

Figure 6. 200-year rainfall event projected over the Gothenburg region. Showing accumulation of water depth > 10cm standing water, in light blue to dark blue gradient © SCALGO Live https://scalgo.com/live/

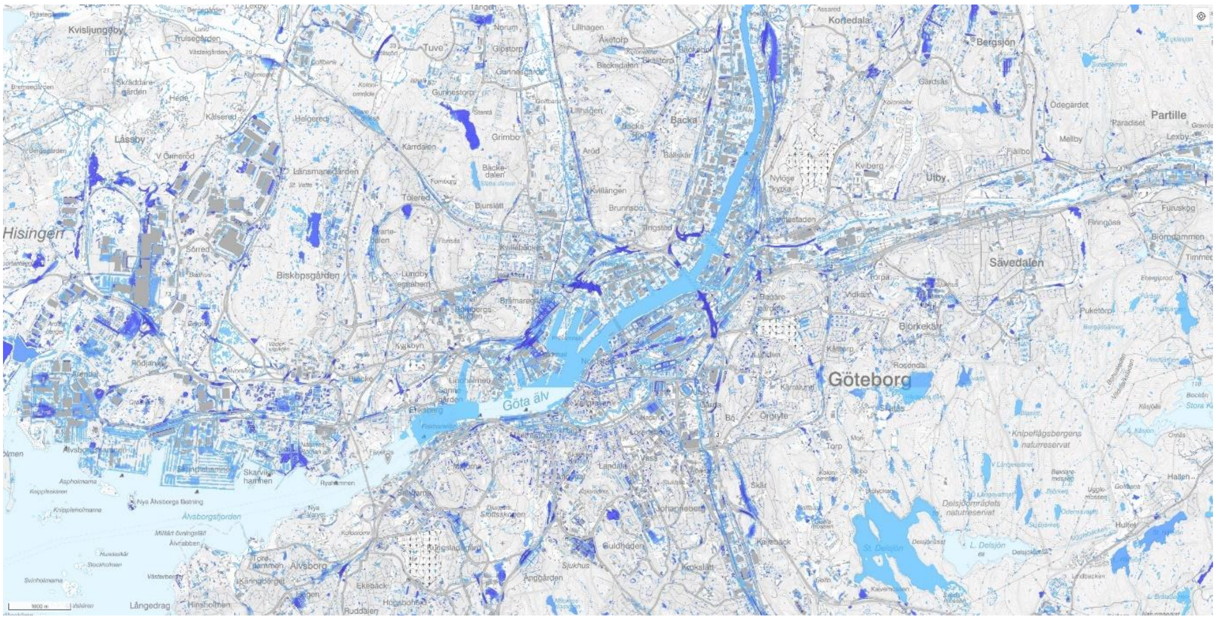

Figure 8. 500-year rainfall event projected over the Gothenburg region. Showing accumulation of water depth > 10cm standing water, in light blue to dark blue gradient © SCALGO Live https://scalgo.com/live/

As the only natural outlet of the lake Vänern, Gothenburg and other inhabited areas are affected when heavy rainfall increases the lake's water level, especially given the limited capacity for quick drainage. Furthermore, the riverbank largely consists of sensitive clay and sediments. This region of Sweden was submerged under water after the last Ice Age and began to emerge as land due to isostatic rebound, a process that has been affecting the area ever since. The region underwent a transformation, from sea, to a closed off lake and eventually to today's uplifted land. This geological process has largely contributed to sensitive clay and sediments that can become unstable once saturated with water. Unstable soil types increase the risk of landslides, which can worsen flooding and cause damage to infrastructure and habitats.

5.1 Historic event - Tuveraset

The region surrounding the Göta River has experienced numerous incidents involving unstable soils and landslides (SGI, 2023). The most severe of which occurred on November 30th, 1977, in Tuve located in the Gothenburg municipality. The area of Tuve contained many single-family homes and during the catastrophe 65 residents were destroyed, leaving 436 people without a home and claiming a total of 9 lives (SGI, 2023). The landslide began with a visible crack that appeared on Tuve Kyrkväg. Shortly after the crack was discovered, a large area of 27 hectares was completely transformed. The landslide evolved in multiple directions and the sliding surfaces followed the steep slopes of the bedrock (SGI, 2023). The Tuve landslide was the result of multiple contributing factors. Firstly, the soil in the area consists mainly of clay, extending up to 40 meters deep, resting on a layer of sand and silt. This composition, combined with steep bedrock and significant groundwater reserves within these layers, created unstable conditions. Secondly, the top layer of soil had been placed under increased pressure due to urban development, as many homes were built in the area, adding additional weight. Lastly, the tipping point is described as the unusually heavy rainfall in the month leading up to the event (SGI, 2023).

The incident marked a turning point in Sweden's approach to landslide risk, leading to increased mapping and planning for vulnerable areas, as well as the establishment of a new commission tasked with investigating the phenomenon and supporting research on the subject (SGI, 2012).

5.2 Hydropower in Göta River

There are multiple large scale hydro plants situated in the Göta River. The river has a natural altitude of 44 meters, mainly positioned in the north part of the river system in close proximity to the town of Trollhättan (Vattenkraft.info, n.d). The two largest hydropower plants are constructed in this area named Oliden and Hojum. With a combined electric efficiency of 283 MW and a yearly production of 1270 GWh of electricity these two hydropower plants are the biggest and most efficient systems in southern Sweden. Additionally, the are a few medium scale hydropower plants located along the river in the areas Lila Edet and Vargån (Vattenkraft.info, n.d).

However, the presence of hydroelectric plants poses a risk to the regions along the river, particularly in the event of extreme weather or structural failures in these engineered systems. A shock event caused by dam failure, intensified by the increased frequency of heavy rainfall, could create huge volumes of water and catastrophic floods downstream, threatening cities such as Gothenburg, Trollhättan and Lilia Edet. Given the population density in these regions the consequences could be severe. The Göta River experienced in the year 2000 severe floodings, resulting in large destruction with water discharged measured up to 1,200 m^3/s, see figure 9 (MSB, 2021). In extreme scenarios such as dam failure, the maximum discharge capacity in the Göta River is estimated to reach approximately 1,400–1,600 m^3/s (MSB, 2021) as plotted in figure 10, zooming in on the area Älvängen for reference. Displaying the river's vulnerability to flooding, especially with overwhelmed water infrastructure.

Figure 9. Discharge amount corresponding to the flood situation in 2000 (waterflow 1200 m^3/s) in Göta River. © MSB https://gisapp.msb.se/Apps/oversvamningsportal/avancerade-kartor/gota_alv.html. Showcasing the rivers risk for overflowing.

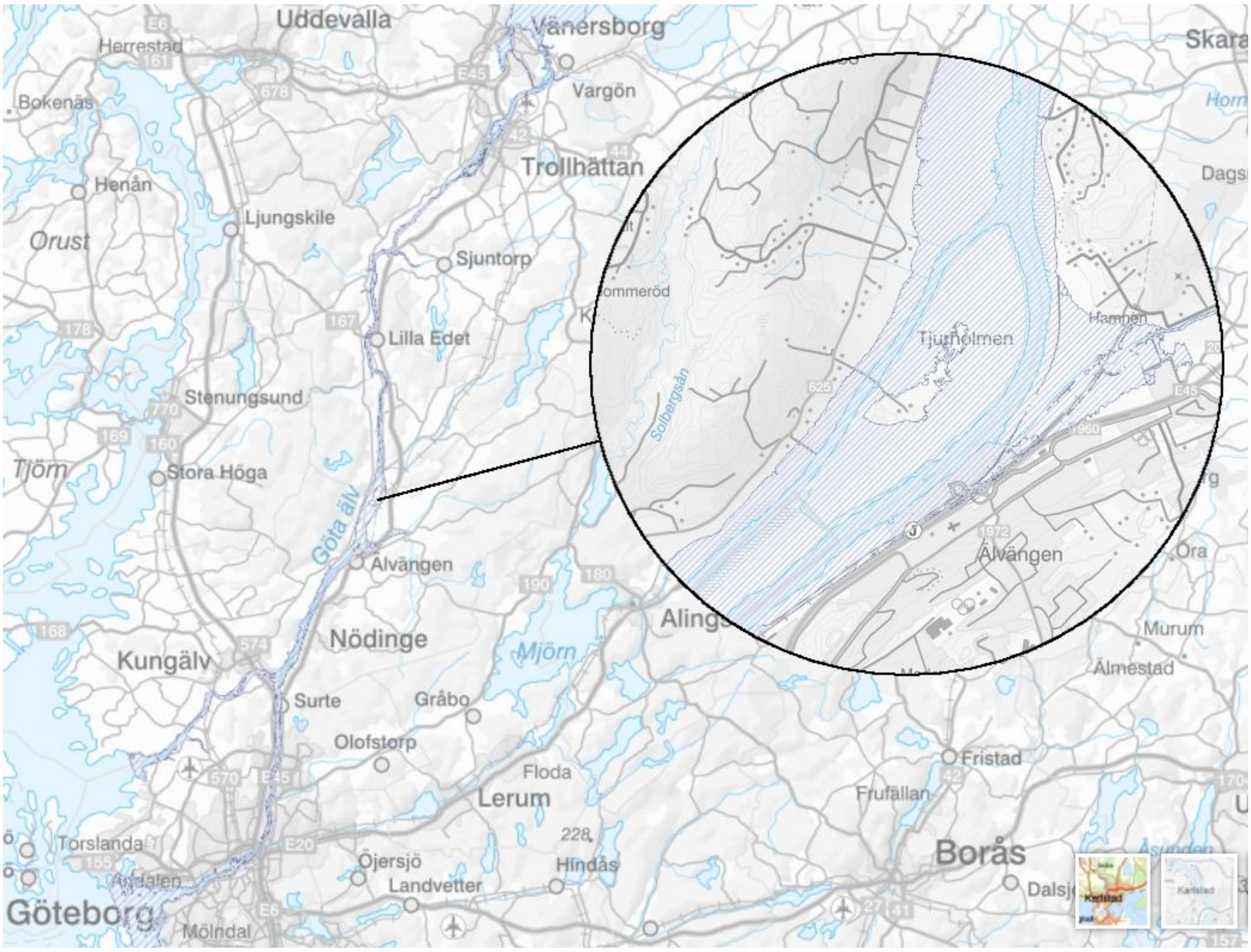

Figure 10. Maximum discharge amount technically possible in Göta River (waterflow 1600 m^3/s). © MSB https://gisapp.msb.se/Apps/oversvamningsportal/avancerade-kartor/gota_alv.html. With planned preventive measures, the river would still be heavily flooded during high flow events

Along the Göta River, hard surface infrastructure such as embankments and concrete walls control much of the riverfront landscapes. These engineered systems have largely disconnected natural floodplains and increased pressures on existing infrastructure. According to regional planning assessments (Länsstyrelserna i Hallands, Västra Götalands, Jönköpings, Kronobergs, Skåne, Kalmar och Blekinge län, 2024), there is growing recognition for alternative approaches, such as NbS, that can provide additional resilience and ecological functions. One of the primary goals according to MSB (2021) is to reduce pressure on dams and other artificial infrastructure, thereby lowering the risk of dam failure. This further highlights the urgent need for sustainable solutions to address these issues.

5.3 Planning practices

In this chapter the current planning practices in Gothenburg are reviewed through the lens of discourse analysis.

MSB (2022), in collaboration with the County Administrative Board of Västra Götaland and the City of Gothenburg has developed a risk management plan for the Gothenburg region extending until 2027, in accordance with the EU Floods Directive (2007/60/EC). The plan is formulated in an urban context and outlines strategies for mitigating flood risks that could potentially affect approximately 3,400 residents and around 1,500 workplaces, employing a total of about 21,500 people. It also addresses the risk of disruptions to critical infrastructure and public services.

Building on previous flood risk management efforts, the County Administrative Board of Västra Götaland and the City of Gothenburg collaborated with government agencies such as the Swedish Transport Administration, as well as private stakeholders in the region.

The plan is centred on the flood-related pressures facing the region and establishes four comprehensive goals to guide urban and regional planning in flood-prone areas, in alignment with the EU Floods Directive (2007/60/EC). These goals focus on protecting public health, the environment, cultural heritage and economic activities:

- *Public health* – The goal for public health aims to protect human life and reduce the number of people who could be negatively affected by potential flooding.

- *Environment* – The environmental goal emphasizes the importance of protecting key ecosystems and minimizing the impact on natural habitats during flooding events.

- *Cultural heritage* – The cultural heritage goal aims to protect and preserve valuable sites and artifacts of historical and cultural significance.

- *Economical activities* – The goal for economic activities focuses on reducing economic losses and protecting essential industries that support society.

A few preventive and protective measures are proposed in the document to avoid and protect areas in the urban context. Aspects such as, a minimum building elevation of +2,8 according to RH2000. As well as stricter regulations regarding developments in waterfront areas and relying on hard surface engineered systems to drain and block water. They recognize the importance of implementing green spaces that are resilient to extreme weather conditions.

> "Gothenburg also needs to adapt to future higher sea levels and extreme weather conditions by making space for water, greenery, and shade in the city" (Göteborg stad, 2019, p. 14)

As outlined in the region's comprehensive plan. This plan calls for protective measures against increased water levels and flow to be implemented between 2030 and 2040 (Göteborg stad, 2019). However, the current risk management plan lacks a clear strategy for integrating these approaches. For high water flows and with a sustainable mindset, improved drainage systems are not enough for the climate issues that we are experiencing today and the more severe situations that we will face tomorrow. Elevated planning levels are a step in the right direction but should not be the sole solution. In the non-construction zone for buildings, ecological solutions would function well as transition zones and floodable areas.

While the risk management plans recognize the importance for sustainable and resilient measures. Although, the plan lacks a comprehensive tool for the integration of NbS in a systematic way. Similarly, the plan lacks a clear implementation framework, even though there are plenty of details regarding proposed timelines, division of labour and collaboration. Especially regarding stakeholder engagement and the involvement of local stakeholders and communities. As previously found, the responsibility for climate-proofing estates lies with the resident owners, although there is limited collaboration with the administrative board.

Comprehensive Plan - Thematic Supplement for Flood Risks

The existing comprehensive plan for the Gothenburg region acts as a guideline for the future developments and decision-making. However, it does not act as legally binding to forthcoming expansions. An additional document: "*Thematic extension to the comprehensive plan for flooding risks"* (2019) has therefore been constructed serving as a strategic framework, integrating flood risk consideration into urban planning as a complement to the comprehensive plan from 2019 (Göteborg stad).

The comprehensive plan aims to support infrastructure projects and development initiatives to prevent damage from projected increases in water levels through the year 2100. It emphasizes that, beyond climate-proofing new developments, existing urban and suburban areas also require further adaptation. Property owners are responsible for protecting properties and land not classified as essential to society. However, water-related climate adaptation is recognized as an interdisciplinary challenge, highlighting the need for enhanced collaboration among the various stakeholders within the municipality to develop an effective climate-proofing strategy for the region.

Before approving new development projects, the City Planning Office of Gothenburg evaluates the suitability of the land using maps of flood risk and soil stability. If developments are situated on critical land, they need to meet the flood protection requirements set in the comprehensive plan, mainly by building on elevated ground, or to construct flood prevention solutions such as floodable parks or technical flood protection such as barriers and embankments. The comprehensive plan calls for further investigations regarding high-water protection methods that were enhanced in the High-Water Protection Program. The necessity for the programme and their working methods is illustrated by the following quote:

> "We work according to the principle of integrating measures when other necessary work is already being carried out. For example, the Urban Environment Administration incorporates high-water protection measures into their harbour reinvestment projects. Based on detailed development plans, we implement the required measures, primarily through robust elevation planning and secondarily through site-specific risk assessments that may justify technical protective measures. Remaining measures are to be addressed through the High-Water Protection Programme." (City Official, 2025).

High-Water Protection Program

To combat the elevated water levels caused by climate change, the municipality of Gothenburg has initiated a program set out to protect important infrastructure and waterways. By incorporating planning, coordination and implementation into a framework, the municipality hopes to make protective measures along the Göta River as well as water ways flowing in urban areas. Therefore, based on conclusions drawn from the comprehensive plan, the High-Water Protection Program was initiated.

To provide a deeper understanding of the program, it is implemented in the following stages:

- *Planning and coordination* – A comprehensive plan constructed to identify and prioritize areas for necessary measures.

- *Construction of protective structures* – Construction consisting of geotechnical and engineered methods such as land elevation, protective walls and pump stations to mitigate high flows.

- *Collaboration* – The project is a collaboration between various companies and departments within the municipality of Gothenburg as well as external partners and stakeholders.

- *Communication* – Open and clear communication with citizens and appropriate stakeholders is essential for participation and understanding.

Protective measures in the city centre consists of seawall construction along two locations in the harbour region. Masthuggskajen and Packhuskajen are located in the central areas of Gothenburg. These are piers that have functioned as industrial and transportation hubs, being artificially built into the water. In the High-Water Program these sites have been chosen to be reinforced with high concrete walls to keep the water out. In addition, to creating a walking path completely built from hard surfaces as shown in Figure 12, 13 and 14 below and is described in the following quote:

> “At present, the programme has not yet entered the project planning phase, as no decision has been made. What is currently ongoing or has already been implemented in the city primarily involves elevation measures based on detailed plans, and for example, flood walls at Masthuggskajen and Packhuskajen.” (City Official, 2025).

It is further explained that there is a strong focus on developing new riparian buffer zones when harbour regions require renovations, as discussed in the following quote. That said, at this stage in the planning process, it is difficult to see any implications

> “The idea is to adapt protections in the most appropriate way. Our ambition is that none of the city’s existing natural structures along the waterways should be removed or diminished. Instead, the goal is to develop new riparian buffer zones where they are currently lacking, or alternatively to expand or at least improve the functionality of existing buffer zones where possible.” (City Official, 2025).

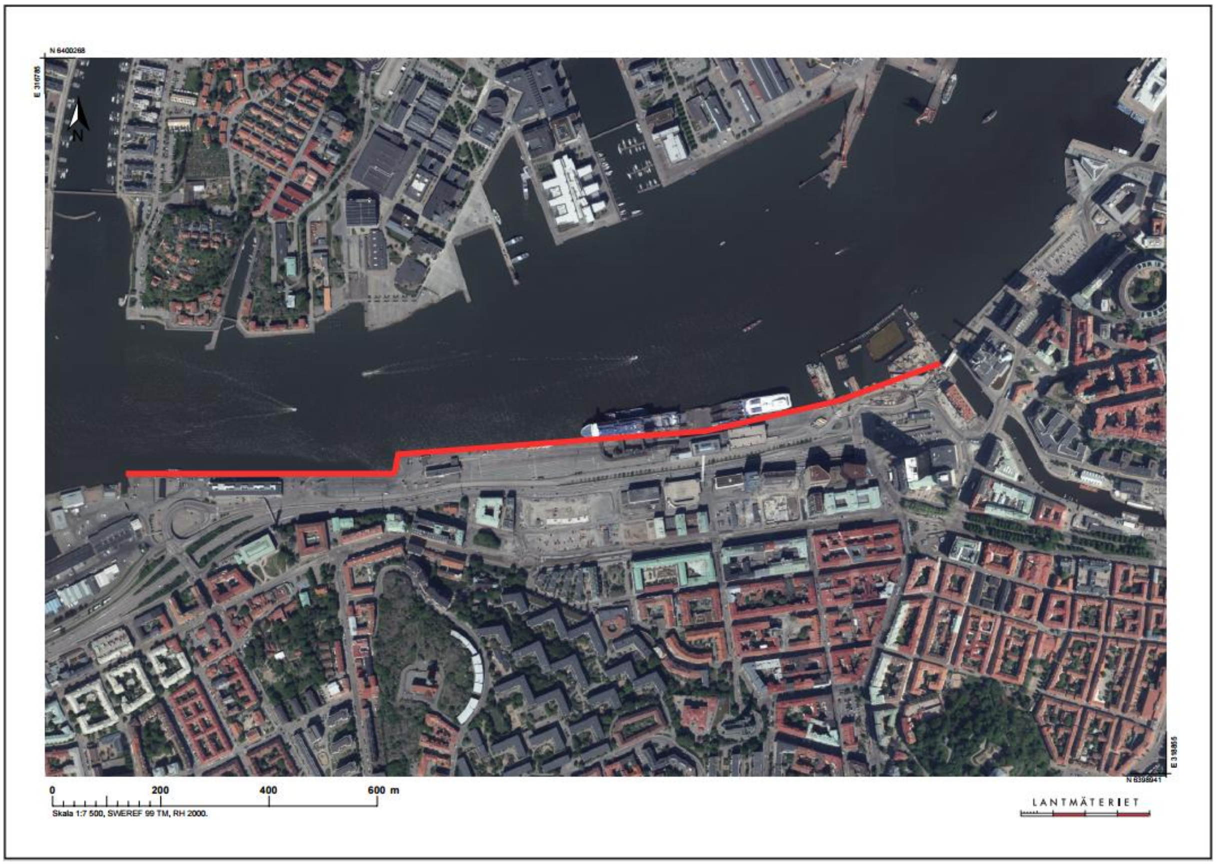

Figure 9. Masthuggskajen, area for proposed seawall construction. © Lantmäteriet https://minkarta.lantmateriet.se/

Figure 10. Packhuskajen, area for proposed seawall construction. © Lantmäteriet https://minkarta.lantmateriet.se/

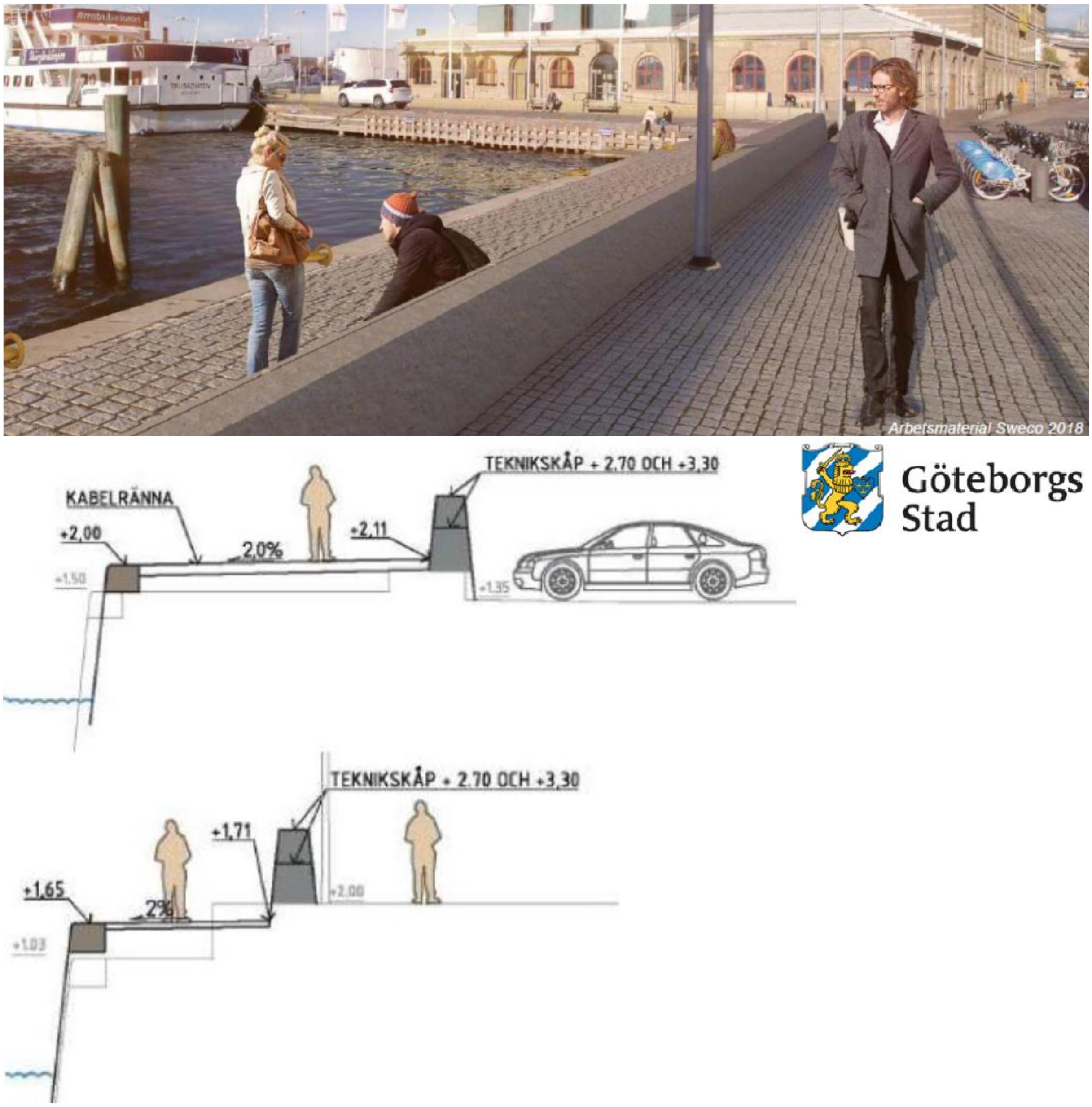

Figure 11. Design proposal for Masthuggskajen and Packhuskajen Göteborg stad and SWECO, (Göteborg stad, 2019). Highly dependent on hard infrastructure.

Until the year 2070, outer protection methods consisting of open and closable sea gates are planned to keep water out. These gates are scheduled for construction at Älvsborgsbron, Norra älv, and Väleniken. SWECO is the chosen consulting firm responsible for designing and planning the sea gates. An early estimate from SWECO places the cost of constructing the gates at Älvsborgsbron alone between 10 and 20 billion SEK (€1–2 billion) (SWECO, 2025). These 5-meter-tall walls, planned for the ports of Gothenburg and upstream along the Göta River, are specifically designed to combat storm surges and high flows during extreme weather, closing only under such conditions, see Figure 15. Most of the time, they will remain open to support river outflow and maintain shipping traffic, as Gothenburg is the largest shipping port in the Nordic region.

However, since the gates will not permanently block the sea, additional solutions such as high concrete walls are planned for low-lying areas in the city centre. These measures will add to the overall costs and urban development, while significantly increasing hard surface coverage, which can negatively impact habitats, social values, human well-being and architectural aesthetics. On the other hand, the responsibility for climate adaptation measures is put on the property owner, decreasing the municipalities accountability for implementation. This is further elaborated on in the following quote.

> "Climate adaptation measures are the responsibility of the property owner, which means that we are currently primarily responsible for actions on land that we own. We have received inquiries from property owners regarding collaboration, and the idea is to develop such partnerships. We are also anticipating a government inquiry (SOU) to be released in May regarding legislation and financing for climate adaptation, to which we have contributed input." (City Official, 2025).

Figure 12. Design principles on outer sea gates proposed in Gothenburg's archipelago (SWECO, 2013)

5.4 Reflections

The comprehensive plan and the High-Water Protection Program developed by the City of Gothenburg reveal several challenges in integrating sustainable and resilient flood risk management strategies for the future. Viewed through an institutional and critical discourse lens, it becomes evident that, despite an awareness of pressing climate issues, the city's response framework remains fragmented, often contradictory and marked by competing priorities. Most notably, housing development along the waterfront and the push for economic growth create significant challenges.

The strong demand for housing pressures low-lying city areas and upstream regions, where much of the remaining undeveloped land lies in flood-prone zones. This reflects a discourse that often favours short-term urban and economic development, rather than long-term climate resilience.

The High-Water Protection Program does propose responses to the pressing challenges. Most importantly, the municipality wants to protect urban areas and important infrastructure. However, when critically analysed, it is evident that in this stage of the planning process, the solutions heavily rely on hard-engineered solutions, such as seawalls made from concrete, elevated land and stricter building permits. This reflects a preference for hard infrastructure solutions over nature-based strategies, which tend to be more adaptive and multifunctional.

Examples of this are sites like Masthuggskajen and Packhuskajen, traditionally industrial areas that now are being reinforced with seawalls for short-term protection. Sites that have potential for increased biodiversity and urban liveability that many NbS strategies would contribute with. The municipality expresses intentions to preserve and enhance riparian buffer zones. However, without clear frameworks for large-scale integration, there is concern these efforts will remain limited.

The proposed outer sea gates represent the most ambitious solution for flooding caused by storm surges in the sea and intense rainfall accumulating in the Göta River. While being interesting and incorporating cutting-edge technology they also raise questions about effectiveness, ecological consequences and socio-political situations where the city centre is being protected but not the rural communities. In addition to the fact that these gates do not function as a permanent protection method, additional strategies would need to be developed. These urban-centric strategies create significant implications for upstream rural and peri-urban municipalities, for example, Lilla Edet and Trollhättan. When the proposed sea gates are activated, they risk displacing large volumes of flood water to the neighbouring municipalities. This reveals a critical urban-rural tension in flood risk management, especially when rural regions are economically and politically less equipped. Furthermore, this highlights a potential for environmental injustice, as Gothenburg fortifies itself, many agricultural stakeholders and smaller upstream municipalities are at risk of becoming sidelined in the decision-making process. This underlines the need for a cross-municipal planning framework that distributes both protection and risk more justifiably.

Moreover, implementation of flood mitigation strategies such as NbS often conflicts with existing land uses such as agriculture, forestry or residential development, which may have to be altered to support flood mitigation strategies. Possibly creating tension with current landowners, especially if landowners fear displacement or loss of income.

In conclusion, Gothenburg’s flood management approach is currently shaped by conflicting priorities. While the High-Water protection Program talk represents awareness of the situation and promotes the presence of natural processes as resilience, it strongly emphasizes grey solutions. In combination with weak legislative support, it declares the need for a systematic integrated approach for resilience to effectively plan for flood management for Gothenburg’s future.

6. Proposal

This chapter provides a proposal for locations to implement NbS aimed at enhancing flood resilience and climate adaptation in the Gothenburg and Göta River regions. By strategically identifying suitable locations for NbS and comparing the most appropriate strategy for each, a targeted approach for NbS implementation is outlined.

6.1 GIS Analysis

To identify appropriate areas for the implementation of NbS within the Gothenburg and Göta River regions, this chapter employs the GIS mapping tool SCALGO Live. The tool facilitates geospatial analysis by accessing digital elevation models and integrating hydrological simulation tools that illustrate water accumulation, runoff patterns and flood-prone areas.

Surface water analysis was performed by simulating water flows for 100-year and 500-year rainfall events, based on predictions from SMHI and MSB.

Layering techniques enabled the integration of various important maps to identify points of interest and areas most in need of climate adaptation. These include maps from Lantmäteriet showing elevation, land cover, and land use; topsoil and landslide-prone area maps provided by SGU; and maps of important natural environments and reserves from Naturvårdsverket. By combining hydrological modelling with the spatial overlays supported by SCALGO Live, a systematic identification of areas suitable for NbS opportunities was achieved. This approach allows integration of water management functions with ecological restoration and resilience. Areas characterized by significant water runoff coverage, sufficient spatial availability and low gradients have been prioritized in this study. However, each NbS strategy has specific spatial and hydrological requirements, which will be presented in this chapter.

Areas Appropriate for Wetland Restoration

The Nordre Älv Estuary and Lärjeån are areas recognized for their ecological importance, supporting a wide range of animal and fish species. However, these areas have experienced significant ecological threats from pollutant discharges and construction activities, which have impacted their ecological character. Given the runoff coverage, large land area and need for ecological restoration, these locations are ideal candidates for wetland development and restoration as shown in Figure 17 and 18 below.

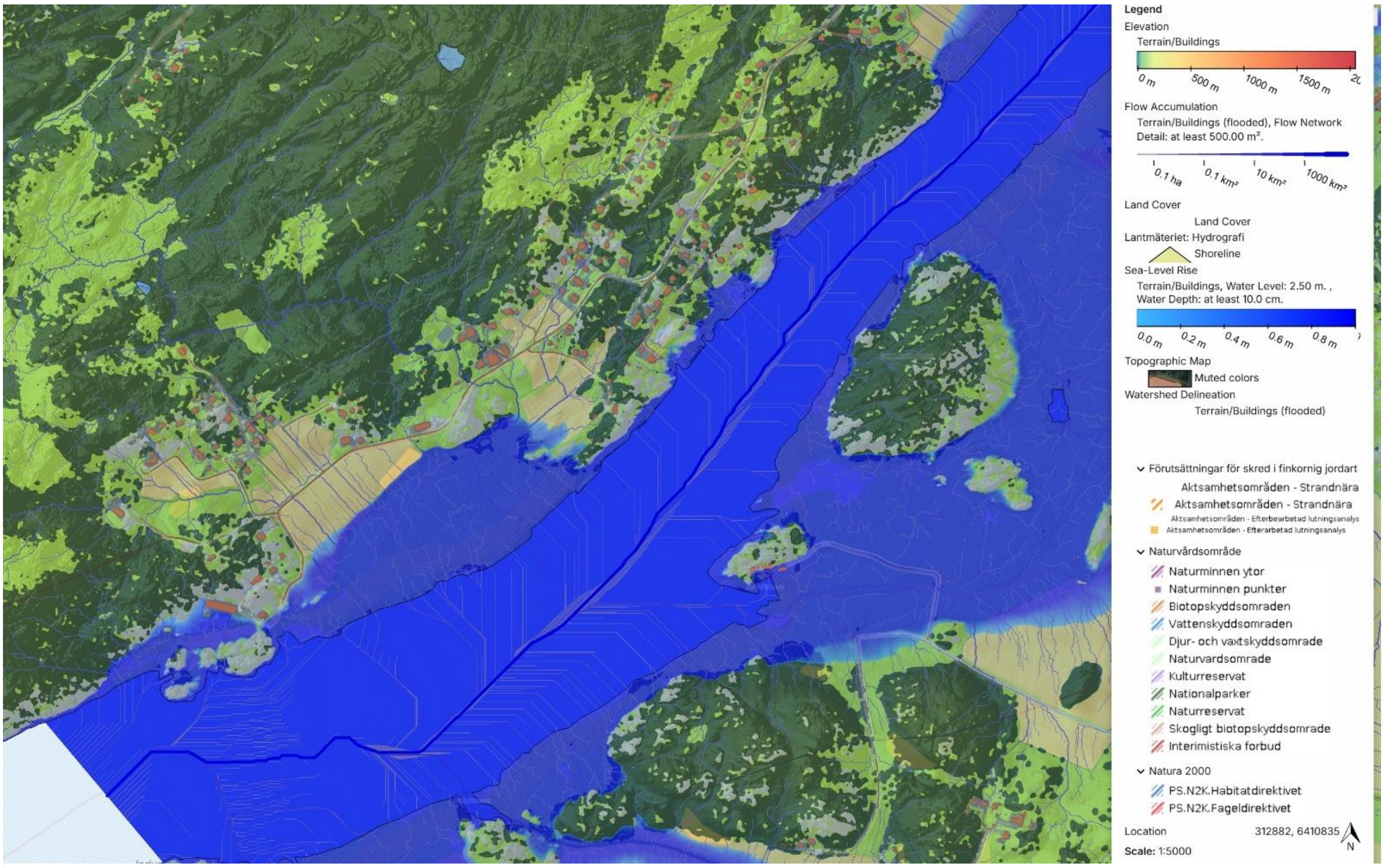

Figure 13 Nordre älvs estuarium. © SCALGO Live https://scalgo.com/live/. These maps show areas along natural watercourses that are suitable for supporting and enhancing wetlands.

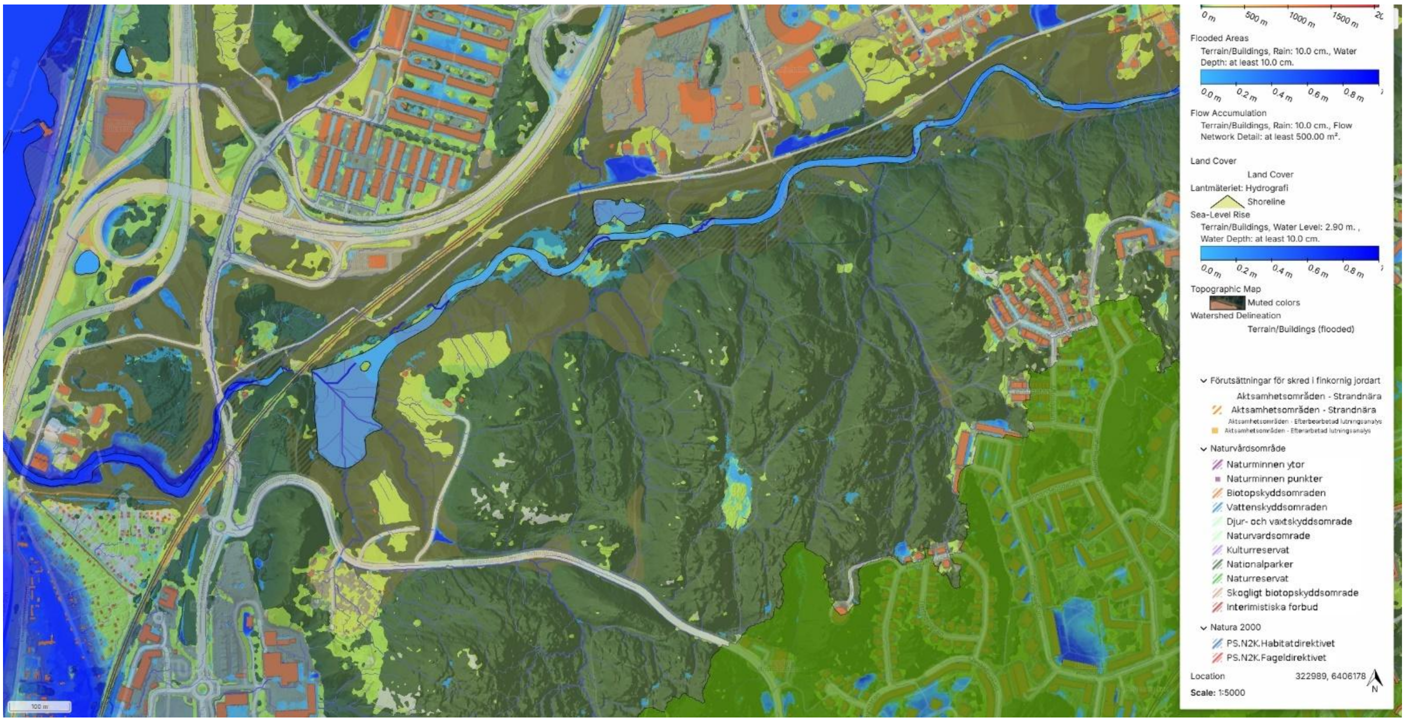

Figure 18. Lärjeån. © SCALGO Live https://scalgo.com/live/. These maps show areas along natural watercourses that are suitable for supporting and enhancing wetlands.

Areas Appropriate for Reinforced Riverbanks and Reforestation

Several sections of the Göta River Valley have historically been prone to landslides and high erosion, particularly in regions with sensitive soils such as quick clays that are highly sensitive to water saturation and disturbances. Using the soil type map from SGI, these areas prone to landslides and riverbank collapse have been identified. In these high-risk zones, reinforced riverbanks with soil-stabilizing vegetation and bioengineered techniques, such as vegetated terracing, offer efficient solutions.

Reforestation in the riparian zones along the Göta River Valley, with strategic plantations of native tree species, enhances root cohesion and soil stabilization. Additionally, it contributes to both hydrological and ecological functions. Spatial analysis in SCALGO Live indicates that reforestation is most effective on the mid and upper parts of the slopes, creating natural retention buffers. Figure 19 shows regions along the Göta River Valley that have soils prone to landslides and many watercourses moisturising the unstable soil.

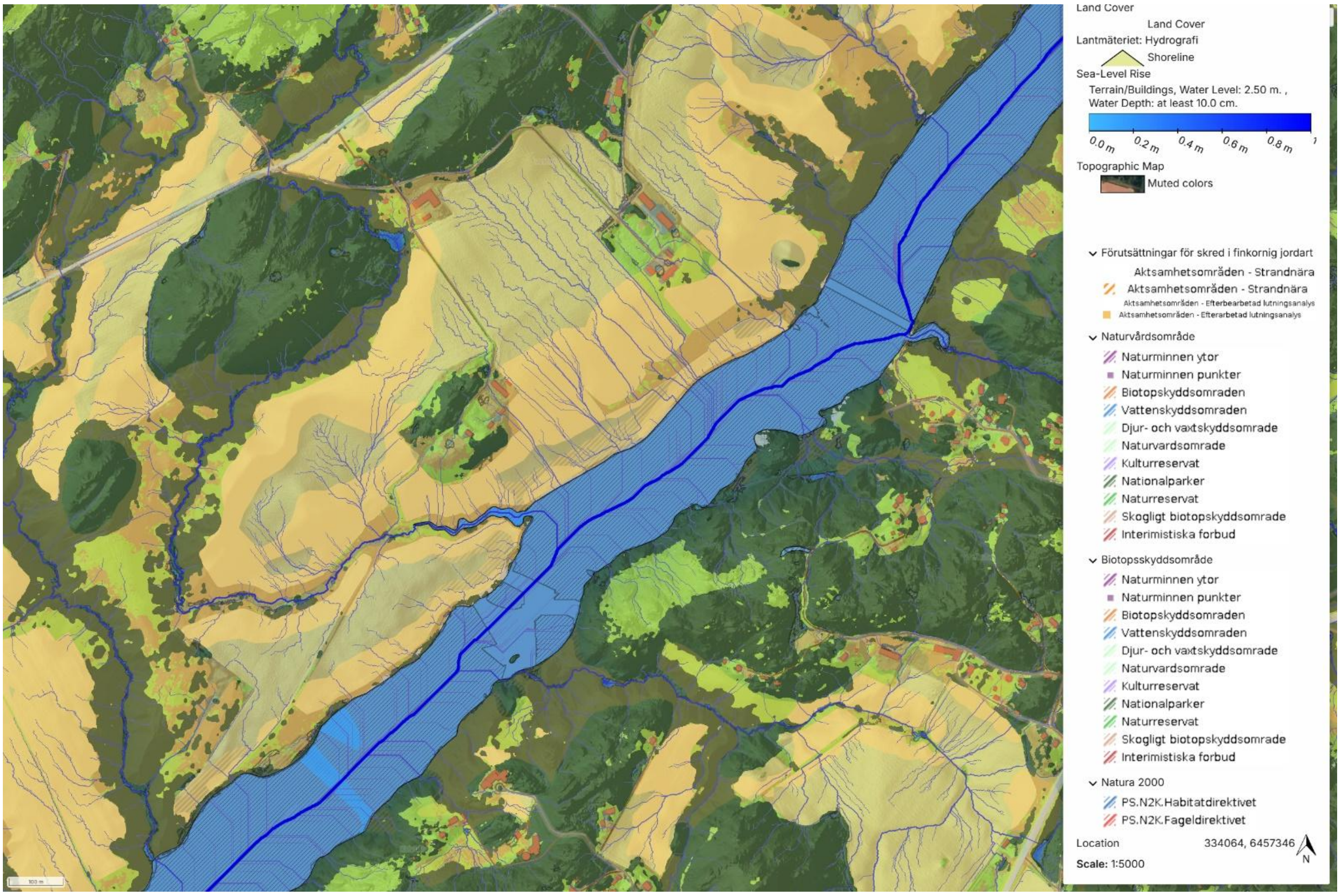

Figure 19. Gröndalsvägen. © SCALGO Live https://scalgo.com/live/. Areas in yellow presents unstable soils that are in need of reinforcement.

Native plants, shrubs and trees are important components of many NbS strategies, especially for reinforcing riverbanks. A summary of native plants to the Gothenburg region that have key benefits for stabilizing soils and thriving in wet conditions is listed in Table 1 below.

Table 1. Native plant list.

Category	***Species***	***Scientific Name***	***Key Benefits***
Trees (Deep Rooted & Water Tolerant)	Black Alder	*Alnus glutinosa*	Thrives in wet soils with strong roots that prevent erosion.
	Grey Alder	*Alnus incana*	Fast-growing, nitrogen capturing and riverbank stabilizing.
	European Aspen	*Populus tremula*	Deep roots, wind resistant, supports biodiversity.
Shrubs (Fast-Growing & Erosion Control)	Common Alder	*Alnus glutinosa*	Capturing nitrogen and stabilizes soil.
	Willows	*Salix spp.*	Various native willows (e.g., *S. purpurea, S. pentandra, S. caprea*) are all good at stabilizing soils.
	Bird Cherry	*Prunus padus*	Thrives in damp soil and has deep roots that prevent erosion.
	Guelder Rose	*Viburnum opulus*	Bushy growth that stabilizes river edges.
	Blackthorn	*Prunus spinosa*	Dense growth that protects soil from erosion.
Ground Cover & Grasses (Soil	Purple Moor Grass	*Molinia caerulea*	Tolerates wet conditions and has

Stabilization & Water Filtration)			deep roots that stabilizes soil.
	Common Reed	*Phragmites australis*	Excellent for water filtration and riverbank stabilization.
	Sedges	*Carex spp.*	Several native species help hold riverbanks in place.
	Amphibious Bistort	*Persicaria amphibia*	Thrives in wetlands and efficiently binds soil.
	Trifid Bur-Marigold	*Bidens tripartita*	Holds onto silt banks and prevents erosion.
Aquatic & Wetland Plants (Water Filtration & Silt Capturing)	Yellow Iris	*Iris pseudacorus*	Strong root system that stabilizes wet soils.
	Cyperus Sedge	*Carex pseudocyperus*	Binds wetland soils and reduces erosion.
	White Water Lily	*Nymphaea alba*	Slows water currents and stabilizes sediment.
	Brooklime	*Veronica beccabunga*	Grows along the water's edge and stabilizes banks.

Sources: Elpel, n.d. & SLU Artdatabanken https://www.wildflowers-and-weeds.com/Plant_Identification/Sweden/Native_Shrubs_Trees.htm & https://www.slu.se/artdatabanken/

Areas appropriate to reconnect floodplains

Älvängen and Lilla Edet are located upstream along the Göta River and combine critical hydrological positioning with underutilized flood prone lands. Hydrological modelling shown in Figure 20 reveals that the region is expected to experience severe high-water levels. The area largely consists of low-lying agricultural fields that have been artificially disconnected from the natural floodplain through strategic ditching, a legacy of historical agricultural land use. These areas offer sufficient spatial availability and the opportunity for a multifunctional landscape that can serve as both productive agricultural land and effective floodplains during peak flow events. This approach would help reduce flood risks downstream and promote sediment deposition.

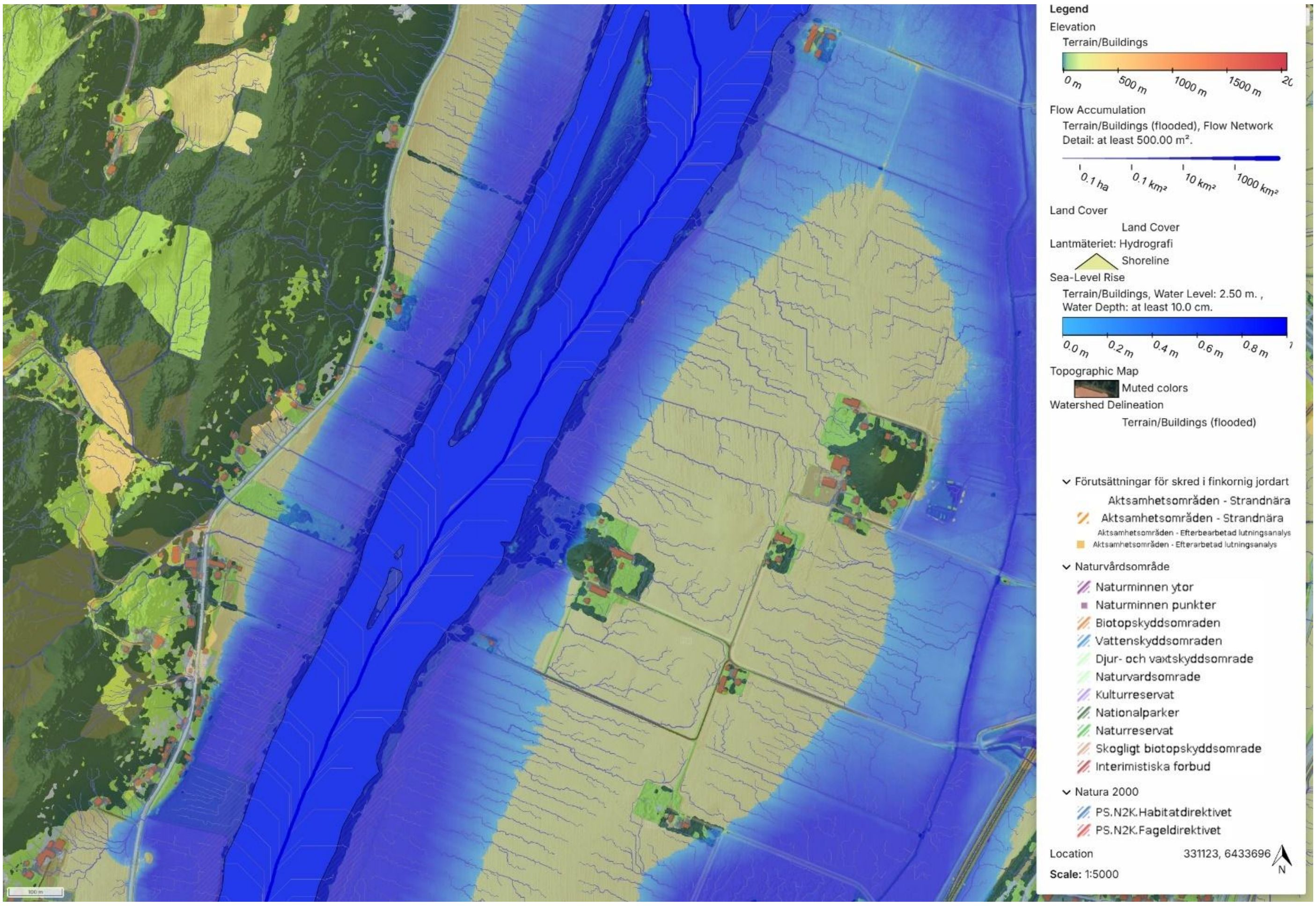

Figure 20. Älvängen © SCALGO Live https://scalgo.com/live/. The agricultural lands in Älvängen are highly prone to flooding and in need of connecting natural waterways.

Areas appropriate for Living shorelines

Frihamnen in central Gothenburg is a former industrial area with a low-lying elevation. The site consists heavily of impermeable surfaces that are exposed to flooding, especially with the ongoing sea level rise. With planned densification and industrial expansions in the area (Göteborgs stad, 2019) it heightens the need for adaptive coastal protection. In the development plan an ambition to include accessible public space is stated, a perfect opportunity to integrate living shorelines with multifunctional green spaces. By emphasizing a gradual shoreline transition, rather than hard-engineered edges, these buffer zones can support flood resilience, ecological habitats and human activities.

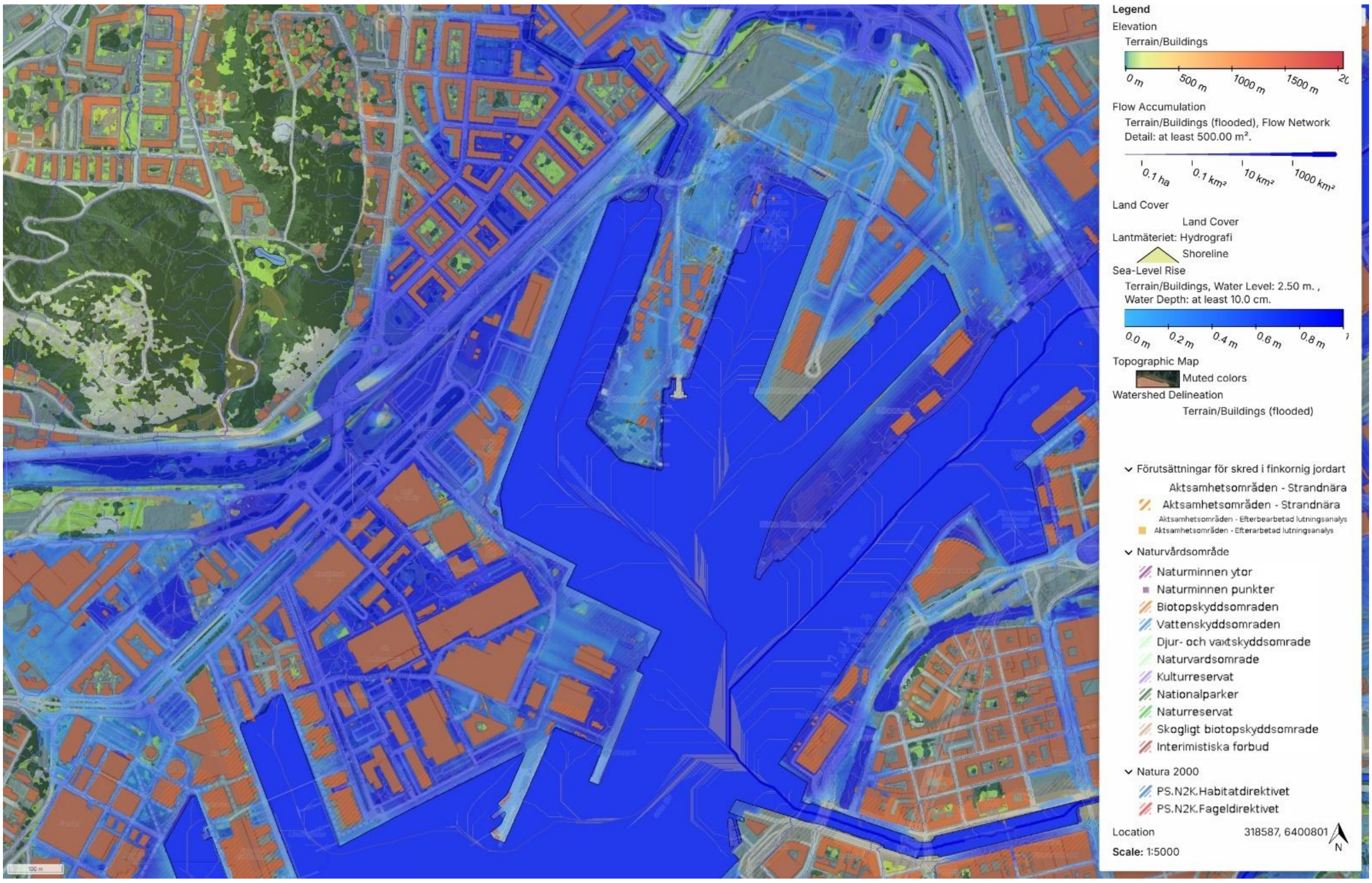

Figure 21. Frihamnen. © SCALGO Live https://scalgo.com/live/. The harbour area of Frihamnen is projected to be heavily submerged in the future, as indicated by the blue gradient.

Areas Appropriate for Oyster reefs

Gothenburg archipelagos provide excellent conditions for the growth of oyster reefs since the Swedish flat oysters (Ostrea edulis) prefers brackish waters, but not freshwater (SLU Artdatabanken, 2025). To close proximity to the river mouth would not be salty enough and threaten the survival of the oysters. Further out in the archipelago the substrate changes to harder seabeds consisting of rock or shell-based, perfect conditions that oysters thrive in. In the right conditions, with the right substrate and moderate wave speeds the oyster reefs can grow more resilient over time, helping coastal protection from wave action and erosion, as well as, enhancing the water quality.

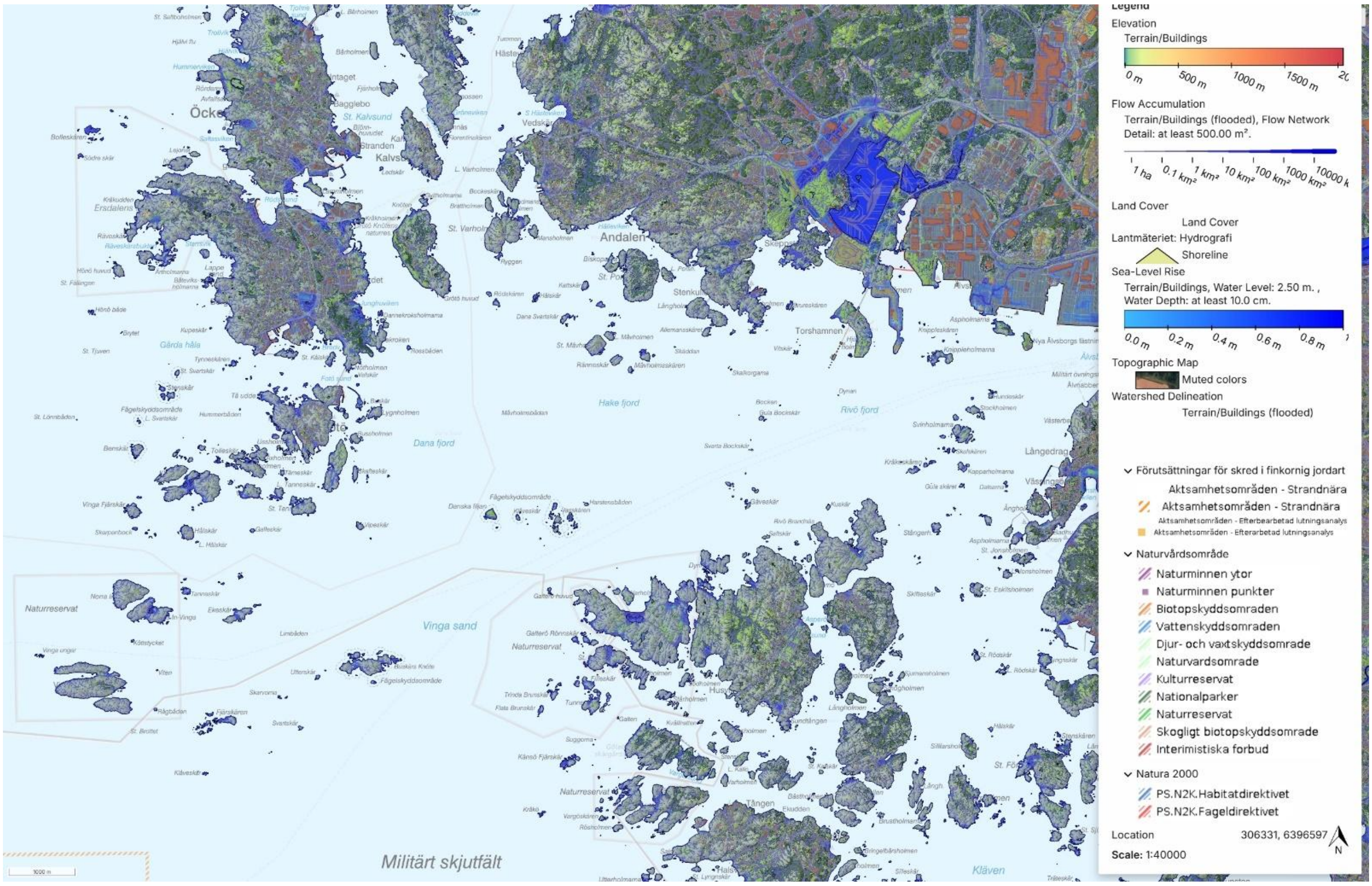

Figure 22. Gothenburg's archipelago. © SCALGO Live https://scalgo.com/live/

Areas appropriate for Seagrass restoration

Seagrass restoration has been the focus for successful research and case studies conducted in the outskirts of the city and further out in the Hake fjord. In the study *ZORRO - Interdisciplinary research about management and restoration of eelgrass in Sweden* (2024) key pilot projects in the Gothenburg region have been examined. Demonstrating the success of such projects on a smaller scale and showing promise for projects on a large scale. Previous projects have been situated in a coastal setting in regions such as Hake fjord, however, seagrass restoration can have importance being planted closer to the city as well. In the urban outskirts pollination is more severe and the plantation of seagrass could help with water purification and local biodiversity. For wave control however, seagrass beds further out in the fjord can play a more significant role.

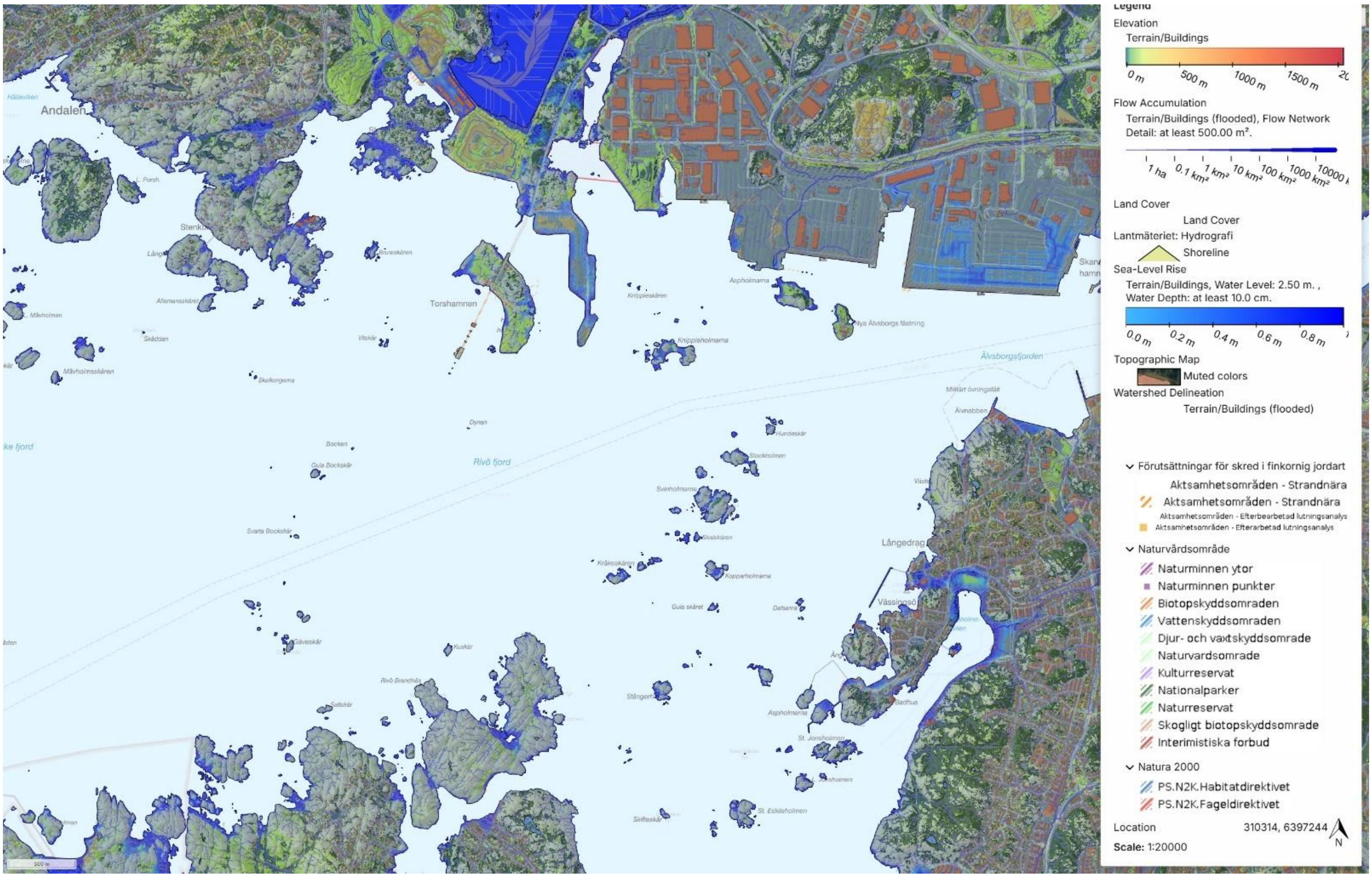

Figure 23. Hake fjord. © SCALGO Live https://scalgo.com/live/

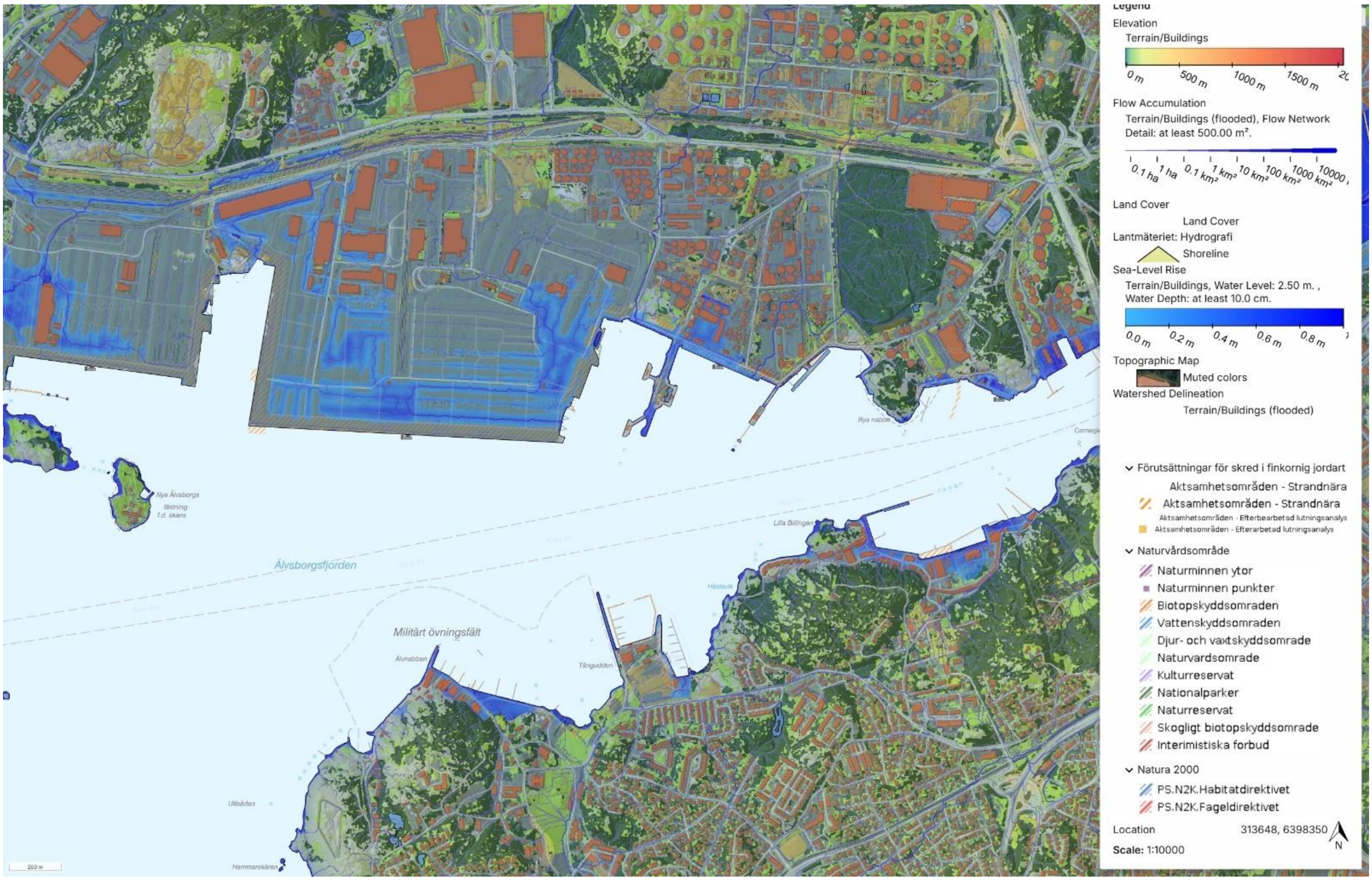

Figure 24. Älvborgsfjärden. © SCALGO Live https://scalgo.com/live/

Areas appropriate for Urban Green Infrastructure

Gullbergvass is significant area for the implementation of Urban Green Infrastructure, while being highly vulnerable to the sea-level rise and accumulation of runoff from rainfalls. Located near Gothenburg Central Station, this former industrial site consists of a low-lying topography, large impermeable surfaces and close proximity to important transportation infrastructure. With the low-lying topology combined with the close proximity to the Göta River, the site is facing increased risks for floodings, driven by climate change. However, the area is experiencing redevelopment plans, creating an opportunity to incorporate climate resilience into the planning. Increasing urban permeable surfaces through green roofs and urban stormwater retention parks would greatly aid with mitigating flood risks and help manage runoff. In addition, to contribute with ecological and social revitalization in an urban hot spot that many people interact with daily. Potentially, portraying as a demonstrative example for how multifunctional NbS strategies can combine flood mitigation, biodiversity and public recreation. Furthermore, the industrial character of the area contributes with large industrial buildings that act as perfect conditions for implementation of intensive or extensive green roofs. The flat roofed structures offer ideal conditions for retrofitting green roofs. Reducing surface runoff by retaining stormwater during heavy rainfall events.

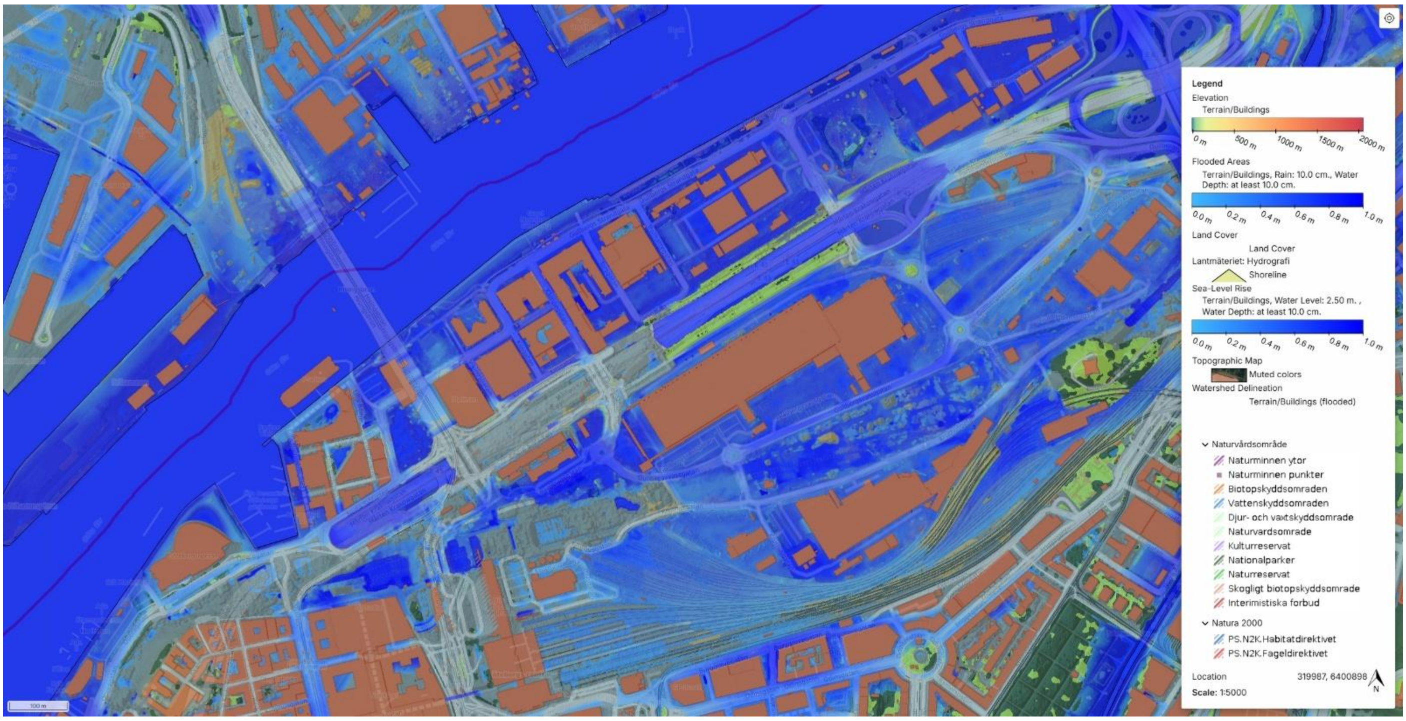

Figure 25. Gullbergvass. © SCALGO Live https://scalgo.com/live/. The critical area of industrial and transportation interests is projected to be heavily submerged in the future, as indicated by the blue gradient.

Overall Analysis

The spatial analysis shows the distribution of suitable NbS systems across the urban parts of Gothenburg and expands to upstream river valleys and out towards the sea, presenting a wide and interconnected resilience strategy. In outer coastal areas strategies including oyster reef and seagrass plantation that contribute to resilience from strong waves, as well as stabilizing sediments and improving the overall water quality. This provides a strong defence for coastal erosion and enhancing marine biodiversity. In the harbour region closer to the city centre the area offers opportunities for strategies such as living shorelines and wetland restoration. This functions as a transitional buffer zones between developed land and marine life. Reducing intensities from floods and containing the water before it reaches the developed land.

Upstream in the Göta River Valley, the impactful strategies change. Approaches such as reinforced riverbanks, reforestation and floodplain reconnection regulates hydrological changes and improves erosion control and sediment capture. Upstream approaches are crucial for mitigating flood risks as soon as possible before it can build up in intensity and destructive force.

The regional perspective illustrates that NbS systems gain from being strategically layered, mitigating risks from different landscape and hydrological functions. And further portraits the need for coordinated planning frameworks that can ease with the integration of both coastal and river systems that can create a coherent and holistic resilience strategy.

The following map (see Figure 26) provides an overview of areas within the Gothenburg and Göta River regions that show high potential for NbS implementation. Based on hydrological modelling and spatial analysis, the map highlights regions where a combination of favourable conditions, such as topography, soil types and hydrology are present.

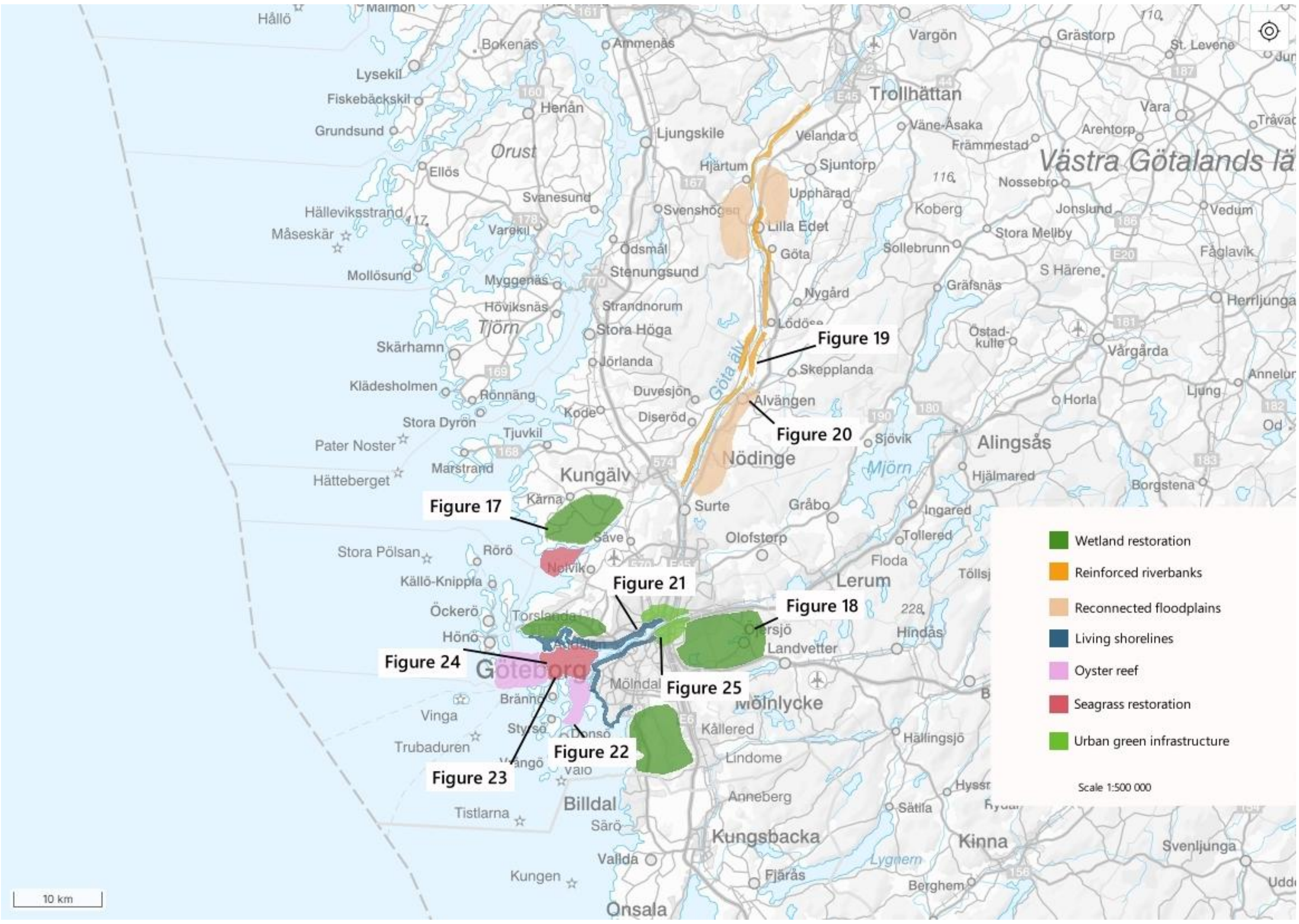

Figure 26. Overall proposal map showing appropriate areas for implementation of NbS strategies. SCALGO Live (modified by Martin Enderskog)

Comparative Summary

To analyse and compare the NbS strategies with each other, a comprehensive table has been constructed (see Table 2). It showcases each NbS strategy according to factors such as its most viable implementation location, the time required to reach maximum effectiveness, a relative indication of cost and the potential for long-term resilience and sustainability.

Table 2 Comparison of NbS strategies

NbS	Most vital location	Implementation time	Effectiveness	Cost	Longevity	Reference
Wetland restoration	Nordre älvs estuarium, Lärjeån	10-30 years	High	Moderate	50-100 years self-sustaining	Kraufvelin, P et.al, (2021)
Reconnect floodplains	Lila Edet, Älvängen	20-50 years	High	Moderate	100 + years permanent	European Environment Agency (2017)
Reforestation & Buffer zones	Göta River valley	20-100 years	High	Low	100 + years permanent and protected from deforestation	Swedish Forest Agency (2023)
Reinforced riverbanks	Göta River valley	10-50 years	High	Low	50-100 years	Rexine.T, (2010)
Oyster reef	Gothenburgs archipelago	10-30 years	Medium-high	Moderate	100+ years self-sustained if water quality stays	Hynes.S, et.al (2022)
Living shorelines	Göta River estuaries	10-50 years	High	Moderate	50-150 years depending on erosion control	Restore America's Estuaries (2021)
Seagrass restoration	Hake fjord, Gothenburg's coastal bay	5-30 years	Medium-high	Moderate	50-150 years if habitats stay equal	Moksnes P-O (2016)
Urban Green Infrastructure	Urban areas of Gothenburg	5-20 years	Medium	Low-Moderate	50 years depending on urban development and	Göteborg Stad (2022)

NbS offers a strong starting point to address the risk of flooding and be less dependent on hard surface solutions. However, to significantly build long-term resilience, a combination of strategies is required. The choice for combination of NbS can be guided by several factors, for example, what level of flood protection that is needed, the timeframe for implementation and the attitude towards financial resources that stakeholders can provide. By tailoring NbS strategies to local conditions, planners can achieve effective solutions that promote multifunctionality and resilience towards the environmental challenges the local area is facing. For the region of Gothenburg these local strategies have been conducted.

Combination 1: Wetland Restoration + Oyster Reefs + Seagrass Restoration

A combination that is tailored to coastal regions that have salty waters and have geographical properties that promote the existence of wetlands. These NbS have a high effectiveness being able to break waves, reduce coastal erosion, stabilize soil and improve water quality, as well as contribute with huge flood control benefits. It is a cost-effective option with oyster reefs and seagrass plantations being even more cost-efficient than artificial barriers and concrete seawalls. Unlike hard infrastructure that degrades over time and requires costly maintenance, these ecosystems can grow over time, be self-sufficient and become increasingly effective as they age. For the context of Gothenburg, advancing with this combination will reduce long-term maintenance, enhance ecology and contribute with land that can be multifunctional, protecting against climate-hazards and supporting habitats for many species. Figure 27 illustrates the spatial logic and ecological function of a restored wetland system. This visual emphasizes how wetlands capture, store and slowly release stormwater, which is especially relevant in low-lying areas of Gothenburg's waterfront, creating a multifunctional NbS strategy for flood resilience. Figure 28 shows a conceptual section of a coastal NbS strategy combining seagrass beds and oyster reefs. Demonstrating how they can be applied along the Gothenburg coastline to manage rising sea levels while restoring local ecosystems.

Figure 27. Representation of wetland restoration. (Illustration: Martin Enderskog)

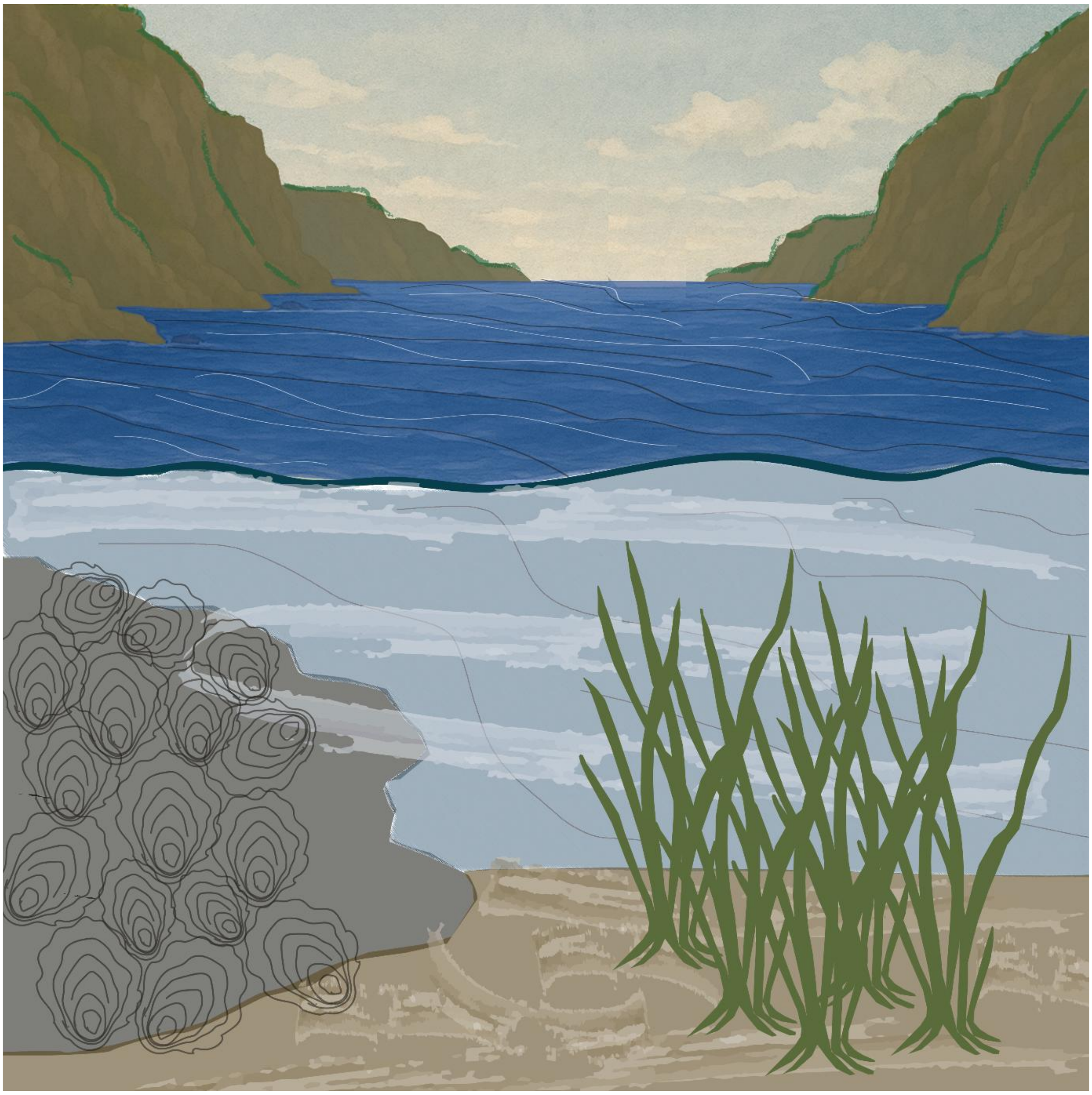

Figure 28. Representation of oyster reef and seagrass plantation. Own illustration (Illustration: Martin Enderskog)

Combination 2: Reinforced Riverbanks + Living Shorelines

This combination presents a strategic solution to both coastal and river flooding risks in Gothenburg. With the method on reinforced riverbanks, the focus is on establishing native plants and trees along the riverbanks, preventing erosion and increasing resilience for floodings. Given the expected increase for landslide on 25% by 2100 and increased water flow speeds (SGI, 2012), stabilizing the sensitive riverbanks should be of highest priority. These measures provide physical stabilization and long-term ecological benefits, improving water quality, biodiversity and providing essential habitats for many species. Living shorelines which primarily protect and stabilize the coastal edge, addressing erosion and flood risk low-lying lands and urbanized areas. As time passes, living shorelines strengthen, vegetation matures and roots become more established, see Figure 29 for spatial implementation in an urban setting in Gothenburg. Their capacity adapts to hydrological conditions making the shorelines resilient. Together these NbS strategies defend and enhance upstream and coastal resilience as well as being exceptionally cost-efficient. Figure 30 illustrates a conceptual design of reinforced riverbanks where the importance of soil binding through native plants is crucial.

Figure 29. Representation of living shoreline. (Illustration: Martin Enderskog)

Figure 30. Implementation of reinforced riverbanks. (Illustration: Martin Enderskog)

Combination 3: Reconnect Floodplains + Reforestation

The combination of reconnect floodplains and reforestation along the Göta River offers a cost-effective solution with longevity and ecological sustainability in both urban and rural parts of the Gothenburg region. This approach is based on mitigating floodings at the early stages in the water basin to reduce the water level threats in the whole region, urban and rural areas. By allowing water to expand in natural retention areas and landscape during peak flow events, it reduces the pressure downstream. It is a restorative approach that would over a large area enhance biodiversity and habitats for many species, supporting amphibians, birds and insects. A method increasing its effectiveness as floodplains and forest matures over time becoming more resilient and functional. Unlike hard surface barriers that tend to degrade over time. In combination with reforestation in riparian zones, soil stability and natural infiltration increases. This creates an approach promoting regenerative and resilient solutions to Gothenburg's planning models. Figure 31 visualizes the re-meandering of river systems and reconnection of natural floodplains, illustrating how restoring dynamic river-floodplain interactions

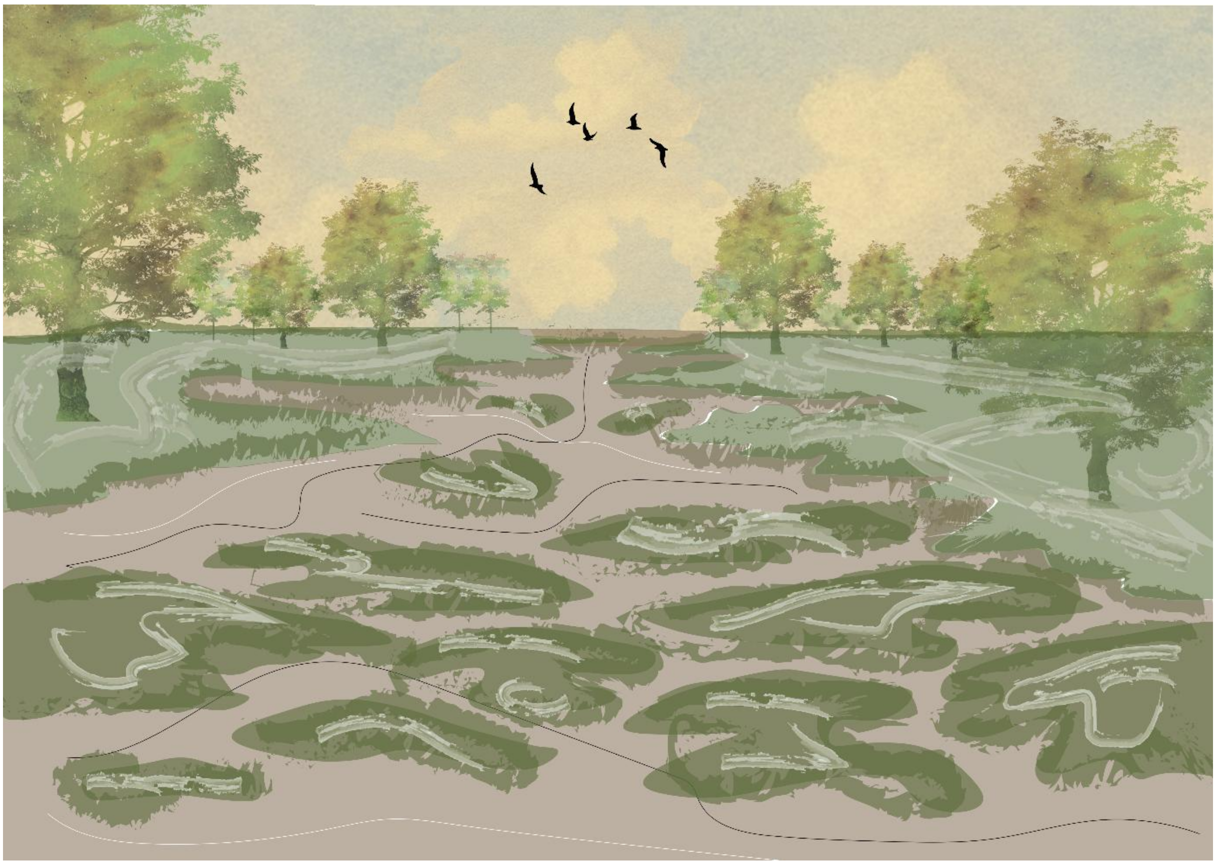

Figure 31. Representation of reconnecting floodplains and reforestation. (Illustration: Martin Enderskog)

7. Discussion

In the following chapter, planning challenges in Gothenburg, including flood risk management, urban-rural dynamics, socio-economic impacts and land use conflicts is discussed.

Discussion on Planning Practices

Gothenburg faces increasingly complex planning challenges, situated in a transition zone between land and water. Drivers such as climate change, rapid urban growth and institutional constraints amplify these concerns. The city operates under a non-statutory planning framework that encourages local flexibility. Nevertheless, it lacks adequate integration of systematic risks such as flooding, land degradation, coastal and riverbank erosion. While strategies have been introduced to address sea level rise and heavy rainfall such as the High-Water Protection Program, which proposes grey infrastructure like seawalls in the inner city and closable sea gates on the outskirts, these solutions primarily reflect a municipality-led approach. They only loosely align with regional strategies and the absence of binding regional plans makes coordinated implementation across municipal boundaries difficult. This coordination is essential to address the increasing water risks posed by climate change, especially in upstream areas where NbS such as wetland creation and floodplain reconnection, could be most effective.

Although non-statutory planning offers flexibility and opportunities for stakeholder engagement, it depends heavily on voluntary collaboration among municipalities, counties and institutions. In practice, this can lead to fragmented implementation. Many large-scale NbS projects require land use changes that may conflict with regional development priorities. Without a statutory framework to enforce coordination, Gothenburg risks carrying a disproportionate share of the burden in adapting its urban landscape, potentially hindering the process.

Discussion on Urban vs Rural Development and Socio-Economic Impact

With the current strategy, the municipality of Gothenburg is planning to implement flood gates to block high water flows from reaching the city centre. This raises critical questions about who is protected and who is left at risk of flooding? By blocking water from the Göta River, upstream urban and rural areas may experience worsened flooding, as natural drainage is blocked. Cities such as Lilla Edet and Trollhättan located upstream, could face elevated water levels. Since these areas are separate municipalities with potentially lower budgets, they may struggle to manage the increased flood risk.

Moreover, rural areas are likely to face higher water levels during peak flow events, potentially damaging homes, farmland, infrastructure and valuable ecosystems. These communities often have fewer financial resources and limited political influence, which can lead to power asymmetries and environmental injustice if no mitigation or compensation is provided as argued previously by Kabisch (2016).

This situation underscores the importance of cross-municipal coordination and the implementation of upstream flood prevention measures. Many of which can be addressed through NbS. Examples include creating buffer zones, reinforcing riverbanks, restoring wetlands and reconnecting floodplains.

Discussion on Land Use Difficulties

An issue that could appear is the priority of land use and the current landowner's interest. Implementation of NbS often requires large areas in proximity to waterways, which often are valuable and productive areas such as, farmlands, land for forestry or land for housing. If municipalities and counties would like to acquire these lands for construction of flood resilient solutions, landowners may feel forced to sell their land for the interest of the authorities or engage in legal disputes, costing valuable time and assets. This could create power imbalances, with municipalities and counties having more power and influence, compared to local landowners. Forming the experience that the landowners weren't consulted enough or compensated fairly.

In the case for proposed wetland restoration or reconnection of floodplains, local agricultural and forestry interest in its proximity may raise concerns. Forestry interests could be negatively affected when soils get waterlogged, stressing and suffocating the root systems for trees. Increasing the risks for pests and diseases, affecting the tree population and a probability for a reduction of productivity. Farmers may similarly experience reduced productivity when frequent floodings can lead to crop failure and soil erosion. Leading to decreased production and revenue.

While NbS systems increase resilience, flood control and biodiversity, they also generate challenges in existing land availability and land use. Perhaps reducing available land for other interests such as farmland, forestry and developments. This complexity distinctly showcases the importance of stakeholder engagement to combat power asymmetry, environmental injustice and the risk for urban-rural tensions.

8. Conclusions

The aim of this thesis has been to explore how the city of Gothenburg, located in the southwestern part of Sweden, can improve the resilience of its waterfront through the implementation of Nature-based Solutions (NbS). By using a qualitative methodology based on discourse analysis as well as site-specific studies and GIS mapping, the thesis sought to critically analyse how sea level rise and increased rainfall caused by climate change are projected to affect the city. The study further investigated which NbS strategies can be implemented to build resilience for the city and the region along the Göta River, as well as evaluated whether the current municipal and regional planning framework to analyse if it supports such approaches.

The findings of this thesis clearly show that Gothenburg is facing escalating flood threats caused by climate change and worsened by Gothenburg's geographical and geological context. Threats from short-term events particularly, extreme rainfalls and long-term stressors such as the sea level rise that pushes into the city. These hazards will increasingly affect residential and industrial buildings, important infrastructures and affect many ecosystems through habitat loss and erosion. Without sufficient adaptive measures, urban and rural areas in the region will see catastrophic destruction in the following decades.

Through a synthesis of the literature review and the GIS-based site analysis, several NbS strategies and suitable landscapes in the Gothenburg region were identified. For protection directly connected to the urban regions, living shorelines strategies are effective as they mitigate erosion, slow down water velocity during storms as well as act as buffer zones with the opportunity for multifunctional green spaces that can capture and infiltrate large volumes of water. Wetland restoration and the reconnection of floodplains are important to capture large volumes of water through the watercourses, slowing down water speeds and infiltrating it before it reaches the urban areas of the city.

To support the crucial Göta River, reinforced riverbanks can reduce erosion, and upstream reforestation can mitigate severe flooding while also decreasing flow speeds and increasing biodiversity.

Current planning practices in Gothenburg show awareness of the climate hazards the city faces and express intent to construct sustainable adaptation measures. However, when critically analysed through an institutional lens, the feasibility of implementing NbS on a larger scale appears limited in practice. The City Planning Office primarily promotes grey infrastructure solutions such as seawalls, sea gates and drainage systems relying on pumps. Although NbS are mentioned in various planning documents, there is a lack of a systematic framework to support their implementation.

The municipality of Gothenburg operates under a non-statutory planning model that promotes flexibility but lacks formal constitutional frameworks regulating planning practices across municipal, regional, and national levels. This creates fragmentation, especially in large-scale projects spanning municipal borders, which many NbS strategies require. Conflicting interests, resistance from current landowners, unclear financial responsibilities, and a lack of binding regulations limit the potential for large-scale NbS implementation.

For successful implementation within a non-statutory model, close cooperation among stakeholders is fundamental.

Implications for Planners

For planners, the challenge of implementing climate adaptations extends beyond traditional regulatory frameworks. Effectively working with NbS strategies requires interdisciplinary knowledge and stakeholder cooperation, combining expertise in urban design, ecology, hydrological processes and land use.

In addition, planners must sustain long-term collaboration across municipalities and regional landmarks, requiring skills in communication and negotiation. Ultimately, planners must be institutionally empowered to change the view on NbS systems: from small-scale alternatives to mainstream, holistic strategies that drive the planning for climate resilient urban and regional development.

8.1 Reflections on Limitations and Future Research

The discourse analysis was applied to critically review municipal and regional planning documents. This method contributed to revealing power dynamics, priorities and underlying assumptions. However, a limitation of the method is its dependence on the availability of planning documents. If not all documents are accessible and reviewed, it may not fully capture governance dynamics and underlying interests, potentially missing crucial information needed to present a complete picture. Future research should extensively engage in frameworks, documents and discussions with stakeholders to provide richer insights on governance challenges and conflicts among stakeholders to deepen the critical evaluation of current planning practices.

Another limitation of the study is the limited engagement with the theoretical framework on reliance and adaptation. Applying such frameworks in the future would strengthen the analytical depth, spot gaps in urban planning and the institutional foundation. Additionally, with stronger theoretical frameworks, more detailed cost-benefit analysis could be done which possibly could provide a more holistic assessment for long-term fundings. A future study could for example make a life cycle cost analysis to help justify investments in NbS.

Continuously, the use of SCALGO Live aligns with a data-driven approach to spatial planning and has helped bridge the gap between conceptual NbS strategies and practical implementation. The tool has been effective in overlaying important maps to identify critical areas. However, GIS alone cannot capture soft values such as political and social processes that influence decisions regarding land use. To uncover these perspectives, further investigation through stakeholder interviews would be necessary to understand attitudes toward the matter. Such interviews would provide deeper insight into landowner resistance, political will and institutional attitudes.

To focus specifically on the Gothenburg region, a case study approach was conducted to contextualize the area. By selecting a region of appropriate size, the broader global and national discourse could be examined in relation to local governance and planning models, to explore Gothenburg's capacity to support NbS implementation. However, the reliance on secondary sources may limit the depth and accuracy of findings

9. References

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