WATER

we gonna do
with all this

WASTE

Water, waste & the city: A circular approach

How can recycled construction waste be reimagined as a resource for sustainable water management strategies in Gothenburg?

Author: Eleonora Rosenberg
Supervisor: David Gough
Examiner: Joaquim Tarraso
Chalmers School of Architecture
Department of Architecture and Civil Engineering_2025

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Author: Eleonora Rosenberg
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Examiner: Joaquim Tarraso
Program: Architecture & planning beyond sustainibility_MPDSD
Profile: Urban & rural design & planning
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Thanks to...

Figure 00.01. Illustrations by the author.

Hello!

When I began studying architecture at Chalmers, I thought it was mainly about designing buildings. Over time, I discovered it is also about exploring the systems that shape our cities and the connections between people and their environments. Since starting in 2019, my education has given me the tools to work across scales, from form and material to urban planning and biodiversity, while encouraging me to see architecture as both a creative and a responsible practice.

Master's in Urban and Rural Design and Planning (MPDSD)

Design studios

- Integrated sustainable building design, architects
- Key projects for sustainable development in a local context

Software and tools used:

- Autodesk Revit
- Autodesk AutoCAD
- Enscape
- Adobe InDesign
- Procreate
- Twinmotion
- QGIS (Quantum Geographic Information System)
- Scalgo

Abstract

This master's thesis explores how Gothenburg can strengthen its resilience to flooding by integrating circular economy principles into urban design. The study investigates how recycled construction waste, such as excavated clay, crushed brick, concrete, dredged sediments and etc. can be repurposed into functional materials for flood prevention infrastructure. It responds to the growing urgency of climate change impacts, including rising sea levels, increased precipitation, groundwater pressure, and extreme weather events such as cloudbursts. These factors are compounded by unsustainable urban development and inefficient waste management, especially in flood-prone areas like the Göta river (hereafter referred to as Göta älv) corridor.

The research examines multiple flood risks affecting Gothenburg, including fluvial, pluvial, and coastal flooding, while analyzing the city's existing flood mitigation frameworks. It identifies opportunities to enhance urban water retention, filtration, and controlled discharge using reclaimed materials within blue-green infrastructure systems. Drawing on principles of sponge city design, the thesis explores how urban surfaces can be transformed from impermeable zones into absorbent, biologically active systems that not only mitigate flooding but also enrich public space.

The outcome is a design proposal for a specific site in Gothenburg, using adaptable strategies that integrate waste reuse with climate-adaptive planning. The design utilizes porous layers made from recycled construction waste to support vegetation, slow runoff, and improve water quality before controlled discharge into receiving bodies. In doing so, the proposal rethinks flood protection not as a singular defense mechanism, but as a layered system of ecological and material functions.

This thesis contributes to the growing discourse on sustainable urban transformation by demonstrating that construction waste, when treated as a resource, offers both environmental and economic value. By merging flood resilience with circular material flows, the project promotes an urban design approach that is adaptable, regenerative, and aligned with Sweden's climate goals. It provides a flexible model that could be applied in other urban areas facing similar challenges, emphasizing that resilient cities can be built through both design innovation and material responsibility.

This thesis will explore the following research question:

How can recycled construction waste be reimagined as a resource for sustainable water management strategies in Gothenburg?

Key words: Water & waste management, Flood resilience, Circular economy, Recycled construction materials, Blue-green infrastructure

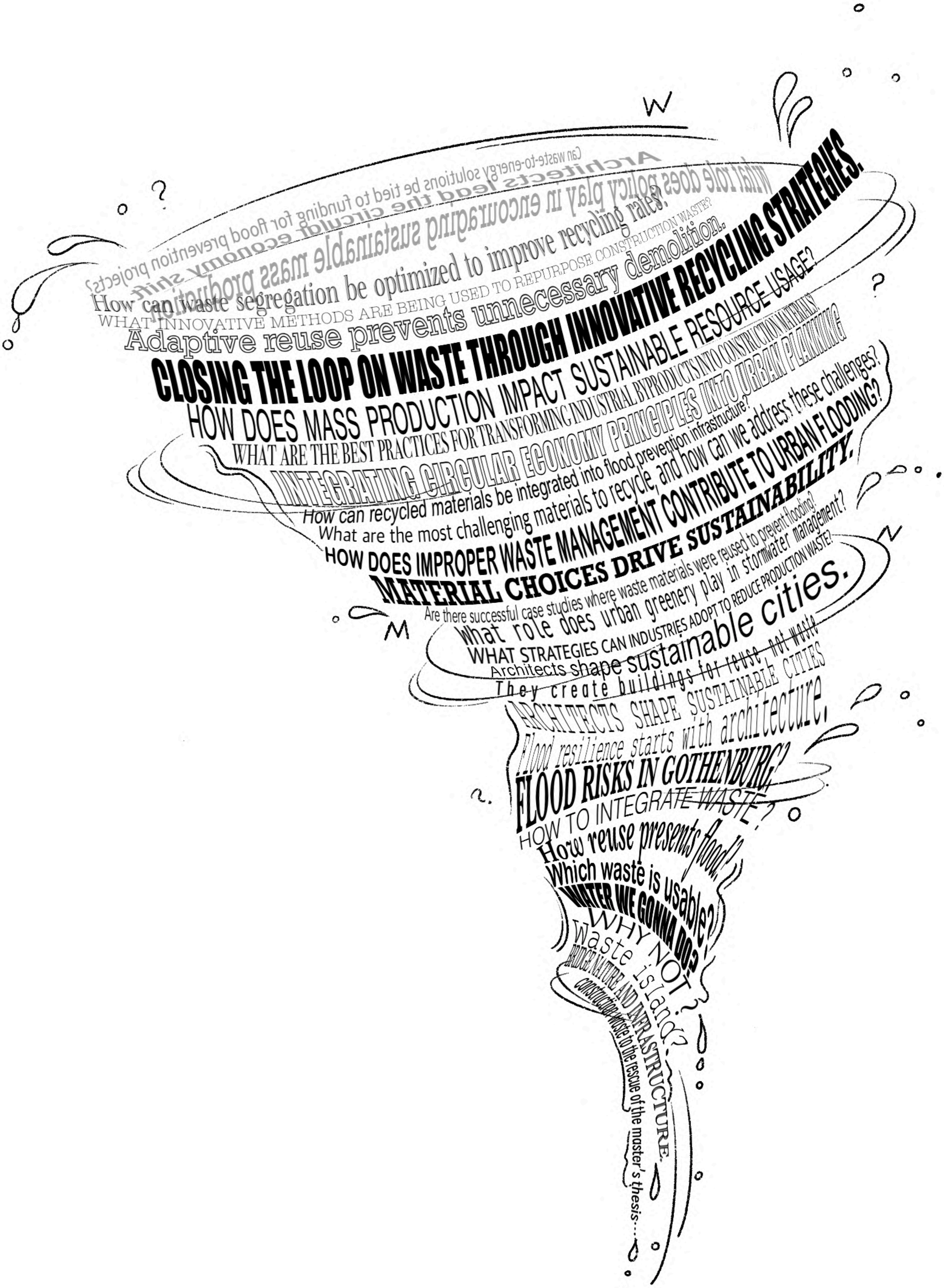


Figure 00.02. An abstract depiction of the urgent link between waste management and water management. This visual metaphor captures the deep interconnection between two of today's most pressing environmental challenges. It serves as a warning and a call to action, highlighting the critical need for integrated solutions before the situation spirals into a disaster as terrifying as a violent whirlwind. Illustration by the author.

Delimitation

Crisis management & emergency response

This thesis does not address the management of flood events after they occur, such as emergency response, evacuation procedures, disaster relief, or post-flood recovery strategies. While the possibility of site flooding is considered as part of the design context, the focus remains on preventive and adaptive measures rather than on crisis response to extreme flood events.

Political aspects

This thesis does not explore in depth the political negotiations, legislative challenges, or bureaucratic processes that may influence the adoption and implementation of flood prevention strategies. While such factors are acknowledged as relevant to the broader context, they fall outside the primary scope of this research and are therefore not analyzed in detail.

Detailed economic perspective

While economic factors are undeniably important, this thesis does not include a comprehensive economic analysis. It does not cover precise cost estimations for implementing flood prevention measures, detailed budget comparisons, or projections of future financial scenarios.

Engineering & construction details

This thesis does not encompass detailed technical aspects of engineering, such as structural design calculations, comprehensive technical drawings, material testing procedures, or specific construction methodologies. While certain technical elements are referenced to provide context and enhance understanding of the design concepts, they are not explored in depth. The primary focus remains on the conceptual and strategic dimensions of the project, rather than on exhaustive engineering specifications.

Animals & the social perspective

Although this thesis does not explicitly focus on animals or social dimensions, both have played an implicit role throughout the design process. Spatial decisions were guided by considerations for the safety, well-being, and experience of both human and non-human users. Due to primary focus of the research, the design is not presented in depth from these perspectives. While humans often remain central in architectural discourse, and their exclusion would be neither practical nor desirable, this thesis prioritizes other core themes.

Maintenance & operational planning

Long-term operation and maintenance strategies for the proposed interventions are mentioned only in general terms.

Flood types

This thesis focuses specifically on flood risks related to sea level rise, river (fluvial) and cloudburst-induced flooding. Other forms of flooding, such as groundwater flooding are not within the scope of this study.

Relevance to sustainable development

This master's thesis contributes directly to the broader objectives of sustainable development by applying circular economy principles and integrating environmental, and social considerations into urban flood prevention strategies. The project emphasizes the reuse of construction and excavation waste, transforming environmental challenges into resources that support long-term climate resilience in Gothenburg. By addressing the impacts of climate change, such as sea level rise and extreme weather events, the thesis aligns with several of the United Nations Sustainable Development Goals (SDGs), particularly:

- SDG 3; Good health and well-being
- SDG 6; Clean water and sanitation
- SDG 9; Industry, innovation, and infrastructure
- SDG 11; Sustainable cities and communities
- SDG 12; Responsible consumption and production
- SDG 13; Climate action
- SDG 14; Life below water

Discussion

This thesis set out to investigate how recycled construction waste can be reimagined as a resource for sustainable water management strategies in Gothenburg. The research question has been addressed by combining scenario planning, sustainability assessment, case study references, and design prototyping at the Skeppsbron site.

The findings demonstrate that construction waste, often regarded as a liability, can be transformed into a valuable input for climate adaptation. By testing the reuse of excavated clay, crushed brick, concrete, dredged sediments and etc., the project showed how these materials can be integrated into porous layers, retention zones, and vegetated surfaces that contribute to water retention, filtration, and controlled discharge. This confirmed that circular material flows not only reduce landfill pressure but also enhance blue-green infrastructure performance and ecological value.

A key assumption underlying the proposal is the availability of material from the ongoing West link (Västlänken) rail tunnel project, which generates vast amounts of excavated rock, clay, and concrete. Anchoring the design to this resource highlights the potential of treating large-scale urban infrastructure projects as material banks for climate adaptation. While this dependence on the West link project limits the immediate transferability of the design in its current form, it illustrates a broader and highly relevant principle: future megaprojects in other cities could equally provide the raw material streams required for circular and climate-resilient urban design.

The thesis also revealed that resilience cannot be achieved solely through technical flood defenses. Instead, it requires multifunctional and adaptive strategies that merge ecological performance, spatial quality, and social accessibility. By proposing interventions that mitigate flooding while enriching public space, the project reframes flood protection as a layered system of hydrological, ecological, and cultural functions rather than a singular barrier.

A secondary objective of the thesis was to gain a deeper understanding of international approaches to flood management, with a particular focus on Copenhagen. This included studying the city's flood control systems, regulatory framework, and ongoing projects such as Lynetteholm, in order to explore how similar strategies could inform and enhance the proposed interventions in Gothenburg. Additionally, further research was intended on potential sites where the design principles could be applied beyond Skeppsbron, to assess broader transferability. Initially, the study also aimed to draw more inspiration from Venice; however, the relevance of Venetian strategies diminished as the research progressed due to the significant geographical and hydrological differences between Venice and Gothenburg. Consequently, the emphasis shifted towards solutions that are contextually appropriate for Gothenburg while remaining informed by lessons from international case studies.

In conclusion, the research question has been answered by showing that recycled construction waste, with the West link project serving as a practical and symbolic resource base, can become a cornerstone of sustainable water management. At the same time, the thesis contributes to ongoing debates on urban resilience by offering a replicable model for aligning circular economy principles with climate-adaptive design.

Methods

Scenario planning

Creating different scenarios to explore the potential outcomes of different strategies. Specially weather scenarios and how they can affect the design.

Web-based source review

The research relies on a review of digital publications and internet-based resources related to flood control technologies, waste management practices, urban resilience, and climate adaptation strategies. These sources include reports, governmental documents, professional guidelines, and relevant case studies accessible through reputable websites.

Design proposals & prototyping

Conceptual design proposals and spatial prototypes were developed to explore flood control structures and urban interventions.

Sustainability assessment

Evaluate flood control solutions based on their long-term sustainability using environmental and social criteria. Ensures that the design is not only effective in flood mitigation but also environmentally and socially sustainable.

Stakeholder interview

Engage with local authorities like Gothenburg municipality, urban planners, and environmental expert through interviews.

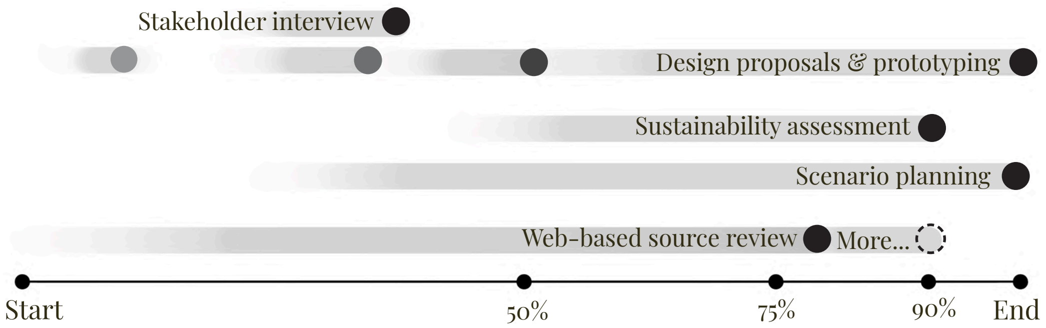


Chart 00.01. Timeline showing when each method was applied during the thesis, from initial research to final design and reflection. Illustration by the author.

Table of contents

Introduction

As urban areas face increasing challenges due to climate change, the need for innovative and sustainable flood management strategies has become increasingly urgent. In Gothenburg, rising sea levels and more frequent extreme weather events pose significant threats to the city's infrastructure, urban fabric, and overall quality of life. This master's thesis explores the potential of utilizing construction and excavation waste (waste management) in flood prevention (water management) systems, aligning with global sustainability goals and the broader transition toward a circular economy. By addressing the intersection between waste and water management), the research contributes to the evolving discourse on sustainable urban development.

City of Copenhagen. (2012) mentions that cities can never be completely safeguarded against flooding, but there is significant potential to improve their preparedness through thoughtful planning and design. (City of Copenhagen, 2012, p. 2) Theoretically, this thesis expands on the role of circular economy principles within urban planning and environmental management. It investigates how the reuse of waste materials (mostly construction) can serve not only as a mitigation strategy for flood risks but also as a catalyst for promoting resource-efficient and climate-adaptive urban environments. From a practical perspective, the research aims to offer actionable insights for urban planners, policymakers, and engineers in Gothenburg and other cities facing similar challenges. The design proposals developed in this thesis demonstrate how waste-based solutions can be effectively integrated into blue-green infrastructure, supporting both water management and ecological function. By proposing a framework for implementing these strategies, the project contributes to the creation of more resilient and regenerative urban landscapes that are better equipped to respond to the impacts of a changing climate.

From Venice to Gothenburg

My fascination with urban water management began during my exchange semester in Venice in the spring of 2024. The city, renowned for its intricate canals and historic architecture, captivated me with its beauty and unique relationship with water. After experiencing several heavy rain events, I was struck by how the city could seem on the verge of submersion one day, yet return to normal the next. This resilience sparked my curiosity about how Venice effectively manages such deluges without succumbing to chronic flooding.

Intrigued, I began to observe the city's drainage systems more closely. I noticed tiny, elongated oval-shaped holes alongside buildings in narrow alleys, (see Figure 0.02) where rainwater flowed into hidden channels. Despite their diminutive size, these drainage points seemed to perform well, directing water away and preventing widespread inundation. This observation highlighted the importance of effective water management in urban settings, particularly in a city so deeply intertwined with its waterways.

My discussions with my professor at Chalmers, Johan Linton, the Associate Professor, Architectural Theory and Method / Architecture and Built Environment Technology, further deepened my interest. He introduced me to the innovative Moses project, a cutting-edge system designed to control flooding during extreme weather events. This project intrigued me not only for its technological sophistication but also because it prompted me to question how Venice coped with flooding before such advancements. Upon returning to Gothenburg, I found myself contemplating how my city manages rainfall and heavy rain events, wondering if it might require a large-scale construction project, similar to Moses, to adequately protect itself from future flooding.

Through my investigation, I aim to explore Gothenburg's current drainage systems, their vulnerabilities, and potential strategies for improvement, including innovative approaches such as repurposing waste materials for flood management. To fully understand these systems and their effectiveness, it is crucial to first study Göta älv, as this main water source plays a central role in Gothenburg's hydrology, influencing both urban flooding dynamics and water quality. Understanding its behavior and interactions with the surrounding infrastructure will provide key insights for enhancing flood resilience in the city.

Figure 0.01. Stone steps descending into a Venetian canal, showing the marks left by fluctuating water levels. The visible gradations indicate the frequent contact between the city's infrastructure and high water, underscoring Venice's constant negotiation with flooding. Photo by the author.

Figure 0.02. Tiny, elongated oval-shaped opening alongside a building in a narrow alley, where rainwater appeared to flow into hidden channels, a detail that sparked curiosity about its precise role in the city's water management system. Photo by the author.

Figure 0.03. Water from the main canal near the Rialto Bridge — Venice's oldest and most iconic bridge spanning the Grand Canal — overflowing into a restaurant's seating area during a rainy day, illustrating how precipitation and tidal levels can combine to cause localized flooding. Photo by the author.

WATER MANAGEMENT

“One thing is sure. The Earth is now more cultivated and developed than ever before. There is more farming with pure force, swamps are drying up, and cities are springing up on an unprecedented scale. We’ve become a burden to our planet. Resources are becoming scarce, and soon nature will no longer be able to satisfy our needs.”

- Quintus Septimus Florens Tertullianus, romersk teolog, år 200

Introduction

Water management has emerged as one of the most pressing urban challenges in Gothenburg, where the effects of climate change are increasingly visible. Along the Göta Älv (Göta River), these changes manifest in the form of intensified precipitation, rising groundwater levels, more frequent flooding, and erosion, factors that pose risks not only to environmental stability but also to urban infrastructure and safety. The city's low elevation, proximity to the sea, and sensitive clay soils exacerbate the impacts of both sea level rise and inland water pressure, placing Gothenburg in a vulnerable area in terms of flood and landslide risk.

Multiple authorities and institutions, including the Swedish Geotechnical Institute (SGI) and the City of Gothenburg, have emphasized the urgency of addressing these interconnected risks. Structural and environmental conditions along the Göta älv require continuous monitoring and the development of site-specific responses to secure urban resilience over the long term. The case of Skeppsbron, the thesis project site, exemplifies this dual vulnerability to flooding and landslides, prompting a need for innovative and multifunctional strategies that benefit not only human communities but also biodiversity and ecological health.

As flood risks grow more complex due to cloudbursts, storm surges, and altered precipitation patterns, traditional engineering approaches must be complemented by adaptive, nature-based, and spatially integrated solutions. Gothenburg's current strategies, including structure plans, return period analysis, and blue-green infrastructure interventions, provide a framework for addressing these challenges in both the short and long term. This chapter explores how the city is navigating these climate-induced pressures and how design can contribute to more resilient water management at multiple scale.

Göta älv

Climate change is a global challenge, but its impacts are increasingly evident at the local scale. In Sweden, and particularly in Gothenburg, the effects are becoming more pronounced, especially in the Göta älv river corridor. According to the Göta Älv Water Management Association (2015), Göta älv originates from Lake Vänern, which is entirely drained by the Göta älv. (see Figure 1.01) Vänern, Sweden's largest lake and one of Europe's largest lakes, covering 5,650 km², receives its main flows from Byälven, Norsälven, Klarälven, and Gullspångsälven in Värmland. (Göta Älv Water Management Association, 2015, p. 14) Climate change in this region is expressed through rising groundwater levels, increased water flow, more frequent flooding, erosion, and the leaching of pollutants, primarily driven by intensified precipitation and surface runoff. Göta Älv Water Management Association (2015) continues that these processes not only threaten environmental stability but also increase the risk of landslides and structural damage along the riverbanks.

The landslide risk situation is further exacerbated by human interventions. Göta älv is identified as one of Sweden's most landslide-prone areas, (see Figure 1.02) largely due to its sensitive clay soils. While minor landslides occur more frequently, larger events, though less common, pose a significant risk. Inspections and maintenance of shoreline stability and erosion protection are routinely carried out, with updates implemented as needed. Oversight and review of planning and permitting in the Göta älv area are handled by the Swedish Geotechnical Institute (SGI), which plays a central role in ensuring the structural and environmental integrity of the region (Göta Älv Water Management Association, 2015, p. 65).

This evolving landscape prompts a critical question for architects: How can we respond, both proactively and reactively, to the complex consequences of climate change?

Swedish Geotechnical Institute (2023) authorities highlight that the risk of landslides along Göta älv is significant, with climate change accelerating this process. SGI monitors the stability conditions along the river and distributes state grants to municipalities for measures that reduce the risk of collapses and landslides. Additionally, the intrusion of saltwater into Göta älv poses a threat to drinking water accessibility, particularly during low water levels in Lake Vänern, when the risk is highest. SGI continues that it has been allocated 73 million kronor to Gothenburg for addressing the Importgatan area along Göta älv, near Bäckebolmotet (see Figure 1.02) located in the northern part of Gothenburg. A solution is being planned involving the injection of lime-cement, known as KC (Kalkcement) piles, to stabilize the riverbank. (Swedish Geotechnical Institute, 2023)

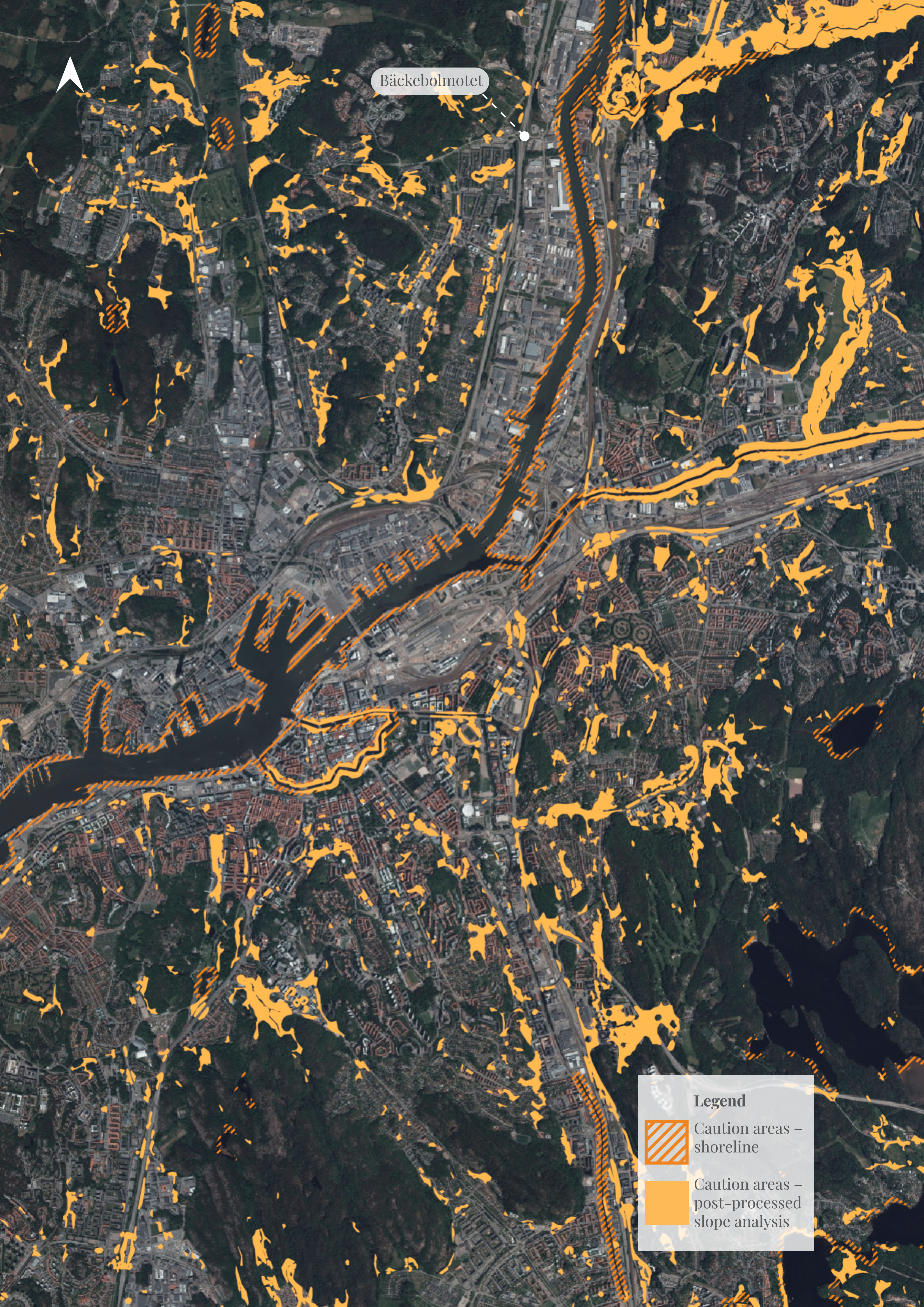
Considering the documented landslide risks along Göta älv, special attention has been given to areas particularly vulnerable to soil instability. One such area is Skeppsbron in central Gothenburg, which has been selected as the main site for this thesis. (see Figure 1.03) Its location within the landslide-prone zone was a deliberate factor in the site selection, intending to investigate alternative solutions that are less costly and offer greater benefits to the environment, biodiversity, and both human and animal life.

Figure 1.01. Map of the Göta älv, highlighted in light white, showing its course from Vänern lake to the Kattegat Sea. Adapted from Lantmäteriet (2025), modified by the author.

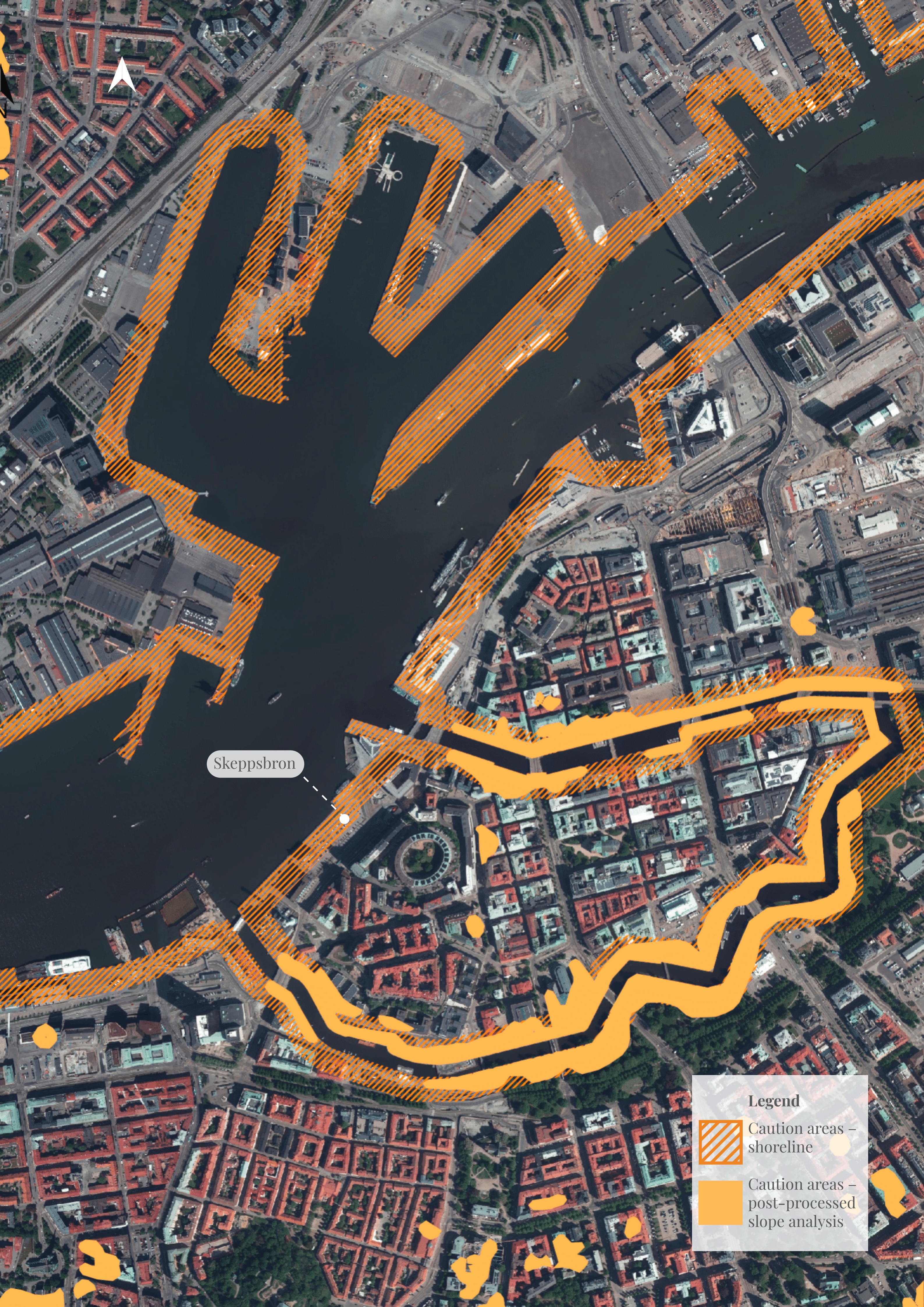
Figure 1.02. Landslide risk areas in central and northern Gothenburg. The map shows areas with potential landslide susceptibility along river corridors and surrounding elevated terrain. The illustration is based on a topographic aerial view overlaid with risk zones, emphasizing vulnerable zones near Göta älv and surrounding districts. Map source: Lantmäteriet. Scale 1:50,000 (A4).

Figure 1.03. Landslide risk zones in Skeppsbron and its surroundings. This map illustrates the potential landslide risk areas surrounding Skeppsbron, the site of the thesis project, located along the Göta älv in central Gothenburg. The marked zones show susceptibility along the waterfront and nearby built environments, indicating areas of geotechnical concern relevant to urban development and climate adaptation strategies. Map source: Lantmäteriet. Scale 1:10,000 (A4).

Vänern lake
Vänersborg
Trollhättan
Lilla Edet
Kungälv
Göteborg
Kattegat sea
Legend
Göta älv marked



Bäckebolmotet
Legend
Caution areas – shoreline
Caution areas – post-processed slope analysis


Skeppsbron
Legend
Caution areas – shoreline
Caution areas – post-processed slope analysis

Gothenburg's position on flood risks regarding cloudburst & sea-level rise

The City of Gothenburg (2019) acknowledges its long-term exposure to multiple flood risks, including sea level rise, river flooding, extreme rainfall events, and rising groundwater levels. (City of Gothenburg, 2019, p. 27) The fact is that, according to SWECO & Arcadis (2015, February 2), Gothenburg is situated at a low elevation, rendering it vulnerable to inundation from rising sea levels. Marine waters can penetrate the city primarily via two channels: the mouths of the Göta älv and the Nordre älv, and an effective management of these conduits requires an integrated flood-protection strategy. (SWECO & ARCADIS, 2015, February 2, p. 8) To address these challenges, the City of Gothenburg (2019) continues that the city highlights the need to evaluate protective strategies in scenarios where sea levels exceed one meter, particularly to inform urban development over a time horizon beyond 100 years. A comprehensive climate adaptation strategy is required, along with a clearer prioritization of necessary investigations, decisions, and implementation measures.

While extreme rainfall may appear identifiable to the eye, the classification of an event as a cloudburst is based on scientific criteria. According to the City of Copenhagen (2012), an extreme rainfall event refers to a short-duration, high-intensity precipitation episode. The Danish Meteorological Institute sets the threshold at more than 15 mm of rainfall within 30 minutes. Additionally, extreme rainfall events present significant challenges that differ by locality and cannot be resolved by a single measure, such as sewer system upgrades, alone. Accordingly, coordinated and integrated actions are required, combining solutions tailored to each specific area. (City of Copenhagen, 2012, p. 5)

In spatial planning, the City of Gothenburg (2019) describes that it is essential that all forms of flood risk are assessed from a holistic perspective. This requires integration into the planning process through systematic risk mapping and adaptation evaluations over both short- and long-term timescales. The city also stresses the importance of establishing clear functional requirements early in the design phase to ensure flood protection measures are compatible with long-term management needs. (City of Gothenburg, 2019, p. 27)

Expanding on the above subject, City of Gothenburg (2019) reports that it is essential to consider where flooding occurs, specifically the types of buildings, businesses, roadways, and other infrastructure affected, and how long inundation persists. Flood damages fall into two categories: direct and indirect. Direct damages include physical losses, such as structural and content damage, when a property is flooded. Indirect damages arise from the event's secondary effects, for example, traffic delays and communication disruptions that incur waiting-time costs, or production losses in commercial operations due to both direct flood damage and subsequent delays in deliveries or workforce shortages. (City of Gothenburg, 2019, p. 17)

Filipova et al. (2012) explain that narrow streets and confined spaces between buildings are particularly vulnerable to flooding, often experiencing the greatest flood depths due to limited capacity for water dispersion. Peak water velocities are observed along major routes such as Magasinsgatan, Östra Hamngatan, and the Rosenlund Canal, where the flow is funneled through urban corridors. (See Figure 1.04) However, even areas with lower water velocities remain at risk, as insufficient drainage infrastructure can lead to prolonged inundation and delayed water recession. (Filipova, et al., 2012, p. 183)

All categories of flood risk must be comprehensively assessed, analyzed, and addressed in detailed development plans, claims City of Gothenburg (2019). The need for protective measures should be evaluated using a structured methodology, as outlined in chart 1.01. Proposed workflow for flood risk management in the planning process. This methodology includes the following steps:

- Identify and map the relevant flood risks.
- Assess the need for adaptation in the

short to medium term.

- Assess the need for adaptation in the long term.

Verify that the proposed plan achieves an acceptable level of residual flood risk.

Collectively, these measures reflect Gothenburg's strategic commitment to climate adaptation and flood resilience, grounded in long-term planning, cross-sector collaboration, and sustainable urban integration. (City of Gothenburg, 2019, p. 31)

Regarding sea-level rise risks, which is more well-known knowledge, (City Planning Department of Gothenburg) (2014, December 19) mentions that the Gothenburg region faces significant future changes in sea level and precipitation patterns. Sea levels are rising due to global warming, but it is less unknown that post-glacial land uplift partially offsets this increase,

(the gradual rise of the Earth's crust in formerly glaciated regions, including Sweden, occurring as the weight of the ice sheets is removed and the mantle slowly rebounds)

the rate of uplift is slower than the projected sea-level rise. As a result, net sea levels along Sweden's west coast are expected to exceed today's averages by the end of the century. In Gothenburg's Torshamnen, climate simulations indicate that the mean sea level will climb by approximately 70 cm by 2100.

Following the previous discussion, the City Planning Department of Gothenburg (2014, December 19) also further explains that seasonal precipitation regimes are also shifting: summers will become drier overall, while winters will experience increased rainfall. However, summer cloudbursts are expected to intensify significantly. Danish studies by the IDA Stormwater Committee suggest that, over a 100-year horizon, the intensity of a 2-year storm will increase by 20 percent, a 10-year storm by 30 percent, and a 100-year storm by 40 percent. A "2-year storm" refers to rainfall events that, on average, occur every other year. (City Planning Department of Gothenburg, 2014, December 19, p. 6)

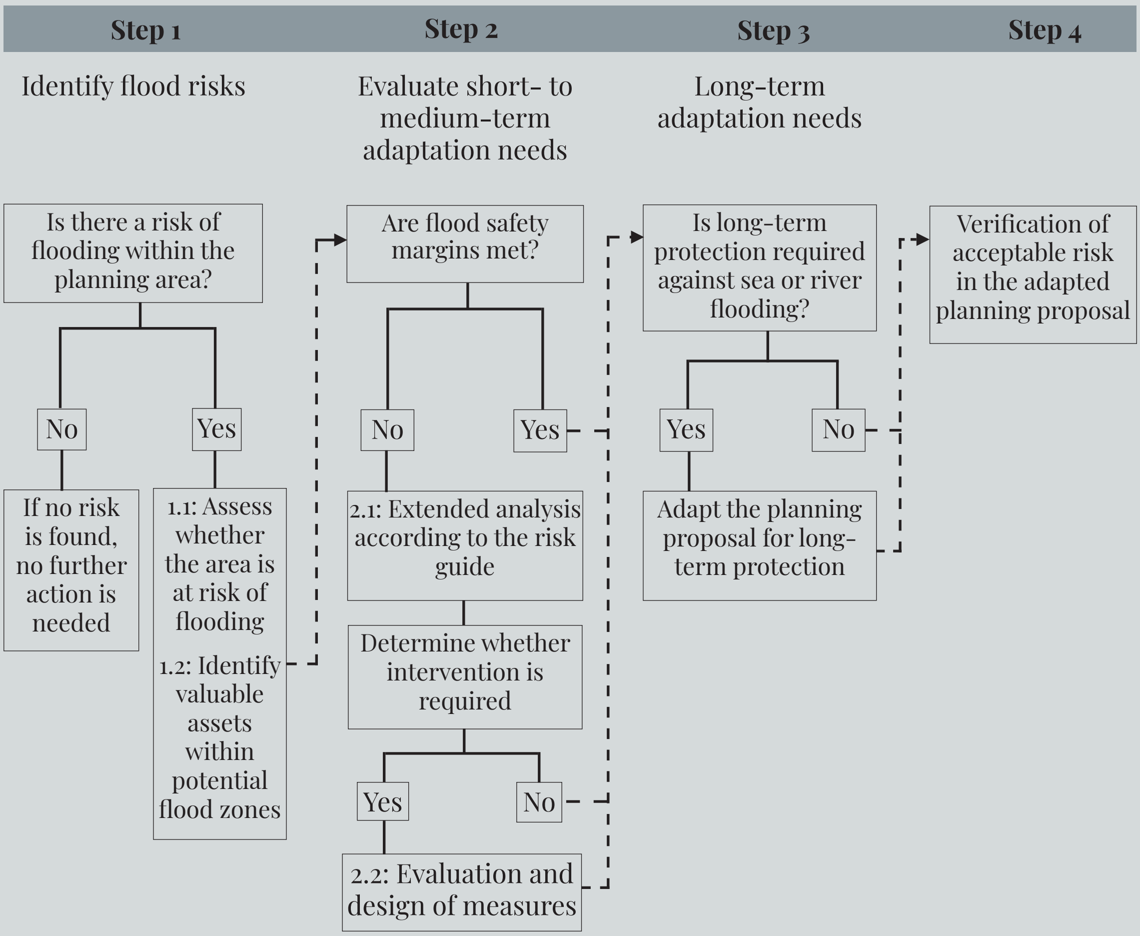


Chart 1.01. Workflow for flood risk management in the planning process. Based on the chart from City of Gothenburg. (2019, p. 31) Modified and translated by the author.

Östra Hamngatan
Magasinsgatan
Skeppsbron
Rosenlund Canal

Strategic guidelines for flood prevention in Gothenburg

Choosing strategic principles for managing urban flood risk involves several trade-offs. The City of Gothenburg (2019) claims that on one hand, general guidelines offer predictable requirements and allow for an efficient planning process with minimal use of resources. However, this approach may oversimplify complex issues and lead to overly conservative safety margins and unnecessarily expensive solutions. On the other hand, stakeholders financing these measures expect the costs to be proportionate to the societal benefits or risk reduction they achieve. This calls for site-specific adaptations, which, although more resource-intensive and requiring greater expertise in the investigation phase, can result in more cost-effective outcomes.

Another key consideration, according to the City of Gothenburg (2019), is how proposed strategies and guidelines can remain flexible in light of evolving knowledge and changing conditions. For instance, national guidelines are currently lacking, and the development of knowledge about climate change is advancing rapidly. One way to manage this uncertainty is by defining a process for how new information should be incorporated, an adaptive approach. In that case, a clear decision-making structure is required, indicating the level of authority required to revise guidelines and when periodic reviews should be conducted.

The city is advised to adopt "general guidance" as a baseline, with the possibility for "site-specific considerations" where justified. This means applying standard elevation-based planning thresholds while allowing exceptions if a detailed risk assessment demonstrates acceptable outcomes. The overarching principle should be to ensure strong societal benefit without compromising the required risk thresholds. Ultimately, the decision on which principles to follow and how to balance societal benefit, process efficiency, and climate resilience is a political one, particularly important in the absence of national standards. (City of Gothenburg, 2019, p.6)

Expanding on the subject introduced above, City of Gothenburg (2019, April 25) explains that key infrastructure, such as riverbank protection along the Göta älv, is recognized as critical. The city emphasizes the importance of taking a coordinated approach to the design, construction, maintenance, and reinvestment of these structures to ensure their long-term functionality. Furthermore, the planning and potential construction of outer barriers should be initiated in collaboration with relevant stakeholders to develop solutions that balance various technical, environmental, and societal interests. (City of Gothenburg, 2019, April 25, p. 27)

As the average sea level continues to rise, reports the City of Gothenburg (2019) that both the frequency of high water events and the magnitude of extreme high tides are expected to increase. The rate at which this occurs depends largely on how effectively global greenhouse gas emissions can be reduced. Based on current scientific understanding, there is no evidence to suggest that the duration of high water events will change in the future, but their occurrence will become more frequent.

The City of Gothenburg (2019) also mentions that they have chosen to plan according to the worst-case climate scenario outlined by the UN's Intergovernmental Panel on Climate Change (IPCC), known as RCP 8.5. This scenario projects a global sea level rise ranging from just under 30 cm to as much as one meter by the year 2100 (see Figure 1.06). However, these projections are subject to considerable uncertainty, and it cannot be ruled out that actual sea level rise may exceed these estimates over time.

The City of Gothenburg (2019) claims that, according to the Swedish Meteorological and Hydrological Institute (SMHI), based on the IPCC's worst-case scenario, the mean sea level in Gothenburg is expected to rise by 70 cm by 2100. This would mean that an extremely high water event in 2100 could correspond to a sea level of approximately +2.7 m. As illustrated in Figure 1.07, the projected mean sea level increase is estimated at approximately 10 cm by 2040, 20 cm by 2055, 30 cm by 2070, 40 cm by 2080, and 50 cm by 2090. (City of Gothenburg, 2019, p. 9)

Figure 1.04. Map highlighting areas of peak water velocity along Magasinsgatan, Östra Hamngatan, and the Rosenlund Canal, where stormwater flow is concentrated within narrow urban corridors. Base map from Lantmäteriet, modified by the author.

City of Gothenburg (2019) outlines that in planning contexts, it is not enough to consider a single year; the cumulative probability over the lifespan of a structure, such as a building, must be evaluated. Table 1.01 presents the cumulative probability of events with different return periods over various planning horizons. While the appropriate time horizon in urban planning is debatable, it is generally recommended to use a span of 50 to 200 years. Over a 100-year period, a 100-year flood event has a 63% chance of occurring, while a 200-year event has a 39% chance.

An extremely high water level corresponding to a 100-year flood event is currently estimated at +1.9 meters in central Gothenburg, while a 200-year event would reach +2.0 meters. (see Table 1.02 & Figure 1.09)

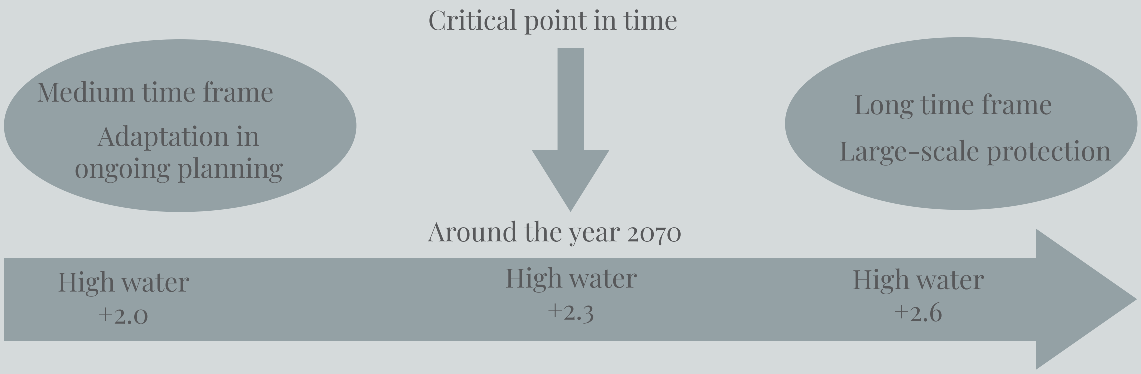
Gothenburg's flood planning starts with projections of future sea levels based on global climate models. City of Gothenburg (2019) refers to the Swedish Meteorological and Hydrological Institute (SMHI), which has translated IPCC climate scenarios into estimates of how high the sea could rise on Sweden's west coast (Torshamn). These projections are inherently uncertain, so they are used in planning rather than treated as precise forecasts. In Gothenburg's case, planners take the expected sea-level rise at the coast and assume a related high-water event in the river to see how far inland flooding might reach.

The estimated water level difference between Torshamnen and central Gothenburg is 0.3 meters, and between Torshamnen and areas north of Marieholm, the difference is 0.5 meters. (see Figure 1.08) These values reflect upstream gradients and should be interpreted as reference levels for planning, not forecasts of exact future sea levels. (City of Gothenburg, 2019, p. 12)

Following the previous discussion, Gothenburg has been relatively spared from extreme rainfall, but an event in August 2011 brought around 83 mm in just over 5 hours to southern Gothenburg, classified as a 100-year event, causing significant disruption and basement flooding. Flood risk management is complex, involving many actors. No single authority has full responsibility. Better collaboration and integrated urban planning are essential for long-term stormwater management. (City of Gothenburg, 2019, p.16)

Based on current knowledge about future sea level rise, Gothenburg's existing planning levels are expected to provide adequate protection for approximately 50 years, i.e., until around 2060–2070. City of Gothenburg (2019, April 25) states that by that time, the mean sea level is projected to have risen by about 0.3 meters, which would eliminate the current safety margin of 0.5 meters embedded in today's planning levels. Therefore, in the long term, the city must develop permanent high-water protection to safeguard infrastructure and developments built according to both current and past planning benchmarks.
In response to this need, Gothenburg has developed a comprehensive flood risk strategy divided into medium-term and long-term actions (see Figure 1.05). (City of Gothenburg, 2019, April 25, p. 24)

Figure 1.05. Timeline for critical flood adaptation decisions in Gothenburg. Conceptual diagram showing sea level projections and the estimated critical decision point around 2070. It illustrates the transition from medium-term adaptation (e.g., planning adjustments) to long-term, large-scale protective measures. Source: City of Gothenburg. (2019, April 25, p. 24). Modified and translated by the author.



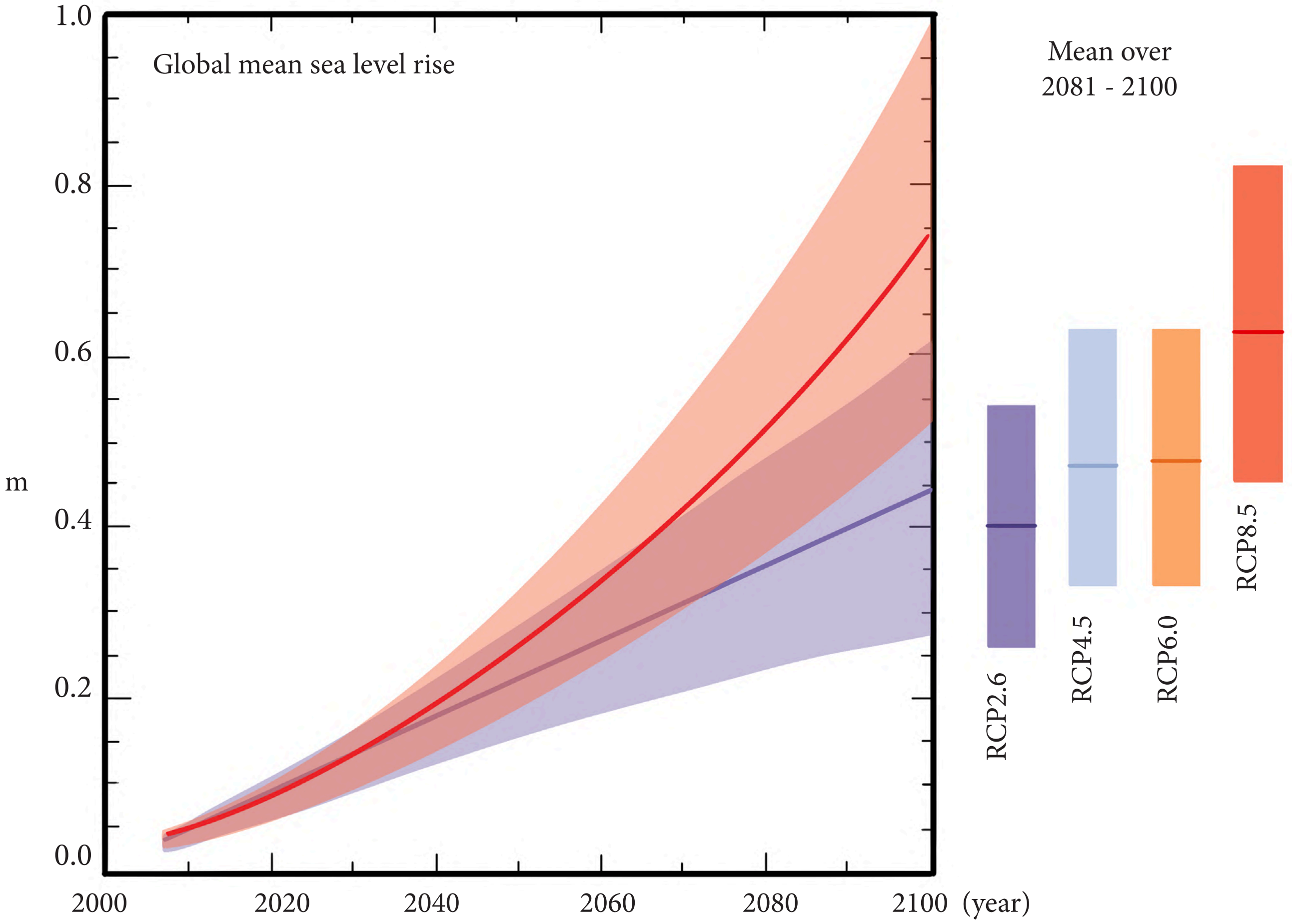


Figure 1.06. Sea level rise under different climate scenarios according to the IPCC (2013). Source: City of Gothenburg (2019, p.10). Modified and translated by the author.

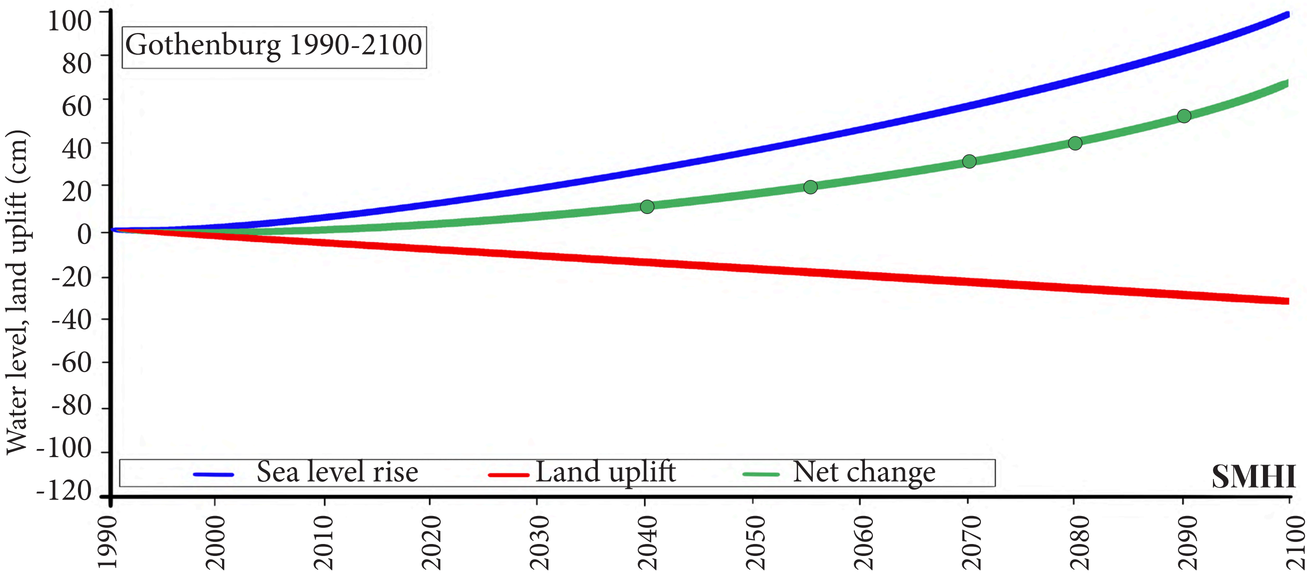


Figure 1.07. Projected change in mean sea level in Gothenburg from 1990 to 2100 based on SMHI's regional climate analysis. Source: City of Gothenburg (2019, p. 10). Modified and translated by the author.

Figure 1.08. Planning levels along the Göta älv river. Map showing designated planning levels in Gothenburg's coastal zone, Torshamn, central city, and north of the Marieholm Bridge, with reference sea level benchmarks of +2.5 m, +2.8 m, and +3.0 m. Source: City of Gothenburg. (2019, April 25, p. 20).


+ 3,0
Marieholm bridge
+ 2,8
Skeppsbron
Torshamn
+ 2,5
Legend
Planning level

Return period (year)	Probability (in percent) for various planning periods (year) 5	10	50	100	200
10	41%	65%	99%	100%	100%
100	5%	10%	39%	63%	87%
200	2%	5%	22%	39%	63%
500	1%	2%	10%	18%	33%
10 000	0%	0%	0%	1%	2%

Table 1.01. Cumulative probability (%) of events with different return periods over various planning horizons. The table shows the likelihood, expressed as a percentage, that an event of a given return period (in years) will occur within different planning periods ranging from 5 to 200 years. The total chance that an event will happen at least once over a period of time. From City of Gothenburg (2019, p.). Translated by the author.

Year	MW	10 year	20 year	50 year	100 year	200 year
2014	0,15	1,5	1,5	1,7	1,9	2,0
2070	0,45	1,8	1,8	2,0	2,2	2,3
2100	0,87	2,1	2,2	2,4	2,6	2,65

Table 1.02. Highest sea levels in Rosenlund for different return periods. Projected maximum water levels (in meters RH2000) in Rosenlund for return periods ranging from 10 to 200 years, shown for the years 2014, 2070, and 2100. Source: Andersson-Sköld, Y., & Davidsson, G. (2016, February 26, p. 13). City of Gothenburg, City Planning Department of Gothenburg. Translated by the author.

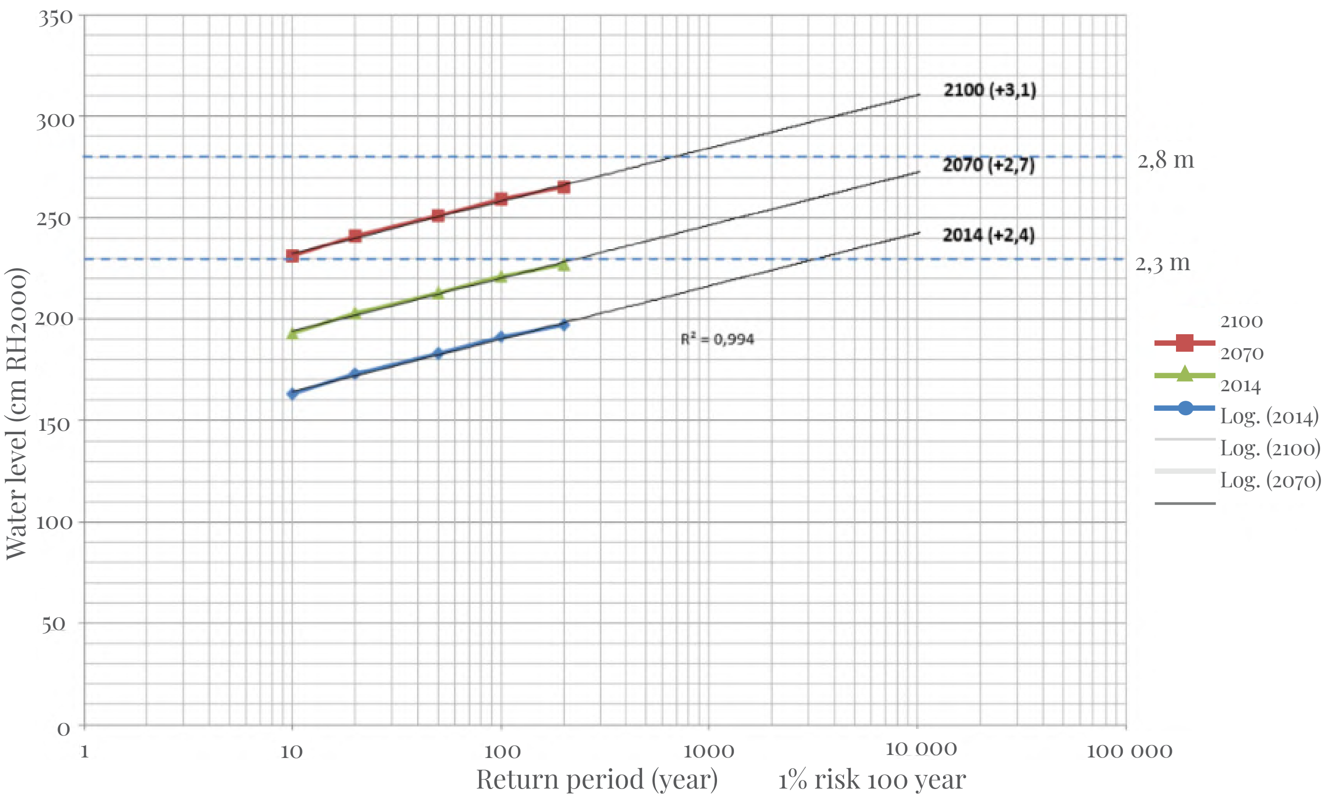


Figure 1.09. Water levels in central Gothenburg. Extrapolated sea level projections for central Gothenburg, shown for the years 2014, 2070, and 2100, based on different return periods up to 10,000 years. Water levels are given in RH2000. Source: Andersson-Sköld, Y., & Davidsson, G. (2016, February 26, p. 13). City of Gothenburg, City Planning Department of Gothenburg. Translated by the author.

Stormwater structure plan for Gothenburg

Gothenburg faces multiple climate-related challenges, including rising sea levels and increasingly frequent, intense cloudbursts. DHI Sverige AB (2020) explains that to reduce the city's long-term vulnerability to flooding, the municipal government has developed comprehensive "structure plans" for flood risk management. These plans divide the urban area into 15 distinct catchments, each with tailored strategies for runoff control and resilience (see Figure 1.10). The area examined in this thesis falls within the Centrum South catchment. (DHI Sverige AB, 2020, p. 2)

Each structure-plan catchment discharges into a water body, emphasizes DHI Sverige AB (2020), and they are designated as the final recipient, defined by its effectively unlimited capacity to absorb cloudburst runoff. In Gothenburg, the sea and the Göta älv fulfill this role. Smaller streams and watercourses, lacking sufficient conveyance capacity, are therefore classified as potential cloudburst channels. (DHI Sverige AB, 2020, p. 23)

Stormwater structure plan for Centrum South

This thesis focuses on a riverside site of strategic importance to central Gothenburg: Skeppsbron, located adjacent to several of the city's key urban nodes. Skeppsbron is situated within the planning area known as Centrum South. The design proposal seeks to establish Skeppsbron as a new urban node and demonstrate an integrated blue-green approach to flood management. (see Figure 1.11) The full details of the design proposal will be described in a dedicated chapter while introducing the location and its context within the Centrum South planning area, providing a necessary foundation for comprehensively understanding the subsequent site analysis.

DHI Sverige AB (2020) indicates that the Centrum South catchment spans approximately 19 km² in Gothenburg, transitioning from steep, vegetated slopes and rocky forest upstream to a densely built urban waterfront along the Göta älv. This spatial gradient, from permeable natural terrain to extensive impervious surfaces, creates rapid runoff and concentrated flow toward the city center. (DHI Sverige AB, 2020, p. 4) Without intervention, polluted stormwater from asphalt and other urban surfaces will flow directly into the Göta älv, worsening water quality. This highlights the need for a system capable of capturing and treating runoff before it reaches the river.

The stormwater structure plan for this catchment area consists of an integrated network of flood management infrastructure, including 48 stormwater channels, 35 stormwater retention areas, and 8 flow control structures, arranged into 28 interconnected management chains.

DHI Sverige AB (2020) states that the area's dense urban fabric, combined with steep slopes and rocky terrain, limits available space for stormwater storage, necessitating strategically linked structures and retention zones to manage runoff effectively. (DHI Sverige AB, 2020, p. 4)

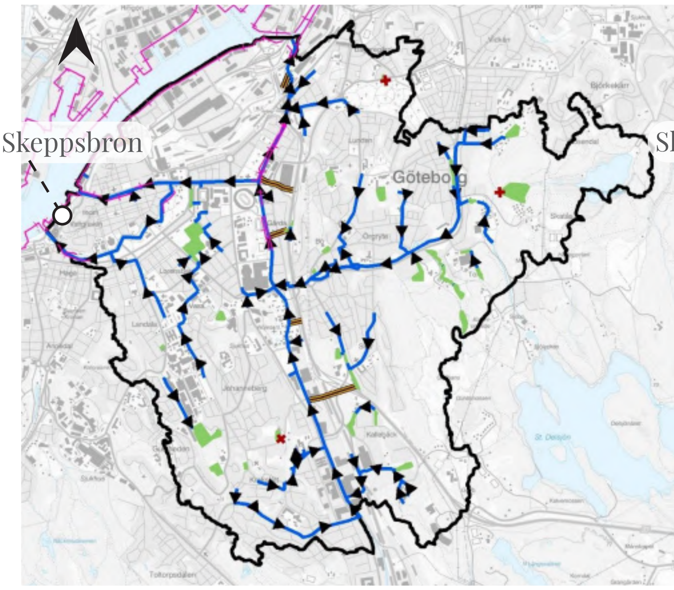
In continuation of this topic, DHI Sverige AB (2020) continues that the primary watercourse is the Mölndalsån, which flows northward into the Göta älv via an interconnected network of canals and ditches. (See Figure 1.10) The existing stormwater infrastructure comprises a mix of aging pipe systems, open channels, and natural streams, all of which discharge into Mölndalsån or adjacent waterways. Variable pipe capacities, due to differing installation standards and slopes, further complicate runoff conveyance. (DHI Sverige AB, 2020, p. 14)

Stormwater retention areas have been positioned primarily upstream, in locations where space and existing natural conditions allow optimal water retention, reducing flooding impacts downstream within the built environment. Many of these retention areas are existing ponds that require increased capacity, while others are current green spaces identified for enhanced stormwater storage. Collectively, these areas provide approximately 116,000 cubic meters of water storage volume, significantly reducing flood risks. (DHI Sverige AB, 2020, p. 4) During extreme rainfall events, green surfaces cannot infiltrate all incoming water, resulting in increased surface runoff.

Figure 1.10. Geographic area covered by the structure plans and their subdivisions. Source: DHI Sverige AB (2020). Modified and translated by the author.


Stora Bommen
Lilla Bommen
Skeppsbron
Rosenlund

Figure 1.11. Key urban nodes of central Gothenburg in relation to the Skeppsbron site. Base map from Lantmäteriet. Scale 1:50,000 (A4). Modified by the author.



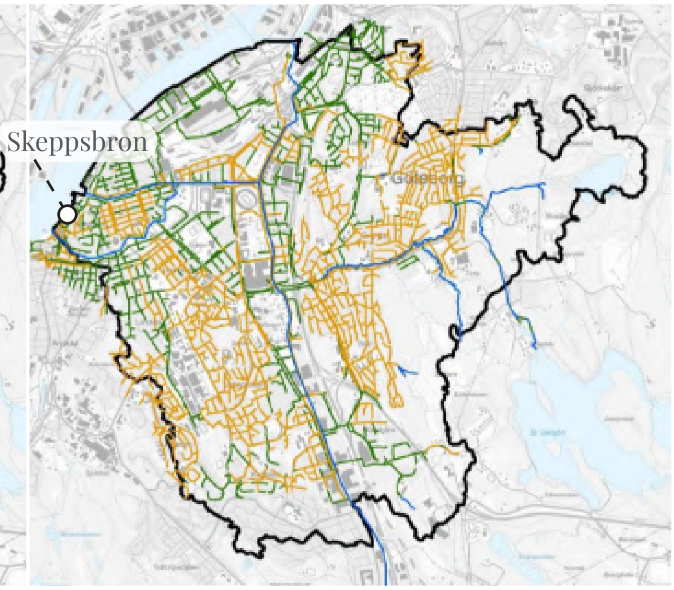
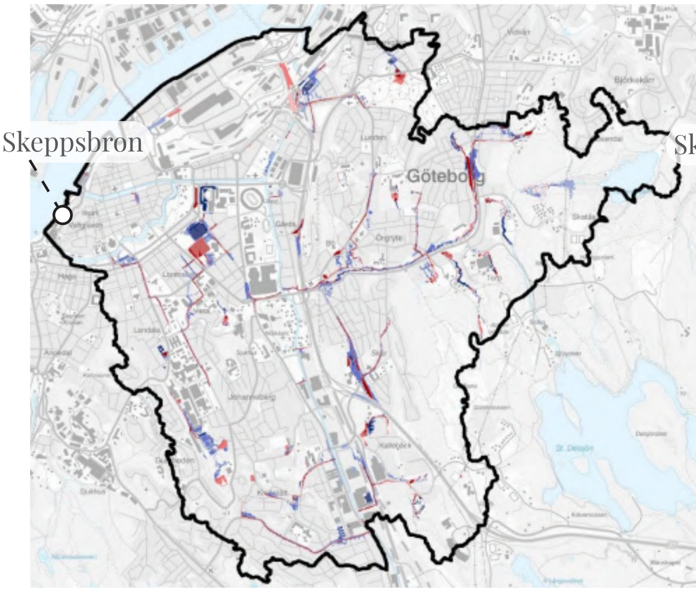


Figure 1.12. Left. Comprehensive stormwater infrastructure network for the Centrum South structural plan area (black), showing primary stormwater channels (blue), complementary channels (purple), high-water protection structures (pink), control installations (red crosses), and retention areas (green hatching). Source: City of Gothenburg, Waste and Water Division. (2020, December, p. 6).

Figure 1.13. Right. Stormwater catchment and drainage network in the Centrum South planning area (black), showing separate drainage (green), combined sewer (yellow), and open watercourses (blue). Source: City of Gothenburg, Waste and Water Division. (2020, December, p. 15).



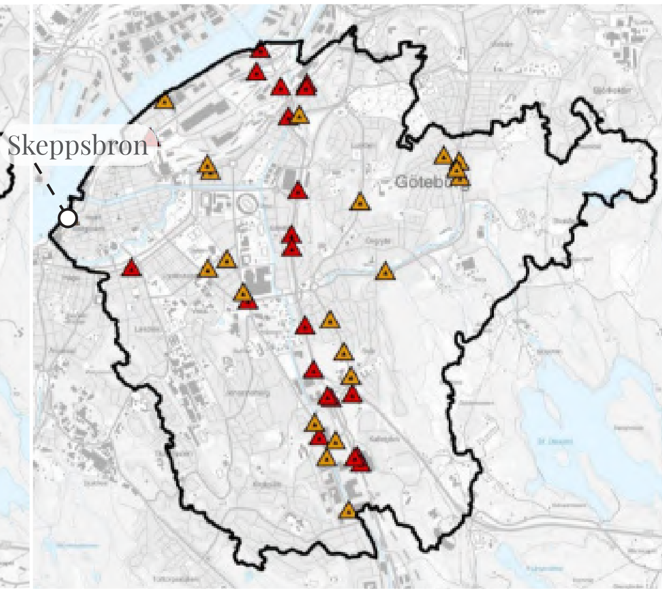


Figure 1.14. Left. Predicted change in maximum flood depth (m) across the Centrum South planning area (black) after implementation of stormwater measures (blue = depth reduction, red = depth increase). Source: City of Gothenburg, Waste and Water Division. (2020, December, p. 7).

Figure 1.15. Right. Locations of high-consequence flood zones and limited accessibility within the Centrum South planning area (black). Class 1: high-priority municipal road network, major national roads (red triangle)
Class 2: high-traffic road network, emergency routes, public transport corridors (yellow triangle). Source: City of Gothenburg, Waste and Water Division. (2020, December, p. 22).

Implementation Prioritization

Although it is clearer which areas demand stronger flood resilience, specific elements within these areas are further categorized and prioritized based on functional importance and response urgency. DHI Sverige AB. (2020) notes that proposed interventions have been classified into three priority levels (A–C) based on the type of activity, building, or infrastructure they are intended to protect. This ranking follows the Swedish Civil Contingencies Agency's (MSB, 2014) guidelines.

- Priority A includes measures designed to safeguard life-and-health services and public safety facilities, where immediate protection (within hours) is critical.
- Priority B covers interventions aimed at protecting schools, municipal leadership functions, and key transportation corridors (Class 1 roads).
- Priority C comprises all other measures and intervention chains.

After this initial classification, further prioritization may consider additional criteria such as construction cost, site accessibility, and feasibility. Figure 1. 16 illustrates the spatial distribution of these priority classes across the proposed structural plan installations. Skeppsbron (the thesis project site) is situated between the Rosenlund Canal and the Stora Hamn Canal, both classified as Priority A measures. These canals are given top implementation priority because they protect critical life-and-health services and public safety infrastructure, where rapid response to flooding (within hours) is essential. (DHI Sverige AB, 2020, p. 36)

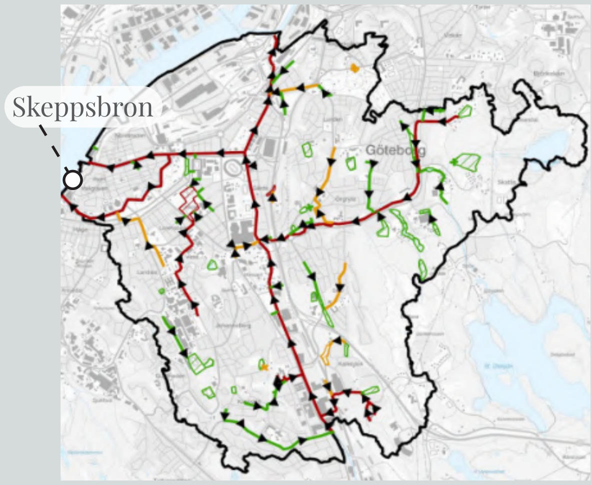


Figure 1.16. Prioritization of proposed stormwater management installations by measure type. Each classified into priority classes A (red), B (yellow), or C (green). Source: City of Gothenburg, Waste and Water Division. (2020, December, p. 37).

Demonstration Installations

The following conceptual overview illustrates how stormwater conveyance and storage elements can be configured and sized in practice. The design proposal integrates some of these practices and refines them through local structure plans and lessons from inspirational case studies. A central principle is to capture polluted runoff from urban surfaces (such as streets) and subject it to sequential filtration and treatment. Only when water quality meets safety thresholds is it released into the Göta Älv, safeguarding the river's ecological integrity. This and more details will be well discussed and explained in the following chapters of this thesis.

Continuing from the earlier section, DHI Sverige AB. (2020) presents in Figure 17. and 18, that four common cross-sections, street square, box culvert, swale, and buried stormwater pipe, are each accompanied by design charts that translate required flow capacities into specific widths and slopes. It then details the three key hydraulic controls: cross-sectional area, longitudinal slope, and surface roughness (Manning's coefficient, M, where a well-maintained swale at M = 40 (M = 40% means the channel drops by 40 mm for every 1 m of horizontal distance (a 4 % gradient), can carry more than twice the flow of an overgrown channel at M = 20). Finally, the overview addresses retention areas by showing how plan-area dictates storage volume and how berms or terraced basins on sloped sites can be employed to achieve the necessary capacity. By combining these section types and sizing parameters, whether pairing swale and pipe or roadway and square culvert, tailored stormwater solutions can be developed that meet the structure plan's performance requirements. Each colored curve represents the flow-capacity for a specific longitudinal slope of the channel or pipe. The legend percentages denote slope as a drop per 100 m of length:

- 0.2 % = 0.2 m drop per 100 m
- 0.5 % = 0.5 m drop per 100 m
- 1.0 % = 1.0 m drop per 100 m
- 2.0 % = 2.0 m drop per 100 m
- 5.0 % = 5.0 m drop per 100 m

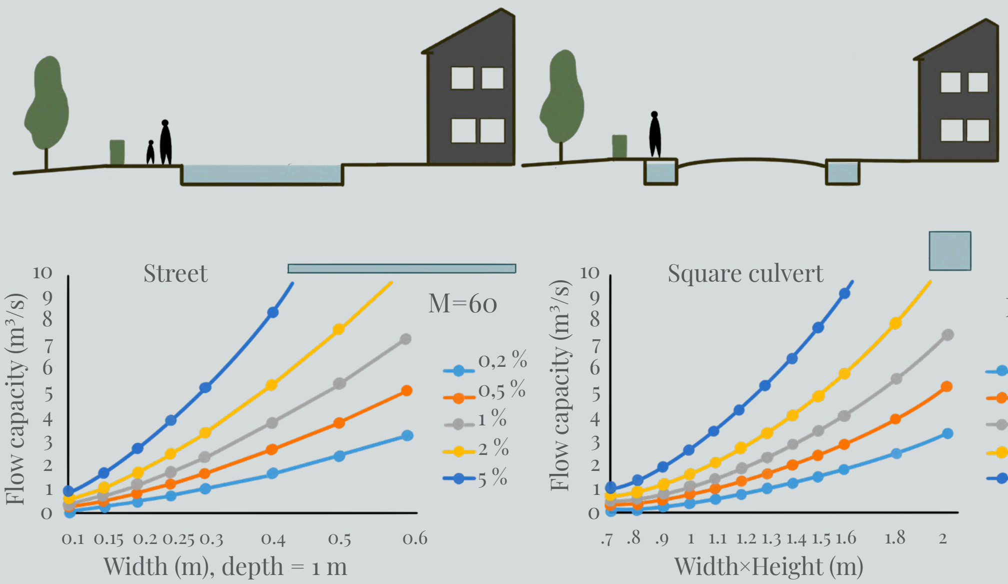


Figure 1.17. Cross-section typologies of a street-level stormwater channel (left) and a square culvert (right), with corresponding flow-capacity curves. The channel chart displays flow rate as a function of water depth and channel width (10 m) for a maximum slope of 60 (M=60). The culvert chart shows flow rate versus conduit width (equal to depth) and slope for a maximum slope of 80 (M=80). Source: City of Gothenburg, Circular Economy and Water. (2020, December, p. 39). Modified and translated by the author.

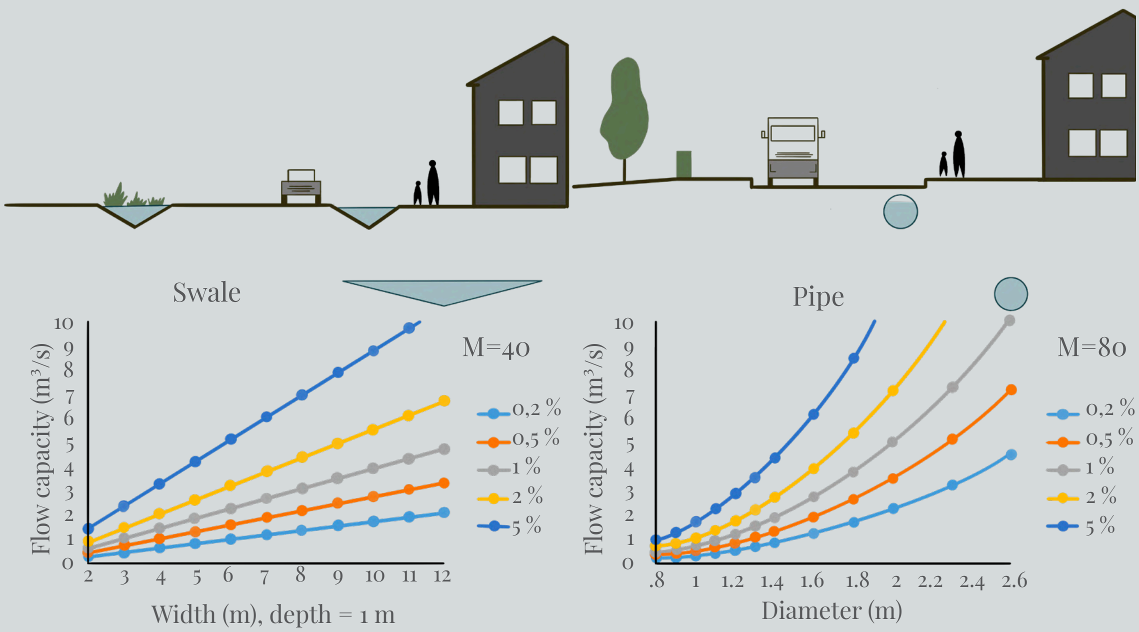


Figure 1.18. Cross-section typologies of a roadside swale (left) and a buried stormwater pipe (right), with corresponding flow-capacity curves. The swale chart illustrates flow capacity as a function of channel width and slope for a 1 m deep swale (M = 40), The pipe chart shows flow capacity versus pipe diameter and slope (M = 80). Source: City of Gothenburg, Circular Economy and Water. (2020, December, p. 40). Modified and translated by the author.

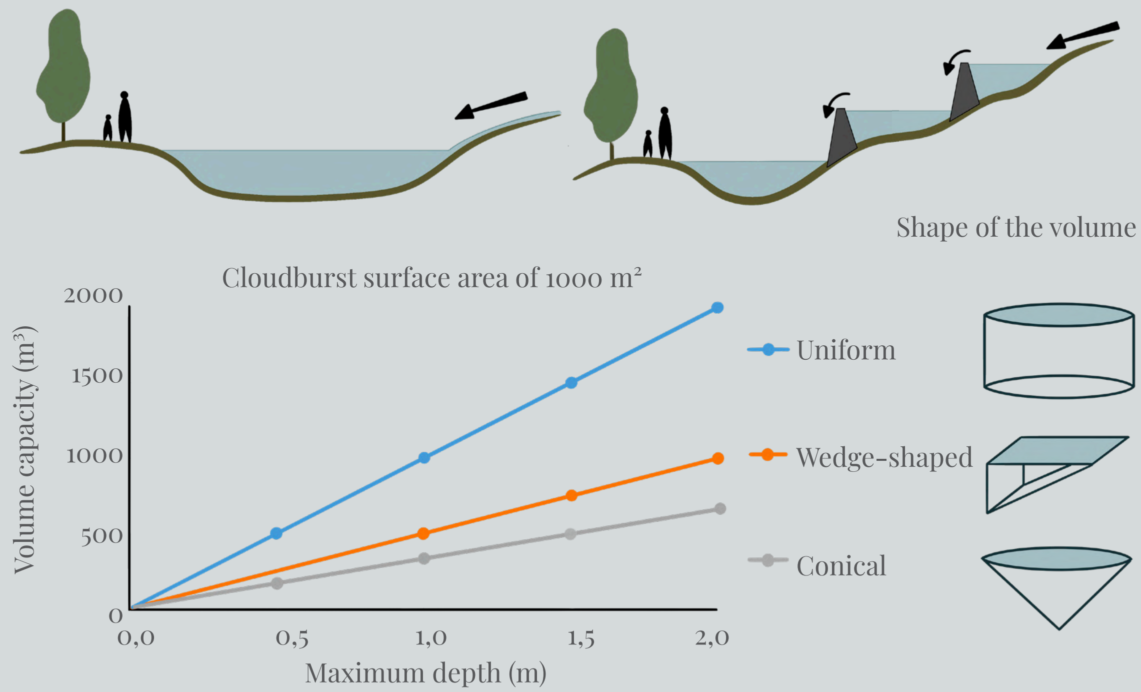


Figure 1.19. Comparison of detention basin typologies: uniform (cylindrical), wedge-shaped, and conical; with corresponding storage capacity curves for a 1,000 m² wetland area as a function of maximum water depth. Source: City of Gothenburg, Circular Economy and Water. (2020, December, p. 40). Modified and translated by the author.

Multifunctional green spaces

City of Gothenburg (2019, April 25) mentions that flood protection solutions should be designed for multifunctionality, enabling them to serve purposes beyond flood mitigation, such as contributing to biodiversity, ecological value, and social amenity. Modeling studies suggest that riverbank protection with or without sheet piling can effectively prevent groundwater intrusion during high-water events, depending on subsurface conditions. During extreme cloudbursts, minor and localized backwater effects may still occur behind such structures. (City of Gothenburg, 2019, April 25, p. 27)

Urban green infrastructure plays a critical role in enhancing environmental resilience and the quality of life in dense urban contexts like Gothenburg. City of Gothenburg (2019, April 25) argues that as urban development intensifies, it becomes increasingly important to preserve and activate underutilized spaces through multifunctional green strategies. Parks, green corridors, and riverfront areas should not be viewed solely as recreational zones, but as essential ecological buffers that support biodiversity, manage stormwater, and contribute to the city's long-term climate adaptation.

Permeable surfaces are particularly valuable in this regard. By absorbing and delaying the flow of large volumes of rainwater, they help reduce pressure on drainage systems and mitigate urban flooding. During drier periods, these surfaces can also function as flexible spaces for play, rest, and social interaction. This multifunctionality offers children more opportunities for movement and exploration in compact city areas, creating stimulating environments for play and learning. (DHI Sverige AB, 2020, p. 23)

City of Gothenburg (2019, April 25) also mentions that along the Göta älv riverfront, flood protection structures such as embankments and riverbank reinforcements should be designed not only for technical performance, but also to reduce physical and visual barriers. When carefully integrated into the urban landscape, these structures can serve as accessible, green public spaces that reconnect residents and visitors with the water. (City of Gothenburg, 2019, April 25, p. 45)

Additionally, regarding Centrum South catchment area, DHI Sverige AB (2020) indicates that Askimsviken serves as the final discharge point for the Centrum South catchment's stormwater and in some cases, integrating stormwater management with existing infrastructure may be feasible; in others, multifunctionality must be achieved by incorporating traffic solutions, recreational and green spaces, or alternative land uses. (DHI Sverige AB, 2020, p. 23)

Ultimately, by combining ecological performance with social accessibility, green and permeable surfaces gain a central role in building a more adaptive, livable, and resilient city, where nature is not treated as a separate entity but as a fundamental component of the urban fabric. (City of Gothenburg,2019, April 25, p. 45)

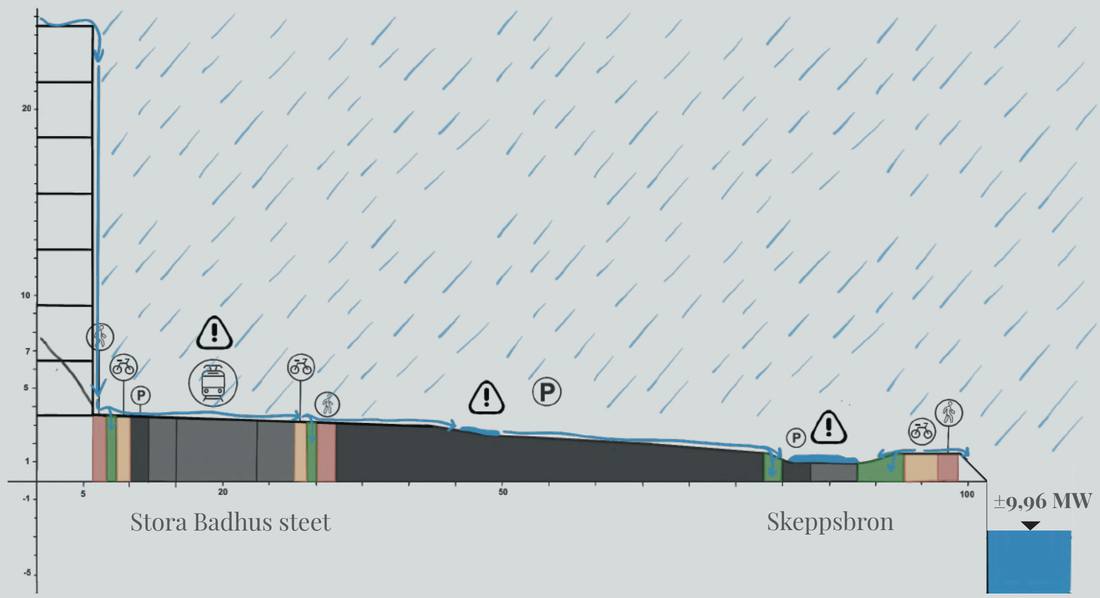
Building on the previous discussion, Desfarges, Q. (2015) also explores how vegetation plays a crucial role in flood prevention, in addition to its well-established benefits such as carbon sequestration, urban heat island mitigation, and temperature regulation through shading and evaporative cooling. To effectively contribute to flood mitigation, he continues that selected plant species must be resilient, capable of withstanding salt exposure and prolonged inundation. Beyond flood control, strategically integrated greenery supports biodiversity by providing food sources, shelter, and habitat for birds, butterflies, and other pollinators. Additionally, certain plant species contribute to water purification by filtering pollutants, further enhancing ecological functions. (Desfarges, Q. , 2015, p. 79) This topic will be discussed in greater detail in the subsequent chapters, as runoff filtration represents a key aspect of the design.

Another key motivation for developing a blue-green design proposal is the interplay of steep upstream terrain and impermeable downstream surfaces, which accelerates runoff, triggers flash flooding, and overwhelms the conventional drainage system. (see Figure 1.22) To address these challenges, the thesis introduces blue-green infrastructure that emulates natural hydrological processes, such as stormwater retention areas, permeable surfaces, and constructed wetlands. The design aims to slow, retain, and filter runoff before its controlled discharge into the Göta älv. The primary objective is to reduce flood risk by strategically directing and temporarily storing stormwater. Implementing these interventions is projected to significantly reduce flooding impacts within the Centrum South catchment area.

Figure 1. 20. Parks and natural areas in Gothenburg 1:50,000 (A4). Source: City of Gothenburg. (2022). Comprehensive plan for Gothenburg.

Figure 1. 21. Parks and natural areas in Skeppsbron 1:10,000 (A4). Source: City of Gothenburg. (2022). Comprehensive plan for Gothenburg.

Figure 1. 22. Section illustration of the existing structure at Skeppsbron. The area is characterized by tall buildings and an extensive use of asphalt, primarily for parking, which significantly limits natural infiltration. The lack of sufficient soil and vegetation reduces the site's capacity to absorb stormwater, thereby increasing the risk of flooding. Illustration by the author.




Legend
City, district, residential-adjacent parks and nature, inner city
Valuable natural and recreational area

Skeppsbron
Legend
City, district, residential-adjacent parks and nature, inner city

Interview

Topics covered: cloudburst causes, types of floods and their consequences, climate change effect on precipitation, Gothenburg's most vulnerable districts, Gothenburg's measures for flood protection, flood prevention challenges, and last but not least architect's role.

Interviewer/Author: Can you explain how a cloudburst happens?

Dick Karlsson Senior Specialist in Climate Adaptation, Kretslopp och vatten (Circulation and Water Urban Development), Unit for Stormwater and Cloudburst Management (SUDS): Cloudbursts happen when warm air holds a lot of moisture, and when that warm air meets cold air, it releases all that moisture quickly. This is typically triggered by very hot conditions during summer or autumn. The warm air can hold more water, and once it reaches a point where it can't hold anymore, a heavy rain or storm occurs. This is why you often experience intense thunderstorms and heavy rain after a period of extreme heat. It's a mix of high temperatures, high humidity, and a sudden shift in air pressure. This type of rainfall is becoming more common, but it's compounded by storm surges and rising sea levels, which are separate issues. While sea level rise will gradually worsen over time, it won't be a major problem everywhere, especially in areas that are higher up, like Angered (Northern suburb of Gothenburg).

Author: What types of flooding are expected to become more frequent or severe in Gothenburg due to climate change, both in the present and in the future?

Dick K.: Rain is a significant issue we face today. Statistically, we expect cloudbursts to occur more frequently, and models show how often a 100-year flood event might happen in the next century. We base our planning on the idea that a 100-year flood should happen once every 100 years. However, by 2100, these events could occur more frequently, possibly becoming a "50-year flood," meaning it could happen once every 50 years instead of once every 100 years. This is a noticeable change. However, it's also possible that a 200-year flood could occur today, and it would be as severe as a 100-year flood predicted for 100 years from now. So, we are facing serious challenges with rainfall events today. As for storm surges related to waterways, we already experience these to some extent, and they are expected to worsen as well.

Author: How will climate change affect precipitation?

Dick K.: Climate change will reduce snowfall at our latitudes, leading to fewer snow-covered days. This results in the "no-snow" problem. As for storm surges, rising sea levels will worsen the severity of storms, particularly in winter, and can cause higher water levels. With changing seasons, heavy rainfall could occur simultaneously with these high sea levels, creating a new challenge. To manage these effects, we're working on adapting stormwater systems. However, with rising sea levels, water won't drain as easily in coastal areas, and we may need to pump water out of low-lying regions more frequently, which will become more common as climate change progresses.

Author: Which districts in Gothenburg do you consider most vulnerable to flooding?

Dick K.: Districts are geographically defined based on factors unrelated to water. Vulnerability depends on factors like drainage basins and terrain structure, which determine where water flows when it rains. Low-lying coastal areas are more exposed to flooding from the sea. At the same time, cloudbursts can cause flooding anywhere, especially in places where the built environment is poorly suited to handle heavy rainfall.

Author: What techniques and measures are currently used in Gothenburg to protect the city from flooding and improve its resilience?

Dick K.: It's largely about balancing and delaying water, similar to Vänern, and directing it to areas where it won't cause damage, essentially avoiding the creation of urban rivers. High water protection involves barriers to prevent rising sea levels from flooding the land, along with pumping systems to manage rainwater when sea levels are high. Additionally, Gothenburg has developed a drainage network with retention areas, stormwater ponds, rain gardens, and permeable surfaces like parks and green spaces to control water flow and reduce flood risks. The city is also implementing nature-based solutions, such as infiltration and wetland creation, to retain water and prevent damage. Vänern, functions as a sponge city. Several urban projects demonstrate these efforts as well, including Maskinparken in Lindholmen, which serves as a retention volume, Opalparken, which has remarkable flood resilience, and The new Munkebäck. Guldhedens forest, near Sahlgrenska Hospital, is another example where natural interventions are being expanded. Additionally, Stabbeparken, near Östra Hospital, is part of ongoing flood resilience planning. It's about finding ways to make spaces multifunctional and supportive of biodiversity.

There are three main military strategies that can be implemented as flood risk managing strategies, which are: "attack," "defense," and "retreat."

The "attack" approach involves keeping the problem away, like using barriers to prevent water from reaching the area.

"Defense" is about mitigating the impact of flooding with solutions like floating houses that rise with water levels, which have been discussed in Gothenburg.

"Retreat" refers to leaving areas that are at high risk because it's not worth investing in protection.)

Author: What challenges do you face when implementing new projects to prevent flooding in Gothenburg?

Dick K.: We encounter several legal and financial challenges, as well as organizational structures that need to settle, which ultimately limit the scope of our projects. The financial aspect is the overarching constraint, often preventing us from advancing certain ideas. For instance, achieving a reasonable level of climate adaptation for Gothenburg by 2100 would require an investment of approximately 50 billion kronor. Such a large-scale transformation is difficult to realize under current financial conditions. At the same time, securing that funding is essential, and finding a fair way to allocate and distribute those resources is a significant challenge.

Author: What role do architects play in ensuring that cities are built to be more flood-resilient?

Dick K.: Making sure we don't continue to build in the wrong places. We need to build in locations where pumping isn't necessary and develop the city in a way that avoids repeating past mistakes. There are regulations in place, such as building codes, that guide us towards these goals. It's similar to how fire safety evolved. We no longer build cities that easily catch fire; we use safer materials and have fire breaks. In the same way, we need to build cities that are resilient to flooding and identify high-risk areas to protect.

A resilient city when we build new.

Reference projects

Maskinparken, Lindholmen, Gothenburg

Figure 1.23. Maskinparken in Lindholmen, Gothenburg, is a sunken urban park designed to manage stormwater and enhance biodiversity. From 02 LANDSKAP. (n.d.)

Maskinparken is a climate-adaptive urban park located in Lindholmen, Gothenburg, designed by 02 LANDSKAP and developed between 2020 and 2021. 02 LANDSKAP (n.d.) shows that this park was created for the City of Gothenburg's Parks and Landscape Administration. The park replaces a former parking lot with a vital green space in a rapidly developing district. Its most notable feature is a sunken lawn that functions as a stormwater basin, capable of retaining up to 500 cubic meters of water during heavy rainfall.

Demonstrating a nature-based solution for flood mitigation and resilient urban planning. Surrounded by meadow-covered hills and tree species, the park supports biodiversity while providing social and recreational value. Carefully designed spatial ensures that the park remains both functional and inviting year-round. As a reference project, Maskinparken exemplifies how green infrastructure can integrate flood control, ecological value, and community space within dense urban environments. (02 LANDSKAP, n.d.)

Jubileumsparken, Frihamnen, Gothenburg

Figure 1.24. A resilient waterfront promenade integrates natural vegetation, rocky edges, and public seating along the shoreline. From Mareld Landskapsarkitektur. (n.d.)

Mareld Landskapsarkitektur. (n.d.) shows on their website that Jubileumsparken, located in Frihamnen, Gothenburg, is a long-term urban strategy and landscape development initiated in 2016 by the City of Gothenburg, with Mareld and Atelier le Balto as lead designers. The project was conceived as a phased and co-created transformation of a former industrial waterfront into an adaptable, ecologically rooted public park. Emphasizing gradual evolution, the design considers the entire Frihamnen area as a potential framework for social, environmental, and spatial growth, integrating nature-based solutions and local ecosystems into the urban fabric.

A defining feature of the park is its carefully controlled water edge, where large stone structures stabilize the shoreline while creating resilient transitions between land and water. Elevated wooden walkways run alongside and above these rocky edges, offering continuous access and new spatial experiences along the waterfront. This integration of infrastructure and landscape demonstrates how flood-conscious design can merge with recreational and ecological functions, making Jubileumsparken a strong reference for adaptive, nature-based urban development. (Mareld Landskapsarkitektur, n.d.)

"Det övergripande målet för miljöpolitiken är att till nästa generation lämna över ett samhälle där de stora miljöproblemen är lösta, utan att orsaka ökade miljö- och hälsoproblem utanför Sveriges gränser."

– Riksdagens definition av generationsmålet.

"The overall goal of environmental policy is to leave to the next generation a society where the major environmental problems are solved, without causing increased environmental and health issues beyond Sweden's borders."

– The Swedish Parliament's definition of the generation goal. From Göta Älv Water Management Association. (2015). p. 92)

WASTE MANAGEMENT

Introduction

Have you ever stopped to consider how many different types of waste we generate? Is it five? Ten? Or perhaps far more than we imagine?

In reality, the list is extensive and continues to grow as our lifestyles and industries evolve. Waste is not a singular issue, it's a complex, layered system that spans across sectors, scales, and materials. Here's just a glimpse into some of the most common and widely recognized categories:

- Agricultural waste: leftover biomass from farming activities.
- Biomedical and clinical waste: any kind of waste containing infectious (or potentially infectious) materials generated during the treatment of humans or animals.
- Construction and demolition (C&D) waste: rubble, concrete, wood, metal, bricks, and other by-products of building and infrastructure projects.
- Electronic waste (e-waste)
- Food waste
- Green or organic waste: any organic waste that can be composted from gardens, parks, and landscaping, such as leaves, grass, and branches.
- Greywater (sullage): domestic wastewater generated in households (sinks, showers, and laundry) or office buildings.
- Hazardous waste: toxic, flammable, or corrosive materials that must be handled properly to avoid damaging human health or the environment.
- Industrial waste
- Slag: a waste matter separated from metals during smelting.
- Sludge: semi-solid waste from wastewater treatment processes.
- Sewage: wastewater from households and industries containing human waste and contaminants.

And this list is far from complete, there are dozens of other waste streams generated by our daily activities and the systems we depend on.

This master's thesis focuses on one of the most visible and resource-rich waste types: construction and demolition waste (C&D). Often considered a burden or a by-product, these materials, when reimagined, hold significant potential as raw inputs for sustainable urban design. The design proposal presented in this thesis is rooted in the reuse of these materials, exploring how construction debris can be transformed into functional, aesthetic, and ecologically sensitive interventions in the cityscape.

In the chapters that follow, the specific waste materials selected for reuse will be identified and discussed in detail, including their origin, properties, environmental impact, and design potential. By understanding the nature of these materials, we can begin to unlock new ways of designing with waste, not against it.

The European Commission (n.d.) outlines fundamental principles for waste management, emphasizing the need to handle waste in a way that safeguards human health and prevents environmental harm. This includes avoiding risks to water, air, soil, flora, and fauna, as well as minimizing nuisances such as noise and odors, and protecting landscapes and areas of special interest. The directive clarifies how waste transitions into a secondary raw material and provides criteria for distinguishing waste from by-products. Additionally, it enforces key concepts such as the "polluter pays principle" and "extended producer responsibility." (European Commission, n.d.)

"Förekomsten av ämnen i miljön som har skapats i eller utvunnits av samhället ska inte hota människors hälsa eller den biologiska mångfalden. Halterna av naturfrämmande ämnen är nära noll och deras påverkan på människors hälsa och ekosystemen är försumbar. Halterna av naturligt förekommande ämnen är nära bakgrundsnivåerna."

–Riksdagens definition av miljökvalitetsmålet

"The presence of substances in the environment that have been created or extracted by society should not threaten human health or biological diversity. The levels of unnatural substances are close to zero, and their impact on human health and ecosystems is negligible. The levels of naturally occurring substances are close to background levels."

– The Swedish Parliament's definition of the environmental quality goal. From Göta Älv Water Management Association. (2015). p. 95)

Circular Economy

Stena Metall Group (n.d. a) indicates that at the core of EU waste management policy is the five-tier "waste hierarchy" established by the directive, which sets a clear priority order for waste prevention, management, and disposal. The hierarchy prioritizes waste prevention (minimization), reuse, material recycling, bioprocessing, energy recovery, and landfill being the least preferred option. (See Figure 2.02) They emphasize that waste management should prioritize actions that move up the hierarchy toward more sustainable solutions. For example, according to the trade organization European Aluminium, recycling aluminum consumes 95% less energy than extracting and refining it from bauxite (the raw, natural ore from which aluminum is extracted), underscoring its substantial environmental and economic benefits. (Stena Metall Group, n.d. a)

In continuation of this topic, Stena Metall and Safir Communication (2024) mention that, unlike the linear economy, which increases the risk of resource scarcity and leads to significant value loss, the circular economy offers a more sustainable alternative. This model focuses on minimizing waste and recirculating materials by introducing an additional phase after waste generation, reintegrating it into the production process. (see Figure 2.02) By assigning value and a new purpose to waste for as long as possible, unnecessary consumption is significantly reduced. Furthermore, the circular economy provides substantial environmental benefits by preserving limited natural resources and circulating valuable materials through reuse and recycling. (Stena Metall & Safir Communication, 2024, p. 18)

In addition, Stena Metall group (n.d. b) claims that the circular economy helps reduce global greenhouse gas emissions, nearly half of which originate from materials, food systems, and the way products are used. They continue that one effective way to tackle greenhouse gas emissions is to rethink and transform the prevailing linear economy, which currently drives global consumption patterns. Shifting away from the traditional 'take-make-waste' model towards a circular economy, centered on reuse, recycling, and revaluation of materials, can significantly enhance resource efficiency. (see Figure 2.03) Embracing this transition not only fosters more sustainable production and consumption systems but also maximizes value creation, benefiting both people and the planet. However, Stena Metall group (n.d. b) continues that

> achieving a truly circular economy requires more than just using resources efficiently; it demands collaboration, partnerships, cooperation, and innovative approaches that challenge the status quo and drive creative solutions.

Based on the previous source, alongside adopting a new manufacturing mindset, it is essential to integrate circular thinking into the design process and value networks from the very beginning. The circular economy extends beyond the initial consumer, taking into account the entire lifecycle of a product, from second and third users to the final stage, while also considering the broader impacts on society and the environment. To achieve this, explains Stena Metall group (n.d. b) that society must focus on minimizing unnecessary resource waste and extending the lifespan of products and materials. Innovation and advanced technologies play a crucial role in driving the transition towards a circular economy, enabling more efficient and sustainable practices. (Stena Metall Group,n.d. b)

Stena Metall and Safir Communication (2024), with over 85 years of experience in transforming waste into valuable resources, emphasize that collaboration with customers and partners is key to achieving a circular economy. This progress is driven by knowledge sharing, showcasing sustainable examples, research and development, and the adoption of new technologies and methods. (Stena Metall & Safir Communication, 2024, p.3 & 18)

An important purpose of this thesis is to contribute to public awareness and education by demonstrating alternative ways of addressing waste management challenges in an urban setting. Through the proposed intervention at Skeppsbron, the project aims to engage not only residents and workers in the surrounding area but also visitors and passersby. Through making sustainable strategies visible and tangible in the public realm, the site becomes a platform for informing people about more adaptive and resource-conscious approaches to pressing environmental issues, particularly the steadily increasing volume of waste, with a specific focus on construction and demolition materials. The thesis also seeks to test a new design concept within the Gothenburg context, challenging conventional practices and encouraging a reevaluation of material use by giving discarded resources a second, third, or even multiple new lives. In doing so, the project promotes a circular and regenerative approach to urban design that supports both ecological resilience and societal learning.

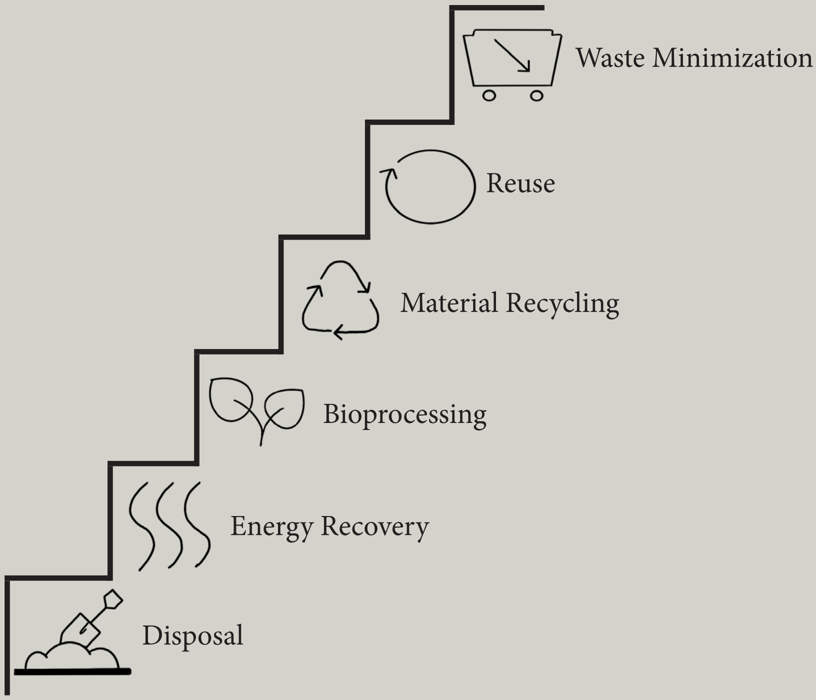


Figure 2.01. The waste management hierarchy. A stepwise model illustrating the preferred order of waste management strategies, starting with the most sustainable, waste minimization, followed by reuse, material recycling, bioprocessing, energy recovery, and finally disposal as the least desirable option. From Stena Metall Group (n.d. a, p. 51)

Figure 2.02. The circular economy model shows the transition from raw materials and sustainable design through production, collection, consumption, reuse, repair, distribution followed by waste management and residual waste handling. The model highlights the goal of reducing raw material use, waste generation, and emissions. From the European Parliament Research Service. (n.d.).

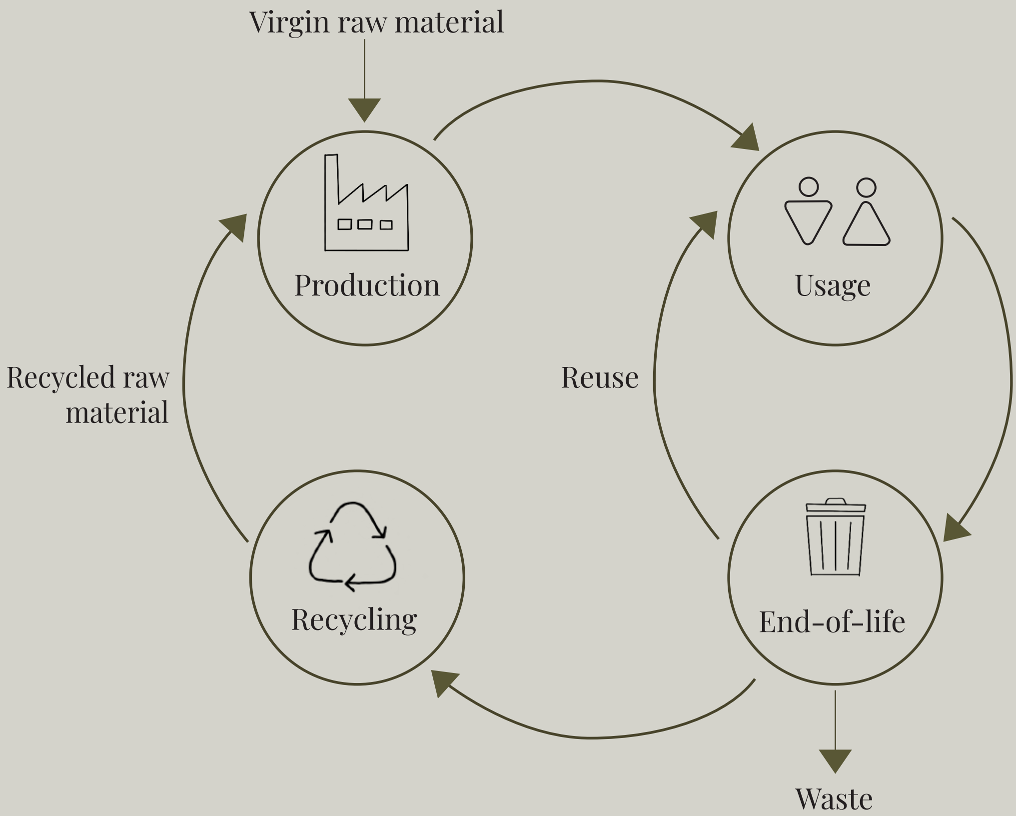


Figure 2.03. Circular flow of materials in a product lifecycle. It illustrates the circular economy approach, where products are made from virgin or recycled raw materials, used, and then either reused or sent to end-of-life pathways such as recycling or disposal. The goal is to minimize waste by closing the loop between production, usage, and material recovery. From Stena Recycling. (n.d.)

Construction ~~waste~~ resources

Today, the construction and civil engineering industry is responsible for 40% of the waste generated in society, claims Renova (2023). Recently, the construction and real estate group Skeppsviken decided to sign the industry's roadmap for achieving climate neutrality and zero greenhouse gas emissions by 2045. This led to the creation of the concept "Nollresan – mot Noll CO2 2045" (The Zero Journey – Towards Zero CO2 by 2045). (Renova, 2023, p. 27) One step was Renova's new workshop in Bönekulla on Hisingen, Gothenburg, the first workshop in Europe to be environmentally certified according to the international BREEAM[1] (Building Research Establishment Environmental Assessment Method). (Renova, 2023, p. 23)

Continuing from the earlier section, City of Emerson, Georgia, (2025, March 25) explains that there are various types of construction and demolition (C&D) waste that can be repurposed as landscaping material and bulk fill for the riverfront extension. They continue that all repurposed materials must be inert[2], meaning they should not leach[3] substances or contain hazardous or soluble pollutants exceeding water quality standards. Therefore, these materials must be properly tested and confirmed to be free of harmful contaminants to ensure full compliance with environmental regulations. (City of Emerson, Georgia, 2025, March 25)

Robinson T. & Mácsik J. (2023) report that 1 to 2 million tons of mineral construction waste are generated annually. They claim that according to statistics from the Swedish Environmental Protection Agency, the majority of this waste is either sent to landfills or managed through unspecified methods, with only 0.5 million tons being processed at municipal recycling centers each year.

The previous source continues that concrete constitutes the largest portion of mineral construction waste, based on waste composition analyses. Mineral construction materials such as concrete, porcelain, and bricks are estimated to make up 60–70% of the total construction waste that can be separated. These materials are of interest to end-users[4] and exhibit promising technical properties, making them particularly suitable for reuse in simple applications in the short term. (Robinson, T., & Mácsik, J, 2023)

Miliute-Plepiene J. et al. (2022b) note that in Sweden, it is the responsibility of the end-user of reused products to ensure that their reinstallation complies with relevant laws and regulations. This includes meeting technical quality requirements, building regulations, CE marking standards[5], and current environmental and occupational health and safety regulations. (Miliute-Plepiene et al., 2022b)

Robinson, T., & Mácsik, J. (2023) explore the increased recycling of mineral construction and demolition waste, presenting findings from a study funded by Sverige Avfall (Sweden Waste) and conducted by Ecoloop, NSR, Renova, the Scandinavian Green Roof Institute, and the Swedish University of Agricultural Sciences. The study highlights that recycling mineral construction waste can significantly reduce emissions and curb the depletion of natural resources. Focusing on materials such as concrete, bricks, tiles, and ceramics, the research was carried out through a literature review, waste composition analysis, and interviews with industry representatives and regulatory authorities. While both regional and national authorities support the recycling of mineral construction waste, this is contingent on factors such as proper documentation and ensuring that materials do not contribute to contamination. When end-use is clearly defined and secure, these materials can be considered valuable resources rather than waste. (Robinson, T., & Mácsik, J. , 2023)

Rock as a ~~waste~~ resource

Tunnels, particularly long railway tunnels, play a critical role in enhancing regional connectivity. Tunnel construction activities generate substantial volumes of excavated material, which has traditionally been regarded as waste. However, as Voit, K., & Kuschel, E. (2020) emphasize, the proper management and recycling of this material significantly influences both the economic viability and environmental sustainability of construction projects. They give an example of the Lötschberg and Gotthard Base Tunnels in Switzerland, where in situ recycling of excavation material into construction aggregates was successfully implemented. Extensive research has explored various aspects of this practice, including the influence of excavation methods (e.g., blasting versus tunnel boring machines), the classification of excavated rock, and its reuse potential in applications such as roadbeds, dam construction, and earthworks. Maximizing the recycling of tunnel excavation material is therefore essential for promoting sustainable construction practices, reducing landfill dependency, and conserving natural resources. (Voit, K., & Kuschel, E., 2020, p.1)

Another source also claims that rocks play a vital role in the design, offering multiple functional benefits, particularly in a riverfront context. The International Tunnelling and Underground Space Association (2004) explains that due to their substantial mass and structural integrity, large rock fragments are well-suited for use as core fill material to build up the new landmass and elevate the riverbed. They continue that their interlocking properties provide a stable and durable foundation, effectively resisting hydraulic forces and current-induced erosion. As typically inert and clean materials, these rocks pose minimal environmental risk; however, any adhered fines, clay, or dust should be either thoroughly rinsed or encapsulated to prevent turbidity and sediment dispersion during placement. (International Tunnelling and Underground Space Association, 2004, p. 14)

A valuable source of rock material for this thesis project is the ongoing excavation work associated with the West link railway connection project (Västlänken), currently taking place in different areas with Central Station and Haga closest to Skeppsbron, the thesis project site. (see Figure 2.04) The use of these materials significantly reduces disposal costs and decreases the demand for newly quarried rock and stone, thereby supporting sustainable resource management objectives. These materials are available in large quantities, and the blasted rock fragments generated from the excavation are well-suited for use as structural fill due to their durability and inert properties. They vary in size, ranging from smaller stones to boulder-sized pieces. (see Figure 2.05)

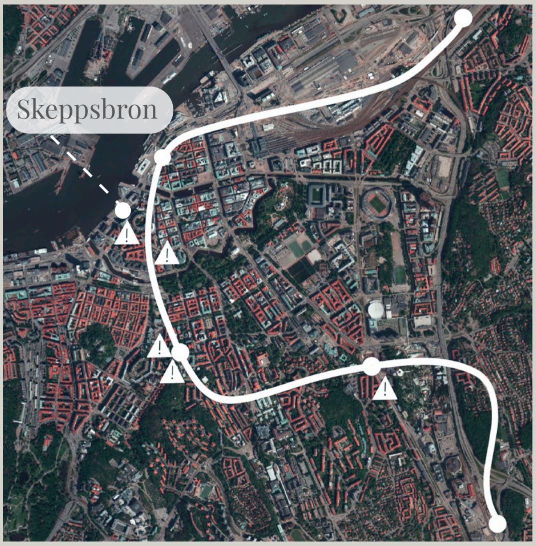


Figure 2.04. The West link railway project route

Figure 2.05. Excavated rock. Photo by the author.

Concrete as a waste resource

Crushed concrete sourced from demolition activities or nearby structures such as old foundations, road slabs, or bridges represents another abundant material resource. The hardened concrete rubble can be processed into aggregate. Washington State Department of Ecology (2022) states that high-quality recycled concrete aggregate (RCA) is durable, free of contaminants, and can be produced in a range of sizes, from coarse fragments to fine particles, depending on project requirements. (see Figure 2.06) One important consideration is that recycled concrete aggregate (RCA) has the potential to leach substances too, which can elevate the pH of water upon contact. However, this high pH effect gradually decreases over time as the material undergoes carbonation[6] through exposure to carbon dioxide in the atmosphere. (Washington State Department of Ecology, 2022, p. 65).

Building on the previous discussion, Deng, Y., & Wheatley, A. (2018) explain that crushed concrete serves as a highly functional material within the design, acting both as structural fill and as a stabilizing agent. It compacts effectively and can occupy voids between larger rock fragments, thereby creating a denser and more stable mass. They continue that well-graded recycled concrete aggregate (RCA) provides an excellent sub-base for pedestrian trails and cycleways as well, offering both load distribution and durability. Additionally, coarse RCA forms a porous matrix that facilitates the conduction of excess water, enhancing subsurface drainage. A significant environmental benefit of incorporating RCA is its capacity to adsorb phosphorus from stormwater, contributing to improved water quality. Environmental performance can be further enhanced by pre-soaking RCA or blending it with natural sand or soil, practices that promote its function as a long-term phosphorus sink. When properly managed, RCA becomes a high-value resource, reducing reliance on virgin aggregates and delivering both structural and water treatment benefits to the landscape. (Deng, Y., & Wheatley, A., 2018, p. 1 & 13)

Figure 2.06. Concrete aggregate. Photo by the author.

Brick as a waste resource

Ali et al. (2024) refer that old brick walls, chimneys, and ceramic tiles serve as valuable sources of reclaimed brick material. Once crushed into angular gravel, these fired clay components, recognized for their chemical stability and inertness, offer significant advantages for landscape applications. They continue that the use of reused or crushed bricks in constructed wetlands offers a promising and sustainable method for treating wastewater. (see Figure 2.07) Constructed wetlands are engineered systems inspired by natural wetlands, where water is filtered through a combination of vegetation, microorganisms, and porous materials. One of the key materials in these systems is the substrate, the layer that supports both water filtration and biological activity. Crushed brick, often recovered from construction waste, is an effective and environmentally friendly substrate option. In wetland design, a substrate layer of crushed brick can be installed at the base of shallow water basins. (Ali et al., 2024, p. 2-3)

Beyond their structural advantages, Ali et al. (2024) highlight that crushed bricks have a porous texture, which allows water to flow through while helping to trap pollutants, including phosphorus and selected heavy metals, thereby improving overall water purification processes. This structure is also highly durable, resistant to decomposition, and provides a surface for beneficial microorganisms to grow, which are essential for breaking down contaminants in the water. The study found that constructed wetlands using brick rubble supported richer microbial communities, which contributed to improved pollutant removal. This kind of wetland is also widely used in the treatment of domestic sewage. Brick material can be crushed to different sizes or blended into soil to improve structure and function. It is evssential, however, to ensure that bricks are free from contaminants such as paint or other residues before use, to maintain their inert properties. (Ali et al., 2024, p. 11 -12)

Continuing from the earlier section, AZoBuild (2024) explains that crushed brick offers multiple advantages for sustainable landscape construction. Its high surface area and porous structure support plant root establishment and promote microbial activity, making it an ideal substrate for applications such as bioswales, rain gardens, and constructed wetlands. Brick rubble can also be effectively used as vertical filter media, enhancing stormwater infiltration and improving water purification processes. In the context of this design, which integrates constructed wetlands, a mixture of crushed brick can be employed to form an effective filtration layer.

In addition to its biological benefits, AZoBuild (2024) continues that crushed brick contributes to landmass stabilization when mixed with other materials. This makes it particularly suitable as a foundation layer before the installation of wetlands, pedestrian paths, or bike lanes. Recycled brick aggregates are well-suited for use as sub-base layers beneath low-traffic infrastructure, such as walking trails and cycling routes, providing both structural stability and enhanced permeability for rainwater management.

AZoBuild (2024) further explains that crushed brick plays a significant role in improving soil by acting as an amendment[7] and can also be spread over the soil surface like organic mulches (e.g., wood chips) to protect the soil. It also helps mitigate the potential alkalinity[8] introduced by crushed concrete, ensuring a more balanced pH environment and reducing the risk of ecological disruption. (AZoBuild, 2024).

According to the findings, it can be concluded that beyond its technical role, reused bricks also offer economic benefits. They reduce the need for newly manufactured materials and turn construction waste into a valuable resource. This makes them an attractive option for nature-based solutions, especially in areas where affordability, simplicity, and sustainability are priorities.

Figure 2.07. Crushed bricks. Photo by the author.

Metal as a ~~waste~~ resource

Stena Metall Group (2023, September 26) discusses the significant reduction in carbon dioxide emissions achieved through the reuse of steel beams and claims that Climate-neutral construction is a major focus in both the construction and real estate industries. In this context, reusing materials offers significantly greater environmental benefits compared to producing new ones, helping to reduce climate impact. Christoffer Muhl Pollari, a business developer at Stena Stål (Stena Steel), has developed a method that demonstrates how steel beams from demolished structures can be effectively reused in new construction projects. (see Figure 2.08)

"Producing one ton of steel from iron ore, for example, emits about three tons of carbon dioxide, so it has a huge impact on the climate. If we instead reuse the steel beams that already exist, we can reduce carbon dioxide emissions to 35 kg per ton, a reduction of up to 98 percent."

- Christoffer Muhl Pollari.

Stena Metall Group (2023, September 26) continues that there are definitely standardized processes to ensure the quality of the newly re-produced steel beams. Some guidelines were introduced in 2021 that explain these standards. Christoffer Muhl Pollari explains that "This gave us the opportunity to develop a method for the reuse and quality assurance of steel beams for load-bearing structures. ... We can make early contact with construction companies that ... have contracts for demolition. We make a reuse inventory of the building before it is demolished. After demolition, the steel beams that we believe can be reused are sent for quality control."

The testing process involves measuring the hardness of the steel beams. Once completed, the softest steel beams are sent to an independent third-party laboratory for further analysis. If the quality and hardness of the reclaimed steel beams meet the required standards, they are approved for reuse and transported to new construction sites for upcoming projects. (Stena Metall Group, 2023, September 26)

In continuation of the previous topic, Stena Metall Group (2023, June 16) discusses transforming waste into valuable raw materials and points out that if current consumption trends continue, by 2050, global resource consumption is projected to triple. As a result, waste generation is expected to increase by 70% compared to today, with the majority of it being either incinerated or sent to landfills. (Stena Metall Group, 2023, June 16)

Inge Svensson, site manager for sorting and transshipment at Högsbo and Skräppekärr, explains that as they work to sort waste and create new products, they have observed a growing demand for reclaimed materials such as mineral wool, metal, window glass, and gypsum. This increasing demand allows them to simultaneously develop a market for recycled materials. He highlights a successful ongoing magnet sorting project that sorts out metal scrap from combustible waste. They were able to recover 70 tons of scrap metal in just two months. Looking ahead, their goal is to scale up this operation to recover 2–3 tons of scrap metal per day. (Renova, 2023, p. 16)

Figure 2.08. Recycled metal pieces

Sheet Piling as a ~~waste~~ resource

Jansson, F. (2023, May) states in his master's thesis that reused sheet piles, particularly tubular steel piles, are suitable for erosion protection due to their mechanical strength and adaptability. These elements can be effectively extracted, cleaned, and reinstalled, making them advantageous for reuse in landscape and infrastructure projects. (see Figure 2.09) Their application as erosion control structures is especially relevant along riverbanks, coastal edges, or other hydraulic environments where soil stability and protection against washout are required.

The reuse of sheet piles contributes to circular construction practices by extending the material's life cycle and reducing the environmental impact associated with producing new steel components. Their robustness allows for long-term use in permanent settings, and their modularity supports flexible installation in various landscape conditions. In addition to structural benefits, reused sheet piles help reduce material waste and project costs, while fulfilling performance requirements in water management and flood protection strategies. (Jansson, F., 2023, May)

Figure 2.09. Reused sheet piling. Photo by the author.

Other possible ~~waste~~ resources

The number of repurposed resources that can be considered for this project is numerous, and here is a list of some of them that are used in the design proposal.

Dredging

Over time, dredging has played a significant role in both landscape transformation and urban development. It has been widely employed for land reclamation, enabling the conversion of water bodies into usable land for city expansion and infrastructure projects. According to Pump & Dredge Wire (2024), dredged material can also be repurposed to restore wetlands and coastal zones, an approach that not only supports the creation of valuable wildlife habitats but also strengthens shoreline resilience. These multifaceted benefits position dredging as a critical practice in civil engineering and environmental restoration, where the demands of development are balanced with the need for ecological sustainability. (Pump & Dredge Wire, 2024)

According to Norén, A., et al. (2022), dredging has been carried out in the Göta älv primarily to maintain the necessary depth for accommodating large vessels. It must be repeated every three to five years to ensure navigability. In a notable example, dredged clay material was used to construct a new 220,000 m² freight terminal in Hisingen, rather than being sent to landfill. (Norén, A., et al. 2022, p. 1-2) Besides that Port of Gothenburg (2016) explains that contaminated dredged material can be stabilized by binding it with cement, slag, fly ash, and similar additives to prevent leaching and form a structurally sound mass. Given that Göta älv is the region's main source of drinking water, all dredging activities must be carried out with great caution and timed carefully to avoid harming aquatic life. (Port of Gothenburg, 2016)

Figure 2.10. Dredging

Excavated clay/silt

During the West link project, significant volumes of excavated clay and silt will become available. In the project's environmental permit application, Trafikverket (the Swedish Transport Administration) (2016) addresses the management of these materials with a particular focus on sustainable reuse. Large quantities of clay and silt are expected to be excavated during the tunnel construction phase. If not properly managed, these materials could pose environmental risks, such as the spread of contamination during handling and transport. Therefore, the Swedish Transport Administration (Trafikverket) (2016) explains that the transportation, disposal, and potential reuse of the excavated material must be carefully planned well in advance of project commencement. The project aims to repurpose as much of the material as possible to minimize environmental impacts and promote resource efficiency. (the Swedish Transport Administration, 2016, p. 8)

As a continuation of this theme, the Swedish Transport Administration (2016, October 4) mentions that the West link project is expected to excavate approximately 2,000,000 m^3 of clay and silt, in addition to rock, from the city's soft ground layers . As the excavated material will be considered primarily as a resource for the design proposal, it is essential to gain a comprehensive understanding of its quantity, composition, and management. the Swedish Transport Administration has developed a mass management strategy that separates contaminated soil from clean, reusable fill material. Only a small portion of the excavated material will be sent for disposal, while the vast majority, approximately 1,795,000 cubic meters, is classified as clean and intended for reuse. By prioritizing the use of excavated clay and silt as fill material, the thesis project minimizes waste generation and reduces the need for landfill disposal, supporting both environmental and societal benefits. (the Swedish Transport Administration, 2016, October 4, p. 4)

The objective is to transform the excavated material into a valuable resource. Clean clay and silt are regarded as usable materials that can be utilized within this project or allocated to other developments. This strategy offers societal benefits by providing sustainable fill material while minimizing the need for long-distance transport or disposal. Overall, the approach ensures that the excavated clay and silt are managed safely, efficiently, and in an environmentally responsible manner.

Figure 2.11. Excavated soil

Table 2.01: The table below summarizes the recommended applications of various construction waste materials in the river park extension, including typical placement guidelines, layer thickness recommendations, and key considerations. Source: Author's own elaboration.

Table Note: Topsoil is included for completeness, although it is not classified as construction waste. It is assumed that an imported or treated soil layer will be necessary to support vegetation. In practice, some excavated soil may be amended and reused as topsoil if it meets appropriate quality standards.

Material	Local source (examples)	Primary uses in design	Key considerations
Recycled brick (masonry rubble)	• Demolition of brick buildings or tiles • Recycled aggregate suppliers	• Drainage/aeration layer in planting soil • Substrate in wetlands for nutrient filtering • Surfacing for footpaths or mulches • Gabion fill or decorative elements	• Highly porous • Improves root zone • Filters pollutants

Material	Local source (examples)	Primary uses in design	Key considerations
Excavated rock (tunnel spoil)	• The West link tunnel project blasting • Nearby quarry or harbor excavation	• Core structural fill for new landmass • Rip-rap armoring of shoreline slopes	• Inert and stable if clean • Geotextile should be used under armor to contain fines • Clay should be washed off to prevent turbidity • Very high load-bearing capacity
Crushed concrete (C&D waste)	• Demolished concrete from old piers, buildings • Road/bridge reconstruction debris	• General fill (void filling among rocks) • Structural sub-base for paths/plazas • Drainage layer under planted areas • Filter medium in wetland basins (P adsorption)	• PH and leachate should be checked • Should be covered with soil or neutral material to avoid direct river contact • Rebar/impurities should be removed • Provides good drainage & harmful nutrient removal
Topsoil & compost	• Clean soil from the site or imported • Local green waste compost	• Planting medium for trees, lawns, gardens • Wetland planting media (if needed atop gravel) • Final grading layer for vegetation	• Must be clean (no invasive weeds or toxins) • Mix sand/compost to ensure permeability • This capping soil also acts as a buffer, separating underlying recycled materials from direct contact with surface water
Reclaimed asphalt (RAP)	• Road resurfacing • Old harbor asphalt yard (e.g., parking lot in Skeppsbron)	• Recycled asphalt pavement for bike paths • Base course under paved surfaces • Filler in the core of embankments (if dry) (primarily to be reused in paving)	• Prolonged water contact should be avoided to prevent PAH leaching[9] • Best used in bound form (repaved) for minimal exposure • Aged RAP leachate[10] shows low leaching • Prevent runoff during construction (cover stockpiles)

Reuse & its limits

Miliute-Plepiene, J et al. (2022) estimate that Sweden's construction and demolition sectors generate approximately 9 million tons of non-hazardous waste annually, accounting for nearly one-third of the country's total waste production. Within the waste hierarchy, reuse holds a high priority as it prevents waste generation and extends the lifespan of materials. However, the reuse of construction waste in Sweden remains relatively low. According to Avfall Sverige's 2019 annual report, only a small fraction, just a few dozen tons of construction and demolition materials are currently being reused at recycling centers. On a more positive note, other reports highlight the significant untapped potential for increasing the reuse of construction materials.

They (2022) continue that in recent years, a growing number of municipalities in Sweden have invested in initiatives to promote the reuse of construction materials. These efforts often involve establishing dedicated waste management facilities or recycling centers. Each municipality is responsible for assessing the specific conditions and opportunities within its context to scale up reuse initiatives. Importantly, sharing knowledge, exchanging best practices, and learning from others play a vital role in accelerating progress in this area.

In addition to the large amount of waste produced by humans daily, there are numerous challenges associated with it that go beyond simply reusing and repurposing. Modin et al. (2022) highlight the widespread presence of PFAS[11] or forever chemical contamination in materials like paper packaging, household products, and construction and demolition waste. PFAS present unique challenges due to their long-lasting nature. Common methods for addressing contaminated water include techniques like absorption, filtration, and other treatment processes. However, the complexity of removing PFAS from waste or dealing with them in mixed water flows creates significant challenges for waste management and regulatory bodies, who must find effective and sustainable solutions. (Modin et al., 2022)

Renova (2023) mentions the harsh reality that some types of waste cannot be repurposed or must exit the loop of resource use, from raw material to recycling, etc., due to their environmental hazards. Unfortunately, in the future, more waste will likely fall into this category, making disposal increasingly costly and challenging. (Renova, 2023, p. 18)

Reuse system typologies

Broadly, existing reuse initiatives in municipalities can be categorized into three types based on Miliute-Plepiene J. et al. (2022a) which are:

1. Sales-based reuse outside Recycling Centers
   - Example: ÅBD, Halmstad Recycling
     - Collects mainly construction and demolition materials
     - Large facilities (up to 16,000 m²)
     - The collection is predominantly (up to 99%) from companies
     - The operations actively seek partnerships with suppliers
     - Offer collection and transport services

Challenge: The materials obtained from recycling centers are often of low economic value.

2. Sales-based reuse within Recycling Centers or circular economy parks
   - Example: Alelyckan in Gothenburg and ReTuna, Halmstad Recycling (2007–2009)
     - Construction and demolition waste reuse
     - Utilize smaller spaces for storage and sales
     - Customers are mostly private individuals

Challenge: High investment requirements and long lead times.

3. Non-sales-based reuse
   - Example: Byggboden in Jönköping, Benjamin's Reuse
     - Prioritizes environmental aspects
     - It is mainly in the pilot stages[12]

- The dedicated collection spaces are small
- Reuse rates are relatively low compared to sales-based models
- Transport services are not included
- Operational costs are significantly lower
- Staff involvement is minimal

Challenge: Low volumes, lack of measurement systems, and the need for further exploration of behavioral changes.

All of these models face several common challenges, including:

- A lack of information, knowledge, and awareness throughout the reuse chain.
- Significant variation in product types, which complicates large-scale reuse.
- Insufficient access to reliable data and statistics.
- High operational costs.
- Limited interest and engagement from the construction sector and its clients.
- Conflicts between social objectives and reuse goals in certain cases. (Miliute-Plepiene, J. et al. 2022a)

Figure 2.12. Map of landfill and waste deposition areas in Gothenburg, Source: The city of Gothenburg & Lantmäteriet. Modified by the author.

Reference projects

Barangaroo Reserve (Sydney, Australia) - 2015

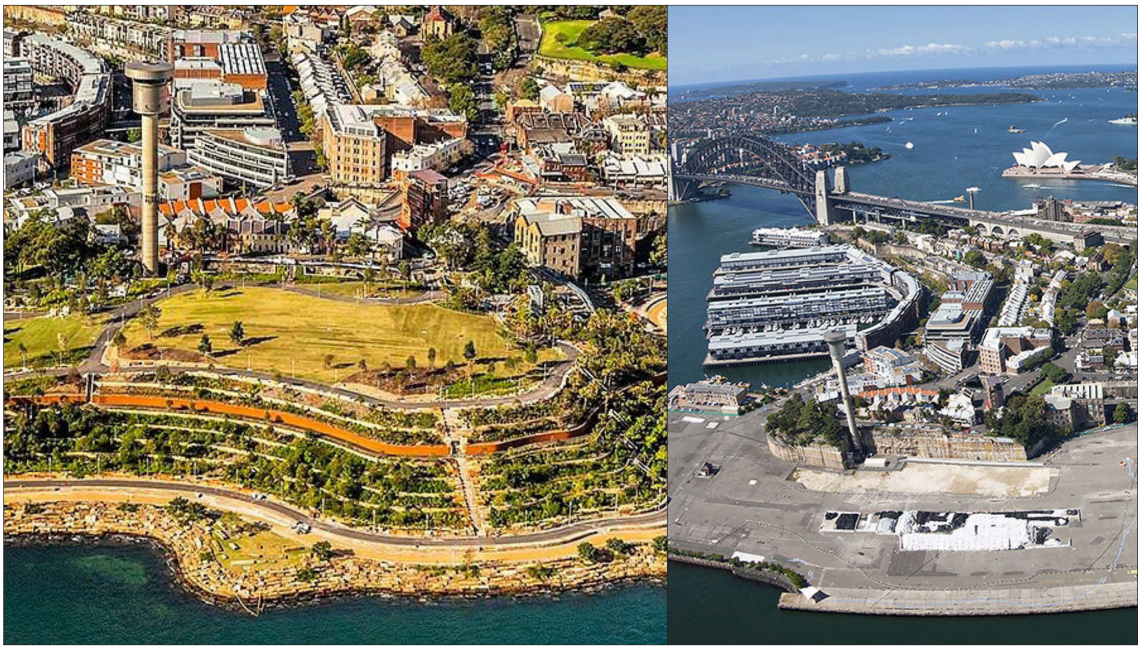


Figure 2.13. A transformation of a former concrete industrial port into a green waterfront park with native vegetation and public spaces. Source: Barangaroo Reserve, Sydney (Land8, n.d.).

In 2015, PWP Landscape Architecture. (n.d.) showed that a 55,000 m2 former container port can be transformed into a headland park. The project used a major amount of 36,700 m3 of excavation material from nearby construction to be reused to build a naturalistic shoreline of terraces. The park's topography is made out of sandstone blocks, which recreate the original harbor headland. Besides that, the soil used throughout the entire park is taken almost entirely from recycled materials like crushed sandstones, recycled glass, and green compost. In this way, it mimics the native soil. This project succeeded in achieving 99% plant survival with 100% recycled soil resources. This is a good example of showing that with proper design, waste materials can perform as well as virgin raw materials. The soil layering is also worth mentioning, as it has an O-horizon of Mulch, an A-horizon of sandy topsoil, and a B-horizon of porous subsoil, all retrieved from waste. (PWP Landscape Architecture, n.d.) The characteristics of these soil types will be further discussed in the next chapter in page 55.

Queen Elizabeth park (London, England)

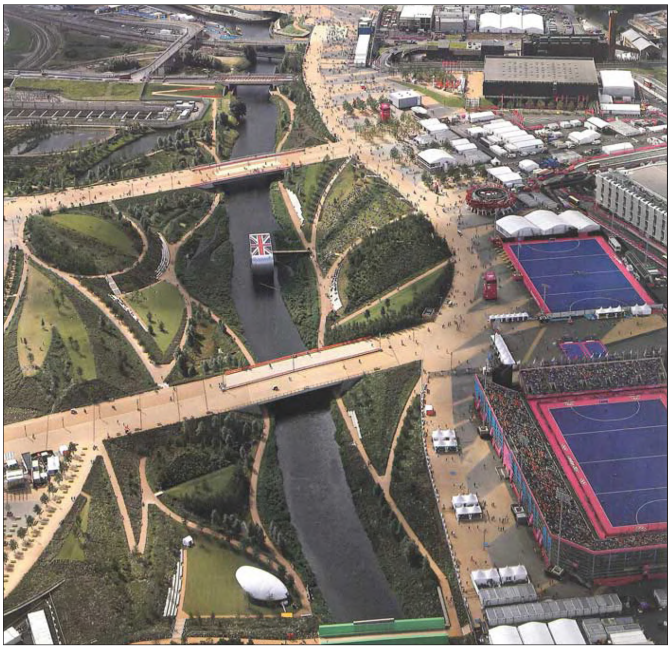
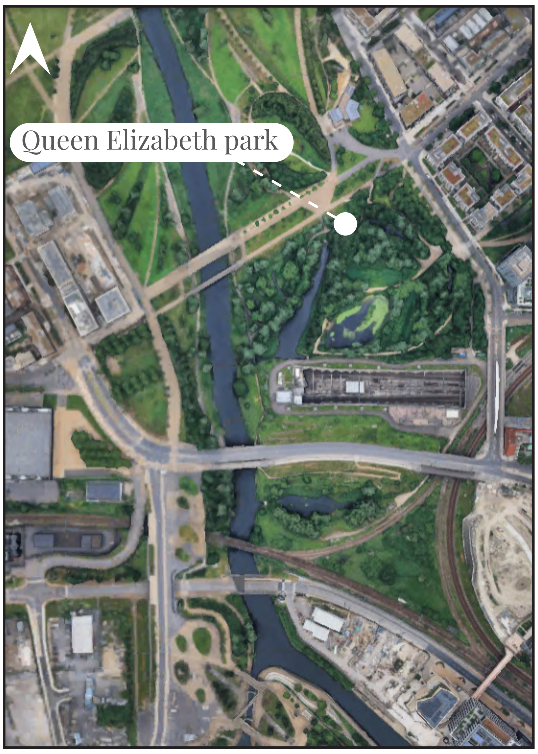
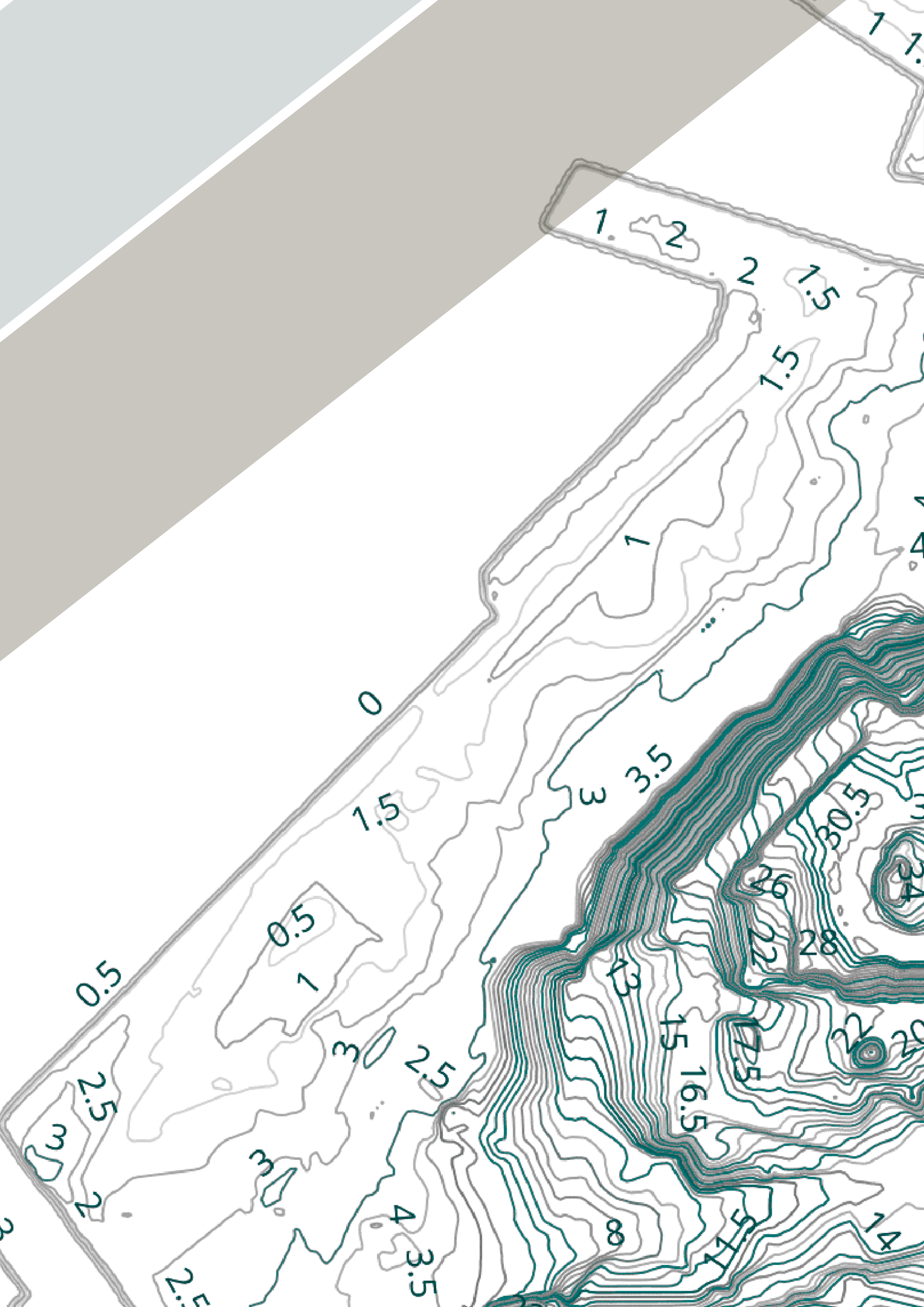


Figure 2.14. Queen Elizabeth Olympic Park demonstrates how urban land can be transformed into resilient green infrastructure through sustainable resource management. Source: Hargreaves Associates. (2016, July 28)

Urban renewal of the Queen Elizabeth Olympic Park. (2025, January 13) shows that the site of the 2012 Olympics, later converted to a public park, is a hallmark of sustainable construction. In preparing the park, over 98% of material from demolition of old industrial structures was reused on site. This included crushing thousands of tons of concrete and brick to make aggregates for new park roads and venues, and remediating contaminated soil to reuse as planting soil. Wetlands and bioswales in the park were built with these cleaned soils and recycled aggregates, helping to clean runoff from the site. (Urban renewal of the Queen Elizabeth Olympic Park, 2025, January 13) Following that London Legacy Development Corporation. (2019) also states that old waste can support new wetlands. The park's green infrastructure incorporates a rich diversity of habitats, including 6.5 km of revitalized waterways and expansive wetland systems composed of reed beds, ponds, wet woodland, and ephemeral scrapes. These wetlands provide critical ecosystem services such as natural flood attenuation, and habitat provision for species including smooth newt, reed warbler, and various invertebrates. The park now supports more than 650 species and has become a national benchmark for combining ecological design with urban development (London Legacy Development Corporation, 2019)



DESIGN PROPOSAL....



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Introduction

This design proposal, as mentioned through the thesis so far, envisions extending the landscape at Skeppsbron into the Göta älv using primarily locally sourced construction waste. The extension will form new land over the existing riverbed, which varies in depth from approximately 1 to 4 meters. The proposed design incorporates spaces for pedestrians, cyclists, and other forms of micro-mobility, complemented by vegetated zones with trees, shrubs, and diverse greenery. Two interconnected water basins (one wetland and one forebay) are introduced, each with distinct depths, sizes, and functions to support both ecological and recreational activities. A key focus of the project is to identify and evaluate suitable types of construction waste for land reclamation and landscaping purposes. Whenever possible, materials from the nearby the West link railway construction sites will be prioritized for reuse.

This site was selected based on multiple analyses (presented in the first two chapters), which indicate that it is located in a flood-prone area. Its proximity to the river and the city center makes it a highly relevant and strategic location for further investigation. Skeppsbron is a dense urban district with a high concentration of office buildings, intensifying the potential impact of flooding. Additionally, the presence of two surrounding canals, functioning as cloudburst drainage channels, further emphasizes the site's importance in the context of urban water management.

Despite its central location, the site today feels disconnected and underutilized, says Nautica Bistro staff. Predominantly covered by grey surfaces and used as a parking lot, it lacks aesthetic appeal and fails to encourage people to linger or interact with the riverfront. The edge between land and water is poorly designed and uninviting, offering no clear or safe access to the water. Pedestrians walking near the waterfront are more likely to pass by than to pause and enjoy the view.

This project seeks to reverse that condition by transforming the area into a vibrant, multifunctional public space that functions well in both dry and wet conditions, especially important in Gothenburg's rainy climate. The design proposes a resilient green landscape where people can safely engage with nature without the risk of surface flooding. While construction waste is subtly embedded within the landform to support sustainability goals, stormwater is managed visibly through integrated, nature-based solutions that contribute to both climate adaptation and the public realm.

Figure 3.01. The project site marked in white covers roughly 340,000 m². Scale 1: 2,000 (A4). Base map source: Lantmäteriet (2025). Modified by the author.


Stenpiren ferry terminal
Stenpiren bus and tram station
Nautica Bistro - Skeppet Eira
Blixtbrickegatan
Skeppsbron
Stora Badhusgatan
Norra Liden
Surbrunnsgatan
Göteborg Energi Rosenlundsverket
Esperantoplatsen
Kungsgatan
Legend
Site plan

Visual first impressions from the site

Figure 3.02-07. Depict the existing conditions of the site, it's steep terrain (see Figure 3.02) which accelerate stormwater runoff. Impermeable surfaces (see Figure 3.03-05) and the spatial relationship to the Stenpiren ferry terminal platform (see Figure 3.06-07) maintain a standardized elevation relative to the river. Photos by the author.

Figure 3.08-13. These photos document the existing surface drainage inlets, (see Figure 3.08) flood protection wall, (see Figure 3.09) and the deteriorating quay structure. (see Figure 3.10) Additionally, the poor design and condition of the interface between land and water creates (see Figure 3.11-12) an uninviting and unsafe edge, making it unsuitable for pedestrians to stand, sit, or engage with the riverfront. The anchor-like sculpture appears neglected. (see Figure 3.10) Photos by the author.

Soil layering strategy

Soil layering strategy for vegetation

Desfarges, Q. (2015) argues that the conventional approach to landscape projects often involves importing new soil, which is both costly and resource-intensive. As a more sustainable alternative, ongoing construction and demolition activities within the city can be seen as valuable resources. Recycled concrete aggregate (RCA), which would otherwise be sent to landfills, can serve as a structural base beneath paved surfaces or built elements.

Additionally, he continues that the composted organic waste presents an eco-friendly substitute for virgin topsoil. By repurposing urban food waste into nutrient-rich compost, soil quality can be enhanced, improving structure, porosity, and density to support healthier plant root systems. This approach also increases infiltration and permeability in compacted soils, helping to mitigate erosion and stormwater runoff. (Desfarges, Q. 2015, p. 93)

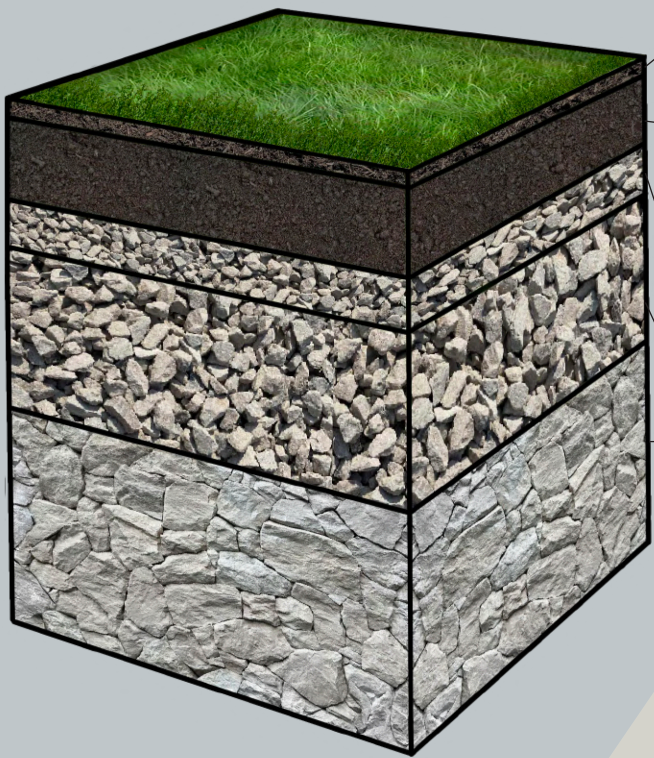
A key element of a good landscape design is to support healthy tree and plant growth on the new land. Harms, B. (2023) claims that a layered soil profile should be added over the structural fill. Covering rubble with a simple and thin layer of dirt will not suffice for a long-term vegetation, instead, a designed soil system is needed which are ordered in O-horizon (Organic and humus), A-horizon (topsoil), E-horizon (eluviated/very leached layer, washed-out minerlas), B-horizon (subsoil), C-horizon (unweathered parent material, like rock, very coarse material) and R-horizon (bedrock). For this urban project, as a reclaimed and planting overfill project, only O-, A-, B and R-horizons are examined, and other layers do not exist. (see also Tabel 3.01)

- O-horizon (Organic); consists primarily of organic matter such as mulch (wood chips or coarse compost) or decomposing leaves, needles (pine needles or conifer needles), twigs, and moss. Depending on site conditions, the O-horizon may vary in thickness, ranging from absent to well-developed. This layer plays a critical role in conserving soil moisture and enriching the soil with nutrients as it decomposes. (Soil Science Society of America, n.d.)

- A-horizon (topsoil): It is composed primarily of mineral material enriched with incorporated organic matter. This layer serves as a vital medium for plant growth and supports a wide range of soil organisms (Soil Science Society of America, n.d.). It is typically darker in color than the underlying horizons due to its higher organic content (Anderson, 2020, August 24). In engineered landscapes, topsoil can be created by blending sand or crushed sandstone with compost and loam to produce a well-drained yet nutrient-retentive growing medium.

- B-horizon (subsoil): It is characterized by the accumulation of minerals that have leached from the overlying A- or E-horizons (Soil Science Society of America, n.d.). It serves as a zone of illuviation, where materials such as clay, minerals, or changes in color and structure become evident (Anderson, 2020, August 24). Typically found beneath the surface layer in developed soils, the B-horizon may be absent in very young or recently deposited materials. In engineered landscapes, this layer acts as a reservoir for plant roots, and recycled materials such as crushed brick, crushed concrete, or crushed sandstone are well-suited for creating a functional subsoil.
- R-horizon (rock, riverbed fill): The lowest layer in the soil profile, consisting of unweathered, consolidated bedrock. Unlike the upper soil horizons, it contains no organic material and is largely impermeable, meaning that water and roots rarely penetrate it. Despite this, the R-horizon provides the geological foundation for the soil above and influences drainage, soil depth, and stability, which are important factors in urban design and flood management. Harms, B. (2023)

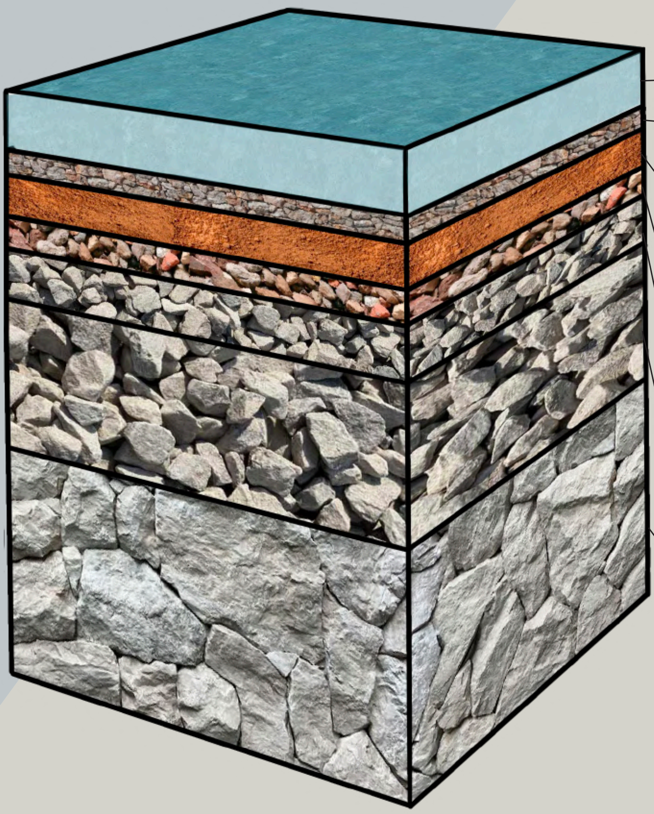
Soil layering for soft ground



1. O-horizon layer; Grass/ 5-10 cm of mulch/bark/wood chips
2. A-horizon layer; topsoil + compost nutrient rich /crushed brick as amendment (10-50 mm), 20-40 cm for plants, 40-60 cm for small trees
3. B-horizon layer; 20-40 cm of well compacted crushed concrete
4. Crushed concrete ~1 m
5. R-horizon layer; Riverbed fill, rock boulders

Figure 3.14. Illustration by the author.

Soil layering for forebay



1. Water
2. Top layer; 10-20 cm of small stone (45-90 mm)
3. Drainage layer; 20-30 cm of finely crushed mortar/tiles/plaster fragments blend with clay
4. Intermediate layer; 15-20 cm of crushed brick
5. Base layer; Coarse crushed concrete (<90 mm)
6. Crushed concrete ~1 m
7. R-horizon layer; Riverbed fill, rock boulders

Figure 3.15. Illustration by the author.

Soil layering for wetland

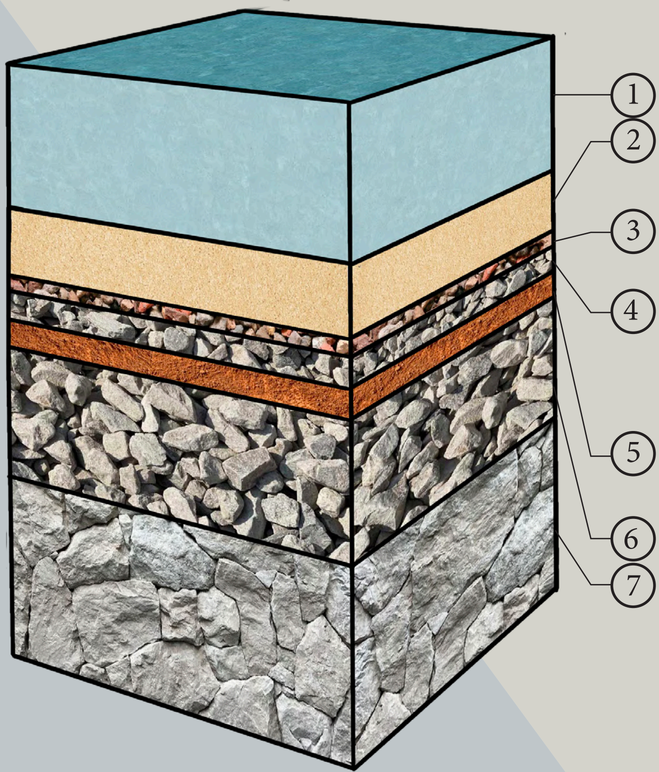


Figure 3.16. Illustration by the author.

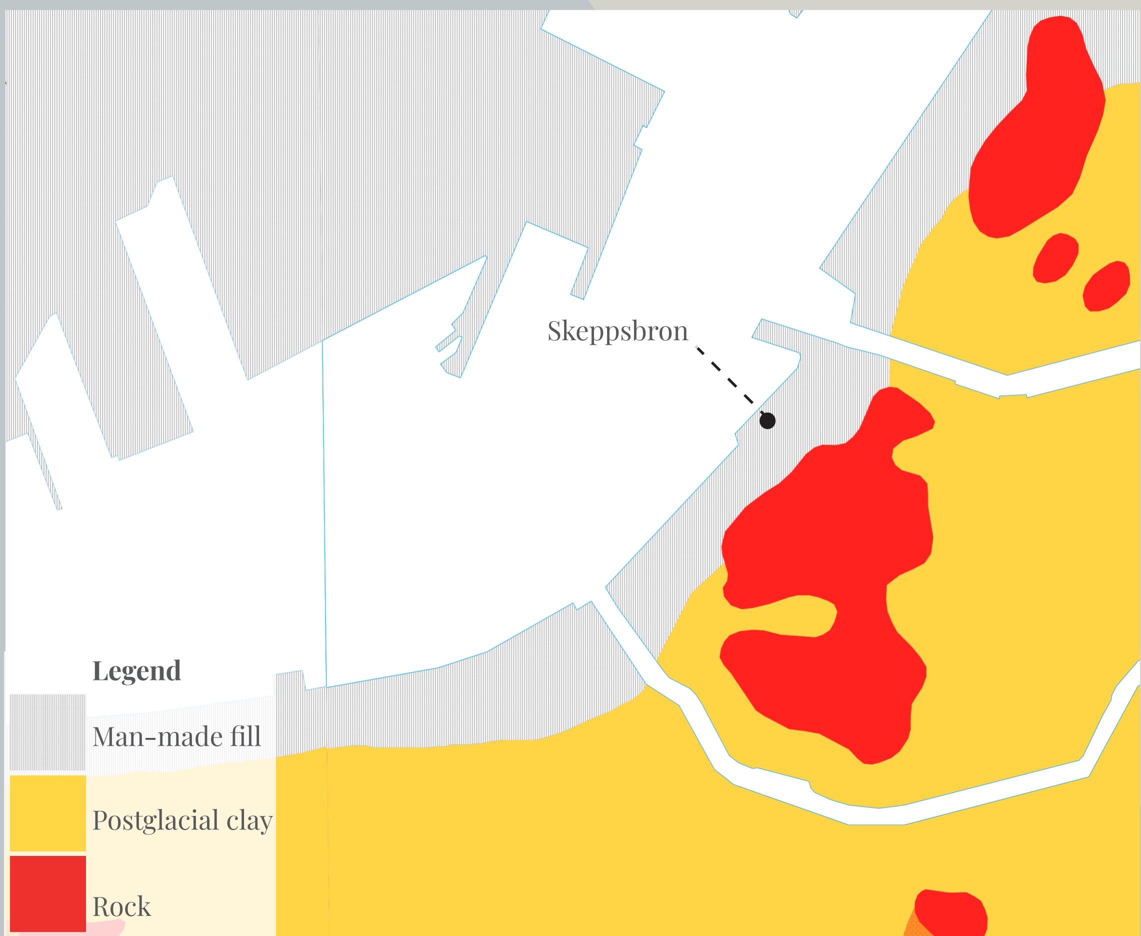


Figure 3.17. Soil classification map of the central Gothenburg waterfront. Source: Lantmäteriet (2025).

Vegetation

Grey alder

Stångby plant nursery states that Alnus incana fk 'Deje E', commonly known as grey alder, is a fast-growing tree characterized by its conical, relatively narrow crown, smooth silver-grey trunk, and coarsely serrated leaves with a slightly greyish tone. Reaching a height of 12 to 15 meters and a width of 5 to 7 meters, this cultivar is notable for its vigorous growth and resilience. Nevertheless, its high tolerance to both salt and polluted air makes it particularly suitable for urban and coastal environments. (Stångby Plantskola [Stångby Plant Nursery], n.d.)

Grey alder is exceptionally well-suited for wetland restoration and design, particularly in temperate climates like that of Gothenburg. In continuation of the previous topic European Forest Genetic Resources Programme (EUFORGEN) (n.d.) explains that it thrives in moisture-rich soils typically found along riverbanks, marshes, and floodplains, making it an ideal species for riparian and wetland applications. Its ability to fix nitrogen through symbiosis[12] with soil bacteria enhances soil fertility and supports surrounding vegetation. The tree's extensive root system plays a crucial role in stabilizing soils and preventing erosion in water-saturated landscapes. As a pioneer species, Grey Alder promotes early-stage vegetation growth and accelerating ecological succession. (European Forest Genetic Resources Programme (EUFORGEN), n.d.) These combined traits make it a highly functional and ecologically valuable choice in sustainable wetland and urban landscape design.

Black alder

Stångby plant nursery states that Alnus glutinosa fk FYRIS E, commonly known as black alder, is a fast-growing tree. It thrives best in moist soils and demonstrates remarkable resilience in extreme site conditions, which makes it particularly suitable as a nurse tree on disturbed soils or for use in shelterbelts. Alnus species are generally sun- and moisture-loving trees and shrubs, and they all share the ability to form symbiotic relationships with nitrogen-fixing bacteria on their roots. These trees are highly undemanding and are capable of tolerating some of the most extreme environments, including standing water and heavy clay soil. They reach a height of 12 to 15 meters and up to 20 meters and a width of 6 to 8 meters. (Stångby Plantskola [Stångby Plant Nursery], n.d.)

European Forest Genetic Resources Programme (EUFORGEN) (n.d.) reports that black alder has a high degree of adaptability, yet it is most commonly found in wet environments such as riverbanks, marshes, and moist woodlands. In these ecosystems, black alder plays a key ecological role by stabilizing soil, preventing erosion, and contributing to flood regulation. The species prefers moderate to cold climates and thrives in deep, moisture-retentive soils with consistently high water tables. (European Forest Genetic Resources Programme (EUFORGEN), n.d.)

Wetlands

How wetlands improve water quality

Wetlands are biologically diverse ecosystems that serve a critical function in enhancing water quality. According to the U.S. Department of Agriculture (1995), wetlands consist of an interconnected system that includes water, soil substrates, vascular and algal plant communities, organic litter (such as fallen vegetation), invertebrates (including insect larvae and worms), and a wide range of microorganisms, particularly bacteria. The interaction among these components supports a variety of physical, chemical, and biological processes that collectively contribute to effective water purification. The following mechanisms outline how wetlands function as natural water treatment systems:

- Sedimentation; Wetlands slow down the flow of water, allowing suspended particles such as silt, clay, and organic debris to settle at the bottom through gravity.
- Filtration: As water passes through the dense matrix of plant litter and substrate, particulate matter and dissolved pollutants are physically filtered out, and certain dissolved substances precipitate out of the water through chemical reactions with soil minerals and organic material.
- Chemical transformation; Wetlands facilitate various chemical transformations that convert harmful substances into less toxic or more stable forms.
- Adsorption: Nutrients and pollutants are bound to the surfaces of plant roots, soil particles, and organic litter through adsorption, preventing them from remaining in the water.
- Microbial decomposition: Microorganisms and plants play a key role in breaking down and transforming pollutants through biological activity and decomposition processes.
- Nutrient uptake and transformation; Nutrients are absorbed and transformed by both microorganisms and wetland plants, helping to reduce nutrient concentrations in the water.
- Pathogen[14] reduction: Pathogens present in the water are reduced through predation[15] by other organisms and natural die-off processes occurring within the wetland system. (U.S. Department of Agriculture, p. 17)
- As for wasted materials to be used in obstructed wetlands, Vishwakarma et al. (2023) examine in their studies that various recycled construction materials like crushed concrete, demolished brick, soil, and mixed demolition waste all had adequate porosity and absorption for use in wetland filter layers, pollutant-recovery media. (Vishwakarma et al., 2023, p. 1352)
- According to the U.S. Department of Agriculture (1995) materials used in these substrate layers include soil, sand, gravel, rock, and organic matter such as compost. Each layer serves specific and multiple functions: coarse gravel and rubble enhance drainage and prevent clogging, sand and clay aid in the removal of suspended solids and the adsorption of nutrients, and topsoil or organic materials provide essential support for vegetation and improve water retention. As reported by the U.S. Department of Agriculture (1995), these substrates not only support diverse biological communities but also help regulate water flow and create active zones for chemical and biological transformation, contributing to the storage and breakdown of contaminants. (U.S. Department of Agriculture, 1995, p. 7)

Advantages of constructed wetlands

- Constructed wetlands represent a cost-effective and technically viable solution for the treatment of wastewater and stormwater runoff, according to U.S. Department of Agriculture (1995). Wetlands offer several key advantages:
- Wetlands can be constructed at a lower cost compared to many conventional treatment systems.
- Operational and maintenance requirements are minimal, with reduced energy and supply demands.
- Maintenance activities are typically periodic rather than continuous, requiring only occasional on-site labor.
- Constructed wetlands are capable of handling variable flow conditions, maintaining treatment performance despite fluctuations[16].
- They support the reuse and recycling of treated water, contributing to sustainable water management.
- Constructed wetlands provide valuable habitat for a wide range of wetland-dependent species.
- They can be designed to integrate seamlessly into the surrounding landscape, enhancing visual appeal.
- Beyond water treatment, they offer ecological and aesthetic benefits, such as supporting biodiversity and enriching open spaces.
- As a nature-based solution, constructed wetlands are widely regarded as environmentally responsible and are generally well-received by the public. (U.S. Department of Agriculture, p. 17)

Limitations of constructed wetlands

Despite their many advantages, the U.S. Department of Agriculture (1995) continues that constructed wetlands also present certain limitations that must be considered:

- Constructed wetlands generally require significantly larger land areas compared to conventional wastewater treatment systems. As a result, wetland treatment is economically viable primarily in locations where land is both available and affordable.
- They require a minimum and consistent supply of water to sustain wetland vegetation. Although wetlands can tolerate temporary periods of low water levels (drawdowns), prolonged drought conditions can jeopardize their function and ecological health.
- Treatment performance may be less consistent than that of conventional treatment systems. Wetland treatment efficiency often varies seasonally, influenced by environmental factors such as rainfall patterns and droughts. Although average annual performance may be acceptable, wetlands may not consistently meet stringent effluent quality standards at all times.
- The biological components of wetlands, including plants and microorganisms, are sensitive to toxic chemicals, which can impair treatment effectiveness.
- Additionally sudden influxes of pollutants or surges in water flow can temporarily disrupt treatment processes and reduce system performance. (U.S. Department of Agriculture, p. 17)

Stormwater management & cloudburst resilience

One of the primary goals of the project is to manage intense rainfall events and cloudbursts while improving runoff management. The integrated system of wetlands and permeable landscapes is designed to function as a sponge and buffer during storm events. The design focuses on maximizing water retention, filtration, and controlled release to ensure resilience against the increasingly frequent heavy downpours associated with climate change. Overall, the project exemplifies a blue-green infrastructure approach, combining water (blue) and vegetation (green) systems to address urban flooding and pollution. By treating water as an asset, the project reduces pressure on Gothenburg's drainage systems and improves the quality of water entering the Göta älv.

The wetland system is structured to manage and treat runoff from the nearby area in sequential stages. The first and smallest wetland functions as a forebay, designed to receive the initial flush, which typically carries the highest pollutant load. As run-off water enters the forebay, the flow slows significantly, allowing larger particles and sediments to settle at the bottom. North Sea Region Programme (2020) dictates that this process captures major pollutants early and initiates the removal of nutrients and metals through sedimentation and biological uptake.

To enhance filtration, the design incorporates multi-layer substrates made from crushed construction waste materials such as brick and concrete. To continue from the previous source, these substrates not only provide a physical filtering medium but also adsorb chemicals from the water, improving water quality before the overflow moves to the wetland through designated filtration pipes and gabion walls.

During normal rainfall events, all collected water is either absorbed into the soil or retained within the basins, eliminating the need for direct discharge. However, during more extreme storm events, the system is designed to release excess water in a controlled manner to prevent urban flooding, particularly in flood-prone areas of Gothenburg. The same source also mentions that proper management of this flow is critical, as unmanaged floodwaters could result in significant economic damage to the city. (North Sea Region Programme, 2020)

An important aspect of the wetland system is ongoing maintenance. Over time, the basins are expected to accumulate sediments and trapped pollutants, which is a key part of their function. To maintain system efficiency, a maintenance plan must include periodic sediment removal, recommended every five to ten years or as necessary based on observed conditions.

Beyond the wetlands themselves, permeable pavements constructed over a crushed concrete sub-base allow rainwater to percolate into the ground, further enhancing infiltration rates. (see Section A-A in p. 67) Additionally, the North Sea Region Programme (2020) explains that planting trees and deep-rooted vegetation throughout the site promotes interception (rainfall caught on leaves) and evapotranspiration, processes that reduce runoff volumes over time. A diverse planting palette, including species adapted to rain garden environments, strengthens the site's capacity to function effectively as a Sponge City component.

Through integrated water management, sediment filtration, controlled discharge, and enhanced infiltration and evapotranspiration[17], this project transforms a former river section into a functional floodplain. In doing so, it not only protects Gothenburg from future flood risks but also enriches the urban environment with ecological and aesthetic value. (North Sea Region Programme, 2020, p. 1-3)

Figure 3.18. Overview map showing vulnerable flood zones and water dynamics across the Gothenburg region. Scale 1:50,000 (A4). Source: City of Gothenburg. (2022). Comprehensive plan for Gothenburg. Modified by the author.

Figure 3.19. Zoomed-in map of the Skeppsbron waterfront, highlighting the project area and its flood-prone zones. Scale 1:10,000 (A4). Source: City of Gothenburg. (2022). Comprehensive plan for Gothenburg. Modified by the author.

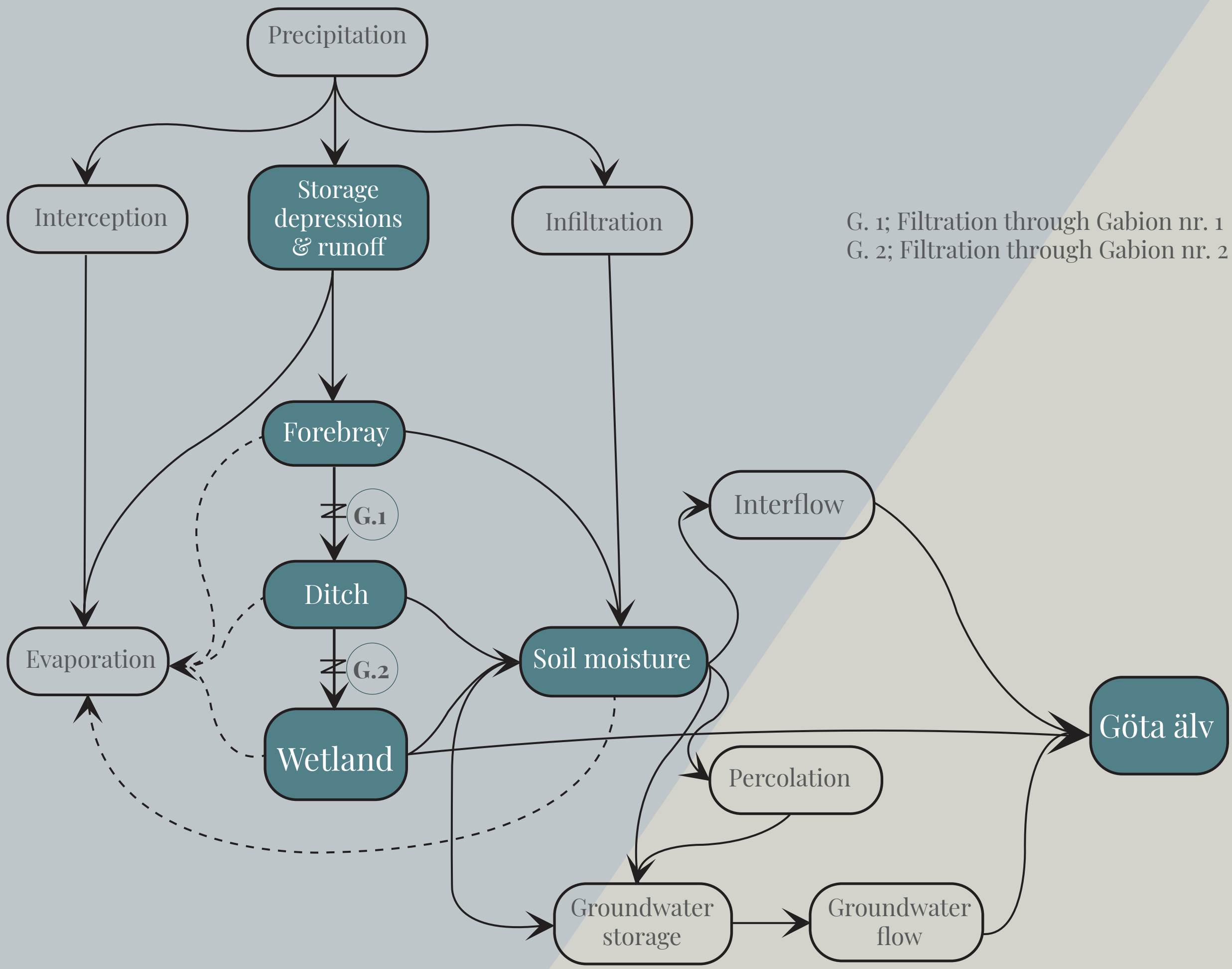


Chart 3.01. This chart illustrates the hydrological processes from precipitation to discharge into Göta älv, while highlighting the interventions introduced through the project (marked in blue). The upper part of the system begins with precipitation, which represents all forms of water input to the site, including rainfall and snowmelt.

From precipitation, part of the water is captured by interception, a process where vegetation, buildings, or other surfaces temporarily hold water, preventing it from directly reaching the ground. Some of this water later evaporates back into the atmosphere. Another portionvvvof the precipitation infiltrates into the soil, while the rest becomes surface runoff, collected in storage depressions. These depressions represent low-lying areas where water temporarily accumulates before moving further through the system.

Within the project interventions, this runoff is first directed into a forebay, a shallow basin designed to slow down water flow and allow sediments and pollutants to settle. From here, water passes into a ditch, where additional slowing and natural filtration take place. The ditch is connected to the forebay and to the wetland through gabion walls, which are wire mesh structures filled with stone, allowing water to filter through while trapping sediments and pollutants.

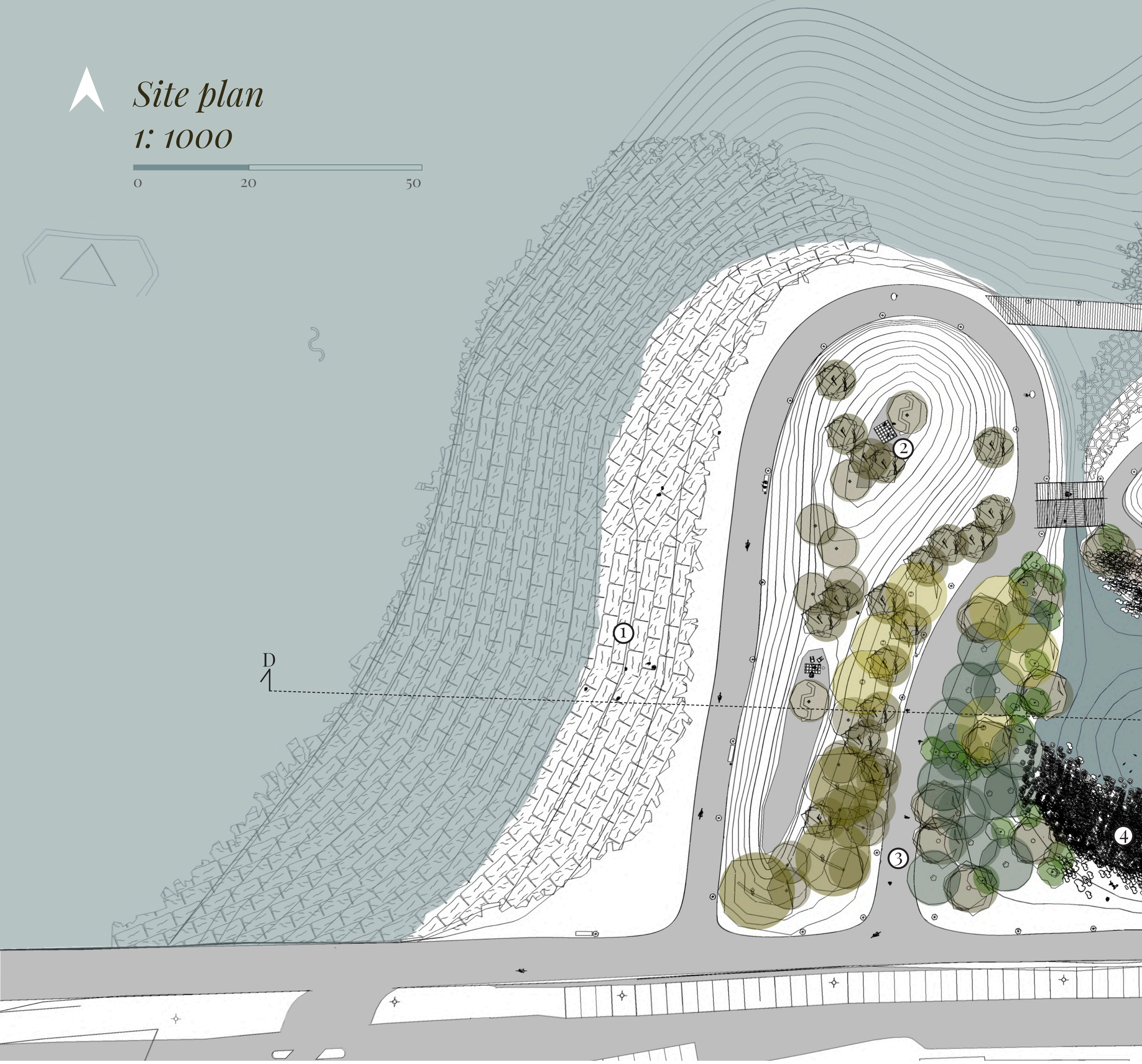
The next stage is the wetland, which functions as a key ecological filter. Wetlands support both biological and physical processes that improve water quality, increase infiltration, and provide storage capacity. These project-based features, forebay, ditch, gabions, and wetland, work together to reduce pollutant loads and enhance the infiltration of stormwater into the ground. Infiltrated water contributes to soil moisture, which is the amount of water stored in the unsaturated soil zone. From this point, the water can follow different pathways: interflow[18] or percolation[19]. Over time, stored groundwater feeds into groundwater flow, the natural movement of groundwater through subsurface layers that can eventually re-emerge into rivers or lakes.

The distinction between interflow and groundwater flow lies in depth and speed: interflow occurs relatively quickly within shallower soil layers, whereas groundwater flow is slower and moves through deeper geological formations.

Finally, both the filtered surface water and subsurface flows converge into Göta älv, completing the system. Through the integration of engineered natural features such as the forebay, ditch, gabions, and wetland, the project enhances infiltration, improves water quality, and reduces flood risks in the Skeppsbron area.


Legend
Flood risk


N
Skeppsbron
Legend
Flood risk

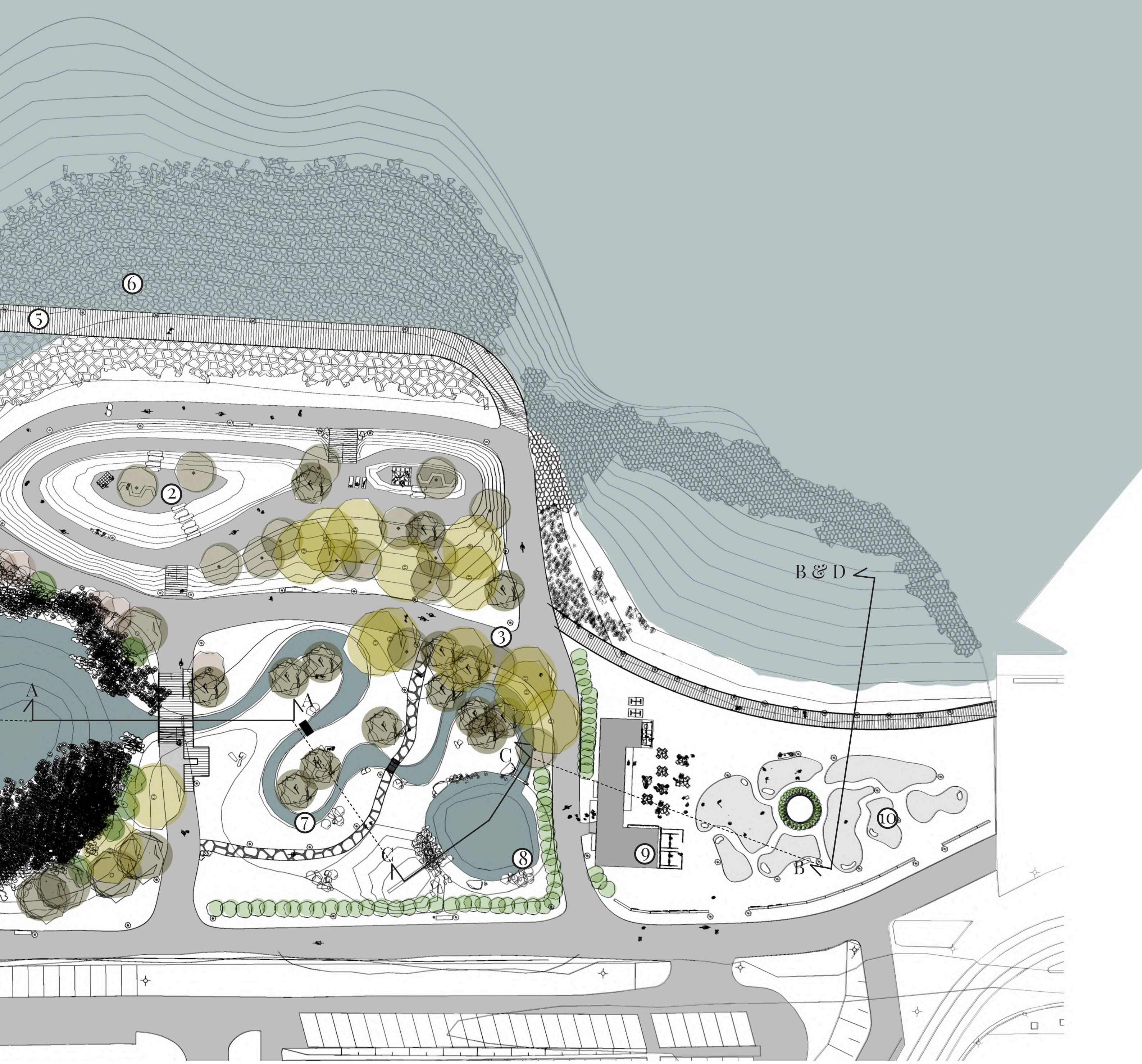


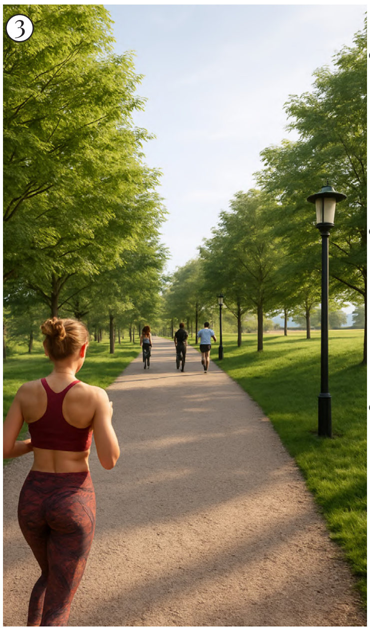
Hard edge

- These structures create spatial niches for public use, inviting new forms of interaction between the city and the water.
- A barrier against the powerful waves approaching from the east.
- By combining protection with openness, the intervention establishes a threshold where the force of nature and human presence intersect.

View point

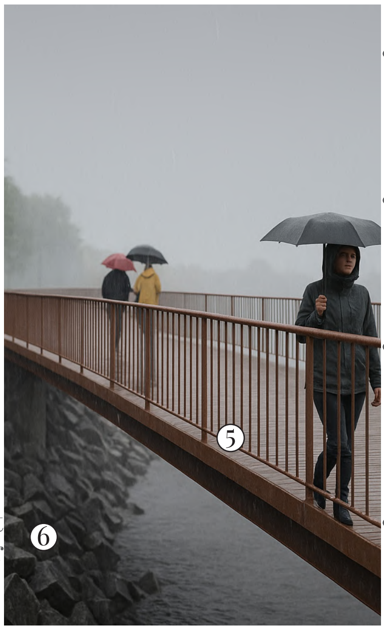
- Viewpoints at the highest point of the project.
- It extends the visual reach of the site, drawing people towards the landscape and the water.
- It provides opportunities for informal gatherings such as picnics, creating a setting where social life and natural surroundings converge.
- Its design supports slower rhythms of use, encouraging lingering and an embodied experience of the environment.





Natural corridor

- These spatial arrangements create a pleasant and inviting atmosphere for walking, jogging, or taking pets out.
- The pathway brings a sense of retreat and tranquility, offering an accessible contrast to the project's central urban location.
- By providing a natural corridor, it enhances both ecological and social values, encouraging movement while fostering a slower engagement with the environment.



Mineral edge

- A bridge extending across a line of rocks, creating an alternative way for visitors to engage with the site.
- Brings people closer to the water, offering new perspectives and sensory experiences of the waterfront.
- The rocks generate distinct micro-environments for aquatic species, while enabling plants to thrive in varied conditions.
- It combines ecological enhancement with recreational and experiential qualities.

Projekt details

Figure 3.20. A constructed wetland designed as a living system where birds, insects, and other species can thrive. Native plants and trees find space to grow, while people are invited to enjoy and reconnect with nature. This landscape not only enhances biodiversity but also contributes to cleaner water and a more resilient city.

Vegetations in this area mostly are;

Black Alder

Grey Alder

Cattail

Reeds

Rushes

Sektion A-A

Connection between wetland and ditch

1:200

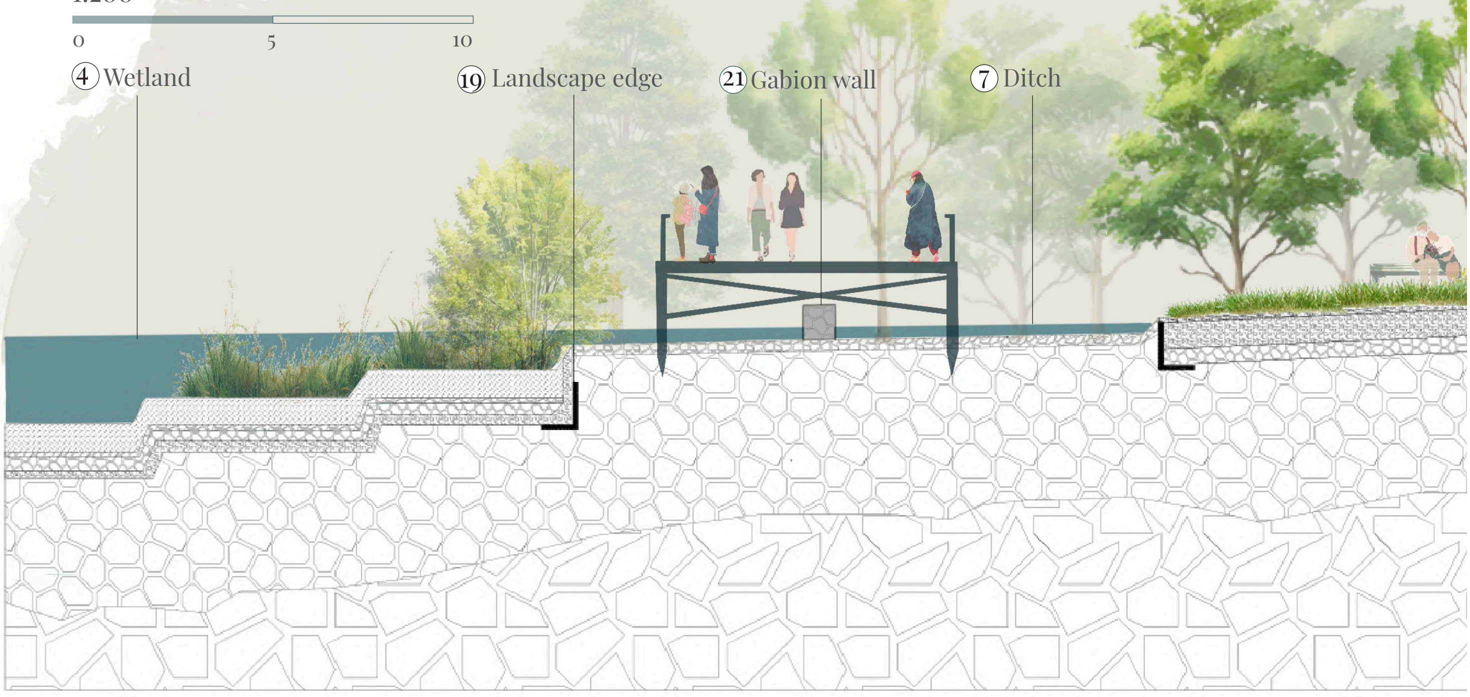


Figure 3.21. The eastern part of the site is envisioned as a multifunctional recreational landscape, integrating a golf course and a café-restaurant complemented by an adjacent playground for children. The terrain is constructed using dredged sediments from the Göta älv, stabilized through sheet piling to ensure structural integrity and long-term resilience. A ridge establishes a continuous spatial connection between the existing Stenpiren terminal and the newly designed landscape, providing opportunities for walking, cycling, and appreciating the expansive views of the Göta älv.

Repurposed shipping container

Reused sheet piling

Natural seating elements (timber logs or stone blocks)

Reused wooden panels

Sektion B-B

Golf course and the café/restaurant
1:200

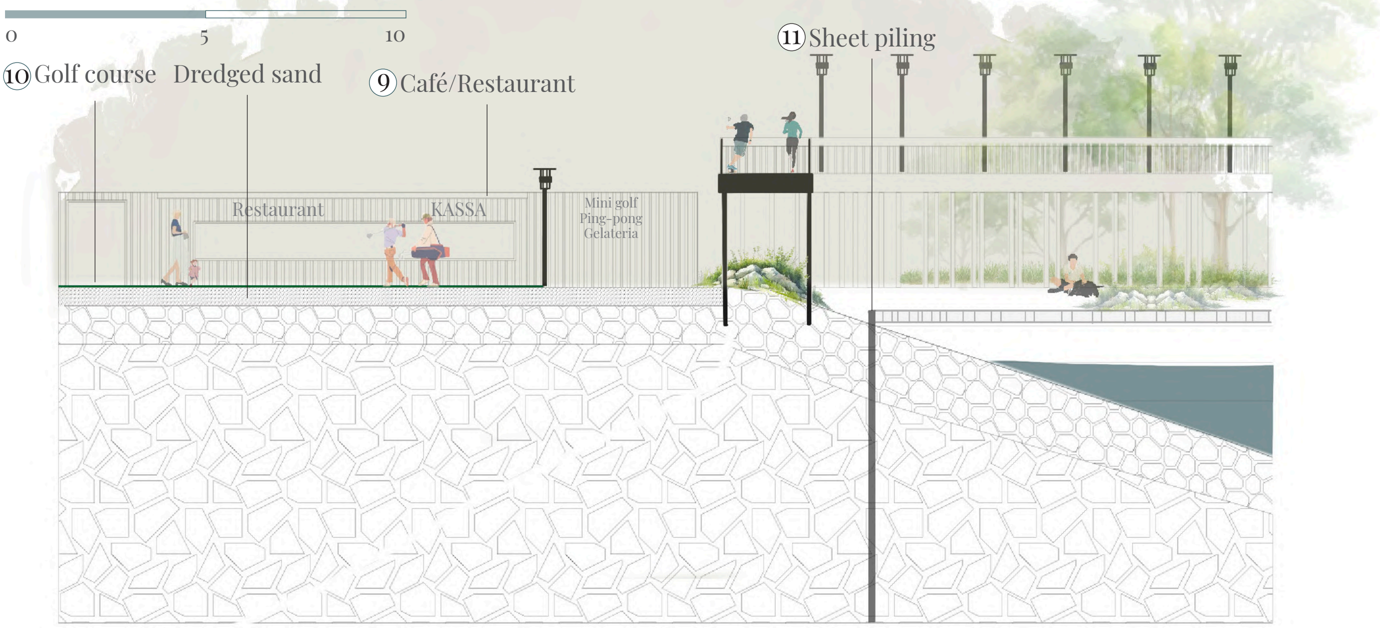


Figure 3.22. This perspective highlights the stormwater system, where water first enters the forebay, then passes through the gabion before reaching the ditch. In the background, the gelateria can be seen in front of the golf course and Stenpiren Resecentrum, linking the new landscape to the urban context.

Walking & running path

Flow control step

stepping stones

Walking path

Long sektion D_D

1:1000

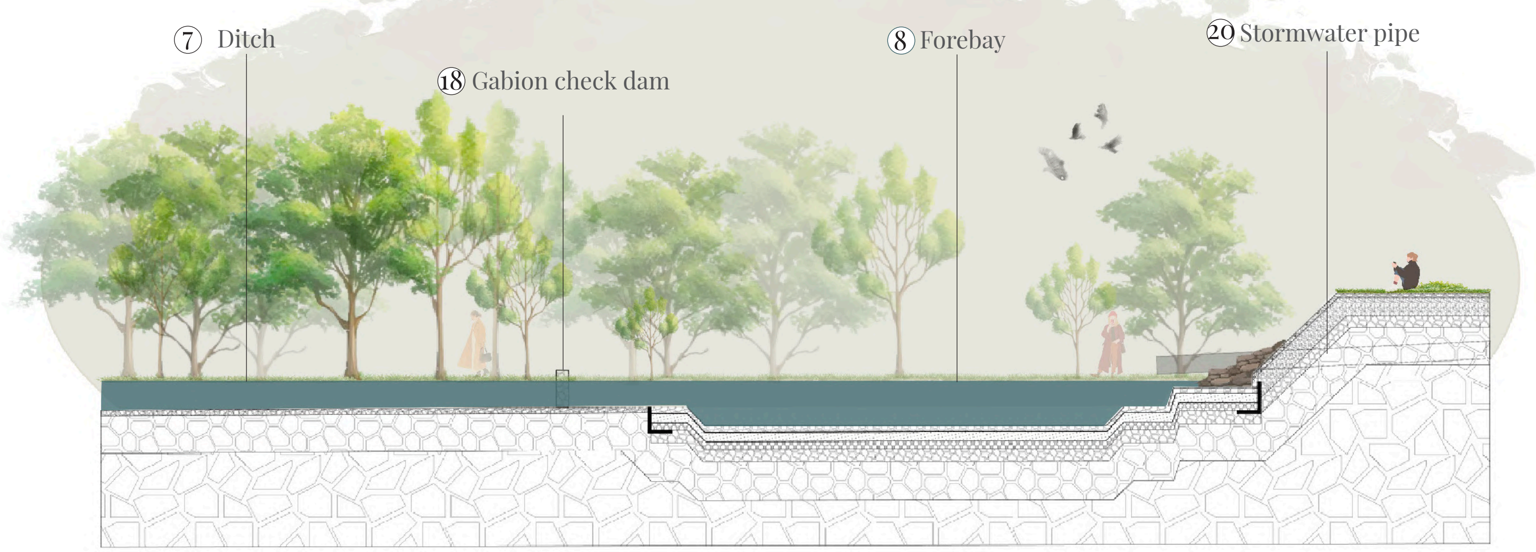
0 20 50

This long section illustrates the entire project area, highlighting the overall topography and its relationship to water, The drawing shows how the terrain gradually shifts in height, creating a varied landscape with both elevated areas and lower depressions designed to collect and guide stormwater. Each black line in the section represents a half-meter distance, making the changes in topography and water levels clearly legible.

Sektion C-C

1:200

0 5 10

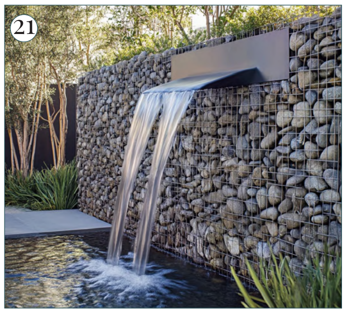


The forebay is connected to the ditch through an inlet structure. Excess runoff and floodwater are directed into the pipe system, where the flow passes through layers of stone that act as a natural filter. Larger debris and sediments are retained, while the cleaner water continues into the forebay for further treatment.

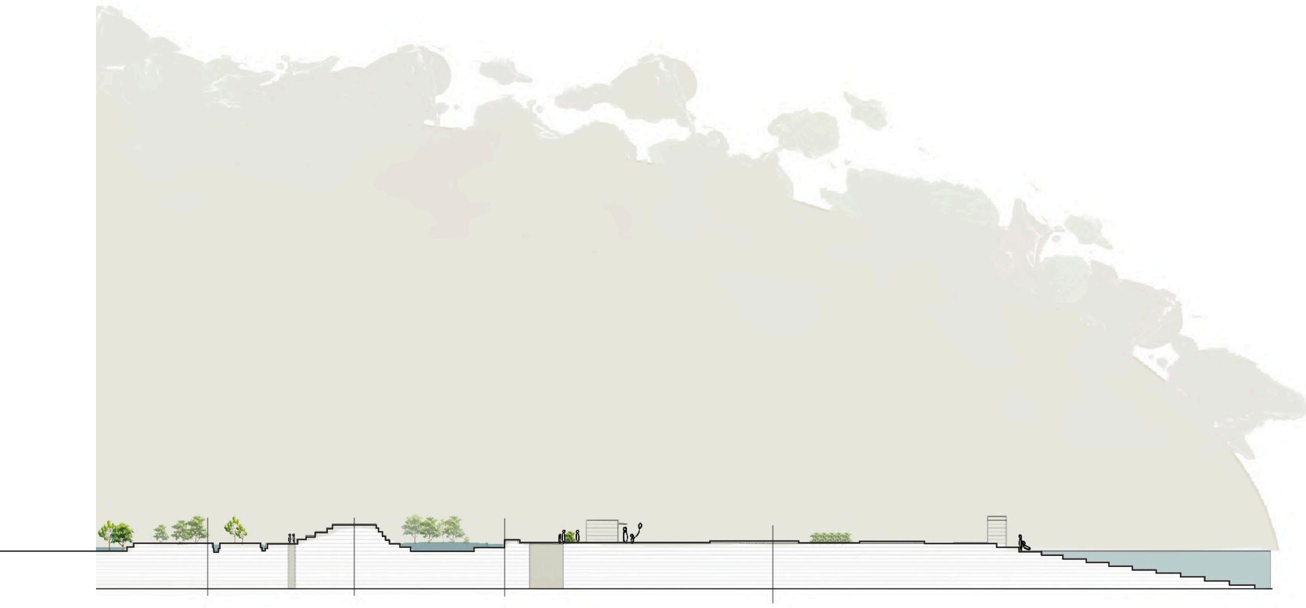
Gabion check dam

Landscape edge

Stormwater pipe



Gabion wall



Future scenarios

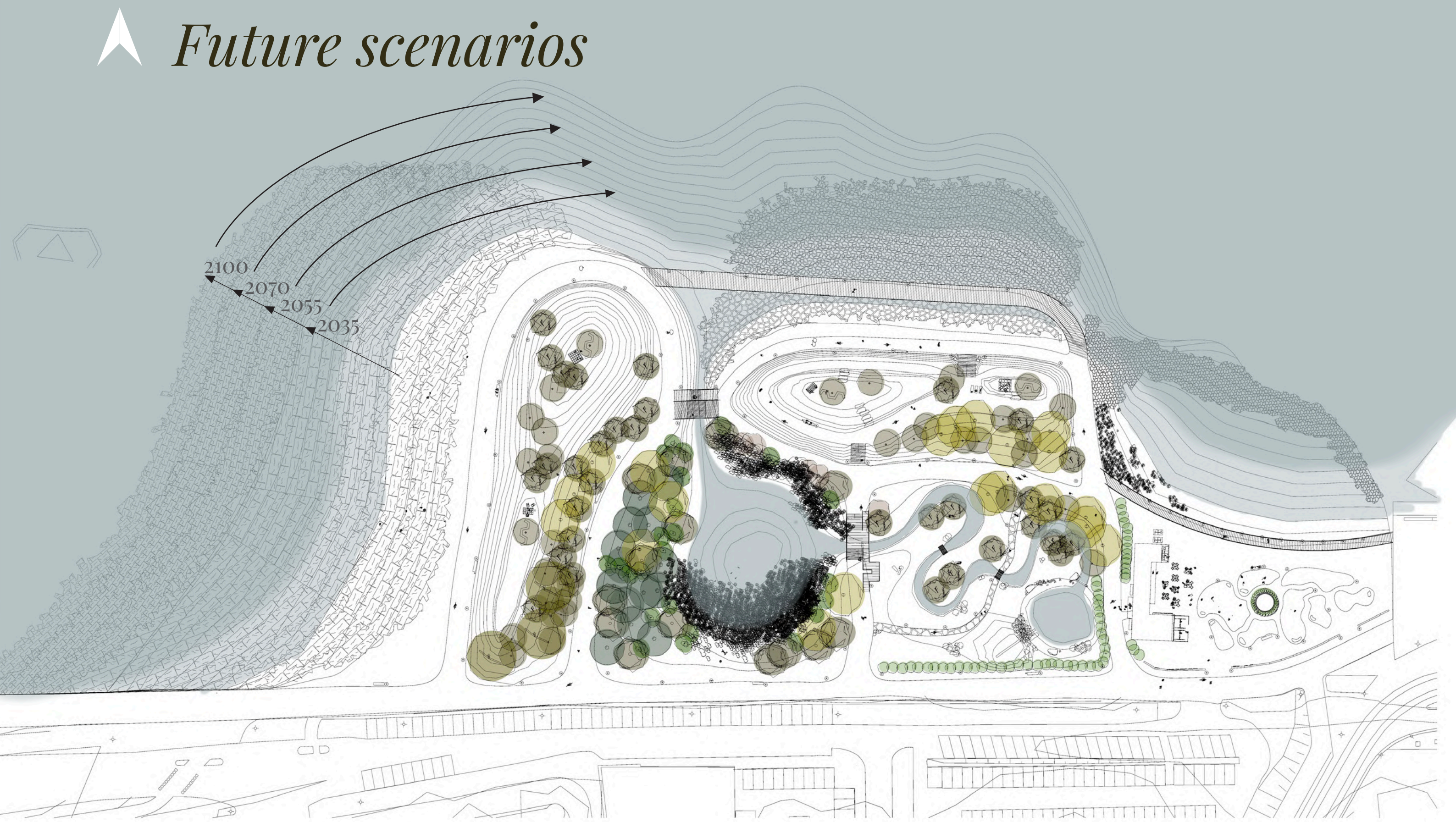


Figure 3.22. Future expantion possibility of the project. Illustration by the author.

Expansion possibility

This proposal is designed with a long-term, flexible framework that allows for gradual expansion in response to future climate scenarios. The concept builds on the idea of incrementally adding new layers of future excavation projects as bedfill, in the same manner as the initial intervention, thereby extending the landmass over time. (see Figure 3.22) Such an approach not only enlarges the park area, creating more accessible public space for people, but also generates new ecological habitats below the water surface. These underwater structures foster biodiversity by providing shelter and breeding grounds for aquatic organisms.

Beyond ecological and social benefits, the expansion serves an important protective function. As sea levels rise and cloudburst events become more frequent, the extended park area acts as a buffer zone and barrier, reducing the risks of flooding. This adaptive capacity ensures that the project remains effective in near-future scenarios such as 2035, while also offering the possibility of further expansion in 2055, 2070, and 2100, depending on the severity of climate impacts.

The concept is not limited to growth in one predetermined direction. Instead, the design is deliberately kept open-ended, enabling extensions to be made in whichever direction is most appropriate given future needs and conditions. This flexibility embodies a resilient design strategy, one that acknowledges uncertainty while ensuring the project can continue to protect the city, support biodiversity, and provide valuable public space across multiple time horizons.

Future water-land scenarios

As mentioned in the first chapter, by 2055, the mean water level of the Göta älv is projected to rise by approximately +0.2 m compared to present conditions. While such an increase may appear moderate, it significantly amplifies the impact of extreme weather events. During cloudbursts, temporary increases of around +1.0 m can occur, leading to combined water levels of up to +1.2 m above today's normal level. Towards 2070, sea-level rise under high-emission scenarios (RCP 8.5) is expected to reach approximately +0.3 m above today's mean water level. When combined with intense cloudbursts and elevated river flows, water levels in the Göta älv may reach +1.3 m above current conditions. By 2100, sea-level rise in the

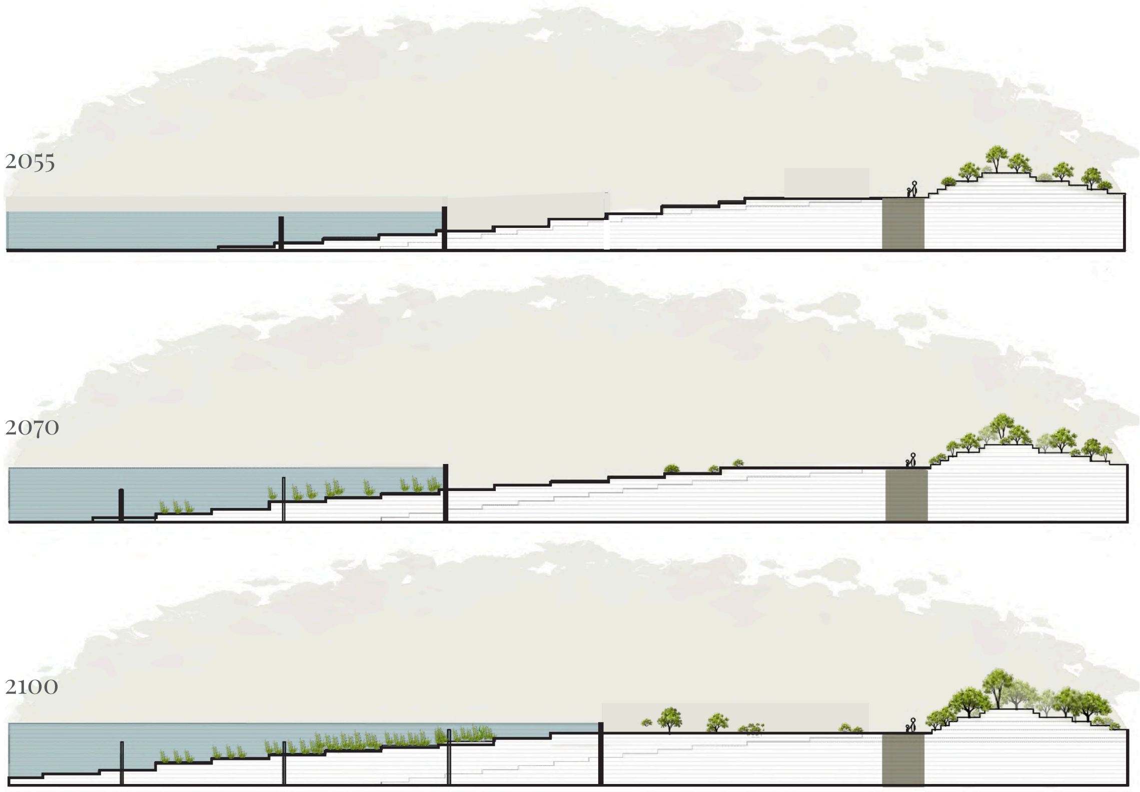


Figure 3.23. Future scenarios for year 2055, 2070 and 2100. Illustration by the author.

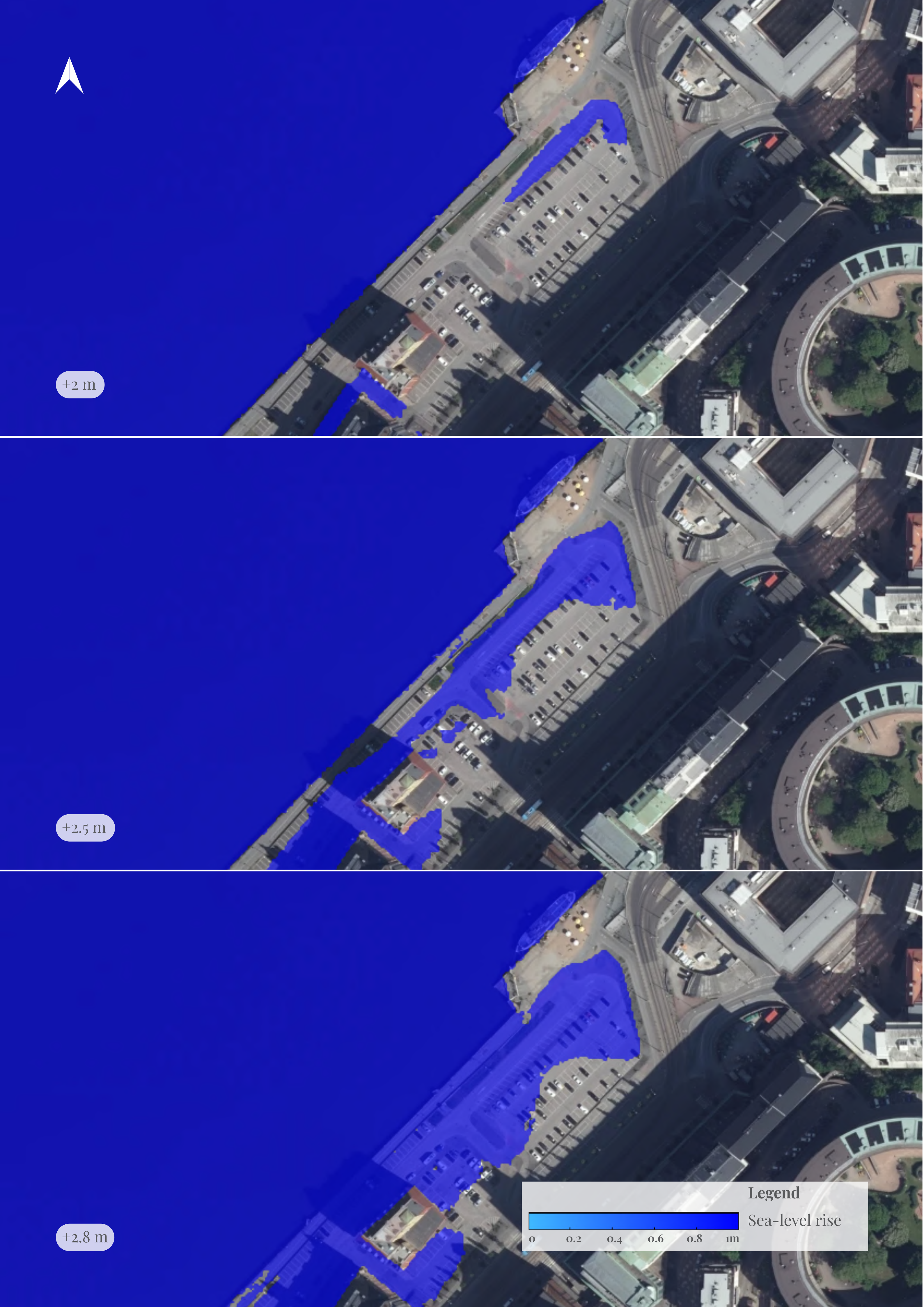
Gothenburg region is projected to reach around +.7 m relative to current levels. Extreme high-water events could result in levels between +2.0 and +2.7 m above present conditions, when storm surges, cloudbursts, and elevated river flows coincide.

The intervention is based on the progressive installation of sheet piling, (see Figure 3.23) which stabilises the land against erosion while creating favourable conditions for vegetation and aquatic habitats. By incrementally adding new sheet piles, the shoreline can expand outward and rise gradually over time. The excavated rock becomes a simple yet effective resource for shaping new landforms. Through this staged process, the waterfront gains both resilience and ecological value, allowing the landscape to adapt dynamically to changing climatic conditions.

As Gothenburg continues to expand and densify, the city's construction sector will inevitably generate increasing volumes of construction and demolition waste.

By locating interventions in strategically selected sites, the project can draw upon this continuous flow of construction by-products, transforming them into functional components of flood prevention and water management solutions. These marked sites therefore illustrate more than just places for technical implementation: they represent opportunities to link Gothenburg's expansion plans with resource recovery and ecological resilience.

Figure 3.24. Key areas along Göta älv waterfront where the project could be implemented.


+2 m
+2.5 m
+2.8 m
Legend
Sea-level rise
0 0.2 0.4 0.6 0.8 1m

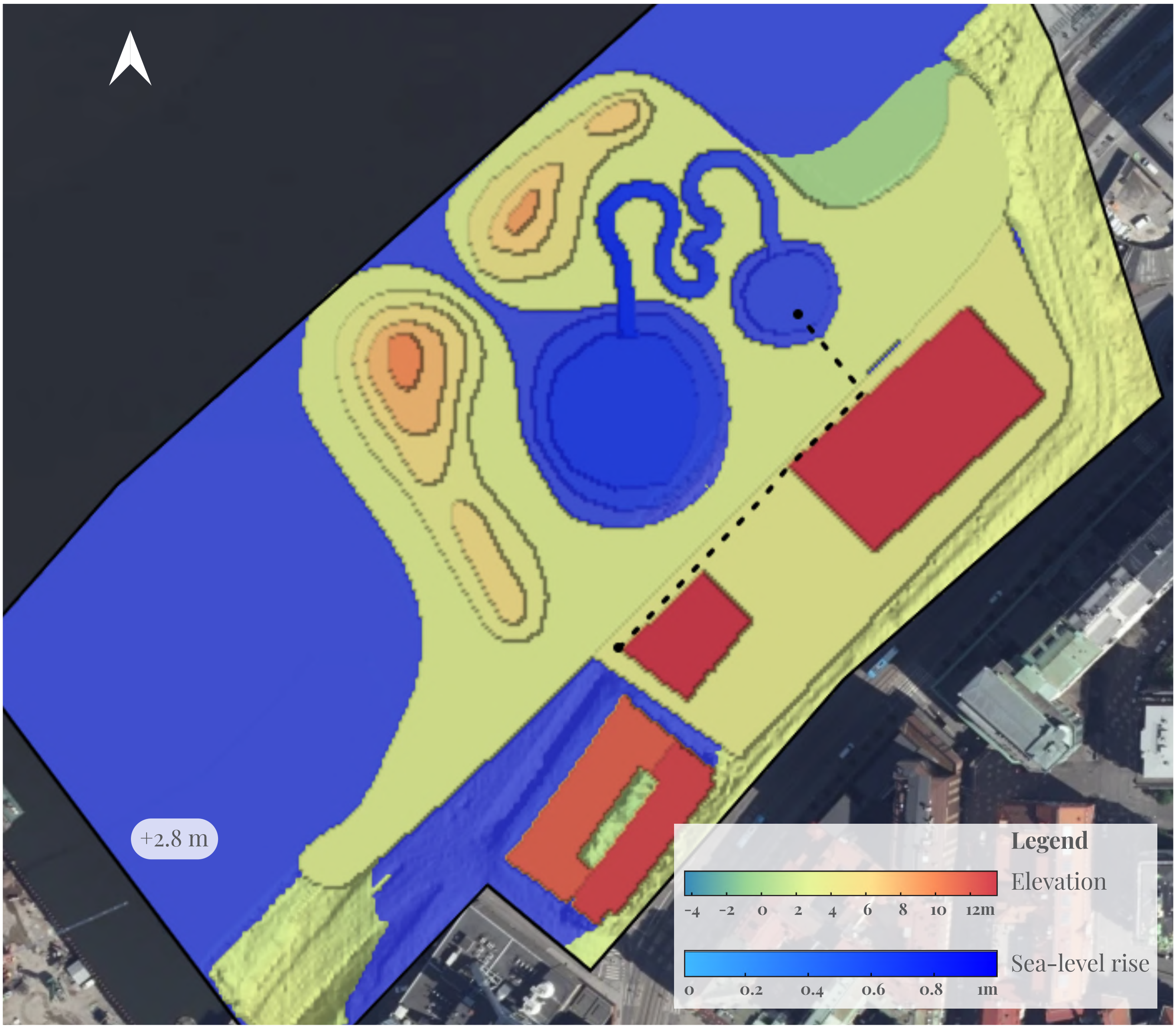
Flood scenario analysis using Scalgo simulation

The maps on the previous page show the site's vulnerability at +2.0 m, +2.5 m, and +2.8 m of sea level rise. Even at 2.0 meters, flooding begins to affect the lower areas, while at 2.5 and 2.8 meters large parts of the parking lot and adjacent spaces are inundated. This indicates that the current condition is poorly prepared to manage future flood risks.

The scenario below illustrates a projected flood level of 2.8 m and is informed by the municipality's long-term development plans for Skeppsbron, where the existing parking area is intended to be replaced with new mixed-use buildings and public spaces. A section of the parking area has been leveled to test an alternative configuration, acknowledging these future transformations. To strengthen the intervention, the adaptation is extended further into the surrounding area, allowing for a broader spatial response to the projected flood risk. In addition, a drainage system is integrated to channel floodwater toward the forebay, supporting more efficient water management and reducing the risk of accumulation on the site.

Figure 3.25-27. Sea level rise simulations generated with Scalgo.se, illustrating land conditions at (from up to down) 2.0 m, 2.5 m, and 2.8 m rise.

Figure 3.28. Modelled scenarios demonstrating the capacity of the Skeppsbron project area to handle and adapt to higher water levels.



Definition of terms

1. **BREEAM**; Building Research Establishment Environmental Assessment Method

2. **Inert**; materials that are chemically stable and do not release harmful or soluble pollutants into the environment.

3. **Leach**; to release or drain substances from a material into surrounding soil or water, often through rain or groundwater movement.

4. **End-users**; the final users or recipients of the repurposed materials in practical applications.

5. **CE marking standards;** ensure that reused construction products meet official EU quality, safety, and performance requirements before being used in construction.

6. **Carbonation;** the process by which concrete reacts with carbon dioxide in the air, gradually lowering its pH and chemical reactivity.

7. **Amendment**; a material added to improve soil quality.

8. **Alkalinity**; refers to the ability of the soil to neutralize acids, often related to its pH level. High alkalinity can make the soil too basic, which may harm plants or disrupt the ecosystem.

9. **PAH**; Polycyclic Aromatic Hydrocarbons, These are organic chemical compounds which are commonly found in bitumen and asphalt. PAHs can be toxic, persistent in the environment, and potentially harmful to humans and aquatic life.

10. **RAP;** Reclaimed Asphalt Pavement, asphalt material that has been removed from old roads or pavements and recycled for reuse in new paving projects. Older recycled asphalt releases only small amounts of harmful substances, making it safer when reused

11. **PFAS**; per- and poly-fluoroalkyl substances, are a large group of man-made chemicals used for their water- and grease-resistant properties. They are found in everyday products, such as paper packaging, household items, and even construction and demolition materials. They are extremely persistent in the environment and do not break down easily. Their persistence and mobility make them difficult to remove from water or waste streams, requiring specialized treatment methods like absorption, filtration, or advanced chemical processes.

12. **Pilot stage;** small-scale, experimental projects designed to test feasibility, operational methods, and user behavior before potential wider implementation.

13. **Symbiosis**; the mutually beneficial relationship between Grey Alder and nitrogen-fixing soil bacteria, which improves soil fertility while supporting the bacteria.

14. **Pathogen**; an organism, such as a bacterium, virus, or parasite, that can cause disease in humans, animals, or plants.

15. **Predation**; organisms in the wetland consuming or breaking down pathogens, which helps reduce harmful microbes in the water.

16. **Fluctuation**; variations in the amount of water entering the system, which constructed wetlands can manage while still maintaining treatment performance.

17. **Evapotranspiration**; the combined process of water evaporating from soil and water surfaces and being released into the atmosphere by plants through transpiration.

18. **Interflow**; lateral movement of water through the upper soil layers, which eventually discharges into surface water bodies such as Göta älv.

19. **Percolation**; downward movement of water through the soil profile to deeper layers. This process contributes to groundwater storage, which represents water held in aquifers below the surface.

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List of figures

Water Management

management framework: Catchment area Centrum South [Report]. Modified and translated by the author.

Figure 1. 20. City of Gothenburg. (2022). Comprehensive plan for Gothenburg. Retrieved February 10, 2025, from https://oversiktsplan.goteborg.se/

Figure 1. 21. City of Gothenburg. (2022). Comprehensive plan for Gothenburg. Retrieved February 10, 2025, from https://oversiktsplan.goteborg.se/

Figure 1. 22. Own illustartion

Figure 1.23. 02 LANDSKAP. (2020, July 8). Maskinparken [Photograph]. Retrieved from https://www.02landskap.se/projekt/maskinparken

Figure 1.24. Mareld Landskapsarkitektur. (n.d.) Jubileumsparken [Photograph]. Retrieved from https://www.mareldarkitektur.se/work/jubileumsparken/

Waste Management

Figure 2.01. Stena Metall Group (n.d. a, p. 51). Retrieved January 21, 2025, from https://www.stenametall.com/about-us/sustainability/sustainability-ambitions/care-for-the-environment/

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Figure 2.03. Stena Recycling. (n.d.) Circular economy in recycling. Retrieved January 21, 2025, from https://www.stenarecycling.com/about-us/circular-economy-in-recycling/

Figure 2.04. Swedish Transport Administration (Trafikverket). (n.d.). [Map]. Retrieved from https://gis.trafikverket.se/portal/apps/dashboards/3ad0c0fdb17f42e4abf180122d0cb1bb. Modified by the author.

Figure 2.05. Excavated rock. Retrieved from https://www.mining.com/usgs-apple-create-new-waste-rock-metric/

Figure 2.08. RCM Recycling. (2022, May 6). What kind of metal can you recycle for money? [Photograph] Retrieved from https://www.rcmscrapmetal.com/what-kind-of-metal-can-you-recycle-for-money

Figure 2.09. Photo by the author.

Figure 2.10. Stockholm Resilience Centre. (2022, June 27). Sand extraction: the biggest resource crisis you've never heard about. [Photograph] Retrieved from https://www.stockholmresilience.org/research/research-news/2022-06-27-sand-extraction-the-biggest-resource-crisis-youve-never-heard-about.html

Figure 2.11. Clean Management Environmental Group, Inc. (n.d.). Soil excavation [Photograph]. Retrieved from https://cleanmanagement.com/service/soil-excavation/

Table 2.01: Author's own elaboration.

Figure 2.12. The city of Gothenburg & Lantmäteriet (2025), Retrieved from https://minkarta.lantmateriet.se/. Modified by the author.

Figure 2.13. Land8. (n.d.). Why Sydney needs Barangaroo Reserve [Photograph]. Retrieved from https://land8.com/why-sydney-needs-barangaroo-reserve/

Figure 2.14. Hargreaves Associates. (2016, July 28). Queen Elizabeth Olympic Park by Hargreaves Associates [Photograph]. Landezine. Retrieved from https://landezine.com/queen-elizabeth-olympic-park-by-hargreaves-associates/

Design

Figure 3.01. Lantmäteriet (2025). Scale 1:2000 (A4). Retrieved from https://minkarta.lantmateriet.se/. Modified by the author.

Figure 3.17. Lantmäteriet (2025). Retrieved from https://minkarta.lantmateriet.se/.

Water we gonna do with all this waste?