Coastal architecture simulations for compound flooding in Trelleborg

Data driven coastal design methodology for Trelleborg

Joel-Wassily Monarrez Lachhein

Independent project • 30 credits

Swedish University of Agricultural Sciences, SLU

Faculty of Natural Resources and Agricultural Sciences

Landscape Architecture for Sustainable Urbanisation - Master's Programme

Uppsala 2024

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Kustarkitektursimuleringar för sammansatta översvämningar i Trelleborg
- Datadriven kustdesignmetodik för Trelleborg

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Credits: 30 credits

Level: Second cycle, A2E

Course title: Independent Project in Landscape Architecture, A2E – Landscape Architecture for Sustainable Urbanisation – Master's Programme

Course code: EX0945

Programme/education: Landscape Architecture for Sustainable Urbanisation - Master's Programme

Course coordinating dept: Department of Urban and Rural Development

Place of publication: Uppsala

Year of publication: 2024

Online publication: https://stud.epsilon.slu.se

Keywords: Coastal Region, Water Level, Design Strategies, Simulation, ARCGIS Analysis.

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ABSTRACT:

This project aims to tackle coastal flooding by exploring and simulating architectural strategies. It combines smart coastal designs from different sources, alongside an original concept, to assess their effectiveness in flood prevention. The project utilises ARCGIS maps to analyse water levels, considering storm surges and precipitation. Virtual simulation tools like Blender and ArcGIS simulate water flow dynamics, including extreme scenarios. Manhole data helps identify areas with infrastructure stress. The project focuses on understanding the impact of rising water levels, storm surges, and precipitation when they converge in coastal areas.

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1. Background and motivation

We frequently hear about the significant impacts of climate change on coastal regions. These effects have been well-documented and established, making climate change one of the most crucial topics for our current generation ((1)Sippel, S., Meinshausen, N., Fischer, E.M. et al., 2020). The consequences of climate change are already evident across the globe, leading to changes in precipitation patterns and intensities. These changes have resulted in an increased risk of pluvial flooding and a volatile climate, contributing to occurrences like heat waves, droughts, and flooding.((2)American Meteorological Society (AMS))

Addressing climate change on a global scale poses significant challenges, as it requires cooperation among nations with a shared goal. However, on a regional level, we can take steps to manage its effects. ((3)R. Berndtsson, P. Becker, A. Persson, H. Aspegren, S. Haghighatafshar, K. Jönsson, R. Larsson, S. Mobini, M. Mottaghi, J. Nilsson, J. Nordström, P. Pilesjö, M. Scholz, C. Sternudd, J. Sörensen, K. Tussupova, 2019) Figure 1 illustrates the considerable impact of climate change on urban flood risk while highlighting the complex nature of managing climate change itself.

Efforts to manage flooding are especially vital in coastal regions and cities. This urgency arises from the rising global mean sea level, driven by a range of factors. This situation places a substantial portion of the global population at risk, particularly given that 14 out of the 17 largest cities worldwide are situated along coastlines. A noteworthy statistic reveals that roughly half to three-fourths of the global population resides within 50-200 km of a coastline. (this might vary depending on the reference)((4)Joel E. Cohen Christopher Small Andrew Mellinger et al. , 1997) This proximity to water has historical significance, tied to economic advantages stemming from ocean navigation, coastal fisheries, tourism, and recreational activities. ((5)United Nations, 2007)

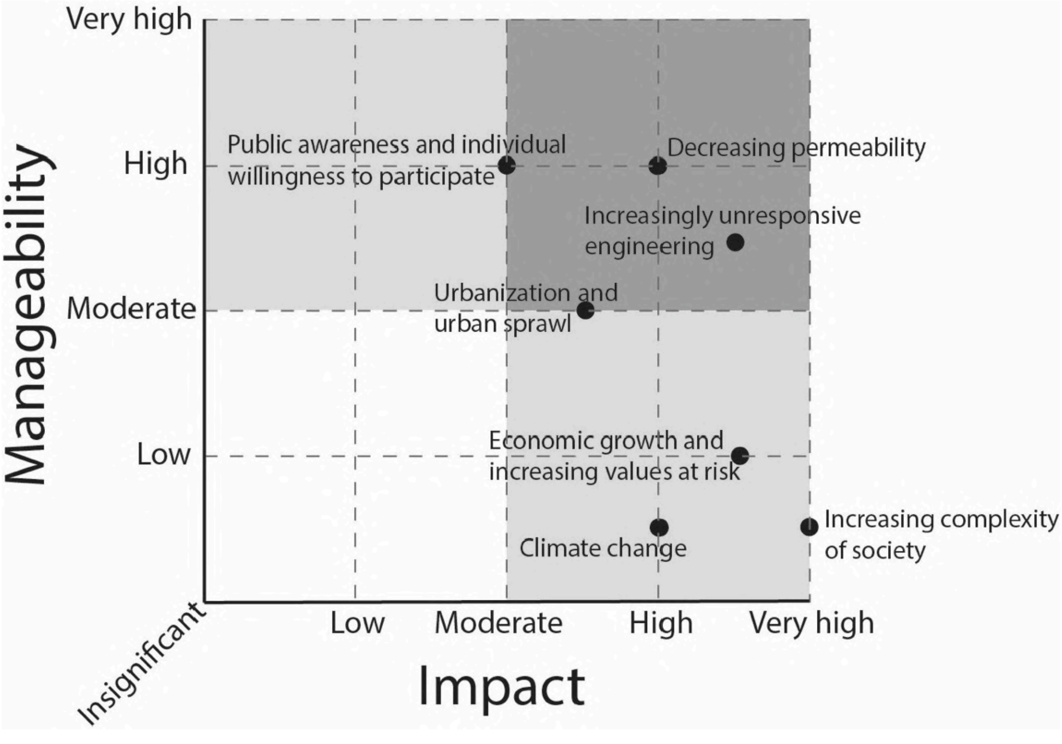


Figure 1: *Identified drivers for urban flood risk with estimated impact and manageability at city level in a time perspective of 30–100 years. ((3)R. Berndtsson, P. Becker, A. Persson, H. Aspegren, S. Haghighatafshar, K. Jönsson, R. Larsson, S. Mobini, M. Mottaghi, J. Nilsson, J. Nordström, P. Pilesjö, M. Scholz, C. Sternudd, J. Sörensen, K. Tussupova, 2019)*

Sweden's major population centres are predominantly situated along its coastline, resulting in its largest cities being coastal in nature ((6)Back, Andreas, 2020). This demographic distribution allows us to witness the tangible impacts of climate change on the country. For instance, in 2013, Sweden and Denmark were hit by two storms in the Öresund region, causing approximately 7.111 billion SEK in damages ((7)HagHigHatafSHar, S., la Cour Jansen, J., Aspegren, H., Lidström, V., Mattsson, A., & Jönsson, K., 2014). More recent instances highlight the vulnerability of southern Sweden to cloudbursts, which have inflicted significant damage on infrastructure and incurred substantial economic costs.

A critical consideration is the concept of compound flooding, which encompasses the combined effects of rising sea levels, storm surges, and heavy rainfall on coastal cities. Historically, intense precipitation and storm surges occurred in separate seasons. However, the changing climate necessitates a more proactive risk-based approach. This entails designing infrastructure to anticipate scenarios where these three factors converge, resulting in compound flooding. ((8)Salar Haghighatafshar, Per Becker, Steve Moddemeyer, Andreas Persson, Johanna Sörensen, Henrik Aspegren, Karin Jönsson, 2020)

Figure 2 visually demonstrates the escalating frequency of climate-related disasters worldwide. This data, sourced from UNISDR (2018) and adopted by Haghighatafshar, underscores the growing significance of this issue ((9)Haghighatafshar, Salar, 2019).

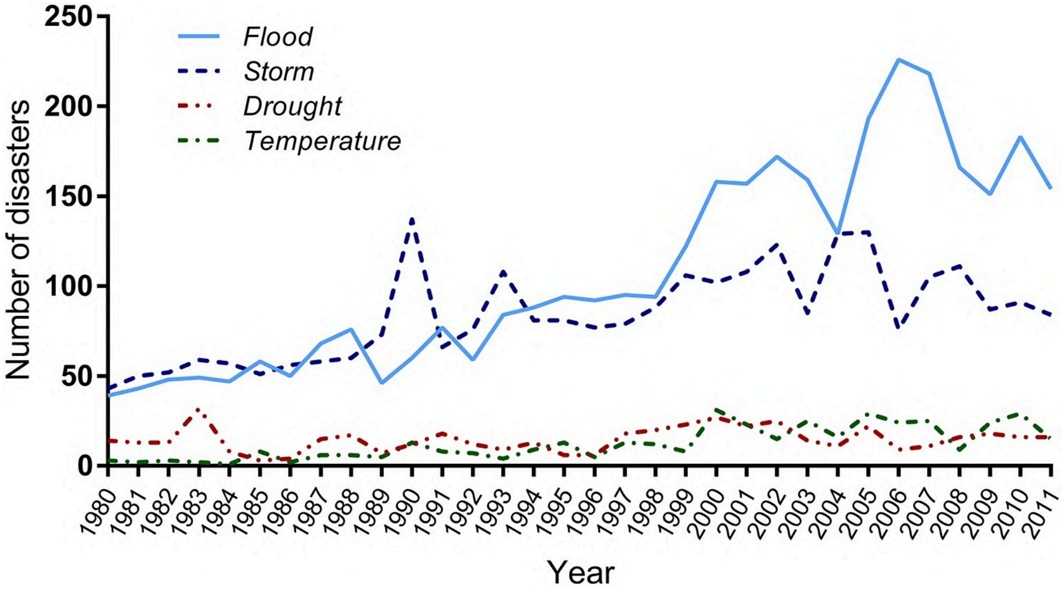


Figure 2: Number of climate-related disasters worldwide (from 1980 to 2011), according to UNISDR (2018) and adopted from Haghighatafshar (2019).((9)Haghighatafshar, Salar, 2019)

This graph clearly illustrates a notable increase in climate-related disasters overall (excluding droughts). It's worth considering that the rise in reported instances of these disasters may partly stem from improved global communication and monitoring. While it can be hypothesised that the increase is connected to climate change, this assumption is contingent on a variety of factors.

Referencing "A methodology for the assessment of compound sea level and rainfall impact on urban drainage networks in a coastal city under climate change," it becomes evident that if intensified rainfall coincides with rising sea levels, leading to more severe flooding, novel strategies must be devised to manage such future scenarios. ((10)Isabelle Laster Grip, Salar Haghighatafshar, Henrik Aspegren, 2021)

Significant insights and technical information have been gleaned from an in-depth study on urban drainage networks within the coastal city of Trelleborg. This article has substantially informed the present research.

Over the past century, the global mean sea level (GMSL) has risen by approximately 15-20 centimetres worldwide, half of which has occurred since 1993. Concurrently, global temperatures have surged by roughly 1 degree Celsius as reported by NASA ((11)NASA). Along the Southern Swedish coastline, the average sea level has risen by about 20 centimetres since the late 19th century. Recent years have witnessed an accelerated rise, according to the United Nations Intergovernmental Panel on Climate Change (IPCC)((12)UN Intergovernmental Panel on Climate Change (IPCC), 2016).

For a more detailed view of sea level increments in Sweden, particularly in Trelleborg, data from the Swedish Meteorological and Hydrological Institute (SMHI) has been explored. While Trelleborg is not specifically listed, an acceptable approach is to draw sea level data from Skanör due to their geographical proximity. This data reasonably represents sea level fluctuations in the region, with a minimal margin of error((13)Swedish Meteorological and Hydrological Institute (SMHI), 2015-2022). Both cities are situated in the same sub-basin of the Baltic Sea, the Western Baltic, thus reinforcing the reliability of this approach.((14)Wolski, Tomasz & Wiśniewski, Bernard., 2021)

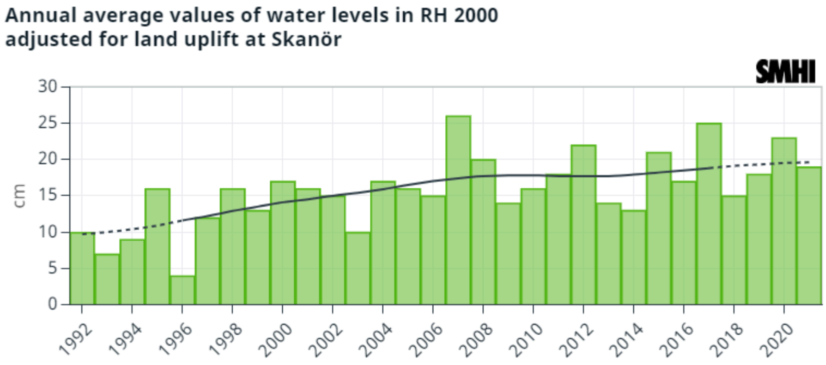
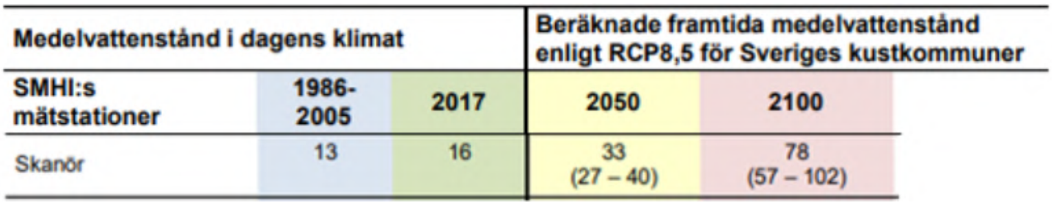


Figure 3: Annual average values of the water level in RH 2000 adjusted for land uplift at Skanör. The line shows a moving average calculated over about ten years. The dashed segment on the line signifies that the mean value is calculated over fewer years. ((13)Swedish Meteorological and Hydrological Institute (SMHI), 2015-2022)

As depicted in Figure 3's graph, the sea level in Skanör has undergone a 9.9cm increase over the last 28 years, indicating an average annual rise of approximately 33mm when adjusted for land uplift. This recent surge in sea level is the most substantial observed across Sweden. While historical data provides context, it's equally vital to look ahead and grasp the projected developments in the years to come. This forward-looking approach empowers coastal cities and regions to prepare effectively for potential disasters and infrastructural challenges.



Medelvattenstånd i dagens klimat			Beräknade framtida medelvattenstånd enligt RCP8,5 för Sveriges kustkommuner	
SMHI:s mätstationer	1986-2005	2017	2050	2100
Skanör	13	16	33 (27 – 40)	78 (57 – 102)

Figure 4: Average water level at SMHI's measuring station in Skanör for the reference period 1986-2005 and for the year 2017. Calculated future mean water levels according to RCP8.5 in Skanör. All values are given as cm in RH2000 ((15)Nerheim, S., Schöld, S., Persson, G., & Sjöström, Å., 2018)

The Swedish Meteorological and Hydrological Institute (SMHI) offers a comprehensive analysis of sea level trends in Sweden within their publication "KLIMATOLOGI Nr 48, 2017/Future sea levels in Sweden((15)Nerheim, S., Schöld, S., Persson, G., & Sjöström, Å., 2018)." This report provides an intricate examination of sea level variations across various measurement stations in the country. It becomes apparent that sea level rise exhibits diverse proportions in relation to land elevation, with the southern part of Sweden experiencing the most significant impact. This insightful report ((15)Nerheim, S., Schöld, S., Persson, G., & Sjöström, Å., 2018) furnishes projections based on different IPCC Representative Concentration Pathways (RCPs) for distinct time frames (2050, 2075, and 2100). For a risk-centered prognosis, we will adopt RCP 8.5 as our chosen scenario.((15)Nerheim, S., Schöld, S., Persson, G., & Sjöström, Å., 2018)

The Representative Concentration Pathways (RCPs) explained: RCPs, or Representative Concentration Pathways, serve as tools to anticipate a spectrum of potential future emissions. These pathways are developed through complex climate models that simulate forthcoming climates by simulating various technologies and emissions. Four primary RCPs exist, which continue to be utilised in contemporary research: RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (measured in watts per square meter - 2.6, 4.5, 6.0, and 8.5).((16)van Vuuren, D.P., Edmonds, J., Kainuma, M. et al., 2011)

While RCP8.5 has faced notable criticism, particularly highlighted in Zeke Hausfather's Nature article((17)Zeke Hausfather & Glen P. Peters, 2020), a valid observation emerges. The article introduces us to SSPs, or Shared Socioeconomic Pathways, shedding light on the rationale behind the development of both SSPs and RCPs. This clarification addresses potential misunderstandings among a limited group of climate and energy modellers ((17)Zeke Hausfather & Glen P. Peters, 2020). Another article on CarbonBrief, authored by Zeke Hausfather, emphasises the complementary nature of RCPs and SSPs.((18)Webpage: CarbonBrief, 2019)

Excluding RCP8.5 from the array of risk-based scenario preventive measures would not be prudent. The dynamic nature of climate change demands a cautious approach, wherein no potential risks should be disregarded. Such risks could impact the lives of countless individuals and the ecosystems of our planet. As previously mentioned, a margin of error exists, and this undertaking focuses on accounting for an exceedingly high baseline emission scenario, transparently acknowledging that the data analysis revolves around "a very high baseline emission scenario."

Another pivotal element contributing to the potential occurrence of compound flooding is tidal surges, also known as storm surges. These surges arise from the interplay of gravitational forces exerted by the sun and moon, and they are intricately linked to the Earth's position, resulting in region-specific tide patterns.
Tidal surges can swiftly elevate water levels by approximately 1 to 2 metres within the span of an hour. There are two primary types of storm surges: those propelled by wind and those propelled by sub-pressure linked to an active low-pressure system ((14)Wolski, Tomasz & Wiśniewski, Bernard., 2021). Notably, over the past six decades, the duration of heightened sea levels has expanded by a third, while the occurrence of tidal surges has surged by a remarkable 56.363% annually ((14)Wolski, Tomasz & Wiśniewski, Bernard., 2021).
It's crucial to grasp that storm surges can have both positive and negative values, indicating that tides can escalate or recede. Examining the period between 2012 and 2019, we observe that the most significant documented storm surge reached 168.6 cm, while the minimum recorded was -132.7 cm. On average, the surge was approximately 17.43519 cm. The data resolution is structured on an hourly time step (reference system RH2000). ((19)R. Berndtsson, P. Becker, A. Persson, H. Aspegren, S. Haghighatafshar, K. Jönsson, R. Larsson, S. Mobini, M. Mottaghi, J. Nilsson, 2019)
An additional crucial factor to consider is the phenomenon of backwater, which can be triggered by elevated tides or other environmental influences. In coastal urban areas, during heavy rainfall excess water is directed toward the ocean. However, when coupled with a storm surge, a confluence of circumstances arises that can lead to intricate challenges within the coastal city. The impact of storm surges is particularly pronounced, as they force seawater inland, inundating streets and structures.
A substantial complication emerges when all three flooding elements manifest simultaneously, as outlined by Isabelle Laster Grip, Salar Haghighatafshar, and Henrik Aspegren. Coastal flooding transpires through the rise in sea level, attributable to the Global Mean Sea Level (GMSL) elevation and localised factors. Concurrently, storm surges and pluvial flooding from heavy rainfall contribute to coastal inundation. When these three variables overlap, the result is known as compound flooding, posing significant threats to coastal cities.
Understanding coastal pipeline infrastructure is crucial. It's essential to know how runoff areas work and where the water ends up. The hydraulic head downstream, which represents the flow's energy, can significantly affect how well the pipe network functions. When sea levels rise alongside storm surges, it adds pressure to the pipes, potentially causing oversaturation and problems.

Aside from urban infrastructural problems, coastal zones are highly dynamic and morphodynamic environments. ((20) e.g., Wright, 1995, Friedrichs and Perry, 2001, De Swart and Zimmerman, 2009) It is very difficult to quantify data in coastal environments due to complicated variable parameters that are presented in these regions due to the morphology of the region. Coastal erosion is one of the factors that influences the evolution of beaches and coastal regions, which is dependent on sediment availability, storms, energy of the waves, sea level rise, the geological configuration of the coastal zone and human intervention on the territory. ((21)George Alexandrakis & Serafim E. Poulos, 2014) Due to the complexity that is presented when analysing coastal erosion, it will be mentioned briefly. Beach erosion in a simulated environment is highly complicated, due to the fact that a high amount of computing power is required to process such simulation.

Historically intensive precipitation and storm surges have yet to occur in the same season in Sweden. Intensive precipitation is mostly during summer ((22)Gustafsson, M., Rayner, D. and Chen, D., 2010, (23)Janusz Niemczynowicz, Olle Jonsson, 1981), and storm surges appear in autumn and winter seasons ((24)Hans von Storch, Wensheng Jiang, Kazimierz K. Furmanczyk, 2015, (25)Ülo Suursaar, Tiit Kullas, Mikk Otsmann, Tarmo Kõuts, 2003). It is important to question the stationary climatic phenomena, due to it being an extremely dynamic and complex process that involves a huge amount of variations in different sets of parameters. Thus scientists and policymakers have to seriously consider the drivers and consequences of climate change, and see how these impact the current stationary paradigm of climate. ((26)Intergovernmental Panel of Climate change, 2014).

Another important factor that has to be mentioned about coastal areas, is the phenomenon called “Coastal Squeeze”. Coastal wetlands are very valuable for coastal management and the coastal ecosystem, but due to sea level rise, coastal salt marshes retreat inland, but their retreat is being blocked by hardened man built infrastructure, causing the phenomenon called “Coastal Squeeze”, which refers to the loss of a coastal habitat (coastal wetland). ((27)Nigel Pontee, 2013) Coastal Squeeze is extremely important to keep in account, taking into consideration that even if you have an effective coastal strategy blocking sea water from coming inlands, it still will have prejudicial effects on other factors, such as the coastal wetlands being eradicated from that area, or infrastructural problems with sedimentation fluctuation.

As landscape architects, it is crucial to embrace the responsibility of overseeing spaces with a forward-thinking approach, considering potential challenges arising from climate change. Taking into account these foreseeable risks is essential, not only to mitigate potential government expenditures on infrastructure repairs but also to safeguard the population and ecology from enduring life-altering events triggered by natural disasters. Motivated by a dedication to tackle climate challenges, landscape architects play a crucial role in formulating resilient coastal strategies. Through the seamless integration of design, ecology, and urban planning, they significantly contribute to the development of sustainable landscapes. These landscapes not only improve the quality of life but also serve as robust defences against the impacts of a changing climate.

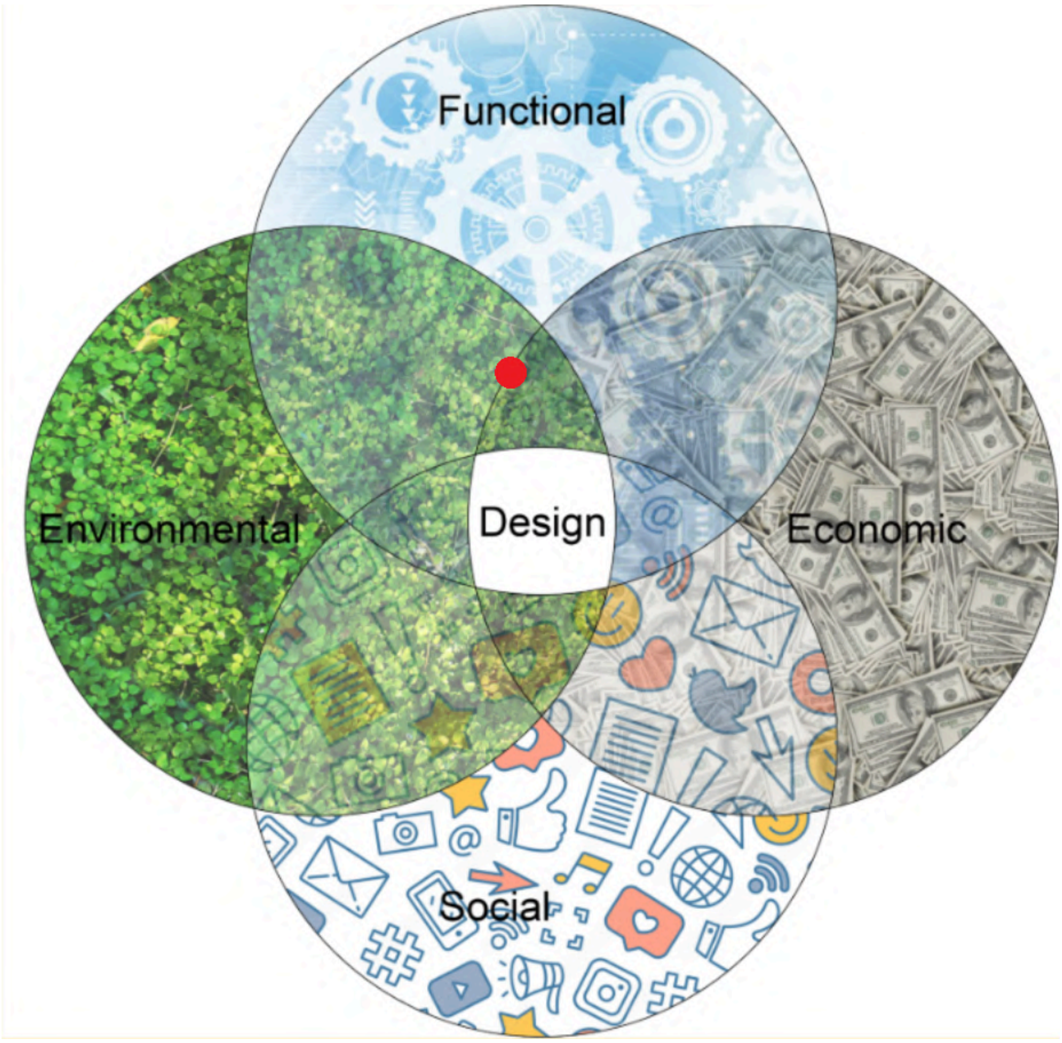


Figure 13(1): Holistic Frame of Thinking diagram/Engineering, environmental, economic and social.

As landscape architects, our professional domain operates within a holistic framework where diverse factors converge, including environmental, ecological, functional, and climatological aspects ((28)McHarg, 1969). Ian McHarg, in his seminal work 'Design with Nature,' underscores the importance of integrating natural systems into the design process. He advocates for an ecological approach that layers various environmental factors to inform sustainable and functional design solutions. This thesis aligns with McHarg's principles by emphasising functional and climatological considerations in the evaluation of architectural coastal design strategies.

Referring to Figure 13(1), the diagram illustrates the placement of the red dot, symbolising the context of the thesis work and highlighting the specific fields where priorities are set.

2. Purpose and research question

Data driven Architecture.
The objective of this thesis is to underscore the significance of an analytical and simulation-based approach to coastal planning, in contrast to traditional design methods reliant on conceptual ideas and data. The escalating impact of climate change has led to a rise in the Global Mean Sea Level (GMSL) and local sea levels, particularly in southern Sweden. This has placed a substantial portion of Sweden's urban infrastructure, as well as its people, ecosystems, and biodiversity, at risk. To formulate effective coastal strategies, comprehensive analysis and simulations are imperative. These endeavours enable us to comprehend potential outcomes and generate the most precise and efficient solutions. This analysis will be conducted within a "high emission baseline scenario," chosen to facilitate a risk-based evaluation that considers the most severe potential outcome.

By adopting an approach that considers worst-case scenarios, we gain insights into how various strategies perform under demanding circumstances, effectively demonstrating the overall efficacy of these design strategies. Through simulations of these intensified scenarios, we can evaluate the effectiveness of diverse strategies.

This thesis centres on a comprehensive risk assessment of compound flooding in Trelleborg, particularly focusing on how future RCP8.5 scenarios might impact the city through elements like precipitation, sea level rise, and storm surges. Alongside this risk assessment, the thesis aims to identify the more practical and effective coastal management systems. These systems will then be simulated under the "high emission baseline scenario." Drawing from the analysis and simulations, a novel form of coastal management system will be devised, grounded in the research findings and simulation outcomes.

Comparisons will be drawn between different coastal strategies, facilitating the assessment of each strategy's effectiveness and yielding a comprehensive overview of their individual advantages. This thesis underscores the importance of data-driven architecture and its capacity to provide data-informed solutions to emerging challenges.

Research Questions:
Is Trelleborg ready to face the consequences of climate change, including rising sea levels, changing rainfall patterns, and more severe storm surges, especially in the context of an RCP8.5 scenario?

What are the advantages and effectiveness of various coastal design strategies, and how can the insights from data-driven simulations be applied to develop more resilient and ecologically sustainable solutions?

3. Methodology

The methodology of this project is divided into 5 sections. The first section is data capture, where necessary data is compiled to perform the analysis and design work, this includes GIS data, 3d models, numerical data, etc. This collection of data primarily aims to illustrate the impact of sea level changes on water levels and the resulting strain on infrastructure in urban areas, like Trelleborg. Second section, entails the production of geographic maps, which will be analysed and represented in cartographic map plans, while simplifying numerical data. The goal is to visually present and clarify data, creating a clear representation of water fluctuations in a city. Third section comprises a compilation of design strategies that have been implemented in coastal regions, as well as a produced coastal design strategy based on the existing research that has been conducted. It's essential to note that the simulations in the fourth section serve as examples due to processing limitations, emphasising their potential when applied to the wider numerical data from the analysis, still there will be a conceptual land use plan presented, to illustrate how the created strategy would work on a wider scale. The last section entails the final results, discussion and conclusion. The goal is to establish a structured methodology that offers a clear and organised framework for conducting the research and design work. This methodology ensures that each step is well-defined and contributes effectively to the project's overarching objectives.

3.1 Datascape

In the early stages of the project, there was an exploration of suitable cities for a coastal water risk scenario analysis. Trelleborg emerged as a positive candidate based on responses obtained during the assessment. Similar inquiries were made about the potential impact of sea level rise on different cities and how each city would be affected. The decision-making process for initiating this project was influenced by considerations such as the selection of the study location. The choice of city for the research was guided by the methodology employed, which is rooted in Data-driven Architecture. Technological advancements and the availability of extensive data have enabled the development of new tools and strategies to address design challenges more effectively. Data-driven architecture, also known as Datascape ((29)TU Delft Faculty of Architecture & the Built Environment, 2021), represents an emerging field characterized by the integration of advanced computational tools and data analytics. According to the International Design Seminar (INDESEM) hosted at the Faculty of Architecture and the Built Environment of Delft University of Technology, the digital era challenges traditional design processes through increased efficiency and accuracy. Leveraging big data enables the generation of optimal designs based on predefined parameters. The data influences the design, considering various factors and parameters that may extend beyond the expertise of the average professional architect.

Datascape or data-driven architecture creates a dynamic artistic realm where data serves as the guiding methodology. Utilising digital tools, such as 3D modelling software, allows for simulations through different parameters to accurately project the outcome of a design . Instead of relying on creative assumptions, the use of data involves setting parameters that aid in simulating design strategies. The goal is to parameterize and complete the design process rather than creating it.

This thesis adopts an approach that does not incorporate specific technologies for design creation. Instead, it focuses on conducting simulations using distinct design strategies within a defined set of parameters. Although these parameters are somewhat simplified, and the scale of simulation is constrained due to data limitations, they are presented as a structured methodology to emulate the design process.

Figure 5: The first images from EG Architects. The last image is a render view of Trelleborg 3d map alongside a QR scan code to a video highlighting the importance of a 3d map of the coastal city.

3.2.Trelleborg

Trelleborg Municipality consists of 8 urban areas, referred to as "Tätorter." In the context of our research, we are focusing on Trelleborg, which is the largest urban area within the municipality. In 2020, Trelleborg had a population of 30,808 residents ((30) Wikipedia, 2023). The city of Trelleborg was chosen because it is the lowest lying coastal city in Skåne and Sweden. While also the selection of Trelleborg is motivated by its sea city development plan for 2025 ((31)Trelleborg kommuns homepage, 2022), which involves the creation of a sea city along the Trelleborg coastline. This plan aligns well with economic and social aspects.

However, it is essential to factor in the potential environmental and infrastructural risks associated with coastal development. Additionally, Trelleborg plays a significant role as a crucial connection point to continental Europe and sustains a thriving coastal trade. Over the years, it has contributed significantly to industrialization, particularly in sectors such as sugar refining and the production of rubber products through its well-equipped harbour.((32)Britannica, 2012) Due to these factors, it is important that Trelleborgs infrastructure is resilient enough to withstand any natural disasters, including the potential occurrence of compound flooding. The thesis work focuses primarily on analysing Trelleborg as a municipality, with a particular emphasis on data-driven factors such as rain data, sea level rise, storm surges, and volumetric simulations incorporating parameters like permeability, friction, and water particle collision. However, it is crucial to set expectations that the analysis is not exclusively data-driven. While the aforementioned factors play a pivotal role, the thesis extends beyond the confines of pure data-driven analysis. Although the analysis primarily focused on quantitative metrics, ecological, economic, and social factors were only briefly considered. The study recognizes their secondary role but acknowledges their importance for a more comprehensive understanding of the municipality's dynamics.

3.3. Data capture

Data from SMHI ((13)Swedish Meteorological and Hydrological Institute, 2015-2022) will be used for Trelleborgs data in Sea water levels. Precipitation data is collected from Trelleborg Kommun through the Adcon Live Data domain ((33)Trelleborg kommun, rain measurement, 2023). Storm surge data is referenced from “A methodology for the assessment of compound sea level and rainfall impact on urban drainage networks in a coastal city under climate change” ((10)Isabelle Laster Grip, Salar Haghighatafshar, Henrik Aspegren, 2021), where excel data was sent by Salar Haghighatafshar, where they compiled the data from Skanörs sea level station ((13)Swedish Meteorological and Hydrological Institute (SMHI), 2015-2022). Data will be applied to the ArcGIS map production and simulations. The Manhole data was provided by Trelleborg Kommun Kretslopp och vatten department ((34)Trelleborg Kommun Kretslopp och Vatten department, 2023), which holds data from both the Municipality in cooperation with Rosim (previously VA-fälttjänst). Most of the GIS map data was taken from the SLU Zeus domain. ((35)Geodata Extraction tool SLU, 2023)
The 3d topography model was sourced from both Google Earth services ((36)Google Earth software and database, 2023) and Trelleborg Kommun, while the 3d city model was supplied by Trelleborg Kommun. ((37)Samhällsbyggnadsförvaltningen, Trelleborgs kommun, 2023)

3.4. Geographic map production

The ARCGIS-created storm surge and sea level rise maps utilize Map Algebra in ArcMaps to analyze water levels for risk management. ArcScene visualizes manhole drainage stresses by importing Excel data into CSV format, creating 3D maps to assess infrastructure strain. These visualizations aid in identifying and managing drainage issues in Trelleborg. Data from Trelleborg Kommun and "Rosim – tidigare VA-fälttjänst" were evaluated to visualize drainage stresses effectively.

3.5. Design Strategies

The compilation of design strategies draws from diverse sources and websites centred on coastal management and specialise in the analysis of coastal strategies: GCSE Geography Revision 2024, Coastal Partners 2024, tweedsandbypass 2020. Several other websites were looked at, just to confirm repetitivity of the most relevant strategies. ((38)GCSE, 2024)((39)Coastal Partners, 2024)((40)tweedsandbypass 2020) Research was conducted to select the most pertinent and commonly employed strategies on the planning practice. The aim was to present these strategies concisely, highlighting their current relevance and functionality. These strategies have been categorised into six distinct coastal management approaches. By incorporating the compiled data and considering future predictions related to sea level rise, tidal storms, and precipitation, we are poised to simulate and analyse the outcomes of these various strategies. This process will allow us to discern the merits of each architectural and engineering design strategy. Within this framework, a novel strategy will be conceptualised and put to the test. This design strategy emerges as a culmination of insights gleaned from the comprehensive data analysis conducted in this study. It effectively amalgamates elements from other strategies, with the selection process guided by the advantageous outcomes observed in the simulations.

The following list provides background references showcasing various strategies implemented globally. While these examples serve as real-life instances, it's important to note that their applicability to Trelleborg may be influenced by distinct environmental factors. The effectiveness of coastal management systems depends on the specific characteristics of each coastal area.

Hold the Line: Galveston Seawall, USA, post-1900 hurricane protection. The Seawall which was constructed after the greatest natural disaster in US history. ((41)Bixel P. B. & Turner E. H., 2000) is a perfect example of the need of a hold the line strategy, due to its drastic need and sped up urgency.

Managed Realignment: Alde-Ore Estuary, Suffolk, UK, restores habitats via realignment. The Alde-Ore Estuary in Suffolk, UK, employs coastal realignment by deliberately breaching flood defences. This strategy creates habitats like salt marshes and mudflats. Stakeholder engagement, site selection, and monitoring ensure effectiveness. ((42)Roger K.A. Morris, 2012)

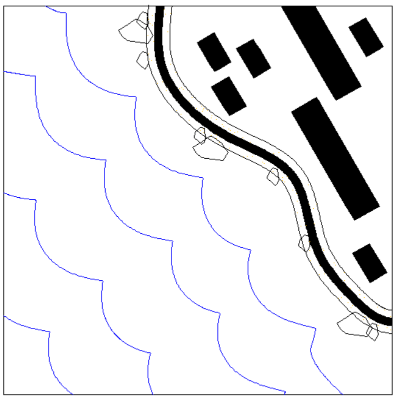
Environmental Multi-layered Realignment: Elkhorn Slough, California, showcases coastal managed realignment, evolving from a river valley to a tidal inlet and estuary. Jetties prevented its transformation into a dry valley, highlighting human intervention's role in coastal stability amid rising sea levels. ((43)David Schwartz, 1983)

Wave Breakers: Dolosse system in Durban, South Africa, 1963. The dolos is a South African coastal structure, arrived late but symbolized innovation and national identity during apartheid. Serving as a wave breaker wall strategy, it reflects South Africa's modernization efforts and underscores the need for comprehensive research in coastal management, focusing on ocean infrastructure's characteristics. ((44)Jonathan Cane, 2021)

Breakwaters: While Palm Jumeirah serves as a notable example of innovative coastal engineering, functioning as a breakwater system to protect against erosion and wave action ((45) Amrousi, Elhakeem, & Paleologos, 2019), it has also led to significant environmental impacts. The construction involved habitat destruction and the alteration of marine ecosystems, resulting in biodiversity loss and changes in natural coastal processes. Additionally, the project has increased coastal erosion in adjacent areas and raised concerns about long-term sustainability and the project's environmental footprint. This underscores the complex trade-offs between innovative coastal management and sustainable practices.

Sea city/eating the sea: Miami Beach faces worsening flooding from rising sea levels and urban expansion into the sea. Post-2006, floods surged, with rain-induced incidents up by 33% and tide-induced by over 400%. Sea level rise rates in Southeast Florida tripled, underscoring the need for localized solutions over global projections in coastal management. ((46)Wdowinski, Bray, Kirtman, Wu, 2016)

3.5.1 Hold the Line



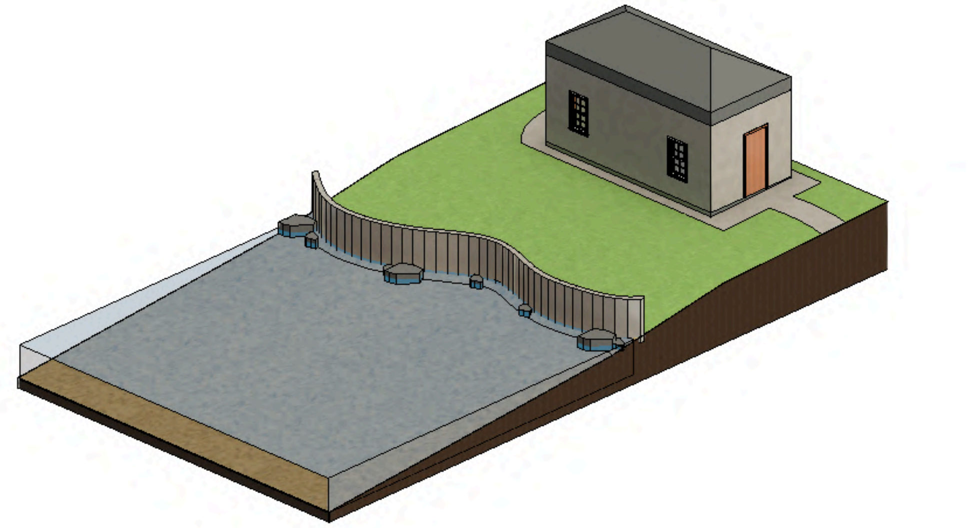
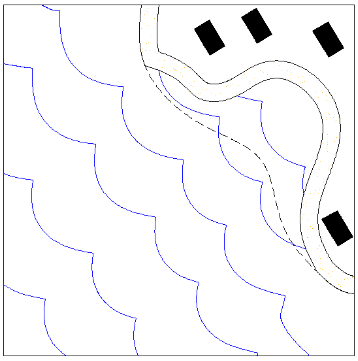


Figure 6: Hold the Line plan and isometric 3d simulation model.

This strategy entails the installation of a retaining wall running parallel to the shoreline. Functioning as a bulkhead, its primary purpose is to shield the city from the encroachment of seawater by providing a physical barrier. Traditionally, this approach often employs a gently sloped seawall rather than a completely vertical one. However, the design may vary depending on the specific conditions of the coastal area. It's important to note that, at times, a vertical bulkhead wall can be more detrimental than a sloped seawall, depending on the coastal context. This is evident in the simulations and is further demonstrated by the "Wave tank simulation" video produced by JBA Trust ((47)JBA Trust, 2016).

Numerous simulations and real-world instances have illustrated that the concave sea wall stands out as one of the most effective methods within the sea wall category for coastal defence. These exemplary cases are widespread, as showcased in the "Wave tank demonstration showing the impact of coastal defences on flood risk" video by JBA Trust ((47)JBA Trust, 2016). This video serves as a clear illustration of the considerable advantages offered by a concave wall design.

3.5.2 Managed Realignment (Retreat)



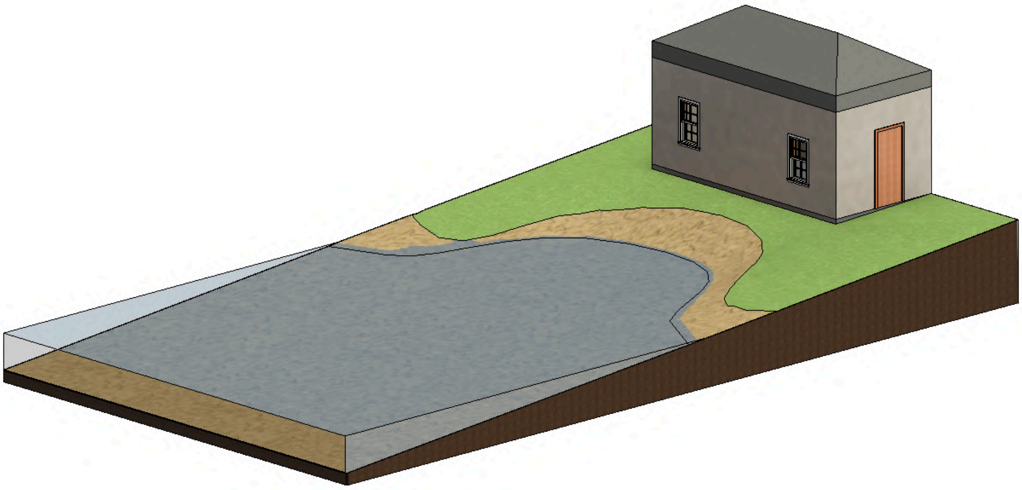
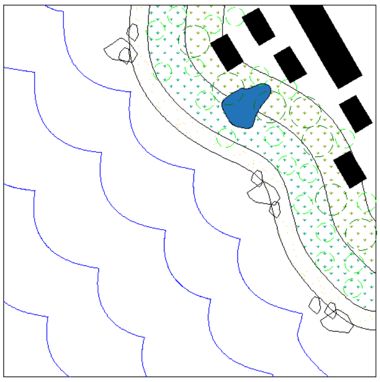


Figure 7: Managed Realignment plan and isometric 3d simulation model.

This strategy involves a deliberate retreat, acknowledging and yielding to the forces of nature by relocating existing infrastructure away from the coastline. This encompasses scenarios where upcoming projects planned near the coast are abandoned. While this approach may be considered, it is less likely to be implemented in major, tourist-driven, or affluent cities. Property values notably escalate the closer one is to the coastline, introducing other influential factors when contemplating managed realignment. Managed realignment, which entails allowing the shoreline to shift inland rather than steadfastly maintaining its position, could prove advantageous in cases where current infrastructure is absent. A comprehensive understanding of the rationale behind this strategy is presented in the article titled "Coastal Risk Management Modes: The Managed Realignment as a Risk Conception More Integrated."((48)Heurtefeux, Hugues & Sauboua, Paul & Lanzellotti, Provence & Bichot, Amandine, 2011) This source elaborates on the criticisms aimed at the economic and environmental shortcomings associated with maintaining the coastline. The article provides a comprehensive comparison of various approaches, including "doing nothing," "managed realignment," "Hold the line," and "Limited intervention." A deep dive into the concept of managed realignment reveals its benefits, including relocating economic assets from vulnerable coastal areas to more secure hinterlands. Additionally, it addresses the hindrance of constructing new assets in precarious locations. ((48)Heurtefeux, Hugues & Sauboua, Paul & Lanzellotti, Provence & Bichot, Amandine, 2011)

3.5.3 Environmental Multi-layered Realignment (embrace)



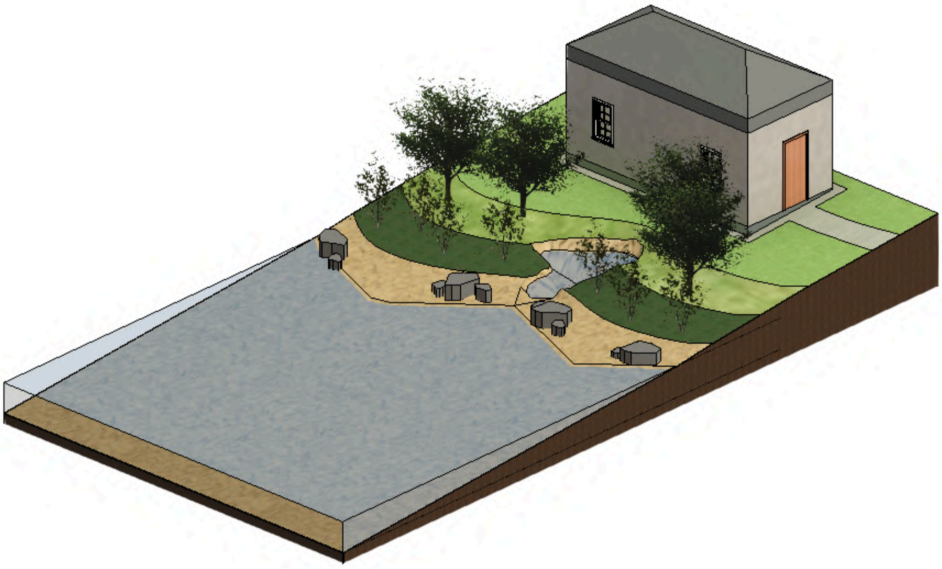


Figure 8: Environmental Multi-layered Realignment plan and isometric 3d simulation model.

The Ecological Multi-layered Realignment strategy encompasses a nuanced approach with multiple ecological design layers, tailored to specific scenarios. Specifically, this concept involves a multi-faceted approach that integrates various limited intervention methods across different ecological layers. These layers work collectively to safeguard economic infrastructure from the encroachment of seawater.

The strategy revolves around deploying an array of living shoreline techniques. These methods include safeguarding coastal wetlands ((27)Nigel Pontee, 2013), utilising erosion control plants in conjunction with sand dunes, incorporating features like edging or sills, employing rocks, and creating topographic pond formations. These measures are strategically designed to attenuate wave energy and function as a protective buffer between human-made structures and the sea.

While this strategy excels in preserving the ecological harmony of coastal regions, it may exhibit certain limitations when compared to conventional man-made hard techniques. The extent of these limitations is explored through simulations, shedding light on the potential trade-offs of this environmentally friendly approach.

3.5.4 Wave breakers (disruptive defence)

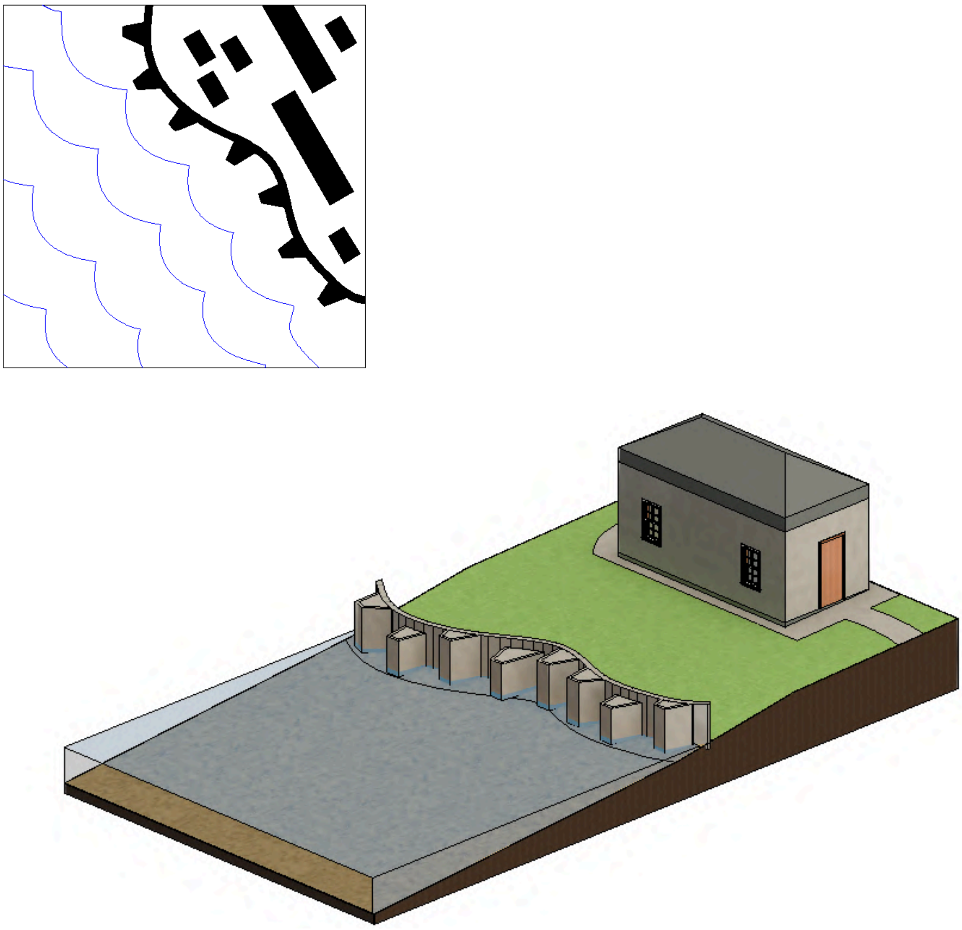


Figure 9: Wave breakers plan and isometric 3d simulation model.

This strategy entails the implementation of a robust and high-cost structural system, characterised by the installation of hard rock or concrete structures. These elements are complemented by a rugged seawall designed to effectively disperse the energy of incoming waves. This strategy manifests in various forms, and although it shares the concept of disruptive defence, its appearance and functionality can greatly differ from other strategies of the same type.

The seawall's geometric configuration is specifically engineered to enhance wave-breaking efficiency. Unlike a flat wall, this design is adept at skillfully slicing through the waves, effectively reducing their force. Various approaches can be employed in crafting a wave breaker wall. To streamline the research process, this study will use an irregular and jagged wall design as an illustrative example of a disruptive defence wall.

3.5.5 Break waters or wave interruptor (Jetties)

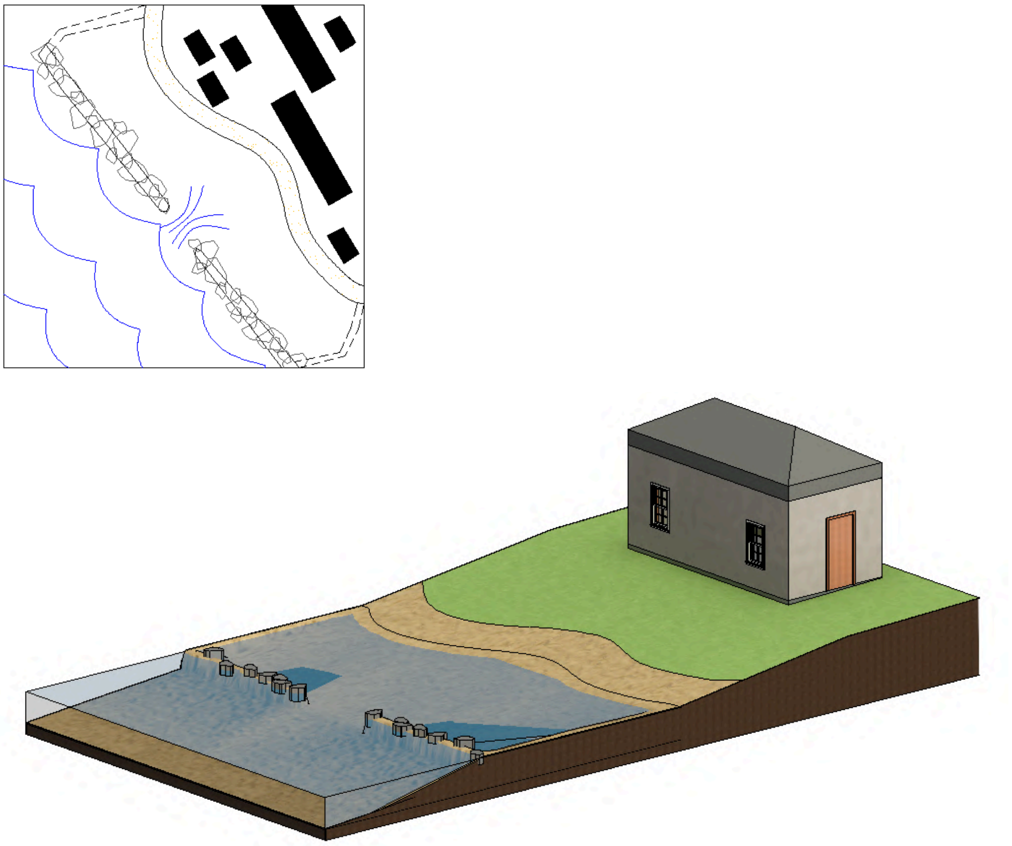


Figure 10: Break waters or wave interruptor plan and isometric 3d simulation model.

This strategy consists of an artificial reef, or an outland break water wall, which disrupts waves before taking momentum and reaching the coast. We can see this strategy commonly being used in the shape of a crab, with its arms stretched out, defending its face with its crusher claws, where the face is the coastline, and the claws are the tide interrupters. These wave interrupters take shape in different ways, we can see it through the Tetrapod structures developed in 1950 by Pierre Danel and Pual Anglés d´Auriac, who designed these concrete structures to protect man-made infrastructure from sea water intake. Other similar structures can be seen by the Xbloc, KOLOS, Dolos and Accropode ((49)Wikipedia, 2023). All of these wave-dissipating concrete blocks are part of the breakwater or wave breaker structure system. A cheaper and more natural way, would be a rock formation tide interruptor, which is the one that will be used for the simulation.

3.5.6 Sea city/eating the sea (Attack)

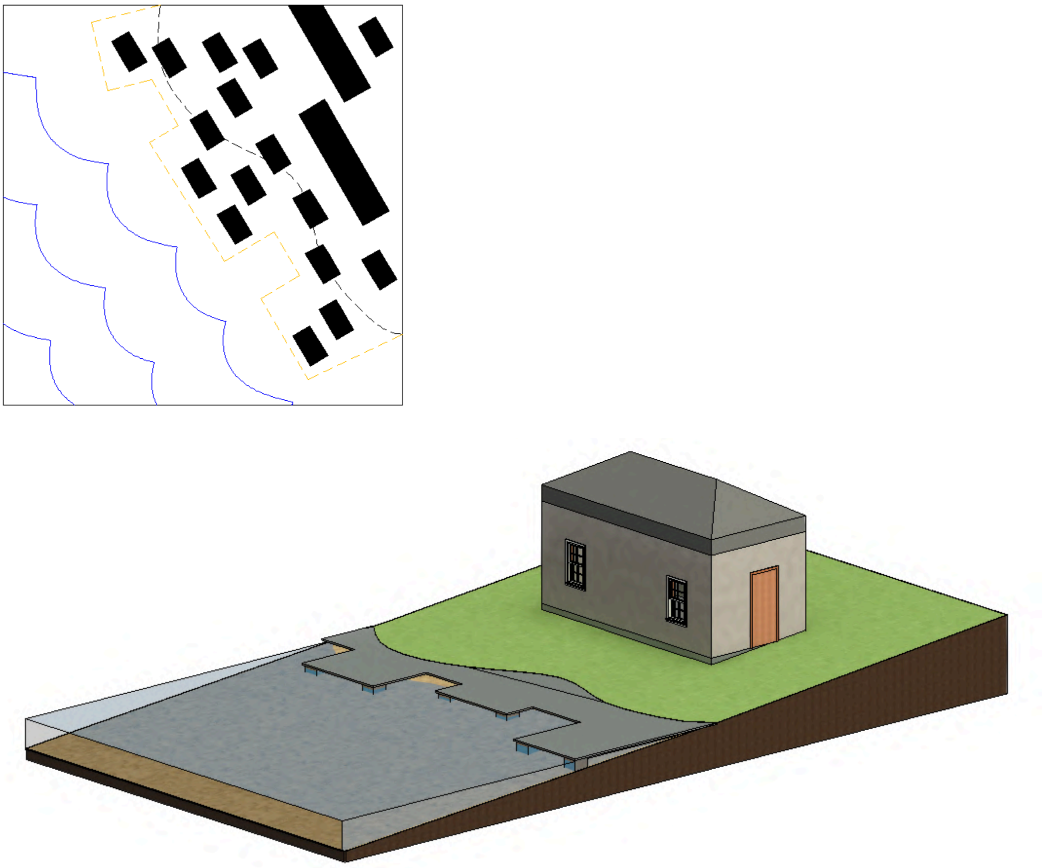
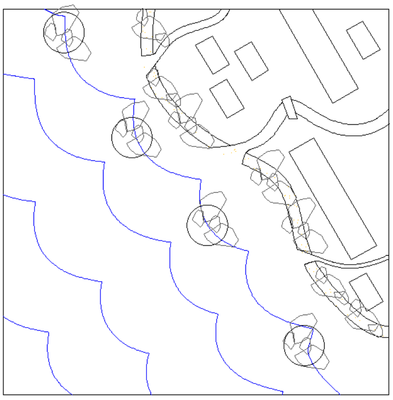


Figure 11: Sea city/eating the sea plan and isometric 3d simulation model.

This phenomenon involves urban expansion into coastal or high-risk areas, often disregarding or neglecting the potential risks associated with sea level rise, storm surges, or pluvial flooding that could result in backwater within the city's infrastructure. Surprisingly common, this trend is driven by the allure of water-adjacent locations, especially coastal regions, which have historically offered significant benefits for human habitation. The economic advantages of developing cities along shorelines can often outweigh concerns about flooding for governmental planners. This pattern has repeated throughout history, as human settlement has frequently gravitated towards water bodies. Numerous instances abound where cities have extended their boundaries toward shorelines, driven by the advantageous proximity to water. This practice reflects the historical trend of civilizations seeking to establish settlements near water bodies. Presently, a substantial number of Asian cities are grappling with the repercussions of sea level rise, having expanded into or established themselves near coastlines.

3.5.7 Strategy Evolution Through Analysed Factors (Data Driven)

Based on simulations and reference design strategies.



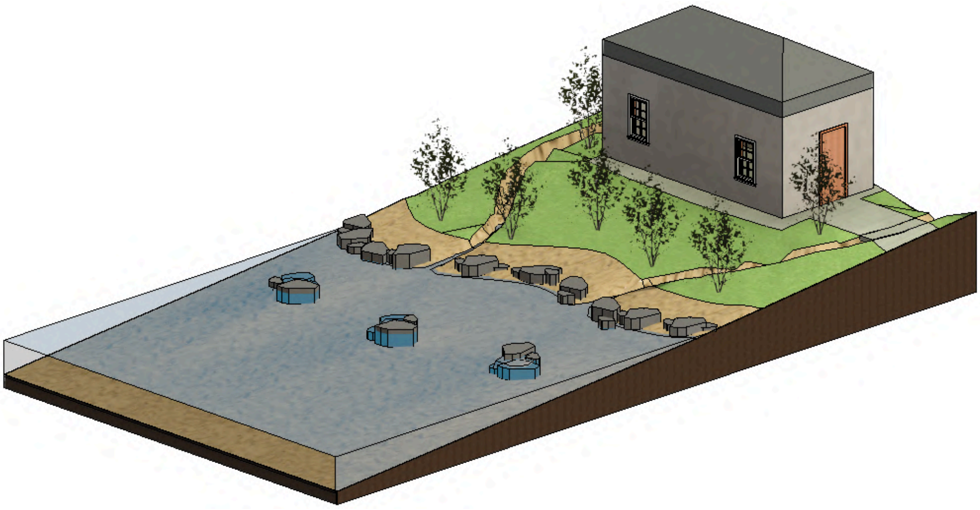


Figure 12(1): Simulation Strategy plan and isometric 3d simulation model.

This approach is rooted in data-driven design, integrating concepts that have demonstrated effectiveness in prior coastal strategies. These proven concepts have been harnessed to shape the development of this strategy. The overarching goal is to showcase the potential efficacy of data-driven landscape architecture, offering a more profound visualisation and understanding of how a design will function through the realm of virtual simulation. The strategy's design process involved continuous analysis/testing of various factors from other strategies. This approach led to conclusions about the efficiency of specific factors within each strategy.

3.6 Strategy Evolution Through Analysed Factors (Data Driven)

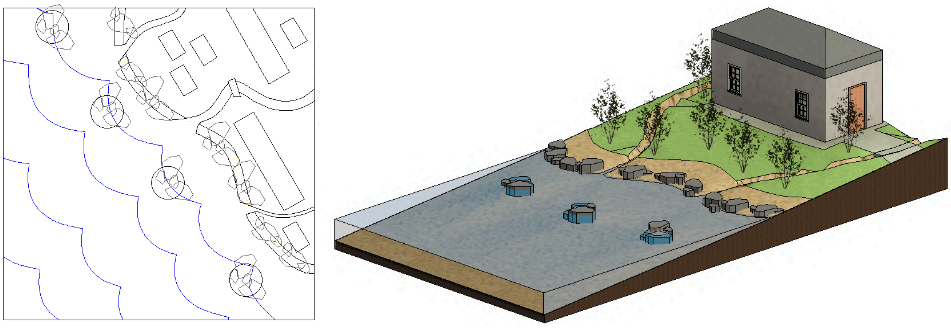


Figure 12(2): Simulation Strategy plan and isometric 3d simulation model.

In this section, I will delve deeper into the underlying logic and functionality of this design, elucidating the distinct purpose it serves compared to other simulations.

This Data-Driven design draws inspiration from various coastal strategies, leveraging the criteria derived from their simulated outcomes and analyses. These simulations have revealed both favourable and unfavourable attributes associated with each design, offering a clear understanding of their performance through rigorous analysis.

While one could argue that our creative faculties could have discerned these insights, the role of data-driven simulations is to enhance our efficiency and functionality in design. This tool aids in simulating scenarios that our cognitive processes might inaccurately envision. In essence, data-driven simulations serve as a valuable aid, enabling us to design with heightened accuracy and effectiveness.

Key observations made during the analysis include:

To begin with, coastal design necessitates the consideration of multiple parameters, each aligned with specific objectives. The design strategy extends beyond the straightforward task of safeguarding urban infrastructure from water, a challenge an engineer could potentially address. The intent of this analysis is to encompass a comprehensive range of factors spanning engineering, environmental, economic, and social dimensions. It is through this holistic framework that the concept depicted in the following mental diagram emerged.

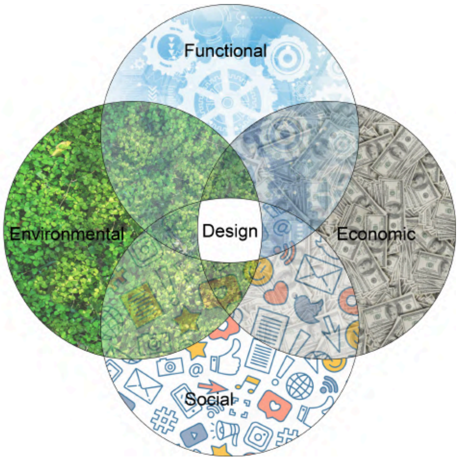


Figure 13(2): Holistic Frame of Thinking diagram/Engineering, environmental, economic and social.

4. Geographic map analysis

The geographic map analysis section aims to underscore the significance of diverse geographic maps and the data they convey. This segment prominently features cartographic maps accompanied by detailed explanations on their generation process and the insights they offer. This inclusion constitutes a substantial component of the project's overall presentation.

4.1 Compound Flooding

Three pivotal factors contribute to flooding in coastal cities. The first factor is pluvial flooding, arising from intense rainfall that overwhelms urban water management systems. The second factor involves the rise of the Global Mean Sea Level (GMSL), which strains the pipe network as excess water is channelled into the sea. Over the long term, GMSL rise requires continual investments in managing local sea levels for coastal cities like Trelleborg. The third factor, Storm Surges, can elevate sea levels by 1-2 metres ((14)Wolski, Tomasz & Wiśniewski, Bernard., 2021), further compounded by accompanying storm waves that heighten water levels.

Although these factors are beyond human control, preparations are essential, not solely for addressing each individual factor, but for the potential convergence of all three. Compound flooding emerges when sea levels are elevated, accompanied by a storm surge and heavy rainfall. This intricate interplay can spell disaster for Trelleborg's urban infrastructure. Comprehensive understanding of each phenomenon, within the context of a "high emission baseline scenario," offers researchers and urban planners a valuable perspective on the potential perils posed by compound flooding to coastal cities and their infrastructure.

4.1.1 Precipitation

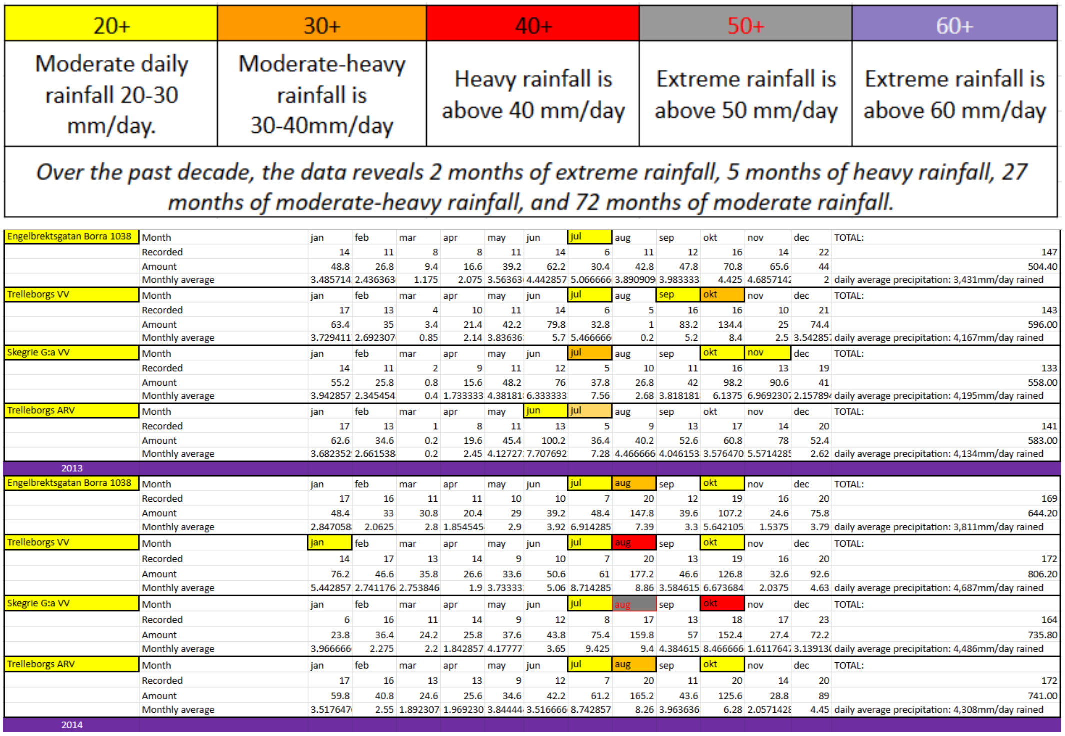
The Water risk assessment was conducted through ADCON LiveData analysis from different water measurement stations located near the main urban area of Trelleborg. The stations where the water measurements were taken are Engelbrektsgatan Borra 1038, Trelleborgs VV, Skegrie G:a VV, Trelleborgs ARV. The data has been revised in daily detail, counting the amount of times in a month it rained, and with which intensity (mm/day). The daily data was compiled in an excel sheet, which made it possible to pinpoint extremities and abnormalities in the weather, mostly focusing on high amounts of rainfall in a short period of time.

An example would be during the month of July in 2021, where over 60 mm of rainfall were recorded in the station of Engelbrektsgatan Borra 1038 in 1 single day. To go through the monthly data, go to Appendix Nr. 1 or look at Figure 14, in which the amount of times and amount of monthly rain has been retrieved from ADCON LiveData site, which was linked by the Trelleborg Kommuns rain measurement page. ((33)Trelleborg Kommun, 2023).

The Excel sheet provides insights into the variability and fluctuations in rainfall across the Trelleborg region, highlighting potential issues in different zones. Notably, an observation was made regarding the highest daily rainfall at Engelbrektsgatan Borra 1038. However, when viewed on a yearly basis, Engelbrektsgatan experiences the least amount of rainfall. This discrepancy emphasises the substantial margin of error when analysing rainfall data annually or even monthly. Such approaches tend to average out extreme conditions like dry spells and heavy rainfall spikes.

To mitigate this, the analysis incorporates actual rainfall data while excluding rainless days. This approach aids in capturing the true extent of rainfall extremes in a more simplified manner, minimising potential errors and providing a clearer depiction of rainfall patterns.

The different categorizations of rainfall are explained and referred to, in the numerical data section.

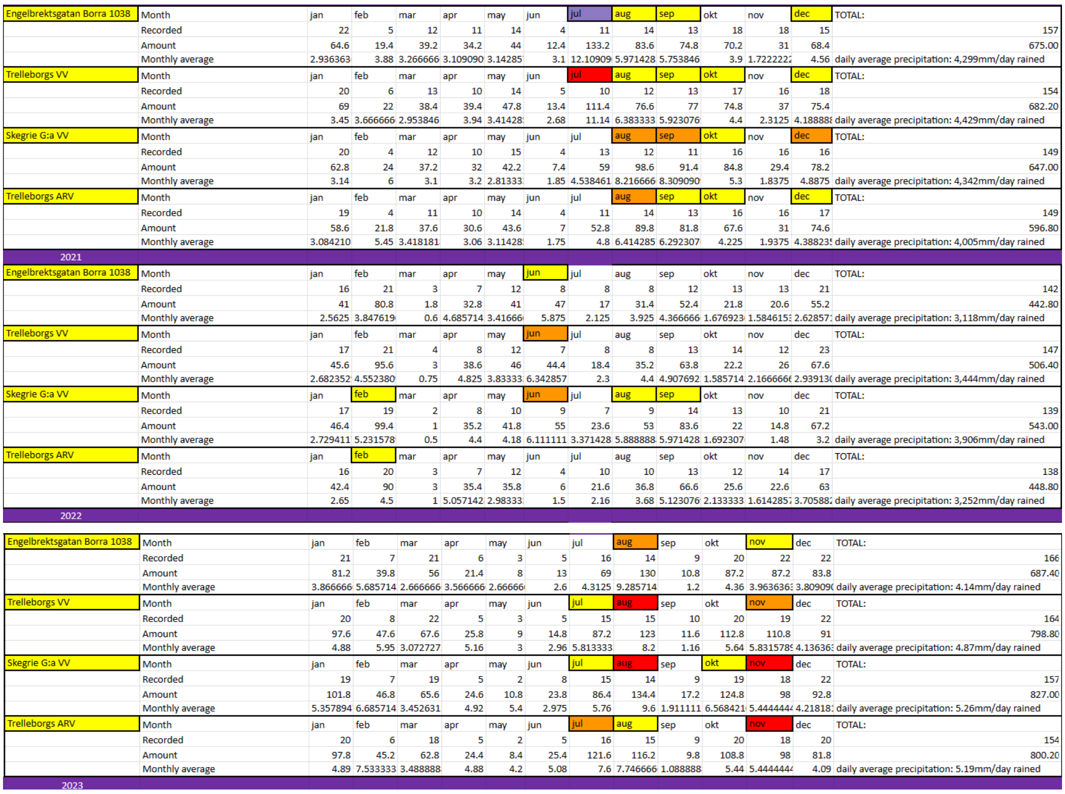


20+	30+	40+	50+	60+
Moderate daily rainfall 20-30 mm/day.	Moderate-heavy rainfall is 30-40mm/day	Heavy rainfall is above 40 mm/day	Extreme rainfall is above 50 mm/day	Extreme rainfall is above 60 mm/day

Over the past decade, the data reveals 2 months of extreme rainfall, 5 months of heavy rainfall, 27 months of moderate-heavy rainfall, and 72 months of moderate rainfall.

Engelbrektsgatan Borra 1038	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	14	11	8	8	11	14	6	11	12	16	14	22	147
	Amount	48.8	26.8	9.4	16.6	39.2	62.2	30.4	42.8	47.8	70.8	65.6	44	504.40
	Monthly average	3.485714	2.436363	1.175	2.075	3.56363	4.442857	5.066666	3.890909	3.983333	4.425	4.6857142	2	daily average precipitation: 3,431mm/day rained
Trelleborgs VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	17	13	4	10	11	14	6	5	16	16	10	21	143
	Amount	63.4	35	3.4	21.4	42.2	79.8	32.8	1	83.2	134.4	25	74.4	596.00
	Monthly average	3.729411	2.692307	0.85	2.14	3.83636	5.7	5.466666	0.2	5.2	8.4	2.5	3.542857	daily average precipitation: 4,167mm/day rained
Skegrie G:a VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	14	11	2	9	11	12	5	10	11	16	13	19	133
	Amount	55.2	25.8	0.8	15.6	48.2	76	37.8	26.8	42	98.2	90.6	41	558.00
	Monthly average	3.942857	2.345454	0.4	1.733333	4.38181	6.333333	7.56	2.68	3.818181	6.1375	6.9692307	2.157894	daily average precipitation: 4,195mm/day rained
Trelleborgs ARV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	17	13	1	8	11	13	5	9	13	17	14	20	141
	Amount	62.6	34.6	0.2	19.6	45.4	100.2	36.4	40.2	52.6	60.8	78	52.4	583.00
	Monthly average	3.682352	2.661538	0.2	2.45	4.12727	7.707692	7.28	4.466666	4.046153	3.576470	5.5714285	2.62	daily average precipitation: 4,134mm/day rained
2013														
Engelbrektsgatan Borra 1038	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	17	16	11	11	10	10	7	20	12	19	16	20	169
	Amount	48.4	33	30.8	20.4	29	39.2	48.4	147.8	39.6	107.2	24.6	75.8	644.20
	Monthly average	2.847058	2.0625	2.8	1.854545	2.9	3.92	6.914285	7.39	3.3	5.642105	1.5375	3.79	daily average precipitation: 3,811mm/day rained
Trelleborgs VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	14	17	13	14	9	10	7	20	13	19	16	20	172
	Amount	76.2	46.6	35.8	26.6	33.6	50.6	61	177.2	46.6	126.8	32.6	92.6	806.20
	Monthly average	5.442857	2.741176	2.753846	1.9	3.73333	5.06	8.714285	8.86	3.584615	6.673684	2.0375	4.63	daily average precipitation: 4,687mm/day rained
Skegrie G:a VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	6	16	11	14	9	12	8	17	13	18	17	23	164
	Amount	23.8	36.4	24.2	25.8	37.6	43.8	75.4	159.8	57	152.4	27.4	72.2	735.80
	Monthly average	3.966666	2.275	2.2	1.842857	4.17777	3.65	9.425	9.4	4.384615	8.466666	1.6117647	3.139130	daily average precipitation: 4,486mm/day rained
Trelleborgs ARV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	17	16	13	13	9	12	7	20	11	20	14	20	172
	Amount	59.8	40.8	24.6	25.6	34.6	42.2	61.2	165.2	43.6	125.6	28.8	89	741.00
	Monthly average	3.517647	2.55	1.892307	1.969230	3.84444	3.516666	8.742857	8.26	3.963636	6.28	2.0571428	4.45	daily average precipitation: 4,308mm/day rained
2014														

Engelbrektsgatan Borra 1038	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	22	8	11	12	15	13	18	16	19	8	24	19	185
	Amount	67.8	14.2	42.6	22	38.6	38.4	25.8	18.2	48.4	20.6	106	69	511.60
	Monthly average	3.081818	1.775	3.872727	1.833333	2.57333	2.953846	1.433333	1.1375	2.547368	2.575	4.416666	3.63157	daily average precipitation: 2,765mm/day rained
Trelleborgs VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	23	9	12	12	16	15	16	11	15	8	23	19	179
	Amount	79.4	20.2	46.6	23.8	45.6	52.4	64.4	48.2	66.6	24.8	146.2	81.8	700.00
	Monthly average	3.452173	2.244444	3.883333	1.983333	2.85	3.493333	4.025	4.381818	4.44	3.1	6.3565217	4.30526	daily average precipitation: 3,910mm/day rained
Skegrie G:a VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	23	10	13	12	15	5	8	11	15	6	21	20	159
	Amount	72.2	16.2	46.8	20	41.4	6.6	6.6	53	64	20.8	128.8	80.2	556.60
	Monthly average	3.139130	1.62	3.6	1.666666	2.76	1.32	0.825	4.818181	4.266666	3.466666	6.133333	4.01	daily average precipitation: 3,500mm/day rained
Trelleborgs ARV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	22	8	13	12	15	14	16	11	14	5	22	19	171
	Amount	75.8	15.6	45.2	19.8	45.4	45	67.8	50.8	74.8	20.8	138.6	82	681.60
	Monthly average	3.445454	1.95	3.476923	1.65	3.02666	3.214285	4.2375	4.618181	5.342857	4.16	6.3	4.31578	daily average precipitation: 3,985mm/day rained
2015														
Engelbrektsgatan Borra 1038	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	15	14	9	11	6	10	13	18	7	20	15	14	152
	Amount	28.8	36	18	66	14.8	76.4	62.6	51.2	26.8	107.8	63.2	38.2	589.80
	Monthly average	1.92	2.571428	2	6	2.46666	7.64	4.815384	2.844444	3.828571	5.39	4.213333	2.72857	daily average precipitation: 3,880mm/day rained
Trelleborgs VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	19	14	11	12	9	10	16	19	9	19	16	15	169
	Amount	34	45	23.6	66	17.8	97.4	65	66.2	34.6	124.2	73.8	44.6	692.20
	Monthly average	1.789473	3.214285	2.145454	5.5	1.97777	9.74	4.0625	3.484210	3.844444	6.536842	4.6125	2.97333	daily average precipitation: 4,095mm/day rained
Skegrie G:a VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	14	15	9	13	8	9	14	16	7	18	15	15	153
	Amount	31	39.6	25.4	54.8	19.4	82.6	79.8	59.8	28.4	97.4	66.2	37.4	621.80
	Monthly average	2.214285	2.64	2.822222	4.215384	2.425	9.177777	5.7	3.7375	4.057142	5.411111	4.413333	2.49333	daily average precipitation: 4,064mm/day rained
Trelleborgs ARV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	16	13	9	12	9	13	12	16	4	19	17	13	153
	Amount	36.4	45	24.8	61.6	16.2	14.8	3.4	26.6	1	63.8	69.6	42.6	405.80
	Monthly average	2.275	3.461538	2.755555	5.133333	1.8	1.138461	0.283333	1.6625	0.25	3.357894	4.094117	3.27692	daily average precipitation: 2,652mm/day rained
2016														
Engelbrektsgatan Borra 1038	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	11	12	15	14	9	13	15	15	13	19	19	21	176
	Amount	14	38.2	44.2	47.8	14.8	79.6	59	47.8	95.8	90	61.6	36	628.80
	Monthly average	1.272727	3.183333	2.946666	3.414285	1.64444	6.123076	3.933333	3.186666	7.369230	4.736842	3.242105	1.71428	daily average precipitation: 3,572mm/day rained
Trelleborgs VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	11	12	14	15	8	13	16	14	14	18	21	22	178
	Amount	20.2	52.2	50.4	57.4	15.4	92.2	79.2	45.4	76	106.2	70.6	46.4	711.60
	Monthly average	1.836363	4.35	3.6	3.826666	1.925	7.092307	4.95	3.242857	5.428571	5.9	3.3619047	2.10909	daily average precipitation: 3,997mm/day rained
Skegrie G:a VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	10	12	12	11	8	13	15	13	13	18	20	18	163
	Amount	15.2	43.2	52.4	65.2	14.8	85.8	86	44.2	105.4	99	73	40.6	724.80
	Monthly average	1.52	3.6	4.366666	5.927272	1.85	6.6	5.733333	3.4	8.107692	5.5	3.65	2.25555	daily average precipitation: 4,446mm/day rained
Trelleborgs ARV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	12	12	14	14	8	13	16	13	13	17	18	21	171
	Amount	18.4	46.2	51	67.6	12.4	86.2	74.6	45.2	102.8	86	79	52	721.40
	Monthly average	1.533333	3.85	3.642857	4.828571	1.55	6.630769	4.6625	3.476923	7.907692	5.058823	4.388888	2.47619	daily average precipitation: 4,218mm/day rained
2017														
Engelbrektsgatan Borra 1038	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	21	5	18	13	4	5	5	12	8	15	9	22	137
	Amount	41.4	6.6	39	32.2	6.8	10.4	9	92.6	16.4	34.4	24.8	73.2	386.80
	Monthly average	1.971428	1.32	2.166666	2.476923	1.7	2.08	1.8	7.716666	2.05	2.293333	2.755555	3.32727	daily average precipitation: 2,823mm/day rained
Trelleborgs VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	21	6	18	11	4	3	3	10	8	16	10	21	131
	Amount	48.2	9.2	63.6	34.4	7.8	9.6	10	99.2	21.2	40.4	28	88.8	460.40
	Monthly average	2.295238	1.533333	3.533333	3.127272	1.95	3.2	3.333333	9.92	2.65	2.525	2.8	4.22857	daily average precipitation: 3,514mm/day rained
Skegrie G:a VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	19	5	14	12	5	5	4	12	8	15	11	21	131
	Amount	47.4	7	48.2	38	4.4	18.4	9	88.4	21	37.6	34	88.6	442.00
	Monthly average	2.494736	1.4	3.442857	3.166666	0.88	3.68	2.25	7.366666	2.625	2.506666	3.090909	4.21904	daily average precipitation: 3,374mm/day rained
Trelleborgs ARV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	20	4	15	12	4	5	3	12	7	15	9	25	131
	Amount	52.2	8.8	41.2	36.8	5	14.4	6	104.2	22	37.8	30.8	78.8	438.00
	Monthly average	2.61	2.2	2.746666	3.066666	1.25	2.88	2	8.683333	3.142857	2.52	3.422222	3.152	daily average precipitation: 3,343mm/day rained
2018														
Engelbrektsgatan Borra 1038	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	18	13	17	6	12	10	11	13	17	19	20	17	173
	Amount	41.6	44.6	72.2	11.4	30.4	81.8	42.2	39.6	76	60.2	46.2	41.8	588.00
	Monthly average	2.311111	3.430769	4.247058	1.9	2.53333	8.18	3.836363	3.046153	4.470588	3.168421	2.31	2.45882	daily average precipitation: 3,398mm/day rained
Trelleborgs VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	17	14	19	6	14	12	11	12	19	21	21	17	183
	Amount	53.6	51.2	87.2	13	34.2	88.2	49.6	49.6	78.8	63	54.2	46.4	669.00
	Monthly average	3.152941	3.657142	4.589473	2.166666	2.44285	7.35	4.509090	4.133333	4.147368	3	2.580952	2.72941	daily average precipitation: 3,655mm/day rained
Skegrie G:a VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	18	13	17	6	9	11	11	14	15	20	21	15	170
	Amount	51.4	50.8	93	13.4	34.6	60.6	43	52.2	86.2	61.6	60.8	50	657.60
	Monthly average	2.855555	3.907692	5.470588	2.233333	3.84444	5.509090	3.909090	3.728571	5.746666	3.08	2.895238	3.33333	daily average precipitation: 3,868mm/day rained
Trelleborgs ARV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	13	13	17	5	10	11	11	14	16	23	22	16	171
	Amount	48.8	47.6	85	10.6	31.4	80	47.6	56.4	73.4	54.8	48.4	45.6	629.60
	Monthly average	3.753846	3.661538	5	2.12	3.14	7.272727	4.327272	4.028571	4.5875	2.382608	2.2	2.85	daily average precipitation: 3,681mm/day rained
2019														
Engelbrektsgatan Borra 1038	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	17	22	12	5	11	9	14	10	12	20	13	16	161
	Amount	72.2	53.2	16.4	8.8	26	43.2	49.8	83.6	38	83.2	23.6	38.4	536.40
	Monthly average	4.247058	2.418181	1.366666	1.76	2.36363	4.8	3.557142	8.36	3.166666	4.16	1.815384	2.4	daily average precipitation: 3,331mm/day rained
Trelleborgs VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	18	22	12	5	11	11	14	9	12	20	14	17	165
	Amount	79.8	59.6	21.2	12.2	25	63.4	53.2	105.2	37	89.6	27.6	47	620.80
	Monthly average	4.433333	2.709090	1.766666	2.44	2.27272	5.763636	3.8	11.68888	3.083333	4.48	1.971428	2.76470	daily average precipitation: 3,762mm/day rained
Skegrie G:a VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	16	22	12	4	13	10	14	11	12	17	13	18	162
	Amount	80.2	59.8	21	11.2	33.4	49.6	56	90	48.6	88.8	34.2	56	628.80
	Monthly average	5.0125	2.718181	1.75	2.8	2.56923	4.96	4	8.181818	4.05	5.223529	2.630769	3.11111	daily average precipitation: 3,881mm/day rained
Trelleborgs ARV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	19	22	9	5	11	10	12	10	11	18	12	18	157
	Amount	77.8	62.2	20	9.4	26	60	50.2	88	38.2	85	27.2	49	593.00
	Monthly average	4.094736	2.827272	2.222222	1.88	2.36363	6	4.183333	8.8	3.472727	4.722222	2.266666	2.72222	daily average precipitation: 3,777mm/day rained
2020														



Engelbrektsgatan Borra 1038	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	22	5	12	11	14	4	11	14	13	18	18	15	157
	Amount	64.6	19.4	39.2	34.2	44	12.4	133.2	83.6	74.8	70.2	31	68.4	675.00
	Monthly average	2.936363	3.88	3.266666	3.109090	3.142857	3.1	12.10909	5.971428	5.753846	3.9	1.7222222	4.56	daily average precipitation: 4,299mm/day rained
Trelleborgs VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	20	6	13	10	14	5	10	12	13	17	16	18	154
	Amount	69	22	38.4	39.4	47.8	13.4	111.4	76.6	77	74.8	37	75.4	682.20
	Monthly average	3.45	3.666666	2.953846	3.94	3.414285	2.68	11.14	6.383333	5.923076	4.4	2.3125	4.188888	daily average precipitation: 4,429mm/day rained
Skegrie G:a VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	20	4	12	10	15	4	13	12	11	16	16	16	149
	Amount	62.8	24	37.2	32	42.2	7.4	59	98.6	91.4	84.8	29.4	78.2	647.00
	Monthly average	3.14	6	3.1	3.2	2.813333	1.85	4.538461	8.216666	8.309090	5.3	1.8375	4.8875	daily average precipitation: 4,342mm/day rained
Trelleborgs ARV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	19	4	11	10	14	4	11	14	13	16	16	17	149
	Amount	58.6	21.8	37.6	30.6	43.6	7	52.8	89.8	81.8	67.6	31	74.6	596.80
	Monthly average	3.084210	5.45	3.418181	3.06	3.114285	1.75	4.8	6.414285	6.292307	4.225	1.9375	4.388235	daily average precipitation: 4,005mm/day rained
2021														
Engelbrektsgatan Borra 1038	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	16	21	3	7	12	8	8	8	12	13	13	21	142
	Amount	41	80.8	1.8	32.8	41	47	17	31.4	52.4	21.8	20.6	55.2	442.80
	Monthly average	2.5625	3.847619	0.6	4.685714	3.41666	5.875	2.125	3.925	4.366666	1.676923	1.584615	2.628571	daily average precipitation: 3,118mm/day rained
Trelleborgs VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	17	21	4	8	12	7	8	8	13	14	12	23	147
	Amount	45.6	95.6	3	38.6	46	44.4	18.4	35.2	63.8	22.2	26	67.6	506.40
	Monthly average	2.682352	4.552380	0.75	4.825	3.833333	6.342857	2.3	4.4	4.907692	1.585714	2.166666	2.939130	daily average precipitation: 3,444mm/day rained
Skegrie G:a VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	17	19	2	8	10	9	7	9	14	13	10	21	139
	Amount	46.4	99.4	1	35.2	41.8	55	23.6	53	83.6	22	14.8	67.2	543.00
	Monthly average	2.729411	5.231578	0.5	4.4	4.18	6.111111	3.371428	5.888888	5.971428	1.692307	1.48	3.2	daily average precipitation: 3,906mm/day rained
Trelleborgs ARV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	16	20	3	7	12	4	10	10	13	12	14	17	138
	Amount	42.4	90	3	35.4	35.8	6	21.6	36.8	66.6	25.6	22.6	63	448.80
	Monthly average	2.65	4.5	1	5.057142	2.983333	1.5	2.16	3.68	5.123076	2.133333	1.6142857	3.705882	daily average precipitation: 3,252mm/day rained
2022														
Engelbrektsgatan Borra 1038	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	21	7	21	6	3	5	16	14	9	20	22	22	166
	Amount	81.2	39.8	56	21.4	8	13	69	130	10.8	87.2	87.2	83.8	687.40
	Monthly average	3.866666	5.685714	2.666666	3.566666	2.66666	2.6	4.3125	9.285714	1.2	4.36	3.963636	3.809090	daily average precipitation: 4.14mm/day rained
Trelleborgs VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	20	8	22	5	3	5	15	15	10	20	19	22	164
	Amount	97.6	47.6	67.6	25.8	9	14.8	87.2	123	11.6	112.8	110.8	91	798.80
	Monthly average	4.88	5.95	3.072727	5.16	3	2.96	5.813333	8.2	1.16	5.64	5.831578	4.136363	daily average precipitation: 4.87mm/day rained
Skegrie G:a VV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	19	7	19	5	2	8	15	14	9	19	18	22	157
	Amount	101.8	46.8	65.6	24.6	10.8	23.8	86.4	134.4	17.2	124.8	98	92.8	827.00
	Monthly average	5.357894	6.685714	3.452631	4.92	5.4	2.975	5.76	9.6	1.911111	6.568421	5.444444	4.218181	daily average precipitation: 5.26mm/day rained
Trelleborgs ARV	Month	jan	feb	mar	apr	may	jun	jul	aug	sep	okt	nov	dec	TOTAL:
	Recorded	20	6	18	5	2	5	16	15	9	20	18	20	154
	Amount	97.8	45.2	62.8	24.4	8.4	25.4	121.6	116.2	9.8	108.8	98	81.8	800.20
	Monthly average	4.89	7.533333	3.488888	4.88	4.2	5.08	7.6	7.746666	1.088888	5.44	5.444444	4.09	daily average precipitation: 5.19mm/day rained
2023														

Figure 14: Rain Data excel sheet, highlighting different levels of rainfall data.

4.1.2 GSML and local sea level rise

As depicted in the upcoming maps, the current sea level has escalated by approximately 16 cm in recent years. These maps also present a projection based on the "high baseline emission scenario," specifically the RCP 8.5 baseline, for the years 2050, 2075, and 2100. It's crucial to emphasise that the rising sea level is progressively encroaching inland. When factoring in storm surges in conjunction with heavy rainfall, the city faces a significant risk of severe flooding and potential infrastructural harm.

Utilising the RCP 8.5 baseline, there exists a considerable likelihood that by the year 2100, the western portion of Trelleborg's coastline will be susceptible to inundation. This estimation solely considers the sea level rise, without accounting for the compounded effects of storm surges and pluvial downpours.

Figure 15: Current Sea Level Rise Map, increment of +16 cm since 1986

Figure 25: *2050 Sea Level Rise Map +33cm*

Figure 26: *2075 Sea Level Rise Map +57cm*

Figure 27: *2100 Sea Level Rise Map +78cm*

4.1.3 Storm Surges

Here an organic projection map will be presented that will show the tidal effect on the sea level rise. The sea level rise adjusted to the land rise is around 9 cm, those 9 centimetres are added towards the 1-2m of tidal impact in the case of a storm surge. The current highest current storm surge is +1.686m, thus the analysis parts from the idea that the storm surges will be consistent and proportional to the sea level rise. If the sea level rise increase is about 20 cm, the storm surge will take the current highest storm surge as a baseline from which to increase. This in reality might vary due to all of the climatic factors that might influence the behaviour of the local tides. It is important to highlight that the data from the storm surges is based on the Skanör measurement station, which is the most related and closest to Trelleborg municipality.

Figure 28: Highest Current Storm Surge map / max +1.686 m.

Figure 29: Highest Storm Surge 2050 map / max +1.856 m.

Figure 30: Highest Storm Surge 2075 map / max +2.086 m.

Figure 31: Highest Storm Surge 2100 map / max +2.306 m.

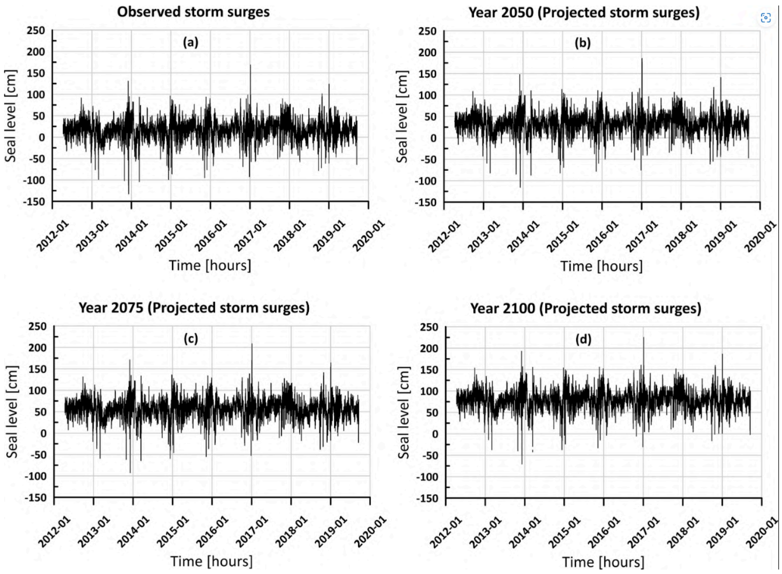


Figure 32: The storm input representing the present state and the projected years 2050, 2075 and 2100 (reference system RH2000). The time step resolution is one hour. ((10)Isabelle Laster Grip, Salar Haghighatafshar, Henrik Aspegren, 2021)

Storm surges are a critical consideration when comprehending coastal regions. These phenomena involve complex hydrodynamic factors, which, if simulated accurately, would necessitate significant computational resources. For practicality, the simulation has been streamlined.

For precise simulation, a comprehensive range of parameters, as outlined in "An holistic approach to beach erosion vulnerability assessment"((21)George Alexandrakis & Serafim E. Poulos, 2014), would be required. These parameters span the domains of topographical morphology, sedimentology, climate, and hydrodynamics. While this approach entails the establishment of an extensive set of rules, translating this complexity into a digital simulation poses challenges.

To simplify the storm surge data, the analysis focuses on observed storm surges between 2012 and 2019, sourced from Salar Haghighatafshar ((10)Isabelle Laster Grip, Salar Haghighatafshar, Henrik Aspegren, 2021). This dataset offers insights into the sea level fluctuations (in centimetres) caused by storm surges, providing a basic yet informative overview of the potential impact of tidal waves on our region. The dataset is based on the Skanör tidal wave measurement gauge.

We can gain insight into the potential damage caused by waves crashing into protected areas by considering the force of the water, which can be roughly estimated using the wave power equation. This equation offers a simplified means of understanding the interplay of potential energy, kinetics, and the pressure exerted by water particles.(50)Talia Santos de Andrade, Paulo Henrique Gomes de Oliveira Sousa, Eduardo Siegle, 2019).

$$P = \frac{\rho g^2 H^2 T}{32\pi}$$

ρ= water density (1027 kg/m3), g= gravity acceleration value (9.8 m/s), H= wave height (m), T= period (s).((50)Talia Santos de Andrade, Paulo Henrique Gomes de Oliveira Sousa, Eduardo Siegle, 2019)

As indicated by the formula, the force carried by a wave is influenced by its height and the duration it persists. Notably, the water particles that bear the greatest impact on our coastline are those situated at the wave's highest peaks.

4.1.4 Manhole and Urban drainage

The following maps depict the outcomes of analysing data generously provided by Trelleborg Municipality. The data includes measurements and detailed reports from various manhole drainage sites across the city. The information was sourced from reports and Excel data produced by the Kretslopp och Vatten department of the municipality, in collaboration with Rosim/VA-fälttjänst.

The initial map illustrates the distribution of studied manholes across the city. Red dots represent manholes from 2022, while blue dots represent those from 2020.

Figures 35 and 36 display water height stress within the Drainage Pipe. These figures present the average, minimum, and maximum water levels for both 2020 and 2022, during rainy periods (2 months) in Trelleborg. Urbanised areas and locations near specific coastal points exhibit significant water stress.

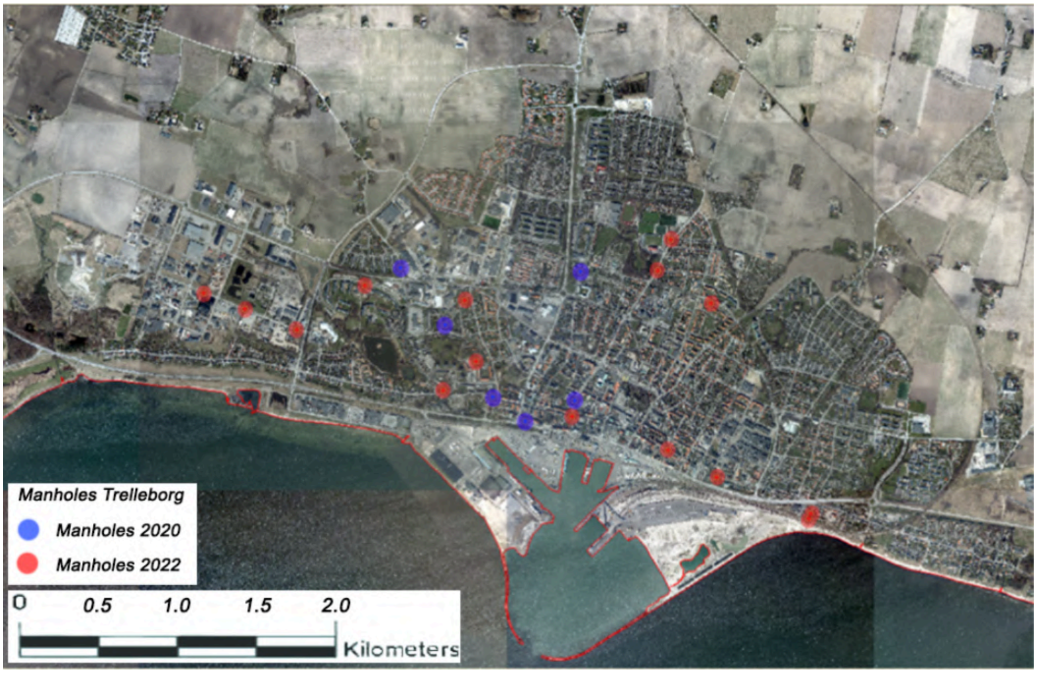


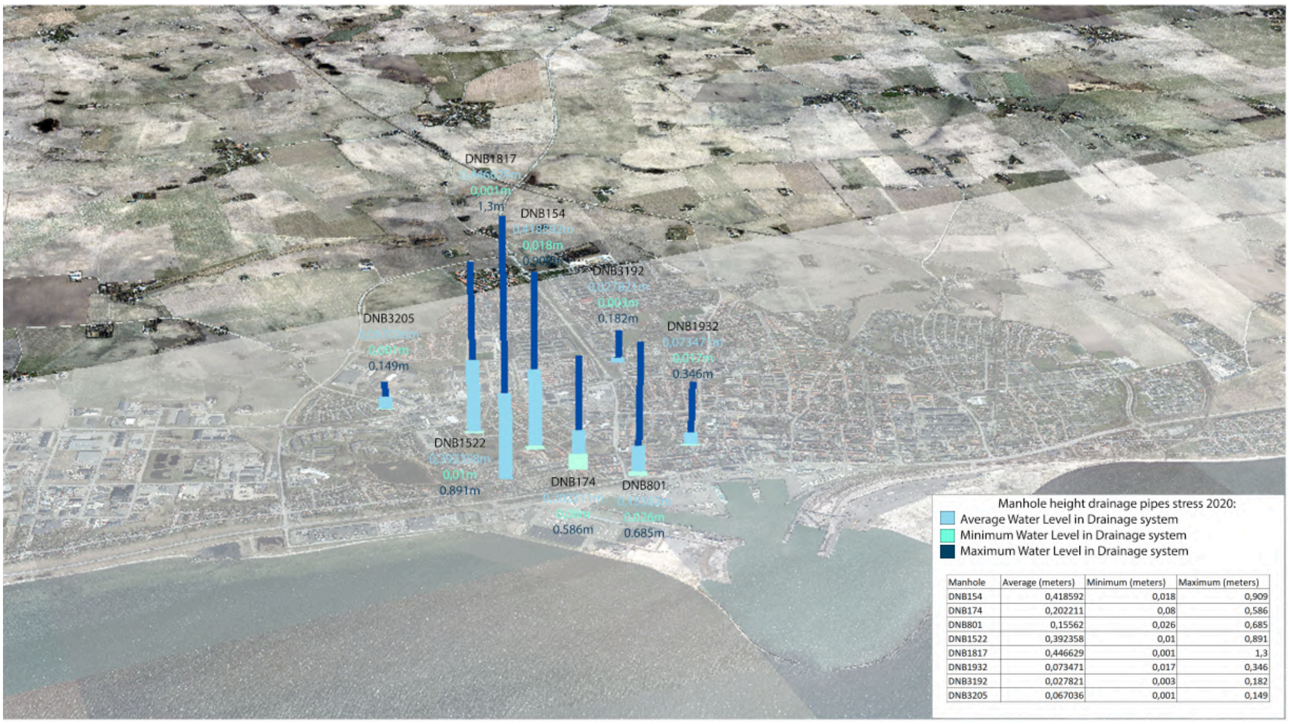
Figure 33: Manhole measuring stations location, 2020 & 2022

Figure 34: Drainage system network in Trelleborg.

The manhole data map is a visual representation displaying the locations of manholes in a given area. In this specific case, the first map shows manholes from two different years, 2020 and 2022, with each year represented by a distinct colour, some overlapping, meaning that 2022 has extra manholes added to their analysis. The purpose of using these manholes is to assess the drainage stress within the city and to understand how the proximity to the sea is impacting the drainage system in Trelleborg.

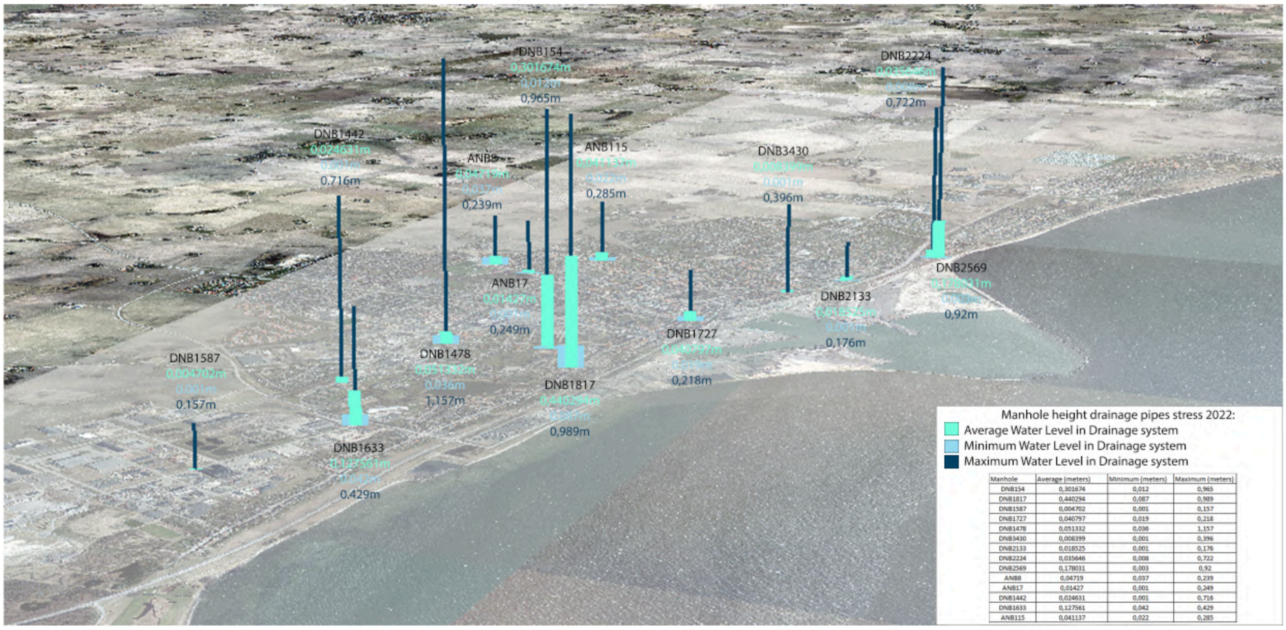
The underlying hypothesis here is that the rising sea levels are leading to a phenomenon where water flows in the opposite direction, negatively affecting the flow rate into the city's drainage system near the coastline. By comparing the manhole data from 2020 and 2022, the data provides a way to visually identify any changes or trends in the drainage system over this period, especially in areas close to the sea. It enables an investigation into whether the data and observed alterations in manhole locations and conditions lend support to the hypothesis that rising sea levels are detrimentally impacting the drainage system.

On the other hand, the two drainage system maps serve the purpose of visually representing how Trelleborg's entire drainage system is structured and functions. These maps provide an overview of the network of pipes, manholes, and other components that manage the flow of water within the city. By using such maps, city planners, engineers, and researchers can better understand the layout and operation of the drainage system. This knowledge is essential for identifying areas where improvements may be needed, optimising the system's performance, and addressing issues such as flooding, especially in areas prone to sea-level rise.



Manhole	Average (meters)	Minimum (meters)	Maximum (meters)
DNB154	0,418592	0,018	0,909
DNB174	0,202211	0,08	0,586
DNB801	0,15562	0,026	0,685
DNB1522	0,392358	0,01	0,891
DNB1817	0,446629	0,001	1,3
DNB1932	0,073471	0,017	0,346
DNB3192	0,027821	0,003	0,182
DNB3205	0,067036	0,001	0,149

Figure 35: 2020 Metre height in Drainage Pipe



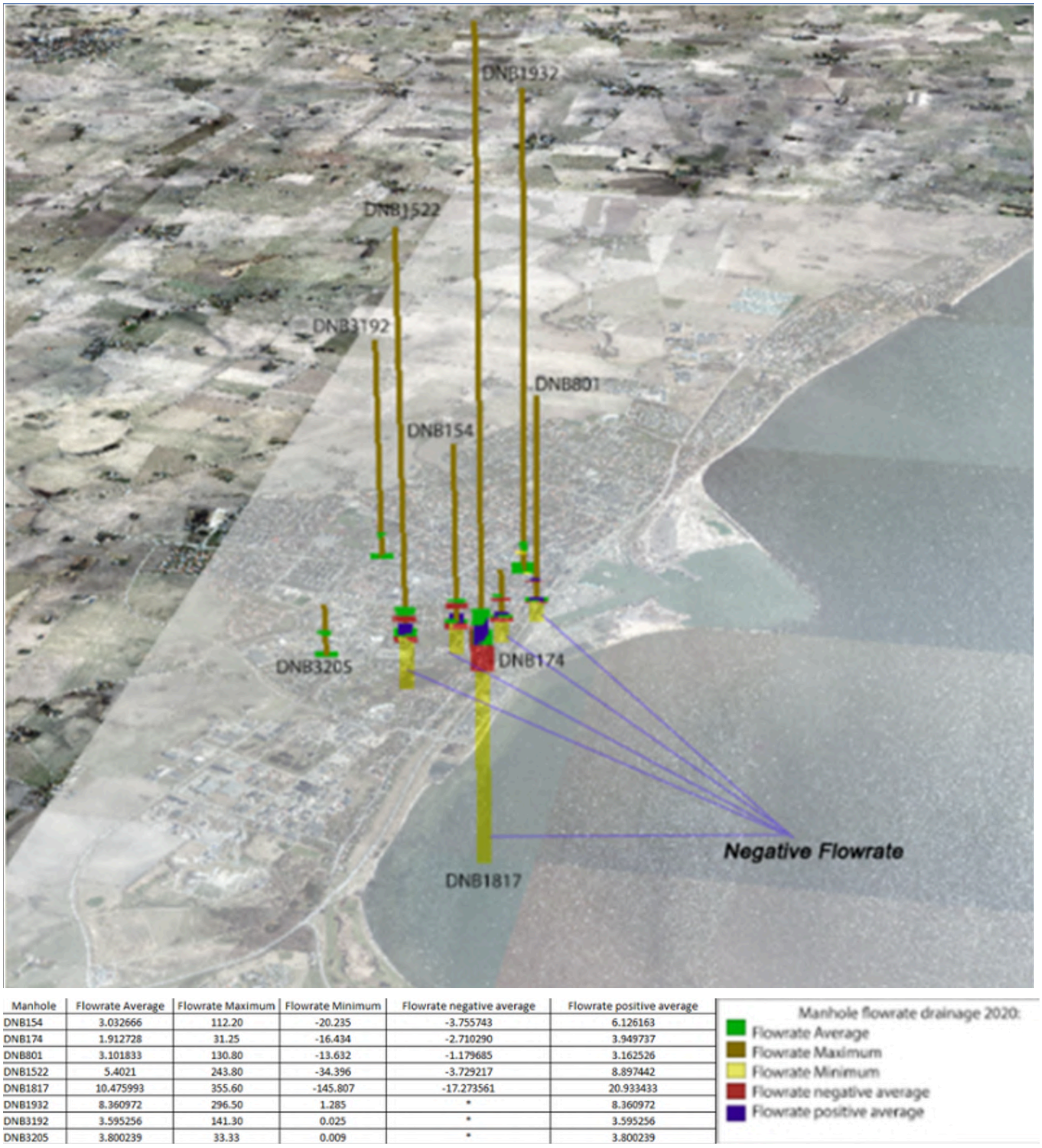
Manhole	Average (meters)	Minimum (meters)	Maximum (meters)
DNB154	0,301674	0,012	0,965
DNB1817	0,440294	0,087	0,989
DNB1587	0,004702	0,001	0,157
DNB1727	0,040797	0,019	0,218
DNB1478	0,051332	0,036	1,157
DNB3430	0,008399	0,001	0,396
DNB2133	0,018525	0,001	0,176
DNB2224	0,035646	0,008	0,722
DNB2569	0,178031	0,003	0,92
ANB8	0,04719	0,037	0,239
ANB17	0,01427	0,001	0,249
DNB1442	0,024631	0,001	0,716
DNB1633	0,127561	0,042	0,429
ANB115	0,041137	0,022	0,285

Figure 36: 2022 Metre height in Drainage Pipe

Figures 37 and 39 showcase the flow rate and other municipality-provided data, aiming to emphasise the interrelation between various factors. These maps reveal that manholes near the coastline experience a negative flow rate, implying instances when water surges create pressure within the system, causing water to flow backward.

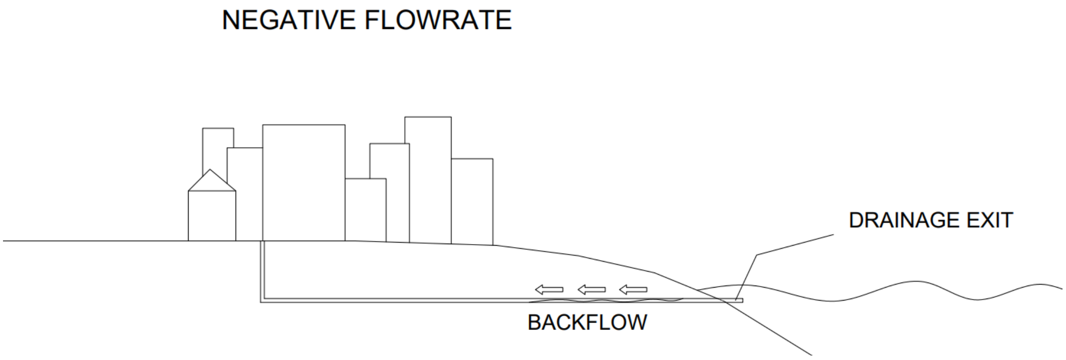
It's important to note that although the examined reports offer valuable insights, they don't entirely encapsulate the complexity of Trelleborg's drainage system.

The system is far more intricate than the representation of dots on a map. Nevertheless, meaningful conclusions can still be drawn from the observed data.



Manhole	Flowrate Average	Flowrate Maximum	Flowrate Minimum	Flowrate negative average	Flowrate positive average
DNB154	3.032666	112.20	-20.235	-3.755743	6.126163
DNB174	1.912728	31.25	-16.434	-2.710290	3.949737
DNB801	3.101833	130.80	-13.632	-1.179685	3.162526
DNB1522	5.4021	243.80	-34.396	-3.729217	8.897442
DNB1817	10.475993	355.60	-145.807	-17.273561	20.933433
DNB1932	8.360972	296.50	1.285	*	8.360972
DNB3192	3.595256	141.30	0.025	*	3.595256
DNB3205	3.800239	33.33	0.009	*	3.800239

Figure 37: 2020 Manhole water flow rate, accompanied by manhole data table.



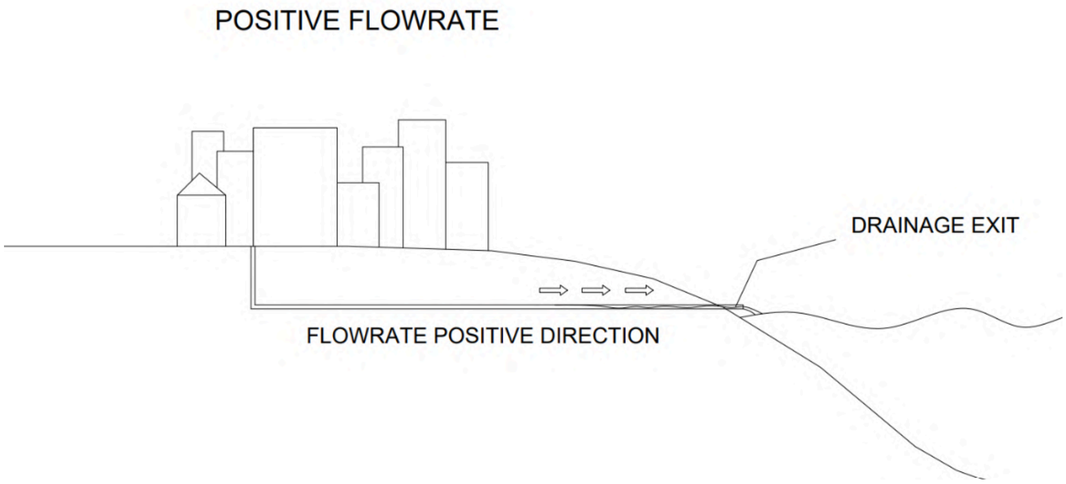
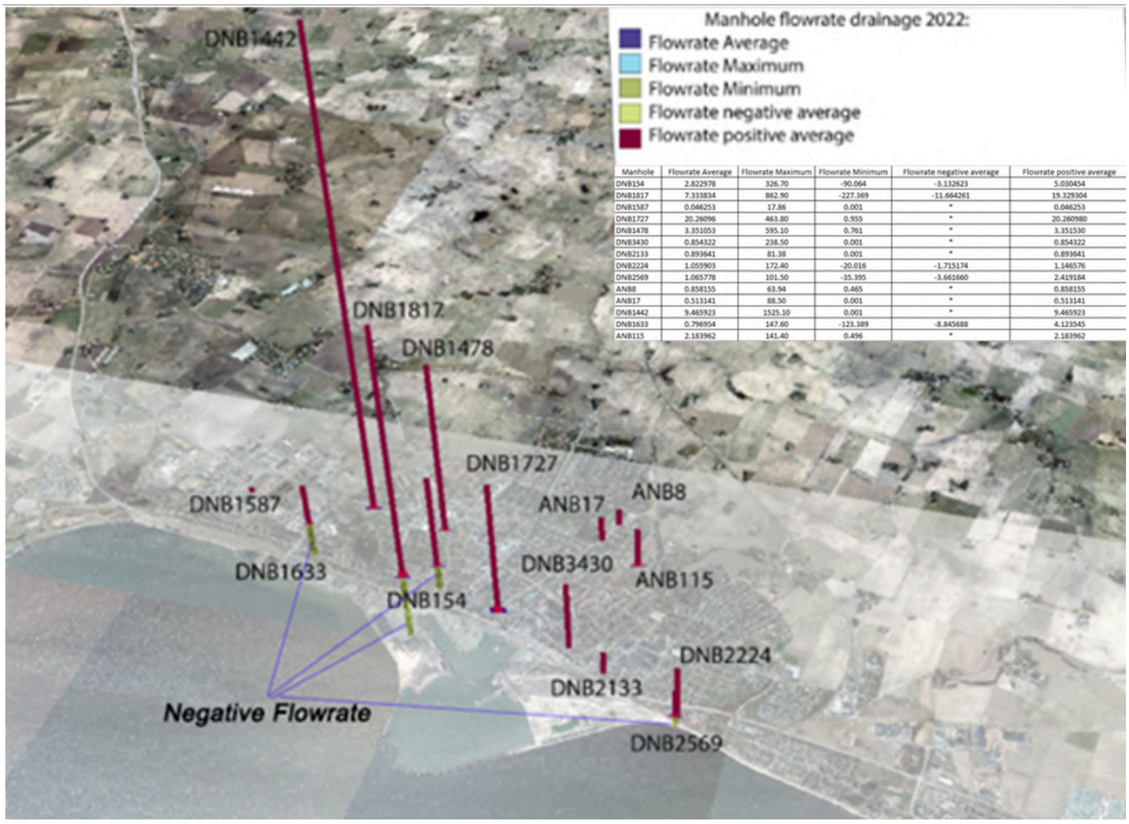


Figure 38: Flow Rate graph simplified visualisation



Manhole	Flowrate Average	Flowrate Maximum	Flowrate Minimum	Flowrate negative average	Flowrate positive average
DNB154	2.822978	326.70	-90.064	-3.132623	5.030454
DNB1817	7.333834	862.90	-227.369	-11.664261	19.329304
DNB1587	0.046253	17.86	0.001	*	0.046253
DNB1727	20.26096	463.80	0.955	*	20.260980
DNB1478	3.351053	595.10	0.761	*	3.351530
DNB3430	0.854322	238.50	0.001	*	0.854322
DNB2133	0.893641	81.38	0.001	*	0.893641
DNB2224	1.055903	172.40	-20.016	-1.715174	1.146576
DNB2569	1.065778	101.50	-35.395	-3.661660	2.419184
ANB8	0.858155	63.94	0.465	*	0.858155
ANB17	0.513141	88.50	0.001	*	0.513141
DNB1442	9.465923	1525.10	0.001	*	9.465923
DNB1633	0.796954	147.60	-123.389	-8.845688	4.123545
ANB115	2.183962	141.40	0.496	*	2.183962

Figure 39: 2022 Manhole water flow rate, accompanied by manhole data table.

In summary, analysing the manhole data has provided insights into the dynamic nature of the drainage system. While two contrasting data extremes tend to balance out into a normal curve, the data itself is characterised by numerous instances of extreme values. This suggests that although the city's average water intake might appear manageable, the sudden influx of water during rain events can significantly strain the city's infrastructure. A particularly intriguing finding is the occurrence of negative flow rates observed in manholes situated near the coastline. This observation lends support to the hypothesis that when storm surges coincide with intense rainfall, the city's drainage system is vulnerable to considerable impact. In essence, the data underscores the importance of preparedness for extreme weather events, especially when storm surges and heavy rainfall converge. This understanding is crucial for enhancing the resilience of the city's drainage infrastructure. Figures 35 and 36 play a crucial role in emphasizing the water stress within the drainage system, presenting the water height. Meanwhile, figures 37 and 39 illustrate the flowrate of the drainage system, providing clear insights into water flow velocity and direction. Accompanying tables offer detailed values corresponding to various manhole measurement stations, enhancing the understanding of the depicted scenes.

4.2 General Map Data Analysis

In this section, we will delve into the General maps—a compilation of data from various years—providing a comprehensive view of the area's flood risk and facilitating a holistic understanding of the situation.

Figure 40: Highest Storm Surges map from current to 2100 projection.

Storm surge transitional map from current maximum storm surge to future proportional projections of storm surges.

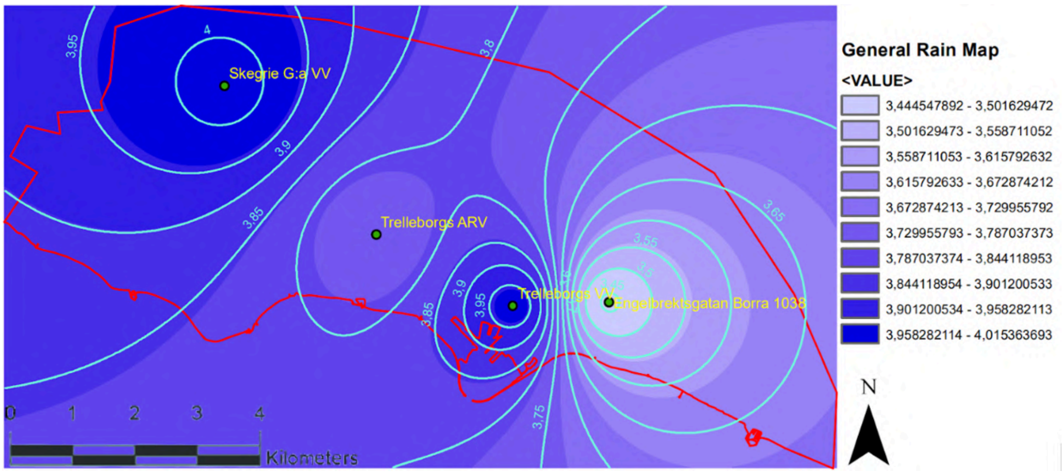


Figure 41: 10 year Rain Interpolation Map 2013-2022.

This General Rain map takes the last 10 years of rain data, and compiles the information into one map. This map reveals variations among rain stations, showcasing distinct rainfall patterns across the region from 2013 to 2022. It provides insights into how precipitation moves differently, highlighting areas with lower and higher rainfall. The importance of the interpolation map is to help us understand which points of the municipality are affected more heavily by rainfall, which helps us understand where there can be critical points to analyse. The averaged out difference is only 1/2 mm, which may seem small at first glance. However, proportionally, it represents a significant 14.2% difference between the Engebreksgatan Borra station and the Skegrie or Trelleborg VV stations. This highlights the areas that have a higher trend of rainfall and underscores the importance of understanding even seemingly minor differences in precipitation data, which are proportionally substantial in the analysis.

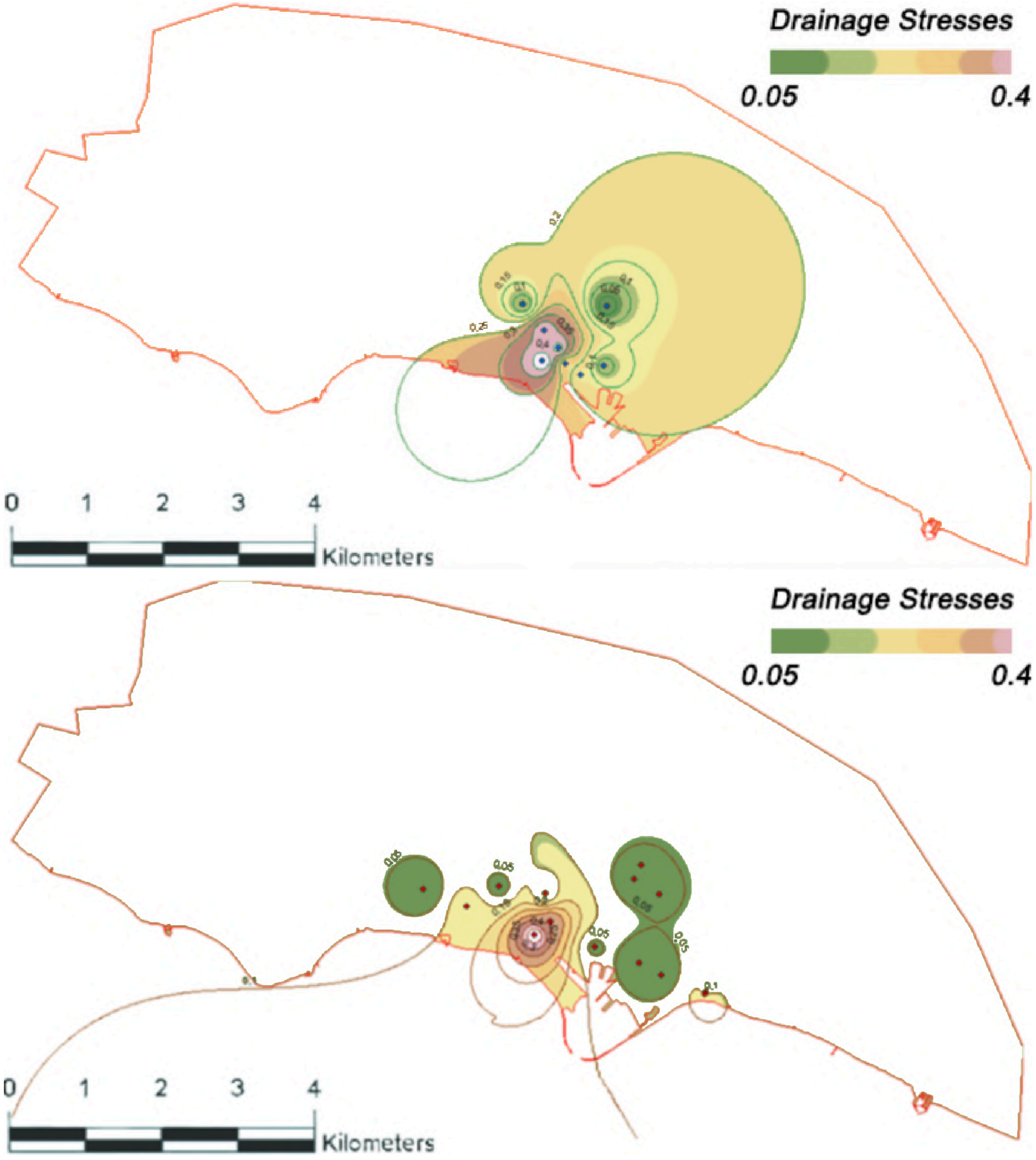


Figure 42: Manhole map averaged out stressed manholes Trelleborg, (1) 2020 (2) 2022.

In this set of maps, the water stress levels across different manhole infrastructure points are depicted, showcasing a range between 0.05 and 0.4+ meters. These stress levels are indicative of the average water levels present in the city of Trelleborg's drainage system. Examining the maps reveals a notable variability in water stress, with higher levels consistently observed near the coastline, densely populated urban areas, and industrial zones.

The depicted stress levels are determined by averaging the height levels across various manholes. Essentially, the maps illustrate the distribution of water across the city's drainage infrastructure, offering a visual representation of the water stress experienced at different points. The clustering of higher stress levels near the coastline implies a heightened susceptibility to water-related issues in these areas.

Furthermore, the correlation observed between the rain interpolation map and the drainage stress maps suggests a connection between precipitation patterns and the resulting water stress. This correlation reinforces the importance of understanding and monitoring the dynamics between rainfall and drainage system performance in Trelleborg. Overall, these maps provide valuable insights into the spatial distribution of water stress, aiding in the identification of areas that may require specific attention in terms of drainage infrastructure management and water resource planning.

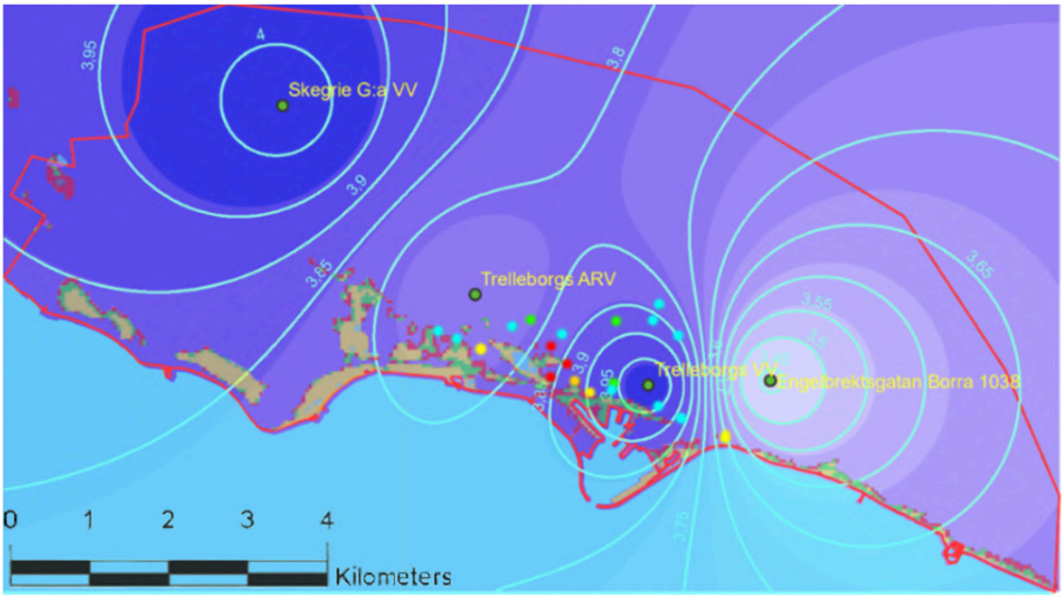


Figure 43: Combined final map of Interpolation, storm surges and manhole data

This map vividly illustrates a noticeable connection between data on rainfall, storm surge predictions, sea level rise projections, and the stresses experienced by the manhole drainage system. The colour-coded dots provide a clear hierarchy: red dots signify the highest water stress levels, followed by yellow, green, and finally cyan, representing the least drainage stress on the infrastructure. Notably, the observation reveals that the most intense drainage system stress occurs precisely at the intersection of areas forecasted for storm surge flooding and those experiencing heavy rainfall.

The convergence of these factors unmistakably signals a potential calamity for the city of Trelleborg if compound flooding were to occur. The evident link between manholes experiencing the greatest stress, primarily located along the coastline, which is projected to be inundated during storm surges in an RPC 8.5 scenario, raises a concerning scenario. In the event of simultaneous heavy rainfall, this alignment of circumstances could indeed lead to a disaster—under the premise of the highest emission scenario.

It's crucial to emphasise that coastal strategies primarily prioritise addressing storm surges and rising sea levels. These factors are closely linked to increased drainage challenges. In contrast, pluvial water, or rainwater, does not appear to be a significant contributing factor due to not having an upward trend and is more predictable in terms of measurement. On the other hand, data for storm surges and sea level rise show a consistent upward trend. As a result, strategies aimed at mitigating the effects of sea level rise and storm surges are of greater significance and impact.

Figure 44: Land Use conceptual proposition map and drainage exits.

In Figure 44, we can see a conceptual map proposing a more convenient land use, incorporating a data-driven strategy. This map involves rearranging land use and introducing a coastal plan based on the Data Driven Strategy. Specifically, the coastal area will feature swamp marshland with versatile landscape architecture designed to adapt to rising tides. It will also include a water redirection system and wave interrupters, as outlined in the strategy. It's essential to note that this is a conceptual plan illustrating how the strategy could be implemented on a broader scale.

The plan also emphasises dike systems, envisioned to create distinctive environments beneficial for both commercial and hospitality-oriented businesses. The allocation of residential housing, industrial zones, and multifunctional land use remains largely consistent with the existing land use, aside from making way for a larger portion of coastal data driven strategy.. Additionally, the drainage system is highlighted, revealing that most drainage water is discharged from the urban drainage system. Notably, there are no drainage outlets on the west side of Trelleborg, in contrast to the east side.

4.3 Virtual Simulation

The process involved a meticulous balancing act between simulation quality and the time available, as well as the computing power. High-definition simulations require approximately 8-12 hours for processing, and an additional 2 hours for rendering at a smaller scale. Incorporating particle simulation, alongside fine-tuning parameters for splash, bubbles, and air effects, significantly prolonged the simulation duration. Hence, adjustments were made to the definition parameters, taking into account the available time and computing capabilities.

Two simulation strategies will be employed: "Instant Impact" wave formation and "Still Water Backpoint" wave generation.

These simulation strategies are contingent upon where the wave originates and the force it carries. At its peak, a wave possesses its maximum force. Upon conducting simulations, I observed that the outcomes vary based on the wave formation location. To establish a baseline, simulations with a constant short-distance wave formation were conducted. However, a margin of error persists due to the inherent variability of wave formation. Consequently, the decision was made to utilize two wave formation points: "Instant Impact," which generates a wave moving directly towards the coastal strategy without any backwater effect, and "Still Water Backpoint," which generates wave force on a tranquil water surface, yielding a different wave result.

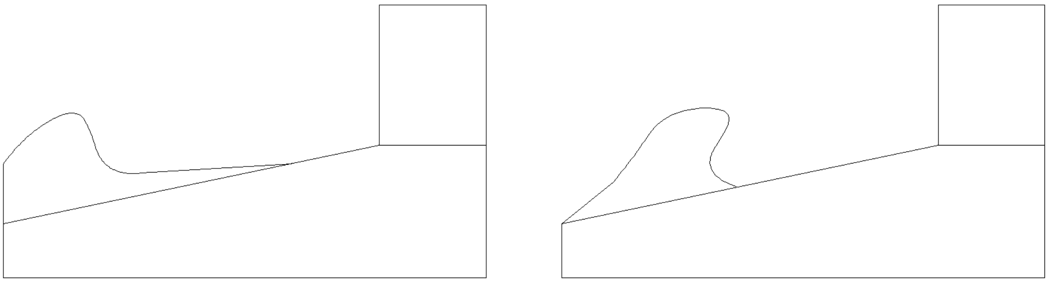


Figure 45: Still Water Backpoint & Instant Impact wave formations.

Explanation of simulation results, accompanied by plan view 3d images and perspective views, as well as a QR code.

In this work, the simulations focusing on coastal strategies are confined to a limited scale and are not directly correlated with the broader data analyzed throughout the thesis. Specifically, these simulations exclusively consider storm surge heights within a small 30x10m area, representing only a fraction of the extensive Trelleborg municipality. It is crucial to note that these simulations function merely as illustrative examples, showcasing the potential of a comprehensive analysis that incorporates the broader scale data. The intent is to emphasise that a more expansive and resource-intensive simulation, encompassing the entire municipality, would require substantial processing power to accurately portray the wider implications of the coastal strategies under consideration. The only empirical data that was used for the simulations was the height presented in the storm surge data. Although an enlarged simulation of the whole territory of the city would provide a more accurate predicting picture, this was not possible due to the lack of more powerful computer hardware to carry out such a simulation.

Hold the Line:

The simulations for the "Hold the Line" strategy were conducted in a straightforward manner. A collision wall was implemented, and the water particles were able to collide with the wall. This approach provided insights into the effectiveness of establishing a barrier between the shoreline water and the urban infrastructure.

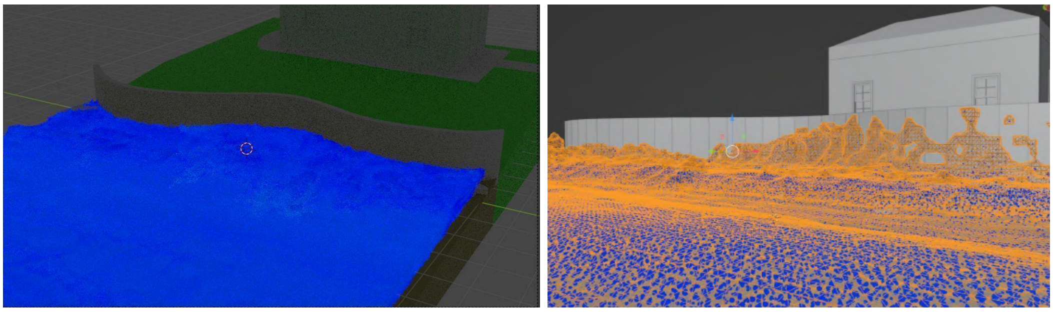
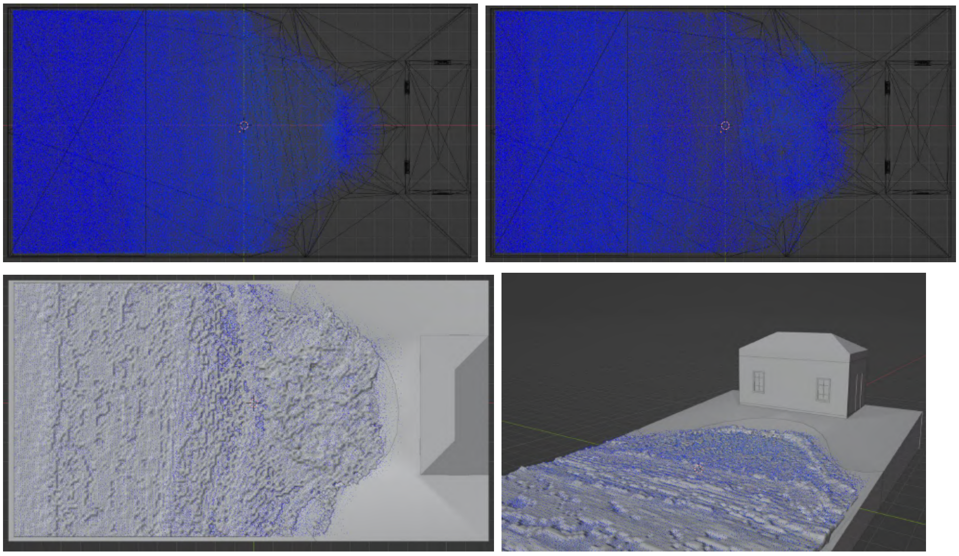


Figure 46: Hold the Line, High and Low definition simulation.

Managed Realignment (retreat):

This simulation was designed to model an urban retreat strategy, along with a topographic restructuring for water management. In this simulation, the urban infrastructure is positioned along the perimeter of the simulation box. Additionally, the coastline has been altered to create a U-shaped opening, allowing water particles to flow into the reconfigured topography.



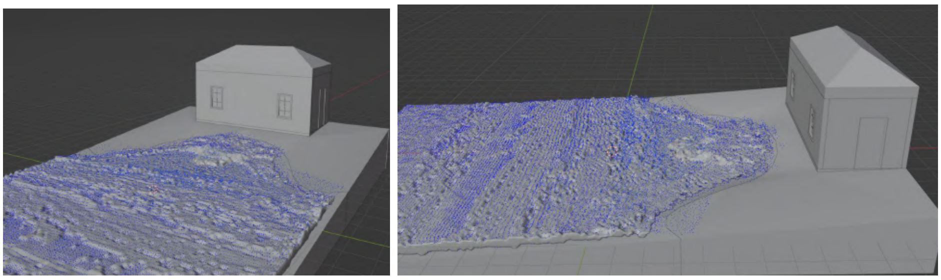


Figure 47: Managed Realignment simulations.

Ecological|Environmental Multi-layered Realignment (embrace):
This strategy showcases a creative approach. It involves incorporating three tiers of friction constants in the simulations to replicate the influence of varying soil types, grass, and plants on water movement. The simulation also includes pillar-like representations of trees, along with an exceedingly low absorption factor. This factor eliminates a minimal portion of particles, emulating the effects of infiltration and water absorption.

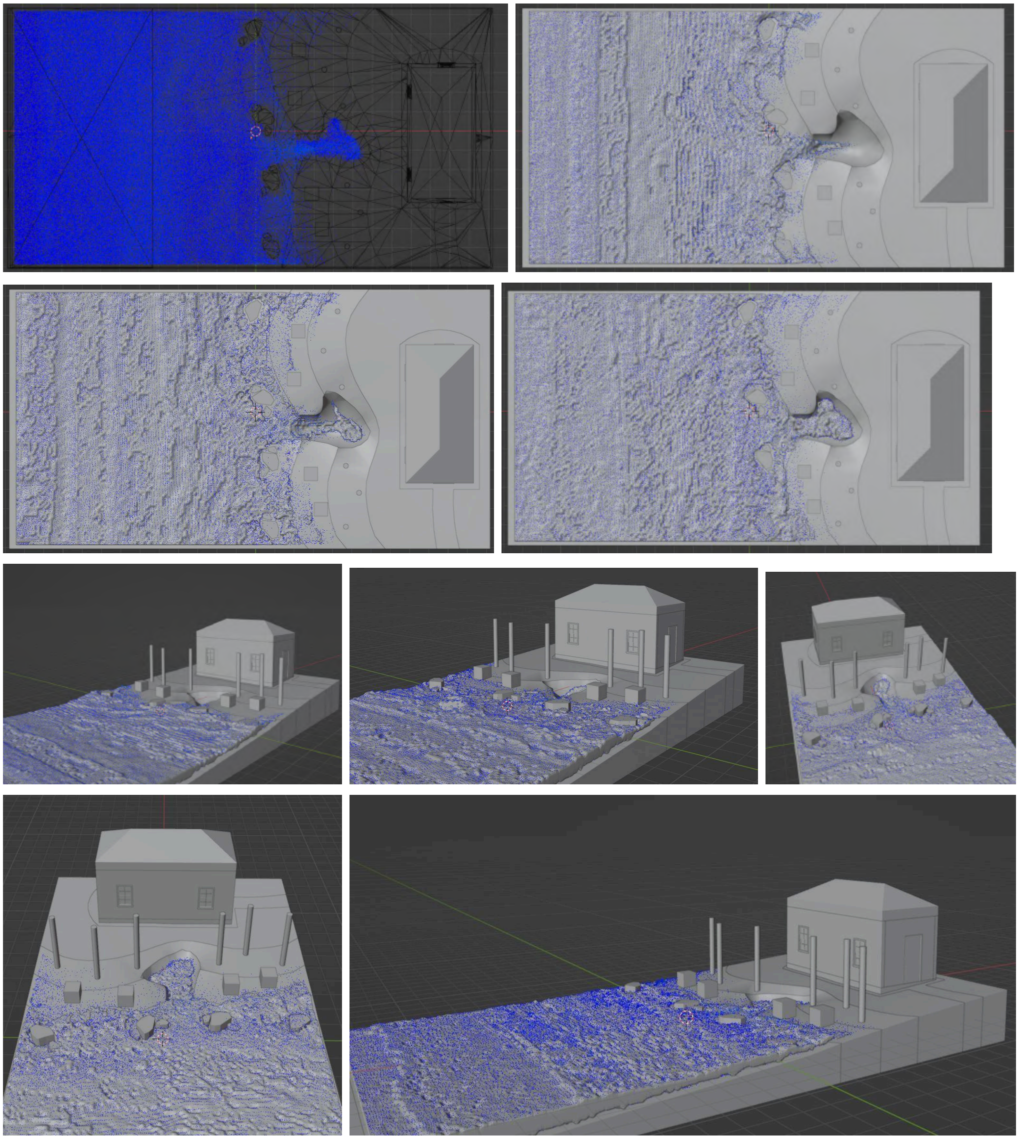


Figure 48: Ecological/Environmental Multi-layered Realignment simulation.

Wave Breakers (disruptive defence):
The wave breaker simulation was developed to illustrate a modified sea wall designed in a breakwater style to counteract the force of incoming waves. The distinct outward-pointing structural features are strategically shaped to intercept and cut through the oncoming water.

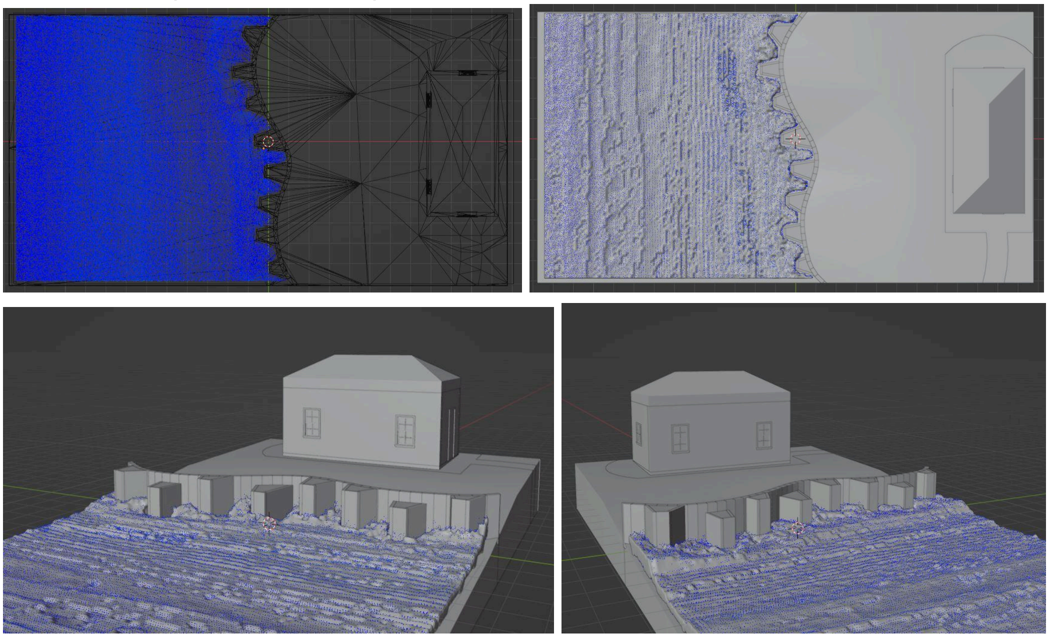


Figure 49: Wave Breakers simulation.

Breakwaters or wave interruptor (Engineering):
This strategy was conceptualized with a design that incorporates an outward topographic uplift from the coastline, complemented by natural rock colliders. The simulation aims to disrupt the kinetic energy of the waves prior to reaching the coastline, generating a calm water buffer behind the breakwater or wave-intercepting structure.

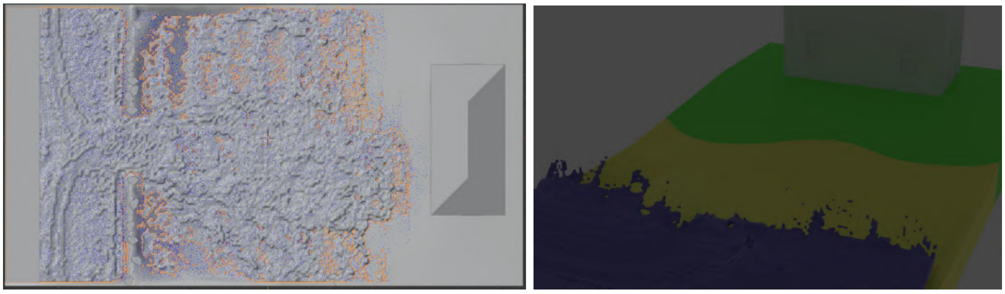


Figure 50: Breakwaters or wave interruptor simulation.

Sea city/eating the sea (Attack):
This strategy was designed to simulate the expansion of urban infrastructure into the sea. Starting from the consistent coastline border used in all simulations, an elevated terrace was positioned beyond the coastline, extending into the sea. The elevation of the terrace is determined by the topographic height, originating from the coastal border and incorporating an additional structural offset.

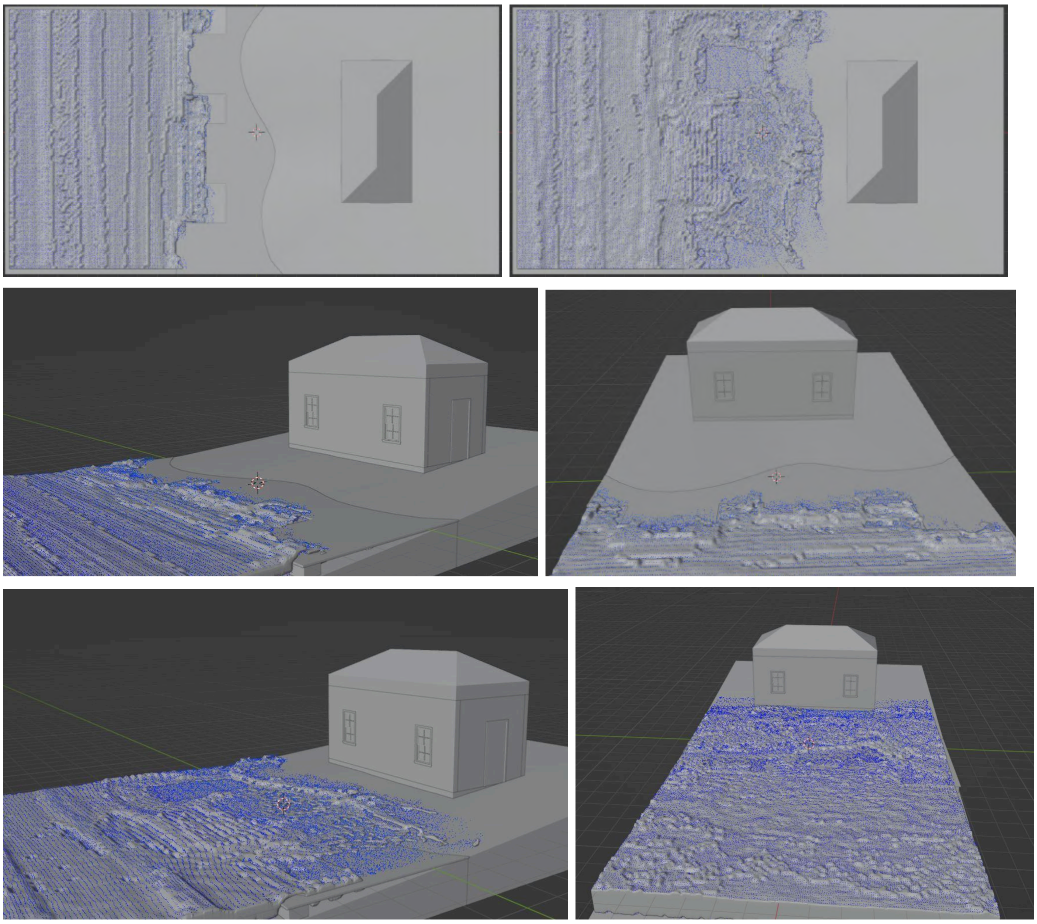


Figure 51: Sea city/eating the sea simulation.

4.4Strategy Evolution Through Analysed Factors

The simulated strategy amalgamated key elements from various other strategies that exhibited positive outcomes. In addition, relevant contextual data, encompassing environmental and social impacts, was factored into the design. The strategy was structured as follows: three elevated nodes in the topography, accompanied by rock colliders; a secondary layer of rock colliders running alongside the coastline; and two dike openings. These components were drawn from the other strategies, contributing to the formulation of this approach.

Each element has its origin:
The concept of elevated topographic structures, combined with stone colliders, draws inspiration from the breakwater or wave interruptor strategy, aiming to disrupt the incoming wave force. The inclusion of a secondary layer of rock colliders functions as a barrier, guiding low-traction water towards the dikes. These dikes serve a dual purpose: acting as both a water containment and redirection system, akin to the Ecological|Environmental Multi-layered Realignment and Managed Realignment strategies. Furthermore, they contribute to the establishment of diverse ecosystems within the dikes.

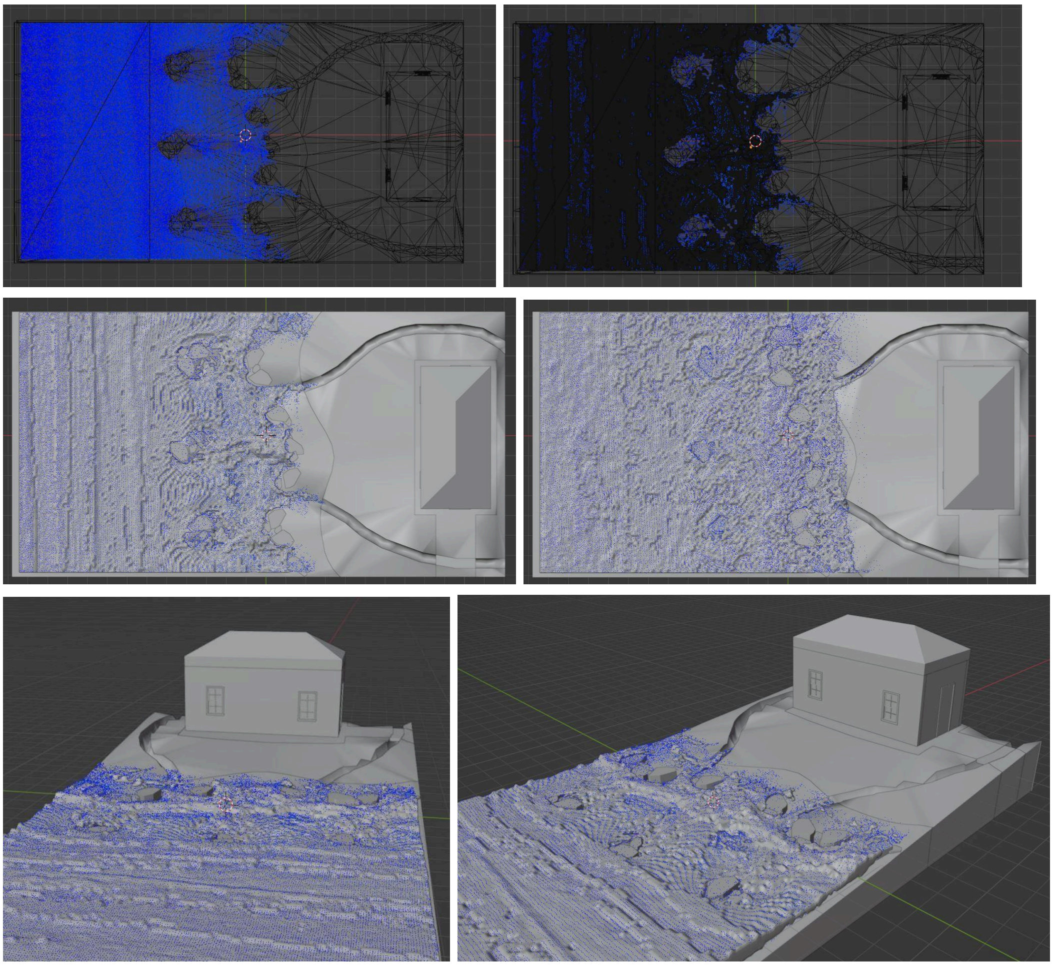


Figure 52: Simulated Strategy Simulation.

Figure 53: QR scan code for coastal simulations

All simulations took into consideration several factors such as infiltration/permeability, friction, collision, etc. which can be observed by the different simulation views.

4.5 Numerical data

Here, we have compiled all the numerical data in a more quantitative format, aiming to provide clarity.

All the data has been organised in Excel sheets, and a summarised version is presented here to offer insight into the underlying numbers behind our maps and simulations.

In Figure 54, the graph showcases extreme daily rainfall instances. This entails days within a month that experienced heavy rainfall, with their respective daily quantities highlighted in the graph. This representation sheds light on the stresses imposed on infrastructure due to rainwater. A more detailed analysis could involve examining the connectivity of daily rain events. For example, heavy rain on one day can result in backwater accumulation in urban systems, which, if followed by subsequent rainy days, compounds the stress. However, due to time constraints, the data has been streamlined into monthly-coded daily rainfall values. Typically, instances of heavy rainfall do not occur more than four times a month, often taking place only once. These monthly measurements have been categorised as 20+ mm/day, 30+ mm/day, 40+ mm/day, 50+ mm/day, and 60+ mm/day. For a deeper dive into the compiled data, a detailed rain data analysis can be found in the appendix.

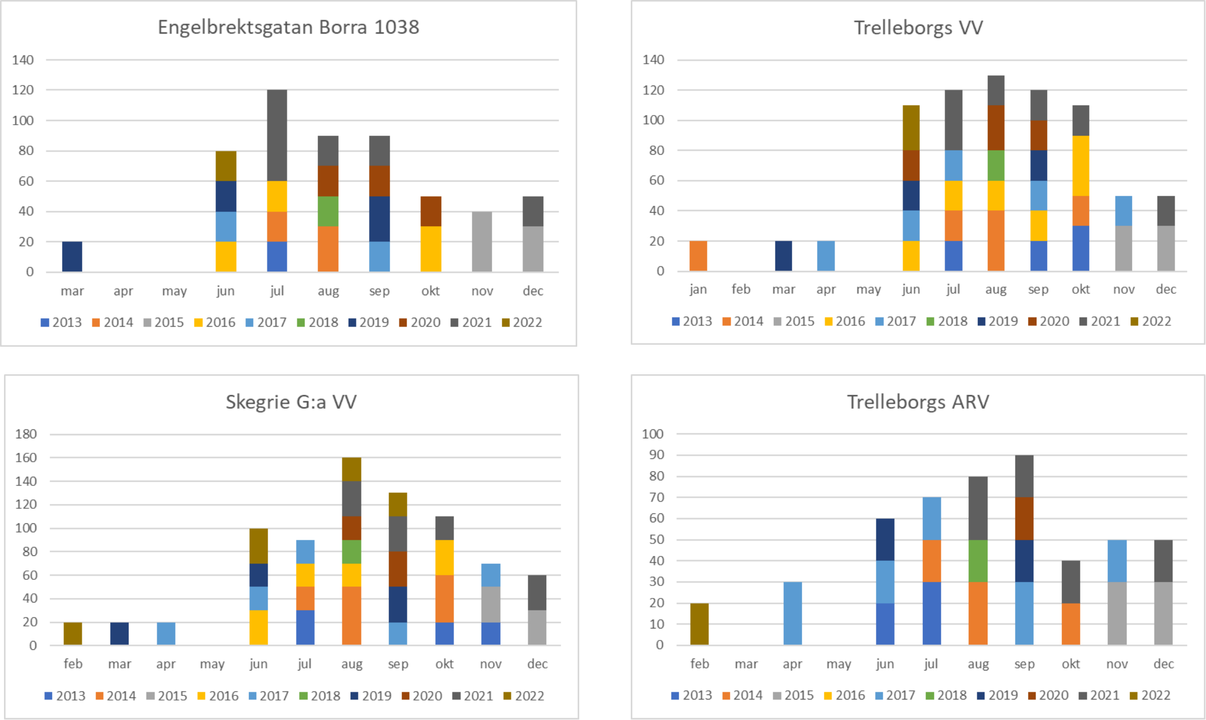


Figure 54: Rainfall quantity graph over the last 10 years. The amount of rainfall is shown by quantity along the Y-axis, for each respective month shown in the

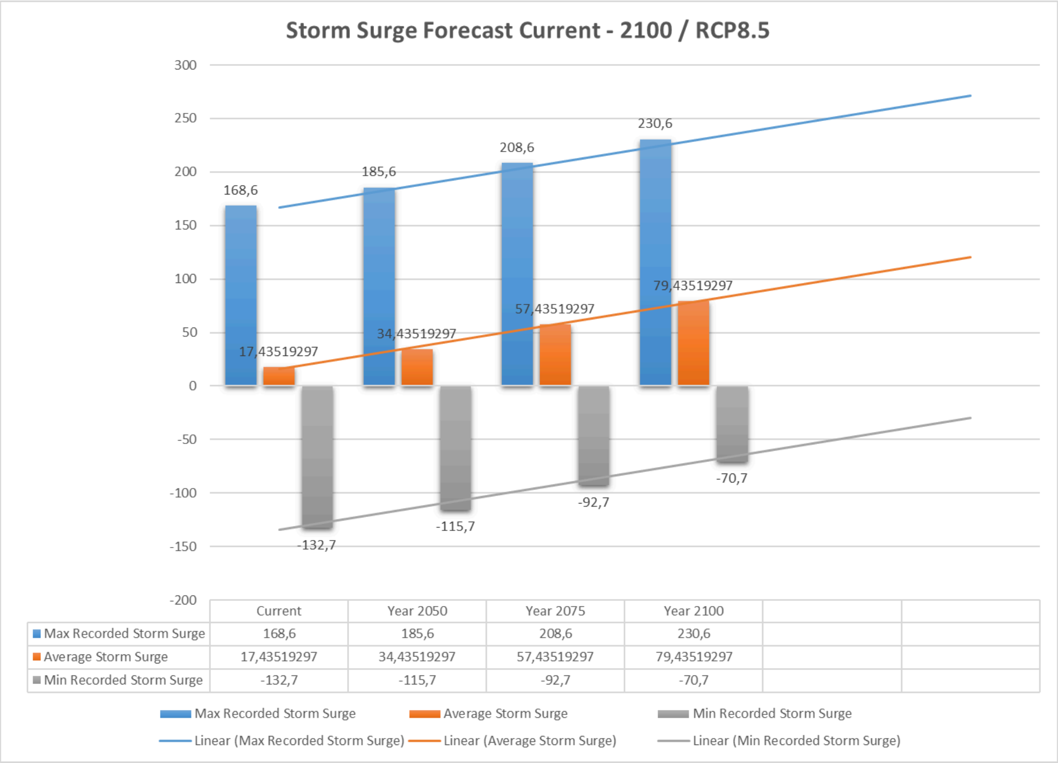
X-axis, and colour coded by year. Each graph is representative of the different measurement stations found in Trelleborg.

According to the study "Evolution of extreme rainfall events over the Indo-Gangetic plain in changing climate during 1901–2010, Journal of Earth System Science,"((51)Bhatla, Rajjev & Verma, Shruti & Pandey, Ritu & Tripathi, A., 2019) the classification for rainfall intensity can vary. They consider "rather heavy rain" to be between 35.6-64.4 mm/day, and "moderate rain" to be between 7.6-35.5 mm/day. However, classifications can differ, as shown in the research "Impact Assessment of Gridded Precipitation Products on Streamflow Simulations over a Poorly Gauged Basin in El Salvador, Water"((52)Jimeno-Sáez, Patricia & Blanco-Gómez, Pablo & Pérez-Sánchez, Julio & Cecilia, José & Senent-Aparicio, Javier., 2021). Due to the complexity of hourly data over a 10-year period, the categorization used on the Adcon website was adapted, where the graph data was limited to 20 mm/day. As a result, different perceptions of heavy rainfall: moderate daily rainfall is considered above 20 mm/day - 30 mm/day, moderate-heavy rainfall is above 30 mm/day - 40 mm/day, heavy rainfall is above 40 mm/day, and extreme rainfall is above 50 mm/day, were estimated.

Over the past decade, the data reveals 2 months of extreme rainfall, 5 months of heavy rainfall, 27 months of moderate-heavy rainfall, and 72 months of moderate rainfall.

Analysing 10-year rainfall data through deviation graphs unveils recent climate shifts. By comparing the last year's precipitation with the preceding nine, we quickly discern changes. This short-term approach, contrary to the traditional 30-year analysis, provides immediate insights into local climate conditions. Incorporating diverse rain stations helps identify regional disparities, and the temporal dynamics reveal cyclic trends or anomalies. Short-term rain deviation graphs are essential tools for adapting to evolving climatic conditions, offering a dynamic understanding of precipitation patterns in a concise format for informed decision-making in critical sectors of the municipality. The rain deviation from different rain stations are important, and these were non-existent before 2013. Rain Deviation graph showing percentage change over a span of 10 years can be seen in Figure 56.

Storm surge data has been a crucial element compiled during this research. The storm surge data and projections were provided by Isabelle Laster Grip, Salar Haghighatafshar, and Henrik Aspegren ((10)Isabelle Laster Grip, Salar Haghighatafshar, Henrik Aspegren, 2021). Salar Haghighatafshar generously shared the data, which facilitated further storm surge analysis. In Figure 32, their comprehensive analysis is depicted, accompanied by the raw data they provided. Among the data, the focus was on understanding maximum recorded and projected storm surges, average values, and the lowest occurrences to inform the simulations to be conducted. In the subsequent figure, the results are illustrated alongside a projected trend post-2100. This simplified graph offers a clear overview of the highest recorded and projected storm surges in a RCP8.5 scenario. This data has been vital for conducting simulations representing worst-case scenarios in our Computational Fluid Dynamics (CFD) simulations.



	Current	Year 2050	Year 2075	Year 2100		
Max Recorded Storm Surge	168,6	185,6	208,6	230,6		
Average Storm Surge	17,43519297	34,43519297	57,43519297	79,43519297		
Min Recorded Storm Surge	-132,7	-115,7	-92,7	-70,7		

Figure 55: Storm Surge Forecast graph from current to year 2100 in a RCP8.5 scenario.

Rain Deviation:

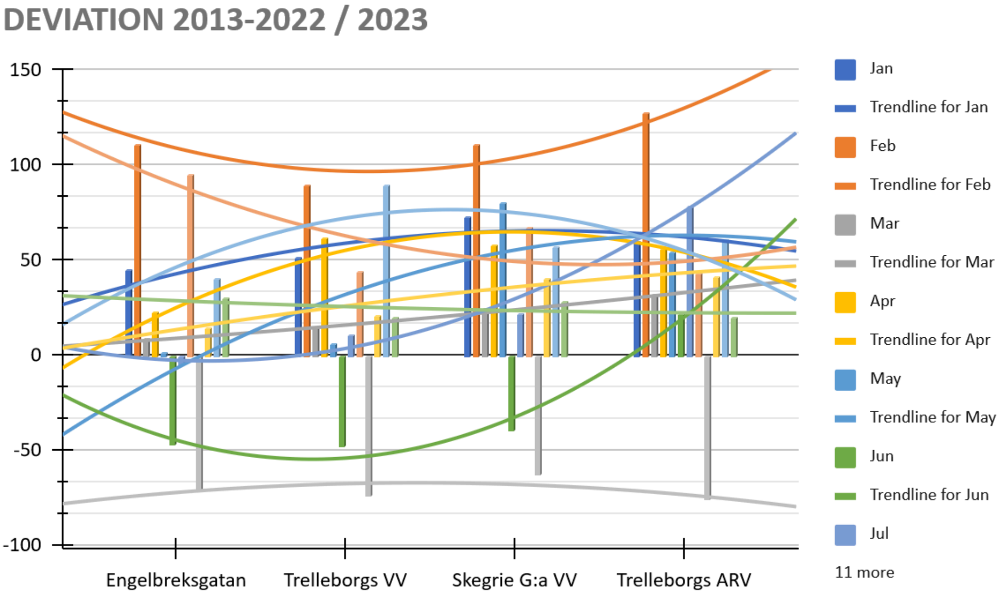


Figure 56: Rain Deviation graph showing percentage change over a span of 10 years.

5. Final Result

The analysis and simulations clearly demonstrate the benefits of employing data-driven simulations in Architectural design. These advantages are evident from the obtained results. Some may argue that simulating these strategies and analysing data are more closely associated with engineering and modelling. However, it's important to recognize that engineering and modelling are integral components of architecture.

- Hold the Line

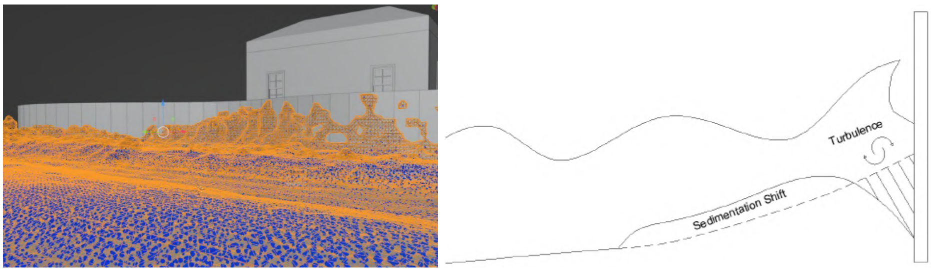


Figure 57: Hold the Line Final Result and Analysis.

While this strategy proves to be highly effective, it comes with notable drawbacks. The forceful collision of water against the sea wall generates turbulent currents that disrupt sedimentation beneath the structure. This long-term disturbance poses a risk to the sea wall's foundation, potentially leading to structural deterioration and eventual collapse. Moreover, the strategy exhibits significant ecological drawbacks, as it detrimentally impacts coastal habitats. As previously discussed, certain coastal management approaches can give rise to "Coastal Squeeze," and this strategy serves as a prime illustration of this phenomenon.

- Managed Realignment (retreat)

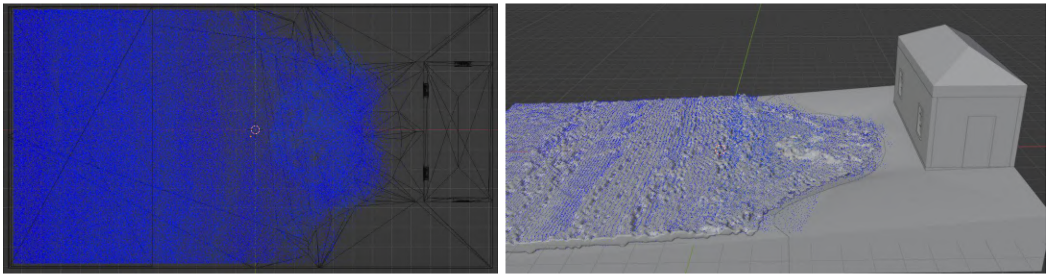


Figure 58: Managed Realignment Final Result, plan view and perspective.

Among the most effective approaches, there is coastal realignment, which involves carefully redirecting water flow and strategically relocating urban structures away from vulnerable areas. However, this strategy comes at a significant cost. It demands substantial investment in extensive topographic modifications and geological interventions. Moreover, it necessitates the sacrifice of existing coastal urban infrastructure. Notably, this implies the potential loss of valuable infrastructure situated near the coastline, which tends to have higher economic value. It's important to acknowledge that there could be governmental motivations to develop the shoreline, closely tied to economic advantages for the coastal community.

- Ecological Multi-layered Realignment (embrace)

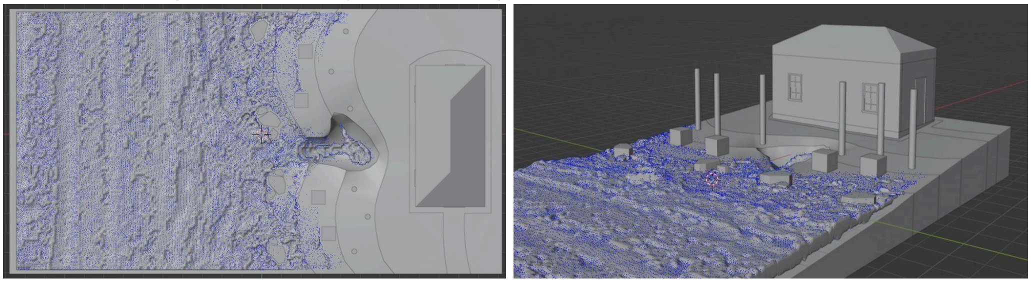


Figure 59: Ecological Multi-layered Realignment plan view and perspective.

While effective, this strategy introduces a potential challenge in the form of turbulence generated by the numerous collider and friction boxes in the simulation. It remains uncertain whether the green layers, meant to mitigate the risk of soil displacement, actually provide the intended benefits. Additionally, the resilience of the various plants and grasses to constant wave fluctuations and Baltic water conditions must be considered.

Furthermore, this approach is intricate and requires a multi-layered implementation, which could result in elevated costs. The strategy involves replacing coastal soil with layers of vegetation designed to act as a buffer against water impact on the soil. These green layers also serve as frictional elements to dampen wave momentum. However, it's important to note that this strategy may encounter challenges in scenarios of reversed water fluctuations, as it also serves as a water retention and barrier zone for rainwater.

- Wave Breakers (disruptive defence)

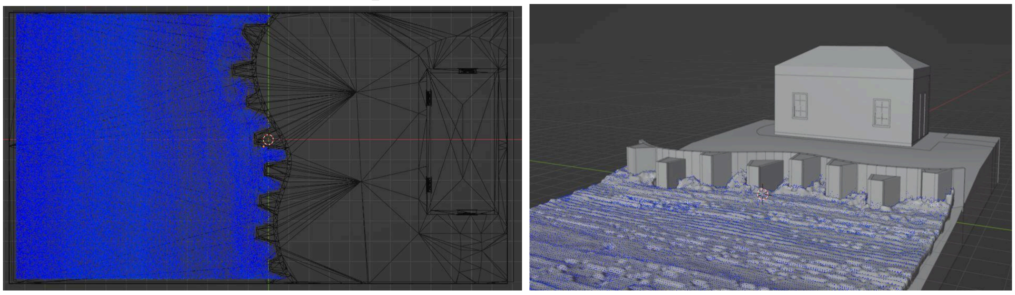


Figure 60: Wave Breakers plan view and perspective.

This strategy shares some similarities with the Hold the Line approach. However, it surpasses the Hold the Line strategy in terms of effectiveness. Unlike the Hold the Line method, this strategy stands out for its ability to reduce wave height significantly. This is achieved by strategically breaking, interrupting, or slicing the waves before they reach the back end of the protective wall. This strategy does entail a more elevated cost, depending on the form and structure.

- Breakwaters or wave interruptor (Engineering)

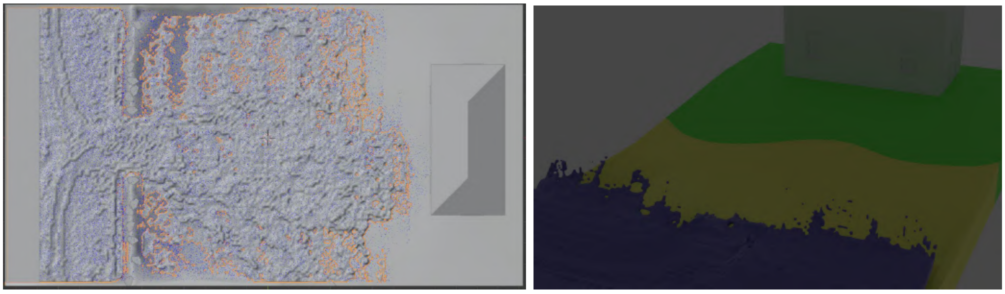


Figure 61: Breakwaters or wave interruptor plan view and perspective.

This strategy stands out as one of the most efficient and environmentally friendly approaches. It effectively establishes a barrier that interrupts or breaks incoming waves, yielding impressive results. However, the outcomes may vary depending on the simulation type employed. Analysis of the simulations indicates that the short-form instant impact wave has limited effectiveness, whereas the still water back point wave formation significantly enhances the water management potential of the Breakwaters/wave interruptor strategy. This difference in impact could be attributed to the presence of still backwater between the wave interrupters and the coastal shore, which arises from the existing wave interrupters and contributes to the formation of a stable water barrier.

- Sea city/eating the Sea (Attack)

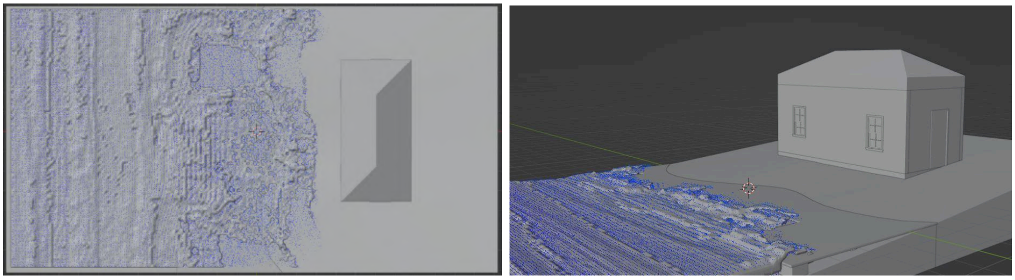
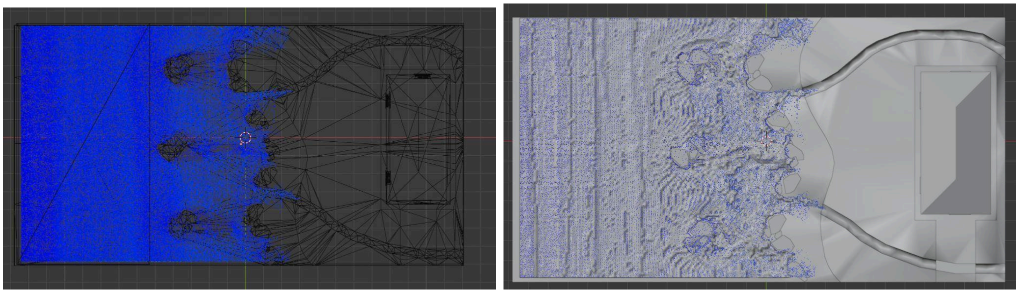


Figure 62: Sea city/eating the Sea, plan view and perspective.

Despite initial observations of a potential advantage, this strategy did not yield significant benefits in the simulation. While the interaction between the water and the underside of the platform seemed to generate a backpush effect during the initial simulations, further analysis and reconfiguration of the simulation revealed less favourable outcomes. Subsequent results indicated that the test house was still prone to flooding, even with the platform's influence.

Strategy Evolution Through Analysed Factors



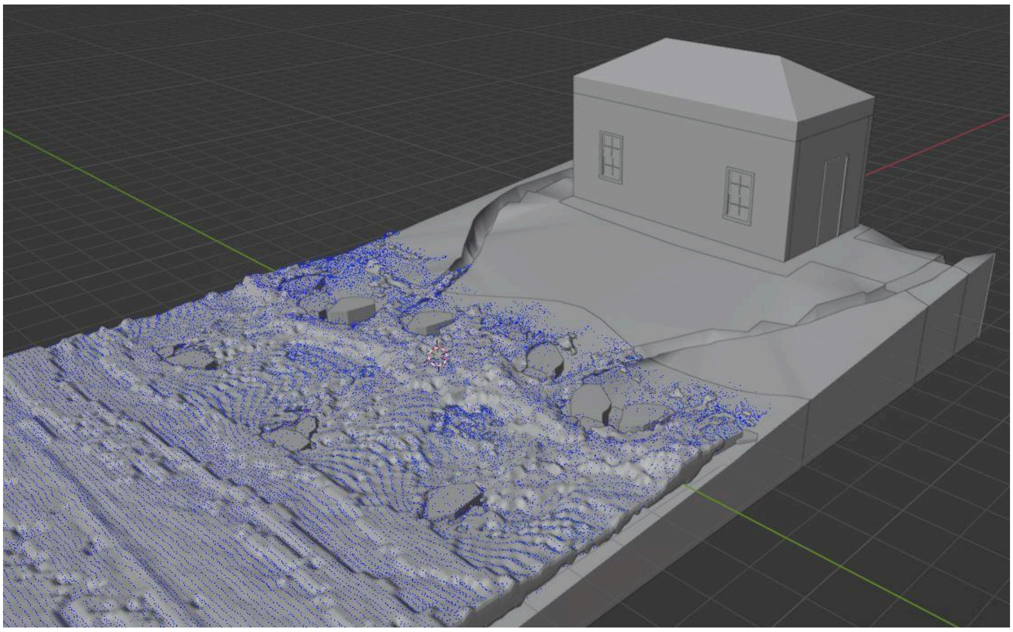


Figure 63: Simulated Strategy, plan views and perspective.

This strategy proved to be successful, although maintaining complete impartiality can be challenging. The simulation results largely demonstrated positive outcomes. The primary objective of this simulated strategy was to outperform other strategies in a holistic sense, which appears to have been achieved. Moreover, financial considerations were integrated into the strategy's design, favouring the utilisation of natural elements over extensive artificial structures. Instead of implementing extensive changes to the topography, the strategy honed in on three specific key topographic nodes. A combination of strategically placed stone colliders and the three topographic nodes effectively guided water toward the dike systems, fostering dynamic and diverse ecosystems. The simulation process proceeded relatively smoothly, with minor discrepancies that were addressed and resolved during the simulation iterations. Additionally, this simulation exhibited fewer instances of high-energy particle clashes compared to other intervention strategies, making it a more transitional and buffering approach.

Figure 53: QR scan code for coastal simulations

Through observations, variations in the effectiveness and advantages and disadvantages of different coastal design strategies were identified. These observations have been instrumental in crafting a data-driven design approach, which has proven highly effective but doesn't directly compete with the more infrastructure-intensive strategies. However, it's important to note that these simulations do not encompass long-term structural wear and tear, ecological consequences, economic costs, social benefits, and other critical factors that must be carefully considered. The following chart and table illustrate the various factors considered in different coastal design strategies. It is important to note that the factors related to flood risk reduction and wave height reduction are derived from simulations. In contrast, the other factors have been evaluated based on literature references.

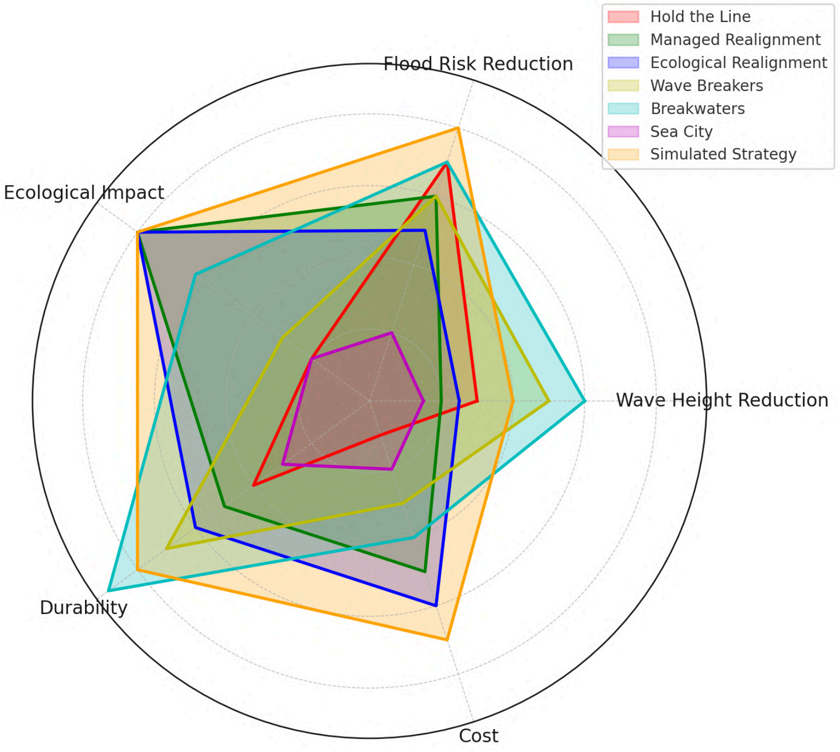


Figure 64: Chart illustrating difference between design strategy

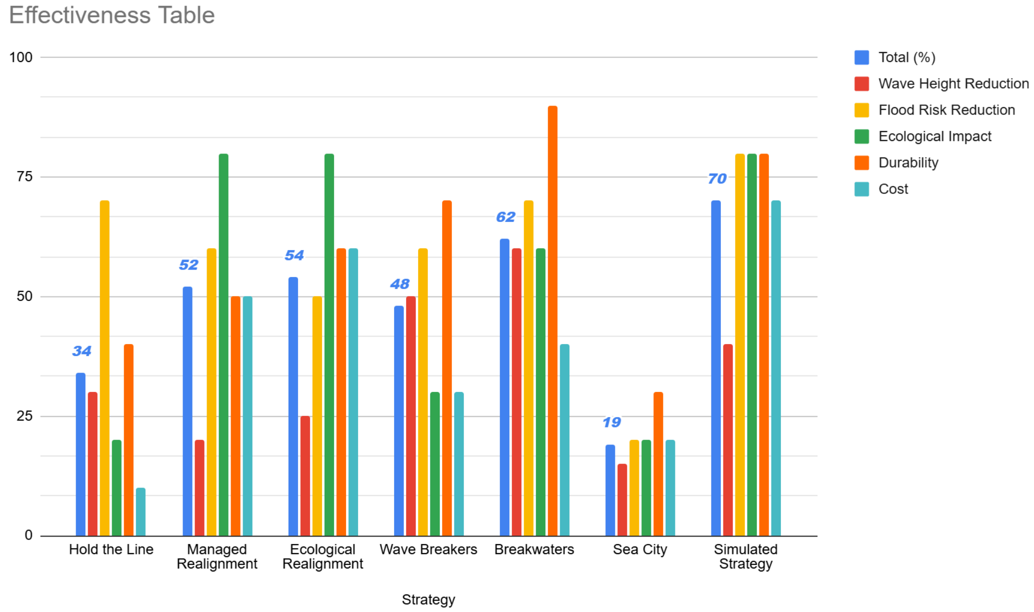


Figure 65: Table illustrating difference between design strategies

6. Discussion

This research faced significant challenges in compiling and managing data to establish accurate parameters for simulating a coastal area. Constraints related to computational processing, data sourcing, and permissions necessitated a recalibration of the project's scope, focusing on effectively communicating core findings rather than conducting exhaustive simulations. A key insight revealed was the adverse flow rate within the coastal drainage system, which, when combined with rainfall, leads to backflow and aggravates flooding. This highlights the interconnectedness of coastal and urban systems, where minor disruptions can trigger cascading effects. While the simulations yielded valuable insights, limitations in exploring critical factors - such as sedimentation patterns and the ecological impacts of specific coastal strategies - persisted. These limitations point to essential areas for future research.

Due to the inability to conduct wider-scale simulations, a conceptual map was developed to extrapolate the small-scale results of the Simulated strategy. This map illustrates how the insights from the simulations could inform city-scale land-use planning, integrating adaptable landscapes and strategic infrastructure to enhance resilience.

The overarching aim of this project is to emphasize the value of data-driven approaches in architecture, particularly amid climate change, as adequate preparedness is crucial for coastal communities facing rising sea levels and severe storm surges.

A central question throughout this research was how executing simulations with established parameters influences our understanding of coastal design strategies and facilitates the development of improved approaches. It became evident that engaging with complex phenomena like coastal flooding significantly informs design methodologies. The correlation between data analysis and the quality of design responses suggests that design choices increasingly align with practical, resilient solutions through simulation. This raises the question of whether design decisions should increasingly rely on data rather than solely on creative intuition. The simulations indicated that a data-driven approach can often surpass subjective design decisions, particularly in the complex context of coastal flood mitigation. Furthermore, the potential for proficient AI to analyze vast datasets and run simulations poses an intriguing possibility for future design practices.

However, the resource-intensive nature of large-scale simulations is a critical consideration. This research was limited by the lack of access to specialized software such as REEF3D, which would have enabled detailed simulations of sedimentation flow and wave interactions. The advanced visualization capabilities of tools like ParaView would have further enhanced the clarity of findings, yet time and resource limitations hindered exploration of these opportunities.

Despite these challenges, the use of Blender for smaller-scale simulations proved effective in generating meaningful insights. This underscores that even basic simulation tools can inform design strategies, emphasizing the feasibility and necessity of data-driven design for addressing complex environmental challenges. Such simulations provide architects with a clearer understanding of how their designs will perform under real-world conditions, enabling earlier strategy refinement and potentially reducing costly missteps.

In conclusion, while technical and logistical constraints impacted this study, it demonstrates the potential of integrating data-driven methodologies into architectural workflows. Simulating and analyzing data within established parameters reveal that evidence-based design can lead to more robust, resilient solutions for coastal flooding. Future research should address the identified limitations by incorporating advanced computational tools and expanding the scope for larger-scale simulations, thereby harnessing the power of data to create sustainable, climate-resilient urban environments.

7. Conclusion

This thesis underscores the critical role of data-driven simulations in shaping coastal design strategies, particularly in addressing the pressing climate challenges faced by urban areas like Trelleborg. Using computational fluid dynamics (CFD), the research directly analysed tidal waves and sea level rise, while other important factors such as sedimentation, erosion, and broader environmental impacts were incorporated through theoretical research based on global case studies.

The analysis revealed that the Simulated Strategy and Wave Breakers provided the most effective balance of flood risk reduction, ecological benefits, and durability, while Sea City proved least effective. Hold the Line offered strong short-term protection but raised concerns over long-term ecological damage, particularly due to sediment disruption. These findings emphasise the need to align design strategies with both ecological and functional goals.

This research also emphasises the importance of city-scale land-use planning. A conceptual map illustrates how the simulated strategy could reshape Trelleborg's coastal zone, integrating adaptable marshlands, wave interrupters, and dike systems for ecological and commercial benefits.

One of the study's key limitations was the lack of computational power, requiring scaled-down simulations. More advanced tools like REEF3D could have offered deeper insights into long-term effects such as sedimentation patterns and ecosystem resilience. Nonetheless, this research highlights the importance of expanding simulation parameters to account for social, ecological, and infrastructural factors, acknowledging that coastal resilience requires more than just physical barriers.

This thesis emphasises the urgency for municipalities like Trelleborg to adopt data-driven methodologies in preparing for worst-case climate scenarios, such as those under RCP8.5. Strategies must integrate ecological preservation with urban flood protection to safeguard both urban infrastructure and fragile ecosystems.

Moreover, incorporating social factors into future analysis is essential. Understanding how communities interact with coastal environments and how design strategies affect human behaviour, access, and well-being is crucial for a holistic approach to resilience.

In conclusion, this research highlights the necessity of data-driven, ecologically integrated design strategies to address climate challenges. Future research should incorporate technological advancements and further explore social-ecological dynamics, urging municipalities to take proactive steps in protecting both urban and natural environments from the looming threats of rising sea levels and extreme weather events.

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Appendix:

- 1. Rain data excels
- 2. Stormwater excels

- 3. Simulation videos and render analysis, Arcgis data and animations