Port Stormwater Sewer Design from an Asset Management Perspective

By Magnus Mulder

Preface

This bachelor thesis was written as a part of the Bachelor curriculum of Civil Engineering in HZ University of Applied Sciences. The project was carried out at North Sea Port, the asset management company responsible for the harbors of Gent and Vlissingen.

This thesis is a valuable change for me to explore my interests I have in the professional field. This engaging topic gave me an opportunity to develop a very multifaceted research. Working with a company that sits between government and private business gave me experience with both types of work. Moreover, new skills of parametric design are obtained during this thesis, opened a different view on how the projects in my future career can be approached.

I would like to thank North Sea Port asset manager Bas de Pagter, my supervisor, who has been very supportive in my approach to the work and has pushed me to refine my work. He gave very straight-forward comments and opinion on my work, helped me to keep-up with the scope when my inspiration flourished to different directions, but at the same supported the originality of my methods. Large gratitude to my university supervisor, Marco Gatto, for constant support and inspiration.

Finally, I would like to thank my family and friends. Even being so far I felt your constant support and it motivated me most of all.

Magnus Mulder, Middelburg, June 2023

Abstract

The following report gives a full description of the Bachelor Civil Engineering graduation project. The graduation is done in North Sea Port. The company requires a new design for the rainwater sewer system in part of the Vlissingen-Oost harbor. The project is done in parallel with that of a company contracted to solve the same problem, the difference being the approach. The main idea of the following thesis is to provide the client with the most efficient design which includes consideration for asset management, functional requirements, and future prospects of the design.

Although the design of the system must be done to consider the existing businesses, it is not enough to look at the problem from the present point of view only. Consideration should be made for the future expansion of the businesses in the area and the need for more drainage.

Based on the need for such an effective design, three alternatives are detailed that provide a range of functionality and preparedness for the future. Then they are scored based on a set of criteria made from the stakeholder requirements and the tenets of asset management. After that, the winning alternative is parametrically developed as a final design of the current thesis project. Stormwater studio is used for the design development and parametric load, nodes, capacities, and cross-sections for the design. Moreover, it is used, and profile drawings are obtained as one of the final products of the project. The conclusion shows that the final design fulfills the consideration of all the requirements for the following research and satisfies the minimum demands of the preliminary hydrological design.

Colophon

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1 Introduction

1.1 Background

North Sea Port[1] is a large European seaport company located in the Netherlands and Belgium. The company was established in 2018 as a merger between the Dutch port of Zeeland Seaports and the Belgian port of Ghent. North Sea Port is now the third-largest seaport in Europe in terms of cargo volume, after the ports of Rotterdam and Antwerp.

The company operates from two main locations: the Dutch port of Vlissingen and the Belgian port of Ghent. North Sea Port offers a range of services to its customers, including cargo handling, warehousing, and transportation. The company's strategic location at the mouth of the Scheldt River and its proximity to major industrial centers in Europe make it an ideal hub for trade between Europe and other parts of the world.

North Sea Port has a strong focus on sustainability and environmental responsibility. The company has implemented a number of initiatives to reduce its carbon footprint, including the use of renewable energy, the development of sustainable transportation options, and the promotion of circular economy principles. North Sea Port also places a high priority on safety, security, and efficiency in its operations.

The company's customer base is diverse, including companies from the chemical, automotive, and logistics industries, among others. North Sea Port's strategic location and excellent infrastructure make it an attractive option for companies looking to import or export goods from Europe.

Due to the continued importance and expansion of the global maritime trade, more and more interest is coming to the harbor of Vlissingen, and thus the need to expands is becoming greater. The benefit for North Sea Port is their role in the port, and their ability to prepare ahead of this expansion. Thus the need to begin the preparation of the infrastructure to cope with the new interest in the harbor areas.

1.2 Research Problem

1.2.1 Location

The Thermphos Terrein[2],also known as the former Thermphos site, is a large industrial complex located in the harbor of Vlissingen-Oost, in the Netherlands. The site was originally owned by the Dutch government and operated as a state-owned phosphate plant. It was later privatized and operated by the company Thermphos International BV from 2005 to 2012.

The history of the Thermphos Terrein can be traced back to the early 20th century when the Dutch government decided to build a fertilizer factory at the site. Construction began in 1913 and the factory started production in 1918. Over the years, the factory expanded and became a major producer of phosphates and other chemicals.

[1] (North Sea Port, 2023) (Provincie Zeeland, 2023)

[2] (Provincie Zeeland, 2023)

During World War II, the factory was occupied by German forces and used for the production of synthetic fuel. After the war, the factory was returned to the Dutch government and continued to produce phosphates until the 1990s.

In 2005, the Dutch government sold the Thermphos Terrein to the company Thermphos International BV, which continued to produce phosphates and other chemicals at the site. However, the company faced financial difficulties and went bankrupt in 2012. The bankruptcy left behind a large industrial complex with significant environmental contamination.

Since the bankruptcy, the Dutch government and the province of Zeeland have been working to clean up the site and prepare it for redevelopment. The cleanup process has been complex and costly, involving the removal and treatment of contaminated soil and groundwater.

Today, the Thermphos Terrein , now the von Cittersterrein, is a brownfield site that is being redeveloped for a variety of uses, including a new port terminal, a green energy park, and a nature reserve. The site's history as an industrial complex has left behind a legacy of environmental contamination, but efforts are being made to transform the site into a more sustainable and valuable asset for the region.

1.2.2 Company Role

One of the main roles of North Sea Port, and the field of research for this project, is underground infrastructure, which plays a critical role in the functioning of harbors. It refers to the network of pipes, cables, and other structures that are located underground and are essential for the operation of various systems and services in the harbor. Here are some examples of underground infrastructure in harbors:

Utility lines

Harbors require a range of utilities to function, including water, electricity, gas, and telecommunications. These utilities are often supplied through underground pipes and cables that run throughout the harbor.

Sewage and drainage systems

Harbors generate a significant amount of wastewater, which needs to be collected, treated, and discharged safely. This requires the installation of a complex network of underground pipes and pumps that collect and transport the wastewater to the treatment plant.

Fuel storage tanks

Large volumes of fuel are required to power the vessels that dock at the harbor. Fuel storage tanks are often located underground to save space and reduce the risk of spills or leaks.

Tunnels and underground structures

Some harbors have tunnels or underground structures that provide access to various parts of the harbor, such as storage areas, workshops, or offices.

Cooling systems

Many harbor facilities, such as power plants and container terminals, require cooling systems to prevent overheating. These systems may include underground pipes that circulate chilled water or other coolants.

1.2.3 Stakeholders

North Sea Port

Flooding and drainage management: Port areas are often at risk of flooding due to their proximity to bodies of water and their low-lying position. Rainwater sewers help to manage the flow of rainwater and prevent flooding, which is important for protecting infrastructure, ensuring safe working conditions, and preventing damage to equipment.

Utility Companies

There are multiple utility companies in a port, as anywhere, and they all have a vested interest in the design of a rainwater sewer system, albeit for different reasons.

- Evides: Evides is the water and water treatment company for Zeeland and thus is directly involved in the system, as the rainwater which is considered contaminated by air pollution or surface materials is generally routed to the wastewater systems for treatment.
- Sloecentrale: In port areas where there is a risk of flooding, the Sloecentrale, or power plant, is interested in the design of rainwater sewers to prevent water damage to electrical equipment and to maintain uninterrupted electrical service.
- Delta: As the communications and energy company in Zeeland, Delta is the involved in the underground infrastructure used to supply the businesses in the area and thus has a vested interest in the safety of their infrastructure. They are interested in the design of rainwater sewers in port areas to protect their infrastructure from damage caused by flooding and to prevent the buildup of water that could potentially pose a safety hazard.

Businesses

The project area is already home to several businesses who will be making use of the new stormwater sewer, as well as multiple new businesses. Each of these businesses has an interest in the new system for safety reasons, both to avoid flooding of their facilities and also potentially for the image of their companies in the public. Another benefit for the companies is the potential for them to establish fire-fighting reservoirs, filled with the rainfall in the area.

Local Government

Many port areas are subject to environmental regulations regarding water quality and drainage management. By designing and implementing effective rainwater sewers, utility companies can ensure that they are in compliance with these regulations and avoid costly fines and penalties.

1.2.4 Asset Management

Infrastructure Asset Management is a type of management system that is used to track and manage the physical components of a company's infrastructure. It includes activities such as inventory tracking, maintenance and repair tracking, cost management, and performance monitoring. The goal of infrastructure asset management is to improve the efficiency of the assets and extend their useful life. It also helps to minimize long-term repair and maintenance costs, improve the quality of service, and reduce the environmental impact of assets. By incorporating the aspects of asset management into the design phase of the assets the potential efficiency and effectiveness of the assets is increased greatly. It also helps keep the system safe and cost effective, by minimizing the lifecycle costs.

1.2.5 Scope

The research scope is defined in order to be able to set an objective for the project and stick to the objective through the entire project flow. Project scope is based on the requirements given by the stakeholders of the following graduation research:

List of Requirements:

- Feasible and safe design
- System can handle design rainfall capacity
- Connected businesses have minimized flooding risk
- The new system should be accessible for good maintenance and monitoring purposes
- Existing segments of the rainwater system must be incorporated into the new system
- Minimal risk of conflict with existing underground infrastructure during construction and use phases

The research in this report focuses mainly on the design of the new rainwater sewer system for the existing and future businesses. Special consideration will be given to the principles of Asset Management when assessing the variants for the final design, to ensure that the system will have an optimal lifespan. The primary rainwater outlet at the southern boundary of the project area will be focused on, however the merits of using an additional outlet on the north side will be considered. The aspects used to assess the merits of each variant will be discussed later in the report.

1.3 Research Question

1.3.1 Main Question

What is the most effective design for the expansion of the rainwater system at the Van Cittersterrein in Vlissingen Oost Harbor, from an Asset Management perspective?

1.3.2 Research Sub-Questions

- What is the most effective flow path for the rainwater system?
- What is the most efficient cross-sectional design for the system?
- How can the system be optimized for Asset Management?
- How can the design be optimized for Maintenance?

1.4 Objective

The goal of this project is to develop an effective and efficient design for a new rainwater sewer system, while taking Asset Management principles. Optimally, the design will cover the safety, hydrological, and mechanical requirements of the stakeholders of the project. Not only should the requirements be met, but the design should be made so that the maintenance and monitoring of the system is as efficient as possible.

2 Theoretical Framework

This chapter gives an opportunity to consider the research problem from several aspects. The majority of the required information on the current project topic is introduced. The theoretical background is separated into three parts: hydrological, mechanical, and asset management requirements of the system. Hydrological requirements contain information on what kind of rainfall and its scenario are used to test the system, what is the calculation procedure that has to be followed in order to obtain reliable results. In order to discuss mechanical requirements, hydrological requirements of the roof have to be primarily considered. The next step is to determine the mechanical requirements of the system: how to calculate the required dimensions etc. and what are the major concerns therein. Lastly, Asset Management is defined to establish the requirements to make it an effective design.

2.1 Hydrological Design

The hydrological design of a stormwater sewer involves determining the amount of stormwater runoff that will flow through the sewer and designing the sewer to safely convey that flow. In the case of this project, the main points for the design are the rainfall scenario and the runoff design.

2.1.1 Rainfall Scenario

The aim for this design is to be able to test a newly designed urban water system against the expected precipitation in the future. In 2015, the KNMI[3] presented scenarios with forecasts of the development of the climate in the future. An increase in extreme precipitation is expected in all scenarios. One of the scenarios, 2050 high, assumes an increase to 25% of the maximum annual hourly sum in 2050. Of the four climate scenarios (2014, 2030, 2050, and 2085) this is the scenario with the largest increase in the extreme precipitation 1. Scenario 2050 low is the most moderate in terms of increase in extreme precipitation; in this scenario, the smallest increase in the maximum annual hourly sum is 5.5% in 2050. The high and low scenarios thus together indicate the bandwidth within which extreme precipitation is expected to develop in 2050.

For this project the scenario 2085 low will be used, largely due to the design being with a 50+ year design lifespan. The hydrograph for this design storm can be seen below in Figure 1. This scenario is for slightly more than 60 years in the future, however it is important to consider the future changes, namely in rainfall, when designing infrastructure. Especially for a system that will be underground in an industrial area.

[3] (KNMI, 2020)

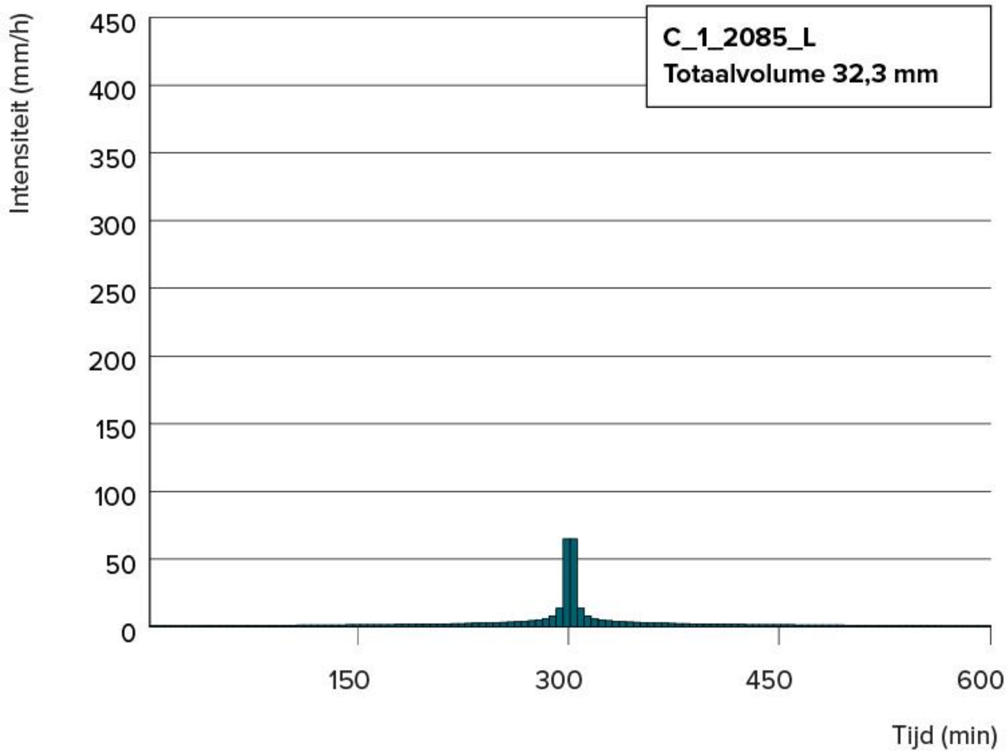


Figure 1: Composite Shower 2085 Scenario Low

2.1.2 Runoff Design

The plan for the design of the runoff collection of the new rainwater sewer is for the companies that will be connected to the new line to do the collection of the rainwater on site and the feed it into the network at a single point each, or, in the case of employing a second outlet to the sea, multiple points. This goes more for the incoming hydrogen plant (D in Figure 2) than the other areas due to the larger area and central location which can be seen in Figure 2 below. The decision to use a second outlet will be explored later, together with the fact that catchment X represents a new rainwater storage basin to be used as a buffer for extreme scenarios.

Figure 2: Overview of Catchment Areas

2.2 Mechanical Design

The mechanical design of a stormwater sewer involves determining the physical specifications and materials required to construct the sewer and ensuring that it will be structurally sound and durable. Based on the hydrological conditions, and with the existing segments of the previous system, the mechanical design of the new stormwater system will be determined.

2.2.1 Pre-Existing Segments

The information of the existing segments of the rainwater system (diameter, rationale, and location) were provided by North Sea Port:

- The existing seawater sewer on the landward side of the dike has an inner diameter of 1400 mm. The material is concrete, with acid-resistant tiles on the inside (Figure 3)
- The connection elevation for the new system to the existing segment is +1.78 m NAP (Figure 4).

- From a collector tank on the landward side of the dike, 2 steel/PE tubes of 1200 mm discharge into the Westerschelde.

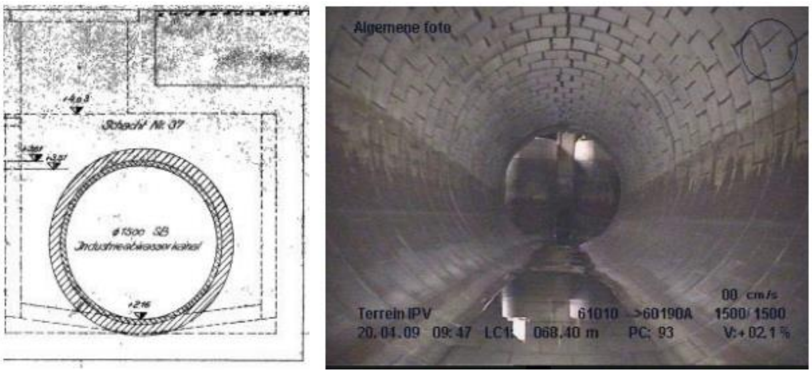


Figure 3: Existing Landward Sewer Cross Section

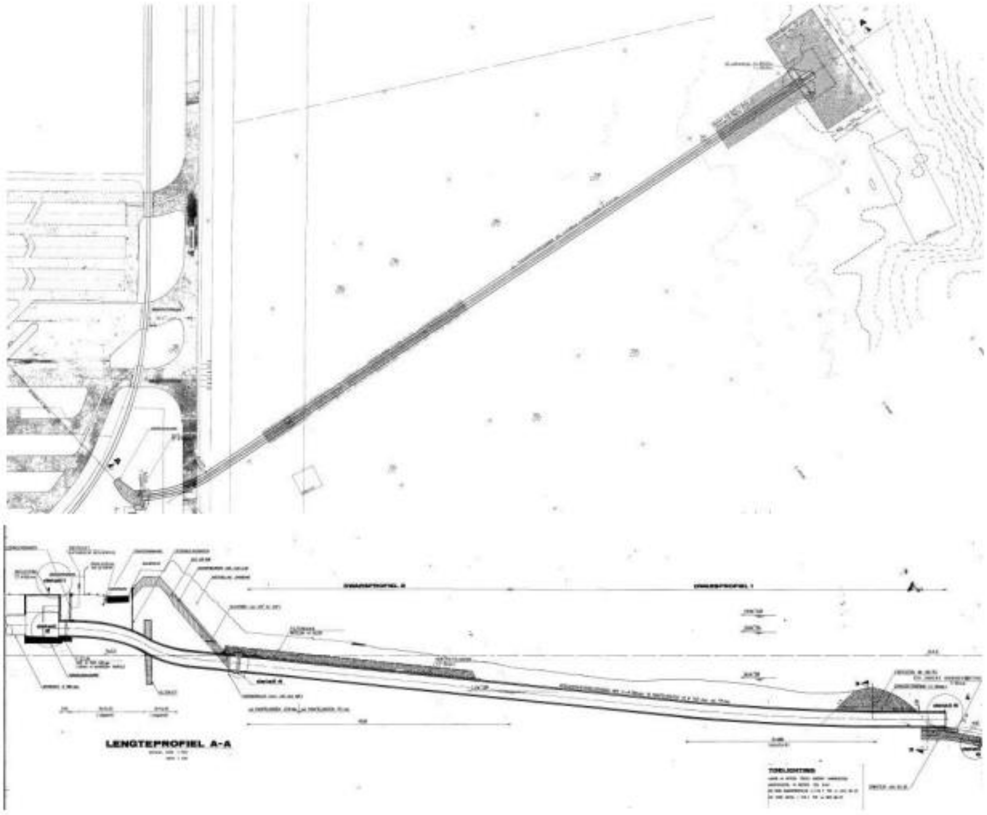


Figure 4: Overview Outlet Westerschelde

Figure 5 Existing Stormwater Outlets

In Figure 5 the locations of the existing outlets to the Scheldt area shown. Each is left from the previous design in the event that new business would need to make use of them, as is the case now. The details and merits of each of these outlets will be discussed later in this report.

2.2.2 New System

There are several parts to the process of designing a new stormwater sewer system, and a few more when taking Asset Management into account during the process. The main tasks and their rationale are shown below, with mode detail later in the report.

Stormwater run-off management

Develop a comprehensive stormwater management plan to ensure runoff is redirected to prevent flooding, inefficient grading and sedimentation, and to mitigate breaching the capacity of the system.

Catchment area designs

Design the catchment area to reduce the risk of flooding and facilitate collection of rainfall runoff in an efficient manner.

Infrastructure requirements

Determine the necessary infrastructure requirements to accommodate the flow of water, such as large pipes or storage areas.

Sewer layout and positioning

Design the sewer lines in a way that minimizes impacts on maintenance, access, and existing infrastructure. It is also done to minimize the cost of the new system and to make use of the existing infrastructure where possible.

Sewer profiles

Design the cross-sections and altimetry of the new system to ensure minimal flow and minimal sedimentation in the system.

2.2.3 Rainwater Storage

A rainwater buffer reservoir plays a crucial role in a port rainwater sewer system by managing and controlling the flow of rainwater runoff. It acts as a storage facility for excess rainwater, preventing flooding and overloading of the sewer system during heavy rainfall events. Here's an explanation of its role:

Rainwater Collection

The rainwater buffer reservoir collects rainwater from various sources within the port area, such as rooftops, paved surfaces, and open areas. The water is channeled into the reservoir through a network of gutters, drains, and pipelines.

Storage Capacity

The reservoir is designed to have a significant storage capacity, allowing it to store a large volume of rainwater during intense rainfall periods. The storage capacity depends on the size of the port and the anticipated rainfall patterns.

Regulation of Flow

When it rains, the reservoir fills up with excess rainwater. Instead of allowing the water to directly enter the sewer system, which can overwhelm the capacity of the system, the reservoir regulates the flow. It acts as a buffer, slowly releasing the collected rainwater into the sewer system at a controlled rate.

Flood Prevention

By controlling the flow of rainwater, the reservoir helps prevent flooding in the port area. It reduces the risk of excessive runoff entering the sewer system simultaneously, which can cause backups, surcharges, and flooding in low-lying areas.

Peak Load Management

During heavy rainfall events, the reservoir absorbs the peak load of rainwater runoff. By temporarily storing the excess water, it reduces the strain on the sewer system, allowing it to function within its capacity. This helps maintain the efficiency and performance of the entire rainwater sewer system.

Water Reuse

In some cases, the rainwater buffer reservoir may incorporate systems for water reuse. The collected rainwater can be treated and repurposed for various non-potable applications within the port area, such as irrigation, washing equipment, or even for fire-fighting purposes. This promotes sustainability and reduces the demand for freshwater resources.

Overall, a rainwater buffer reservoir is an essential component of a port rainwater sewer system. It acts as a control mechanism, ensuring the efficient management of rainwater runoff, preventing flooding, and protecting the integrity of the sewer infrastructure.

2.3 Asset Management

Asset management in rainwater sewer design involves identifying and managing the physical assets associated with rainwater sewer systems. The primary objective of asset management in rainwater sewer design is to ensure the reliable and efficient performance of the sewer system, while minimizing maintenance costs and ensuring long-term sustainability.

2.3.1 Maintenance

Maintaining stormwater sewers in harbor areas is crucial for the efficient and sustainable management of water resources, prevention of flooding, and protection of the marine environment. These sewer systems are designed to handle large volumes of water runoff during storms, ensuring the smooth flow of water from urban areas into the harbor without causing damage or pollution. Regular maintenance and inspection of stormwater sewers are necessary to identify and address potential issues, minimize the risk of system failures, and ensure the overall functionality of the infrastructure. This article will explore the importance of stormwater sewer maintenance in harbor areas and discuss some essential practices.

Inspection and Cleaning

Regular inspection and cleaning of stormwater sewers are fundamental maintenance activities. Sediment, debris, and pollutants can accumulate in the sewer pipes, leading to reduced capacity and increased risk of blockages. Periodic inspections using CCTV cameras can help identify any signs of damage, cracks, or obstructions. High-pressure water jetting and vacuum cleaning techniques can be employed to remove accumulated sediment and debris, restoring the sewer's capacity and flow efficiency.

Preventive Maintenance

Preventive maintenance plays a crucial role in minimizing the occurrence of major sewer failures. It involves routine checks, repairs, and replacements of aging or damaged components. This can include the repair of cracks, joints, or leaks in the sewer pipes, as well as the replacement of worn-out or corroded sections. By addressing potential issues before they escalate, preventive maintenance helps ensure the reliability and longevity of the stormwater sewer system.

Vegetation Management

Harbor areas often contain a significant amount of vegetation, including trees and shrubs. While greenery enhances the aesthetics of the surroundings, it can also pose challenges to stormwater sewer maintenance. Tree roots, for example, have the potential to infiltrate sewer pipes, causing blockages and structural damage. Implementing a proactive vegetation management plan, which includes regular pruning and root barrier installations, can help mitigate these issues and prevent costly repairs.

Public Awareness and Education

Creating awareness among the public about the importance of stormwater sewer maintenance is essential. Educating residents, businesses, and other stakeholders about the proper disposal of waste, the impact of pollutants on the marine environment, and the need for responsible water management can contribute to the overall health of the stormwater sewer system. This can be achieved through public campaigns, informational materials, and community engagement programs.

2.3.2 Monitoring

Inspection of stormwater sewers in harbor industrial areas is of utmost importance to ensure the proper functioning of the drainage system, prevent environmental contamination, and maintain regulatory compliance. These areas often experience higher volumes of runoff, potentially containing pollutants from industrial activities, making regular inspections essential. By conducting thorough inspections, potential issues can be identified early on, allowing for timely maintenance and repairs. Here are some key aspects of stormwater sewer inspection in harbor industrial areas.

Scheduled Inspections

Implementing a regular inspection schedule is crucial in harbor industrial areas. A predetermined frequency should be established based on the specific needs of the area and the potential risk of pollution. Depending on the size and complexity of the stormwater sewer system, inspections can be conducted monthly, quarterly, or semi-annually. These scheduled inspections ensure that any emerging problems are detected promptly.

Water Quality Sampling

In harbor industrial areas, stormwater runoff may carry various pollutants such as heavy metals, chemicals, oils, and sediments. As part of the inspection process, water quality sampling can be conducted at specific locations within the stormwater sewer system. This involves collecting water samples and analyzing them for pollutant levels. Monitoring water quality provides valuable data on the effectiveness of pollution control measures and helps identify potential sources of contamination.

Record-Keeping

Maintaining comprehensive records of stormwater sewer inspections is crucial for tracking maintenance activities, identifying recurring issues, and demonstrating compliance with regulatory requirements. Records should include inspection dates, findings, repairs conducted, and any water quality test results. This documentation serves as a valuable reference for future inspections and allows for a proactive approach to maintenance.

Compliance with Regulations

Harbor industrial areas are often subject to stringent environmental regulations concerning stormwater management. Inspections should align with these regulations, ensuring compliance with permits and requirements set by local or national authorities. Regular inspections help identify potential violations and provide an opportunity to take corrective action promptly, avoiding penalties and reputational damage.

Collaborative Approach

Effective stormwater sewer inspection in harbor industrial areas requires collaboration between different stakeholders, including environmental agencies, local authorities, and industrial facility operators. Establishing partnerships and communication channels among these entities facilitates information sharing, ensures coordinated efforts, and promotes a holistic approach to stormwater management.

2.4 Design Approach

2.4.1 Stormwater Studio

Stormwater Studio is a comprehensive software program used for stormwater management and analysis. It is designed to assist engineers, urban planners, and environmental professionals in modeling and evaluating stormwater runoff, drainage systems, and water quality impacts. Stormwater Studio provides a range of tools and features to simulate, analyze, and design stormwater management strategies.

Key features of Stormwater Studio include:

Hydrologic Analysis: The software allows users to perform hydrologic analysis by employing various methods such as the Rational Method, SCS (Soil Conservation Service) method, or the NRCS (Natural Resources Conservation Service) curve number method. These methods estimate stormwater runoff based on rainfall characteristics, land use, soil type, and other parameters.

Hydraulic Analysis: Stormwater Studio enables hydraulic analysis by simulating the flow of stormwater through different drainage systems, including pipes, channels, culverts, and detention/retention ponds. It considers factors such as pipe sizes, slopes, and hydraulic constraints to evaluate flow rates, velocities, and water surface elevations.

Water Quality Analysis: The software includes capabilities to assess the water quality impacts of stormwater runoff. It considers pollutant loadings, such as sediment, nutrients, and metals, and provides tools to estimate pollutant removal efficiencies of various stormwater treatment practices.

Stormwater BMP Design: Stormwater Studio supports the design of best management practices (BMPs) or stormwater control measures (SCMs) to mitigate the impacts of stormwater runoff. These may include bioretention basins, infiltration trenches, rain gardens, green roofs, or proprietary treatment devices. The software assists in sizing and locating these BMPs based on site-specific conditions and regulatory requirements.

GIS Integration: The software often integrates with geographic information system (GIS) platforms, allowing users to import and work with spatial data such as digital elevation models, land use maps, and hydrologic features. This integration enhances the accuracy and efficiency of stormwater modeling and analysis.

Visualization and Reporting: Stormwater Studio typically provides graphical outputs and visualization tools to help users interpret and communicate the results of their analyses. It generates maps, charts, and reports that summarize key findings and aid in decision-making processes.

HEC-22

This is the methodology prescribed by HEC-22, Third Edition. The finer details and equations used in this method is beyond the scope of this report but can be found in the referenced publication. This method follows three fundamental steps and computes energy losses in each step.

Step 1. Entrance Loss

Determines an initial energy level based on either inlet control (weir and orifice) or outlet control (partial and full flow) equations.

Step 2. Additional Losses

This step makes adjustments to the energy level computed in Step 1. These adjustments are based on benching, angles of incoming lines, and plunging flows.

It should be noted that these adjustments can be positive or negative. For example, benching tends to reduce energy losses in which case you may see the EGL line decrease across the junction. In all cases, the adjusted energy level cannot be below the initial energy level as computed in Step 1.

Step 3. Exit Loss

An exit loss is computed from each inflow pipe and is added to the adjusted EGL in Step 2. This newly computed energy level is used as the starting energy (EGL) for the incoming line(s).

3 Methodology

3.1 Design Variants

The variants for this project were designed with several fixed values corresponding to parameters such as terrain elevation and rainfall intensities, to name a few. These values will be explained in the following sections, to be able to highlight the variables that were changed for each of the variants and to provide the necessary clarity for the MCA.

3.1.1 Rainfall Data

Return Time

It must be remembered that within the urban water cycle, there are going to be dry and wet periods. For this reason, for the design process, the maximum rainwater events will be analyzed, to then create a pluvial system that could safely support the worst-case scenario. This is given by the maximum discharge, which depends on the maximum intensity of the rain event and the probability of the return time of the event. The return time chosen in this first step has been assumed to be 60 years. This value has been chosen based on the composite showers predicted by RIONED and the KNMI[4]. The design rainfall events from RIONED, as mentioned earlier, are from 2014, 2030, 2050, and 2085 where 2085 is the chosen scenario. Moreover, the lifespan of the rainwater system that will be designed in this report, has been chosen to be more than 60 years, as a structure that could only last 25 years or less is nowadays not feasible. Safety needs to be provided for the population of the urban area, but at the same time the structure needs to be cost effective as well. This means that designing a system based on a 25-year life span is not effective, as after the life span improvements need to be made. All these requirements connect to the chosen return time to be 60 years, meaning that this report assumes that the worst-case rain event has a high probability to return in 60 years

IDF Curve

The IDF curve expresses the relationship between rainfall intensity (I), duration (D), and the frequency of occurrence (F). It helps engineers and planners understand the expected intensity of rainfall for a given duration and return period (or recurrence interval). The return period represents the average number of years between the occurrences of rainfall events of a particular magnitude.

The general form of an IDF curve is as follows:

$$I = (\frac{C}{D})^k$$

Where:

I: the rainfall intensity in millimeters per hour (mm/hr)

C: the coefficient related to the average rainfall depth for a specific duration and return period

D: the rainfall duration in hours

[4] (RIONED, 2020)

k: the exponent that determines the shape of the curve and depends on climatic conditions and location.

The IDF curves are typically plotted on a logarithmic scale, with rainfall intensity (I) on the y-axis and rainfall duration (D) on the x-axis. Each curve on the graph represents a specific return period, such as 2-year, 5-year, 10-year, 25-year, or 100-year.

The IDF curves can be used to determine the design rainfall for a specific project by selecting the desired return period and duration. This information is crucial for designing infrastructure to handle different intensities of rainfall events. It helps engineers determine the appropriate capacity and dimensioning of stormwater drainage systems, for example, to ensure they can handle the expected rainfall.

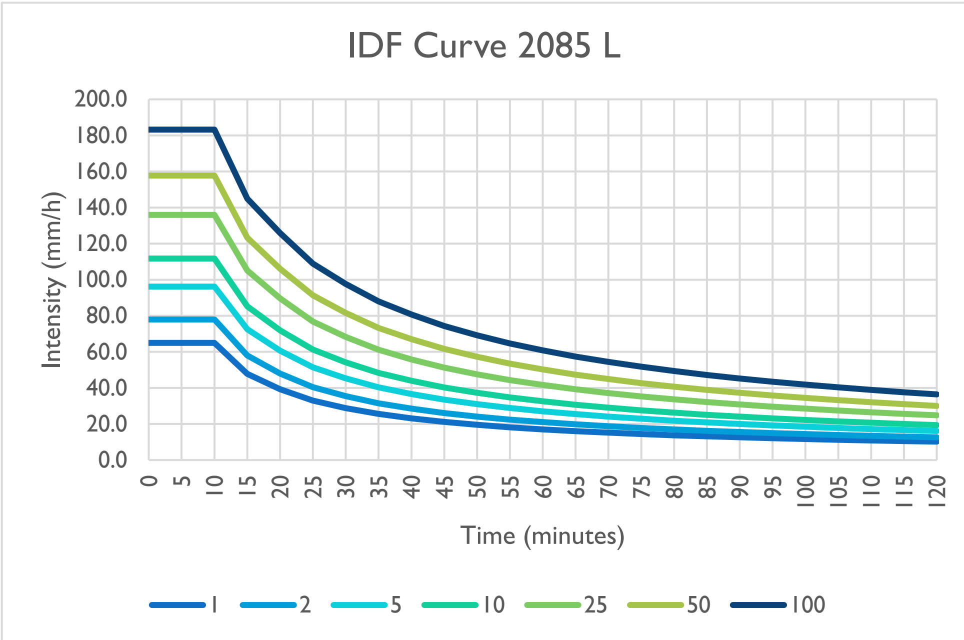


Figure 6 IDF Curves for Design Scenario

Runoff Coefficients

In a harbor area, the runoff coefficients can vary depending on the specific land uses and surface types present. Here are some common runoff coefficients for different land uses in a harbor area:

Impermeable Surfaces: Impermeable surfaces, including paved areas, concrete or asphalt surfaces, roofs, and sidewalks, have high runoff coefficients. These coefficients generally range from 0.80 to 0.95, indicating that a significant portion of the rainfall becomes runoff.

Permeable Surfaces: Permeable surfaces, such as grassed areas, vegetated slopes, and certain types of permeable pavements, allow some infiltration of rainfall into the soil. As a result, the runoff coefficients for these surfaces are lower than for impermeable surfaces. Typical runoff coefficients for permeable surfaces range from 0.20 to 0.50.

Vegetated Areas: Areas with dense vegetation, such as parks, gardens, or green spaces, have relatively lower runoff coefficients due to the interception and absorption of rainfall by the vegetation. Runoff coefficients for well-established vegetated areas can range from 0.10 to 0.40.

It's important to note that these values are general guidelines, and local conditions, including soil types, slopes, and rainfall patterns, can influence the specific runoff coefficients in a harbor area. Local regulations, engineering guidelines, or studies specific to the area may provide more accurate or region-specific runoff coefficients. A table of the ranges for the runoff coefficients can be seen below in **Error! Reference source not found.**.

Ground Cover	C	
	Low	High
Lawns	0.05	0.35
Forest	0.05	0.25
Cultivated land	0.08	0.41
Meadow	0.10	0.50
Parks, cemeteries	0.10	0.25
Unimproved areas	0.10	0.30
Pasture	0.12	0.62
Residential areas	0.30	0.75
Business areas	0.50	0.95
Industrial areas	0.50	0.90
Streets		
bricks	0.70	0.85
asphalt	0.70	0.95
concrete	0.70	0.95
Roofs	0.75	0.95

Table 1: Runoff Coefficients

For the purposes of this project, the catchment areas will be considered uniformly impermeable, which will give a more extreme situation than would be in reality. This is done to make sure the system is safe under normal and extreme situations. The runoff coefficient used in the design of the variants is: **0.90** which corresponds to impermeable concrete in an industrial area. This is the high end of the range given in the table in **Error! Reference source not found.**, however once again this is done as a safety factor.

3.1.2 System Design

Catchment Areas

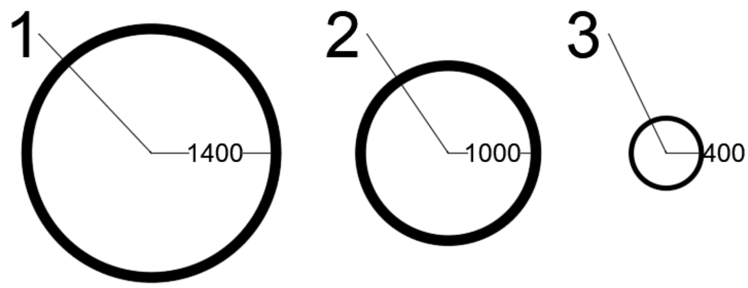
The catchment areas for the project are defined as the areas that are subject to a ground lease contract to the different companies in the project area that will be making use of the new system. Each area corresponds to a business, with the businesses E, F, G, and H having a combined area for the purposes of estimation for the MCA phase, however in the design phase will be considered separately. An overview of this can be seen in Figure 7, below where the areas have been shaded to distinguish them.

Figure 7 Catchment Areas

Duct Cross Sections

The ducts for the project will all be considered to be made of concrete, a circular form due to the majority of existing outlets also being circular, as well as the cost benefit of the shape. The one exception is the existing outlet 2, see Figure 5, which is ovoid (1500mm high and 1000mm wide) and thus the connecting duct will be maximum 1000mm in diameter to simplify the connection and ensure the capacity of the outlet is not breached. Below, in Figure 8, is an overview of the maximum connecting duct cross-sections corresponding to each outlet as defined in Figure 5.

Figure 8 Maximum Duct Cross-Sections



3.1.3 Variant 1: S Route Single System

Figure 9 Variant 1 Layout

Goal

The goal of this design is to provide the most direct and cost-effective solution to provide rainwater drainage to the businesses in the area. Beyond that, this design addresses only the businesses that are confirmed for the location, without addressing the future leasing of the remaining land of the area.

Route

The design consists of a single drain line leading to outlet 1, connecting all of the catchment areas. Catchment areas A and B are connected to the existing segment at outlet 1, and thus contribute to the total capacity of the new system, yet do not impact the route of the new design.

Capacity

The only downside to the design is that the risk of breaching the capacity of the system is greater than the other variants due to its singular outlet. The exact risks will be defined for the chosen design based on the MCA, however due to the large catchment area for business D the risk for exceeding the capacity would likely occur at the most upstream part of the new system.

Maintenance

This design represents the simplest and most feasible solution to connecting the businesses along an area that will remain part of North Sea Port, thus allowing for easy maintenance of the system. The new line runs along a grass belt which is between the defined property limits of the businesses. By having access along the entire line, the client does not need to create maintenance access agreements with the businesses, which they would have to do if the line crossed any of the leased property.

Cost

Of the three designs, variant 1 represents both the lowest upfront and lifetime costs, due to the smaller size of the system. It being a single line and a large diameter pipe, access for inspection is very feasible and uncomplicated. By having only the segment of the line connecting businesses D-H being underneath a road, means that the access for maintenance, and thus the costs for maintenance, means that the design has lower costs than the other two designs.

3.1.4 Variant 2: Dual System Outlets 1 and 2

Figure 10 Variant 2 Layout

Variant 2 represents both the safest and the most expensive option for the design. By making use of all 3 outlets, the design

Goal

The goal of this design is for the short term to provide the safest design for the businesses confirmed for the project area with the lowest risk of exceeding the runoff capacity, while laying the groundwork for the arrival of future businesses. It takes advantage of the open area around the segment connecting outlets 2 and 3 to catchment D to lower the complexity and cost of installation.

Route

The route for this design can be seen in Figure 10, which consists of two parts; a trimmed version of variant one (red) and second segment connecting outlets 2 and 3 (yellow and orange). The red segment is to service the all the catchment areas with the exception of area D, which will be making use of the second line. This second segment will allow for the future expansion of the runoff system, with the initial benefit of servicing the relatively large catchment D.

Capacity

The capacity of this variant is the largest of the three due to its use of the three outlets to service the entire project area. By having catchment D separate from the other areas, the red segment will have a very low risk of exceedance, especially considering the future expectations for extreme rainfall scenarios to occur more frequently and have a larger magnitude. It also means that the northern segment has little to no risk of exceedance as well and can be augmented as new businesses come to the area.

Maintenance

The maintenance for this design is very similar to that of the other two designs, however it is of a larger scale. A major difference is the segment in yellow is 1000mm in diameter, which is still relatively accessible for inspection and the orange segment, 400mm in diameter, is as well but requires different method for inspection. The short length of the 400mm segment does mean that the increased complexity for maintenance is of a relatively small impact.

Cost

Of the three designs this is the most expensive. The total upfront cost comes from the total length of ducting being the longest, as well as the varying duct sizes leading to more complex installation. Equally the complexity increase for maintenance and monitoring adds to the lifecycle cost. What must be considered however is the fact that this design is made with an eye to the future, since there is currently little obstruction to the area around the northern segment and thus it is easier to construct.

3.1.5 Variant 3: Dual System New Outlet

Figure 11 Variant 3 Layout

Goal

The goal of this design is to provide a balanced solution which can best accommodate the needs of the businesses in the project area both now and in the future.

Route

The red segment connecting all catchments with the exception of D is the same as in variant 2, with the big difference being the new segment (dark yellow). This new segment is a 1500mm duct, connected to a new outlet that is also 1500mm. One feature of the new system is that the two lines converge at the new reservoir and thus connect the system.

Capacity

The capacity of this system is the greatest of the three, approximately twice that of Variant 1and approximately 25% more than Variant 2. This ensures that the given catchment areas have a low risk for exceeding the capacity of the new system.

Maintenance

The maintenance of the system is aided by the large duct sized, which ensures that inspection can be done in person. One challenge however is the section of pipe that crosses the area leased by business D, which can be seen in Figure 11, which means that any maintenance work on that segment would need to be done in conjunction with the business.

Cost

The cost of the system will be the highest of the three due to the new outlet as well as the large duct size. This is mostly upfront cost, as the ease of maintenance as stated above leads to reduced maintenance costs.

3.2 Multi-Criteria Analysis

The criteria for the MCA will be graded on. A scale from 1 to 5, with 1 being the worst and 5 being the best. The exact valuation for each value will be explained in this section of the report.

3.2.1 Criteria & Sub-Criteria

Safety

For the purposes of this project, the risk and the severity of the rainfall capacity of the systems. This means that the two factors that will be scored in the MCA are as stated: risk and severity. Risk is a function of the likelihood that the system capacity will be exceeded and with what frequency. The severity refers to the impact of the exceedance and how it could impact the business in the project area. Due to the importance of the safety for both the client and the businesses, the weight for safety is set to 30%, split evenly between risk and severity. This is done to balance the fact that frequent minor exceedance is as harmful in many cases as infrequent major exceedance. As with the other criteria, risk and severity are graded 1 to 5, with 5 representing the least risk and least impact while 1 is the inverse.

Cost

The cost for a new system is the second factor to determine the effectiveness of a solution. It is broken down into upfront cost and lifecycle cost, to take asset management into account. The evenly split weighting of 20% for each sub-criteria is a departure from a traditional analysis where the upfront cost would be weighted higher. This is done to reflect the importance of the long-term nature of a stormwater sewer system, which is designed for 50+ years. It also reflects the relative nature of the costs with relation to the potential income that the system would contribute to. In this case a score of 5 represents lower costs while 1 represents high costs.

Management

For this project, management refers to asset management and the main principles thereof. In this case the sub-criteria that correspond to the management are: accessibility, monitoring, and maintainability. Accessibility is important for the system design for the party that needs to manage the system, especially in cases where the ducts cross areas leased to businesses which subsequently leads to required agreements for accessibility. Another important factor is the monitoring of the system which is tied to both the accessibility and the duct sizing. The most important factor for the management of the system is the maintainability. Therefor the weighting for the maintainability of the system is set at 20%, of the 30% for the management total. Once again 5 represents a score of the best value, while 1 is the worst.

3.2.2 MCA Table

Critera	Weight	Var 1	Var 2	Var 3	Best
Safety	30.00%	2.5	4.0	5.0	Var 3
Risk	15.00%	2.0	4.0	5.0	Var 3
Severity	15.00%	3.0	4.0	5.0	Var 3
Cost	40.00%	4.5	2.0	2.0	Var 1
Upfront	20.00%	4.0	2.0	1.0	Var 1
Lifecycle	20.00%	5.0	2.0	3.0	Var 1
Management	30.00%	5.0	3.3	5.0	Var 1
Accessibility	5.00%	5.0	5.0	5.0	Var 1
Monitoring	5.00%	5.0	3.0	5.0	Var 1
Maintainability	20.00%	5.0	2.0	5.0	Var 1
Total	100.00%	4.05	2.80	3.80	Var 1

Table 2: MCA Results

3.2.3 MCA Results

Based on the results from the MCA the highest scoring variant is Variant 1. The cost effectiveness and the maintainability of the variant make it an effective solution. The one area it falls behind is in the safety, which is one of the main goals for the client and the businesses. It is for this reason that the variant that best fits the needs of the client is Variant 3. The fact that the design is the safest and also the most maintainable means it comes a closer second in the scoring and thus the most effective solution. That said, the cost is the highest of the three variants., however this is relative since the cost of the design is small in comparison with the potential revenue from businesses in the area and the future expansion capacity.

4 Results

4.1 Final Design Parameters

Rainfall

The rainfall for the final design has been explained previously in this report, with the situatio0n being determined by the 2085 Low estimation made by STOWA and RIONED. An overview of the IDF curves used in the design can be seen in Figure 6.

Duct sizes

the duct sizes for the final design have been shown in Figure 8, however they bear extra explanation. For the southern segment of the design, the existing outlet has a diameter of 1400mm and thus the new segments should match that. The issue with this is that the closest standard duct size is 1500mm, thus 100mm larger. This is actually not as much of an issue, since the interior diameter of the duct is approximately 1375mm. this interior diameter is what will be used for the design of both segments of the new design.

Elevations

The elevations for both the surface and the existing ducts has been given by North Sea Port via ArcGIS. For the new outlet on the north side of the project area, Outlet 4 in Figure 11, the elevation will be assumed to be equal to that of Outlet 1.

Standard Values

There area several assumptions made when using Stormwater Studio to do the calculations for the design, and these can be seen in Figure 12.

Assumed Values		
Name	Value	Units
Existing Duct Diameter	1,400	mm
New Duct Diameter	1,500	mm
Mannings Coefficint	0.013	
Min Slope	0.10	%
Runoff Time	10.00	minutes
Runoff Time X+D	30.00	minutes
Return Time	1.00	year
Runoff Coefficient	0.85	
Min Velocity	1.00	m/s
Min Cover	1.20	m

Figure 12 Assumed Values Stormwater Studio

The exact catchment area sizes are given below in Table 3.

Catchment Areas		
area	ha	m2
A	9.58	95,793.00
B	2.26	22,626.00
C	3.14	31,438.00
D	19.12	191,228.00
E	0.52	5,178.00
F	0.10	971.00
G	0.24	2,407.00
H	1.05	10,547.00
X	0.50	5,000.00
Total	36.52	365,188.00

Catchment Areas		
area	ha	m2
A	9.58	95,793.00
B	2.26	22,626.00
C	3.14	31,438.00
D	19.12	191,228.00
E	0.52	5,178.00
F	0.10	971.00
G	0.24	2,407.00
H	1.05	10,547.00
X	0.50	5,000.00
Total	36.52	365,188.00

Table 3: Catchment Areas

4.2 Final Design

The final design will be split into two segments: North and South, which can be seen in Figure 13. The runoff from catchments X and part of D will be handled by the North segment due to their location, while the rest will be connected to the South Segment. The North Segment will be more than sufficient for the catchments assigned to it, however this is done to allow for future expansion, which significant area along the route yet to be leased out to businesses.

Figure 13 Final Design Segments

Catchment D will be separated into three parts to account for the phased construction of the area as well as the capacities of the two new segments of rainwater sewer. The phasing of construction and the division of the drainage areas can be seen below in Figure 14. Area 1 will be drained by the Southern line, via reservoir X and constitutes an area of approximately 7.33 hectares. This is done to accommodate the first and most immediate phase for business D and is capable of being drained by the Southern segment of the new system. Area 2 will be drained by the completely new North line and has an area of approximately 10 hectares. This is done to balance the capacity for the new line based on current and future businesses. Lastly, the area 3 will be drained by a new line as yet to be determined due to the expected time before the implementation of the 3rd part of business D. by then there is expected to be more business in and around the outlet 2, and thus a new drain line can be designed to account for the final part of Catchment D.

Figure 14 Phasing Catchment D

4.2.1 South Segment

Figure 15 South Segment

For the implementation of the new design of the rainwater sewer system the first part to be built is the South Segment, or South Line. This is done to accommodate the established incoming businesses and due to the presence of the existing outlet. The layout for the line can be seen in Figure 15 above. With this in mind, the layout was put into Stormwater Studio to model the new system and check the capacity thereof. The layout and resulting profile with HGL line can be seen in Figure 16 and Figure 17 respectively.

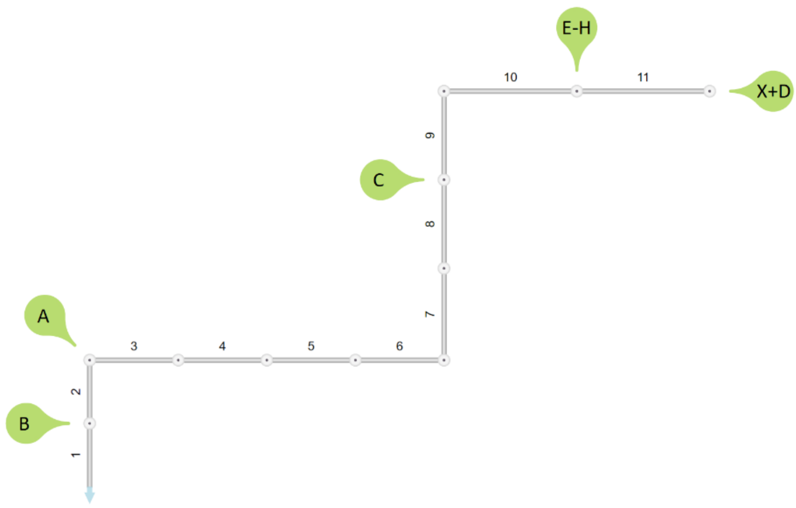


Figure 16 South Section Layout

As seen above in Figure 16, the layout of the South Section is presented as in the program. The numbers represent the lengths between approximated access points for maintenance. The letters represent the points along the line at which each catchment business will connect their runoff drain. The location for these is determined by the location of the catchment along the drain line.

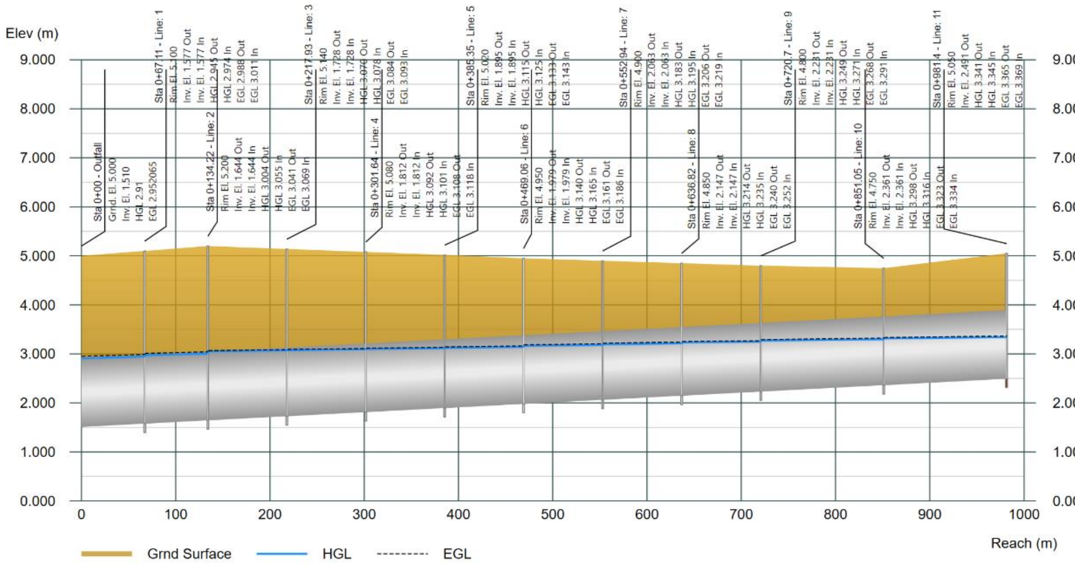


Figure 17 South Section Profile

Above is the profile of the South Segment of the new system with the HGL and EGL lines. Both the lines show that the line is at approximately maximum capacity, reinforcing the decision to only drain part of the catchment D into this line. This can be seen by the HGL and EGL lines at the outlet (left) being at the top of the duct. Under Normal conditions this would be unacceptable, however the rainfall scenario used in the design is an extreme case and thus under normal conditions the levels would be much less. It can also be determined that the businesses along this line will not experience any flooding in this extreme scenario and thus can be considered safe.

4.2.2 North Segment

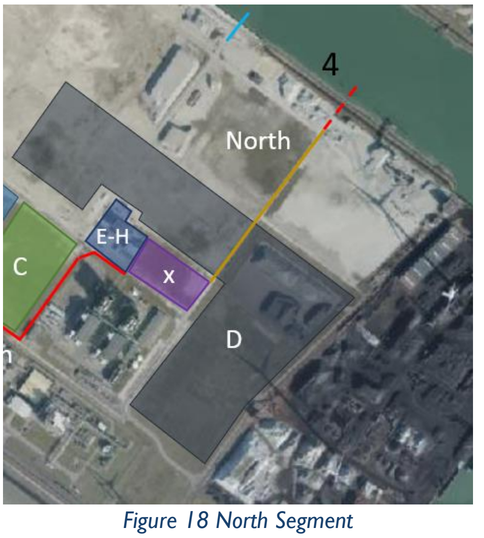


Figure 18 North Segment

The North Segment of the new system represents the second phase for the implementation of the new design. It is in itself a larger undertaking due to the need to construct a new outlet and to install the segment that crosses the area of business D. That said, due to the phased implementation of said business, the construction of the North Segment is largely unobstructed by businesses in the area.

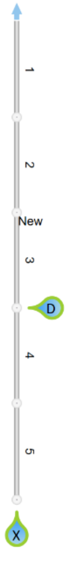


Figure 19 North Segment Layout

Above is the layout of the North segment as in Stormwater Studio (Figure 19). Once again, the numbers represent the lengths between the approximated access points and the letters show the connection points for the catchment areas.

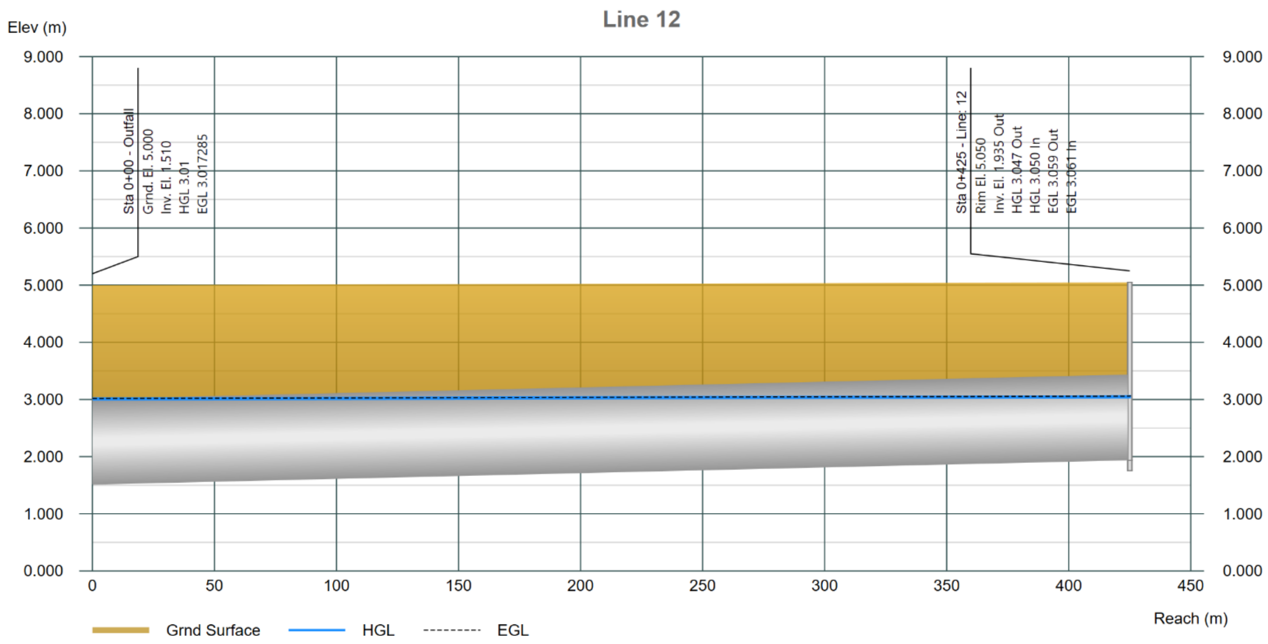


Figure 20 North Segment Profile

Figure 20 shows the profile of the new North Segment and the HGL and EGL lines. Both lines show the system to be at near maximum capacity and thus demonstrate the need to split the runoff from Catchment D into three parts. What is interesting to note is that the water level at the most upstream point is at such a high level considering the drained runoff from the Reservoir X is relatively small. This is due to the large drainage from Catchment D and the relatively shallow slope of the system. The safety of the system is ensured due to the extreme scenario used to create this design as well as the use of valves to ensure that there is no backflow of rainwater.

4.2.3 Design Results

Based on the previous sections of this report it can be determined that the new system is capable of dealing with the predicted rainfall scenario for 2085. In this scenario both segments are at approximately maximum capacity, however this is acceptable due to the extreme nature of the rainfall. One thing to note is that both segments also are connected to the reservoir X which allows for the shifting of the amount drained to each segment based on need. Another point is that catchment D is not fully drained, with Area 3 unaccounted for in either segment. This is done due to the capacity constraints of the segments and the phased construction however, it could be drained to the North Segment should the need arise.

4.3 Asset Management

Maintenance/Monitoring Tasks			
Element	Frequency	Aspect	Repair Work

Outlet Structures	5 years	Flooding, erosion	Remove siltation, restore riprap/structure
Duct Tiling	5 years	Erosion	Clean/restore as needed
Duct Connections	5 years	Erosion, Cracking	Clean/restore as needed
Manholes	2 years	Debris, Access	Clear, restore/replace
Reservoir	5 years	Detention volume, Sediment volume	Restore/replace lining, Dredge bottom

Table 4 Maintenance and Monitoring Tasks

During the first phase of this design, the maintenance and monitoring will only need to be done for the South Segment of the system, however the North Segment will have one addition to the maintenance requirements. The route runs through the area for business D and thus requires agreements for the timing and duration of the maintenance of the ducts there. Fortunately, it is also an area where several other utilities cross and thus should be feasible to arrange such a compromise.

The main tasks to be done to maintain and monitor the system can be seen in Table 4, together with the frequency thereof. They are primarily to ensure the structural integrity of the system and to prevent sediment buildup.

One benefit the client has is the existing experience with the area and the management thereof. This is how the tasks such as maintenance of the green areas around the project area are already being undertaken. The benefit of this is that once the new system is in place the maintenance of the green areas will be taken care of already, approximately 3-4 times per year.

5 Discussion

5.1 Asset Management

The main question of this project being to create a design from an "asset management perspective" means the direction for this report is very broad. The topic of Asset Management is broad as well, meaning that this report needed to focus on a part of the whole. In this case the maintainability and the lifecycle were two principles of Asset Management that area used. By looking at a future rain scenario the future suitability is accounted for, as best as can be predicted. The incorporation of maintainability into the MCA also demonstrated the integration of Asset Management. It helps push the final design to be as efficient as possible.

One of the main objectives for the project, and North Sea Port as a whole, is safety. This is translated into the project in the form of the weighing of the MCA, the design of the system, and the implementation of the buffer. With this the design for the system can be made as safe as possible, given the constraints of the area.

5.2 Implementation

One topic briefly discussed throughout this report, but warranting more attention, is the implementation of the system. On the bigger scale, the southern segment of the system is the first part to be implemented due to the confirmed businesses being in the southern half of the project area predominantly. This will allow for those businesses to start operation and allow for the client to take the time to plan for the remaining leasable area as it is given out. This lack of concrete planning for the unleased area is the main reason to potentially hold off on constructing the northern segment of the system as it is difficult to estimate the needs of the businesses and using the entire area for the estimation is grossly inefficient.

Another topic for the implementation of the system is how the proposed northern segment would cross catchment D. as mentioned in the report earlier, the new segment would run along a cable and duct channel that crosses the area leased to business D and thus would be part of a larger maintenance agreement with the business and North Sea Port. What is also of interest is that the regulations in the Netherlands prevent the construction of buildings and other structures above such channels for safety reasons. This would be something to discuss with the business and work together to ensure that the situation is handled well.

5.3 Water Management

One of the conditions not taken into account for the new system is the fact that the outlets are all below sea level and that the tide rises and falls. The spring tide can be in excess of 3.5m NAP and thus dramatically raises the water level in the system. Due to the inclusion of the reservoir, which funnels approximately half the rainwater from the project area, the impact of the seawater is reduced but by exactly how much needs to be investigated.

Saltwater is highly corrosive, and when it flows backward into a stormwater sewer, it can accelerate the corrosion process. The corrosive properties of saltwater can damage pipes, pumps, valves, and other infrastructure components. This can lead to leaks, structural failures, and increased maintenance costs. The backflow of saltwater can contribute to localized flooding in the port area. If the stormwater sewer system becomes overwhelmed by saltwater, it can impede the proper drainage of rainwater during storms or high tides. Flooding can damage infrastructure, disrupt port activities, and pose risks to personnel safety.

On the topic of the reservoir, the exact distribution method of the contained water from the reservoir is also for future consideration. For this design it was considered that both segments get equal, simultaneous flow to discharge, with none of the water retained, just a delayed flow time. The exact scope of how this could be managed is for future consideration.

The assumption that the entire project area can be considered largely impervious is also a conservative estimate, designed to present a worst-case scenario. In reality there will be large parts of green, which will both reduce the inflow of rainwater and serve as a buffer for if the capacity of the system is exceeded.

6 Conclusion & Recommendations

6.1 Conclusion

To create the most effective design for a rainwater sewer system from an Asset Management perspective, the critical aspects were determined. The safety, cost, and management of the system are the key aspects used to determine the best design for the system at the von Cittersterrein. With the main focus for North Sea Port being the safety and management of the area and facilities they lease to businesses, these aspects align perfectly and thus are key for an effective design.

One of the key differences between a normal design and one with asset management in mind is the consideration of the lifecycle during the design phase. It is for this reason that for this project the rainfall scenario used is the 2085 scenario as mentioned earlier in the report. It is an extreme scenario that ensures the system will still be viable in the future, with a potential lifespan of more than sixty years. It also allows for the future expansion of the system, mostly in the northern segment due to the unassigned area that has yet to be leased out. This consideration of the lifespan of the system is also shown in the phased implementation of the final design, with the south segment being needed for the known businesses in the project area. The capacity needs for the south segment can also be estimated and thus make it the logical first phase of the design. By implementing the north segment later, there is more flexibility for the design thereof. It allows for adjustment should there be more capacity required due to new businesses coming to the northern part of the project area.

The final design makes efficient use of the existing sewer outlet on the south side of the area, and maintains the aforementioned flexibility to adapt the new outlet on the north side by staggering the implementation. Once the two systems are in place, they can be effectively used by the reservoir X as well, adding to the adaptability, and thus safety, of the system.

Finally, for a stormwater sewer system to have an effective design from an Asset Management perspective, it must be safe, cost-effective, and manageable. The design detailed in this report fulfills those requirements, by providing safety for the existing situation, flexibility for future expansion, and ease of maintenance for years to come.

6.2 Recommendations

As previously mentioned, the system should be implemented in phases to be able to adapt to future changes. To this end it would be very beneficial to do a deeper investigation into the most optimal design for the new segment in the northern part of the project area. This could be done at any point, depending on the need for a system in that area, as the southern segment combined with the reservoir is sufficient for the existing businesses.

On the topic of the reservoir, it would be wise to research the most efficient control system for the discharge of the captured rainwater. Ideally the system would be able to divert water as necessary to the segment with sufficient vacant capacity, with fine control over the amount of discharge in the segments and of the reservoir. Realistically this may not be cost-effective and require more resources than make financial sense. Therefore, more research is prudent to determine the best situation.

When modelling the new design, the largest omission was the seawater level, at any level, and thus would be the logical step to take before committing to any design. Ideally the spring tide would be considered, as the rest of the situation is modelled with the most extreme values. It is a very real concern that flooding could occur in a heavy rainfall event during high tide. Because of this it would also be worth looking into having ducts running to the reservoir from catchments other than catchment D.

7 Bibliography

KNMI. (2020). Composite storms for climate scenarios. Netherlands.

North Sea Port. (n.d.). Retrieved from https://www.northseaport.com

North Sea Port. (2023). Retrieved from https://www.northseaport.com

Provincie Zeeland. (2023). Retrieved from https://www.zeeland.nl/thermphos-terrein

RIONED. (2020, 07 01). Hydrogrammen composietbuien scenario's 2085. Netherlands.

STOWA. (2019). Neerslagstatistiek en -reeksen voor het waterbeheer 2019. Netherlands.

(2020). Systeemstudie energie-infrastructuur Zeeland. Retrieved from www.ce.nl

(2020). System study of energy infrastructure Zeeland. Retrieved from www.DeepL.com/pro

U.S. Department of Transportation. (2013). URBAN DRAINAGE DESIGN MANUAL . Hydraulic Engineering Circular No. 22, Third Edition.

8 Appendices

8.1 Rainfall Data

8.2 Calculation Data

Input Data South Segment

	Segment	Length m	Inflow Var 1	surf elev	pipe elev	area (ha)
upstream	4.00	260.69	3.80	5.05	tdb	21.03
	3.00	251.63	0.00	4.80	tdb	0.00
	2.00	334.82	0.75	4.95	tdb	3.14
downstream	1.00	134.22	2.84	5.20	1.78	11.84
	total	981.36		5.00	1.51	36.02

Cost Estimation

cost				
item	unit price	var1	var2	var 3
length 1400		850.00	700.00	981.36
length 1000		0.00	605.00	0.00
length 400		0.00	62.00	0.00
manholes		11.00	18.00	16.00
pipe 1400	285.00	242,250.00	199,500.00	279,687.60
pipe 1000	170.00	0.00	102,850.00	0.00
pipe 400	100.00	0.00	6,200.00	0.00
manhole	3,600.00	39,600.00	64,800.00	57,600.00
total		281,850.00	373,350.00	337,287.60
relative scoring		1.23	0.00	0.48

Sub Segments

North Sub-Segments			
segment	length	num sub	sub length
5	255.00	3.00	85.00
6	170.00	2.00	85.00
South Sub-Segments			
segment	length	num sub	sub length
1-2	134.22	2.00	67.11
3-6	334.82	4.00	83.71
7-9	251.63	3.00	83.88
10-11	260.69	2.00	130.35

Outlet Constraints

Outlet dimensions			
name	shape	dimensions	max O pipe diam.
exit 1	circle	r1400	1,400
exit 2	ovoid	1000x1500	1,000
exit 3	circle	r400	400
exit 4	circle	r1500	1,500

8.3 MCA Table

Critera	Weight	Var 1	Var 2	Var 3	Best
Safety	30.00%	2.5	4.0	5.0	Var 3
Risk	15.00%	2.0	4.0	5.0	Var 3
Severity	15.00%	3.0	4.0	5.0	Var 3
Cost	40.00%	4.5	2.0	2.0	Var 1
Upfront	20.00%	4.0	2.0	1.0	Var 1
Lifecycle	20.00%	5.0	2.0	3.0	Var 1
Management	30.00%	5.0	3.3	5.0	Var 1
Accessibility	5.00%	5.0	5.0	5.0	Var 1
Monitoring	5.00%	5.0	3.0	5.0	Var 1
Maintainability	20.00%	5.0	2.0	5.0	Var 1
Total	100.00%	4.05	2.80	3.80	Var 1