BACHELOR THESIS

Water system modifications for Peursumsekade reinforcement

Wout Schutten
S2129450

Civil Engineering,
Faculty of Engineering Technology (ET)

EXAMINATION COMMITTEE
Supervisor internal: Rik Gijsman
Supervisor external: Jeroen Kooman (WSRL)

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University of Twente
Commisioned with Waterschap Rivierenland

Waterschap Rivierenland

UNIVERSITY OF TWENTE.

Preface

This report is the final deliverable for my bachelor thesis at the University of Twente, which is written to fulfil the graduation requirements for the Civil Engineering Bachelor study. The research, described in this thesis report, is conducted in association with and by order of Waterschap Rivierenland. My academic knowledge and interests are mainly related to water management and engineering. Which is also one of the reasons why I chose to conduct this research and in collaboration with Waterschap Rivierenland.

Waterschap Rivierenland is an excellent source of knowledge, experience, connections and they put a lot of time and effort into developing upcoming water engineers, which I have upmost appreciation for. One of these fantastic instructors is Jeroen Kooman, who was my supervisor and helped me out a lot when writing this report. Without him, this research and therefore my graduation would not have been possible. I want to thank him sincerely for that. Furthermore, I would like to thank the whole team ‘Projectmanagement en Ondersteuning’. Although I have not been able to visit the office a lot, I still got the opportunity to meet some of you. I would also like to thank Ellen Vonk, for getting me into contact within Waterschap Rivierenland and for her feedback on my drafts and research method. Another team I had good contact with, during my period at Waterschap Rivierenland is ‘Team Baggeren’. Since the research also involved their field within Waterschap Rivierenland, I would like to thank Jasper van Gestel for his time explaining me, giving feedback and introducing me within in his team. Furthermore, I thank Thijs Schelling for letting me join a day in the field of his dredging project and physically experience what it is about, the problems that occurred and how the team solved them.

The University of Twente also helped me a lot when conducting my research. Especially I want to sincerely thank Rik Gijsman, for being my supervisor and all the useful feedback I received and his time he spent guiding me through the research. His views really elevated and improved my report a lot.

I really enjoyed the process of researching and writing this report, especially since it is the first major report I have written on my own. Although the current situation, working mostly from home because of Covid-19, made it sometimes harder to motivate myself and the research done during the summer break, which brought some additional challenges regarding vacations and planning, I still learned extremely much about conducting research, office work and about organisation and planning.

I hope you find this research interesting and gain something from it.

Wout Schutten

Lichtenvoorde, September 22, 2021

Table of content

Table of figures

Summary

This research addresses the drainage capacity problem of the side channel of the Peursumse Vliet. The Peursumse Vliet is a polder drainage channel north of Giessenburg, in the Alblasserwaard, South-Holland. This research was done, in commission and in collaboration with Waterschap Rivierenland, which is the responsible water authority of the area. The aim of this research is to create and evaluate design scenarios with alternate solutions to increase the drainage capacity of the channels near the Peursumse Vliet without dredging.

To achieve this aim, two scenarios with alternate solution and a reference scenario are created. However, the water system of the Alblasserwaard and the Peursumse Vliet are described first. And furthermore, the context and urgency of the problem are explained. After, alternate solutions for the problem are devised and two scenarios and a reference scenario are created.

The reference scenario is a scenario with minimal measures, instead of making major adjustments to the area and water system, just maintaining the current situation and managing the current assets is the goal of this scenario. The first scenario (scenario 1) makes use of a temporary pumping station to drain water out of the polder. This way, less water has to flow through the concerned channel and therefore stress on those channels is relieved. The second scenario (scenario 2) adds a second channel alongside the Peursumse Vliet in order to increase the drainage capacity of the system. The goal of this measure is to release stress on the current channel and improve the drainage capacity without having to dredge.

After the creation of the scenarios, the scenarios are evaluated following the stakeholder wishes using a multi-criteria analysis. Therefore, a stakeholder analysis is performed first. The main stakeholders are the different departments of Waterschap Rivierenland, neighbouring inhabitants, wildlife and the municipality. From these stakeholders, the following set of design criteria are chosen to evaluate the scenarios on: costs, time, durability, technicality and risks. The multi-criteria analysis gives scores to the different scenario's based on the criteria and their respective weights.

Concluding from the design evaluation, the second scenario with the additional channel is the most preferred. Using the weighting strategy, that best suits the goals of Waterschap Rivierenland and the Peursumse Vliet, which gives the second scenario has a MCDA score of 128 while the others have 119 and 120 respectively. In my opinion, the second scenario is indeed the most preferred solution, and the cost would be good value, mainly because of the long durability of the solution and the fact that a temporary bridging solution is able to continue into a permanent solution in the future.

1 Introduction

Since the 13th century, the low-lying peatland of the Alblasserwaard region has been surrounded by a ring dike. This would turn out to be the first of many water management structures for the region, to prevent flooding and waterlogging. Later on, in the 14th century, polder drainage channels and canals were made, for better water drainage of the area (van Groningen, 2011). These polder drainage channels and waterways will not last forever, they have to be strengthened once in a while, to keep up with the safety standards of today. A study from Waterschap Rivierenland in 2017 showed that, the embankments of the channels have to be strengthened again (Waterschap Rivierenland, 2017). Therefore, Waterschap Rivierenland started a new project to reinforce the embankments and improve the water system following the vision for 2050. However, increasing the stability of the embankments of these channels is not always so straightforward. At one location, in the Alblasserwaard region, some problems occur when developing a method to strengthen the embankments. This is where my thesis research comes into play.

1.1 Project

Two of the projects currently running that are involved in this thesis are the following:

- Area development plan Alblasserwaard-Vijfheerenlanden (A5H)
- Dredging near Leerdam and Giessenburg

The, in the introduction, mentioned project is Area Development Plan Alblasserwaard-Vijfheerenlanden (A5H), in which structural solutions are made to apply a vision for 2050 to the water channels in the area of Alblasserwaard-Vijfheerenlanden. These structural solutions are needed since a lot of embankments in the area do not satisfy the current safety standards. Because the consequences of climate change and the large amount of soil subsidence in the area, increase the hazard of failing embankments. Furthermore, the water levels are increasingly more difficult to control, because illogical drainage flow routes have been created over the years. Waterschap Rivierenland are reinforcing the embankments and making adjustments to the water system in this project A5H. The water system measures ensure for a more controllable water levels and decreases the stress on the embankments, which results in less embankments to be strengthened. The embankments that still do not satisfy are reinforced (Waterschap Rivierenland, 2019). Later in Chapter 2, there will be more detail about the planned water system measures and the embankment reinforcements as described in the project A5H.

Furthermore, a local dredging project of Waterschap Rivierenland is important for this thesis, project 'Baggeren omgeving Leerdam en Giessenburg'. Dredging is the process to remove the silt at the bottom of waterways. This makes the waterways cleaner and deeper, to create more space to catch and discharge the water during heavy rainfall. The cleaner waterways also make a positive contribution to life in and around the water. Channels are generally dredged every 15 years (Waterschap Rivierenland, 2014).

1.2 Problem Description

The problem that has resulted in this thesis consist of a bottleneck that occurred when combining the measures taken in both of the relevant projects.

The problem of the first project is that, part of the water development plan A5H of Waterschap Rivierenland, the reinforcements of the grass embankments of the polder drainage channel. One location at which the embankments are in poor condition, is the Peursumse Vliet, more detail about the project area of the problem will be included later. The embankments of the Peursumse Vliet need to be strengthened because they do not satisfy the current safety standards. However, strengthening the embankments would mean that the side channels have to be removed. Waterschap Rivierenland is planning on solving the problem by reinforcing the embankments in about two years.

Secondly, since there is too much dredge in all of the channels within the polder Peursum, the polder that lies alongside and drains its water via the Peursumse Vliet, those channels are not satisfactory to drain the water properly. Therefore, Waterschap Rivierenland's dredging team is going to dredge all the water channels in the polder due autumn 2021.

Both problems already have a solution, which will be described later. However, the problem that is tackled in this research thesis is that there is a bottleneck that occurs because of the combination of both problems, since the side ditch of the Peursumse Vliet is lying in between and therefore part of both renovation projects. The embankments of the Peursumse Vliet are in very poor condition, so the side ditch cannot be touched by the dredging team. However, since the embankments are only reinforced in two years, and the side channels needs dredging due autumn 2021 since it is an important drainage channel, a solution needs to be found in order to increase the drainage capacity until the embankments are strengthened.

1.3 Project Area

The study area of the water development plan A5H is the Alblasserwaard region which can be described as a low-lying and predominantly sparsely populated, agricultural area enclosed by rivers and canals. Since the area consist largely of polders and is enclosed by large rivers, the area is vulnerable to flooding and waterlogging. The location of the Alblasserwaard within the context of the province can be seen in Figure 1. The Alblasserwaard is the most western region within the operation area of Waterschap Rivierenland (Figure 2).

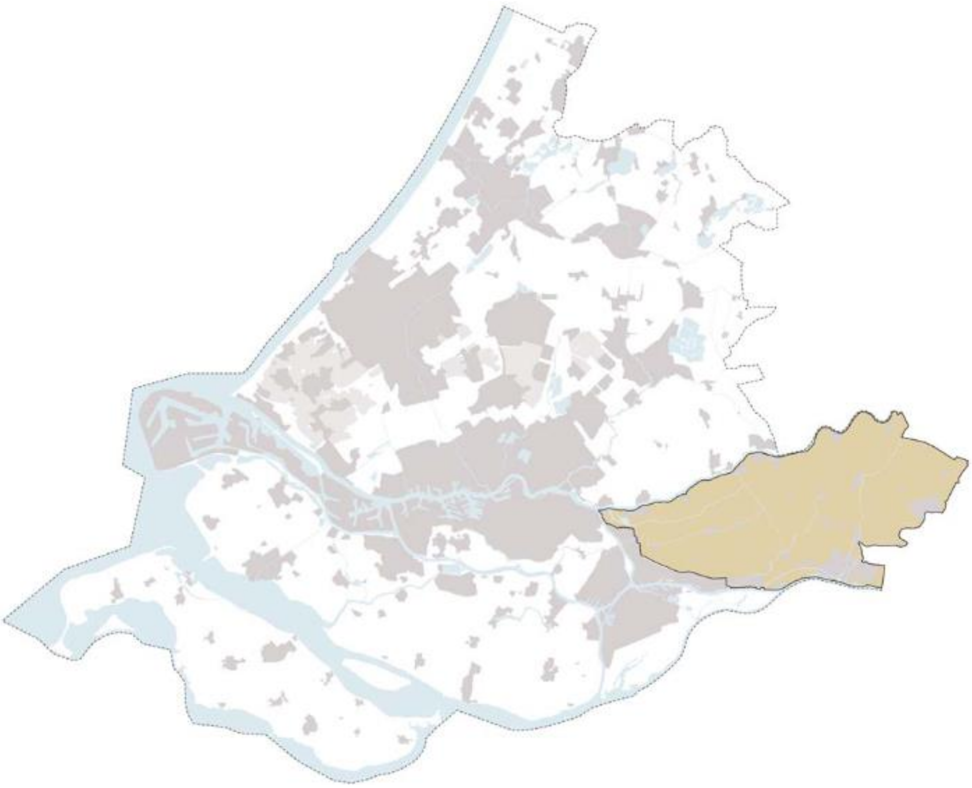


Figure 1: Location of the Alblasserwaard within Zuid-Holland (Provincie Zuid-Holland, 2012)

The project area of the problem is Peursumse Vliet and the polder Peursum, located north of Gorinchem, in the province of South Holland. The area municipality of Molenlanden.

1.4 Stakeholders

The water development plan Alblasserwaard-Vijfheerenlanden (A5H) is started and executed in commission of Waterschap Rivierenland. Together with consultancy companies, contractors and other parties, Waterschap Rivierenland will execute the water development plan A5H. The entire plan has a huge impact on the water structure of the region, and for its inhabitants, farmers, recreational users, businesses, nature and wildlife.

Waterschap Rivierenland is responsible for the management and maintenance of the regional defences in the Alblasserwaard and Vijfheerenlanden region. Waterschap Rivierenland is a waterboard, which is a governmental organisation which takes care of the water management in a certain area. A waterboard ensures water protection for the area, clean and enough water and ensures navigable waterways.

Other stakeholders are the municipality of Molenlanden, Rijkswaterstaat, inhabitants of the area, nearby landowners and farmers, wildlife and nature organisations.

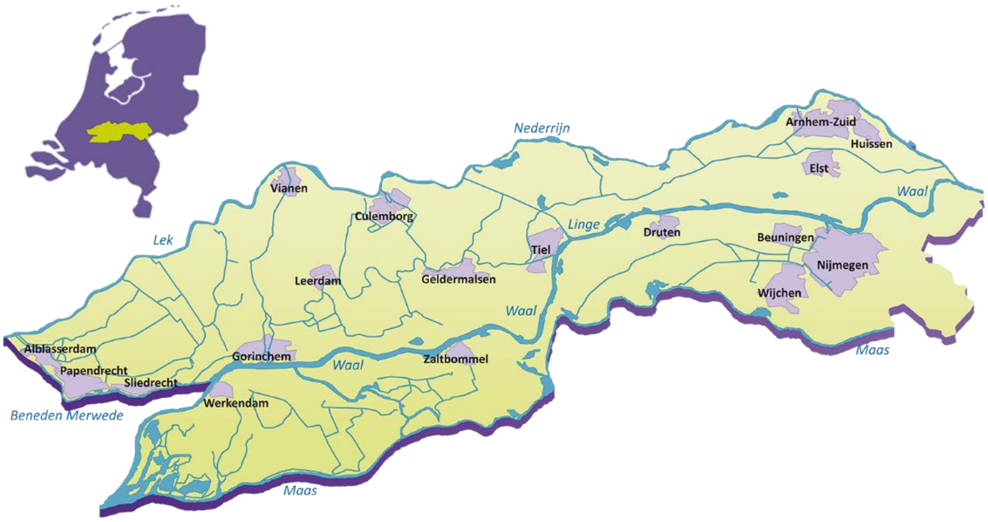


Figure 2: Operating area of Waterschap Rivierenland; stretched out area from Zuid-Holland towards to border with Germany, in between some large international rivers like the Meuse and Rhine (Waterschap Rivierenland, 2021).

1.5 Research Objective

The research objectives can be split into two parts. Developing and evaluating several design scenarios to optimise the polder water system of the Peursumse Vliet and find a solution in which the water system has enough drainage capacity without dredging.

- Create design scenarios with measures following a strategy in which the drainage capacity increases without dredging
- Evaluate the design scenarios using a multi-criteria decision analysis in the context of a stakeholder analysis

1.6 Research Questions

Following from the research objective, three main research questions are created. The first question is about the current state of the problem, the second question is about the creation and elaboration of different solutions which corresponds to the first research objective. Lastly, the third question is about the evaluation of the different solutions, which is about the second research objective. After answering these questions, a main conclusion and some advice on the overall problem statement can be given.

1. To what extent is the problem of the Peursumse Vliet urgent?
   1.1 What is the state of the current water system?
   1.2 What are the expected water levels for the area with the current system?

2. How can the drainage capacity of the channels be improved using an alternative solution?
   2.1 Which scenarios with alternative solutions can be created?
   2.2 How does the water system perform in the scenarios?

3. What would be the most suitable solution for the Peursumse Vliet?
   3.1 Which are the major design features to consider when evaluating?
   3.2 Which scenario scores the best in a multi-criteria decision analysis?

1.7 Research Method

The research method will be split up into two sections, one for each objective. The methodology used in this thesis is shown in Figure 3. The research started by analysis the current water system, which is part of the first research question. Then the research is split up, for the different research objectives. As part of the first objective, design scenarios are determined in which the drainage capacity is increased using alternative solutions, the solutions are created using knowledge of Waterschap Rivierenland, views of different people at the different departments and my own insight. The second path follows the creation of the multi-criteria analysis in which the designs are evaluated using the goals of the stakeholders.

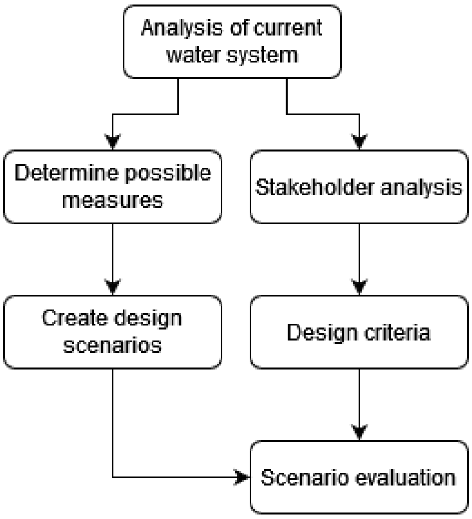


Figure 3: Methodology and research path

1.8 Reading Guide

The first chapter was about the introduction of the research and the associated problem description and project description. The next chapter is about the current state of the problem. In this chapter, the first research question will be answered. Chapter 3 is about the creation of the design scenario's and looking at the set of solutions, this covers the second research question. In the fourth chapter, the design scenarios are evaluated using a multi-criteria decision analysis and certain weighted design criteria. The third research question is answered in this chapter. Following from this evaluation, a conclusion will be drawn. The report ends with a discussion of the results and the research itself.

2 State of current system

In this chapter, the current state of the project area is described, the behaviour of the current water system and the problem with the current water channels. The chapter is dived into a couple sections. First the study area and water system of the whole area is described into more detail, and the measures of Waterschap Rivierenland are shown and explained. After, the scope is set on the Peursumse Vliet and the polder Peursum and its water system, and the state of the area. Ending with the visualisation of the combined bottleneck.

2.1 Water system Alblasserwaard

The study area of the water development plan is the Alblasserwaard and Vijfheerenlanden area, which is almost entirely bounded by rivers: the Lek in the north, the Linge in the east, the Upper and Lower Merwede in the south and the North in the west. The area is characterised by meandering dikes and quays, the open meadows, the elongated parcel structure with ditches in a fixed rhythm, and the dense village centres with churches and windmills that can be seen from afar (Eo Wijers-stichting, 2021). Since the area consist largely of polders and is enclosed by large rivers, the area is vulnerable to flooding and waterlogging. Therefore, it is essential to strictly regulate the water levels in the area.

The Alblasserwaard-Vijfheerenlanden is a prime example of a rural area. The agricultural sector owns about 70% of the land and thus determines a large part of the region's appearance. The environment is characterised by openness, the characteristic succession of plots and ditches, the meandering dikes and the small villages. A number of major social issues are topical in the region: issues that could mean a turning point for the region as it is today. There is a great deal of friction, and the solutions are not simple (Eo Wijers-stichting, 2021).

In the current water system of the entire Alblasserwaard, the water of all the polders is drained via the Kinderdijk pumping stations. The current system is shown in Figure 4. In this figure, the water levels of the polders are shown, as well as the direction of the water drainage and the location of water infrastructure elements. Since the water channels to be examined in this thesis, are the Peursumse Vliet and the major water channels behind the embankments of the Peursumse Vliet, the relevant polder is magnified. The Peursumse Vliet is directly supplied by two pumping stations in the Peursumse Vliet, draining four polders. Furthermore, the Peursumse Vliet discharges all the pumped polder water upstream.

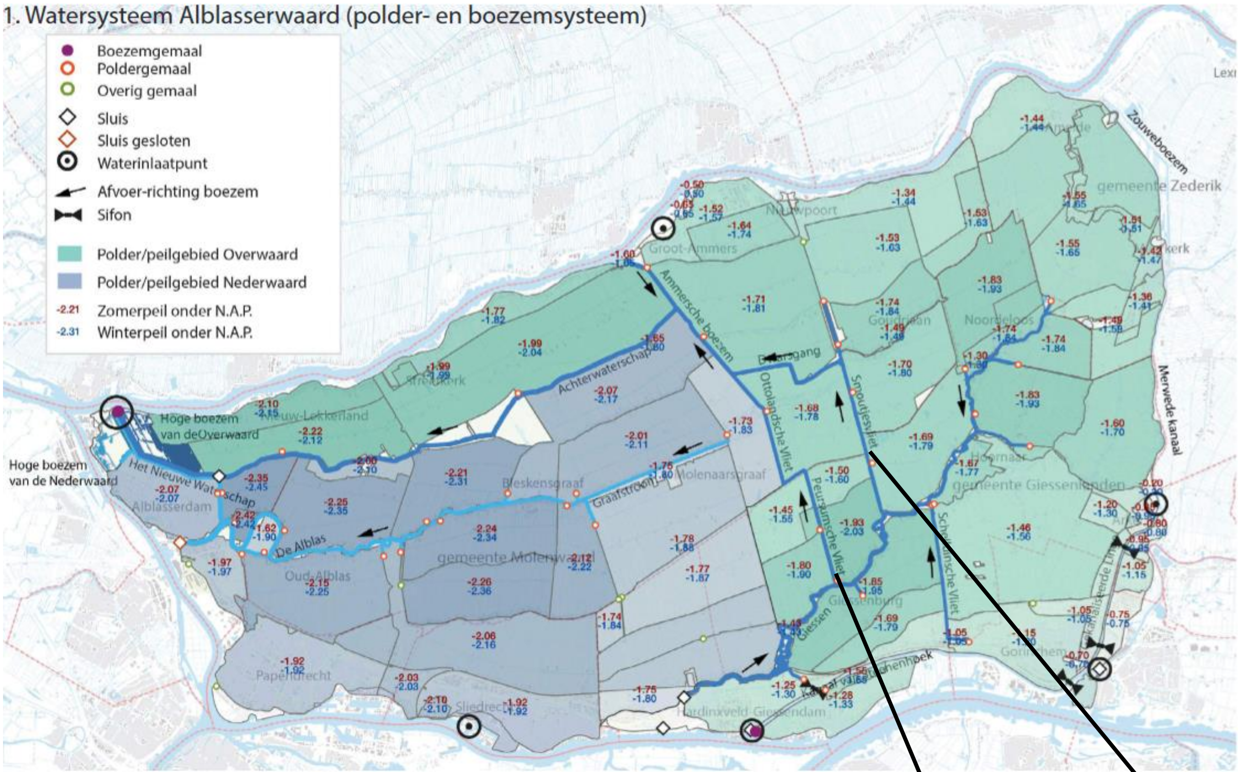


Figure 4: Water System Alblasserwaard (Waterschap Rivierenland, 2017); the figure shows all polders in the area with their respective water level. Furthermore, it can be seen that the main water drainage flow of the area is from southeast towards west (following the black arrows). Lastly, the area is divided into two regions, the green coloured polders are belonging to the Overwaard, while the blue coloured polers are belonging to the Nederwaard.

2.2 Project measures

In the project A5H of Waterschap Rivierenland, there are in total six main water system measures, as can be seen in Figure 5, which are about changing pumping stations and the flow through streams and channels, with the goal of improving the water flow and relieve stress on the embankments, and therefore solve the problems as described in the paragraphs above.

The first measure are new polder pumping stations for the Overwaard. One pumping to the Lek in the north, and one pumping to the Merwede in the south. This will create more drainage options to drain water out of the region and into the big rivers, and therefore relieve stress on the Kinderdijk pumping stations and the neighbouring drainage channels. These new pumping stations are also able to pump water out the river and into the Alblasserwaard, in times of drought. The possibility to pump water both ways gives a lot more control of the water in the region.

The second measure, as part of the A5H program, is a sealant to make a separation between the Overwaard and the Nederwaard. The sealant will be a combination of a lock, four tipping weirs and a fish passage. The goal is to keep it closed most of the time, but there is the possibility to be opened when needed. This sealant is important because it ensures that the water drains to the appropriate pumping stations and gives the possibility to have different water levels in the Overwaard and the Nederwaard. Therefore, giving the Waterschap more control of the water in the area.

The third measure is to open the Middelkade, which is the supply channel of the Kinderdijk pumping stations. With this opening, the streams of the current Overwaard and Nederwaard are connected, and the drainage capacity will be increased, this is required to make the north-western part of the current Overwaard part of the new Nederwaard. The last measure is a sealant at the Graafstroom. This solution has been chosen because strengthening the embankment at that location would be very expensive and difficult. This sealant gives the possibility to close off the Graafstroom from the rest of the water system. Therefore, no improvements to the embankments are required.

In the current water system, Figure 4, there is not a good separation of the Overwaard and Nederwaard and almost all water is drained via the Kinderdijk pumping stations. This is not optimal because the area is encircled with big rivers, which gives way more drainage options than only using the Kinderdijk. With these measure in place, there is a clear separation of the Overwaard and the Nederwaard, with both their own polder pumping stations and drainage channels with a logical flow route in which water is drained at better locations to the big rivers. With this new system, the Overwaard and Nederwaard are still connected. However, this passage will be closed most of the time, in order to have separate water levels in both areas. But it can be opened which gives the possibility to accommodate each other when needed. The new water system is shown in Figure 5.

Figure 5: Water system measures A5H (Waterschap Rivierenland, 2019)

Regarding the embankments, examination showed that 100 out of the 237 kilometres of embankments do not meet the safety standard (Waterschap Rivierenland, 2019). Through the water system measures, most important unqualified embankments are taken care of. However, there are locations in which more drastic measure are needed, as seen in Figure 6. Waterschap Rivierenland is reinforcing the embankments in two stages, based on the necessity and the impact of the water system measures, this can also be seen in Figure 6. Currently, Waterschap Rivierenland is accessing the first tranche of embankments whether the embankment is in need of strengthening and what would be the best approach for every location. Some possible measures that can be used to reinforce the embankments are heightening the embankments, strengthening or deepen the water channels (Waterschap Rivierenland, 2017).

Figure 6: Embankment reinforcement locations (Waterschap Rivierenland, 2019)

2.3 Water system Peursumse Vliet

Peursumse Vliet is a polder drainage channel which serves to collect and drain polder water. The Peursumse Vliet is located in between the polders Peursum and Giessen – Oude Bovenkerk and stretches from Giessenburg to N214 in the north, as can be seen in Figure 7. The Peursumse Vliet consist of a main channel of on average about 25 meters wide, and two side channels of on average about 9 meters, as seen in Figure 8. The boundaries of the Polder Peursum are shown in Figure 9.

Figure 7: Study Area of the Peursumse Vliet; The Peursumse Vliet is the water channel flowing from Giessenburg towards the Provincialeweg from south to north, around 2.75 km long

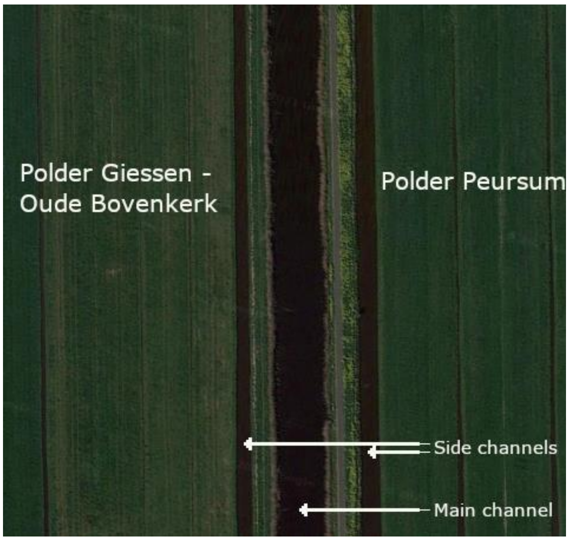


Figure 8: Top-down view of the Peursumse Vliet (Google Maps, 2021); The Peursumse Vliet consists of a main channel which drains the water through the larger area. And two side channels, each belonging to a polder system, and these are important drainage channels for draining the water out of the polder into the Peursumse Vliet

Figure 9: Boundaries polder Peursum; The polder Peursum is one the polers from which the side channels of the Peursumse Vliet are part of and is located northeast from Giessenburg

The waterflow in the polder is shown in Figure 10. In this figure, it can be seen that the pumping station is in the south-west indicated by a red square in the figure. Furthermore, the major water channels that drain water out of the area are indicated by a darker blue colour. Smaller channels are indicated by a slightly lighter blue arrow, and small ditches are indicated by very light blue lines in the polder.

When taking a close look at the direction and the magnitude of the channels, it is clear that the channel alongside the Peursumse Vliet is very important for the drainage, since all water of the northern part flow via the west side to the pumping station south. The waterflow is mainly first going from east to west, and afterwards flowing south. The only exception are some smaller channels towards the middle of the polder that flow north towards bigger channels first, and then continue as described above.

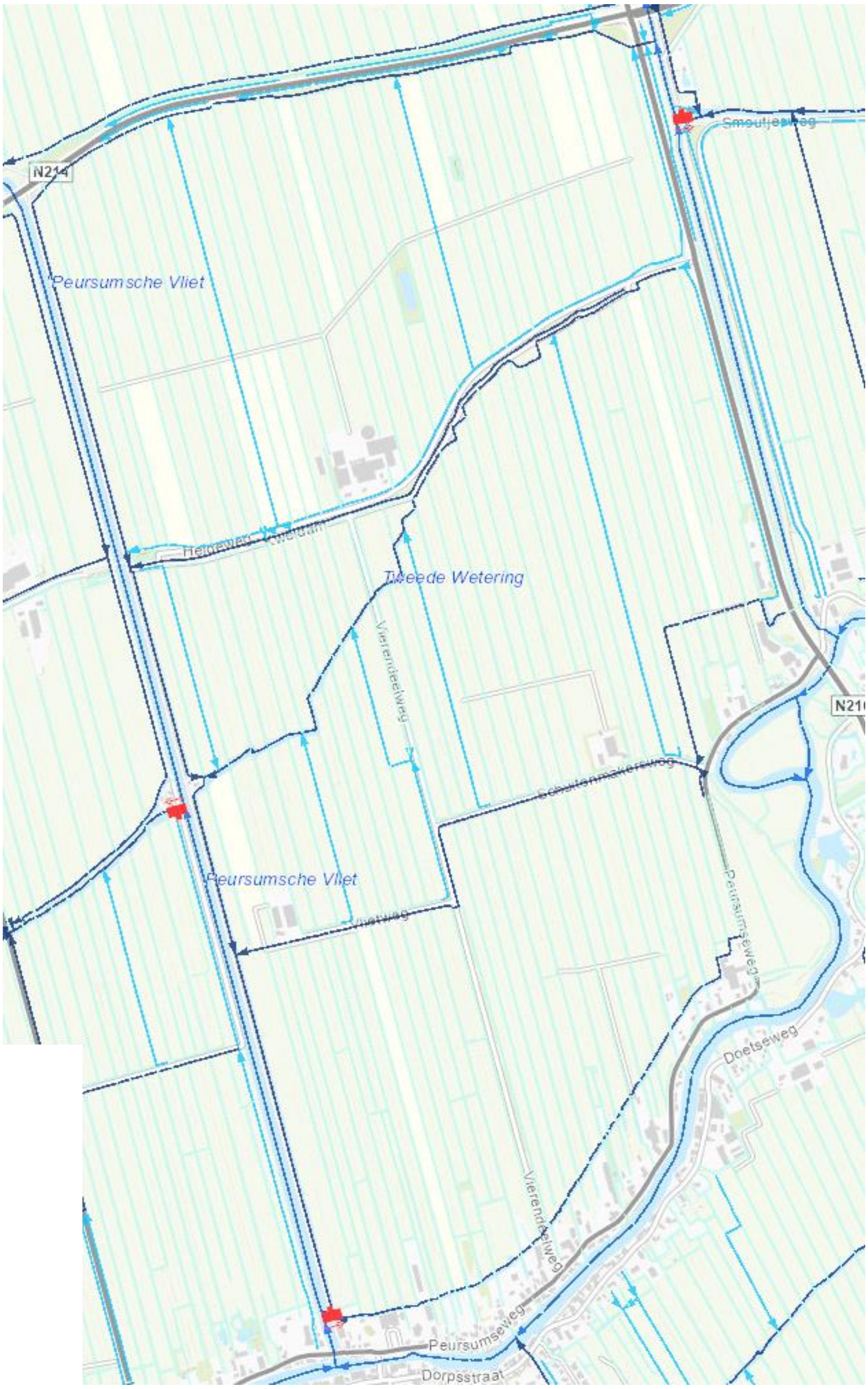


Figure 10: Waterflow in the area; Water is drained out the polder following the blue arrow in the figure which is approximately from north to south after east to west. The colour of blue depicts the magnitude of the channel, the darker blue are bigger drainage channels (among others the side channels of the Peursumse Vliet), the slightly lighter blue are smaller channels, and the light blue are small ditches. The water is drained of the polder via the pumping station in the southwest, depicted with a red icon.

2.4 Instability of the embankments of the Peursumse Vliet

The Peursumse Vliet is a polder drainage channel which serves to collect and drain polder water. In 2014, the embankments of the Alblasserwaard were assessed, from which concluded that the Peursumse Vliet, amongst others are in need of reinforcement. In 2020, all embankments in the Alblasserwaard were reassessed, with the goal of reducing the number of rejected embankments to be improved by changing some guiding principles and new ground research (Bersan, 2020), the report concerns only the test for the failure mechanism macro-stability using a model. Concluding from the report of Waterschap Rivierenland (Bersan, 2020), it is clear that the embankments of the Peursumse Vliet do not satisfy for the macro stability failure mechanism. The embankments will be reinforced in a few years since they can still last a little.

Table 1: Assessment embankments Peursumse Vliet (Bersan, 2020)

Dike location (Figure 11)	Safety Factor	Assessment
GG103.(a)	1,01	Sufficient
GG103.(b)	0,73	Insufficient
GG103.(c)	1,02	Sufficient
GG109.(b)	0,55	Insufficient
GG109.(a)	0,86	Insufficient
GG115.+04	0,66	Insufficient
GG131.+69	1,18	Sufficient
GG142.	0,76	Insufficient
GG150.	1,01	Sufficient

Figure 11: Locations of the assessment point of the Peursumse Vliet (WSRL, 2012)

2.5 Insufficient drainage capacity

Another part of the polder system of the Peursumse Vliet that causes a problem, are the channels in the polder that drain water out of the polder and supply the pumping station at the Peursumse Vliet. The profile of the channels is inadequate to be able to discharge the water properly. Therefore, the channels in the polders need to be dredged. Because, over the years, sediment, sand and silt accumulate at the bottom of the channels, the drainage capacity of the profile slowly decreases. In order to repair the profile and have the drainage capacity again as designed, the channels need to be dredged. This happens mostly once in 15 years, following from personal communication with the dredging team. However, since the embankments of the Peursumse Vliet are in poor state. Waterschap Rivierenland has concluded that the eastern stretch of the ditch alongside the Peursumse Vliet cannot be dredged until the embankments are reinforced, see Figure 13, since that will be detrimental for the embankment. However, then the problem arises that those channels, which cannot be dredged, are not able to drain water properly. The polder channels will be dredged in September 2021, and all the plans and contracts are already finished (see appendix).

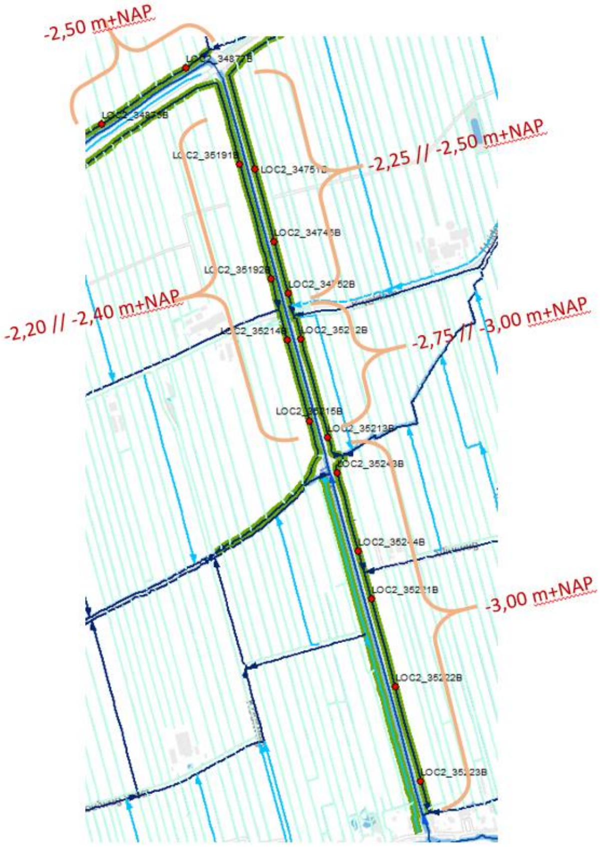


Figure 12: Bottom depth to be dredged

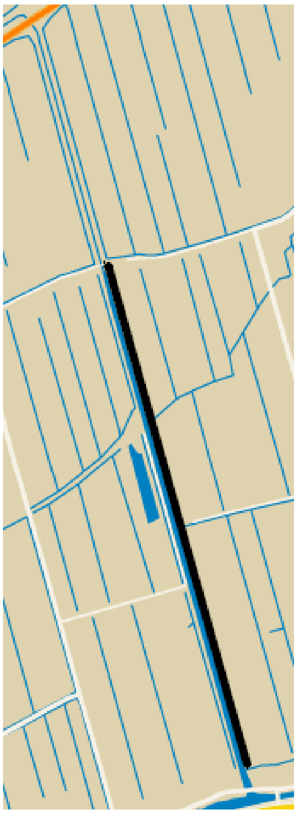


Figure 13: Part that cannot be dredged

3 Development of design scenarios

Solution for the problem with the dredging of the ditch. After meeting up and discussing with the project leader of the dredging team about the guiding principles of their plans, 2 possible scenarios with solutions are created, which are described in the next paragraphs. A reference scenario is created to show what the possibilities are with minimal measures and without major water system adjustments. The reference scenario will be used to make conclusions about the validity of cost, time and impact of the scenario’s compared to a scenario with minimal measures. Furthermore, it can help to show whether the additional cost, time and impact of realising a scenario are significant improvements over a reference scenario.

3.1 Reference scenario

The reference scenario is the scenario with minimal measures and used to show whether the other scenarios make significant improvements. The reference situation is all about maintenance and management. Instead of making major adjustments to the area and water system, just maintaining the current situation and managing the current assets is the goal of this scenario. This includes the following set of measures.

1. Inspections

More frequent inspections on the state of the embankments and monitoring possible holes, damaged part and other defections of the embankments which are in need of immediate reinforcement. However, if this happens, those spots need to be repaired and the bare spots to be filled in. Mole control and controlling other animals that could damage embankment also plays a role in the inspections.

2. Mowing

Mowing operation will be improved. So, the embankments of the channel will be mowed more regularly and to the minimal mowing height. This will lead to a greater flow of water and therefore a greater drainage capacity. The cutting height will be set to 10 cm, which is the minimal cutting height according to Waterschap Rivierenland (Waterschap Rivierenland, 2014). The mowing operations will continue as of the policy regulations of Waterschap Rivierenland, which include protection of plants, animals and their habitat with the least possible nuisance to the environment. Since the mowing operations will cover the whole year, the breeding season has to be taken into consideration. When mowing on 15 March to 15 July, at least 50% of the vegetation need to be kept, and the channel will look like Figure 14 (Waterschap Rivierenland, 2014). Outside the breeding season, 1 April to 1 October, 25% of the vegetation need to be kept, like in Figure 15.

3. Protection Zone

Temporary increase the size of the protection zone. The protection zone has the purpose to protect the embankment from any activities that could affect the stability of the embankment. Waterschap Rivierenland has set a norm for the protection zone of at least 5 meters (Waterschap Rivierenland, 2014). Doubling this to 10 meters, would decrease the possible impact from neighbouring activities on the embankment.

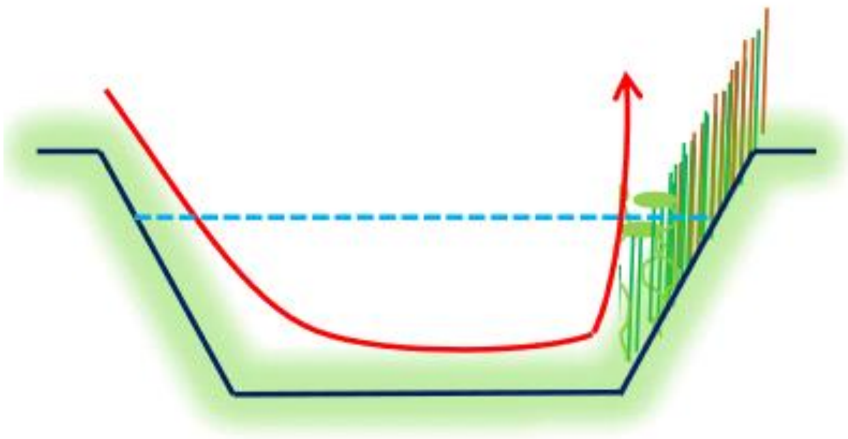


Figure 14: Mowing operation in the breeding season

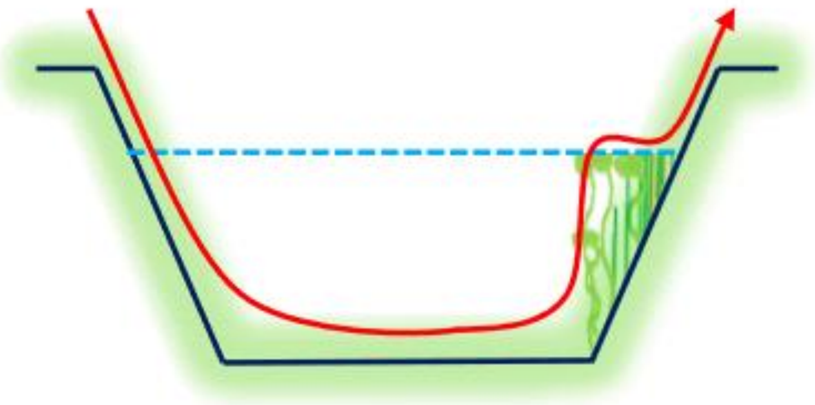


Figure 15: Mowing operations outside the breeding season

3.2 Scenario 1: Additional pumping station

The first solution makes use of a temporary pumping station to drain water out of the polder. This way, water has to flow less through the channels that cannot be dredged and therefore release stress on those channels and still have enough drainage capacity. The optimal location of that pumping station would be opposite of the Bovenkerkse Molen. This location is close to the middle of the Peursumse Vliet and at the end of the largest drainage channel in the polder (black dot in Figure 16). That makes the location optimal, because most water from that drainage channel can be pumped out through the new pumping station directly, without having to flow through the ditches of the Peursumse Vliet which cannot be dredged. This leaves only water directly drained besides the ditch and behind the old pumping station to flow through the ditches of the Peursumse Vliet.

The advantages of this approach is that it is relatively quick to implement, which is an important factor to consider. Furthermore, this solution gives the possibility to convert the temporary pumping station or immediately set a new pumping station at the given location. The disadvantages of this solution is that a pumping station is quite expensive, especially for a temporary measure.

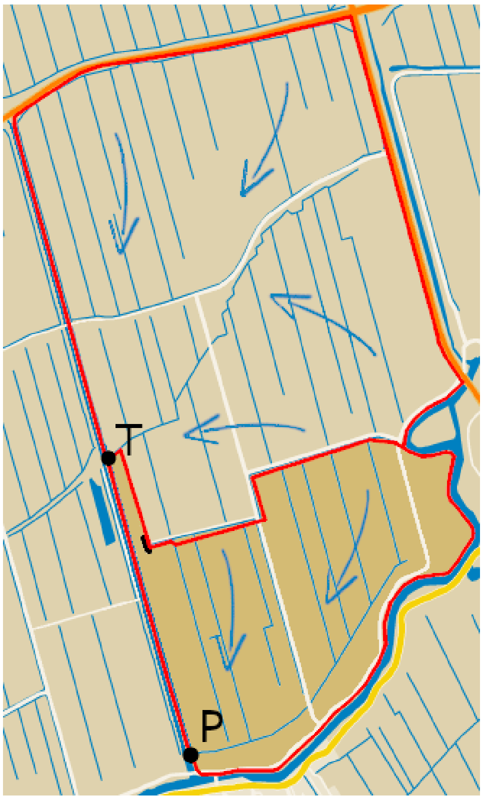


Figure 16: Sketch of water system for scenario 1; The black dots represent the pumping stations, the P is the already existing permanent one, while the T is the new and temporary one. The marked areas show what part of the polder is served by which pumping station

The already existing pumping station (noted with 'P' in Figure 16) has a length of 2.66 meters and a width of 3.15 meters, following the GeoWeb map data of Waterschap Rivierenland (WSRL, 2012). The pumping station is a supplying autonomous mortar pumping station, which means that is has the function to drain water out of the area using a mortar as pumping method (Figure 17). The maximum capacity of this pumping station is 35 m^3/minute (WSRL, 2012). For the, in this scenario, introduced pumping station (noted with 'T' in Figure 16), the assumption is made to use the same size and type of pumping station as 'P'.

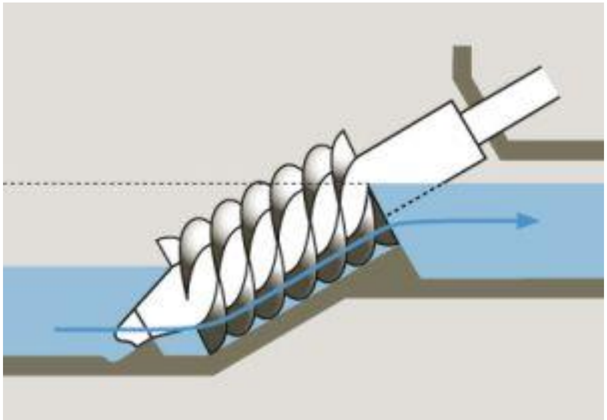


Figure 17: Mortar method of pumping (De Nederlandse Gemalen Stichting, sd)

The catchment area for each pumping station is the area outlined in red. This division is made based on flow routes of water, as can be seen in Figure 10. In the current situation, there are three main flow routes from the polder area to the side ditch of the Peursumse Vliet and then to the pumping station. The main routes are denoted by the darker blue lines in Figure 18, the slightly lighter blue colours are smaller channels, and the lights blue lines are small ditch channels in which very little flows through. Therefore, the division of the two areas for each pumping station is made based on the darker blue main channels. To make the explanation easier, the routes are numbered. Since the water from the southern part flows via Route B and C from east to west, and water from the northern part via route A and B, a logical division would be somewhere around route B. Since the water from the smaller channels flow North to South above route B (towards route A), cutting off the last part of route B will make a natural division as shown in Figure 19. The red line is the division line, and as can be seen the northern and southern part are pumped separately. This causes less stress on the side ditch of the Peursumse Vliet, since it not primarily used as main flow channel. The northern part is drained via route A and B and the new pumping station, while the southern part is drained mainly via route C and a bit of the ditch of Peursumse Vliet to the existing pumping station.

Figure 18: Closer look at water flow in the current situation

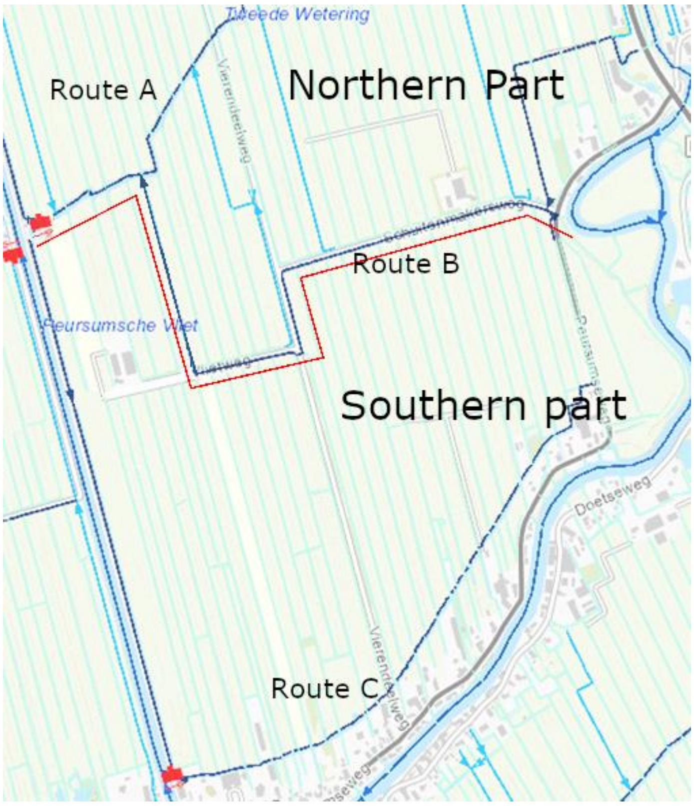


Figure 19: Closer look at water flow in scenario 1

3.3 Scenario 2: Additional water channel

Another solution would be to add another channel alongside the Peursumse Vliet in order to increase the drainage capacity of the system. The goal of this measure is to release stress on the current channel and improve the drainage capacity without having to dredge. This solution would solve the problem with dredging the side channels alongside the Peursumse Vliet. Furthermore, this solution creates more space for the embankments of the Peursumse Vliet which can be enlarged in this scenario. The advantage of this approach is that the water system would be effective for a long time, and it makes space for the reinforcement of the embankments. Since adding onto the current embankment as reinforcement would need the channel to be moved anyway. The disadvantage of this approach is that would need more time to be implemented that the first approach. Furthermore, some land has to be acquired.

The pumping station, in this scenario, is the already existing pumping station and the same as 'P' in Figure 16. With a length of 2.66 meters and a width of 3.15 meters, and a maximum capacity 35 m^3/minute (WSRL, 2012).

In this scenario, an additional channel will be created 65 meters beyond the current ditch at the east side. The drainage capacity of the ditch will be 0.55 m^3/s. So, 0.55 cubic meters of water can be drained per second. Having a drainage capacity of 0.55 m^3/s is possible since 0.55 m^3/s = 33 m^3/minute, and the pumping station has a maximum capacity of 35 m^3/minute. The water depth in the winter and summer is set to 55cm. To achieve the drainage capacity, the depth of the channel will need to be -2,72 m +NAP to -3,02 m +NAP descending from north to south. The profile of the additional channel for the respective location A, B and C are shown in appendix B.

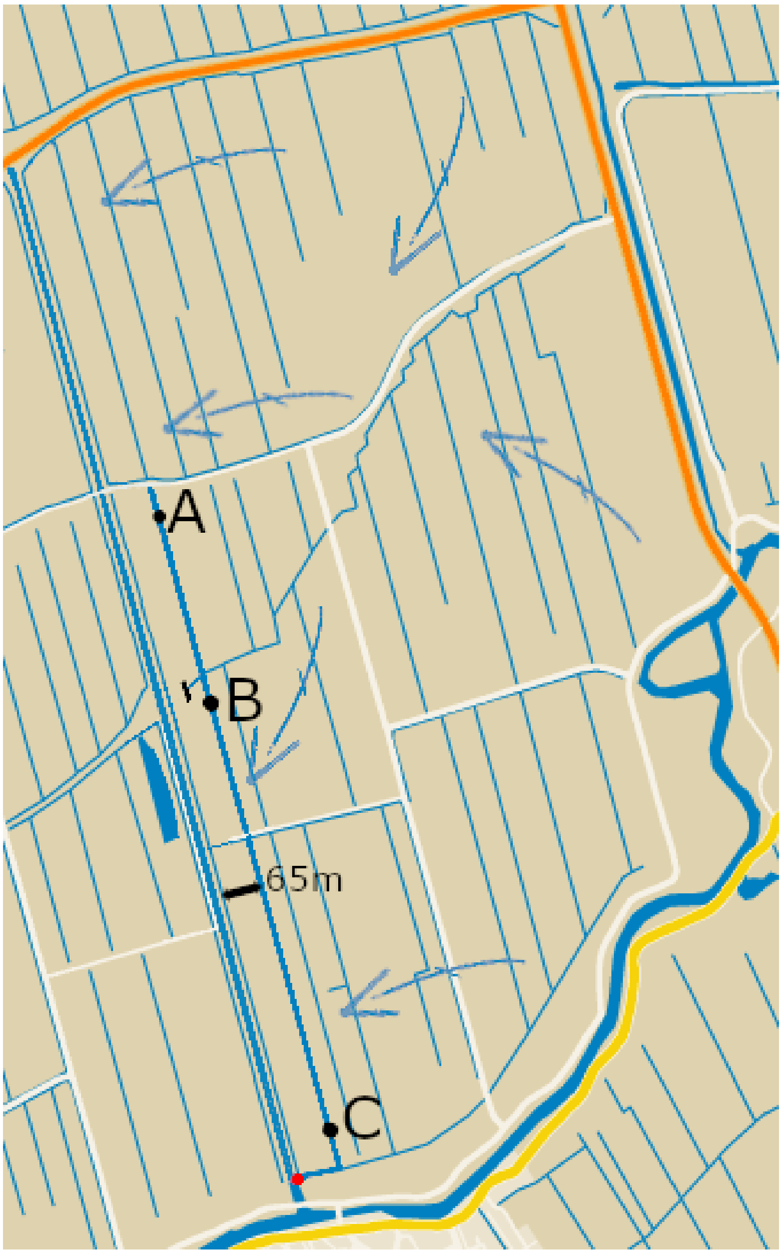


Figure 20: Sketch scenario 2; an additional new channel will be located 65 meters east of the current location, for location A, B and C profiles are shown in the appendix

Figure 21: Closer look at water flow in the current situation

Figure 22: Closer look at water flow in scenario 2 bridging period; in the bridging period some connection between the new and the current channels are still in place

Figure 23: Closer look at water flow in scenario 2 after embankment reinforcement; the current channels is gone, and no connection are still present

4 Design scenarios evaluation

This chapter includes evaluation of the design scenarios on a few major design features following a multi criteria decision analysis.

4.1 Stakeholder analysis

The design criteria, on which the design scenario's will be evaluated, are also derived from the stakeholder analysis. Since it is important to adhere to the stakeholder wishes as much as possible, when designing and constructing with social impact and certain interest of concerned parties. Therefore, the stakeholder analysis is an important factor for the selection of major design criteria. The following stakeholders are analysed, and their role, interest, values and expectations are described. The intern stakeholders and the different teams of departments of Waterschap Rivierenland. They all have different wishes, problems and responsibilities. The extern stakeholders are other organisations like the municipality and Rijkswaterstaat and other extern stakeholders like residents and local stakeholders.

4.1.1 Waterschap Rivierenland

The first, and arguably the most important, stakeholder is Waterschap Rivierenland itself. As research principal, governmental body and as responsible authority of water in the area. Waterschap Rivierenland has to make sure the area is protected from flooding, but also has enough water in periods of drought. Since Waterschap Rivierenland has huge interest in the area and is a governmental body and therefore have more power, the stakeholder is considered a key player. The goal, and therefore the interest, is the intersection of two projects and will be considered separately.

The goal of project A5H, is to optimise the water system in the Alblasserwaard following the vision Watervisie 2050. Therefore, the interest of the project is to make sure the embankments meet the safety regulations, and the water system is optimised.

The goal of team dredging is actuated by hydrology team and includes the dredging of the polder channels in order to increase the drainage capacity in the polder. The interest is to make sure that the polder channels are able to drain polder water properly again.

Since the intersection of the two projects cause a problem and the dredging is due September 2021 and needs a solution, the time and applicability of the design scenario's is in interest. Furthermore, the sustainability of the design scenario is of importance, satisfying Watervisie 2050. With the sustainability it is meant for how long the design can last.

4.1.2 Municipality

The relevant municipality of the study area is 'gemeente Molenlanden'. The municipality is involved since it has many responsibilities in the area. The goals of the municipality are to have as little land acquisition as possible and more importantly, have as little nuisance as possible.

4.1.3 Local inhabitants

Another stakeholder is the neighbouring farmers. Since they own nearby or even conflicting land and can suffer from nuisance from the measures and the realisation in a scenario. The goals of the local inhabitants are to minimise nuisance during and after construction, maintain property value or receive compensation.

4.1.4 Environmental groups

Since the area is full of wildlife and plants, and biodiversity in rural areas are important to retain. The environment is also taken as a stakeholder, in the shape of environmental groups. The area is established habitats of moor frogs, natterjack toads, mudskippers, black tern and all sorts of nesting birds (WSRL, 2012). Furthermore, a lot more wildlife is present in the area. The goals of the environmental groups are to protect local nature, explore opportunities for the expansion of biodiversity and minimise water and air pollution.

4.2 Design features

The design features are following from the stakeholder analysis and are the most important features that satisfy the stakeholders. Since the multi criteria analysis helps making a decision based on the wishes of the stakeholders. The five design features, on which the scenarios will be evaluated, are described in the following paragraphs.

4.2.1 Costs

Costs are the monetary purchase of land, materials and costs for the contractors combined that are needed to realise a scenario. For the scope of the thesis, an estimation of the costs is made for each scenario. The costs need to be minimized and is a feature for Waterschap Rivierenland, since they settle payment for the realisation of a scenario.

4.2.2 Time

Time is the amount of time that is needed for the realisation of a scenario. Since the problem needs a solution as soon as possible, time is considered important by Waterschap Rivierenland. In this analysis, the time is estimated for the urgency and the implementation time.

4.2.3 Durability

Durability is the duration of time that a scenario can be used. It is important that a scenario can be used for as long as possible, which is also in line with sustainability goals. A dredging project need to last at least 15 years, and, following Waterschap Rivierenland. Adaptability is the extent to which it is possible and the amount of work in order to make adaptations to a scenario. The adaptability has influence on the durability since an adaptable design can be used longer than a lesser adaptable design.

4.2.4 Technicality

Technicality is the technical performance of a scenario. To what extent the scenario satisfies with the technical requirements and how well the scenario will probably perform. The technical requirements can be described but the performance will be an estimation based on principles of Waterschap Rivierenland.

4.2.5 Risks

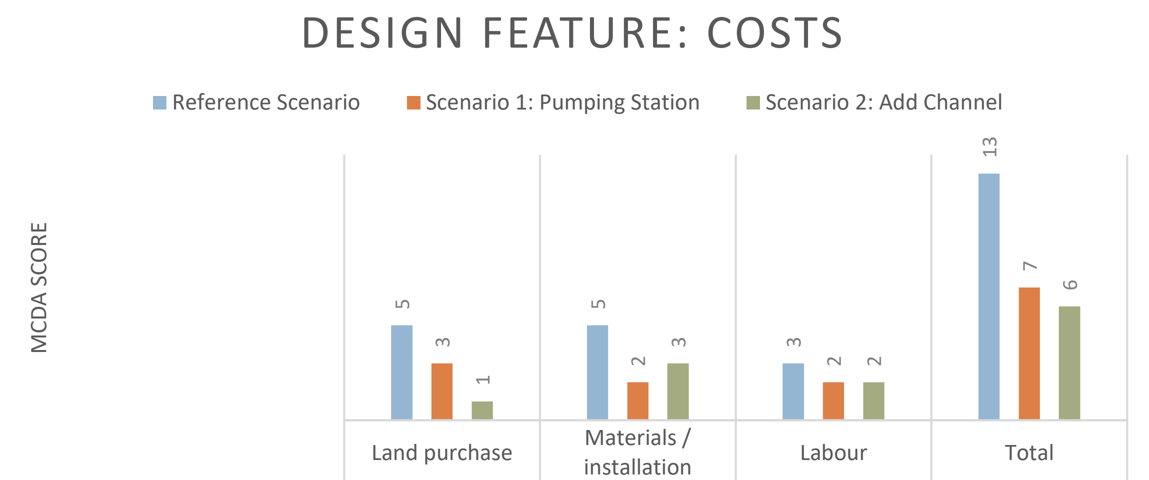
Risks are the amount and the extent of risks that are incidental to a scenario. Depending on the occurrence and the significance of the risks, they can lead to additional costs, time, nuisance and performance loss. Therefore, big risks should be avoided.

4.3 Analysation of the scenario's

The following paragraphs show the analysation of the scenario's based on the design features as mentioned in the previous section. The evaluation is based on a score from 1 to 5, with 5 means the best as in the most positive. So, for cost, 5 means it costs the least while 1 means it cost the most. For the results of the multi criteria decision analysis (MCDA), a score and weight are given to each design criteria. Summing all scores and multiplying by their respective weight will give a total score. The most preferred scenario will be the scenario with the highest total score

4.3.1 Costs

Table 2: MCDA costs



	Land purchase	Materials / installation	Labour	Total
Reference Scenario	5	5	3	13
Scenario 1: Pumping Station	3	2	2	7
Scenario 2: Add Channel	1	3	2	6

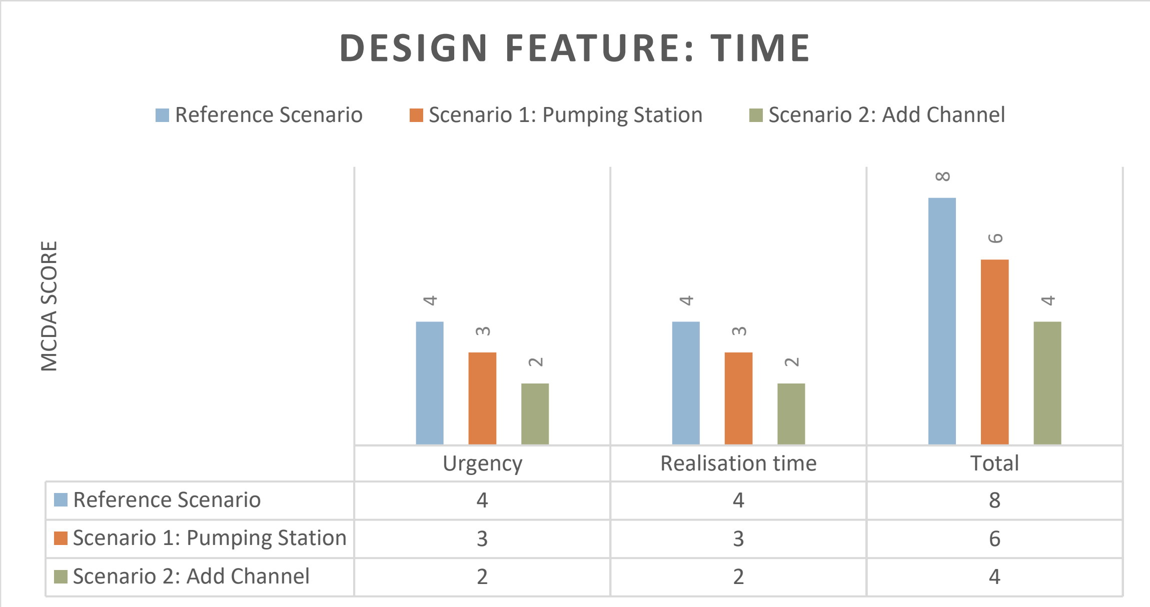
For the reference scenario, no land and materials need to be purchased. The only costs of this scenario are the increased labour cost of inspections, mowing operations and possible repair operations.

For the first scenario, some land has to be purchased, estimated about 1600 square meters. However, the most amount of costs for this scenario are in the additional pumping station and small amount of water system adjustments. The labour costs are the for the installation of the pumping station and the adjustments of the water system

In the second scenario, less materials and installation costs are needed, since the measures in this scenario are way cheaper. However, more land has to purchased, estimated around 4 hectares. The labour costs are for the realisation of new channels.

4.3.2 Time

Table 3: MCDA time

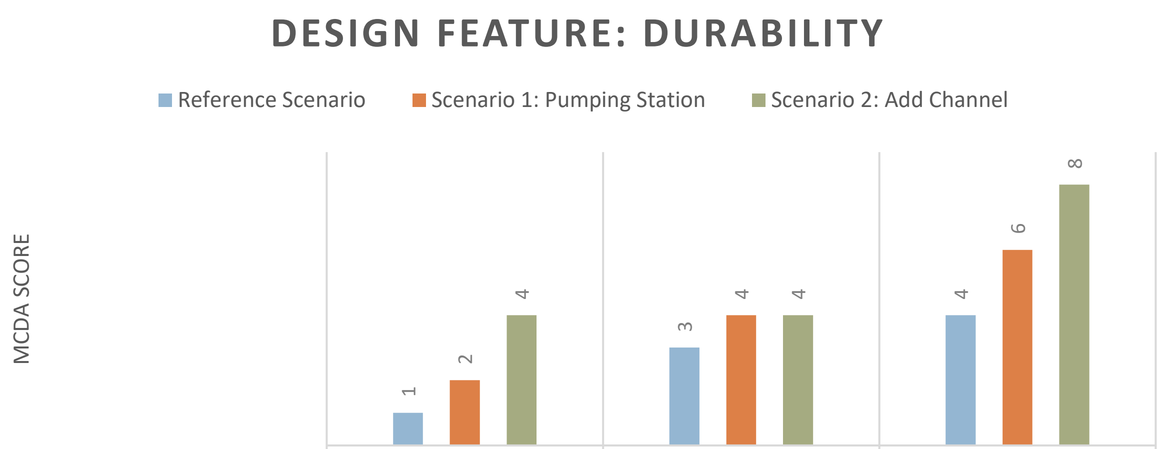


	Urgency	Realisation time	Total
Reference Scenario	4	4	8
Scenario 1: Pumping Station	3	3	6
Scenario 2: Add Channel	2	2	4

The reference scenario can be implemented as of within a week, therefore the high scores for urgency and realisation time. The first scenario can be implemented within one to two months, since the adjustments to the water system are minimal and installation of a new pumping station can be done fairly quickly, and little land has to be acquired. The second scenario can be implemented in approximately half a year. Since the adjustments to the water system are more drastic and require more planning, better elaboration of plans and negotiations over the realisation and the acquisition of land.

4.3.3 Durability

Table 4: MCDA durability

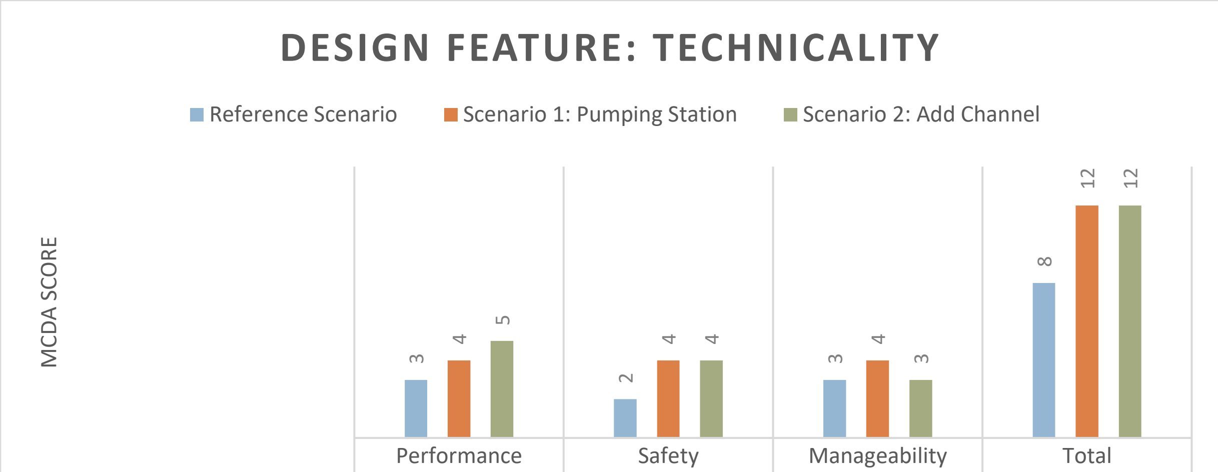


	Sustainability	Adaptability	Total
Reference Scenario	1	3	4
Scenario 1: Pumping Station	2	4	6
Scenario 2: Add Channel	4	4	8

The reference scenario is not sustainable, since the state of the embankments are currently poor, and the reference situation has only some small measures to improve the lifespan of the embankment. The first scenario only provides a temporary measure for the coming 2 years, which makes it more durable than the reference situation. The second scenario provides a sustainable solution for the bridging period and the future, which makes it the most sustainable. Regarding the adaptability of the designs, the reference situation is neutral, is has options for adapting the scenario like going for one of the two other scenarios when the reference scenario is not enough for the embankments to hold in the bridging period. However, this will be seen as a missed opportunity. Both other scenarios are somewhat adaptable since there is plenty of space and possibilities for adaptations in the future.

4.3.4 Technicality

Table 5: MCDA technicality



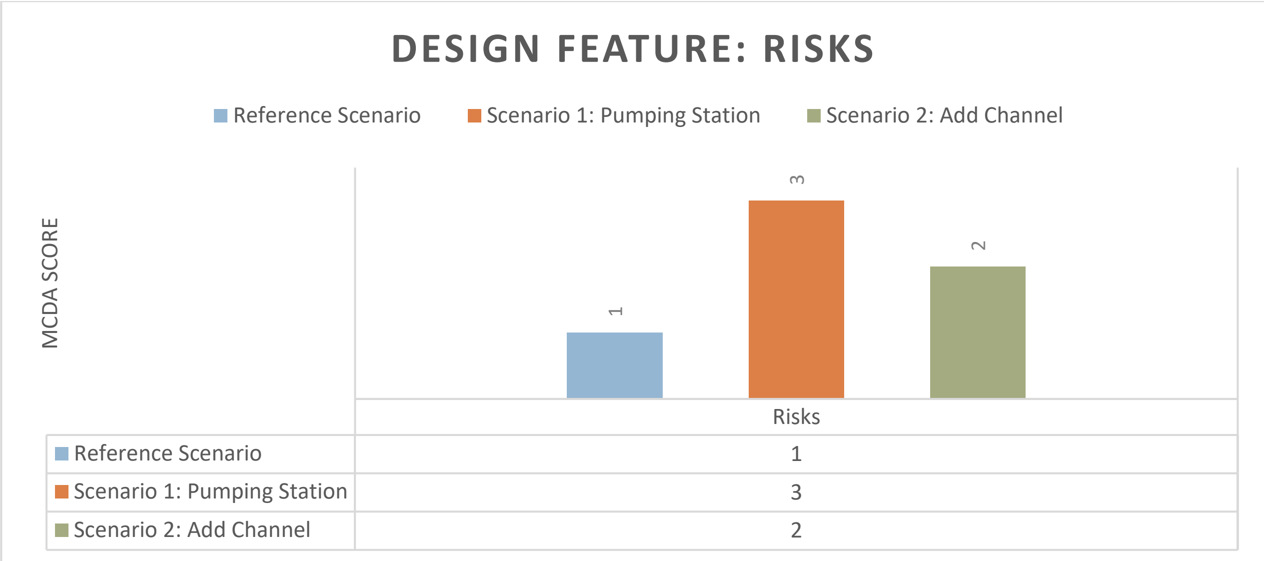
	Performance	Safety	Manageability	Total
Reference Scenario	3	2	3	8
Scenario 1: Pumping Station	4	4	4	12
Scenario 2: Add Channel	5	4	3	12

No in-depth calculations or models are used for the evaluation of the technicality of the scenarios. The reference scenario does not change the technical behaviour of the system, therefore is has a neutral score. Safety is lowered since the scenario is the least safe because of the lack of change in technical behaviour. The other scenarios are regarded as safe solutions. The manageability is only applicable for the first scenario, since having multiple pumping stations gives more control over the water levels in the system.

Concerning the performance of the scenarios, the following scores have been given. The reference scenario has been given a neutral score. The second scenario has a drainage capacity of 33 m^3/minute. The first scenario has a drainage capacity increase of 35 m^3/minute. However, since the drainage capacity of the first scenario is only increased at the pumping station, while the second scenario has an increase in the channels, it gets a higher score.

4.3.5 Risks

Table 6: MCDA risks



The reference scenario has the highest amount of risks, mostly regarding the safety concerns of the embankments and the risk that the embankments will not hold. The first scenario has the least amount of risks while the second scenario has some risks involved.

4.4 Conclusion MCDA

Depending on different prioritisation scenario's, different optimal scenarios and conclusions can be drawn from this evaluation. Prioritising certain criteria's over other in many combinations, all yield different results. In this analysis, the focus is set on three different approaches. A risk-free approach, a cost reduction approach and water vision 2050.

4.4.1 Risk free approach

The first approach for which the results will be gathered, is the risk-free approach. For some situations, it is important to minimize risks. This mostly dependent on the amount of risks, the chance of failure and the amount of possible damage. In this approach, the weights are set according to Figure 24. Risks obviously has the most amount of priority. Thereafter, the technicality and time are important since the scenario has to work as good as possible and has to be implemented quickly. The costs are the least important since the risks has to be avoided no matter the costs.

Figure 24: Weight division for a risk-free approach

The results of this approach can be seen in Figure 25. Both scenarios are a major improvement over the reference scenario in terms of risks reduction. The first scenario of the additional pumping station has the highest score. This is due because this scenario is quicker to implement and has less risks.

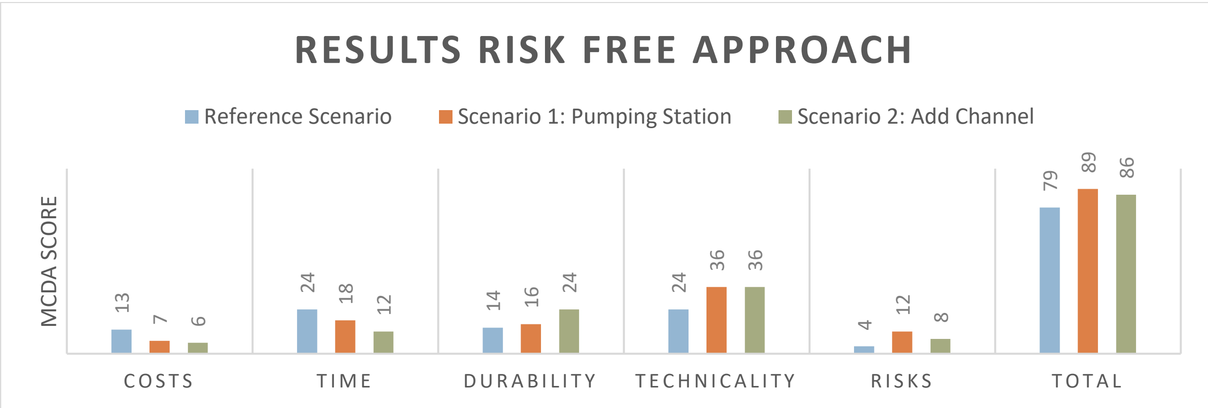


Figure 25: Results risk free approach

4.4.2 Cost reduction approach

Another approach is the cost reduction approach. In certain situations, it can be useful to look at the scenario which is the cheapest. In this approach, small prioritisation has been given to time and risk while the durability and the cost are the most important. The weight division for this approach has been given in Figure 26.

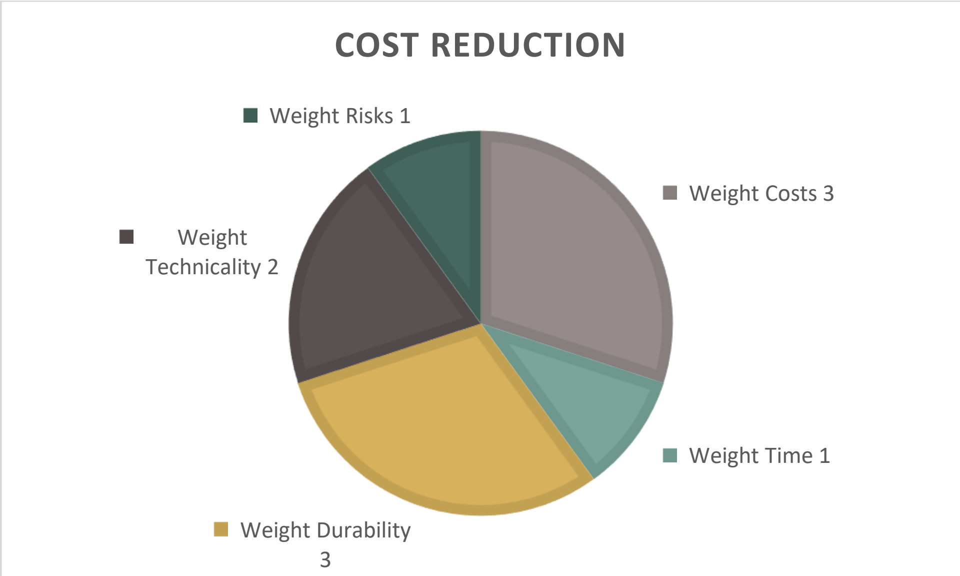


Figure 26: Weight division for a cost reduction approach

When applying this approach, results in the following as can be seen in Figure 27. The reference scenario comes out best, mostly because of the low cost. However, the second scenario also has a high score because of its high durability compared to the reference scenario.

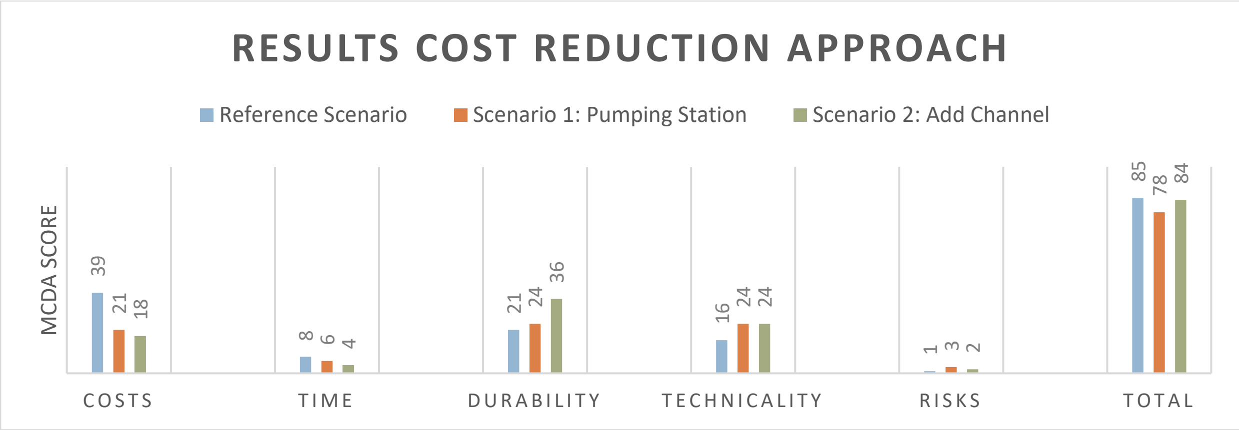


Figure 27: Results cost reduction

4.4.3 Water vision 2050

The last approach is Water vision 2050, applying the vision for 2050 as set up by Waterschap Rivierenland to the Peursumse Vliet in my own context. In this approach, durability and time are the most important features, being an objective of Waterschap Rivierenland. The total division of the weight are given in Figure 28.

Figure 28: Weight division water vision 2050

The result of applying this approach is given in Figure 29. Concluding from this analysis, the second scenario would be the best solution for the Peursumse Vliet. The first scenario would also be an improvement over the reference scenario but only by a small margin.

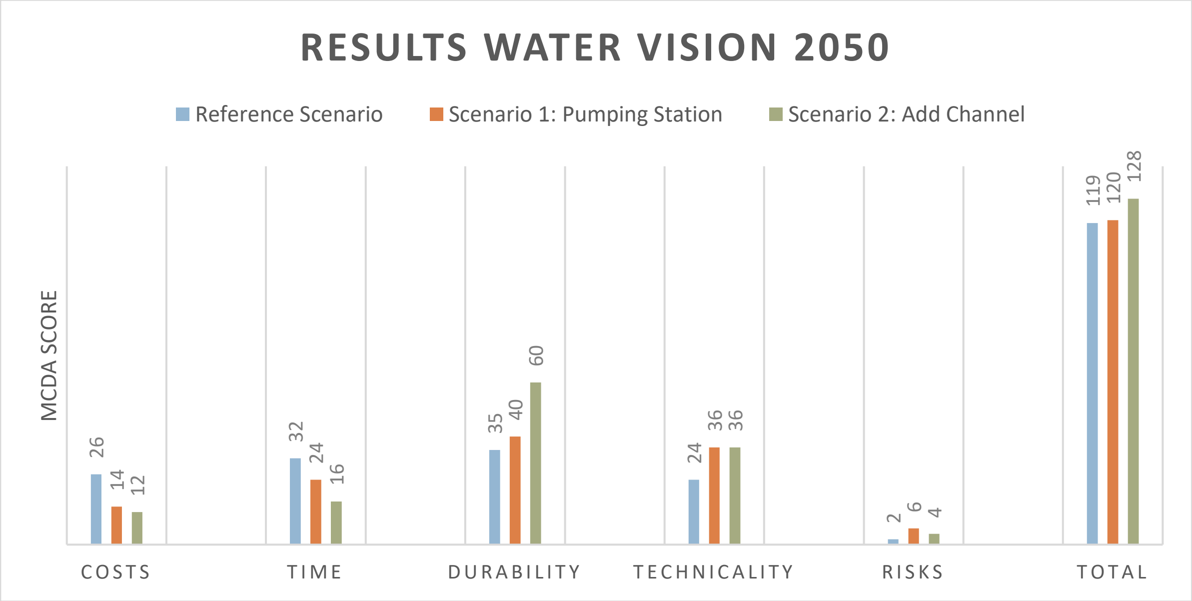


Figure 29: Results water vision 2050

5 Discussion

This paragraph is about the interpretation of the research in which the factors that has influence on the results are discussed. The results show what scenarios would be the best solution for the Peursumse Vliet applying certain approach and over a set of design criteria. However, some choices, assumption and limitations are attendant to the results.

First of all, since the research is executed at Waterschap Rivierenland, and most issues about the problem were discussed with employees, it surely influenced my vision and analysis. Also, because Waterschap Rivierenland is also a major stakeholder of the problem, above average attention has been given to the objectives of the client.

Not all stakeholders are individually spoken to, which results in more inaccuracy of the stakeholder analysis and therefore, the design criteria. This is also complementary to point discussed above, since this also has effect on my vision and view of the problem.

Since the timescale of the research is only 10-weeks, no model could be set up to evaluate the scenarios. This way, the evaluation is more based on the social aspects of designs instead of in-depth technical aspects and performance calculations. This has to be taken into account when concluding the results.

The method of determining and creating alternative solutions for the Peursumse Vliet, and the method of evaluating the solutions could be different. Another method may have led to different results and a different conclusion. A multi-criteria analysis has been chosen in this research because it is more experienced. However, other possible methods could also have been used. The method of creating scenarios and the amount of scenarios are also limited. The creation of scenarios is mostly defined by discussion with employees of the different departments. However, other methods such as literature research could have been used to come up with alternate solutions and more scenarios could have been evaluated.

Some assumptions that are applied in this research are the following. In the reference scenario, the assumption is made that the embankments are able to hold up in the current situation and that only mowing is enough maintenance.

In the first scenario the assumption is made that the natural gradient of the area is ignored. Since there is a natural gradient, with the lowest point at the current pumping station, some flows would need to be evaluated whether it is logical and realistically possible with regard to the slope in the area. However, since the area is really flat and it is outside of the scope of the research, this assumption has been made. Another assumption is that the new pumping station is the same as the already existing pumping station. Since it is outside the scope to determine the maximum capacity of the new station, this assumption has been made.

Lastly, in the second scenario, the assumption has been made that all required land is possible to be acquired. The cadastral boundaries and the physical objects in the area has been taken into account, resulting in the required land being only farmland. The assumption is made that this land is being able to be acquired within a very small timeframe. Since in real life, land acquisition could take a long time and therefore the whole project could be postponed.

The recommendations I would have for further studies is making more use of the other stakeholders but most importantly, make use of a model to determine the qualitative characteristics of each scenario and meet the technical aspects of the solutions.

6 Conclusion

In this paragraph, the research is concluded by coming back to the research questions and objectives. The research was done to solve the problem of a too small drainage capacity because of the disallowance to dredge the channel. The problem is stated by the following objective:

- Create design scenarios with measures following a strategy in which the drainage capacity increases without dredging
- Evaluate the design scenarios using a multi-criteria decision analysis in the context of a stakeholder analysis

With the goal to create and evaluate design scenarios with alternate solutions to increase the drainage capacity of the channels near the Peursumse Vliet without dredging. The research question is about the different steps in the methodology in order to achieve the research objectives. To conclude this research, the research question is answered and advise Waterschap Rivierenland about the possible solutions to the problem.

The first research question is about the current state of problem: "*To what extent is the problem of the Peursumse Vliet urgent?*". This is covered in chapter 2 of this report. To answer this question, I researched the current state of the water system and analysed the water levels for the area. The water level in the northern part of the polder is -1.50 m +NAP in the summer and -1.60 m +NAP in the winter. The southern part has a water level of -1.93 m + NAP in the summer and -2.03 m +NAP in the winter. According to research using a model to determine the failure of the embankments, the embankments of the Peursumse Vliet do not satisfy. Without dredging, the side channels do not have enough drainage capacity to drain water out of the polder.

The second research question is about the creation of alternative solutions in scenarios in which the drainage capacity is improved: "*How can the drainage capacity of the channels be improved using an alternative solution?*". Two scenarios are created using two different alternative strategies to solve the problem and a reference scenario is described. The reference scenario is the scenario with minimal measures, instead of making major adjustments to the area and water system, just maintaining the current situation and managing the current assets is the goal of this scenario. The first solution makes use of a temporary pumping station to drain water out of the polder. This way, water has to flow less through the channels that cannot be dredged and therefore release stress on those channels and still have enough drainage capacity. The second alternative adds another channel alongside the Peursumse Vliet in order to increase the drainage capacity of the system. The goal of this measure is to release stress on the current channel and improve the drainage capacity without having to dredge.

The last research question is about the evaluation of the scenarios and which design features and weighting strategy to use: “*What would be the most suitable solution for the Peursumse Vliet?*”. To answer this question, I looked at the major design features based on a stakeholder analysis, and the weighting strategy which best suits Waterschap Rivierenland. The answer to the question about which of the scenarios is the best depends on the weighting scenario and other areal factors. However, for the Peursumse Vliet, the following answer and advise is given to Waterschap Rivierenland.

Concluding, the multi-criteria analysis answers by preferring the second scenario of an additional channel as the best scenario. Using the Water Vision 2050 weighting strategy, which fits best for the Peursumse Vliet in my opinion. The second scenario has a MCDA score of 128 while the other has 119 and 120 respectively. However, this does not immediately mean that this scenario is the most suitable for the Peursumse Vliet. Every stakeholder has a different value to the urgency and the value of money regarding the best solution. So Waterschap Rivierenland has to make the consideration and the trade-off whether the additional cost is worth the solved problem. However, in my opinion, the second scenario is indeed the most preferred solution, and the cost would be good value, mainly because of the long durability of the solution and the fact that a temporary bridging solution is able to continue into a permanent solution in the future. Important note is to take into consideration the points mentioned in the discussion about the validity of the results.

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Appendices

Appendix A: Dredging

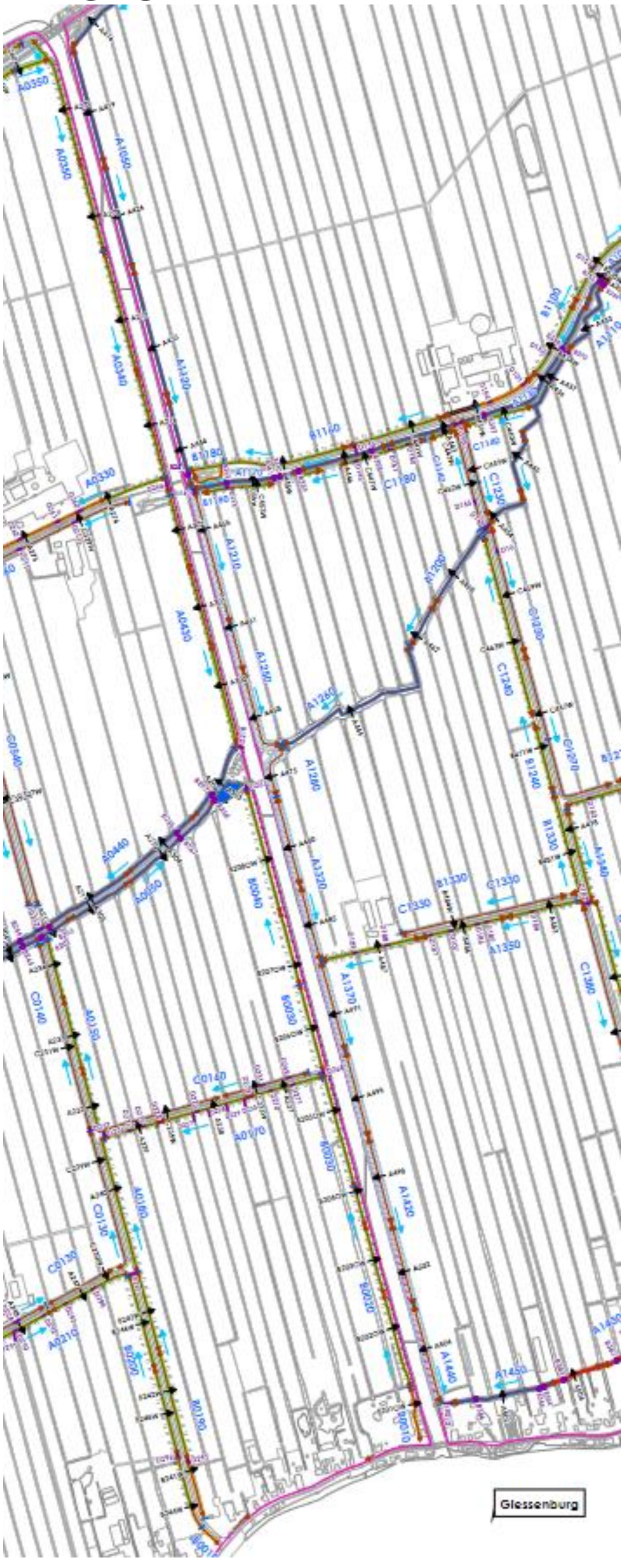
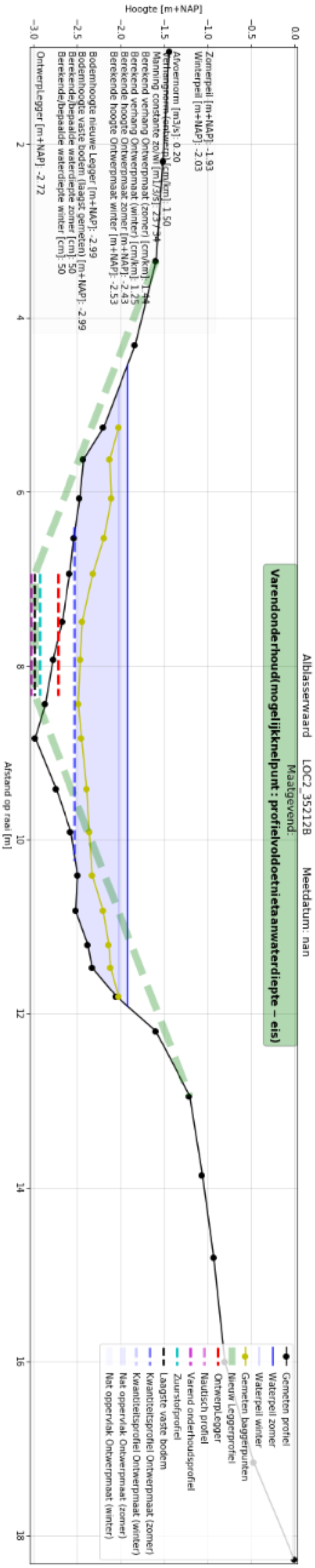
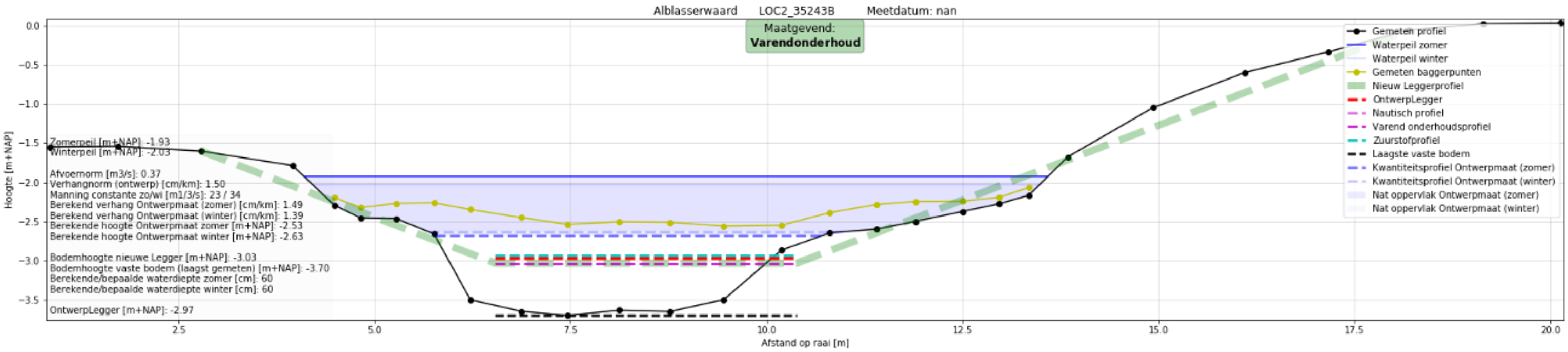
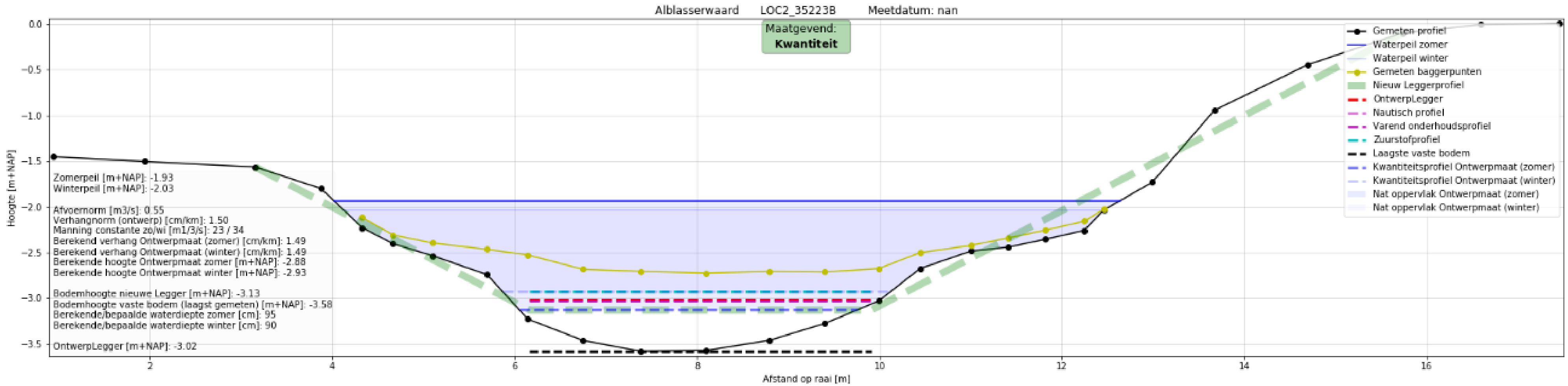


Figure 30: Dredging plans for the area

Appendix B: Profiles for additional channel scenario




Alblasserwaard LOC2_35243B Meetdatum: nan
Maatgevend:
Varendonderhoud
Hoogte [m+NAP]
Afstand op raai [m]
Zomerpeil [m+NAP]: -1.93
Winterpeil [m+NAP]: -2.03
Afvoernorm [m3/s]: 0.37
Verhangnorm (ontwerp) [cm/km]: 1.50
Manning constante zo/wi [m1/3/s]: 23 / 34
Berekend verhang Ontwerpmaat (zomer) [cm/km]: 1.49
Berekend verhang Ontwerpmaat (winter) [cm/km]: 1.39
Berekende hoogte Ontwerpmaat zomer [m+NAP]: -2.53
Berekende hoogte Ontwerpmaat winter [m+NAP]: -2.63
Bodemhoogte nieuwe Legger [m+NAP]: -3.03
Bodemhoogte vaste bodem (laagst gemeten) [m+NAP]: -3.70
Berekende/bepaalde waterdiepte zomer [cm]: 60
Berekende/bepaalde waterdiepte winter [cm]: 60
OntwerpLegger [m+NAP]: -2.97
Gemeten profiel
Waterpeil zomer
Waterpeil winter
Gemeten baggerpunten
Nieuw Leggerprofiel
OntwerpLegger
Nautisch profiel
Varend onderhoudsprofiel
Zuurstofprofiel
Laagste vaste bodem
Kwantiteitsprofiel Ontwerpmaat (zomer)
Kwantiteitsprofiel Ontwerpmaat (winter)
Nat oppervlak Ontwerpmaat (zomer)
Nat oppervlak Ontwerpmaat (winter)



Alblasserwaard LOC2_35223B Meetdatum: nan
Maatgevend:
Kwantiteit
Zomerpeil [m+NAP]: -1.93
Winterpeil [m+NAP]: -2.03
Afvoernorm [m3/s]: 0.55
Verhangnorm (ontwerp) [cm/km]: 1.50
Manning constante zo/wi [m1/3/s]: 23 / 34
Berekend verhang Ontwerpmaat (zomer) [cm/km]: 1.49
Berekend verhang Ontwerpmaat (winter) [cm/km]: 1.49
Berekende hoogte Ontwerpmaat zomer [m+NAP]: -2.88
Berekende hoogte Ontwerpmaat winter [m+NAP]: -2.93
Bodemhoogte nieuwe Legger [m+NAP]: -3.13
Bodemhoogte vaste bodem (laagst gemeten) [m+NAP]: -3.58
Berekende/bepaalde waterdiepte zomer [cm]: 95
Berekende/bepaalde waterdiepte winter [cm]: 90
OntwerpLegger [m+NAP]: -3.02
Gemeten profiel
Waterpeil zomer
Waterpeil winter
Gemeten baggerpunten
Nieuw Leggerprofiel
OntwerpLegger
Nautisch profiel
Varend onderhoudsprofiel
Zuurstofprofiel
Laagste vaste bodem
Kwantiteitsprofiel Ontwerpmaat (zomer)
Kwantiteitsprofiel Ontwerpmaat (winter)
Nat oppervlak Ontwerpmaat (zomer)
Nat oppervlak Ontwerpmaat (winter)
Hoogte [m+NAP]
Afstand op raai [m]