Nature-based bank design for the east side of Buiteneiland, IJburg, Amsterdam

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NATURE-BASED BANK DESIGN FOR THE EAST SIDE OF BUITENEILAND, IJBURG, AMSTERDAM

A thesis submitted to the Delft University of Technology in partial fulfillment of the requirements for the degree of

Master of Science in Civil Engineering

by

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Marieke van der Velden: *Nature-based bank design for the east side of Buiteneiland, IJburg, Amsterdam* (2020)

The cover photo is the dike of Durgerdam and is self-made.

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I would like to thank the Engineering Office for offering this opportunity to conduct my graduation research at their office. I extend my sincere thanks to my colleagues from the Engineering Office for their openness and critical questions to improve my work. Especially, Kelvin, my daily supervisor, who helped me focus on what is important. During the weekly meetings on Thursday morning I felt always free to ask and discuss anything.

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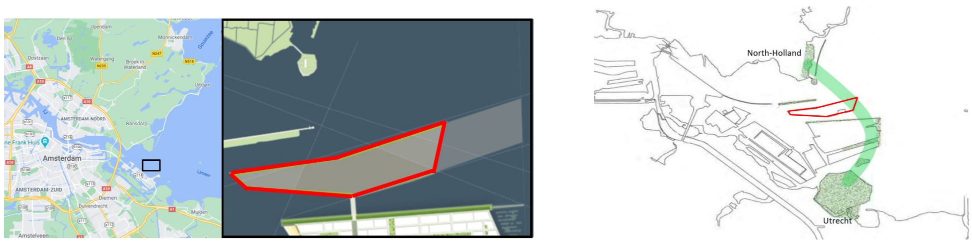
I hope you enjoy reading it, as I enjoyed writing.

Marieke van der Velden
Amsterdam, December 2020

SUMMARY

The Engineering Office of the municipality of Amsterdam (Ingenieurs Bureau van Amsterdam) is developing six man-made islands in the IJmeer. One of the last islands will be Buiteneiland.



(a) Shape and location Buiteneiland

(b) 'Boog om de Oost' location indication

Figure 0.1: Location of island in IJmeer and Markermeer. Shape of Buiteneiland, the area of interest is indicated by a darker grey color east of the green island border and reaches till the municipality border

The location and orientation of Buiteneiland is been agreed when IJburg was designed and can be found in Figure 0.1. The area of interest of this study is the land-water transition at the east side of the island. The orientation of the east side of Buiteneiland is in hydraulic engineering aspects not most efficient in protecting the island, but the shape and orientation are not negotiable.

Buiteneiland (Dutch for 'outdoor island') needs to get land-water transition that provides water safety with a green character. In this study this aim is translated into the concept: a nature-based hybrid solution. Figure 0.2 shows the definition of a hybrid solution.

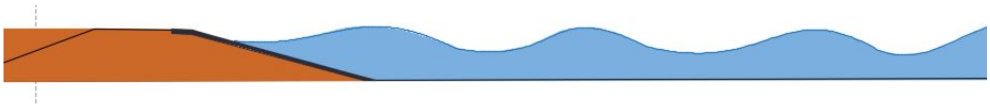
The IJmeer's morphology is storm driven and the prevailing waves in this low energy environment, have limited reshaping capacity. Therefore, the land-water transition needs to consist of erosion protection. At the same time, the east side of the island will contribute to the 'Boog om de Oost', a provincial arch that connects the province of Utrecht with North-Holland via outer dike reed fields (see: Figure 0.1).

For the Engineering Office, this was the reason to ask for an approach to deal with a hybrid solution, that combines a nature-based foreshore with an erosion protection for the east side of Buiteneiland. Figure 0.2 shows two possible land-water transitions, a traditional dike and a nature-based hybrid solution.

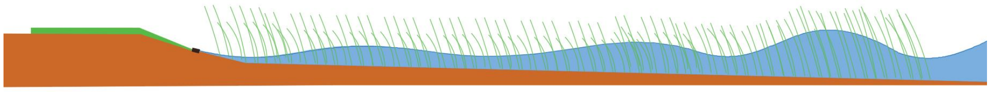
This composed the research question for this study: *What is a safe and nature-based hybrid solution for the case study: east side of Buiteneiland, IJburg?*.

Design of alternatives for the nature-based hybrid solutions is done according to the method of de Vries et al. [2016]. This Building with Nature method is developed for nature-based type of projects. The Building with Nature method contains the five clear steps that have been worked through iteratively.

The most suited nature-based hybrid solution for the east side of Buiteneiland seemed the Hard Arch variant (see Figure 0.3). When implementing a nature-based hybrid solution, components and concepts of this solution can be extracted and implemented individually. New build or restored land-water transitions at least consists of a vegetated foreshore. Hydra-NL is an often used program for the design of bank and shore protections. Despite that, this program is not able to design dike profiles with a grass cover, combined with a vegetated foreshores. Initially, the crest height of the dike is therefore determined according to a rule of thumb. The breaker criterion of Miche (1944) is used to determine the wave height at toe of



(a) Basic Concept; a traditional way, with rubble mound cover indicated by grey area



(b) Hybrid solution; with grass covered dike indicated by green

Figure 0.2: Two bank design options. The traditional dike (Basic Concept) that fulfills its function by only one component. A hybrid solution combines more than one component, in this figure a foreshore with a dike and reed field. A hybrid solution can reduce construction costs while offering the same protection level. At the waterline wooden erosion protection is placed. This figure only shows the definition of a traditional dike and a hybrid solution. These are not eventual cross-sections.

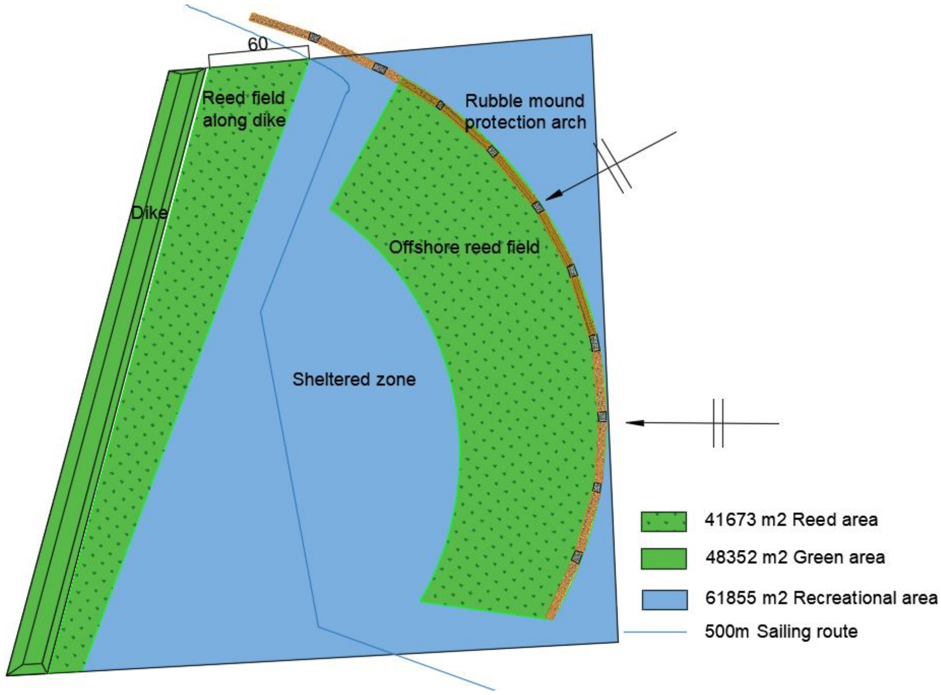
dike. This means that the reducing effect the reed could have on the wave height, is not yet taken into account which lead to a conservative approach. Eventually, the contribution of vegetation has on the wave height is determined according to the vegetation model of Vuik et al. [2018] (parameters adjusted apply to reed). By using the vegetation model and taking the reed into account, the crest height was estimated too conservative by 13 cm. For lower wave height (occur more often) the improvement of estimation in crest height for a dike is less. According to these results, it can be stated that in determining a crest height with a vegetated foreshore in a preliminary phase, it does not make significant difference when making use of this rule of thumb and not taking the vegetation contribution into account.

The dike of the Basic Concept (is a dike without a foreshore or vegetation), covered by grass requires a crest height of 2.27 m. The hybrid solution as the Hard Arch variant, the grass covered dike only requires a crest height of 1.61 m, while offering the same protection level. The costs estimate for the found hybrid solution is a factor 5.5 higher than for the Basic Concept. However, the hybrid solution does have a lot of extra benefits next to safety. A lot of natural capital is added to the IJmeer and for the citizens of Amsterdam, in terms of vegetation above and below the water surface. Furthermore, social value and inspirational values are added to the Markermeer, where other new islands or shore restorations can be inspired by this nature-based hybrid solution.

The last years, he Netherlands has made a lot of budget available for the creation of natural added value, as can see for other nature-based projects like Houtribdike, Pettemer sea defence and the Markerwadden. The larger budget is mostly due to the ongoing Nitrogen crisis and the creation of more awareness in the importance of natural value. To give an indication; the estimated cost for the Markerwadden project were €100 million. This resulted in a costs to nature ratio of 10 $€/m^2$. This ratio is much less than the ratio for this study namely, 46.5 $€/m^2$. When creating a larger area, the cost per square meter will decrease eventually, but still the costs of this solution per square meter is quite high.

Thus, this nature-based hybrid solution is more expansive, but a solution like this maximizes the benefits for local communities, nature and economy. Overall, the use of a nature-based hybrid solution is a way of combining the development of new nature and ecosystems with coastal protection providing safety and prosperity for local community.

(a) Cross section



(b) Plan view

Figure 0.3: The Arch Alternative with The Hard Arch variant. With respectively a once every 830 years and once every 10 years incoming wave height of H_s = 1.17 m and H_s = 0.85 m and prevailing direction 60 °N and 90 °N (N is up). With two reed fields (by spots indicated area has 1m water depth) and a sheltered zone (blue area has 3m water depth) in between.

CONTENTS

1 INTRODUCTION

The world's population is growing and climate change is going faster than expected. Apart from the rise in population, a rapid rise in global consumption contributes significantly to increased climate change [Cumming [2016]]. Our global consumption is causing a large carbondioxide (CO_2) emission. To slow down this process, our CO_2-footprint should not only be set stable but should be negative if possible. This is only achievable by giving the world her resources back, when or where possible [Cumming [2016]].

The effect of growing population around coastal areas, together with the rise of sea level due to climate change, increases the economic losses during flood hazards. The sea level is rising rapidly and not all coastal protection areas are built with this in mind.

That is why coastal areas need very thoughtful designs. Coastal protection studies need to include the protection of the coasts against natural erosion [Deltares [2014]]. Sandy coasts' protection needs to be adaptive to rising water levels and the increase in impact of storms. Moreover, the designer should acknowledge their responsibility in compensating project-related CO_2 emissions.[Cumming [2016]].

Clearly, in the design of the new island, Buiteneiland in the *IJmeer* the compensation is also applicable. The Engineering Office (*het Ingenieursbureau*) of Amsterdam is responsible for the design of the new islands in the *IJmeer* [*Contouren en dijkprofielen Buiteneiland* [2020]]. Buiteneiland will be the newest island of *IJburg* and is going to be located northeast of Amsterdam. The location of the island is shown in Figure 1.1.

The Engineering Office is partner of the municipality of Amsterdam. Within the field of technology and project realization in ground, road and hydraulic engineering, they advise and manage projects from idea to implementation [*Buiteneiland: groen anker van Amsterdam* [2020]].

The area of interest of this study will be the east side of this island. This area is shown in Figure 1.1 by a black line. The light grey area on the right-side indicates an approximately 400 meter off-shore orientated area. This area is to-be designed. The shape of the island (indicated by red shape) is part of the full IJburg archipelago and is not negotiable.

Figure 1.1: The location of interest; the east side of Buiteneiland in the *IJmeer*. The land-water transition is marked with black line. The grey area east of the island indicates the municipality's area. [*Contouren en dijkprofielen Buiteneiland* [2020]]

The Engineering Office aims at the first place to design a safe Buiteneiland [*Contouren en dijkprofielen Buiteneiland* [2020]]. The aim is about the water safety of the island that needs to be established according to the Dutch regulations. The second aim the Engineering Office wants to create, is an island with a green, circular and outdoor character.

1.1 PROBLEM DESCRIPTION

The Engineering Office needs a design for the east side of the newly built Buiteneiland. safe, green, circular and outdoor character for Buiteneiland. This is done by using The vision is that this island, located in the IJmeer, gets a safe and nature-based shore character. In this study for the east side of the island, these terms are translated by one overarching term; nature-based area that fulfills the safety as well. The east side of the island will participate at the 'Boog om de Oost' [Amsterdam [2009]]. Which is a provincial arch that connects province of Utrecht with Noord-Holland via outer dike reed fields.

The IJmeer is a low energy environment and no tide is present. The island's morphology in this sheltered and shallow lake is storm driven. Prevailing wave conditions have limited reshaping capacity [A.M.Ton et al. [2019]], to repair the storm driven erosion. This is why the newly built, sandy island needs protection from erosion.

Vegetation strength and wave attenuation capacity is researched. However, how to engineer with the contribution of vegetation is not completely discovered. For example, Hydra-NL is the most used tool by governmental authorities for the assessment and safety of dikes in the Netherlands [Duits [2019]. Currently, Hydra-NL is not able to design a dike where vegetated foreshore is contributing to the water safety. This design tool is not useful for every case study, for example it is not possible to asses wave dissipation due to vegetation.

Existing studies focus on the wave damping process only, but do not consider the effect of vegetated foreshores on the required dimensions and strength of the dike itself [Vuik et al. [2016]]. Wave energy dissipation by vegetated foreshores allows for lower crest heights, and consequently, relatively slender dike bodies [Vuik et al. [2016]]. Previous research only investigates the vegetation itself but the implementation of vegetation is less researched.

This leads to the main focus of this research: the need of a a nature-based solution. This nature-based solution will be designed by a Building with Nature method. Knowing that the prevailing designing tools are not able to give output about nature-based solutions and keeping in mind that the east side of the island will have to deal with storm driven erosion and participate in the 'Boog om de Oost'. The Markerwadden [IJff et al. [2018]] and the Houtribdijk [A.M.Ton et al. [2019]] are examples that we can be learned from. More knowledge on how to engineer with nature-based solutions makes it possible to apply more often.

1.2 BACKGROUND INFORMATION

The IJburg archipelago (where Buiteneiland will be part of) are artificial islands built in the last 10 years and will be built in the coming 30 years. IJburg is part of district East of Amsterdam. The first stage of the project IJburg currently consists of a number of islands located in the IJmeer: *Steigereiland*, *Haveneiland*, *Rieteilanden* and *Centrumeiland*. In the second stage, more islands will be added: *Strandeiland* and the nature reserve Buiteneiland. In total, six islands will be reclaimed [*Buiteneiland: groen anker van Amsterdam* [2020]].

Buiteneiland will become an unique island with a green character, with space for sports, recreation and culture for the citizens of Amsterdam and a residential program of not more than 500 homes.

Like this, Buiteneiland will get the 'green anchor' image. Amsterdam can add a considerable amount of public green space to the city. Buiteneiland will be developed gradually, sustainable and circularly. During construction the island will be filled up gradually by vacant soil. The Engineering Office wants to try to make use of only residual resources from other projects within Amsterdam as much as possible [*Buiteneiland: groen anker van Amsterdam* [2020]].

The planning for the outer shape and the concept of the island is has started beginning of 2020. The final design of the boundaries of the island is planned to be completed in early 2021. After that, a final plan will be made and final decisions about the program and design will take place. This will not be earlier than 2023.

In addition, clarification about the outer boundaries of the island is given. First only the dike-ring will be developed. The actual start of the land reclamation for the dike-ring is expected to be in mid-2023. With the vacated ground from the ground bank of Amsterdam the island will be filled, in the coming 15-20 years. The speed of land reclamation depends on the available material in the city and settlement of the island. Therefore, it is expected that the first land reclamation activities will take place after 2025 [*Buiteneiland: groen anker van Amsterdam* [2020]]. In the coming approximately 15 years, no people will be able to live on the island. The team of designer of the *Contouren en dijkprofielen Buiteneiland* [2020], takes the opportunity to develop a green and nature-based design for the east side of Buiteneiland, after the island has totally filled up. For the current study, the dike-ring will be approached as a primary flood defence, so that the dike can be remained and the eventual design can be applicable to other locations as well.

1.3 RESEARCH QUESTION

With he problem description and the background information, the main research question is formulated. Four sub-questions have been formulated to be able to answer the main research question.

The main goal of this thesis is to design a safe and nature-based solution that preserves the ecosystem in lake environment. This is established with a hybrid solution. In this report, a hybrid solution is defined as: a defence that retains the water not only by one component [van Wesenbeeck et al. [n.d.]. An example of a hybrid flood defence is a dike with a shallow foreshore, so that the dike and the foreshore have positive influence on water safety see Figure 6.2. The different design statements are bundled and the main design question is formulated as follows: *What is a safe and nature-based hybrid solution for east side of Buiteneiland, IJburg?*

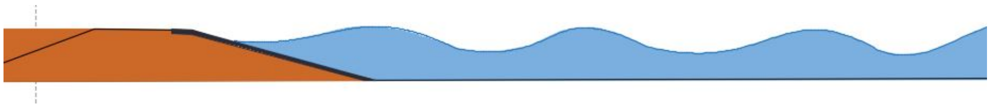
The design statements **safe** and **nature-based** are explained.

Safe

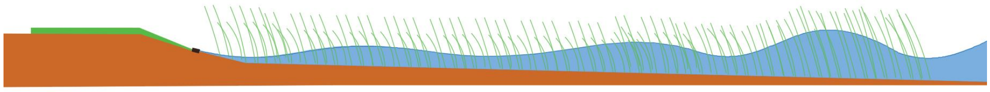
The inhabitants behind the flood protection have the right to live according to probability of failure set by the Wateract [OI2014v4 [2017]]. The shore design has to meet all different statements, but safety will always be the most important requirement and the design has to meet the safety standards. With a hybrid solution, more than one component will be used to ensure safety. A hybrid solution combines more than one component, in Figure 1.2 a foreshore with a dike, can reduce construction costs while offering the same protection level.

Nature-based

With this design statement it meant that the shore design itself and the construction need to be as nature-based as possible. The aim is to use as much nature-based



(a) Bank design; a traditional way, with rubble mound cover indicated by grey area



(b) Bank design; a hybrid solution, with grass cover indicated by green area

Figure 1.2: Two bank design options. The traditional dike (Basic Concept) that fulfills its function with only one component. A hybrid solution combines more than one component, in this figure a foreshore with a dike, can reduce construction costs while offering the same protection level. At the waterline wooden erosion protection is placed. This figure only shows the definition of a traditional dike and a hybrid solution.

material and make use of nature-based processes as possible. In the initial phases, people could help nature by creating an environment that gives the nature and the desired nature-based processes, the possibility to be successful. A healthy ecosystem could be used as nature-based processes. This means that diverse flora and fauna are able to live in the area and at the same time are part of the nature-based hybrid solution. Therefore, a diverse environment is required to meet the needs of the different flora and fauna. To realize this statement it is important to understand the current (eco)system.

Sub-questions
To come to an answer to the design question, four sub-questions are formulated.

- What stakeholders, processes and ecosystem services will work on and around Buiteneiland?
- Which possible alternatives could meet the requirements?
- How to detail a nature-based hybrid solution design in the IJmeer?
- What are the cost of the safe and nature-based hybrid solution compared to a basic concept?

1.4 RESEARCH APPROACH

First, a comparison between two progressive design methods is done. Both are developed because of the rise in interest in multifunctional designs and the desire to add value to society. Future adaptations of flood defence systems can be complicated and therefore, a well-considered method needs to be chosen. In this section the approach of the shore design will be elaborated.

Building with Nature (BwN) principles for conceptual design described de Vries et al. [2016]
This concept design method is an iterative method and contains a list of clear steps. It starts with the conceptual design, and then, after several iteration steps will turn into more detailed design. BwN stands for a design process aiming to work with natural processes and providing opportunities for nature as part of the infrastructure development process. With the aim to maintain the productivity of the natural system, ecosystem services are used to value natural components. For this reason

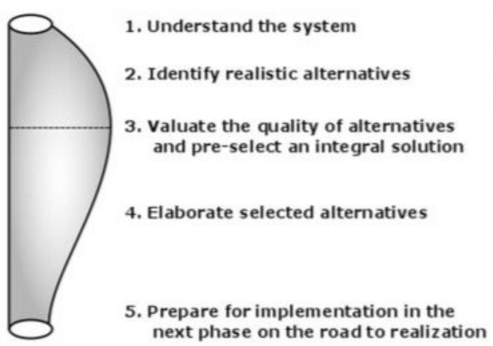


Figure 1.3: Multi objective design at conceptual level for Building with Nature approach [de Vries et al. [2016]]

the possible value of a system is understood better by the stakeholders.

Design principles of multifunctional flood defences by Voorendt [2017]
The aim of this design method is combining hydraulic structures, infrastructures and shared use in a flood defence. Combining these function will not necessarily cause specific designing problems, when following this design method. Integrated and multifunctional solutions deal with the lack of space and, thus, deliver added value to society. Functions of the coastal zone are combined with functions of buildings, infrastructure and hydraulic structures.

Conclusion
The conceptual shore design for the Buiteneiland-case is desired to become nature-based. No infrastructure or buildings will be around the land-water transition. Therefore the BwN-method after de Vries et al. [2016] will be the method for the concept design of the east side of Buiteneiland, although the ideas of the designing method of Voorendt [2017] will be kept in thought.

Method
The BwN-method according to de Vries et al. [2016] is used for the approach to this master thesis. The idea of this method is five clear steps that will be repeated until the desired results are found. With every step the aim, to maintain the productivity of the natural system is obtained.

First, the system needs to be understood quite well. Second, realistic alternatives will be identified. It is important to involve the stakeholders to find the most suited solution. Therefore, a stakeholder analysis will be done. The quality of the alternatives will be valuated according to the functional requirements of the stakeholders in a multi-criteria analysis. Third, the selected alternative is prepared for implementation in the following phase, the new iteration step. This is repeated at least three times. Lastly, one of the alternatives is pre-selected. The selected alternative is elaborated to check the safety and stability. In every iteration step the detailed level will be increased and eventually a preliminary design at conceptual level will be developed. After the last step, the preferred alternative is developed and will be compared in different ways with the basic concept. In Figure 1.3 the described steps are shown.

1.5 SCOPE

This study will focus on only the east bank of Buiteneiland in the IJmeer. This means that sea dikes and river dikes will not be considered in this study. During the development of the design, no physical test will be used to gain results. When vegetation is used in the design, it needs to be able to grow in a Dutch climate and in the lake's wave climate. This means low energy and no tidal environment. Furthermore, the current water system with the current hydraulic boundary conditions are taken into account. The requirement set for fulfilling the safety assignment is stated as follows; the dike reinforcement design is related to the minimum required safety standards; 'safer' solutions are not considered.

The location of interest is in a shallow, non-tidal, fresh water lake, with a maximum fetch of 40 km. So no higher waves than H_{m0}=1.5 m are expected. The area of interest is the east side of thei sland. The size of the land-water transition is about 300 m and from the shore till the governmental boundary is approximately 400 m. The final result will be a preliminary design.

1.6 RESEARCH OUTLINE

The following chapter, Chapter 2, describes the method that is used in this research to address the problem and what steps are taken during the design process. Chapter 3, will give the description of the current and desired (eco-)system. In this chapter the physical boundary conditions and requirements from stakeholders are prescribed. Then, the Basic Concept and the alternatives will be shown in Chapter 4. This chapter also includes the comparison between the alternatives and the Basic Concept. In Chapter 5, the selected alternative will be elaborated in more detail, the results are presented and a discussion about the results is given. The last part (Chapter 6) will consist of final conclusions are drawn and recommendations for implementation and further research are given.

2 BUILDING WITH NATURE DESIGN METHOD

The design of hybrid flood defences is a complex process and therefore the risk caused by combining functions from the method obtained by Voorendt [2017] are kept in mind during the developing stage.

As a designer, a specific design thinking process will be followed. This process is divided in six phases that succeed each other. The process is not linear but an iterative process, some phases may turn out to take longer or the designer is forced go back to a previous phase, when something turns out to be inconsistent, not sufficient or incomplete. The first phases will be diverging, which means that more information is generated and more ideas are created. All these options are converged afterwards to come to a final conclusion used in the following steps.

BwN attempts to meet societal needs for infrastructural functionality, and to create room for nature development. At the same time all stakeholders want diversity in all directions e.g. bed slope, hydrodynamic energy, salinity and geo-climatic region In this case study, considering a low energy and sheltered environment, soft shores with high biomass can be expected to be the solution [Van Koningsveld et al. [2008]]. This often results in a mix of sand and mud, stabilized by (root systems of) vegetation cover. The aim is sustainable hydraulic engineering through building with nature [de Vries et al. [2016]].

For the scope of this research a conceptual design will be made. This will be done according to the Building with Nature method [de Vries et al. [2016]], the method's steps will be discussed in the sections below.

2.1 UNDERSTAND THE SYSTEM

Step 1: Understand the system. This is everything that could be interested to know before starting the design process, this includes ecosystem services, values and interests. The system to be considered depends on the project objectives. In its own way the project objectives are influenced by the system by problems and opportunities. The information about the system will be derived from various sources as historic, academic and local. It is important to look for user functions and ecosystem services beyond those relevant for the primary objective.

By in involving stakeholders in the valuation and selection process [Deltares [2020b]] a concept will be found that suits all parties. Different stakeholders have different reasons for participating in, or opposing project development in a specific area. By a structured brainstorming session, the stakeholders are identified. The project group of already finished islands of IJburg have attended this session. The other islands have the same stakeholders and therefore, it can be assumed that the most important stakeholders were taken into consideration. The role, the different stakeholders will play in the project development will be identified. The matrices found in Figure 2.1, with power versus interest could help creating groups and strategies. Stakeholders will have access to specific relevant knowledge, perspectives and resources that contribute to better ideas and helps to make projects feasible and successful [Deltares [2020b]]. In BwN projects, stakeholders are important because BwN projects affect the physical environment. Environments to which stakeholders have interest several functions. The results of this step can be found in Chapter 3. First, the failure mechanisms will be elaborated. Than the hydraulic boundary conditions and ecosystem of the environment of Buiteneiland with its flora and fauna will be elaborated as well. At last, the stakeholders will be analysed and some conclusions will be drawn. The first sub-question is *'What stakeholders, processes and ecosystem services will work on and around Buiteneiland?'* will be answered with this step.

Figure 2.1: Stakeholder analysis [Deltares [2020b]]

2.2 THE ALTERNATIVES

Step 2: Identify realistic alternatives that uses and/or provides ecosystem services [de Vries et al. [2016]]. The traditional perspectives will be turned into a proactive perspective by using and/or providing ecosystem services. By involving different stakeholders as academic experts, field practitioners, community members, business owners, decision makers and other stakeholders when formulation the alternatives. According to the conclusions of Chapter 3, the alternatives can be found in Chapter 4.

2.3 COMPARISON ANALYSIS

Step 3: Qualities of each alternative will be evaluate and an integral solution will be preselected [de Vries et al. [2016]]. In this step it is important to keep in mind that more value does not necessarily imply higher construction cost and embrace innovative ideas. The ideas will be tested and it will be shown if and how they work out in practical examples.

2.4 PRELIMINARY DESIGN

Step 4: Fine-tune selected solution in the way that practical restrictions are considered and the governance context is found. In this step, conditions and restrictions provided by the project are considered. For every condition or restriction it will be these are negotiable or non-negotiable [de Vries et al. [2016]]. For the implementation of the preselected concept from step 3, involvement of the stakeholders is required.

Step 5: Prepare the solution for implementation in the next project phase [de Vries et al. [2016]]. In this step essential elements of the solution will be made explicit to facilitate uptake in the next phase. The level of detail increases per phase. The second sub-question is *'Which possible alternatives could meet the requirements?*. With the previous two steps of the conceptual design method, the second sub-question will be answered and results can be found in Chapter 5.

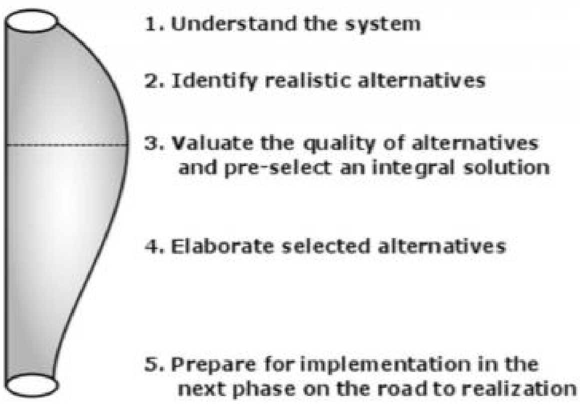


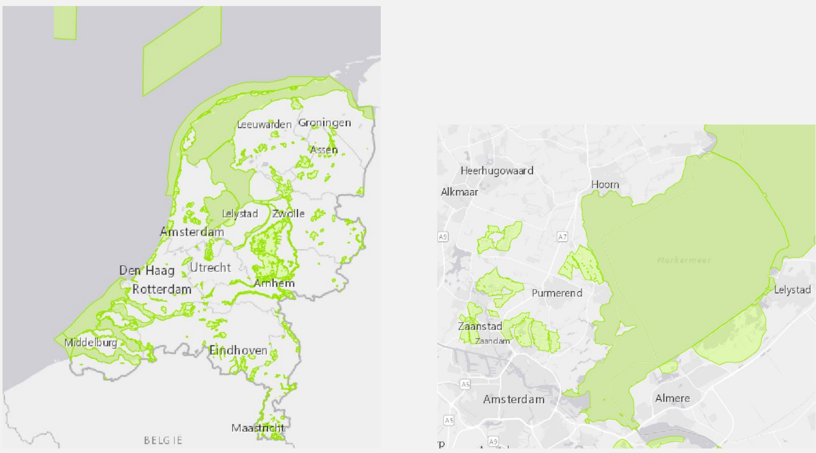
Figure 2.2: Multi objective design at conceptual level for Building with Nature approach [de Vries et al. [2016]]

For the third sub-question, *'How to detail a nature-based hybrid solution design in the IJmeer?'*, another approach is established. The main purpose of this sub-question is to give the world a method/tool/approach to address a nature-based design for hybrid solution as in this case. To deal with vegetation, and most interestingly reed, in a shore design and make use of the energy reducing strength of the vegetation are not yet functions in the prevailing programs, for example Hydra-NL. The designing programs are not able to involve vegetation in a reliable way. The paper of Roode et al. [2019] made a small start in involving the foreshore and the vegetation in measuring the strength of the total flood protection. By making use of the used method for the previous two sub-questions this sub-question will be answered.

3 UNDERSTAND THE SYSTEM

The IJmeer, as well as the Markermeer, are part of the IJsselmeer area. This area is one of the largest fresh water lakes in north-west Europe. Therefore, the lake area itself and the connection with the Waddensea is of international importance. Furthermore, IJmeer and Markermeer are part of the regulations of Natura2000 areas [*Natura 2000 - gebied Markermeer IJmeer* [2009]]. This is the (eco)system in which Buiteneiland will be build. Building something in an existing system results always in disturbing that ecosystem. Therefore, it is important to know how the current ecosystem works. Additionally, how the east side of Buiteneiland can improve that ecosystem.

Natura2000
In these areas, animals, vegetation and their natural living environment is protected, to improve the biodiversity [*Ministerie van Landbouw, Natuur en voedselkwaliteit* [n.d.]]. In Europe the diversity in flora and fauna could be improved. Therefore nature protection laws came for whole Europe. In 1979 the bird regulations were drawn up, in 1992 the habitat regulations came. All European Union countries indicated specific habitat environments of birds and other animals. The Natura2000 network consists of all areas with this indication in Europe. The indicated areas in the Netherlands can be found in Figure 3.1. While the islands self does not belong to these regulations, the surrounding water does. Natura2000 is the European nature protection law.



(a) The Netherlands (b) Markermeer

Figure 3.1: Natura2000 areas in the Netherlands and around the Markermeer *Ministerie van Landbouw, Natuur en voedselkwaliteit* [n.d.]

Understand the system is the first step within the shore design process. This chapter will give a complete overview of the current (eco)system at the location of the new shore and what is desired in the new ecosystem. The ecology of the IJmeer will be elaborated, that includes local ecosystem services and local flora and fauna. Next, the hydrology and hydraulic boundary conditions will be explained and the possible failure mechanisms that could lead to flooding are discussed. The stakeholders are discussed and a stakeholder analysis is done. This all, in order to answer the first sub-question: What stakeholders, processes and ecosystem services will work on and around Buiteneiland?. The answer will be given in the end of this chapter. An overall conclusion will describe the current situation and final desired situation according to the stakeholders. This conclusion will consists of the design statements for the subsequent design steps.

3.1 ECOSYSTEM OF THE IJMEER

An ecosystem is a dynamic complex system of plant, animal, and micro-organism communities and the nonliving environment interacting as a functional unit ["Ecosystems and Human Well-being. A framework for assessment" [2003]]. To be able to design and create an area where the shore is constructed sustainable and nature-based, and where for example reed is able to grow successful, it is important to understand the system of the IJmeer. The design needs to connect the existing environment with the newly built ecosystem [Slinger [2016]]. This connection will be most successful when the new ecosystem is most similar to the current ecosystem in the Markermeer. Next to the current situation, there are aims for improving the ecosystem; increase in biodiversity, use of ecosystem services, decrease in turbidity, and the increase in biodiversity, in both flora and fauna. The approach of the ecological research is mostly based on Slinger [2016] and its ecological design principals. This approach helps in order to create an ecosystem that is resilient for setbacks.

3.1.1 Biodiversity

That the biodiversity of the IJmeer and Markermeer has reduced after 1990 has probably a connection with the construction of the Houtribdike and the subsequently reduction of the nutrient resources [van Herpen et al. [2015]]. Furthermore, lots of sludge did not improve the water quality and its transparency.

With the Markerwadden initiative [IJff et al. [2018]], the turbidity will decrease, and at the same time the Markermeer will get more natural elements. The main reason for the lack of natural elements is the lack of in the natural land-water transitions and for example outer dike reed fields are hardly found. Nowadays, the Markermeer shores are shaped by static and artificial land-water transitions. To improve the land-water transitions reed fields has been built, causing a living environment for other aquatic plants. Fish will find sheltered places to spawn. Where aquatic plants grow, insects, crayfish, arthropods, seaweeds and other small animals will find their place. This flora and fauna determines the biodiversity of the water and bottom. For the east side of Buiteneiland, this means that a natural land-water transition, biodiversity could be created.

3.1.2 Ecosystem services

To give value to a shore design, ecosystem services could help in order to get a clearer understanding in the value of ecosystems [TEEB [n.d.]]. Ecosystem services and the use of them are in line with the used building with nature method [de Vries et al. [2016]]. How these services could help creating the desired result for the shore and the implementation in the design will be discussed. As definition for ecosystem services the following from "Ecosystems and Human Well-being. A framework for assessment" [2003] is used: the benefits people obtain from ecosystems. Dynamic preservation implies the goal to make optimal use of natural processes.

Ecosystem services are divided into four categories; supporting, provisioning, regulating and cultural services. Every category has services that could be used to value the shore design ["Ecosystems and Human Well-being. A framework for assessment" [2003]] and will be used for the development of the east side of

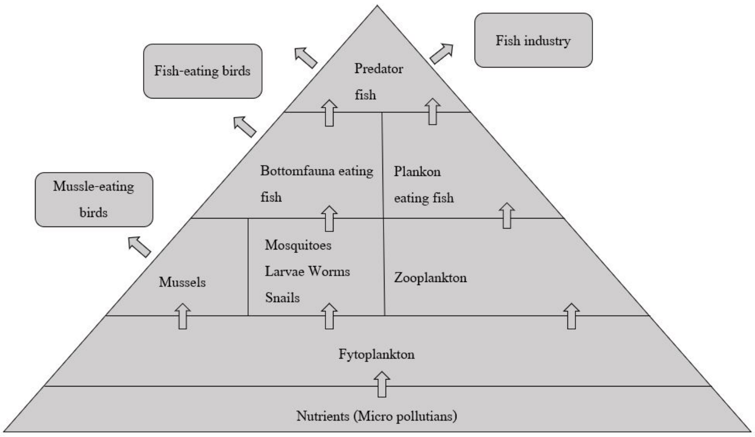


Figure 3.2: Ecosystem pyramid Markermeer [Lammens & Hosper [1998]]

Buiteneiland. The supporting services are for the health of all ecosystems [Deltares [2019]] and are for the production of all other ecosystem services ["Ecosystems and Human Well-being. A framework for assessment" [2003]]. The services in this category are soil formation, nutrient cycling and primary production of organic matter from CO_2. For the provisioning services, the most relevant are the food (fish) and fiber (reed/willows) production and the fresh water production. Regulating services such are the regulation of climate, erosion (vegetation helps retaining the soil), air quality maintenance and water regulation and purification. At last, cultural services such as educational, recreational, aesthetically, inspirational and other non material benefits. All these services exists with a healthy ecosystem. The ecosystem services explained above does increase the value of the area immense an without high investment or maintenance costs.

3.1.3 Flora and fauna

In this section the natural, local flora and fauna will be discussed. These flora and fauna species live in the IJmeer. When the circumstances are right in the area of interest, these species will be able to be successful. What the local species and the right circumstances are, will be elaborated here. The reason why these flora and fauna are important is also explained.

Flora

Aquatic plants create important shelter for zooplankton and juvenile fish and are the food source of various types of (protected birds). Aquatic plants have a successful competition with algae, especially in terms of nitrogen and phosphate. They can absorb nitrogen from the bottom as well as from the water. Because of their large biomass (incl. the algae that grow on the plants), aquatic plants as wreaths act as storage for nutrients during the growing season. When aquatic plants live under equilibrium circumstances, they contribute in improving water quality and thereby generating their own specific habitat, which is a self-reinforcing process [Arts et al. [2013]]. These aquatic plants have the ability to reduce bioturbation and resuspension and promote sedimentation and sediment stability.

From Steensma [2017] the three main water plants found in the IJmeer are Potamogeton perfoliatus (Full grown fountainweed), Potamogeton crispus (Crimped Fountainweed) en Myriophyllum spicatum (Aarvedic herb). Ruthermore, reed is a vegetation that easily grows in the IJmeer. The waterplants are depicted in Figure 3.4. The problem could be the lack of this type of vegetation or the overload. These types vegetation will grow when the water is bright and clean. With overload

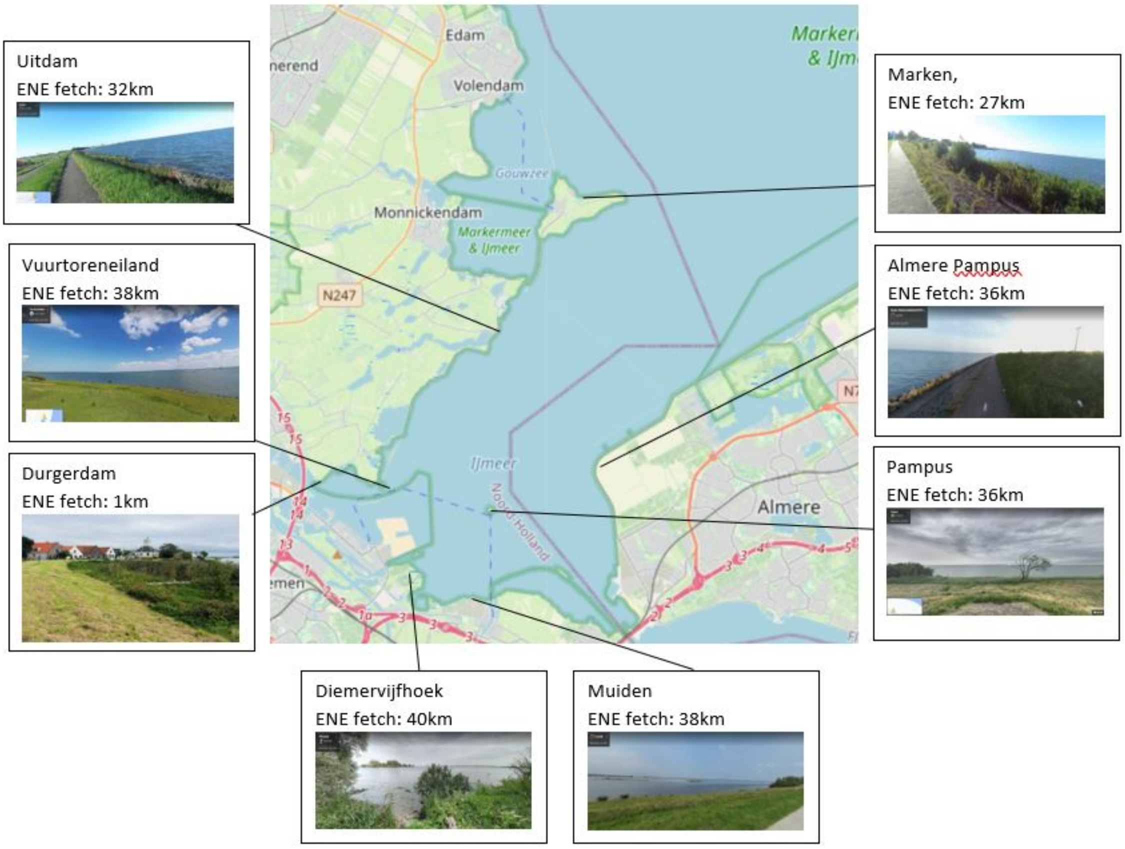


Figure 3.3: Locations with similar wave climate, similar fetch length, with photo's from Google's Streetview. The photo of Durgerdam location is self-made

the vegetation will grow, therefore the sunlight penetration will decrease and the livability for other flora and fauna will decrease.

Reed

To the latter, reed vegetation, some extra elaboration is needed. Reed is requested from the 'Boog om de Oost'. The 'Boog om de Oost' is a green initiative that will be elaborated on in Section 3.5. But if reed as vegetation will grow succesfully, is discussed in this section.

Reed is able to withstand significant daily wave height of 0.25 m. Occasionally (no more than 5000 waves per year and not in a consecutive period) the wave height may be 0.40 m [*CUR 201* [1999]]. The prevailing wave heights are higher, see Figure 3.8. A hydraulic structure could help to create more sheltered environment to protect the reed from breaking. In Figure 3.3, bank vegetation for different locations with similar wave climate (similar fetch, water depth and wind speed result in similar wave heights) as for Buiteneiland, are shown. In none of the Google Streetview pictures outer dike reed fields are found.This shows that for Buiteneiland it would not be possible to let reed successfully grow in the prevailing wave climate without protection. Wave height reduction needs to be placed to let the reed be able to germinate and grow. This is because of that reed will break during storm conditions. The roots of the broken reed are still able to protect the soil beneath from eroding. Sand between the reed and the reed roots is able to withstand a flow velocity bottom level of 0.75 m/s [*CUR 201* [1999]]. Without maintenance, the next storm will take the roots and the sand from the subsoil so that no reed will be able to grow back again. Furthermore, during winter time ($\approx$ storm season) the reed stems are weak and not able to reduce wave penetration [Vuik et al. [2016]].

Reed vegetation is only able to settle and germinate in a long period of dry land [van Herpen et al. [2015]]. The water level of the IJmeer is fixed and contra-natural (the water level is higher during winter time) dry periods not exist often. Therefore the construction of the reed fields need to be done by burying roots in the soil [van Herpen et al. [2015]] and bottom needs to be at water level. During the growing process with the burying roots method, the young reed can be threatened by grazing gooses. Grazing protection would be necessary. The rate of succession of the reed also depends on the quality of the soil it grows on. Reed requires nutrient rich soil. So dynamic sand bed without nutrients is not a suitable environment.

Mowing of reed

Mowing of the reed is required to conserve the reed character and against afforestation. To keep the natural value, perennial reed needs to be conserved [van Herpen et al. [2015]]. It is the matter to not mow every year. At least once in 10 years is advised to keep the diversity high. The moment the reed is grown and stay in 50 cm of water, the natural and ecological values are very high. This is because the reed creates spawn and feeding places for different species. For some bird species that breed in early spring, mowing needs to be done before. Mowing during winter could improve the growth of the reed vegetation. The biomass of the reed is decreased with mowing and therefore the strength decreases as well. A winter storm will damage the weak reed as well, the mowing works deceases the strength even more.

To create an optimal environment, perennial reed of at least 50 m width is needed. In the IJsselmeer, a low density of reed stems (60 stems/m2) is related to a large diameter and a large height (2.5-3 m) [van Eerden et al. [2007]]. Vice versa, a high density of stems (225 stems/m2) is related to less height (2 m) of the reed bed and a smaller stem diameter. If reed fields are managed (mow) or the hydrodynamics are small, the number of shoots per square meter increases but shoot diameter decreases [van Eerden et al. [2007]]. The IJsselmeer data generally shows a higher number of shoots at a smaller diameter. Places with the largest hydrodynamics, due to wind, show the coarsest types [van Eerden et al. [2007]]. It seems that the reed is trying to find an optimum strength against the load (waves or management).

The current state of the main vegetation in the IJmeer is shown in Figure 3.5. The coverage rate of the mainly found vegetation, the Fountain weed and of the total aquatic plants is shown in Figure 3.5.

The coverage rate of vegetation in general is average. Although it is important to keep this rate and where possible improve the current situation. In most of the projects it is the case to keep the growth of the vegetation within the limits. Mowing the weeds will be necessary to keep the water depth for sailing.

Fauna

To create a habitat that leads to most biodiversity, it is important to know what species will, can and does live in that habitat. The species will be evaluated according to the ecosystem pyramid of the IJmeer, which is shown in Figure 3.2 Lammens & Hosper [1998]. The pyramid is a non-closed system, it receives nutrition and has users from the outside. All these components are necessary to have a healthy and bio-diverse ecosystem. Most birds that visit the Markermeer are there to foraging on fish and the Zebra mussel (Dreissena polymorpha). Three different bird categories can be identified in the IJmeer. These are the fish-eating birds (Great crested Grebe, Cormorant, Smew, Goosander, Small gull, Black Terns and Plovers). This first category depend on fish, mostly the Rivierdonderpad [*Natura 2000 - gebied Markermeer IJmeer* [2009]]. It is very likely that this fish specie also depends on the Zebra mussels. This is because of the fact that the fish not only lives close to the rubble stones of a dike but also near the mussel banks of the Zebra mussels. The Futen and Black Terns always comes to the Markermeer in large amounts to moult in August. This is the moment the Spiering fish has in highest biomass of

(a) Aveder weed

(b) Fountain weed

(c) Curled fountain weed

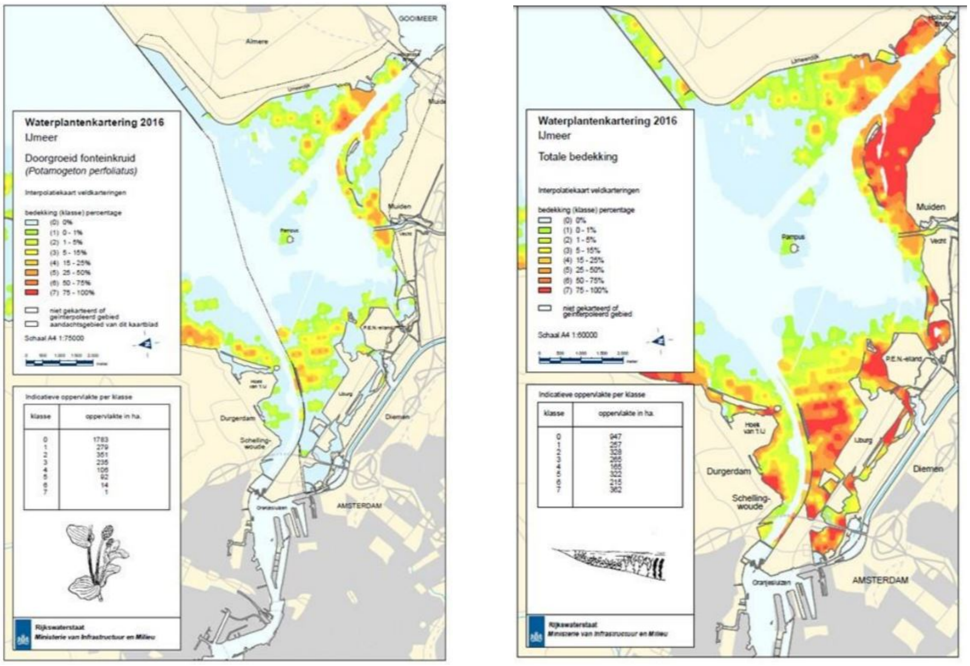
(d) Reed (Phragmites australis)

Figure 3.4: Main water plants IJmeer

the year [Lammens & Hosper [1998]]. Secondly, the mussel-eating birds (Tufted Duck, Pochard and the Scaup). Zebra mussels and Quagga mussels have their natural habitat in the Markermeer. The Quagga mussels are eaten more by the birds because of the softer shell [van Emmerik [2014]]. Thirdly, the aquatic plant-eating birds, Red-crested Pochard, Coot, Pochard [*Natura 2000 - gebied Markermeer IJmeer* [2009]]. For these bird species, lots of fish, mussels and aquatic plants are the required food sources. Furthermore, the birds need to be able to find shelter to breed and moult. Other animals as, insects, lobsters, grass snake, amphibians, arthropods and other small animals and mammals needs a diverse and sheltered place to eat, grow and spawn.

3.1.4 Turbidity

Aquatic plants have a lot of functions and benefits that are of great importance to create a successful and biodiverse ecosystem. The last main described beneficial function of the vegetation (reduction of bioturbation and resuspension) needs more elaboration. This is due to the fact that the turbidity (troelbelheid) causing low visibility is a current problem in the IJmeer and Markermeer. The disadvantage of a too large volume of sludge could have is the bad water quality. The bad water quality is a consequence of the high turbidity , which leads to less penetration of sunlight and therefore less oxygen concentration in the water column. Because of the construction of the Houtribdike the sludge has nowhere to discharge to naturally. The sludge is very mobile by water movements due to wind and waves and easily to get in resuspension. Which also depends on the wind speed and direction. With wind coming from east/east west the turbidity in the IJmeer is quite high. The lake consists of Bream, a fish that seeks its food (macrofauna) in the soil of the bottom of the lake, which results in resuspension of the sludge [*Ministerie van Landbouw, Natuur en voedselkwaliteit* [n.d.]]. Where, with the decrease of sunlight penetration, the aquatic plants will disappear and the lack of oxygen will grow. Furthermore,



(a) Fountain weed found in IJmeer

(b) Total vegetation found in IJmeer

Figure 3.5: Covering of water plants IJmeer *GeoWeb Rijkswaterstaat - waterplantenbedekking IJsselmeergebied* [2016]

fish, like roach, will take the opportunity to eat all the available zooplankton when the water column has a high concentration. That will result in a fast grow of algae, what also leads to turbidity. With catching of these fish species, which is called biological management, the water could return to be clear. Which in this moment will lead to the return of aquatic plants [*Ministerie van Landbouw, Natuur en voedselkwaliteit* [n.d.]]. This kind of management could be used in the final design.

3.2 SAFETY AND FAILURE MECHANISMS

The height of a traditional dike is determined to a significant extent by wave overtopping restrictions. The width of the dike is determined by geo-mechanical stability requirements and the need to extend the seepage length in order to prevent piping. As this dike will not be a 'traditional' dike but a half-hidden dike. In Figure 3.6 the half-hidden dike is shown. A traditional dike will only have the inspection profile. In this case the ground body at the left side will prevent mechanisms from occurring. The inspection profile will be build out of clay and sand where perfect conditions are assumed. The ground body will be filled by investigate soil from the ground depot of Amsterdam.

This section will give the failure mechanisms and their contributions. The four main mechanisms that can lead to dike failure which are: insufficient height, instability, piping and cover.

Insufficient height

The first failure mechanism discussed here is height, this contains too much overflow and too much overtopping. Overflow: the water level reaches a higher level than the crest height, water will flow over the dike. Wave overtopping: the water level does not reach the crest height but waves does overtop the crest. A sufficient height is when for an overtopping discharge waves are overtopping the dike for the given return period [Deltares [2020a]]. When overflow or overtopping this happens

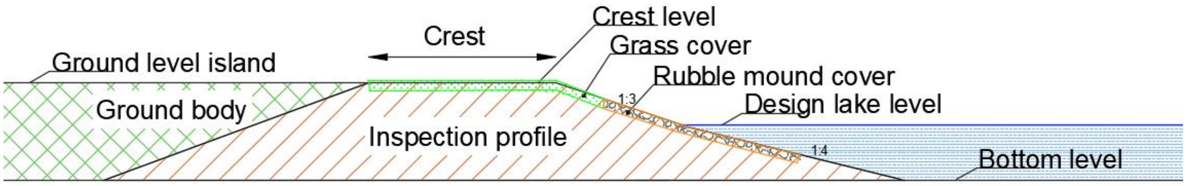


Figure 3.6: Half-hidden dike with important terms, standard slopes and ground and water levels. Figure 4.1 shows the final water levels.

more often than the given return period the function of the dike is uncertain. Furthermore, the following failure mechanism are more likely to occur.

Outer dike stability
Outer side instability and inner side instability by regarding this failure mechanism are often combined. The strength of the soil decreases by the increase of the water level. With both the cause of the failure is the rapid fall of water level, and outer side of the dike have more instability probability. Inner side stability will not be able to occur because of the shape of the dike. The outer side stability is assumed to be sufficient because of the fact that in the initial phase the slopes of the dike will be built much more gentle. After a while the final slopes will be excavated.

Piping
The failure mechanism of piping, heave and bursting up [Deltares [2020a]] is combined and could occur when the cohesive layer is built on a sandy permeable layer. With high outer water levels a small stream can exist, by taking out particles. In this case piping, as well as inner side stability, does not need to be taken into consideration because of the fact that the mainland will be built at crest height. Therefore it is possible to use the failure mechanism budget for other mechanisms [OI2014v4 [2017]]. The failure mechanism budget will be discussed further in paragraph named Fault tree.

Cover erosion
The failure mechanism erosion and/or damage to the dike cover. Cover erosion may take place in case of grass cover. A grass cover is able to withstand a high wave (Hs=0.75 m) event of 8 hours, by assuming good quality grass mat [Verhagen [2000]]. Furthermore, a water velocity of 3 m/s during 8 hours [Verhagen [2000]]. The cover (either grass or rubble mound) of the dike needs to be designed that damage is allowed under two conditions. First, after damage of the cover this needs to be repaired. Second, in the period will the reparation is done the dike may not fail due to erosion or instability. The height and strength of the cover need to be determined. The requirement is that the height of the cover (where the rock cover meets the grass cover) of the dike is not allowed to break before the dike itself fails, due to the lack of height of the cover. The solution to this requirement is to heighten the rock cover [Deltares [2020a]].

Other
Other failure mechanisms as micro-instability, drought, animal and humanly activity or fire, that are into consideration, will be scaled under the heading 'other'[Deltares [2020a]]. The probability of occurrence are so small and the probability of economical or human threat as well. So that this will fall out of the scope of the research.

Fault tree

The fault tree with the corresponding failure mechanisms, assumed to be independent or more precise mutually exclusive, can be find in Figure 3.7. The failure mode piping can be considered to be not able to take place because the ground level behind the dike that prevents piping and inner slope stability from happening at all. One mechanism that could occur failure is the cover erosion, this could result in breaching of the dike. Because of the fact that the island will be at crest level of the dike, the dike will actually only have revetment functions. A dike in the Netherlands has one water retaining side and one low lying polder side. A revetment is more like a protection of a soil body against water. As the word dike have been used so far, the word dike will be used in the coming sections as well.

The used values in the Figure 3.7 are the values for ω and N for 'traditional' dikes without redistribution. The failure mechanism for insufficient height and cover erosion will be considered to determine the geometry of the flood defence.

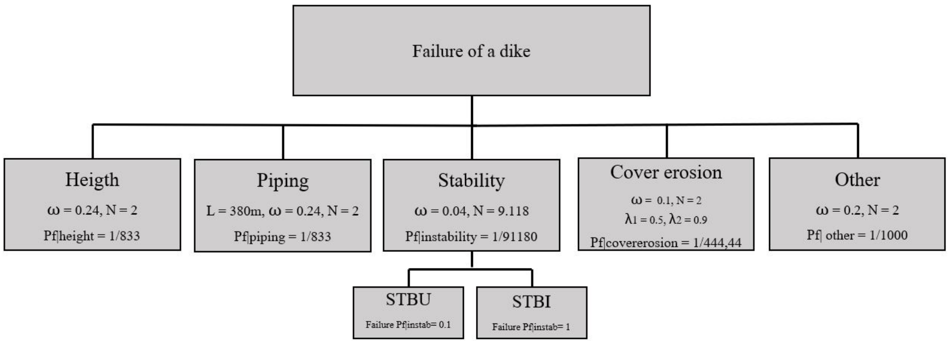


Figure 3.7: Failure tree

The summation of the failure probability contributions of all failure mechanisms cannot exceed the norm at intersection level. To determine the probability of failure at intersection level by using the length contribution factor, N is shown in following equation from OI2014v4 [2017].

$$P_{require} = \frac{P_{max} * \omega}{N} \tag{3.1}$$

where $P_{max} = 1/100$ is lower limit [*Regeling Veiligheid Primaire Waterkeringen* [2017]. Where N, length effect, for the failure mechanism height, because the deviation in height over the length is assumed to be small because of the assumption the strong dependence between the sections and therefore to be small and set at 2 by OI2014v4 [2017]. This is because the height of a flood defence has a relatively low spatial variance [*Flood risk in the Netherlands VNK2* [2012]]. In principle, finding the optimal values for ωj is an optimization problem, in which the largest part of the system failure probability would be assigned to the failure mode that is the most expensive and/or the most difficult to reduce [Jonkman et al. [2018]]. A redistribution could result in a more effective approach of the failure mechanisms and their contribution [OI2014v4 [2017]].

3.3 HYDRAULIC BOUNDARY CONDITIONS

This section contains the different physical hydraulic design conditions. These boundary conditions determine the load and the strength the shore design will calculated with and is showed in Table 3.1. The parameters will be explained briefly afterwards.

Table 3.1: Hydraulic boundary conditions

Parameter	Symbol (unit)	Value
Water depth at boundary	d (m)	$\mu = 3.0m, \ \sigma = 0.2m$
Wind speed determined by Hydra-NL	U10 (m/s)	20.2 m/s
Wind direction	°N	60-90°N
Safety level [OI2014v4 [2017]]	$P_{occurence}$ (1/year)	1/830
Overtopping discharge	q (l/s/m)	10 l/s/m

- The water depth varies with summer or winter. The bottom at the municipality boundary lies between -2,9 m +NAP (Nieuw Amsterdams Peil (Dutch normal water level) (NAP)) and -3,3 m + NAP [van Vree [2020]]. With a regulated water level [Rijkswaterstaat [2018]], during winter -0.40 m +NAP and during summer -0.20 m +NAP shown in Figure E.1, the water depth is 2.50 m and 3.10 m respectively. These water levels are without storm surge. The storm surge is taken into account within the local water level provided by Hydra-NL and will be elaborated in Section 3.4.3. The highest lake level is -0.1 m + NAP. But the design lake level is determined by Hydra-NL with the use of an input file is -0.19 m +NAP. For simplicity reasons it is assumed that the water depth is normally distributed with a means of μ = 3.0 m and a standard deviation of σ= 0.2m.

- The wind speed at 10 meters above water level is 20 m/s found by Hydra-NL which used KNMI [Caires [2009]].The KNMI-measuring station Schiphol is located on land, tens of kilometers away from the IJmeer (see Figure C.1). This means that spatial interpolation of wind information, taking transitions from land to water into account and vice versa, is required [Caires [2009]]. The KNMI-data cover 4 decades, which means that statistical extrapolation is required. A wind rose of the IJmeer can be found in Figure D.1.

- Wind direction. As the direction of the edge of the island has its normal 110 °N, the waves from east-northeast (60 °N) have the longest fetch (40 km). The waves coming from the east side (90 °N) have a smaller fetch but the wind speed coming from east is little higher according to the databases of Hydra-NL and Figure D.1. Therefore the waves between 60 and 90°N are normative.

- Probability of occurrence. For the populated shores in the Netherlands a design limit is given for the probability of occurrence of a flood protection in the Ultimate Limit State (ULS). In the Wateract [*Regeling Veiligheid Primaire Waterkeringen* [2017]] it is stated that every individual has the minimum required probability of being killed by a flood of 1/100.000. With this Rijkswaterstaat determined a lower limit for the IJburg archipelago (P_f=1/100) and signaling value (P_f=1/300) for every dike section [OI2014v4 [2017]]. By using Equation 3.1 the design limit for the $P_{require} = (1/100) * 0.24/2 = 1/830$ for the islands of IJburg. More elaboration about the probability of failure can be find in Section 3.2. For the serviceability of the reed the serviceability limit state is determined.

- Overtopping discharge. The design overtopping discharge is chosen to be q = 10 l/s/m. This means that for a probability of exceedance this discharge flows over the dike. According to [van der Meer [2002]] that states: "Whichever criterion is applicable also depends on the structure of the dike and any buildings. In certain cases, such as with a protected crest and inner slope, when water enters, sometimes 10 l/s per m can be used". For an armoured inner slope this low criterion can be used. The inner slope is armoured because the ground level of the island will be at or above crest height of the dike, so inner slope damage will not occur.

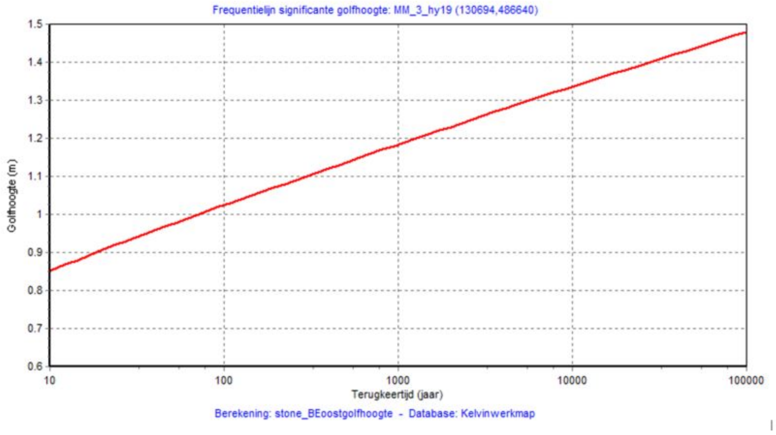


Figure 3.8: Frequency line: return period to significant wave height for the relevant directions for the (320-120 °N) for the location of Buiteneiland IJmeer, Hydra-NL windspeed database Schiphol

- Water bottom. The bottom where Buiteneiland will be located consists of a layer of approximately 2 meters of sludge [van Vree [2020]]. Soil surveys can be found in Figure B.1.

3.4 HYDRAULIC ASPECTS

In this section hydraulic aspects that will be of interest for the development of design statements will be explained here. First, the effect a foreshore could have. Followed by the effect of the oblique incident wave attack. The sediment transport, caused by the oblique incident waves, is approach according to a S-ϕ-curve Figure D.1

3.4.1 Foreshore

In case of a very shallow (depth/Hs,toe < 3á4) foreshore, the wave height distribution can not assumed to be Rayleigh distributed and a peak period can not be determined anymore. Therefore the 'classic' wave run-up ($z_{2\%}$) formula is not able to determine the run-up adequately [van der Meer & Janssen [1995]]. In the case with the very shallow foreshore, the wave run-up has another influence on the water retaining structure. Because of the fact that the significant wave height at the toe is in most cases unknown, wherefore the 'deep water' significant wave height is taken, the wave run-up height is overestimated. Wave height with (very) shallow foreshore can than be approximated [*Lecture notes Coastal Dynamics 1* [2015] based on the breaker criterion of Miche (1944) by :

$$Hs = min(Hm0, 0.5 * (water\ level - foreshore\ depth)). \tag{3.2}$$

The *Regeling Veiligheid Primaire Waterkeringen* [2017] dedicates that the foreshore (if present) needs to be taken into consideration in the schematizing and the assessment even if the foreshore is not included in the juridical location of the flood defence structure. This, because of the effect the foreshore has on the lifespan of the dike. The contribution the foreshore has on the water retaining function of the dike, applicable to this case, are the following. First the wave height reduction is discussed. Where failure due to instability and erosion of the outer side cover will decrease [Roode et al. [2019]]. Moreover, it is also the case that because of the foreshore, the wave period changes and longer waves will appear. In that case the wave height reduction will nullify. The foreshore stabilises the dike due to the reduction possibilities of planes sliding outwards [Roode et al. [2019]]. Next to the positive effects the foreshore has, it is good to keep the possible treats of the effects in mind. An example for this is the settlement of the foreshore wherewith the wave height reduction decreases and the probability of failure due to wave overtopping and cover erosion increases. A substantial settlement of the foreshore level could also lead to increase of the phreatic level in the dike and so decrease in the macro-stability [Roode et al. [2019]].

3.4.2 Oblique wave attack

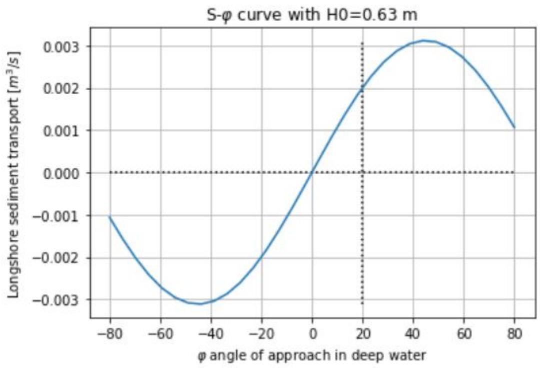


Figure 3.9: Bulk long shore transport rates, S_b as function of the deep water wave angel φ_0. The dotted line indicates for the incoming wave angel to the shore normal. φ is positive for a Sb in the direction of a positive alongshore coordinate axis.

The design wave attack will be either from 60°N or from 90°N. Both will not have its direction perpendicular to the shore. The wave power is dissipated by the bottom friction and is used in transporting sediment as bed load. The mean frictional force applied to the whole sediment bed per unit crest width where the mean friction velocity relative to the bed with in the surf zone and is assumed to be proportional to the orbital velocity near the bottom just before wave breaking.

With the CERC (Coastal Engineering Research Center of the American Society of Civil engineers *CERC Shore protection manual* [1984]) formula the bulk sediment, alongshore can be estimated. In the surf zone, the wave oscillatory motion, with angle of incidence φ, is thought to set an amount of sediment. Originally derived for beaches with sand grading of 170μm to 1000μ. Furthermore, beaches crosses the water surface plane. Angle of incidence is relative to the assumed straight and parallel depth contours. With larger bottom slope (or larger relative bottom slope) would decrease the sediment transport. This is due to the fact in this Equation 5.4 the breaker parameter ($\gamma_b = 0.78$) is assumed to be constant [*CERC Shore protection manual* [1984]], but with larger bottom slope (as is the case here) the Irribarren number will increase.

S_b-φ-curve

With CERC formula of Equation 5.4 the Sb-φ-curve in Figure 3.9 is plotted, Sb is in m^3/s and φ is in radials.

$$S_b = \frac{Ka}{32((ss-1)(1-p))} * cb * sin(2\varphi) * H0^2 \qquad (3.3)$$

Incoming wave height is Ho=0.85, with a maximum incoming wave angle of β =60 °N gives an incoming wave height to shore or structures' normal of 20 °, $\varphi = \frac{\beta}{180*\pi}$. Ka=$\frac{1}{\sqrt{(2)}}^{\frac{5}{2}}$, s = 2.65 -, is the relative density of the sediment ($\frac{\rho_S}{\rho}$). The porosity of sand in water p=0.4 -, the water depth the waves break is hb=0.78*Ho [*Lecture notes*

Coastal Dynamics 1 [2015]]. The wave velocity of the incoming waves for shallow water at breaking point ($L = 1.56 * Tp^2$= 24.3 m, hb/L0=0.05) so cb= $\sqrt{g * hb}$. As can be concluded from Figure 3.9, is that the more perpendicular the waves approaches the shore (or structure), the less attack of wave breaking will be experienced on the shore (or structure).

Intermezzo: Hydra-NL

Hydra-NL is the most used tool by governmental authorities, and is used for the assessment and safety of dikes in the Netherlands [Duits [2019]. It is a probabilistic model with a large databases, where return periods are extrapolated [Duits [2019]].

Functions

Hydra-NL is able to give per location the water levels and the hydraulic load level for the failure mechanisms of 2% wave run-up and (per given overtopping discharge) the wave overtopping [Geerse [2003]]. Normally these are the normative failure mechanism, although macro instability is a failure mechanism that is also investigated. Hydra-NL works with four databases. The hydraulic boundary conditions are based on the following databases for the local lake level, the wind speed and wind direction and storm duration and are given for return period from 10 to very large return periods. For a return period less than 10 years, Hydra-NL will extrapolate which makes this little bit less reliable. For the wave run-up and wave overtopping failure mechanisms the hydraulic load level could be used for the minimum required dike height. The definition of hydraulic load level is the height of the water maximum may reach above NAP, that the critical overtopping discharge is flowing over the dike for the given probability of failure [Geerse [2003]]. Hydra-NL is able to give normative/design combination of the water level and waves. This combination will not be the highest water level combined with the largest waves. This is due to the fact that high water levels have low probability of occurrence and high waves as well. So the moment that these high values occur at the same time is even lower. Therefore, normally a smaller water level together with large waves will give the critical height wherewith the dike needs to be designed.

Limitations

Although Hydra-NL works very reliable, there are some other remarks with the program. Foreshores and (submerged) structures are not able to put in the boundary conditions of the program. Hydra-NL is not able to determine, local water depths, significant wave height, peak periods and the hydraulic load level for hybrid foreshore solutions. The second limitation are about the shower oscillations. Hydra-NL is not capable of taking these oscillations into account. Therefore this water level rise needs to be put in manually and no probabilistic calculation is used for this parameter. The next thing to take into account by using Hydra-NL is that the model is actually semi-probabilistic. The load-part of the model is fully probabilistic but the strength is determined by using a calculation value for the critical overtopping discharge. This overtopping discharge is coming from a calibration study. The used values for the overtopping, depends on the quality of the cover of the inner side of the dike [Smale [2018]], are 1, 5 or 10 l/s/m. Because of the required high applicability, these values are in most cases conservative. It is therefore assumable that the calculation using fully probabilistic method for the critical overtopping discharge the crest height will be reduced. The distribution of the strength of rubble mound does already exist. This distribution depends on the quality of the rubble mound layer and the wave height in the design point of the outer slope erosion calculation. For grass on sand (this situation) the overtopping discharge distribution does not exist yet.

3.4.3 Crest height determination

Insufficient height of the crest of the dike is one of the aspects leading to possible failure mechanisms. As Hydra-NL is not able to determine the crest height of the dike for dikes other than standard dikes without foreshore or vegetation, the crest height of the dike needs to be composed manually. Determine the crest height with a cover other than rubble mound the reliability goes down. The crest height is formulated as the height of the outer crest line and in Figure 3.10 is shown how the crest height need to be composed. Every component is explained below.

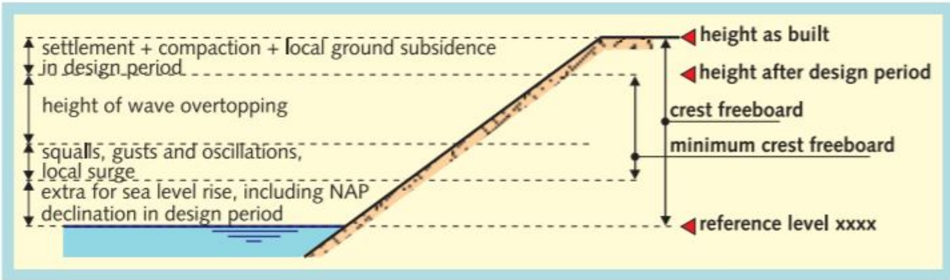


Figure 3.10: Crest height [van der Meer [2002]]

Table 3.2: Determination of crest height out of different components with source

Component	Source
Freeboard, hk (m)	Equation 3.4
Reference (m+ NAP)	Hydra-NL output
Local water level (m)	Hydra-NL output
Additions (m)	OI2014v4 [2017]
Lake level rise (m)	Waterplan 2014
Dike height (m+NAP)	-

- Start at the bottom of Figure 3.10, the reference level and in Table 3.2 this is called Refecrence (m+ NAP). This is the design lake level in meters above NAP. As Hydra-NL has a database a probability of exceedance for possible lake levels.

- Lake level rise that is used for design purposes is predicted by the Dutch Water act. The value that is calculated with for the cumulative water level rise of the lake till 2071 is 0.1 m (0.08 m) ["Nationaal water plan 2016-2021" [2014]].

- In Table 3.2 what contains the Additions is explained. The uncertainty in water level rise is large. First, extra height because of knowledge uncertainty in water level in the lake because of uncertainty in sea level rise, of 0.3 m is added by Waternet that will take the management of the water retaining structure. The next thing is the shower oscillation. This arises because of higher and lower pressure areas. The grown water level differences in the closed basin Markermeer will lead to the oscillation. The Water act requires an addition of 0.1 m. This addition is assumed to be too low so 0.26 m is added. In Hydra-NL there is no other location to count with this uncertainty. In total this gives an addition because of uncertainty that is 0.56 m [Pantano & van Bemmelen [2016]].

- Height of wave overtopping or freeboard in Table 3.2. This height is determined according to [van der Meer et al. [2004]] for a overtopping discharge of

10 l/s/m. The wave height is found by Hydra-NL (see Appendix K for Hydra-NL output for wave height and peak period). Hydra-NL provides for different probability of occurrences (in this case 1/830, 1/10 and 1/1) a corresponding wave height and peak period. With the formula for overtopping Equation 3.4 [van der Meer [2002]] the freeboard height (hk) can be determined. The waves break as plunging waves, therefore Equation 3.4 is used for the determination of the crest height. The freeboard due to wave overtopping is calculated in relation to the height of the outer crest line and it is assumed that this wave overtopping also reaches the rear side of the slope and the inner slope. In reality there is no constant discharge over the crest of a water defence during wave overtopping. The highest waves will push a large amount of water over the crest in a short period of time, less than a wave period [van der Meer [2002]].

$$q = \frac{0.067}{\sqrt{tan(\alpha_{rep})}} * \xi_0 * exp(-4.3 * \frac{hk}{Hi} * \frac{1}{\xi_0 * \gamma_f * \gamma_\beta * \gamma_b}) * \sqrt{g * Hi^3} \quad (3.4)$$

with

$$\alpha_{rep} = tan^{-1}(\frac{3 * Hi}{L_{talud}}), L_{talud} = 1.5 * Hi * \frac{1}{slope1} + 1.5 * Hi * \frac{1}{slope2} \quad (3.5)$$

Where slope1=1/3 and slope2=1/4. With ξ_0 is the Irribarren number (breaker parameter), $\xi = \alpha_{rep}/\sqrt{s0}$ with $s0 = Hs,i/L_0 = \frac{2\pi * Hs,i}{g * Tp^2}$. Hs,i is the incoming significant wave height at the toe of the dike. That means that the wave height may be reduced compared to the offshore wave height that is found in Hydra-NL Output (Appendix K). γ_f is the parameter that counts for the friction of the slope, γ_β= 1-0.0022$|\beta|$, is the factor that count for the direction of incoming waves. The larger the incoming wave height the less the attack of the waves at the dike. γ_b takes the (if present) berm into account.

- Local water level is provided by Hydra-NL. The local water level is predicted according to measurements by Hydra-NL and extrapolated to a specific return period. This component contains storm surge.
- Extra construction height needs to be added for the predicted settlement.

3.5 STAKEHOLDER ANALYSIS

BwN projects affect the physical environment. These changes will affect stakeholders that attribute in various functions in that location. All stakeholders have different reasons for participating or being involved in the project development. Therefore it is helpful to do a stakeholder analysis, to clarify which parties exist and what their perceptions are. It is possible that stakeholders have different perception on possible problems and suitable solutions [IJff et al. [2018]]. Careful selection of partners and management of opposition helps to make projects feasible and successful [Deltares [2020b]]. In this section the stakeholders will be discussed. The influence and requirements of the stakeholders are composed during a stakeholder analysis brainstorming session and can be found in Figure F.1. It is possible that during the process the parties with large interest and power will grow toward each other [IJff et al. [2018]].

3.5.1 Stakeholders

The stakeholders, that have either power or interest in the project, are found during a brainstorming session. Together with the project team of IJburg of the Ingenieursbureau the stakeholders are summed. The brainstorm team consisted of two technical managers, that have worked on successfully completed islands of IJburg. The stakeholders of Buiteneiland are similar to those of other islands within IJburg. Two hydraulic specialists helped specify the requirements and desires of the stakeholders. Finally, the brainstorm session is finished with an agreement of the all participants. One stakeholder, Ruimte en Duurzaamheid (Space and Sustaianbility) is also part of the municipality of Amstersdam and therefore, there was more contact with this party than with others. This might have biased some requirements. In Figure 3.11 the different stakeholders are categorized by power (vertical axis) and interest (horizontal axis). In the four quadrants the management strategies are mentioned; monitor, keep informed, manage closely and keep satisfied. There are eight stakeholders that need more elaboration because of their high power and/or interest, this can be found in Figure 3.11.

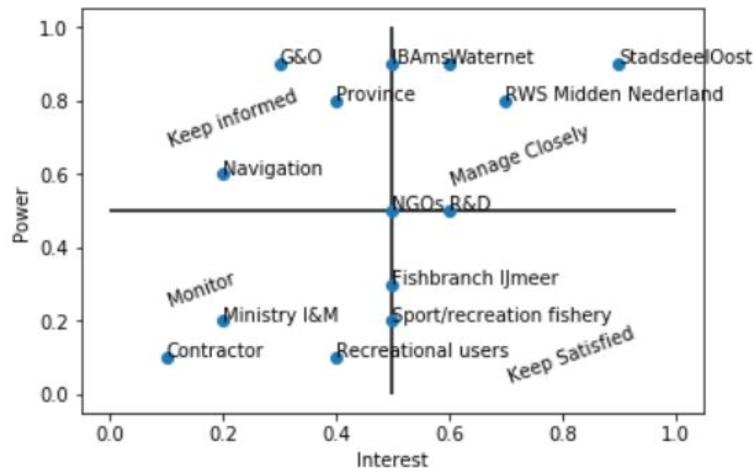


Figure 3.11: Indication different stakeholders and their power to interest position

The Engineering Office

The Engineering Office (IBAms (Ingenieursbureau Amsterdam) in Figure 3.11 has moderate interest, but large power. Eventually, the engineers of the Engineering Office are the designers and have the responsibility to the municipality and the other stakeholders. This research is written to advice this party.

Waternet

The first main party is Waternet, which needs to be involved closely. Waternet wants a water retaining structure with the smallest area to manage as primary flood defence. Their power is large. At the other side, almost all other parties want a green, sustainable and unique flood protection area, which also will be taken into account.

Groundbank of Amsterdam (G&O)

The second party with a lot of influence is the Groundbank of Amsterdam. This company manages the ground flow within Amsterdam. Most of the time, they have a plenitude of soil without destination. The aim of the Groundbank is to get rid of as much soil as possible. The Ingenieursbureau will get refund by taking the soil. The PFAS-rules are quite strict and does not allow all soil with diverse origin to be dumped at the foreshore. For the construction of the dike and the foreshore pure sand will be used.

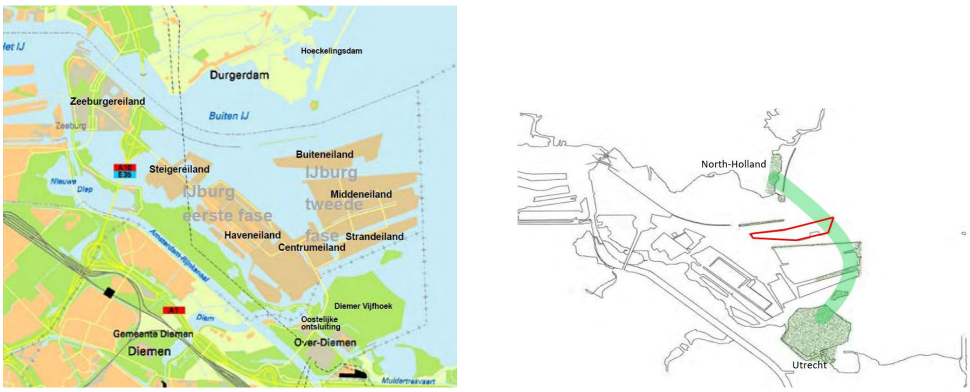
Stadsdeel Oost Amsterdam

The district municipality of east of Amsterdam (Stadsdeel Oost), is a party with large interest and large power. Their desire is to create a green and circular island.

So, the more green and nature, the better. Furthermore, rubble mound is desired for the cover of hydraulic structures, as flora and fauna are able to live at and around these stones.

Province of North-Holland

For the province of North-Holland, the aim is to provide as much as natural and environmental value to contribute to the biodiversity of the IJmeer/Markermeer. In this way the Amsterdam residents are able to enjoy the nature close to the city. Ko & Post [2020] and the *Contouren en dijkprofielen Buiteneiland* [2020] would like to create at the east side of the islands, Strandeiland, Middeneiland and Buiteneiland outer dike reed fields. These reed fields will contribute to the 'Boog om de Oost'. A provincial 'arch' provide a nature connection between Vechtstreek, more precise the Diemervijfhoek (South of IJmeer) with Waterland (Hoeckelingsdam in Figure 3.12) (North of IJmeer) Timár [2014]. See Figure 3.12 the green arch that shows the location of the arch. In order to make this ecological connection for the development of the Boog om Oost, outer dike reed fields are necessary of about 25 hectares in the arch [Ko & Post [2020]]. So for Buiteneiland holds the more the better but approximately 25000 m^2 (10% of the 25 hactares) needs to be fulfilled. The reed fields will create location for animals to be able to go in and out of the water easily [Amsterdam [2009]]. This approach aims to create an ecological system that is flexible enough to absorb future changes without a substantial loss of quality [Timár [2014]].



(a) (b)

Figure 3.12: The 'Boog om de Oost' is indicated by green arch [Amsterdam [2009]]

Ruimte en Duurzaamheid (R&D)

Ruimte en Duurzaamheid (English: Space and Sustainability) is part over Ingenieursbureau Amsterdam. Their aim is to develop a planologic strong and sustainable design for IJburg and so for Buiteneiland as well. Next to the fact this party also wants to create a green and sustainable island, the viewing lines (Figure 3.14) from Durgerdam (indicated by starting point of two green lines left in Figure 3.14) and Vuurtoreneiland (indicated by red circle with black dot in Figure 3.14) are of great importance. From Durgerdam and from Vuurtoreneiland the viewing lines crosses the east side of Buiteneiland. So higher structures are not allowed, as structures above water level disturb the clear view over the lake. Therefore the the east side will get a natural environment for the citizens of east of Amsterdam, but the land may not rise too high out of the water (approx. + 1.20 m NAP).

NGO's and fishing branch

Than the NGO's and the fish branch, it is the aim to keep them satisfied. these can be taken together as they have the following overarching desires, the current water quality of the IJmeer may not be deteriorated. Furthermore, the diversity is

Figure 3.13: The 'Boog om de oost' [maps.amsterdam.nl]

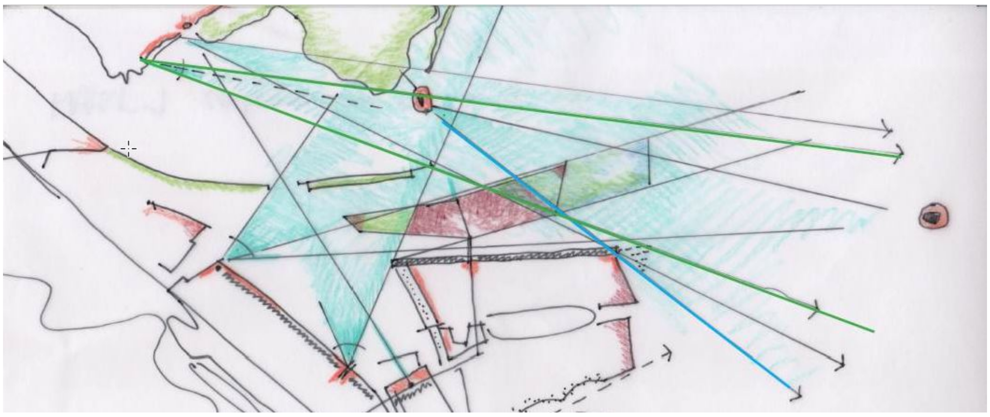


Figure 3.14: View lines from Durgerdam and Vuurtoreneiland over IJmeer [*Buiteneiland: groen anker van Amsterdam* [2020]]

important in order to create an ecosystem that is resilient for setbacks. To have benefits from ecosystem services the biodiversity needs to be great. The foreshore environment will exist of a great biodiversity with a variety in all aspects (depth, current, waves, temperature, salinity and soil properties). Ecosystem services, as all the natural value of reed will be taken into account.

Recreational guests
The recreational guest of the island can come from all different directions, so also by boat from the IJburg marina. Their desire is to have some sheltered spots to moor and swim.

3.5.2 Influence of stakeholders

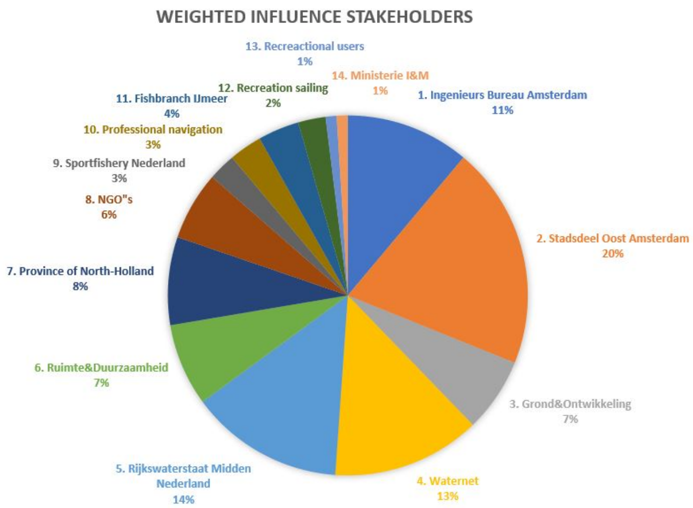


Figure 3.15: Influence of the stakeholders

The influence of stakeholders is not equal. Stakeholders with low interest will not use their high power and the other way around. From Figure 3.11, the stakeholders and their stakes are weighted. This weighting is found by multiplying the power by interest values. Therefore it is assumed that power and interest are proportional to each other. In that way, criteria of stakeholders with a large power and large interest get a large weight in the multi-criteria analysis and vice versa. The found value is normalized and the shares for the different stakeholders are shown in Figure 3.15. The final score per alternative is the summation of the score per criteria. The criteria score is multiplied with the normalized weighting factor per stakeholder. So for example, 2. Stadsdeel Oost Amsterdam has a power * interest factor of 0.81. This value is normalized by the summation of the weighting factors which is 4.05. So 0.81/4.05 = 0.2, this is the normalized weight factor for Stadsdeel Oost Amsterdam. Each alternative is scored for the criteria of Stadsdeel Oost Amsterdam (Large nature area). This scoring is multiplied by the normalized weighting factor.

Not all criteria can be scaled in terms of money. Most of the criteria are quantified differently. Each stakeholder has different requirements or desires, in Table 3.3 the requirements are summarized into one criteria.

Table 3.3: Stakeholders with their requirements or desires. The weighting factor power*interest (Pwr*Int) is given with the normalized (weighting) factor which is summed 1 together

Stakeholders	Criteria	Pwr*Int	Normalized factor
1. Ingenieursbureau Amsterdam	Sustainable and nature-based	0.45	0.11
2. Stadsdeel Oost Amsterdam	Large nature area	0.81	0.20
3. Grond&Ontwikkeling	Low cost, large nature area	0.27	0.07
4. Waternet	Low maintenance for safety	0.54	0.13
5. RWS Midden Nederland	Improved water quality	0.56	0.14
6. Ruimte&Duurzaamheid	Structures below WL	0.3	0.07
7. Province of North-Holland	'Boog om de Oost'	0.32	0.08
8. NGO's	Large diversity	0.25	0.06
9. Sportfishery Nederland	Improve sheltered mooring	0.1	0.02
10. Professional navigation	No hinder	0.12	0.03
11. Fishbranch IJmeer	Improve fish diversity	0.15	0.04
12. Recreation sailing	Improve sheltered mooring	0.1	0.02
13. Recreactional users	Structures below WL	0.04	0.01
14. Ministerie I&M	Safe and according rules	0.04	0.01
	Total	**4.05**	**1**

3.6 CONCLUSIONS

In this section the sub-question: What stakeholders, processes and ecosystem services will work on and around Buiteneiland? is answered. The answer of this sub-question has lead to the design statements for coming design steps. First, the stakeholders and their requirements are discussed. Followed by, the (hydraulic) processes and the ecosystem services. Then, the main stakeholders and their requirements are discussed and are formulated in design statements for the coming design steps. Design statements help to obtain engagement by the stakeholders. It is important to show why steps have been made. This helps to obtain understanding and believe in the design by the stakeholders. The stakeholder analysis is used to show what parties and what different desires and requirements there exist. The Engineering Office aims to create a safe and nature-based hybrid solution for the east side of Buiteneiland. The influence of the *Ingenieursbureau Amsterdam, Stadsdeel Oost and Grond* & *Ontwikkeling* have large amount of the total influence as these stakeholders are the initiators and needs to be managed closely. 'Ruimte en Duurzaamheid' has large influence in this project. Their aim is to keep a clear view over the IJmeer. Therefore, hydraulic structures need to be built below water surface as much as possible. Furthermore, the dike also needs to be as low as possible because of the clear lake view from Durgerdam and Vuurtoreneiland. For the recreational guests that come by boat, different sheltered spots will be created. It is assumed that the inhabitants of the island are included by the recreational guests. The inhabitants of the island will not live close to the natural area and therefore the inhabitants will also be recreational guests of the natrual area. At last, the requirements of Waternet, the future owner of the primary flood defence, are taken to the next design steps. Waternet requires a solution with minimum maintenance to function as a primary flood defence. Hydraulic boundary conditions determine the load against the to be build system. The hydraulic boundary conditions need to be known to create a safe area behind the solution. Safety is determined by the probability of failure of the total hybrid solution. In the fault tree the failure probability for the failure mechanism cover erosion is determining. The OI2014v4 [2017] prescribed a norm of 1/100 years for the islands in the IJmeer. Therefore, the requirement of probability of failure is set at once every 830 years for the primary flood defence. A corresponding significant wave height is Hs=1.17 m and peak period of Tp=4.43 s, from the east-northeast and east direction. Hydra-NL can be used for the dimensions of a 'traditional' dike. The east side of Buiteneiland will not be a 'traditional' dike. Therefore, the dimensions of the hybrid solution will be determined manually. The aim is to optimize the dimensions of the solution. The dimensions of the solution could be reduced with a lower significant wave height at the land-water transition. Lower significant wave height can be established by the use of shallow foreshore and vegetation. A shallow foreshore has multiple functions. Namely, it is able to stabilize a dike, a foreshore create a plateau for the vegetation to grow on and a foreshore reduces the wave height. Furthermore, a vegetated foreshore will be able to trap sludge causing a higher light penetration and therefore more ability of vegetation growth. Therefore, a shallow foreshore would be recommended to use in the coming design steps.

Finally, the ecosystem services are discussed. Vegetation can have multiple ecosystem functions and ecosystem services. Reed is a vegetation that is able to grow easily in the IJmeer. Furthermore, Buiteneiland will contribute to, the 'Boog om de Oost'. For the 'Boog om de Oost', at least 2.5 hectare of outer-dike reed needs be developed at the east side of the island. Therefore, reed fields will recommended to use in the coming design steps. Reed is able to withstand a critical wave height of 0.4 m with a maximum of 5000 waves per year according to *CUR 201* [1999]. The prevailing waves (Hs=0.63 m for yearly waves) are larger than the critical wave height. Therefore, wave height reducing structures needs to create a suitable environment for the reed to grow. Additionally, nowhere around the Markermeer reed fields are able to grow without wave height reducing structures. Therefore, it is recommended to design these structures. Finally, in this stage of the design process, it is recommended to not yet take reed induced wave attenuation into account for the flood safety. This is because during storm season, wave reducing effects of the vegetation cannot be guaranteed. Therefore, it can be concluded that the amount of effect reed has on the wave attenuation is uncertain.

4 COMPARISON OF ALTERNATIVES

The aim of this research is to find a safe and nature-based hybrid solution for the east side of Buiteneiland. This means that the hybrid solution needs to fit all requirements and design statements from the different stakeholders that are obtained in the previous chapter. In this chapter the second sub-question: *Which possible alternatives could meet the requirements?* will be answered. This will be done in the following parts of the chapter. The first part of this chapter describes the Basic Concept. In Figure 4.1 the section and plan view of the Basic Concept is shown. As seen in the figure the ground level of the island will be at crest level of the dike, this is called a half-hidden dike. The second part of this chapter contains the alternatives for the safe and nature-based hybrid solution. These alternatives are established with the conclusions of Chapter 3 in mind. The Basic Concept was the starting point for the development of the three alternatives (Figure 4.2). The last part of this chapter contains the comparison between the alternatives and the Basic Concept. This comparison is done according to a Multi-criteria Analysis (MCA).

4.1 THE BASIC CONCEPT

The Basic Concept for the east side was given by and shown in Figure 4.1 and will be used as the starting point to develop the alternatives. Furthermore, the Basic Concept is used as a draft version for Buiteneiland [Ko & Post [2020]]. The dike is a 'regular' and rubble mound flood defence. The dike will be build out sand and perfect conditions are assumed. For the Basic Concept it is assumed that no extra maintenance is needed in the coming 50 years. 50 years is the design lifetime. Although monitoring and management is required for every dike. In Figure 4.1 the minimum required dike height and slopes are depicted. The crest height is determined on the basis of the failure mechanism of insufficient height.

Above mean lake level the slope can be 1:3 but below the minimum required slope is 1:4. Therefore a representative slope is used again. This is the slope that represents the two different slopes. The failure mechanism macro instability can be refuted because of the fact that the dike will be constructed under milder slopes, after a while, the dike will get its final geometry from the figure, as the soil will be excavated. Table 4.1 shows how the crest height is built up, where the storm surge is included in the Local water level (see Section 3.4.3 for more explanation). The cover layer will consist of a rubble mound units. The choice is partly because of the

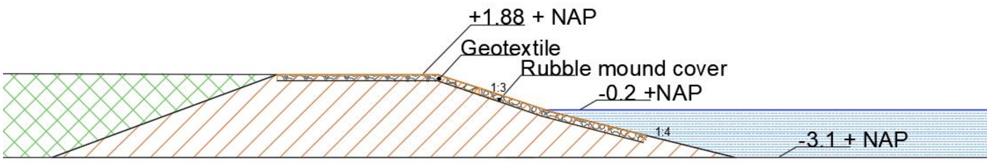


Figure 4.1: The half-hidden dike, the Basic Concept with minimal crest height, design lake level. The dike will be made out of high quality sand. No clay is needed because of half-hidden dike properties. The values are in meters.

Table 4.1: Hydraulic boundary conditions with γ_f=0.55 (rubble mound cover) for overtopping discharge of 10 l/s/m and prevailing wind conditions from ENE and E according to crest height determination of Section 3.4.3

Wave direction °N	-	60 °N (ENE)	90 °N (E)
Overtopping discharge, q (l/s/m)	Hydra-NL input	10	10
Peak period (s)	Hydra-NL output	4.43	4.43
Significant wave height offshore (m)	Hydra-NL output	1.17	1.17
Significant wave height toe (m)	Theoretical approach	1.17	1.17
Freeboard, hk (m)	Equation 3.4	0.41	0.41
Reference (m+ NAP)	Hydra-NL output	-0.19	-0.22
Local water level (m)	Hydra-NL output	1.05	0.77
Additions (m)	OI2014v4 [2017]	0.56	0.56
Lake level rise (m)	Waterplan 2014	0.1	0.1
Dike height (m+NAP)	-	1.93	1.65

reason that flora and fauna will be able to live on and between these stones more than for example placement blocks.

The dn50 is determined with the formula from Van der Meer (1988) for plunging waves. $s0 = \frac{2*\pi*Hm0}{g*Tp^2}$, $\xi = \frac{\alpha}{\sqrt{s0}}$=1.35 and cot($\alpha$)≥4 therefore the plunging wave formula is chosen. with notional permeability of P= 0.4. Number of waves during one storm, N = 7500. The damage factor, S= 3, Δ = 1.65, Hs = 1.17 m.

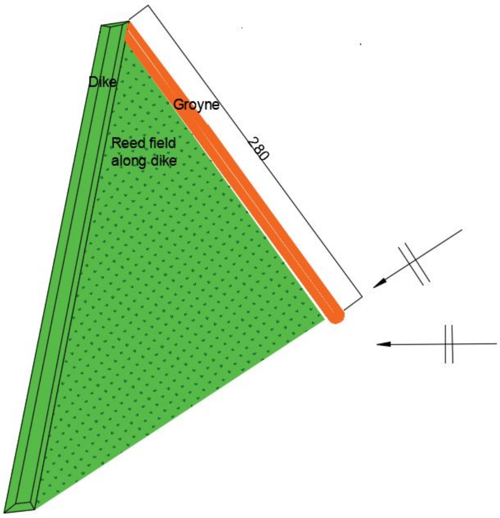
$$\frac{Hs}{\Delta * d_{n50}} = 6.2 * P^{0.18} * \frac{S}{\sqrt{N}^{0.2}} * \xi^{-0.5} \tag{4.1}$$

d_{n50}= 26 cm. Due to cost efficiency the chosen standard rubble mound grading of EN13383 is LM_A 10-60 with a median nominal diameter d_{n50} of 21 cm. To give extra strength, the rubble mound will have a thickness of two times the nominal diameter.

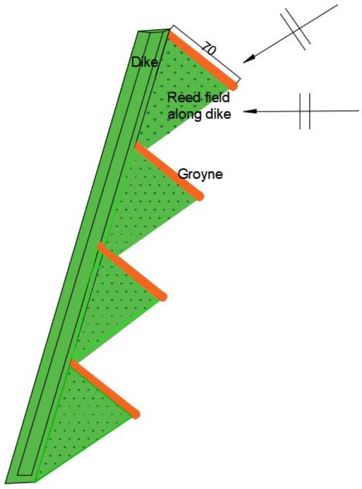
The required sand volume for the full length of the dike (380 m) of the Basic Concept is 19953 m^3. The amount of rubble mound is 3226 m^3. The estimated costs with 35% accuracy (the mean plus and minus 35% of the mean) is cost bandwidth, which is € 0.7 million and € 1.3 million. Which is determined by using calculation sheet of R. Tijsterman [2002]]. These are the costs for the east side of the dike of the island and for the described geometry with clean sand for the core of the dike with a rubble mound cover.

4.2 THE ALTERNATIVES

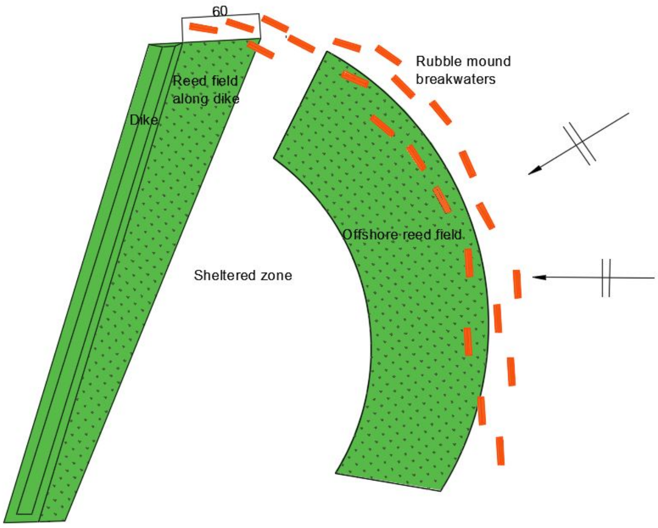
The shape of the island in combination of the boundary conditions are determined. And with the conclusions of Chapter 3 in mind, a brainstorm and sketching session was held to generate the following three alternatives. A lot of other alternatives are conceivable. But these three alternatives are diverse, potential but simple. With the three alternative the possibility to explain concepts is sufficient.



(a) One groyne



(b) Four groynes



(c) The arch

Figure 4.2: Concepts of the three alternatives, with waves from east-northeast and east, where north is up. Values are in meters

The shape of the island and more relevant the orientation of the dike, is in hydraulic aspects not efficient. The orientation would have been more efficient if the dike is orientated perpendicular to the incoming waves. The shape is not negotiable. More efficient ways of protecting the land behind are used in the alternatives of Figure 4.2. The final preferred alternative will need to meet the conclusions of the previous chapter (Chapter 3) as much as possible. In the following section, there will be elaborated on how much or less the concepts fulfil the requirements and desires. In Figure 4.2 the three alternatives are given. The first alternative, Alternative A: The One Groyne Alternative is shown in Figure 4.2.a. This alternative is characterized by one groyne and the large reed field in front of the grass covered dike. The second alternative, shown in Figure 4.2.b is Alternative B: The Four Groynes Alternative. As the names is self-explaining,the alternative has four smaller groynes (than the previous alternative) and with four smaller reed fields are places in front of a grass dike. The last alternative is called Alternative C: The Arch Alternative and is shown in shown in Figure 4.2.c. The arch is curved around a sheltered area. The curve is based on the idea that breakwaters are the most effective when they act perpendicular towards the waves.

The aim of the alternatives is to decrease the crest height and make the dike more green in comparison to the Basic Concept. The wave height is one of the few components that is adjustable. So to reduce the crest height, the significant wave height needs to be reduced before the waves reach the dike. The same dike slopes are taken from the Basic Concept. The crest height value is determined by the summation of the following, as for example shown in Table 4.2 for the One Groyne Alternative. The freeboard, reference water level, the local water level, additions and predicted lake level rise are summed to get the minimum crest height. For the reduction of the different wave height reducing structures the following formula for the transmission coefficient (Kt), [van der Meer et al. [2004]] will be used:

$$Kt = -0.4 * \frac{R_c}{H_i} + cos^{\frac{2}{3}}(\beta)(1 - e^{-0.5*\xi}) * 0.75 * \frac{B}{H_i}^{-0.31} \tag{4.2}$$

Hi is the incoming wave height at the toe of the structure. Rc is the crest freeboard of the groyne of breakwater and B, the width. β is the incoming wave angle. ξ is the Irribarren number which is used to account for the breaking processes. The limits are: $1 < \xi_{op} < 3$, $0° < \beta < 70°$ and $1 < B/Hi < 4$.

Rubble mound cover

In order to limit the use of material, the slopes of the groynes or breakwaters is taken 1:2 for all wave height reducing structures. The formula from van der Meer & Janssen [1995] in combination with the aim to have low maintenance cost, it is chosen to have rubble mound cover. The rubble mound grading is taken LM_A=10-60 with d_{n50}=0.21 m, which gives a thickness of 2*d_{n50}=0.42. The calculations are made without taking reed reduction effects into account, this applies to all alternatives.

Settlement

With applying sand bodies on the bottom of the IJmeer, a settlement process will be set in motion. Settlement of the applied sand body needs to be be considered for determining the construction levels. The theoretical final settlement will be achieved after a long period. A period for which approximately 30 years is taken [Ko & Post [2020]]. The settlement process will develop naturally, so without accelerating measures such as vertical drainage. The soil surveys can be found in Figure B.1, B.2, B.3 and B.4. The settlement for the total area of interest is assumed to be 1.0 m in 30 years. Over the years an exponential settlement will be taken into consideration over the full area of the sand body. This means that any area, sand will be placed on, needs to be raised by 1.0 m. The volumes for each alternative in the following sections are taking this raising into account. This assumption of raising all the applied sand bodies with 1 m is important but quite conservative and has a large uncertainty.

Due to settlement, the bottom level of the reed fields will be at water level, which is the construction level. At this moment the reed roots are able to germinate. In 2 seasons the reed will be successfully grown and the water depth may increase. Due to sedimentation around the reed stems, the assumption is that the settlement will be compensated. When this is not the case extra sand suppletion will be needed to prevent the reed from drowning.

4.2.1 Alternative A: The One Groyne Alternative

The first alternative is shown in Figure 4.3. The plan view is divided into components and each will be explained. The outer dike reed field will have an area of 39300 m^2. The required rubble mound volume will be 1346 m^3.The required sand volume will be 144766 m^3. The volume of sand is the summation of the groyne, the foreshore and the dike. The estimated costs with 35% accuracy the cost bandwidth is € 3.4 million and € 6.3 million determined by using calculation sheet of R. Tijsterman [2002]. The development of the design is an iterative process. Due to the gain

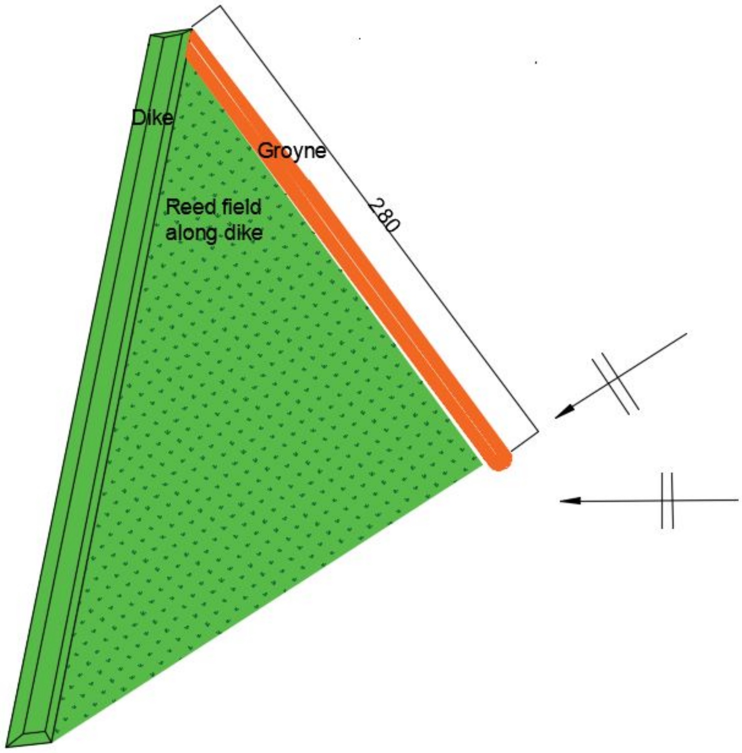


Figure 4.3: The one groyne alternative (value is in meters and indicates the scale)

of more knowledge, the size and shape of the groyne is not accurate anymore. At the moment this alternative would have been chosen, the geometry and materials would have been optimized. The wave load compared to the strength of the reed fields were not yet considered.

The submerged groyne

The submerged groyne connects to the island and this is because of the east-northeast incoming waves. Reduction of the wave height is made by one long wide groyne. The crest of the groyne will be 30 cm below water surface, so that this structures will not disturb the view over the lake. The wave height reduction will be than approximately 45% [van der Meer et al. [2004]]. This quite stationary concept will only satisfy the diversity in different parameters due to the changing current alongshore and wave penetration. Along the outer side of the foreshore the reed field will be placed, rubble mound cover protection is needed.

The reed field

The requirement of the outer dike reed fields for the 'Boog om de Oost' is fulfilled. The reed (grows at 1 m water depth) will create a lot of extra natural value to the island and the lake. Because of the location of the reed field close to the dike, this reed is easy to mow and maintain. The foreshore itself will contribute to a wave height reduction [Roode et al. [2019]] for waves from the east direction and diffracting waves from east-northeast direction.

4.2.2 Alternative B: The Four Groynes Alternative

The second alternative (see Figure 4.4) contains four submerged groynes. Between two groynes a bay has been created. The outer dike reed field will have an area of 10020 m^2. The required sand volume will be 65179 m^3. The required rubble mound volume will be 1964 m^3. The volume of sand is the summation of the groynes,

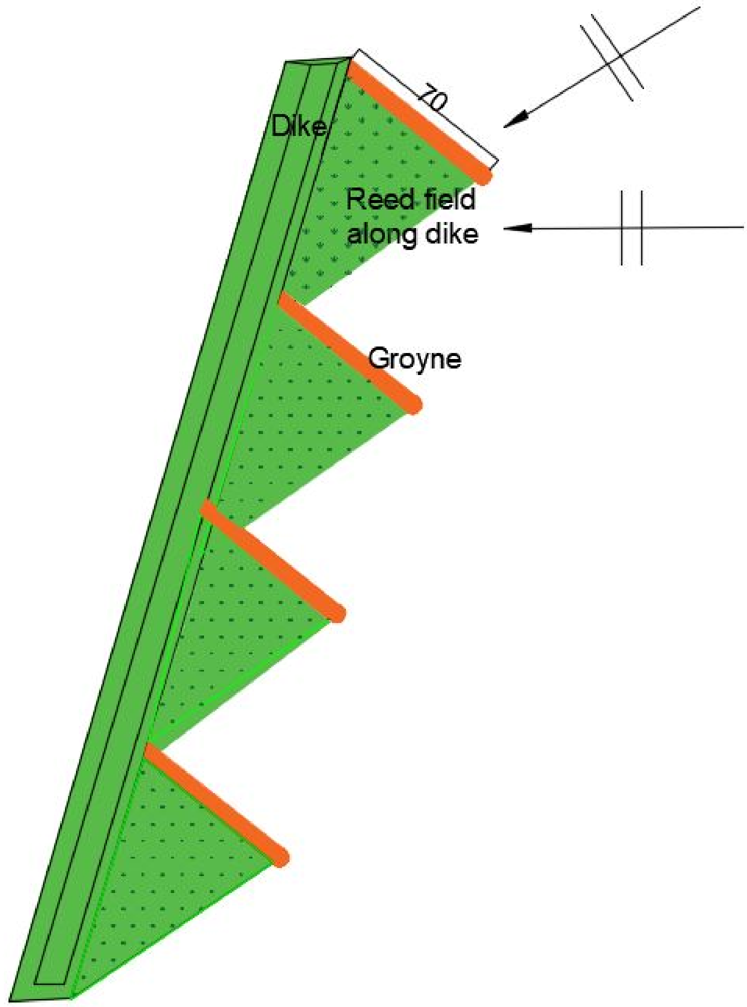


Figure 4.4: The Four Groynes Alternative (value is in meters and indicates the scale)

the foreshores and the dike. The approximate cost, according to determined by using calculation sheet of R. Tijsterman [2018] with 70% certainty € 2.0 million and € 3.7 million. The Figure 4.4 is divided into components and each will be explained.

The groynes

The groynes will be below water surface and therefore the maximum wave reduction is 45% [Visser et al. [2015]]. Because of the wave height reduction, downwind of the groyne, reed is able to grow.

The reed fields

The reed fields will contributes to the 'Boog om de Oost'. The 2.5ha outer dike reed field is not fulfilled. Upwind of the following groyne a recreational unstable beach will be under mild wind and wave conditions. Under storm conditions the beach will probability be eroded. The direction normal to the shore will turn into the dominant wave direction. The beach will be eroded during storms, during moderated periods the beach will be developed. Because of the number of groynes a lot of diversity is created in this concept. The bay that will be created hereby, will give differences in wave penetration and vegetation spots. The sheltered spots by northwest wind for sailing recreants is only at the downwind side of the last groyne. Primary flood defence will contain not only the dike itself but also the groynes and the foreshore that will be lead to wave breaking. The foreshore will be as high that reed is able to grow easily and be capable of protecting the foreshore material from eroding [Roode et al. [2019]]. The advantage this concept has over the previous one is the extra safety in case of groyne failure. When one groyne fails, there are others in protecting the land from flooding. Along the outer side of the reed fields, rubble mound cover is needed to protect the sand from eroding.

4.2.3 Alternative C: The Arch Alternative

The Arch Alternative is shown in Figure 4.5 and is the most diverse alternative in aspects as wave penetration and bottom height. The outer dike reed field will have an area of 43159 m^2. The required rubble mound volume will be 1178 m^3.The required sand volume will be 133508 m^3. The volume of sand is the summation of the arch, the foreshores and the dike. According the calculation sheet of R. Tijsterman [2020], the cost will be with 70 % certainty € 4.5 million and € 8.4 million. Figure 5.4 is divided in components and each will be explained.

The arch

The arch form together a protection arc, so that the influence of the waves angle of incidence is always little as possible. In other words: the breakwaters are placed so that a large part of the waves are coming-in perpendicular to the breakwater. Because of the water depth is reducing towards the breakwaters and further towards the dike, the refraction effect is turning the waves more perpendicular to the breakwaters. The dominant wind is coming from the east-northeast direction. The small submerged breakwaters, that will have their crest at 30 cm below mean lake water, will reduces the wave height with 50% [van der Meer et al. [2004]].

The reed fields

Behind the arch a large reed field is placed, which will grow on a sandy foreshore one meter below lake level. The arch will be build out of sand covered by rubble mound. There will be two reed field, one downwind of the breakwaters and an reed area along shore. All together, this will give a lot of diversity in different directions and sheltered locations for recreational sailing. Along the outer side of the reed field arch, rubble mound cover is needed to protect the sand from eroding. Furthermore, the plateaus will be able to trap sludge causing a higher light penetration and therefore more ability of vegetational growht.

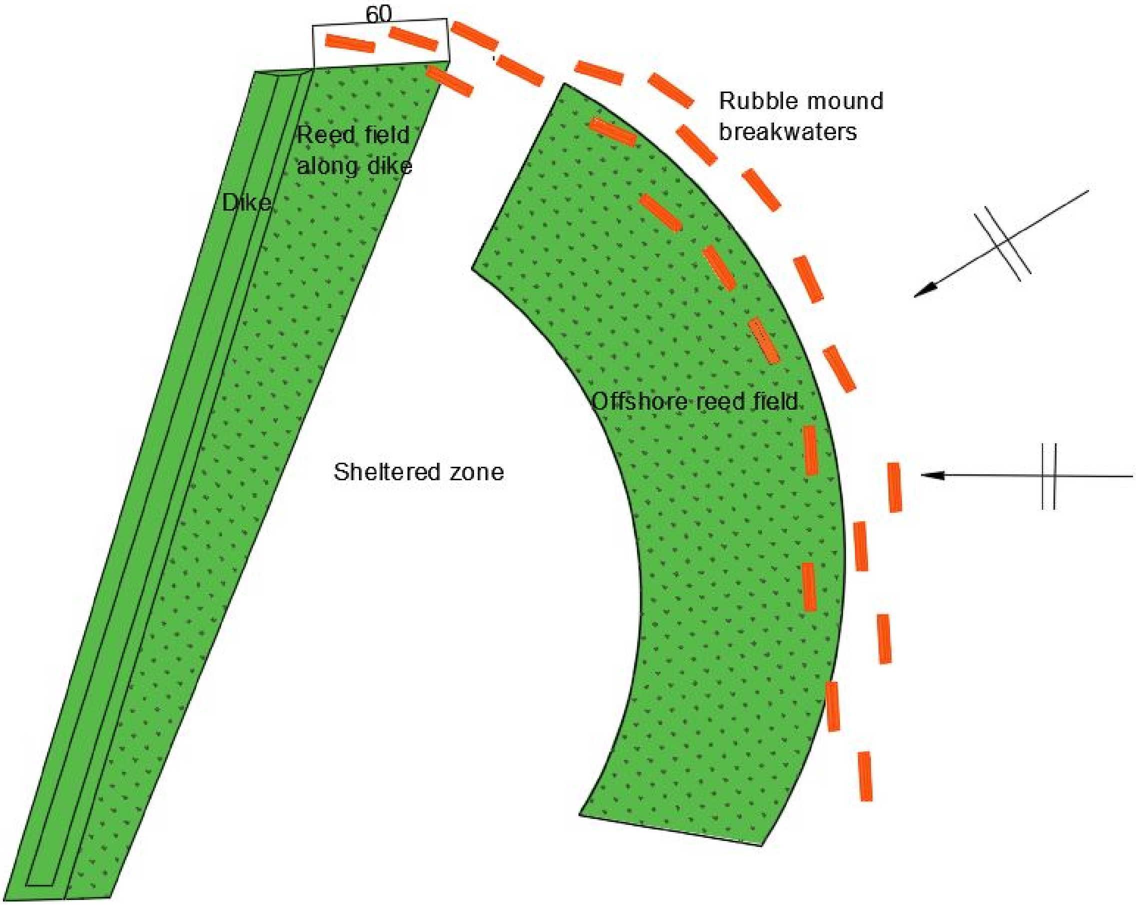


Figure 4.5: The Arch Alternative (value is in meters and indicates the scale)

Table 4.2: For the Arch Alternative: hydraulic boundary conditions with γ_f=1 (grass cover) for overtopping discharge of 10 l/s/m and prevailing wind conditions from ENE and E

Wave direction °N	-	60 °N (ENE)	90 °N (E)
Overtopping discharge, q (l/s/m)	Input	10	10
Peak period (s)	Hydra-NL	4.43	4.43
Hs offshore (m)	Hydra-NL	1.17	1.17
Hs dike toe (m)	Theoretical	0.5	0.5
Freeboard, *hk* (m)	Equation 3.4	0.28	0.28
Reference (m+ NAP)	Hydra-NL	-0.19	-0.22
Local water level (m)	Hydra-NL	1.05	0.77
Additions (m)	OI2014v4 [2017]	0.56	0.56
Lake level rise (m)	Waterplan 2014	0.1	0.1
Dike height (m+NAP)	-	1.80	1.49

4.2.4 Crest height of dike for the alternatives

For the three alternatives the approach and the characteristic parameters are the same. The dike is located in the area between the reed field and the main land of the island. In Table 4.2, one can see how the crest height is determined. The freeboard is dependent on the wave height at the toe of the dike. The waves from east-northeast direction are reduced by the submerged groyne by 50% of the wave height (=1.17*0.5=0.58 m). Downwind of the groyne, the waves will refract towards the dike. The waves will be reduced by the very shallow foreshore to a 0.5 of the water depth which is Hs,foreshore= 0.5*1 m= 0.5 m. The reed will reduced this wave height even more. To make a more reliable and safe crest height this is not taken into account here. Waves coming from the east will only be reduced by the foreshore and reed field. Therefore only one reduction of 50% is taken into account because of the foreshore. As can found in Table 4.2 the determining direction is 60N with a corresponding crest height that needs to be at least 1.80 m.

4.3 THE COMPARISON

This section describes how the comparison has been set up. The alternatives from Section 4.2 will be compared to the Basic Concept. This serves to get insight in the possibilities of hybrid solutions and how they fulfil the desires of the stakeholders compared to the Basis Concept. A multi-criteria analysis is used in the decision making. This analysis ranks alternatives according to different criteria [Hellendoorn [2001]].

The decision making is done according to the following steps:

- Desires and requirements of the stakeholders (Section 3.5) are summarized in one criteria per stakeholder and showed in Table 3.3.
- Influence per stakeholder is determined by power times interest, to get weighed influence on the solution (see Section 3.5.2).
- Each criteria is explained in Section 3.5.2, the scoring scale is divided by two or three, either for complexity reasons.
- The Basic Concept and the three alternatives are scored per criteria (see Section 4.4).
- The scores are summed and one alternative will suit the problem best (see Figure 4.6).

Table 4.3: Conclusion table (Stone is rubble mound stones with grading LM_A 10-60)

Alternatives	Stone (m^3)	Sand (m^3)	Reed area (m^2)	Ratio Reed/Sand	Ratio Stone/Sand
Basic Concept	3226	19953	0	-	0.24
One Groyne	1635	112107	35157	0.31	0.01
Four Groynes	1700	42945	12024	0.28	0.04
The Arch	1178	153461	43159	0.28	0.008

- In Section 4.5 the decision is made and the conclusions of the multi-criteria analysis are given.

The Engineering Office (Ingenieursbureau Amsterdam)
The criteria are formulated according to the stakeholders. The aim of the Ingenieursbureau is to develop a hybrid solution for the east side of Buiteneiland. The hybrid solution needs to be nature-based and sustainable, needs to contribute to the 'Boog om de Oost', low in emission, effective in placement of reed and rubble mound, climate adaptive, low in costs and in expected maintenance.

Nature-based
The alternatives that used nature-based processes to contribute to the safety will score high for this criteria. An example for nature-based process is reducing turbidity by the use of water plants, causing and increase in the water quality. The sediment will be captured which causes a stronger foreshore [IJff et al. [2018]]. With reducing the turbidity, the water quality will be improved Visser et al. [2015].

Ratio reed area to sand volume
The most effective reed placement can be found in the ratio reed area to sand volume. This gives the relative amount of reed compared to the sand that is needed. The higher this ratio is, the more efficient the reed is placed. The larger the ratio, the more efficient the reed is placed and the better the alternative is appropriate. This ratio can be found in Table 4.3.

Ratio sand volume to rubble mound
The most effective reed placement can be found according to Table 4.3 the ratio sand volume to rubble mound for the Basic Concept and the alternatives can be found. One function of rubble mound is protecting the sand from eroding. The ratio rubble mound to sand gives the efficiency of the location and placement of the rubble mound and in how efficient the rubble mound is protecting the sand. This ratio can be found in Table 4.3.

Low costs
Under this heading the costs for the Basic Concept and the three alternatives is scored. The aim of the Ingenieursbureau Amsterdam is to develop a suitable solution as cheap as possible. The costs contains the following components, the volume sand for the dike, volume sand for the foreshore, volume rubble mound protection and reed fields. The dike of the Basic Concept is also add up to the alternatives. The difference between the dike of the Basic Concept and the alternatives is the cover, rubble mound and grass. The reduction of the dike height the foreshore and structures could cause is compensated by the grass cover. So the reduction in sand volume for the alternatives is not changed significantly. The cost estimation is done by the use of an excel sheet provided by Ingenieursbureau Amsterdam [René Thijsterman [2018]]. This document has also been used for the cost estimation of Buiteneiland by the Ingenieursbureau during the conceptual phase. This estimation contains prices for material volumes, execution cost and placement of rubble stones or reed fields. To get a realistic cost estimation, all obvious, similar cost are also taken into account. The material volumes have been determined before subsidence

Table 4.4: Cost estimate determined by using calculation sheet of R. Tijsterman [2020], mean ±35%

Alternatives	Mean cost −35%	Mean cost +35%
Basic Concept	€ 0.7 million	€ 1.3 million
One Groyne	€ 2.8 million	€ 5.3 million
Four Groynes	€ 1.2 million	€ 2.2 million
The Arch	€ 4.5 million	€ 8.4 million

could have taken place, the construction profile is used. The cost per alternative can be found in Table 6.1. With this criteria the alternatives are ranked. Because two alternatives (One Groyne Alternative and The Arch Alternative) have their cost estimates in the same order, therefore the scale is divided by three.

Little maintenance
With the criteria Low maintenance (Sand suppletion), that during a storm the reed may break and the roots are able to stay, it is assumed that this reed will come back afterwards. But when the roots are destroyed the sand below will eroded as well which is not accretion afterwards. That is the moment sand suppletion is required. Especially wide reed fields will have advantage of mowing less often [*CUR 204* [1999]]. It is chosen to let the waves lead to destruction of the reed, so that maintenance is done by nature. This may be done once every 10 years. This is chosen, to keep the reed more dynamic and the damage/removal will be part of the maintenance [*CUR 204* [1999]].

4.4 MULTI-CRITERIA ANALYSIS

The comparison is done according to a MCA, the conclusions of Chapter 3 are used in the analysis. The comparison table will exist of the requirements and desires from the stakeholders and can be found in Figure 4.6. Reason for this is that the stakeholders standing for all different aspects that could be required. With a multi-criteria analysis, different criteria can be compared in a transparent way [Hellendoorn [2001]]. The Basic Concept is compared to the alternatives and the alternatives are compared to each other. All the alternatives are considered in final stadium so after growth of reed and settlement of the subsoil.

In Figure G.1, the multi-criteria analysis with the final score to every alternative can be found. The alternatives have been taken independently to each other. The alternative with the largest score will be the one that is the most suitable solution. This means that the final score is an indicator for the suitability of the alternative. The scoring is done as follows: if the alternative satisfies the criterion, yes or no (1 or 0 points). When some more differences needs to be shown, than the scale is divided by three.

Requirement/desires	Normalized factor	Basic concept Score	One groyne Score	Four groyne Score	The arch Score
Sustainable nature based	0.11	0	1	1	2
Large nature area	0.20	0	1	1	2
Low cost, large nature area	0.07	0	1	1	1
Low maintenance for safety	0.13	2	1	0	0
Improved waterquality	0.14	0	1	1	1
Structures below WL	0.07	1	1	2	1
Boog om de Oost	0.08	1	1	1	1
Large diversity	0.06	0	1	1	2
Improve shelterd mooring	0.02	0	1	1	1
No hinder	0.03	1	1	1	1
Improve fish diversity	0.04	0	1	1	2
Improve shelterd mooring	0.02	0	1	1	2
Structures below WL	0.01	0	1	1	1
Safe and according rules	0.01	1	1	1	1
	1	0.46	1.00	0.93	1.22

Figure 4.6: Multi-criteria analysis, the requirements with the normalized weighted factor and the score per alternative gives the highest score to the most suited solution

4.5 CONCLUSIONS

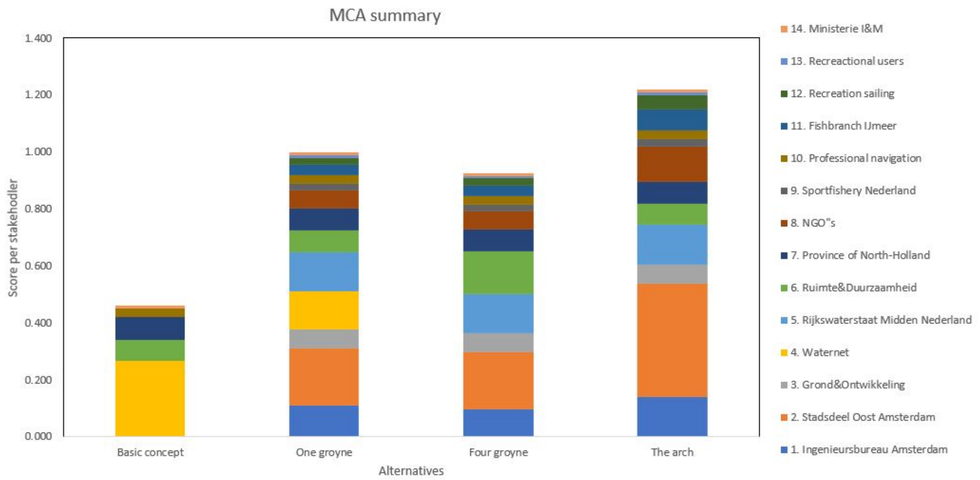


Figure 4.7: MCA summary, highest score for the alternative that suits best

In this section answer to the second sub-question is given. The sub-question was: *Which possible alternatives could meet the requirements?*. The alternatives are compared and the best-suited solution is scored highest according to the MCA. As can be found in Figure G.1 and Figure 4.7 The Arch Alternative has the highest score. Figure 4.7 shows the different parts of the score that belongs to the stakeholders. At the same time, The Arch Alternative has the highest cost estimate. The high cost estimate is mostly due to the following arguments. First, the high score is because of the large area of reed fields. Second, the created diversity within the alternative is a large advantage. Third, the effective placement of the reed and rubble mound and the creation of sheltered places resulted in the high score. The costs estimation is much larger than the estimation of the Basic Concept, this is mostly based on the volume of sand that is required. The dimensions of The Arch Alternative needs to be optimized to reduce the volumes and decrease the costs. This means that the wave height reduction over the reed fields needs to be determined with more accuracy. The Arch Alternative will be elaborated more in the next chapter. Limitations will be discussed and components will try to optimize and costs will possibly be reduced.

5 PRELIMINARY DESIGN

The Arch Alternative has scored highest in comparison of Chapter 4 and will be worked out in more detail in this chapter. The east side of Buiteneiland will get a hybrid solution, this results in a solution that consists of components. The components are optimized in terms of **material use** and **geometry**. Figure 5.2 gives a depth profile of The Arch Alternative with the function of the main components.

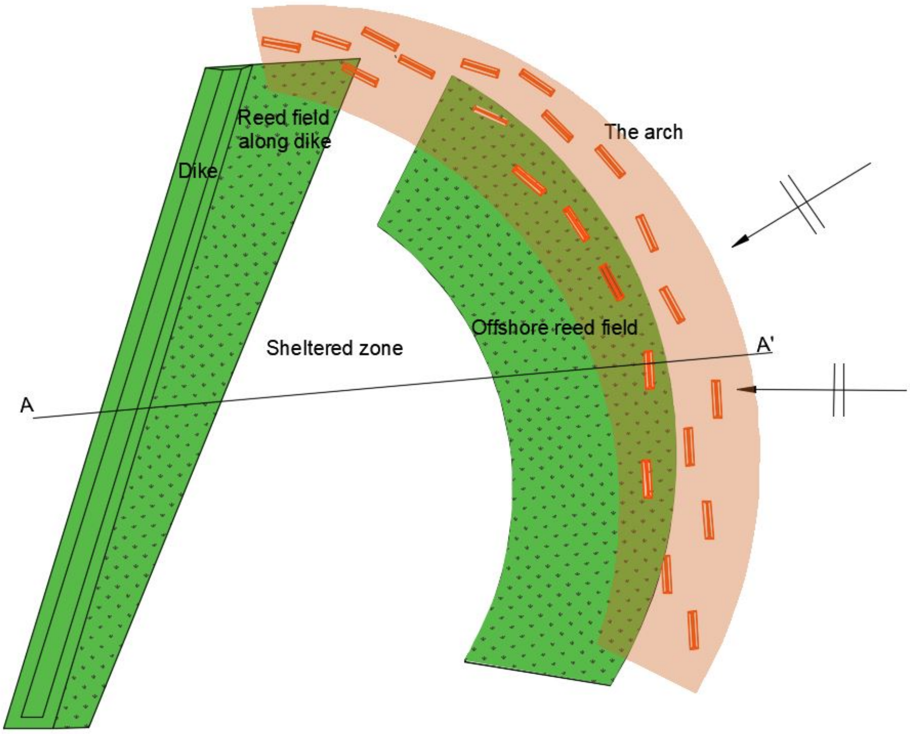
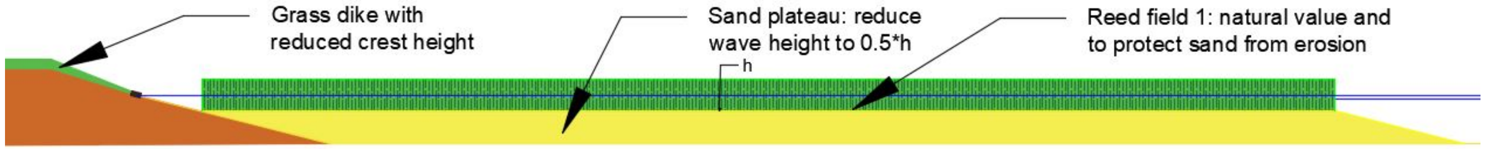
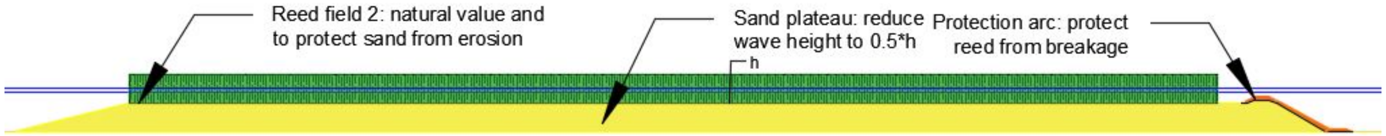


Figure 5.1: The Arch Alternative with location of the cross section of Figure 5.2.



(a) Reed field along dike



(b) Offshore reed field and the arch

Figure 5.2: Depth profile (h = 1m in the figures) of The Arch Alternative is divided into two parts with ax description of components and their function, after settlement of 1.0 m in 30 years. The detail of the protection arch within the box for the Hard Arch Variant can be found in Figure 5.5 and the Soft Arch Variant Figure 5.7

In this chapter, Alternative C: The Arch Alternative will be optimized to obtain the best possible solution. The solution needs to meet the desires of the stakeholders (a combination of the safest, most nature-based ánd low in cost) for the final solution. The plan view of The Arch Alternative is cut into components appointed from east to west. This is done to make the optimization per component more clear. In this chapter the components obtain more detail. The components that will be described are: the dike, reed field 1 and reed field 2, the protection arch and the sheltered area in between (see Figure 5.2). The protection dam is the most complex component. That component will be optimized and obtain more detail. This means that for The Arch *Alternative*, two different *variants* will be made on the protection dam. One *variant* with a rubble mound covered protection dam, called: variant 1: The Hard Arch variant. The other *variant* with a protection dam out of sand, called: variant 2: The Soft Arch variant. In this chapter, the two variants will be compared, the comparison will be based on costs and material volumes. With this comparison an answer for the fourth sub-question: *What is the cost estimate of the safe and nature-based hybrid solution compared to the Basic Concept?* is given. After that, a numerical model will be used to determine the effect of the reed fields on the crest height reduction. This is to answer the third sub-question: *How to detail a nature-based hybrid solution design in the IJmeer?*. The chapter will end with conclusions on the decision of the final alternative for the Engineering Office of Amsterdam in Section 5.5. The most optimal variant is chosen. With this, the research question: *What is a safe and nature-based hybrid solution for the east side of Buiteneiland, IJburg?* is answered. Finally, in Section 5.6, the found conclusions will be discussed.

5.1 COMPONENTS DESCRIBED IN DETAIL: DIKE, REED FIELDS AND SHELTERED AREA

The dike

The dike, located on the border of the island, will be covered by grass with a slope above water level of 1:3 and below water level 1:4. In Table 5.1 the dike height is determined for two different directions of incoming waves. As can be found in Table 5.1 the determining direction is 60°N with a corresponding crest height that

Table 5.1: Required crest height for the Arch Alternative (with grass covered dike) compared to the Basic Concept (with rubble mound covered dike) and in the case the Basic Concept would have a grass covered dike. 60 °N (ENE) is the found normative wave direction. This difference shows the benefits of the hybrid solution in terms of crest height reduction when nature-based character is asked.

Alternative	**The Arch**	**Basic Concept**	**Basic Concept**
Dike cover	Grass	Rubble mound	Grass
Friction coefficient	$\gamma_f = 1$	$\gamma_f = 0.55$	$\gamma_f = 1$
Wave direction °N	60 °N (ENE)	60 °N (ENE)	60 °N (ENE)
Overtopping discharge, q (l/s/m)	10	10	10
Peak period (s)	4.43	4.43	4.43
Hs offshore (m)	1.17	1.17	1.17
Hs dike toe (m)	0.5	1.17	1.17
Freeboard, *hk* (m)	0.28	0.36	0.75
Reference (m+ NAP)	-0.19	-0.19	-0.19
Local water level (m)	1.05	1.05	1.05
Additions (m)	0.56	0.56	0.56
Lake level rise (m)	0.1	0.1	0.1
Dike height (m+NAP)	1.80	1.93	2.27

needs to be at least 1.80m + NAP.

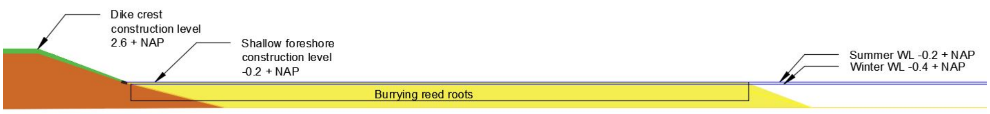
In Figure 5.2 it is explained how the wave height will reduce over the depth profile towards the toe of the dike according to rules of thumb.

The waves from east-northeast direction are reduced by the submerged protection arch. The breakwaters have crest height that reduces the waves at least with Kt is factor half of the wave height. The Kt =0.5 determined by the Equation 5.3. $WH_t = H_{i,\frac{1}{830}} * k_t$=1.17*0.5=0.58m, t is transmitted and $\frac{1}{830}$ is the return period of the incoming wave (subscript i), k is reduction coefficient of the transmitted wave divided by the incoming wave [van der Meer et al. [2004]]. Then, the waves will be reduced by the very shallow foreshore to 0.5 of the water depth which is Hs,foreshore= 0.5*1m= 0.5m [*Lecture notes Coastal Dynamics 1* [2015]] based on Miche (1944) breaker criterion]. The reed and bottom friction will reduce this wave height even more. In order of simplicity the wave height reducing effect of reed and friction is not taken into account yet. This will result in a conservative outcome of the crest height. In Section 5.4 the influence of reed and bottom friction is simulated by a numerical model and will be reconsidered.

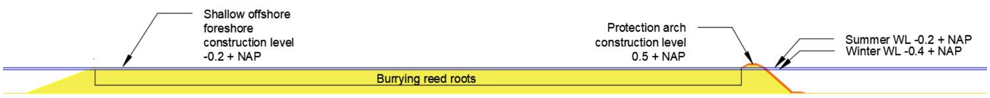
The only hydraulic function of the reed is assumed to be prevention of erosion. The wave height will be reduced by the shallow foreshore of the second reed field less than 0.5 of the water depth (Ht=0.5 m as the water depth is 1 m). Due to bottom friction the wave height decreases further. So that the waves at the toe of the dike will have a height of less than 0.5 m.

Reed fields

There are two reed fields within this alternative. One located close to the dike and one located more offshore. The reed stems needs protection from incoming waves with a wave height that corresponds with a return period of once every 0.1 year (once per 37 days) or larger. Furthermore, the reed needs management once every 10 years. This requirement will be used for the determination of the protection arch in front of the reed fields. A wave height with return period of once every 10 years is Hsig(1/10years)= 0.85m (see Figure 5.8). The nature value rises when vegetation stands in the water what will, after settlement, be the case. For the construction levels before settlement see Figure 5.3.



(a) Reed field along dike



(b) Offshore reed field

Figure 5.3: Levels immediately after construction when taking settlement into account (values are in meters)

Next to the nature value the reed fields have, the reed is also able to slow down the waves (an effect which is not taken into account here but will be in Section 5.4). The width of the reed fields is 80 m. As the wavelength is Lo=1.56*Tp^2, (Tp = 3.75s which is assumed to stay constant over the foreshore), Lo=21.9m. The wavelength is smaller than the width of the foreshore and so the effect of the (vegetated) foreshore can be taken into account. Furthermore, the plateaus will be able to trap sludge causing a higher light penetration and therefore more ability of vegetation growth is possible. This also makes the solution more climate adaptive, when the plateau is able to rise with the lake level rise.

Sheltered area
In the sheltered zone, the zone between the dike and the offshore reed field, recreational boats like sailing or canoeing and fishers will be able to moor. In this area vegetation will be able to grow which will slow down and reduce the waves as well. Most likely, successful vegetation will be the local and natural vegetation discussed in Section 3.1.3, as Full Grown Fountainweed and Crimped Fountainweed. The problem will probably not be the lack of this type of vegetation but an overload. Overload could create hinder for boats and fishery. A management plan will be required to keep a plague away, or and even better create a sufficient biosphere for bird species that will eat the vegetation and so create a balanced situation. The water depth is approximately 3m. For this depth reed will not be able to grow. To sail through this area and to keep the reed away it is important to keep the water depth of approximately 2-3m.

5.2 ADJUSTED COMPONENT: THE PROTECTION ARC

The function of the protection arc protecting the reed area from eroding and breakage behind it. The protection arc needs to reduce the incoming wave height till a threshold for reed breakage. The protection arc will be optimized in the amount of required material of the breakwaters and the material itself.

The number of breakwaters is considered to be high in the first version Figure 5.4. The construction is more complicated and will take longer. Furthermore, the required amount of sand volume and rubble mound volume are considered to be large and could be optimized. Because of these two reasons the cost are expected to be higher than necessary. The aim is to reduce the cost for the municipality of Amsterdam. To reduce the cost, the use of materials needs to be more efficient. The amount of breakwaters could be reduced. The breakwaters are located in front of the offshore reed fields, therefore a lot of extra material is required to build the breakwaters.

The design wave height to determine crest level protection arc
The graph in Figure 3.8 is made by Hydra-NL according to a database with exceedance probabilities for wind speeds. Hydra-NL is not able to depict the wave height for the one year return period. The database is used to interpolate for wave height with a higher return period. This is higher than the critical wave height for reed, which is Hs=0.4 m [*CUR 201* [1999]]. This means that without protection, every year a part of the reed field will break and lose its function. To keep the reed healthy and diverse, management (or breakage due to storm) of reed every 10 years is recommended [*CUR 201* [1999]]. The significant wave height for the ten year return period is 0.85 m (see Figure 3.8). This ten year return period is higher than the critical wave height

In the following sections two possible materials for the protection arch will be prescribed. First, the variant of The Hard Arch (the rubble mound covered protection arch) is discussed. This is followed by The Soft Arch (the sandy protection arch variant).

5.2.1 Variant 1: The Hard Arch variant

First, the Hard Arch variant, the protection arch with a rubble mound cover will be elaborated. In Figure 5.4, the adjusted and more detailed version of The Arch Alternative can be found.

As shown in Figure 5.4, the number of breakwaters (indicated by the orange arch) is reduced from 23 to 10. Furthermore, the breakwaters are placed on the sand plateau (in stead of behind). This optimizes the volume of the required sand. The

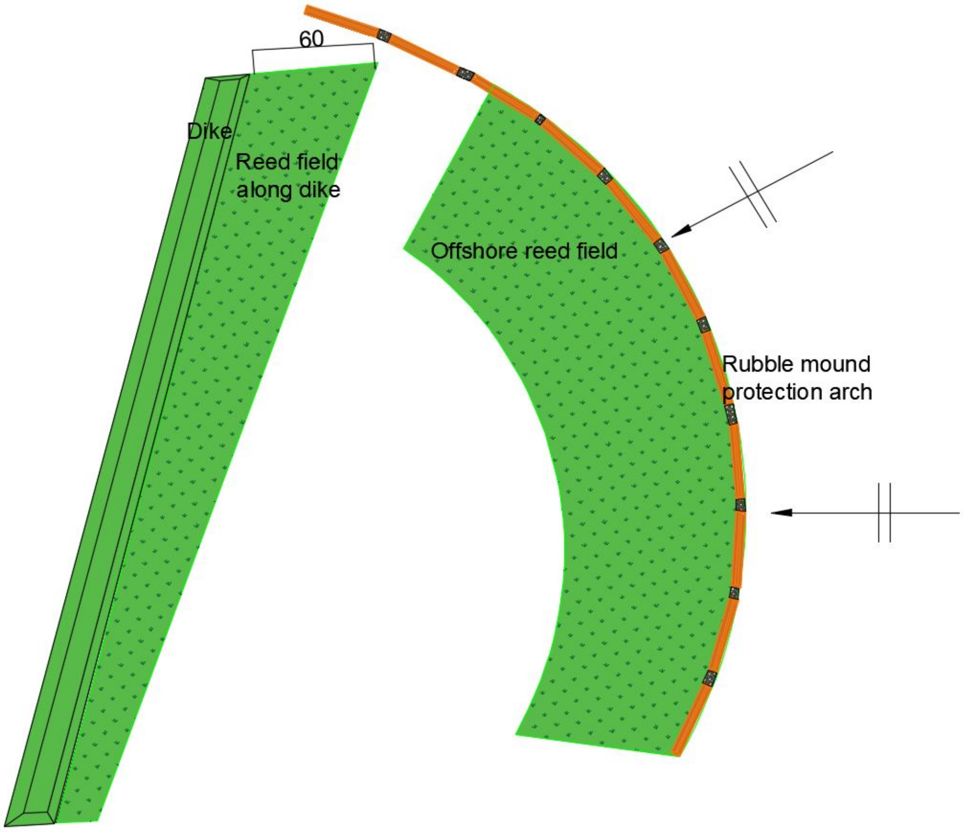


Figure 5.4: The Arch Alternative with the Hard Arch variant, a rubble mound protection arch (The value is in meters and indicates the scale)

geometry of the breakwaters has not changed. The 10 breakwaters is the minimal amount of breakwaters to fulfill the arch completely, with corresponding gullies in between. The gullies between the breakwaters will result in a in and out flow of water at level of the sand plateau. This will result in height differences in the sand plateau due to (little) creeks.

Scour protection

The small areas between the breakwaters could be a disadvantage (Figure 5.4) (indicated by the grey squares between the orange breakwaters). Between the breakwaters larger flow velocities are being reached which could initiate scour behind the gullies. The flow velocity in these gullies will be for example higher when the wind (from the north-east) pushes the water towards the shore (set up). This will create a water level difference between in and outside the breakwater arch. Wind from southwest creates water level reduction, storm from northeast will lead to a increased water level at Buiteneiland. Large scour holes could create instability for the breakwaters and the sand plateau. Protection will be necessary to prevent scour holes to grow.

5.2.2 Variant 2: The Soft Arch variant

In this subsection the Soft Arch variant, which is a sand based protection arch as variant on The Arch Alternative is described. This results in a hybrid solution without any rubble mound.

The Soft Arch variant will create a more dynamic environment. In this variant, the protection arch is made out of sand and will be located where the yellow arch drawn in Figure 5.6. The sandy protection arc, will be submerged, continuous and

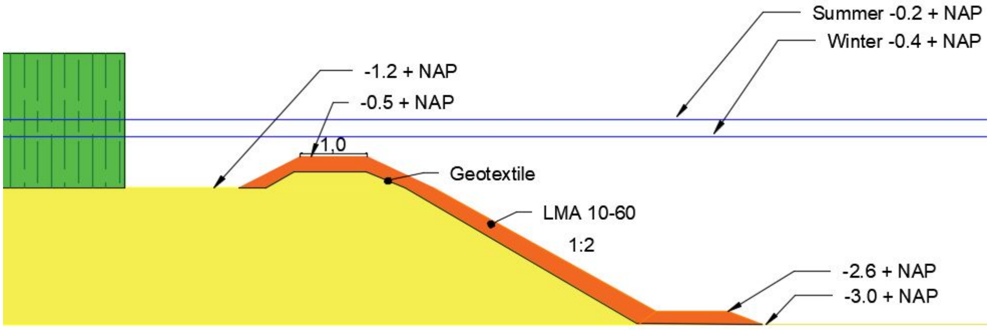


Figure 5.5: The Hard Arch variant. Rubble mound dam section, with summer and winter lake levels, geo-textile below the rubble mound of grading sort LM_A 10-60. Values are in meters. Situation after settlement

solid. This means that the water will not be able to flow between the breakwaters (as in previous variant) but only flow over and around the protection arc, therefore it can be called a sand dam. Based on the hydraulic boundary conditions, the geometry of a breakwater will be designed. The breakwater will be design exactly in the way that is reduces the wave height inside the sheltered zone, so that the reed stems will not break.

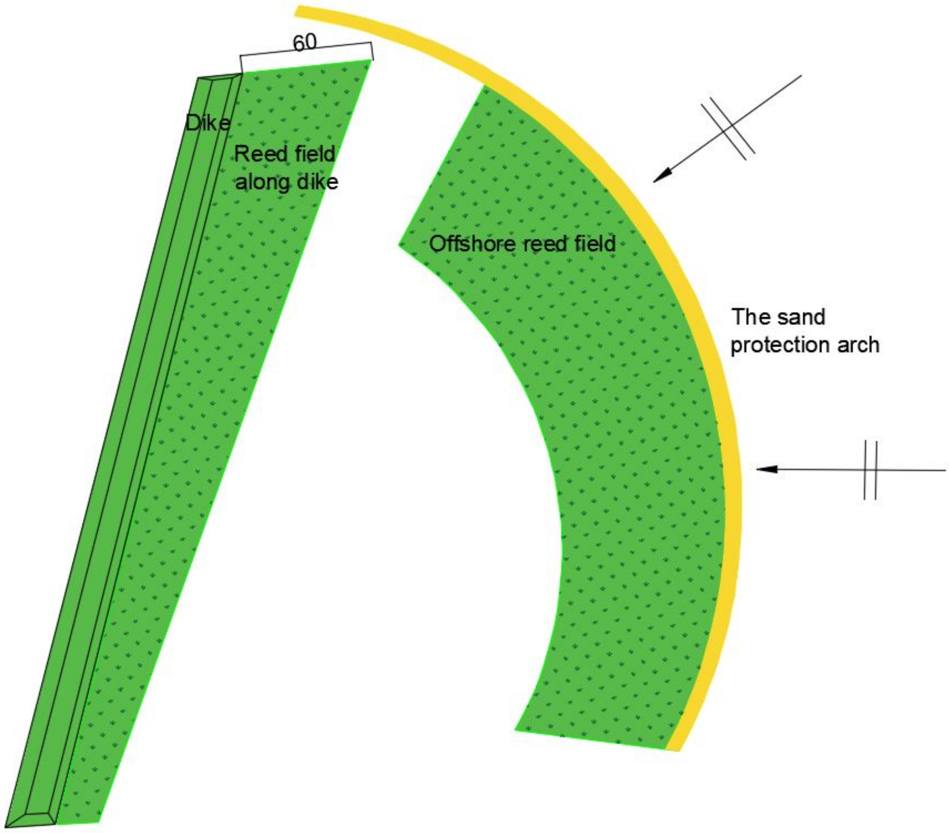


Figure 5.6: The Soft Arch variant

Geometry of the Soft Arch variant

The initial geometry of the protection arch will be the same as for the Soft Arch variant (see Figure 5.2). The slope of the outer edge of the soft protection dam will

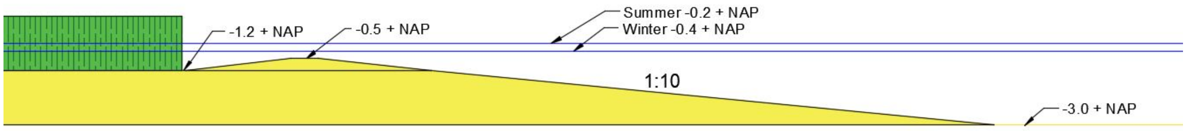


Figure 5.7: Section of the Soft Arch variant with winter and summer lake levels, values are in meters

be 1:10. The crest height of the dam is different because of the used material here is sand instead of rubble mound.

The function of the dam is to protect the reed from too often breakage. The height of the crest of the dam depends on the significant wave height that may be transmitted. The transmission wave height depends on the load the reed is able to withstand. The load can be calculated according to the critical horizontal orbital velocity for reed.

So far, it was assumed that the critical wave height for reed vegetation was 0.4 m with 5000 non-continuously incoming waves found in *CUR 201* [1999].

In this section the critical wave height for reed vegetation is determined by an approach of Vuik et al. [2018] in order to verify the *CUR 201* [1999]. The used parameters for this approach are shown in Table 5.2.

Table 5.2: Input parameters to determine the critical velocity for reed and the orbital velocity at z, distance from water surface

Input parameter	Symbol	Value
Return period	(1/year)	1/10
Water depth	h (m)	1
Peak period	Tp (s)	3.75
Vegetation height	hv (m)	2.5
Maximum bending stress	σ_{max} (MN/m^2)	43
Stem diameter vegetation	bv (m)	0.007
Inner diameter vegetation	bv$_{in}(m)$	0.4*bv
Correction coefficient	Ac (-)	1.7
Bulk drag coefficient	Cd (-)	1

$$u_{crit} = \sqrt{\frac{\sigma_{max} * \pi(bv^4 - bv_{in}^4)}{8 * Ac * Cd * \rho * bv^2 * (\alpha_r h)^2}} \tag{5.1}$$

The critical orbital velocity u_{crit} (m/s), the maximum bending stress σ_{max} (N/m^2). With bv (m) is the stem diameter, and bv_{in} (m) the inner stem diameter. A correction factor Ac (-), hv (m) is the vegetation height. Cd (-) is the bulk drag coefficient and d is the water depth.

The bending stress has a large influence on the critical orbital velocity. Therefore, the maximum bending stress is varied with 43 MN/m^2 in the calculations. The value is obtained from a three-point bending tests and is the average value of the test data.

The function of Vuik et al. [2018] for u_{crit} is related to the $\alpha_r h$, the relevant height the force is acting on. α_r is the ratio of stem length to water depth (α_r) multiplied by water depth (d). The relevant height, $\alpha_r h$ is equal to water depth when vegetation length*cos(θ) is larger than water depth, which is here the case. Therefore the bending angle does not have influence on the critical orbital velocity. The occurring horizontal orbital velocity for shallow water (kd≪1 as here is the case) is uniform over the depth and can be described by:

$$u_{orb} = \frac{H}{2d}\sqrt{gd} \tag{5.2}$$

where H (m) is the normative wave height, d (m) is the water depth and g is the gravity acceleration of 9.81 m/s^2.

Table 5.3: Critical wave height with corresponding critical velocity for shallow water, for varied maximum bending stresses

Source	σ_{max} (MN/m2)	Hcrit (m)	u_{crit} (m/s)
CUR 201 [1999]	n.d.	0.4	0.626
Equation 5.1 [Vuik et al. [2018]]	38	0.27	0.55
Equation 5.1 Vuik et al. [2018]	43	0.34	0.68
Equation 5.1 Vuik et al. [2018]	48	0.39	0.78

Results and discussion

In Table 5.3 the results of the critical wave height determination. The critical wave height according to Equation 5.1 of Vuik et al. [2018] is different compared to *CUR 201* [1999].

First, one reason that can explain that difference is about the difference in research approach. In the research of Vuik et al. [2018], strength of reed is approached by a hollow cylinder. Therefore, the critical breakage velocity is based on the strength of one cylindrical reed stem. The research, that *CUR 201* [1999] is based on, is done with a large number real reed stems with different properties. In *CUR 201* [1999] the critical wave height of the reed with a reliability factor is taken because not all stems have the same strength. The second remark is about the critical wave height found in *CUR 201* [1999]. The critical wave height found in *CUR 201* [1999] is H=0.4 with a load of 5000 waves within one year and not for a continuous period. In *CUR 201* [1999] it is not mentioned which specific wave height is meant. The assumption for Vuik et al. [2018] is that a representative wave is formed height equal to $H_{1/10}$ of the waves breaks the stems ($H_{1/10} = 1.27 * Hsig$). In Table 5.3 both critical wave heights are assumed to be the significant wave height (= mean wave height of the highest third of the waves).

The critical wave height that will be used for the following design steps is Hcrit= 0.34 m. This is the wave height that may transmit the arch after 10 years. This wave height is conservative but as a design parameter this is will lead to a more safe design.

The reduction of the incoming wave height

In Figure 5.8, wave height to return period is showed again. As Hydra-NL was not able to give wave heights for lower return periods than 10 years, the dashed line is assumed.

The wave height with return period once every 10 years is Hsig = 0.85 m (red line in Figure 5.8). This wave height with return period once every 10 years needs to be reduced to Hsig=0.34 m (blue line in Figure 5.8). This reduction will be done by the protection arc. By using of the function of van der Meer et al. [2004], it is able to determine the transmission coefficient.

$$Kt = -0.4 * \frac{R_c}{H_i} + cos^{\frac{2}{3}}(\beta)(1 - e^{-0.5*\xi}) * 0.75 * \frac{B}{H_i}^{-0.31} \tag{5.3}$$

Hi is the incoming wave height at the toe of the structure. Rc is the crest freeboard of the groyne of breakwater and B, the width. β is the incoming wave angle. ξ is the Irribarren number. The limits are: $1 < \xi_{op} < 3$, $0° < \beta < 70°$ and $1 < B/Hi < 4$.

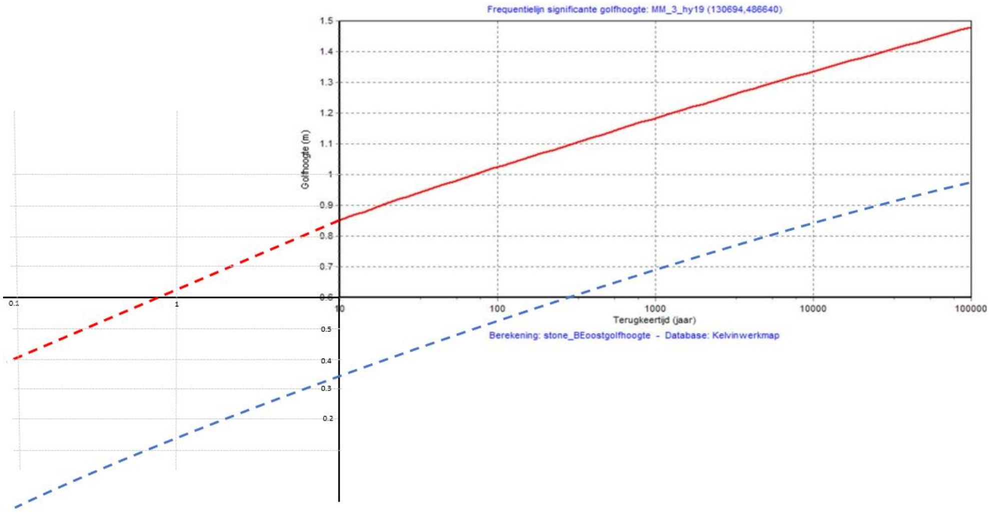


Figure 5.8: Wave height to return period 10 to 10000 years (red continuous line) obtained from Hydra-NL database with interpolated line (dashed red line) to return period 10 to 0.1 year. Decreased in wave height to once every 10 years of Hcritical=0.34 m (blue dashed line)

The sand volume depends on the geometry of the dam in front of the reed field. The length of the arch is 480 m. To create a stable and constructable slope, the slope of the sand dam is taken 1:10, which is for saturated sand a mild slope. The found design height for the crest of the protection arch is -0.5 m +NAP. The construction level of the crest of the dam will be 1 meter above design level of -0.5 m +NAP. The total amount of sand in the dam will be: 27720 m^3 (see: Appendix J for the overview of the calculations of the material volumes).

Maintenance

As described in Section 5.2, without protection every year breakage of the reed will occur. Reed is able to withstand significant wave height of 0.34 m with return period of once per year. Therefore the sandy protection arch will be build. The yearly waves will erode the sand, therefore maintenance is needed. The amount of maintenance is determined according to the following steps:

1. A large part of the reed stems needs to break once every 10 years as maintenance and keep dynamics.

2. Critical wave height for reed breakage needs to occur once every 10 years. So the wave height needs to be reduced. See Figure 5.8

3. The incoming wave height is reduced by a sandy breakwater, that needs to be eroded exactly once in 10 years in a perfect statistical period (come back on that later).

4. Erosion is determined by the *CERC Shore protection manual* [1984] formula (see Equation 5.4).

5. The amount of sand of the sand dam needs to be equal to the total erosion that occurs within 10 years (in a statistically perfect period).

6. Then the construction crest height and the amount of maintenance is determined, using Equation 5.3 from van der Meer et al. [2004].

The amount of erosion in 10 year will be determined by the *CERC Shore protection manual* [1984] formula. With the CERC (Coastal Engineering Research Center of the

American Society of Civil engineers *CERC Shore protection manual* [1984]) formula the bulk sediment alongshore (Sb) can be estimated.

$$Sb = \frac{Ka}{32((s-1)(1-p))} * cb * sin(2\varphi) * H0^2 \tag{5.4}$$

Incoming wave height is H0=0.85 m, with a maximum incoming wave angle of β =60 °N gives an incoming wave height to break water normal of 20 °, $\varphi = \frac{\beta}{180*\pi}$. Ka=$\frac{1}{\sqrt{(2)}}^{\frac{5}{2}}$, s = 2.65 -, is the relative density of the sediment ($\frac{\rho_S}{\rho}$). The porosity of sand in water p=0.4 -, the water depth the waves break is hb=0.78*H0=0.66 m [*Lecture notes Coastal Dynamics 1* [2015]]. The wave velocity of the incoming waves for shallow water at breaking point ($L = 1.56 * Tp^2$= 24.3 m, hb/L0=0.05) so cb= $\sqrt{g * hb}$.

How the sandy protection arch will develop in time, can be compared with a perturbation in the shoreline, researched by Ashton & Murray [2006]. The upper plan of Figure 5.9 shows the terms and axis. The lower plan of Figure 5.9 shows a perturbation in a shoreline and the response to small angle (<35) incoming waves. The sediment transport increases with an increasing angle w.r.t. the shore. The sediment transport due to incoming wave angles less than 35°, results in straighten the perturbation. The waves try to decrease the arch shape and flatten the perturbation as shown in Figure 5.9. This means that deposition at the two ends will occur. Erosion will occur at the location where the waves attack the most.

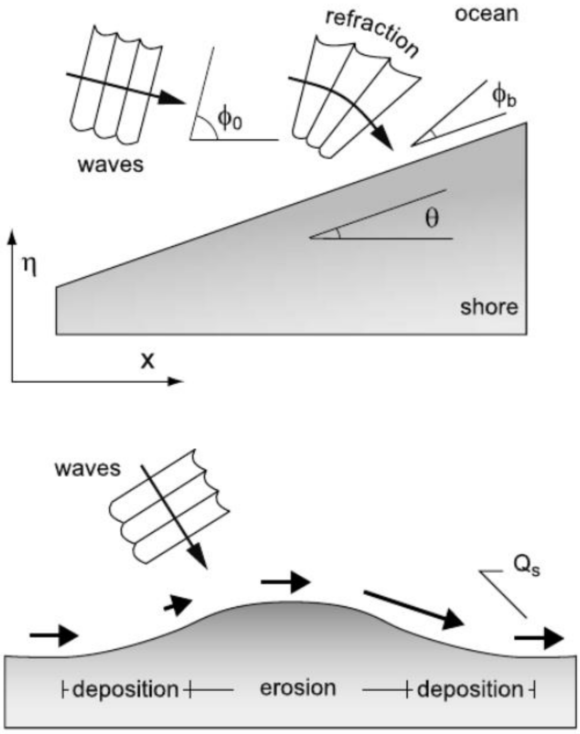


Figure 5.9: The protection arch compared with a perturbation in the shoreline. The response of a perturbation is shown. In the upper plane, the terms and axes are depicted. The lower plane shows the response to low-angle waves [Ashton & Murray [2006]].

The amount of maintenance in sand suppletion is the amount of eroded sand in 10 years. Assumed is that in 10 years the number of storms is statistically perfect. So, it is therefore assumed that a 1 in 2 year (1/2 year) storm event occurs 5 times a in a period of 10 years and so on.

The average duration of one storm is assumed to be 4 hours (14400 sec). In Table 5.4 the total amount of sand loss in the ten year period is calculated.

By using of Equation 5.4, it with a specific wave height the corresponding alongshore sediment transport rate (Sb in m^3/s) is determined. This amount is multiplied by the storm duration of 4 hours and by the times this storm occurs in 10 years (last column of Table 5.4).

For example, the alongshore sediment bulk transport is Sb=0.0047 m^3/s for a one in ten year wave. During a one in ten year storm event of about 4 hours (based on Hydra-NL database), the sediment that will be transported is approximately 67.7 m^3.

Table 5.4: For given return period, the corresponding wave height, Sb and total Sb, x storms in 10 years, assumed one storm is 4 hours

Return period (1/year)	**No. storms in 10 years**	**Hs (m)**	**Sb (m^3/s)**	**Tot. Sb (m^3)**
1/1	10	0.639	0.002	298.9
1/2	5	0.711	0.0027	195.2
1/3	3.33	0.749	0.003	148.2
1/4	2.5	0.774	0.0034	120.7
1/5	2	0.794	0.0036	102.9
1/6	1.667	0.809	0.0037	89.9
1/7	1.42	0.822	0.0039	79.8
1/8	1.25	0.833	0.004	72.5
1/9	1.11	0.843	0.0041	66.4
1/10	1	0.85	0.0047	67.7
Total	27.28		0.0351	1241

One remark about the CERC fomula *CERC Shore protection manual* [1984] (US Army Corps of Engineers) is that it results in a conservative approach in low wave conditions (so the estimation of erosion is very large compared to reality) [van Rijn [2002]]. For the purpose of this calculations the conservative estimation in low wave environment is considered to be used as extra safety.

Waves with cross-shore direction will result in sediment transport in cross-shore direction. This sediment will be removed from the protection arch and transported towards the reed field behind the sandy dam. A large period of the year, wind is coming from the west. It is assumed that with this wind, the sand will return towards the dam again. The alongshore sediment transport will be permanent and therefore maintenance is required for that part of the sediment transport.

According to the statistically perfect period of 10 years the amount of sediment that will be eroded has a volume of 1241m^3. This results in a crest height reduction of 0.50 m over the full arch area (see: Appendix J). Taking settlement into consideration see Figure 5.10.

Maintenance plan

In this section it is explained how the maintenance will be planned over the life time of the full area. First the construction height is determined, followed by the amount of maintenance works.

The construction height of the sand dam depends on the settlement over a period and the erosion in the same period. It is assumed that the settlement of 1 m will be reached after 30 years and after that no more settlement is considered (see Section 4.2). The erosion depends on the wave loads and is determined exact that the full sand dam erodes in 10 years. This means that the construction level of 1.14 m (see: Figure 5.10) is the summation of: 1) the predicted settlement, 0.64 m over the first 10 years, according to a exponential settlement progress. And 2) the predicted erosion over 10 years which is 0.5 m. Assumed here is that the settlement does not influence the erosion or vice versa.

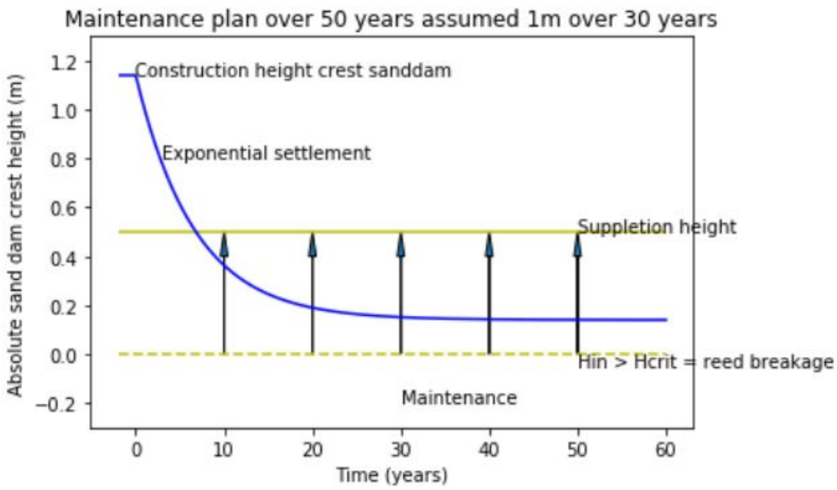


Figure 5.10: Maintenance plan for 50 years after construction

The dashed yellow line in Figure 5.10 indicates the crest level of the sand dam is when reed breakage occurs (Hin>Hcrit = reed breakage). This is the case when the full sand dam is eroded. This causes the incoming wave height to be larger than the critical reed breakage height. The crest height does not need to be raised till the construction height again but to the minimum height the sand dam protects the reed again.

The total amount of sand that needs to be supplied, taking erosion and settlement into account is expected to be five times the erosion 1241*5=6205 m^3 of sand. This is the amount of sand over 50 years (the design period), with every ten years maintenance works. Furthermore, it will be recommended to have a yearly check on the height of the sand dam.

5.3 COSTS

In this section the costs of the alternatives are compared. The costs for the alternatives and the two variants depend mostly on the amount of material volumes. In Table 5.5, the amount of material volumes per alternative are shown. The Basic Concept does not have any reed in its design. The Soft Arch variant does not have rubble mound in its design.

Table 5.5: Volumes of stone (read: rubble mound), and sand and reed area for the variants to The Arch Alternative, contains maintenance

Variant	Stone (m^3)	Sand (m^3)	Reed area (m^2)
Basic concept	3226.2	19953	0
The Arch	1178	243761	43159
Hard Arch	2355	174611	41673
Soft Arch	0	304489	41673

Table 5.6: Cost estimate determined by using calculation sheet of R. Tijsterman [2020], mean ±35% for The Arch Alternatives, the cost estimates are a factor x higher compared to the Basic Concept. The cost estimates contain maintenance

Variant	Mean cost −35%	Mean cost +35%	Factor higher
Basic Concept	€ 0.7 million	€ 1.3 million	-
The Arch	€ 4.5 million	€ 8.4 million	6.4
Hard Arch	€ 3.8 million	€ 7.0 million	5.5
Soft Arch	€ 5.1 million	€ 9.5 million	7.2

Volume reduction of material intended for the dike is 1780 m^3 over the full length and with a considered width of 10 m and due to crest height decrease by wave attenuation. However, this does not compensate for the additional required material for the foreshore and protection arch.

The cost estimate is done according to the calculation sheet of R. Tijsterman [2018]]. See Table 6.1 for the results of the cost estimate. The cost estimate for the variant with the Hard Arch is less than the previous The Arch Alternative. Which was also the purpose of the optimization of the Hard Arch variant. The Soft Arch variant has (as assumed) a larger cost estimate.

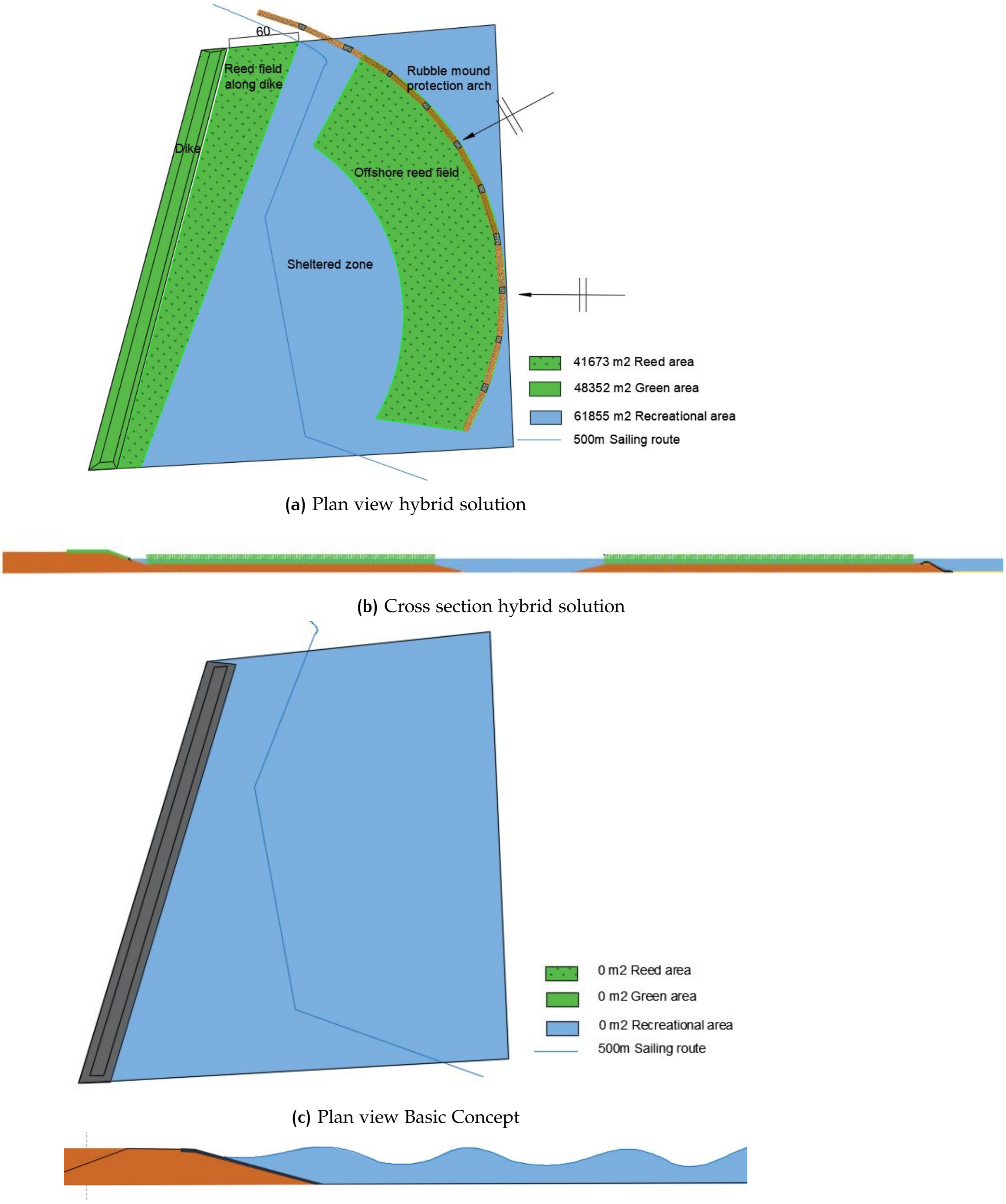
Still the costs estimates for the different alternatives and variants are much larger than for the Basic Concept. But this is only the costs estimate in terms of money.

The return of investment is not only a safe shore design as the Basic Concept is given to Buiteneiland. The two variants do have a lot of extra benefits next to one function: safety. First, a lot of natural value is added to the IJmeer and for the Amsterdam citizens. This can be found in terms of vegetation above and below water surface which attracts (bird) species. This leads to a more climate adaptive design, which reduces required investments in the future. Furthermore, the added natural value increases potential for housing and commercial enterprises [Winckel et al. [2008]]. Second, social capital is added, in for example meeting other recreants on a boat. As it is more fun sailing between reed fields in stead of sailing along a rubble mound high dike (see: Figure 5.11). At last, inspirational capital is added to the Markermeer where other new islands or shore restorations can be inspired by this nature-based hybrid solution. When the area of interest will be monitored, other projects will be able to learn from the data.

The total amount of sand that is required for the sand dam eroded The sand dam of the Soft Arch variant has the total volume of 6205 m^3. Due to the sand suppletion, the costs are estimated higher than the Hard Arch variant (averaged cost estimate € 5.4 million).

The nature area of the Hard Arch variant is 61855 m^2 + 41673 m^2 = 103528 m^2 (see: Figure 5.11.a). The averaged estimated costs for the natural added value are the total costs, minus the estimated amount of material for the dike (cost of dike € 0.6 million). This may be subtracted because the dike has a safety function which the Markerwadden does not have. The averaged estimated costs for the nature added value only are considered to be € 4.8 million. For the Hard Arch variant, the estimated cost to nature area ratio is € 4.8 million / 103528 m^2 = 46.5 €/m^2.

As comparison, the Markerwadden project is taken. This project is chosen because of similarities in location and the used Building with Nature principle. The Markerwadden will consist out of 5 man-made islands, where no people will live on and its purpose is only added natural value. The area is in total 10 million m^2 (1000 ha) of nature above and below water surface [*Markerwadden Facts* [2017]]. The total estimated costs for this project are 100 million euro's [Geelen [2020]]. For the Markerwadden, the estimated cost to nature area ratio is 10 €/m^2.



(a) Plan view hybrid solution

(b) Cross section hybrid solution

(c) Plan view Basic Concept

(d) Cross section Basic Concept

Figure 5.11: Reed and green added value for the hybrid solution and for the Basic Concept

5.4 NUMERICAL SIMULATION FOR THE HARD ARCH VARIANT

This section will show how conservative the rule of thumb approach is. In previous sections of this chapter, wave heights were approached by the rule of thumb of Miche (1944) and the reed reducing effects on wave height were not taken into account. The assumptions that have been made for the Rule of thumb approach are shown in Figure 5.12 the upper panel. The waves are coming in from the right and will encounter the hard protection arch. The wave height reduction is determined by the 'Kt equation' from Equation 5.3. Then the wave height is approached by the rule of thumb the breaker criterion of Miche Equation 3.2. In Section 3.4.1 and Section 5.1 this rule of thumb is explained.

The rule of thumb approach will be compared with the use of a vegetation model, Figure 5.12 the lower panel. In the coming section, the difference in required dike height for the two approaches will be found. So the answer on how conservative is the use of the rule of thumb.

The wave height over the cross section of the Hard Arch variant will be simulated by the model. This is not done for the Soft Arch variant. This is because the cross sections are the same after construction. The only difference in cross section is the material of the protection arch. However, the geometry of the Hard and the Soft arches are designed so that the transmission coefficient (Kt) over that protection arch is exact the same. The situation that the protection dam of the Soft Arch variant is eroded away is simulated as there is no arch.

Vegetation model

Known is that the reed stems do have an effect on the wave height. The wave height at the toe of the dike determines the freeboard for the crest height of the dike. A

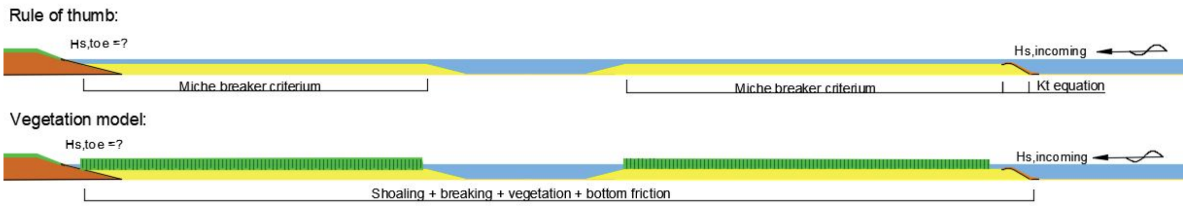


Figure 5.12: The assumptions that have been made for the two approaches. The rule of thumb approach and the vegetation model approach

vegetation model is used for simulation the wave height reducing effect by reed. This vegetation model is a model of Vuik et al. [2018] and also used by Godfroy [2017]. This model was made and calibrated for cord grass type vegetation. For this study, the parameters are adapted to reed (Phragmites) vegetation. This is done according to results of a three-point bending test for reed vegetation. The reed used in the bending test, was growing at the Zaag, an island in the New Maas close to Krimpen aan de Lek.

Table 5.7: Input parameters for the return period of 1/830 year

Return period	h (m)	U10 (m/s)	Hm0 (m)	Tp (s)
1/830	3	20.2	1.17	3.49

Table 5.7 gives the input parameters for the numerical vegetation model. In Table 5.7, the reed characteristics are given. In the paper of Godfroy [2017], cord grass vegetation (Spartina Anglica) have been investigated. For that type of vegetation, parameters from different research papers were sampled and averaged. As

Table 5.8: Vegetation characteristics for the numerical model from Godfroy [2017] and adjusted characteristics for reed vegetation and broken reed

Parameter	Cord grass Godfroy [2017]	Grown reed	Broken reed
Nv (stems/m^2)	491	200	200
bv (m)	0.006	0.007	0.007
hv (m)	0.58	2.0	0.5
C_D (-)	0.4	0.4	0.4

cord grass is little thinner and the stems are less height, the reed parameters are adjusted.

Nv is the number of stems per square meter. As the reed stems are thicker (bv) than the cord grass the number of reed stems per square meter are assumed to be less. Nv = 200 stems/m^2 as found in van Eerden et al. [2007]. The averaged height of the cord grass is 0.58 m. The height of the grown reed is assumed to be 2.0 m [van Eerden et al. [2007]]. Figure 5.12 gives a representation of the different ways of the inclusion vegetation.

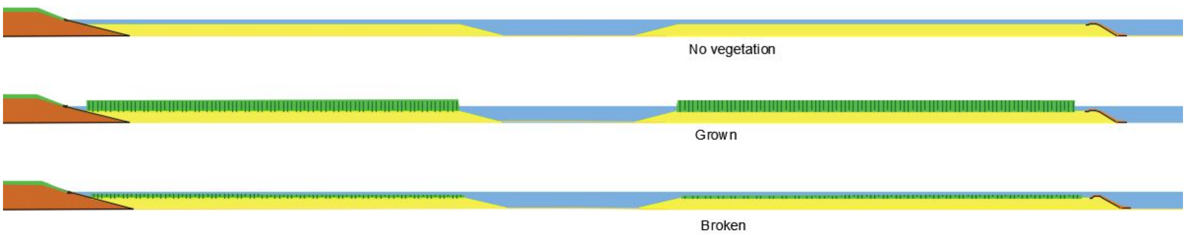


Figure 5.13: Cross section of the Arch Alternative in three different ways include the vegetation. First, without vegetation, second, with grown reed vegetation and the last figure with broken reed vegetation.

Results

Figure 5.14 shows the wave attenuation over the cross shore profile of the Hard Arch variant. The green area in the lower plot shows the location of the reed field. The reed characteristics can be found in Table 5.8. One made assumption within this model is that the storm duration is taken infinitely long, so that the duration becomes stationary and therefore non-essential.

Figure 5.15 shows also the wave attenuation over the cross shore profile, without the protection arc. In the situation that the Soft Arch variant when the sand of the arch has eroded away. The same reed characteristics have been used.

In Figure 5.14 and Figure 5.15, the changing wave height due to the vegetation over the depth profile is shown. In these figures, the way the protection arch on its own influences the incoming wave heights for return period of 1 in 830 years, can be found.

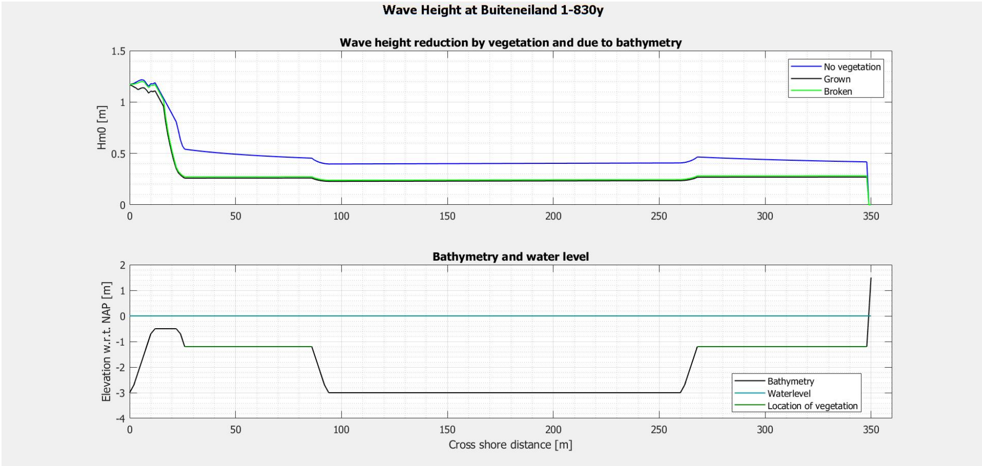


Figure 5.14: Wave height in cross shore direction for 1/830 year return period conditions. Wave height at the toe of the dike is given in the graph. For grown reed and broken reed. Attention: offshore is left, dike is right in this figure.

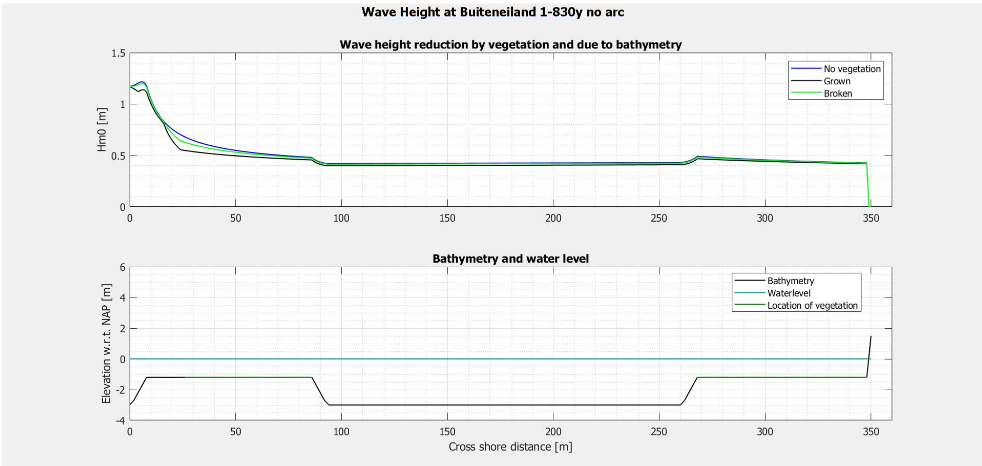


Figure 5.15: Wave height in cross shore direction for 1/830 year return period conditions without the protection arc. First line in the graph is without vegetation, second line is with grown reed, the third line is with broken reed. Attention: offshore is left, dike is right in this figure.

Table 5.9: For different return period with and without protection dam the wave height at the toe of the dike determined with the numerical model of Vuik et al. [2018] for grown and broken reed.

Variant	Ho (m)	No vegetation $H_{toe}(m)$	Grown $H_{toe}(m)$	Broken $H_{toe}(m)$
Rules of thumb	1.17	0.5	$<$ 0.5	<0.5
1/830 year with arc	1.17	0.42	0.28	0.28
1/830 year no arc	1.17	0.42	0.42	0.42
Rules of thumb	0.63	0.5	<0.5	<0.5
1/10 year with arc	0.63	0.22	0.17	0.18
1/10 year no arc	0.63	0.4	0.39	0.4

Conclusions on numerical simulation results

What can be concluded from Figure 5.14 is that the expected wave height at the toe without vegetation, so only due to bathymetry, and according to the rules of thumb (see: Section 5.1) is almost similar to the determined wave height by this numerical model. See Table 5.9 for an overview.

What can be concluded from the last figure (Figure 5.15), where no protection arch is taken into account is the following. When there is no protection arc, the effect the vegetation has on the wave height is very small for the strong and broken reed (no vegetation line (blue) is similar to the grown and broken vegetation). This is also shown in Table 5.9. The assumption to not take vegetation into account for wave attenuation can be found to conservative as the alternative has a protection arc. However, the difference in wave height, when assuming grown vegetation and without vegetation, is small. Similar graphs for hydraulic parameters for lower incoming wave heights (return period of 1/10 year) can be found in Figure H.1 and no arch in Figure H.2.

In Chapter 4 the assumption is made that the wave height reducing effect the reed could have, will not be taken into account for the determination of the crest height.

By using the vegetation model and taking the reed into account, the crest height was estimated to conservative by 13 cm. For a dike crest height of 1.8 m, this is a small improvement of estimation. For lower wave heights (occur more often) the improvement of estimation in crest height for a dike is even less. According to these results it can be stated that in determining a crest height with a vegetated foreshore in a preliminary phase, it is not necessary to take the vegetation contribution into account. The dike of the final design is covered by grass. The crest height is determined with taking the wave attenuation by reed vegetation according to Vuik et al. [2018] into account. The crest height calculation can be found in Table 5.10.

Table 5.10: Dike height for return period of 1/830 with grass cover (γ_f=1) for overtopping discharge of 10 l/s/m and prevailing wind conditions from ENE and E for The Arch Alternative, taking wave attenuation by reed into account.

Wave direction °N	60 °N (ENE)	90 °N (E)
Overtopping discharge, q (l/s/m)	10	10
Peak period (s)	4.43	4.43
Significant wave height offshore (m)	1.17	1.17
Significant wave height dike toe (m)	0.28	0.28
Freeboard, *hk* (m)	0.09	0.09
Reference (m+ NAP)	-0.19	-0.22
Local water level (m)	1.05	0.77
Additions (m)	0.56	0.56
Lake level rise (m)	0.1	0.1
Dike height (m+NAP)	1.61	1.30

The freeboard depends on the wave height at the toe of the dike. This parameter is adjustable in contrast to the other parameters. This means that the crest height can be lowered due to lower wave heights at the toe of the dike, till the Freeboard parameter is 0m. This can only be established when the wave height at the toe of the dike is lowered till at least Hs=0.15 m. This could result in a required crest height of 1.52 m. Optimizing the foreshore height and/or the reed field properties, could help to achieve this.

Influence of wave attenuation per component

To understand for what component most accuracy is recommended, depends on the influence the component has on the wave attenuation. Therefore, it is important to know how large the influence is on the wave attenuation per component. For components with large influence on wave attenuation it is worth to create large accuracy on the wave attenuation. In Appendix I the influence of the wave attenuation of different components are depicted, for 1/830 year waves and for 1/10 year waves and with and without arc. In Table 5.11 the contribution of the different components in percentage of the total reduction is shown for the situation of the Hard Arch variant

Table 5.11: Influence of wave attenuation per component

Hard Arch variant	Reduction (m)	Contribution (%)
Arc	0.62 m	69.7 %
Reed	0.13 m	14.6 %
Foreshores	0.14 m	15.7%
Total reduction	0.89 m	100 %

so with protection arc and for design waves of 1/830 year. Every component has its own contribution on the total safety in the hybrid solution. The protection arc is called arc and is the first obstacle that the wave will encounter. Without an arc, the plateau itself without vegetation is the first obstacle the wave will encounter. Second, the waves will feel the offshore reed field, which has its height at the same level as the plateau (see Figure 5.15).

In the case of large waves (Hs =1.17 m is for a return period of 830 years) the arc has the largest effect on the wave attenuation. Without arc, the plateau (at 1m water depth) has the same amount of effect on the wave attenuation.

For smaller waves (Hs =0.63 m is for a return period of 10 years), the arc is responsible for 100% of the wave attenuation. The influence of the reed field is therefor 0%. Without an arc, the plateau (at 1m water depth) is only responsible for 20 % of the wave attenuation and the largest reduction is done by the offshore reed field (65%). This is probably due to the fact that larger waves height are present there. From this, it can be concluded, that for smaller waves (0.45 m <Hs<0.60 m) at the edge of a reed field, the effect of wave attenuation by the reed is largest. However, the difference between grown and broken reed is negligible. For this situation, simulation the effect of the reed on the wave height attenuation by a vegetation model is recommended.

Overall it can be concluded that the whether the arc or the plateau break the first and largest part of the waves and has therefore the highest influence on the total wave height reduction in this cross section. It is recommended to investigate the wave attenuation by the protection arc and create large accuracy. For smaller waves, reed field influence could require larger accuracy.

5.5 CONCLUSIONS

In this chapter, the Arch Alternative is optimized to obtain the most optimal solution for the preliminary design. To answer the main research question the following steps have been taken. First, answer to the fourth sub-question: *What are the costs of the safe and nature-based hybrid solution compared to The Basic Concept?* is given. The two variants are compared, based on costs and material volumes. The first variant, the Hard Arch variant and the second variant, the Soft Arch variant. The advantages and disadvantages of the two variants are elaborated. The Hard Arch variant has a wave height reducing structure at the edge of the offshore reed field made out of rubble mound. Furthermore, the Hard Arch variant has lower estimated cost than the previous version of The Arch Alternative of Chapter 4. he Hard Arch variant has a lower cost estimate than the Soft Arch variant. This is due to less material volumes the Soft Arch variant has in the 1:10 sloping protection dam. Therefore, the Hard Arch variant is chosen.

The overall cost of the Hard Arch variant compared to the Basic Concept are still a factor 4 higher. The return on investment needs to be found in the added natural, social and inspiration value. These added values compensates for the larger costs. To illustrate, the rubble mound cover allows small fish and vegetation to live and grow on. The plateaus will be able to trap fine sediments causing a higher light penetration, which leads to higher succession rate of vegetation. Due to higher flow velocities over the plateaus behind the protection arch, gullies will be created, were erosion will take sediment. The trap of sludge and the erosion gullies will result in a sand plateau with height differences. These height differences create diversity for different vegetation and animal species. For the Hard Arch variant, the estimated cost to nature area ratio is € 4.8 million / 103528 m^2 = 46.5 €/m^2. As illustration, the Markerwadden has estimated cost to nature area ratio is 10 €/m^2. The ratio for the Markerwadden is significantly lower than for the preliminary design of Buiteneiland.

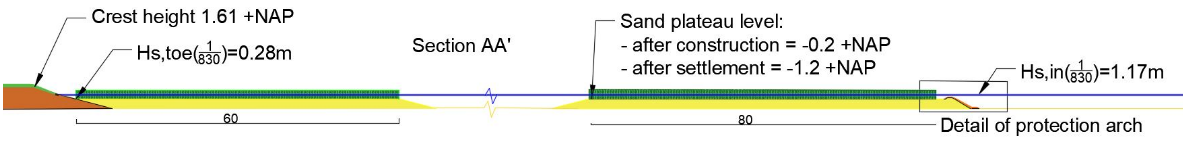
The ratio of Buiteneiland could be optimized to reduce the difference and make the design for the east side of Buiteneiland more feasible. For example to increase the area of natural added value by increasing the sheltered area between the arch and the dike. This results in a larger natural area without increasing the costs. Moreover, the Markerwadden contains a much larger area so the comparison might be unfair. Moreover, in the future, when more land-water transitions are nature-based, the difference of the cost ratio between the two projects would be less when the full IJburg archipelago would have been taken into account.

The Soft Arch variant is a hybrid solution without any rubble mound. Rubble mound is expansive and often won outside the Netherlands. However, sand is available in the Markermeer. In this hybrid solution, erosion will need to be taken into considered and maintenance needs to be accepted. The sandy protection arc has high loads compared to the critical shear stress of the sand as resistance. The expectation is that little vegetation will be able to settle on the outer edge of the sandy protection arch. After every sand suppletion, vegetation needs to germinate and grown again. A solution to the maintenance works, could be to place enough sand for the coming 50 years for erosion. However, this does not result in a natural breakage process of the reed stems. Furthermore, the costs of this variant are much higher than for the Hard Arch variant. A lot of maintenance works and monitoring is one thing Waternet (future owner of the area) does not want because safety can be less guaranteed.

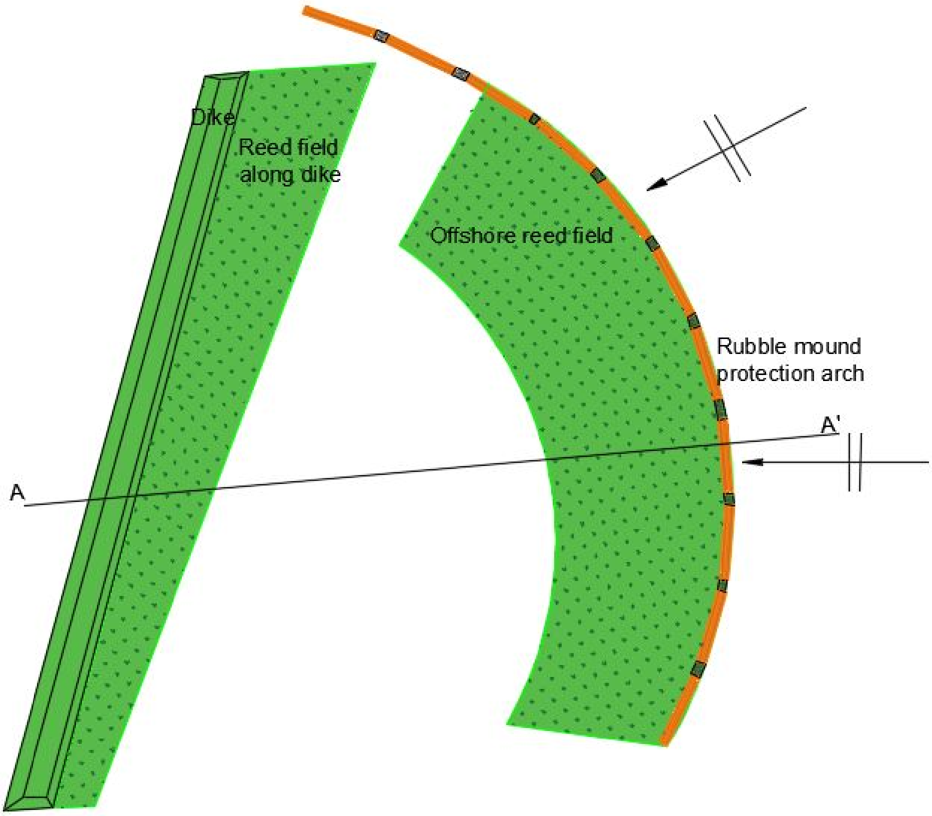
Now the third sub-question: *How to detail a nature-based hybrid solution design in the IJmeer?* will be answered. Two ways to detail a nature-based hybrid solution in the IJmeer have been compared. Both ways are for a preliminary stage in the design process, as was the case here.

Chapter 4 explains the wave height reducing effect of the reed is not yet taken into account for the determination of the crest height of the dike. The results are obtained fast but are conservative. By using the vegetation model and taking the reed into account, the crest height was estimated too conservative by 13 cm. Moreover, for larger waves (flood situation) the arc or the plateau will break the waves already and the influence of the reed field on the wave attenuation is small. According to these results, it can be stated that in determining a crest height with a reed field on a shallow foreshore in a preliminary phase, it does not make a significant difference when taking the vegetation contribution into account. The height difference, determined with and without the vegetation contribution, is very small. This difference in crest height will not change the decision of the alternative comparison. Moreover, in the wave climate of the IJmeer (return period 1/830 year; Hs=1.17 m and Tp=4.43 s), it is imperative to have a protection structure for incoming waves for the reed fields. The component from this design with most influence on the wave attenuation is the protection arc.

After taking all facets of this study into account, the Hard Arch variant is the best-suited solution to the east side of Buiteneiland, IJburg. This answers the main research question: *What is a safe and nature-based hybrid solution for the east side of Buiteneiland, IJburg?*. For an overview of the Hard Arch variant see Figure 5.16.



(a) Section view



(b) Plan view

Figure 5.16: Overview The Arch Alternative with rubble mound protection variant. For a return period of 1/830 year, the incoming wave height is Hs,in=1.17 m. Due to reduction of the bathymetry and the vegetation contribution Hs,toe =0.28 m, resulting in a required crest height of +1.61 m +NAP. Can be found in upper panel. Two cross sections of the Hard Arch variant. Recreation of swimming, sailing or fishing is possible in the sheltered area. Values are in meters

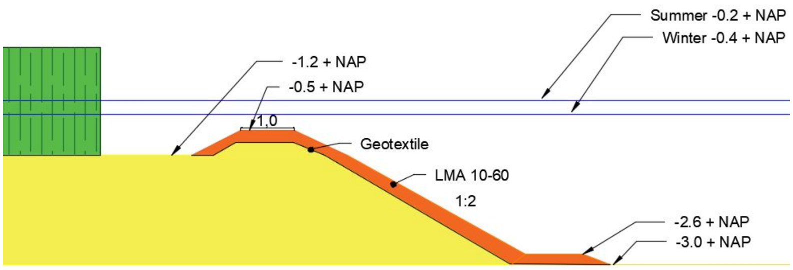
5.6 DISCUSSION

In this section, the results and the effects of certain assumptions are discussed. Some remarks need to be given, before using the results and conclusions. First, the input uncertainties and its nature will be discussed. Second discussion point is about the methodology uncertainties. Finally, the interpretation of the outcomes are discussed.

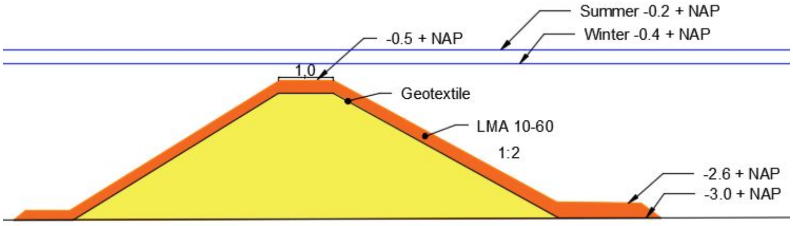
5.6.1 Nature of the input uncertainties

A few discussion points appear with the use of specific input parameters. Those are discussed here briefly.

The stakeholder 'Ruimte & Duurzaamheid' (Space & Sustainability) were more involved in the design process than other stakeholders. This stakeholder is part of



(a) Section AA′



(b) Section BB′

Figure 5.17: Section of the protection arch at two location. Section AA′ is made in the middle of the reed field. Section BB′ is made in the upper part of the arch. The values are in Meters.

the Municipality of Amsterdam. Therefore, the design might be biased to their requests. Moreover, Waternet (future owner of the primary flood protection) assumed to have large power and interest in this project. Due to this assumption, the Soft Arch variant has scored low. Moreover, the Hard Arch variant has scored high due to the fact that the Hard Arch variant is more easy to maintain. No conversation with Waternet is done so the amount of power to interest is uncertain, even though this party have had large influence on the design and the decisions.

The input parameters about the properties of the reed vegetation (e.g. reed breakage strength) and the number of stems have been assumed. The properties are assumed according to literature and data sets which make the properties quite reliable. Moreover, the uncertainties regarding reed strength have not been taken into account. This means that the design could be uncertain. On the other hand, due to the survival of the fittest, pioneer reed stems will stand in front. Pioneer reed stems are the stronger reed stems that can withstand larger wave loads. Because of these reasons it can be stated that the results can not be found fully reliable.

In this research, the settlement is assumed to be 1.0 meter and occurs in the sand bodies and holds for both variants. This settlement is achieved in an exponentially way over 30 years, where after no more settlement is considered. This has major influence on the material required and after all the decision on the final solution. It is known that the settlement will differentiate mostly at the sloping edge of a rubble mound or sand body. In this case, the protection arch of the variants will settle significantly more than the reed field behind. This has to be taken into account and therefore, phased construction should be considered. Within the Soft Arch variant, the settlement over the slope will deviate less. This could be an advantage. It needs to be pointed out, in this study settlement has large uncertainty and has, at the same time, large influence on the results.

The level of maintenance depends on erosion during the storm conditions. Storm duration of four hours with a constant high wind speed is assumed. The number of storms for 10 years is assumed to be statistically perfect. However, in reality, the storm duration and the amount are not as straight forward as assumed. These assumptions about the input parameters of storm properties will make the required materials per variant less reliable.

5.6.2 Methodology uncertainties

In this subsection the uncertainties of the methodology that have influenced the results in some way are discussed here.

The first discussion point concerns the analysis done in the vegetation model of Vuik et al. [2018]. Overall, the use of the vegetation model was successful. The model was able to identify the effect the vegetation has on the wave attenuation. However, the amount of stems that survive a storm are not taken into account in the model at all and the residual attenuating capacity of the vegetation field after damaging part of reed field is not investigated in this vegetation model. The potential wave attenuation of a reed field is still some uncertain.

The CERC formula can be used to determine the amount of sediment loss for a sandy beach coast. The use of the formula for the Soft Arch variant resulted in a conservative result due to the fact that the lake does not have same sediment carrying capacity. Therefore, the results does only give an indication.

The Soft Arch variant has a slope of 1:10 in offshore direction. This mostly influences the more material required for this variant. It is assumed that on this foreshore little vegetation will be able to withstand the large wave loads and (10 yearly) maintenance works. This assumption is also based on the fact that reed will not be able to germinate there. The idea of the Sand motor project (dump sand needed for 50 years) may prevent that, but this does not lead to the use of nature-based processes to damage the reed every ten years. It may therefore be the case that, if vegetation is able to grow on the slope, the Soft Arch variant might be more suitable than is now the result.

5.6.3 Interpretation of the output

The dike of the Basic Concept (is a dike without a foreshore or vegetation), covered by grass requires a crest height of 2.27m. The hybrid solution as the Hard Arch variant, the grass covered dike only requires a crest height of 1.61 m, while offering the same protection level. With this result, the aim could be to lower the dike even further. However, the ground level of the island will be at crest height of the dike, lowering of the crest height is not a goal in itself.

Cost comparison between Markerwadden and Buiteneiland is done to place the costs perspective and to show examples of projects that have been realised with only or mostly nature as purpose. But the comparison might be a little unfair. The total Markerwadden area is much larger and therefore scaling effects have reduced the costs per square meter. Moreover, the cost estimates of Buiteneiland are calculated by using an excel sheet which also has taken a large certainty range for predictive purpose. The costs of the Markerwadden are determined afterwards, where it is unknown what have been taken into account (i.e. taxes).

The total amount of sand material required for the design is uncertain due to the assumptions made about the settlement. Therefore, the costs estimations for the found design are uncertain as well.

One can argue that the term dike in this study might be not chosen well and better terms could be an erosion protection, revetment or bank as the function of the land-water transition only is the prevents erosion. The term dike suggests at one side lower land and water at the other side is the case. In this study, however, the dike has land at crest level at one side and water at the other side. The first function of the dike is a ring dike at the moment the island will be filled. From that moment the dike will function as a primary flood defence. Moreover, due to the fact that of the universal understanding of the term and the primary flood defence function the term is chosen to remain.

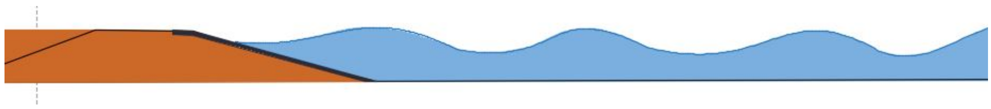
6 CONCLUSIONS AND RECOMMENDATIONS

The aim of this research was to design a safe and nature-based hybrid solution for the east side of Buiteneiland in the IJmeer. In Section 6.1 the conclusions are presented, to eventually find an answer to the main research question: *What is a safe and nature-based hybrid solution for the east side of Buiteneiland, IJburg?*. The recommendations for the Engineering company and for future research are provided in Section 6.2.

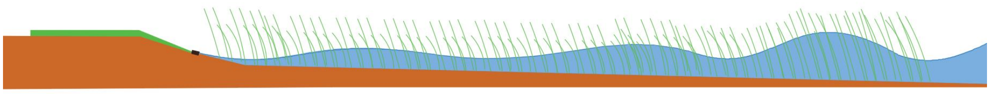
6.1 CONCLUSIONS

In this section the conclusions of this study are drawn. The overall conclusion starts with that it is possible to design a nature-based hybrid solution for the east side of Buiteneiland in the IJmeer. The most suited solution seemed the Hard Arch variant (see Figure 6.1). When implementing a nature-based hybrid solution, components and concepts of this design can be extracted and be implemented individually. New build or restored land-water transitions in the IJmeer at least needs to consist of a vegetated foreshore.

The design of the Hard Arch variant effectuates a lower dike height than a traditional dike of the Basic Concept. The dike of the Basic Concept (a dike without a foreshore or vegetation), covered by grass requires a crest height of 2.27m. The hybrid solution as the Hard Arch variant, the grass covered dike only requires a crest height of 1.61 m, while offering the same protection level. Moreover, a hybrid solution spreads the risks, that not only one component is responsible for the total safety (see: Figure 6.2). The foreshore will also add extra stability to the dike.



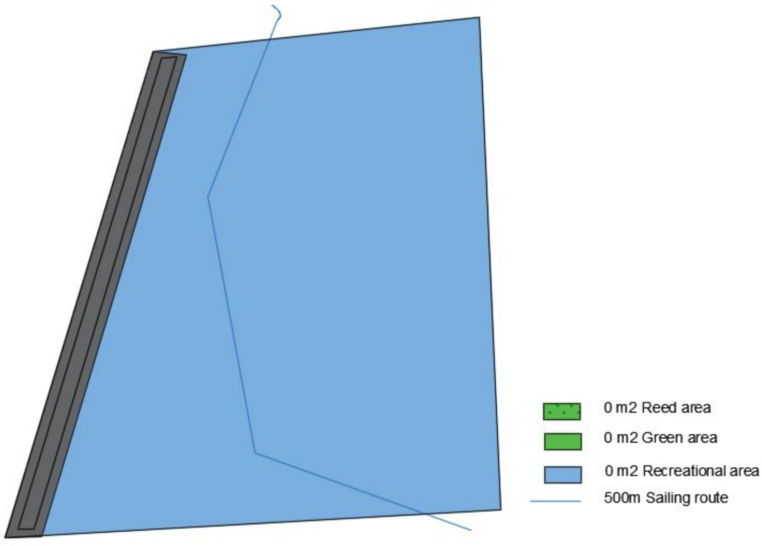
(a) Basic Concept



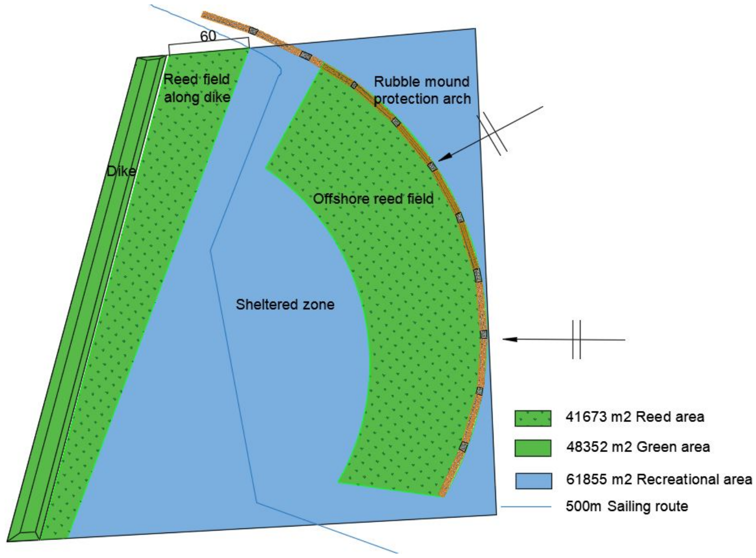
(b) Hybrid solution

Figure 6.2: Difference between a basic dike (The Basic Concept) and a hybrid solution (The Hard Arch Variant). By reducing wave height at dike toe, a hybrid solution that combines vegetation conservation with a dike can reduce construction costs while offering the same protection level. At waterline wooden erosion protection.

This nature-based hybrid solution has a cost estimate that is a factor 5.5 higher than the Basic Concept. The Netherlands has made a lot of budget available for the creation of natural added value for for example nature-based projects as Houtribdike, Pettemer sea defence and the Markerwadden. This is mostly due to the current Nitrogen crisis and the creation of more awareness in the importance of natural value. To give an indication; the estimated cost for the Markerwadden project were €100 million. This results in a costs to nature ratio of 10 €/m^2. This ratio is much



(a) Basic Concept



(b) The Hard Arch variant

Figure 6.1: A comparison of added reed, green and recreational values, for two solutions for the east side of Buiteneiland.

less than the ratio of this study which is 46.5 €$/m^2$. When creating a larger area, the cost per square meter will decrease eventually, but still the costs of this solution per square meter is quite high.

The rule of thumb gave a quick but little conservative indication of the wave height at the toe of the dike. When using the vegetation model and taking the wave attenuation due to reed into account, the crest height was estimated too conservative with 13 cm compared to the rule of thumb approach. For a dike crest height of 1.8 m, this is a small improvement of estimation. For lower wave heights (occur more often) the improvement of estimation in crest height for a dike is even less. According to these results, it can be stated that in determining a crest height with a vegetated foreshore in a preliminary phase, it does not make a significant difference if taking the vegetation (with lack of knowledge about reed strength) contribution into account.

Due to the participation of the east side of Buiteneiland in the 'Boog om de Oost' project, reed fields are requested in the design. Reed fields do not contribute much to the wave attenuation. However, reed functions as natural habitat for animals and prevention of soil from the bottom to erode. In the wave climate of the IJmeer (return period 1/830 year; Hs=1.17 m and Tp=4.43 s), it is imperative to have a protection structure for incoming waves for the reed fields. Moreover, the component from this design with most influence on the wave attenuation is the protection arc. It can be stated that when a the protection arch is present, designing of the structure needs most attention. This is because this component has two functions; wave attenuation for lower dikes and creates sheltered zone for vegetation to grow. The advice is for IJburg, IJmeer or even the Markermeer, build an efficient protection structure further offshore in order to create a larger sheltered zone. In the sheltered zone, create water depth differences where reed and other vegetation will be able to grow on. This could lead to feasible cost per square meters ratio.

Overall, a hybrid solution has a lot of extra beneficial functions next to its safety function. A lot of natural value is added to the IJmeer and for the Amsterdam citizens, in terms of vegetation above and below the water surface. Moreover, the plateaus will trap fine sediments causing a decrease in the turbidity. Which results in a higher light penetration, which yields to a higher success rate of vegetation. High turbidity is currently a problem in the Markermeer and the IJmeer. The trap of sediments could also leads to a more climate-adaptive design, which reduces required investments in the future. Due to higher flow velocities at some locations, gullies will arise, where sediment will be eroded. The trap of fine sediments and the erosion of gullies will result in a sand plateau with height differences. These height differences create diversity in successful vegetation and the attraction of animal species as fish and aquatic plants eating birds. The Markerwadden project uses this principle already successfully. When the area of interest will be monitored, other projects can learn from this data. Lastly, inspirational value is added to the Markermeer, where other new islands or shore restorations can be inspired and can learn from this nature-based hybrid solution.

Thus, this nature-based hybrid solution is more expansive, but a solution like this maximizes the benefits for local communities, nature and economy. The use of a nature-based hybrid solution is a way of combining the development of new nature and ecosystems with coastal protection providing safety and prosperity for local community.

Table 6.1: Cost estimate determined by using calculation sheet of R. Tijsterman [2020], mean ±35% for the Basic Concept compared to the nature-based hybrid solution: the Hard Arch.

Variant	**Mean cost** −35%	**Mean cost** +35%
Basic concept	€ 0.7 million	€ 1.3 million
Hard Arch	€3.8 million	€ 7.0 million

6.2 RECOMMENDATIONS

Based on the discussion and conclusions, several recommendations have been formulated. The recommendations are written either for the Engineering Office or future research. The most important recommendations are in bold.

6.2.1 For the Engineering Office

- **Failure requirement less conservative**
  The east part of the island will be used for recreation and sports facilities and only the west part of the island will be accessible for living purposes. Therefore, it is recommended to the Engineering Office to investigate whether the probability of failure requirement can be adjusted (make it less conservative).

This can be adjusted based on the fact that no people will live close to the dike.

- **Redistribution of failure budget**
  The dike will be at ground level of the island (the dike is a half-hidden dike). Therefore, for example, the failure mechanism piping is not possible to take place. The failure probability distribution (failure budget) for these failure mechanisms can be redistributed. A redistribution could result in a more effective approach of the failure mechanisms and their contribution. In OI2014v4 [2017] it is recommended to not change the failure budget even though failure mechanisms are not present. In this case, the redistribution could provide changes in the outcome significantly. Waternet will be the future owner of the flood protection and requires little risks. Therefore it is recommended to obtain a compromise with Waternet.

- **Engineering Office responsible for own emission**
  Future land-water transitions where the Engineering Office will be responsible for, will need to at least consists of a vegetated foreshore. The use of vegetation is a way of giving back the world their resources, instead of using the resources to build high concrete walls. Moreover, the Engineering Office needs to feel responsible in making sustainable and conscious choices. Due to the gaining and transportation of new rubble mound, the use of rubble mound in a design is not sustainable and emits lots of CO_2. Therefore, the recommendation is to use used rubble mound from other projects around Amsterdam. The reuse of rubble mound reduces the CO_2 emission significantly of the total project. The quality of the rubble mound might be lowered after usage. But in this project, the rubble mound does not have a direct human protection function.

- **Large lake level rise**
  This study has not taken extreme lake level rise into account. The predicted lake level rise is taken into account in the design. However, it is possible that the lake level regulations need to be reconsidered. It is recommended to consider this design and the islands of IJburg with large lake level rise.

- Improve settlement approximation
  The settlement that have been taken into account is assumed with large uncertainty. More research in the settlement and its location is recommended before the implementation of one or more components of the in this study suggested nature-based hybrid solution.

- Use of storm data
  The Soft Arch variant could be an interesting solution to the problem. The uncertainty in the eroded sediment and therefore the amount of maintenance is still too large. The Soft Arch variant needs to become more reliable. Therefore, it is recommended to take the number of storms and the storm duration from real-time data, to predict the maintenance better.

- Feasibility of the 'Boog om de Oost'
  The feasibility of the 'Boog om de Oost' project overall needs to be checked. The 'Boog om de Oost' will create large natural value but therefore, this area will need lots of protection from waves to create a suitable environment. The question is if it out-weight each other.

- Hydra-NL implementation of vegetation
  A recommendation to investigate the possibility to design with vegetated foreshore in Hydra-NL. This could be done by implementing a data set with strength parameters of vegetation for vegetated foreshores in hybrid solutions. This data set needs to consists of the wave height reduction coefficients for

different vegetation types and for different return periods, for different water depths and different widths of vegetation fields. The implementation of vegetation strength parameters in Hydra-NL could be the first step towards more hybrid solutions with vegetated foreshores at land-water transitions.

6.2.2 For future research

- **Sediment fluxes in lakes**
  If the debate on the Soft Arch variant is to be moved forward, a better understanding of the sediment erosion in the IJmeer and Markermeer needs to be developed. This low energy environment has different influence on a coast than the sea has. The precise mechanism of the wave climate in a low energy environment of the IJmeer needs more research.
- **Engineering with vegetation**
  As found in this study most reduction over a cross-section is due to the breakwater. However vegetation has large potential. More detailed research on how to design bed, bank, and shore protection with taking reed vegetation into account is recommended. Investigate questions like: what is the erosion prevention's effect?, or how reliable is a reed field for a primary flood defence?, could be interesting to investigate. With more knowledge on the reducing vegetation potential, it will be known how to maximize the reduction.
- **Mussel reefs as breakwater**
  Future research about mussel reefs as breakwater is recommended. The mussels on a breakwater could create also a nature-based hybrid solution and could therefore create a win-win situation. The mussels will not only have wave height reducing contribution but will also filter the lake water. The added natural value will increase with the increase in the number of mussels. At the same time, the mussels will attract birds and fish species. The feasibility needs to be investigated and the geometry of the breakwaters needs to be optimized. It can be expected, that the mussels will grow on the rubble mound protection arch already. Otherwise, manual mussel placement can be considered.
- Vegetation on sandy slope in IJmeer
  A sediment transport model (for example Xbeach) will be able to predict the vegetation on the sandy slope according to the orbital velocities at the bottom. The Soft Arch variant has large natural and dynamic values that need further research. The erosion of the Soft Arch variant is influenced by the maintenance frequency and the amount of suppletion. It is recommended to study the erosion to make a better prediction on the needed material volumes and the costs.
- Geometry optimization of the Soft Arch variant
  To reduce the amount of sand for the Soft Arch variant, geometry optimizations could be done. The width of the protection arch is now assumed to be constant over the arch. The arch may be much smaller at the outer edges because of sediment transport towards these directions and the wave loads are less. With this geometry the amount of sand will be reduced. After this optimization, the Soft Arch variant can be reconsidered.

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ACRONYMS

A HYDRA-NL INPUT SHEET

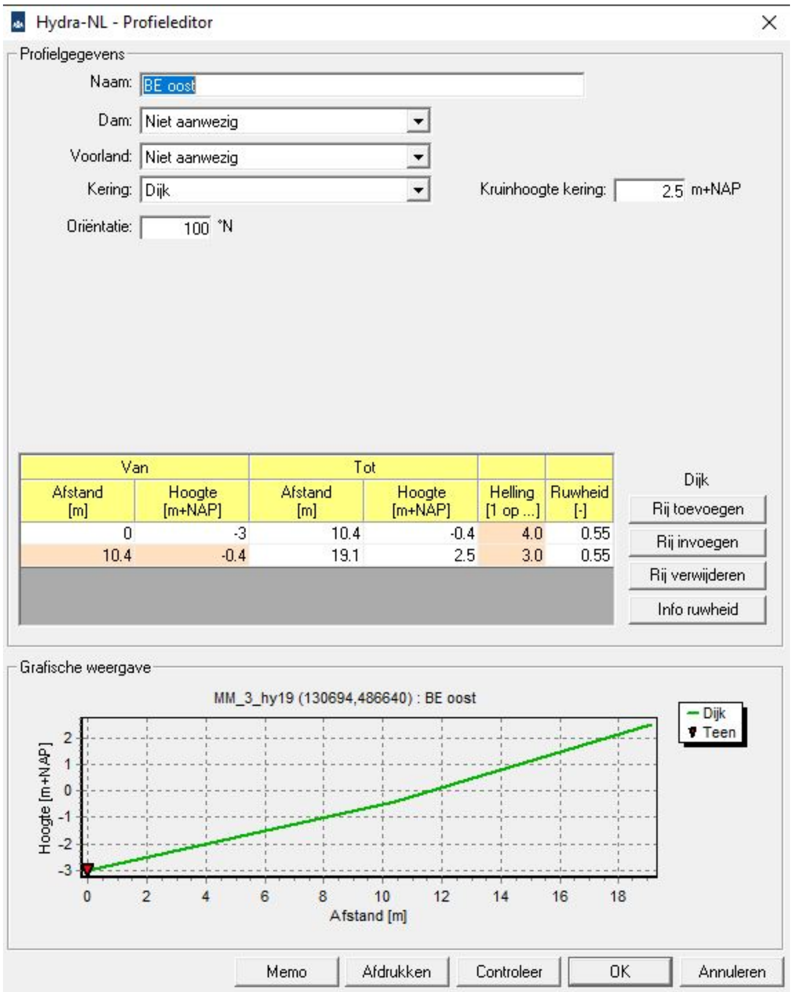


Figure A.1: Hydra-NL input slope 1/3 and 1/4, rubble mound cover

B SOIL SURVEY

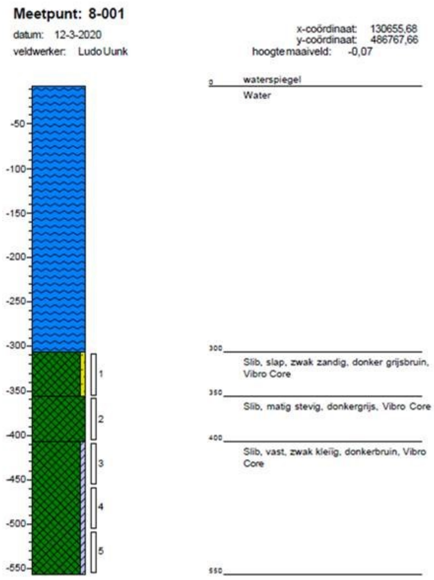


Figure B.1: Soil survey, location 8-001 [van Vree [2020]]

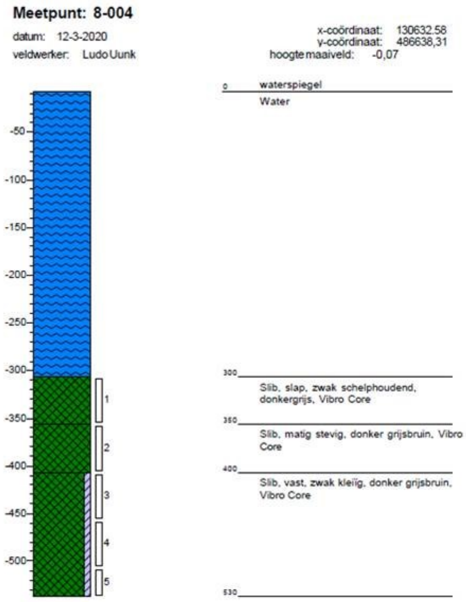


Figure B.2: Soil survey, location 8-004 [van Vree [2020]]

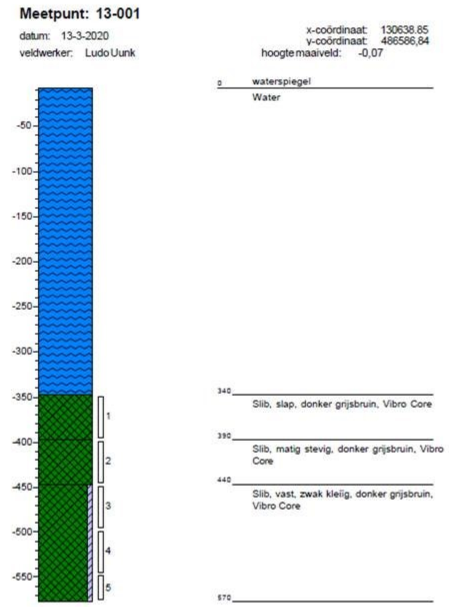


Figure B.3: Soil survey, location 13-001 [van Vree [2020]]

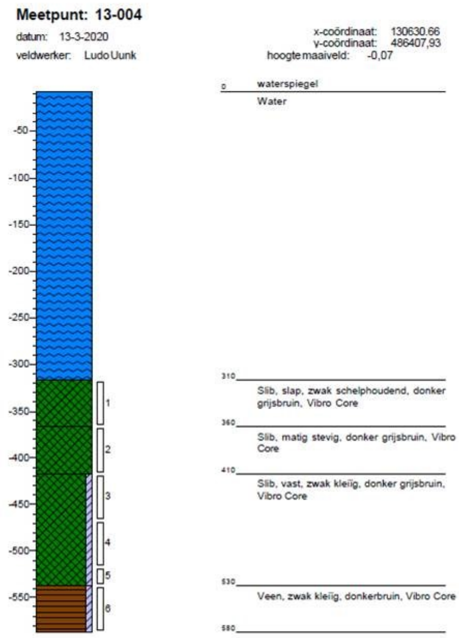


Figure B.4: Soil survey, location 13-004 [van Vree [2020]]

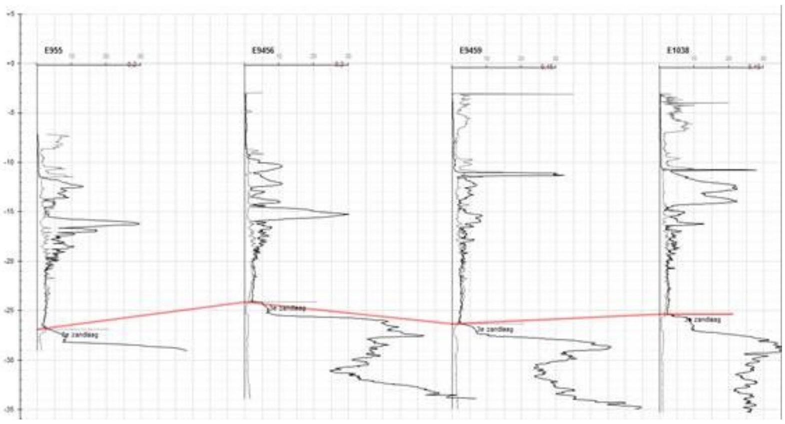


Figure B.5: CPT's from West to East [*Bouwrijp maken IJburg tweede fase* [1994, 2003]]

C | SCHIPHOL DATA AND WEIBULL FIT

A Weibull fit with scale parameters: l=6 and k=2 [Seguro & Lambert [2000]], which is shown in Figure C.1 . Because of 1.1*$log(830) \approx 3$, the 90%confidence lines are for the wind speed $\pm$ 30%. The probability of occurrence of the wind speed with direction 60 °measured at Schiphol is also plotted in Figure C.1. This data set is not spatially interpolated to the IJburg location.

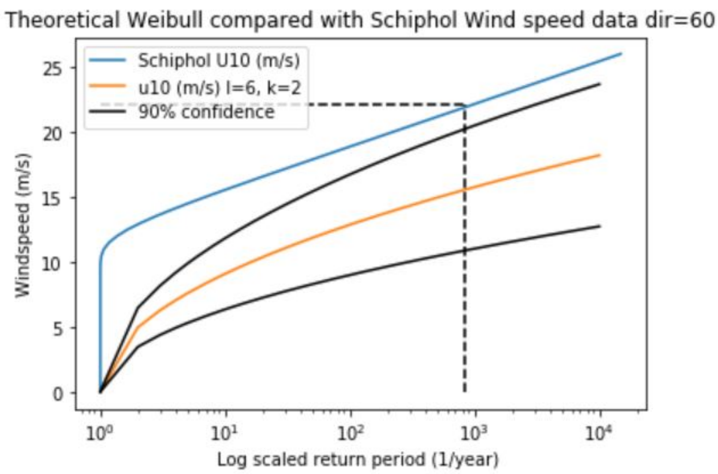
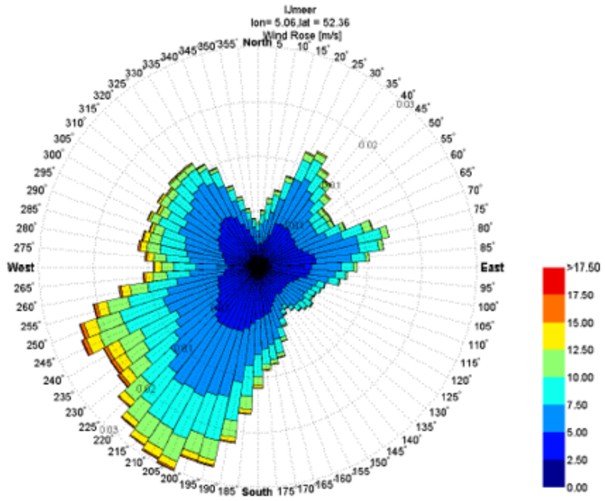


Figure C.1: Weibull distributed wind speed over the return period T=50 (log-scale) with 90% confidence

The potential wind speed is the measure used to describe the wind and represents the wind speed 1 hour average at 10 metres height after correction for nearby sheltering, so that it is representative for an open grass area with a so-called roughness length of 3 cm. The data considered in the analysis are from the 1970-2008 period (39 years) and as much as 21 stations with almost no data gaps can be considered in this period. They also include distributions per wind direction sector. The updated wind statistics are to be made available for the inference of hydraulic boundary conditions for the Dutch primary water defences by the Wettelijk Toets Instrumentarium (Legal Assessment Instruments) team. The required level of protection may vary 250 to 10,000 year loads Measurements from March 1950, with sampling frequency of 3Hz [Verkaik [2001]]. Accuracy wind speed 0.5 m/s for U<5 m/s and for U>5 m/s 10%. The range the wind speed is taken is 5-75m/s.

D WIND ROSE FOR POINT IN IJMEER



Figuur 2.1: Golfroos op basis van 35 jaar hindcast afkomstig uit HIRLAM voor een punt in het IJmeer (5.06°N,52.36°E).

Figure D.1: Wind rose based on 35 years of hindcast from HIRLAM for a point in the IJmeer

E REGULATED WATER LEVEL MARKERMEER

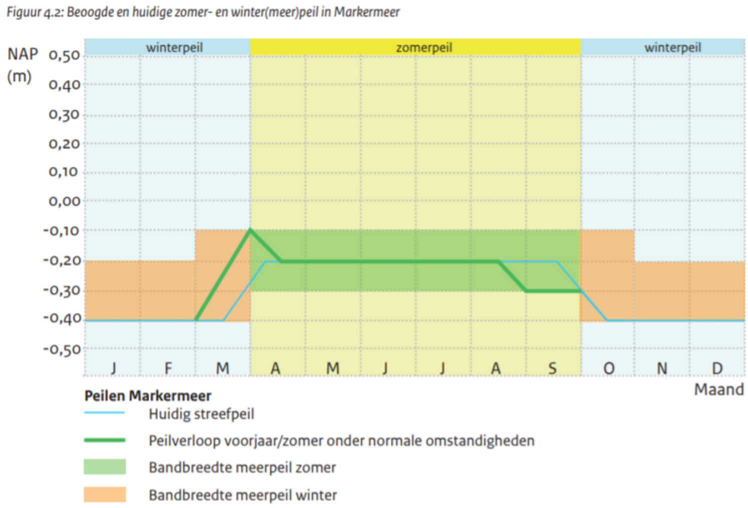


Figure E.1: Regulated Water level in Markermeer Rijkswaterstaat [2018]

F STAKEHOLDER ANALYSIS

Stakeholders	Category	Role in Initation phase	Role in Construction phase	Role in mangement phase	Institutional resources	Social/technical/knowledge resources	Financial resources	Concerns	Causes of problem	Disered solution
Ingenieurs Bureau Amsterdam	Executive party	Excecution of design and initiative	Responsible for construction advice, project management	Monitoring N2000, ecology and safety	Competent authority for design	Technical	-	Cheap and low in emission during construction, Reed fields and no view disturbances	Have to deal with regulations	Technical safe design
Ruimte&Duurzaamheid	Designing party	Implement city's vision into design	Manage the construction			Technical	-	Design of the foreshore will be of high maintenance kost	Want large underwater nature ecosysstem	Green and unique design as compensation for green in Ijburg
Grond&Ontwikkeling	Authority	The amount and property of soil knowledge	Delivery of soil		Only party that deliveres soil, No ground no island	Soil properties	++	Not in line with vision municipality, so budget is not in balance, Too many restrictions,	Few residential locations on island, need soil from groundbank, Free soil and delivery	Unique island with special story, Easy dumping and easy access
Stadsdeel Oost Amsterdam	Local government	Authority and inititative and financial	Management and financing	Owner responsible for management, facilitate research and recreateion	Competent authority for management and financial responsible authorised licening	Knowledge and technical resources by expericence by management of islands	+++	Lack of nature and recreation for Ijburg and Amsterdam-Oost inhabitants	Too many buildings, lack of nature, lack of intrest	Green, sustainable, special design for inhabitants of Ijburg and Amsterdam Oostreed for Boog om oost
Rijkswaterstaat Midden Nederland	Authority	Design that makes water quality best		Responsible for water quality and level	National authority, power about the dredging of national waters (gemandateerd aan ILT)	Experienced in large projects, contract involvement	-	Water quality improvement, Problems with Sludge	Lack of natural land/water transitions	Self water purification by vegetation, decreased sudge problems
Waternet	Owner of primary flood defence	Wants straight primary (1/830) flood defence		Owner and management of primary flood defence, drinking water and riool	Owner of flood defences, only party	company is licened and experienced and only possible party	+++	Smallest area to manage	Low cost for maintainance to primary flood defence	Straight primary flood defence dike
Sportvisserij Nederland	Knowledge	Need to be involved	The less hinder as possible	recreational land water transition to fish		Knowledge on ecosystem and fish population	-	Lack of nature environmental spots to fish	Places did not exsists	More fish and places to fish shelterdly
Professional navigation	Commercial party	hinder the professional navigation	The less hinder as possible	-	Institutional resources	-	+	Hinder over their sailing routes		No activities nor submerged breakwaters in/near sailing route
Fishbranch IJmeer	Knowledge	Knowledge required for ecosystem design	management of fish healthy ecosystem	Monitoring fish and ecosytem		Knowledge on ecosystem and fish population	+	Healthy large fish population	Lack of regulations, disturbance in ecosystem	More large fish of specific species
Provincie Noord-Holland	Regional government	Possible financial support, naturereserve act	Supervision	Monitoring N2000, ecology and safety	Regional authority, responsible for ecological and nature compensation	Knowlegde on large ecosystems and N2000	++	No connnection between Vechtstreek and Waterland	In the past less interest in N2000	Boog om oost and N2000, green design
Natuurmonumenten	Society	Design to get most nature value	Construction hinder for ecosystem	Management of nature preservation	Large amount of members	Large group of supporters	+	More nature, more diversity	Lack of natural land/water transitions	Nature reserve around Ijburg
Other NGO's	Society	Design to get most nature value	Construction hinder for ecosystem	Management of nature preservation	large small parties	Social resources	-	More nature around Ijburg	lack of biodiversity	More nature around Ijburg
Ministerie I&M	National government	Financial responsible		Natura2000 maintained	National authority	-	-	Natura2000not yet met		N2000 target of more biodiversity in Ijmeer
Recreation sailing	Society	Design to get most value recreation	The less hinder as possible	Shelterd mooring locations		Social resources	-	Lack of routes to sail, moor and swim for recreation in nature environment	Places did not exsists	Places to moor, lay shelterd in nature
The Users of the Island	Society	Design that give most recreation, estethical, natural value	-	Make use of aesthetical, natural, recreational, safe		Social	-	No location to do recreation around Ijburg, a lot of nature but no view disturbances	Places did not exsists	Most nature for recreation as swimming, bathing, view over the lake, unique Dutch nature
Contractor	Commercial party		Responsible for construction							efficient project excecution, keep good reputation

Figure F.1: Excellsheet stakeholder analysis

G MULTI-CRITERIA ANALYSIS

	Power* Intrest	Normalized weight factor	Requirement/desires	Scoring	Basic concept Score	Basic concept Weighted score	One groyne Score	One groyne Weighted score	Four groyne Score	Four groyne Weighted score	Small breakwaters Score	Small breakwaters Weighted score
1. Ingenieurs Bureau Amsterdam	0.45	0.11			4	0.444	8	0.889	7	0.778	10	1.111
1.a Nature based		0.125	Use of nature-based processe	yes=2, medium=1, no=0	0	0	1	0.125	1	0.125	2	0.25
1.b Boog om de Oost		0.125	Area of reed field	high=2, medium=1, low=0	0	0	2	0.25	1	0.125	2	0.25
1.c Low in Emission		0.125	Low transport costs	low=1, high=0	1	0.125	0	0	1	0.125	0	0
1.d Effective reed placement		0.125	Ratio Reed/Sand	high=2, medium=1, low=0	0	0	2	0.25	1	0.125	2	0.25
1.e Effective use of stone to prevent sand erosion		0.125	Ratio Stone/Sand	low = 1, high = 0	0	0	1	0.125	0	0	1	0.125
1.f Climate adaptive		0.125	Adaptive to climate	yes=2, medium=1, no=0	0	0	1	0.125	1	0.125	2	0.25
1.g Costs		0.125	Low costs	low=2, medium=1, high=0	2	0.25	0	0	1	0.125	0	0
1.h Maintenance (sand suppletion)		0.125	Little maintenance	yes=1, no=0	1	0.125	1	0.125	1	0.125	1	0.125
2. Stadsdeel Oost Amsterdam	0.81	0.20	Large nature area	high=2, medium=1, low=0	0	0.000	1	0.200	1	0.200	2	0.400
3. Grond&Ontwikkeling	0.27	0.07	Low cost, large nature area	yes=1, no=0	0	0.000	1	0.067	1	0.067	1	0.067
4. Waternet	0.54	0.13	Low maintenance for safety	low=2, medium=1, high=0	2	0.267	1	0.133	0	0.0	0	0.0
5. Rijkswaterstaat Midden Nederland	0.56	0.14	Improved waterquality	improved=1, same=0	0	0.000	1	0.138	1	0.138	1	0.138
6. Ruimte&Duurzaamheid	0.3	0.07	Structures below WL	yes=1, no=0	1	0.074	1	0.074	2	0.148	1	0.074
7. Province of North-Holland	0.32	0.08	Boog om de Oost	yes=1, no=0	1	0.079	1	0.079	1	0.079	1	0.079
8. NGO"s	0.25	0.06	Large diversity	high=2, medium=1, low=0	0	0.000	1	0.062	1	0.062	2	0.123
9. Sportfishery Nederland	0.1	0.02	Improve shelterd mooring	high=2, medium=1, low=0	0	0.000	1	0.025	1	0.025	1	0.025
10. Professional navigation	0.12	0.03	No hinder	yes=1, no=0	1	0.030	1	0.030	1	0.030	1	0.030
11. Fishbranch IJmeer	0.15	0.04	Improve fish diversity	high=2, medium=1, low=0	0	0.000	1	0.037	1	0.037	2	0.074
12. Recreation sailing	0.1	0.02	Improve shelterd mooring	high=2, medium=1, low=0	0	0.000	1	0.025	1	0.025	2	0.049
13. Recreactional users	0.04	0.01	Structures below WL	yes=1, no=0	0	0.000	1	0.010	1	0.010	1	0.010
14. Ministerie I&M	0.04	0.01	Safe and according rules	yes=1, no=0	1	0.010	1	0.010	1	0.010	1	0.010
Sum weighting factors	4.05	1		Final score		0.90		1.78		1.61		2.19

Figure G.1: Comparison between basic concept and three alternatives

H VEGETATION MODEL FOR HS=0.63M

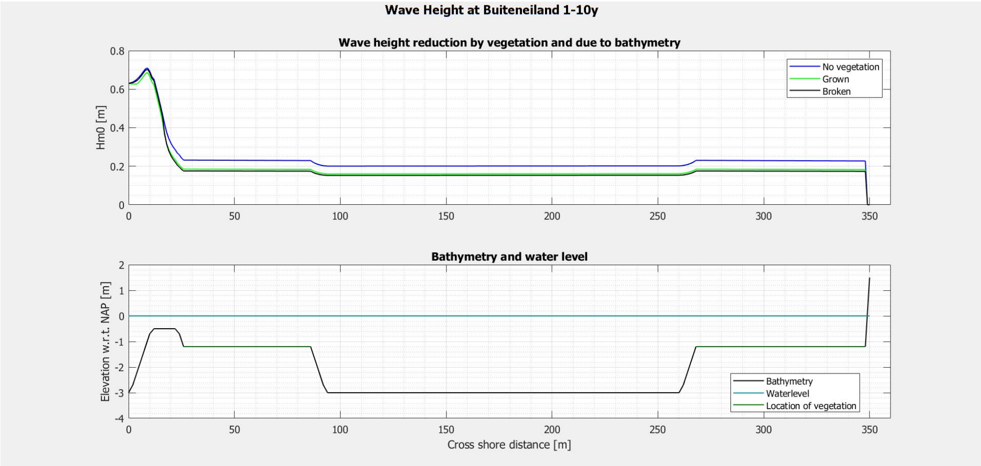


Figure H.1: Wave height in cross shore direction for 1/10 year return period conditions. Wave height at the toe of the dike is given in the plot. For grown reed and broken reed. Offshore is left, dike is right

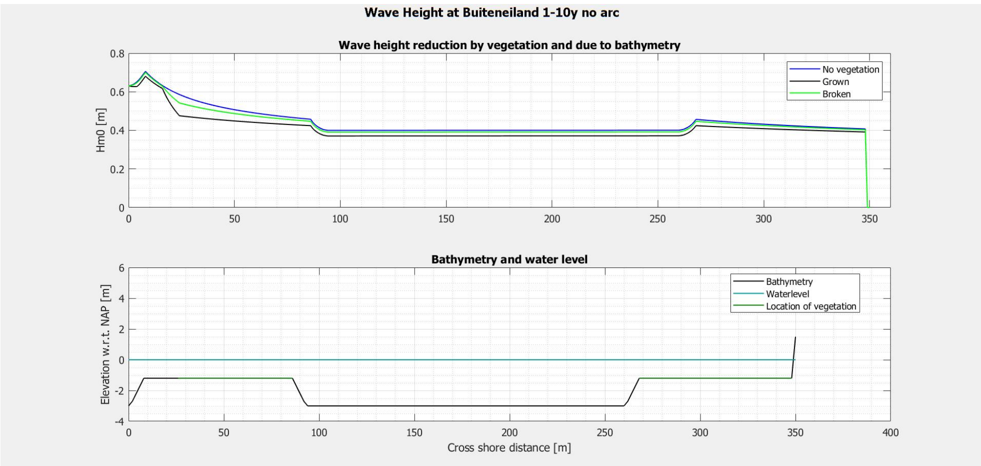


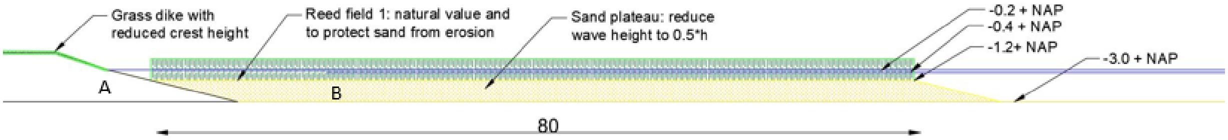
Figure H.2: Wave height in cross shore direction for 1/10 year return period conditions without the protection arc. First plot is without vegetation, second plot is with grown reed, the third plot is with broken broken. Offshore is left, dike is right

I INFLUENCE OF WAVE ATTENUATION OF COMPONENTS OVER CROSS SECTION

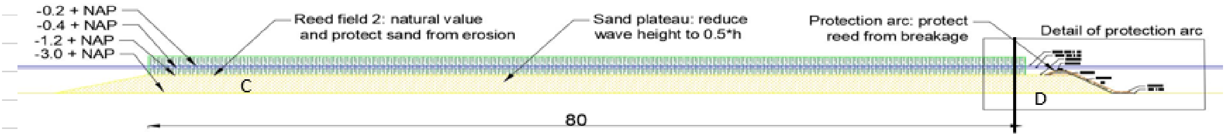
Determine influence of wave height reduction of different components in the cross section								
1.830 arc	no vega	grown	broken		**1.830 arc**	no vega	grown	broken
reduction by arc (m)	0.62	0.62	0.62		arc %	81.58%	69.66%	69.66%
Reed self (m)	0	0.13	0.13		Reed self %	0.00%	14.61%	14.61%
Foreshores	0.14	0.14	0.14		RF offshore %	18.42%	15.73%	15.73%
total reduction(m)	0.76	0.89	0.89		tot reduction	100.00%	100.00%	100.00%
1/10 arc	no vega	grown	broken		**1/10 arc**	no vega	grown	broken
reduction by arc (m)	0.38	0.38	0.38		arc %	100.00%	84.44%	84.44%
Reed self (m)	0	0.07	0.07		Reed self %	0.00%	15.56%	15.56%
Foreshores	0	0	0		RF offshore %	0.00%	0.00%	0.00%
total reduction(m)	0.38	0.45	0.45		tot reduction	100.00%	100.00%	100.00%

Figure I.1: Influence of wave attenuation per component over cross section of the Hard Arch variant

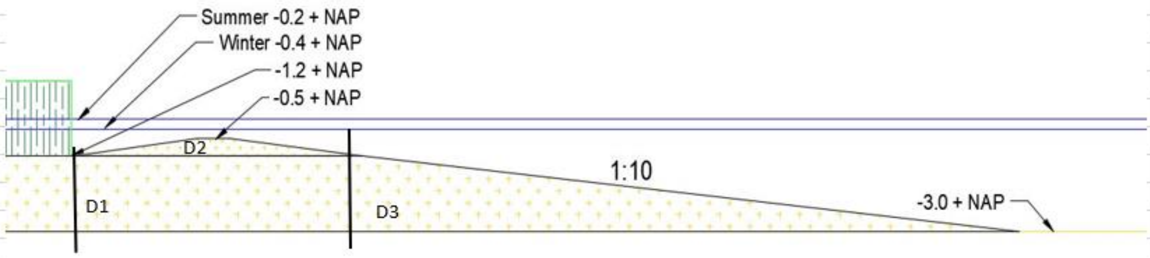
J | MATERIAL VOLUMES FOR CONSTRUCTION



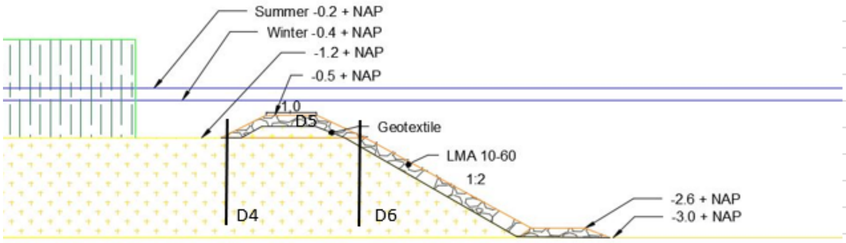
		A	B	
Construction height		Dike	Reed field 1	
Length	m	380	380	
Height above b	m	5.88	2	
Area	m2	86	140	
Sand volume	m3	32680	53200	
Rubble mound	m3	0	0	
Reed	m2	0	14471	



C					
Reed field 2					
Length	m	480	Area	m2	33493.33
Height above bottom	m	3		(1/3)*(Rout^2-Rin^2)*PI	
Rout-Rin	m	160-240			
Sand volume	m3	79722			
Rubble moun	m3	0			
Reed	m2	26574			



	D1		D2			D3		
Height	m	3	Height	m	0.5	Height	m	3
Rout-Rin	m	240-180	Rout-Rin	m	240-229	Rout-Rin	m	270-240
Area	m2	26376	Area	m2	5399.753	Area	m2	16014
Sand volume	m3	79128	Sand volur	m3	2699.877	Sand volur	m3	16014



D4			D5			D6		
Height	m	3	Heigth rep	m	0.1	Sand heigt	m	2.6
Rout-Rin	m	243-240	Rout-Rin	m	251-245	Rout-Rin	m	257-251
Area	m2	1516.62	Area	m2	3114.88	Area	m2	3190.24
Sand volur	m3	4549.86	Sand volume	m3	311.488	Sand volur	m	4147.312
			Rubbemound height	m	0.5	thickness	m	0.4
			Vtot-Vsand	=(1/3)*(3.14*(251^2-245^2)		Vtot-Vsan	=(1/3)*(3.14*(257^2-251^2)*(1/2)*3-J61	
			Rubble mound	m3	1716.847	Rubble mc	m3	638.048

		no arc	Sand arc	Rubble mound arc
Sand volur	m3	165602	269618.8767	174610.66
Rubble mc	m3	0	0	2354.895333
Reed area	m2	41045	41045	41045
maintenar	m3	0	6175	0

K | HYDRA-NL OUTPUT

```
Hydra-NL             Versienummer: 2.7.1            november 2019
Berekeningsresultaten
Naam gebruiker                                        = marie
Gebruikersmodus                                       = Test
Datum berekening                                      = 24-09-2020 09:02:51

Invoerdatabase                                        = C:\MyPrograms\Hydra-
NL\werkmap\Kelvinwerkmap\Copy_Copy_WBI2017_Markermeer_aslocaties_v01.sqlite
Locatie                                               = MM_3_hy19
  X-coördinaat                                        =  130694 (m)
  Y-coördinaat                                        =  486640 (m)

De golfparameters uit de database zijn in de berekening gebruikt.


Berekeningstype                                       = Significante golfhoogte

Bestand met transf. van potentiële naar open-water-wind = C:\MyPrograms\Hydra-
NL\data\invoer\Restant\Up2U\Up2U10.dat
Er is gerekend zonder extra steunpunten
Laagste piekwaarde meerpeiltrapezia                   =       -0.40 (m+NAP)
Hoogste piekwaarde meerpeiltrapezia                   =        1.80 (m+NAP)
Stapgrootte piekwaarde meerpeiltrapezia               =        0.05 (m)
Meerpeiltrapezia worden afgetopt bij bovengrens       =        0.10 (m+NAP)

Stijging meerpeil t.g.v. klimaatverandering           =        0.10 (m)

Discretisatiestap meerpeiltrapezia                    =       12.00 (uur)

Verhoging van de waterstand (b.v. als beheerruimte)   =        0.56 (m)

Bovengrens windsnelheid                               =       50.00 (m/s)

De waterstanden en (golf)belastingen zijn voor het meerpeil gerepareerd.

Berekening met onzekerheid in de waterstand en golfhoogte.
De parameterwaarden van de modelonzekerheid zijn uit de database afkomstig.
  Verwachtingswaarde onzekerheid waterstand           =        0.00 (m)
  Standaarddeviatie onzekerheid waterstand            =        0.25 (m)
  Aantal gebruikte waarden onzekerheid waterstand     =           7
  Verwachtingswaarde voor onzekerheid golfhoogte      =        0.95 (-)
  Standaarddeviatie voor onzekerheid golfhoogte       =        0.11 (-)
  Aantal gebruikte waarden onzekerheid golfhoogte     =           5

  Onzekerheid waterstand en/of golven in meerpeiltrapezia:
   percentage voor afhankelijke waterstandsblokken    =      100.00 (%)
   percentage voor onafhankelijke waterstandsblokken  =        0.00 (%)

1 gegevensblok
Som van de basisduren voor alle gegevensblokken       =      180.00 (dagen)
Totaal aantal trapezia                                =           3

Gegevensblok 1
  Aantal keer dit gegevensblok                        =           3
  Bestand met overschrijdingskansen meerpeil          = C:\MyPrograms\Hydra-
NL\data\invoer\Meerpeil\Markermeer\Ovkans_Markermeer_piekmeerpeil_2017_metOnzHeid.txt
  Bestand met overschrijdingskansen windsnelheid      = C:\MyPrograms\Hydra-
NL\data\invoer\Windsnelheid\Schiphol\Ovkanswind_Schiphol_12sectoren_2017_metWindDrag_metOnzH
eid.txt
  Bestand met momentane kansen van de windrichting    = C:\MyPrograms\Hydra-
NL\data\invoer\Windrichting\Schiphol\Richtingskansen_Schiphol_12sectoren_2017.txt
  Bestand met kansen op de stormduren                 = C:\MyPrograms\Hydra-
NL\data\invoer\Restant\kansstormduur.txt

  Parametrische weergave van (geknikte) meerpeiltrapezia
  Tabel met topduren van de meerpeiltrapezia          = C:\MyPrograms\Hydra-
NL\data\invoer\Topduur\Markermeer\Topduur_Markermeer_2017.txt
```

Basisduur trapezium = 60.00 (dagen)
Blokduur wind = 12.00 (uur)
Insnoeringsfactor hoogte meerpeiltrapezia = 100.00 (%)
Insnoeringsfactor horizontale breedte meerpeiltrapez. = 100.00 (%)

Berekeningsresultaten

Frequentie:	Significante golfhoogte:	
1/ 830	1.171 (m)	Illustratiepunten Uitsplitsingen
1/ 10	0.851 (m)	Illustratiepunten Uitsplitsingen
1/ 1	0.639 (m)	Illustratiepunten Uitsplitsingen

Terugkeertijd (jaren)	Significante golfhoogte (m)
10	0.851
30	0.937
100	1.025
300	1.100
1000	1.184
3000	1.257
10000	1.336
30000	1.404
100000	1.480

Illustratiepunten voor de significante golfhoogtes:

Waarschuwing: Er zijn illustratiepunten berekend in combinatie met aftoppen.
De berekeningsmethode hiervoor is niet geheel correct.
De illustratiepunten zijn daardoor niet altijd betrouwbaar.

Illustratiepunten bij significante golfhoogte 1.17 (m) en terugkeertijd 830 (jaar)

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 1.17 (m)
Terugkeertijd = 830 (jaar)
Overschrijdingsfrequentie = 1.20E-03 (per jaar)

r	meerp. m+NAP	-- --	-- --	windsn. m/s	waterst. m+NAP	Hm0 m	ov. freq *0.001/whj	ov. freq %
30.0	-0.20	--	--	21.4	1.20	1.17	0.153	12.7
60.0	-0.19	--	--	20.1	1.05	1.17	0.944	78.4
90.0	-0.22	--	--	19.7	0.77	1.17	0.042	3.5
120.0	0.04	--	--	23.6	0.77	1.17	0.000	0.0
150.0	--	--	--	--	--	--	0.000	0.0
180.0	--	--	--	--	--	--	0.000	0.0
210.0	--	--	--	--	--	--	0.000	0.0
240.0	--	--	--	--	--	--	0.000	0.0
270.0	--	--	--	--	--	--	0.000	0.0
300.0	--	--	--	--	--	--	0.000	0.0
330.0	0.01	--	--	41.2	2.31	1.17	0.000	0.0
360.0	-0.19	--	--	27.2	1.58	1.17	0.065	5.4
som							1.205	100.0

Onzekerheidswaarden (let op: deze zijn reeds verwerkt in de weergeven waterstanden/golfparameters)

r	h onz. m	f_Hm0 -	f_Tm-1,0 -	f_Tp -	ov. freq %
30.0	0.00	1.08	1.00	1.00	12.7

60.0	0.00	1.08	1.00	1.00	78.4
90.0	0.00	1.20	1.00	1.00	3.5
120.0	0.00	1.20	1.00	1.00	0.0
150.0	--	--	--	--	0.0
180.0	--	--	--	--	0.0
210.0	--	--	--	--	0.0
240.0	--	--	--	--	0.0
270.0	--	--	--	--	0.0
300.0	--	--	--	--	0.0
330.0	0.00	1.20	1.00	1.00	0.0
360.0	0.00	1.08	1.00	1.00	5.4

Betekenis van de gegevens:

- r = De windrichting
- meerp. = De ruimtelijk gemiddelde waterstand van het Markermeer in m+NAP
- windsn. = De potentiële windsnelheid van Schiphol in m/s
- waterst. = De waterstand op de HR-locatie in m+NAP
- Hm0 = De significante golfhoogte op de HR-locatie in m
- ov.freq = De overschrijdingsfrequentie van de significante golfhoogte voor de bijbehorende windrichting in gemiddeld aantal keer per winterhalfjaar en als percentage
- h onz. = De verhoging van de waterstand ten gevolge van de onzekerheid in de waterstand in m vóór een eventuele transformatie over een voorland
- f_Hm0 = De vermenigvuldigingsfactor van de golfhoogte als gevolg van de onzekerheid in de golfhoogte vóór een eventuele transformatie over een voorland
- f_Tm-1,0 = De vermenigvuldigingsfactor van de spectrale golfperiode als gevolg van de onzekerheid in de spectrale golfperiode vóór een eventuele transformatie over een voorland
- f_Tp = De vermenigvuldigingsfactor van de piekperiode als gevolg van de onzekerheid in de piekperiode vóór een eventuele transformatie over een voorland

Hoofdillustratiepunt bij significante golfhoogte 1.17 (m) en terugkeertijd 830 (jaar)

windrichting r (bijdrage aan ov.freq)	60.0 (78.4%)
Markermeerpeil m [m+NAP]	-0.19
potentiële windsnelheid u [m/s]	20.1
lokale waterstand h [m+NAP]	1.05
significante golfhoogte [m]	1.17
onz. lokale waterstand [m]	0.00
onz. significante golfhoogte [-]	1.08

Illustratiepunten bij significante golfhoogte 0.85 (m) en terugkeertijd 10 (jaar)

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 0.85 (m)
Terugkeertijd = 10 (jaar)
Overschrijdingsfrequentie = 1.00E-01 (per jaar)

r	meerp. m+NAP	-- --	-- --	windsn. m/s	waterst. m+NAP	Hm0 m	ov. freq *0.001/whj	ov. freq %
30.0	-0.23	--	--	15.0	0.71	0.85	17.666	17.7
60.0	-0.19	--	--	14.0	0.69	0.85	69.747	69.7
90.0	-0.21	--	--	15.3	0.58	0.85	7.403	7.4
120.0	-0.18	--	--	16.2	0.46	0.85	0.094	0.1
150.0	-0.18	--	--	21.4	0.40	0.85	0.003	0.0
180.0	-0.18	--	--	31.0	0.42	0.85	0.000	0.0
210.0	--	--	--	--	--	--	0.000	0.0
240.0	--	--	--	--	--	--	0.000	0.0
270.0	--	--	--	--	--	--	0.000	0.0
300.0	--	--	--	--	--	--	0.000	0.0
330.0	-0.21	--	--	28.9	1.17	0.85	0.019	0.0
360.0	-0.19	--	--	19.3	0.94	0.85	5.068	5.1

som		100.000	100.0

Onzekerheidswaarden (let op: deze zijn reeds verwerkt in de weergeven waterstanden/golfparameters)

r	h onz. m	f_Hm0 -	f_Tm-1,0 -	f_Tp -	ov. freq %
30.0	0.00	1.08	1.00	1.00	17.7
60.0	0.00	1.08	1.00	1.00	69.7
90.0	0.00	1.08	1.00	1.00	7.4
120.0	0.00	1.20	1.00	1.00	0.1
150.0	0.00	1.20	1.00	1.00	0.0
180.0	0.00	1.20	1.00	1.00	0.0
210.0	--	--	--	--	0.0
240.0	--	--	--	--	0.0
270.0	--	--	--	--	0.0
300.0	--	--	--	--	0.0
330.0	0.00	1.20	1.00	1.00	0.0
360.0	0.00	1.08	1.00	1.00	5.1

Betekenis van de gegevens:
- r = De windrichting
- meerp. = De ruimtelijk gemiddelde waterstand van het Markermeer in m+NAP
- windsn. = De potentiële windsnelheid van Schiphol in m/s
- waterst. = De waterstand op de HR-locatie in m+NAP
- Hm0 = De significante golfhoogte op de HR-locatie in m
- ov.freq = De overschrijdingsfrequentie van de significante golfhoogte voor de bijbehorende windrichting in gemiddeld aantal keer per winterhalfjaar en als percentage
- h onz. = De verhoging van de waterstand ten gevolge van de onzekerheid in de waterstand in m vóór een eventuele transformatie over een voorland
- f_Hm0 = De vermenigvuldigingsfactor van de golfhoogte als gevolg van de onzekerheid in de golfhoogte vóór een eventuele transformatie over een voorland
- f_Tm-1,0 = De vermenigvuldigingsfactor van de spectrale golfperiode als gevolg van de onzekerheid in de spectrale golfperiode vóór een eventuele transformatie over een voorland
- f_Tp = De vermenigvuldigingsfactor van de piekperiode als gevolg van de onzekerheid in de piekperiode vóór een eventuele transformatie over een voorland

Hoofdillustratiepunt bij significante golfhoogte 0.85 (m) en terugkeertijd 10 (jaar)

windrichting r (bijdrage aan ov.freq)	60.0 (69.7%)
Markermeerpeil m [m+NAP]	-0.19
potentiële windsnelheid u [m/s]	14.0
lokale waterstand h [m+NAP]	0.69
significante golfhoogte [m]	0.85
onz. lokale waterstand [m]	0.00
onz. significante golfhoogte [-]	1.08

Illustratiepunten bij significante golfhoogte 0.64 (m) en terugkeertijd 1 (jaar)

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 0.64 (m)
Terugkeertijd = 1 (jaar)
Overschrijdingsfrequentie = 1.00E+00 (per jaar)

r	meerp. m+NAP	-- --	-- --	windsn. m/s	waterst. m+NAP	Hm0 m	ov. freq *0.001/whj	ov. freq %
30.0	-0.19	--	--	11.2	0.65	0.64	185.184	18.5
60.0	-0.19	--	--	10.5	0.61	0.64	654.073	65.4

90.0	-0.19	--	--	11.4	0.54	0.64	104.357	10.4
120.0	-0.19	--	--	13.3	0.42	0.64	6.101	0.6
150.0	-0.19	--	--	17.3	0.38	0.64	0.950	0.1
180.0	-0.18	--	--	25.6	0.40	0.64	0.042	0.0
210.0	--	--	--	--	--	--	0.000	0.0
240.0	--	--	--	--	--	--	0.000	0.0
270.0	--	--	--	--	--	--	0.000	0.0
300.0	--	--	--	--	--	--	0.000	0.0
330.0	-0.23	--	--	24.3	0.88	0.64	1.038	0.1
360.0	-0.22	--	--	14.9	0.66	0.64	48.256	4.8
som							1000.000	100.0

Onzekerheidswaarden (let op: deze zijn reeds verwerkt in de weergeven waterstanden/golfparameters)

r	h onz. m	f_Hm0 -	f_Tm-1,0 -	f_Tp -	ov. freq %
30.0	0.00	1.08	1.00	1.00	18.5
60.0	0.00	1.08	1.00	1.00	65.4
90.0	0.00	1.08	1.00	1.00	10.4
120.0	0.00	1.08	1.00	1.00	0.6
150.0	0.00	1.08	1.00	1.00	0.1
180.0	0.00	1.08	1.00	1.00	0.0
210.0	--	--	--	--	0.0
240.0	--	--	--	--	0.0
270.0	--	--	--	--	0.0
300.0	--	--	--	--	0.0
330.0	0.00	1.08	1.00	1.00	0.1
360.0	0.00	1.08	1.00	1.00	4.8

Betekenis van de gegevens:
- r = De windrichting
- meerp. = De ruimtelijk gemiddelde waterstand van het Markermeer in m+NAP
- windsn. = De potentiële windsnelheid van Schiphol in m/s
- waterst. = De waterstand op de HR-locatie in m+NAP
- Hm0 = De significante golfhoogte op de HR-locatie in m
- ov.freq = De overschrijdingsfrequentie van de significante golfhoogte voor de bijbehorende windrichting in gemiddeld aantal keer per winterhalfjaar en als percentage
- h onz. = De verhoging van de waterstand ten gevolge van de onzekerheid in de waterstand in m vóór een eventuele transformatie over een voorland
- f_Hm0 = De vermenigvuldigingsfactor van de golfhoogte als gevolg van de onzekerheid in de golfhoogte vóór een eventuele transformatie over een voorland
- f_Tm-1,0 = De vermenigvuldigingsfactor van de spectrale golfperiode als gevolg van de onzekerheid in de spectrale golfperiode vóór een eventuele transformatie over een voorland
- f_Tp = De vermenigvuldigingsfactor van de piekperiode als gevolg van de onzekerheid in de piekperiode vóór een eventuele transformatie over een voorland

Hoofdillustratiepunt bij significante golfhoogte 0.64 (m) en terugkeertijd 1 (jaar)

windrichting r (bijdrage aan ov.freq)	60.0 (65.4%)
Markermeerpeil m [m+NAP]	-0.19
potentiële windsnelheid u [m/s]	10.5
lokale waterstand h [m+NAP]	0.61
significante golfhoogte [m]	0.64
onz. lokale waterstand [m]	0.00
onz. significante golfhoogte [-]	1.08

Uitsplitsingen van de overschrijdingsfrequentie bij opgegeven terugkeertijden:

Waarschuwing: Er zijn uitsplitsingen berekend in combinatie met aftoppen.
De berekeningsmethode hiervoor is niet geheel correct.
De uitsplitsingen zijn daardoor niet altijd betrouwbaar.

Uitsplitsingen bij significante golfhoogte 1.17 (m) en terugkeertijd 830 (jaar)

Uitsplitsingen naar windrichtingen
Uitsplitsingen naar meerpeilen
Uitsplitsingen naar windsnelheden
Uitsplitsingen naar windsnelheden en windrichtingen

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 1.17 (m)
Terugkeertijd = 830 (jaar)
Overschrijdingsfrequentie = 1.20E-03 (per jaar)

Uitsplitsingen over de windrichting onafhankelijk van de stormduur over alle gegevensblokken

richting	bijdrage
30.0	12.735%
60.0	78.362%
90.0	3.504%
120.0	0.001%
150.0	0.000%
180.0	0.000%
210.0	0.000%
240.0	0.000%
270.0	0.000%
300.0	0.000%
330.0	0.000%
360.0	5.398%
som	100.000%

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 1.17 (m)
Terugkeertijd = 830 (jaar)
Overschrijdingsfrequentie = 1.20E-03 (per jaar)

Percentielen van het meerpeil (m+NAP) over alle gegevensblokken

percentiel	waarde
5%	-0.31
10%	-0.29
25%	-0.25
50%	-0.20
75%	-0.13
90%	-0.04
95%	0.03

Uitsplitsingen over de meerpeilen over alle gegevensblokken

meerp. (m+NAP)	bijdrage	cond. cumul.
-0.40 - -0.30	5.795%	5.795%
-0.30 - -0.20	44.236%	50.031%
-0.20 - -0.10	32.099%	82.130%
-0.10 - 0.00	11.168%	93.298%
0.00 - 0.10	4.573%	97.871%
0.10 - 0.20	2.129%	100.000%
0.20 - 0.30	0.000%	100.000%
0.30 - 0.40	0.000%	100.000%

0.40 - 0.50	0.000%	100.000%
0.50 - 0.60	0.000%	100.000%
0.60 - 0.70	0.000%	100.000%
0.70 - 0.80	0.000%	100.000%
0.80 - 0.90	0.000%	100.000%
0.90 - 1.00	0.000%	100.000%
1.00 - 1.10	0.000%	100.000%
1.10 - 1.20	0.000%	100.000%
1.20 - 1.30	0.000%	100.000%
1.30 - 1.40	0.000%	100.000%
1.40 - 1.80	0.000%	100.000%
som	100.000%	

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 1.17 (m)
Terugkeertijd = 830 (jaar)
Overschrijdingsfrequentie = 1.20E-03 (per jaar)

Percentielen van de windsnelheid (m/s) over alle gegevensblokken

percentiel	waarde
5%	18.0
10%	18.3
25%	19.3
50%	20.8
75%	22.4
90%	24.9
95%	26.7

Uitsplitsingen over de windsnelheden over alle gegevensblokken

windsn. (m/s)	bijdrage	cond. cumul.
0.0 - 4.0	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%
8.0 - 12.0	0.000%	0.000%
12.0 - 16.0	0.000%	0.000%
16.0 - 20.0	35.517%	35.517%
20.0 - 24.0	49.879%	85.395%
24.0 - 28.0	11.705%	97.100%
28.0 - 32.0	2.474%	99.574%
32.0 - 36.0	0.404%	99.978%
36.0 - 40.0	0.021%	99.999%
40.0 - 50.0	0.001%	100.000%
som	100.000%	

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 1.17 (m)
Terugkeertijd = 830 (jaar)
Overschrijdingsfrequentie = 1.20E-03 (per jaar)

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.0 - 16.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

16.0 - 20.0	4.116%	30.845%	0.555%	0.000%	0.000%	0.000%
20.0 - 24.0	7.372%	39.840%	2.364%	0.000%	0.000%	0.000%
24.0 - 28.0	1.182%	6.829%	0.585%	0.001%	0.000%	0.000%
28.0 - 32.0	0.089%	0.545%	0.072%	0.000%	0.000%	0.000%
32.0 - 36.0	0.004%	0.032%	0.004%	0.000%	0.000%	0.000%
36.0 - 40.0	0.000%	0.001%	0.000%	0.000%	0.000%	0.000%
40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
som	12.735%	78.362%	3.504%	0.001%	0.000%	0.000%

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.0 - 16.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
16.0 - 20.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
20.0 - 24.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.304%
24.0 - 28.0	0.000%	0.000%	0.000%	0.000%	0.000%	3.108%
28.0 - 32.0	0.000%	0.000%	0.000%	0.000%	0.000%	1.768%
32.0 - 36.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.365%
36.0 - 40.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.020%
40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.001%
som	0.000%	0.000%	0.000%	0.000%	0.000%	5.398%

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	-----	-----
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	-----	-----
8.0 - 12.0	0.000%	0.000%	0.000%	0.000%	-----	-----
12.0 - 16.0	0.000%	0.000%	0.000%	0.000%	-----	-----
16.0 - 20.0	32.250%	39.499%	15.510%	0.000%	-----	-----
20.0 - 24.0	90.010%	90.516%	81.529%	15.267%	-----	-----
24.0 - 28.0	99.271%	99.261%	97.874%	81.077%	-----	-----
28.0 - 32.0	99.967%	99.958%	99.895%	98.168%	-----	-----
32.0 - 36.0	99.999%	99.999%	99.997%	99.972%	-----	-----
36.0 - 40.0	100.000%	100.000%	100.000%	100.000%	-----	-----
40.0 - 50.0	100.000%	100.000%	100.000%	100.000%	-----	-----

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	-----	-----	-----	-----	-----	0.000%
4.0 - 8.0	-----	-----	-----	-----	-----	0.000%
8.0 - 12.0	-----	-----	-----	-----	-----	0.000%
12.0 - 16.0	-----	-----	-----	-----	-----	0.000%
16.0 - 20.0	-----	-----	-----	-----	-----	0.000%
20.0 - 24.0	-----	-----	-----	-----	-----	5.454%
24.0 - 28.0	-----	-----	-----	-----	-----	61.308%
28.0 - 32.0	-----	-----	-----	-----	-----	93.075%
32.0 - 36.0	-----	-----	-----	-----	-----	99.627%
36.0 - 40.0	-----	-----	-----	-----	-----	99.983%
40.0 - 50.0	-----	-----	-----	-----	-----	100.000%

Uitsplitsingen bij significante golfhoogte 0.85 (m) en terugkeertijd 10 (jaar)

Uitsplitsingen naar windrichtingen
Uitsplitsingen naar meerpeilen
Uitsplitsingen naar windsnelheden
Uitsplitsingen naar windsnelheden en windrichtingen

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 0.85 (m)
Terugkeertijd = 10 (jaar)
Overschrijdingsfrequentie = 1.00E-01 (per jaar)

Uitsplitsingen over de windrichting onafhankelijk van de stormduur over alle gegevensblokken

richting	bijdrage
30.0	17.666%
60.0	69.747%
90.0	7.403%
120.0	0.094%
150.0	0.003%
180.0	0.000%
210.0	0.000%
240.0	0.000%
270.0	0.000%
300.0	0.000%
330.0	0.019%
360.0	5.068%
som	100.000%

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 0.85 (m)
Terugkeertijd = 10 (jaar)
Overschrijdingsfrequentie = 1.00E-01 (per jaar)

Percentielen van het meerpeil (m+NAP) over alle gegevensblokken

percentiel	waarde
5%	-0.31
10%	-0.29
25%	-0.26
50%	-0.21
75%	-0.15
90%	-0.07
95%	-0.00

Uitsplitsingen over de meerpeilen over alle gegevensblokken

meerp. (m+NAP)	bijdrage	cond. cumul.
-0.40 - -0.30	6.867%	6.867%
-0.30 - -0.20	48.122%	54.988%
-0.20 - -0.10	30.745%	85.733%
-0.10 - 0.00	9.454%	95.187%
0.00 - 0.10	3.391%	98.578%
0.10 - 0.20	1.422%	100.000%
0.20 - 0.30	0.000%	100.000%
0.30 - 0.40	0.000%	100.000%
0.40 - 0.50	0.000%	100.000%
0.50 - 0.60	0.000%	100.000%
0.60 - 0.70	0.000%	100.000%
0.70 - 0.80	0.000%	100.000%
0.80 - 0.90	0.000%	100.000%
0.90 - 1.00	0.000%	100.000%

1.00 - 1.10	0.000%	100.000%
1.10 - 1.20	0.000%	100.000%
1.20 - 1.30	0.000%	100.000%
1.30 - 1.40	0.000%	100.000%
1.40 - 1.80	0.000%	100.000%
som	100.000%	

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 0.85 (m)
Terugkeertijd = 10 (jaar)
Overschrijdingsfrequentie = 1.00E-01 (per jaar)

Percentielen van de windsnelheid (m/s) over alle gegevensblokken

percentiel	waarde
5%	13.0
10%	13.6
25%	14.4
50%	15.6
75%	17.1
90%	19.1
95%	20.5

Uitsplitsingen over de windsnelheden over alle gegevensblokken

windsn. (m/s)	bijdrage	cond. cumul.
0.0 - 4.0	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%
8.0 - 12.0	0.053%	0.053%
12.0 - 16.0	57.106%	57.159%
16.0 - 20.0	36.456%	93.615%
20.0 - 24.0	5.577%	99.193%
24.0 - 28.0	0.705%	99.897%
28.0 - 32.0	0.086%	99.984%
32.0 - 36.0	0.015%	99.999%
36.0 - 40.0	0.001%	100.000%
40.0 - 50.0	0.000%	100.000%
som	100.000%	

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 0.85 (m)
Terugkeertijd = 10 (jaar)
Overschrijdingsfrequentie = 1.00E-01 (per jaar)

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	0.000%	0.053%	0.000%	0.000%	0.000%	0.000%
12.0 - 16.0	9.309%	44.244%	3.550%	0.003%	0.000%	0.000%
16.0 - 20.0	7.527%	23.637%	3.330%	0.072%	0.000%	0.000%
20.0 - 24.0	0.671%	1.933%	0.368%	0.015%	0.003%	0.000%
24.0 - 28.0	0.030%	0.121%	0.022%	0.001%	0.001%	0.000%
28.0 - 32.0	0.001%	0.007%	0.001%	0.000%	0.000%	0.000%
32.0 - 36.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
36.0 - 40.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
som	17.666%	69.747%	7.403%	0.094%	0.003%	0.000%

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.0 - 16.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
16.0 - 20.0	0.000%	0.000%	0.000%	0.000%	0.000%	1.890%
20.0 - 24.0	0.000%	0.000%	0.000%	0.000%	0.000%	2.586%
24.0 - 28.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.529%
28.0 - 32.0	0.000%	0.000%	0.000%	0.000%	0.010%	0.066%
32.0 - 36.0	0.000%	0.000%	0.000%	0.000%	0.008%	0.006%
36.0 - 40.0	0.000%	0.000%	0.000%	0.000%	0.001%	0.000%
40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
som	0.000%	0.000%	0.000%	0.000%	0.019%	5.068%

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	-----
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	-----
8.0 - 12.0	0.000%	0.076%	0.000%	0.000%	0.000%	-----
12.0 - 16.0	53.076%	63.285%	48.818%	3.474%	0.000%	-----
16.0 - 20.0	95.991%	97.053%	94.615%	82.161%	2.974%	-----
20.0 - 24.0	99.820%	99.815%	99.678%	98.919%	79.433%	-----
24.0 - 28.0	99.992%	99.989%	99.983%	99.965%	98.071%	-----
28.0 - 32.0	100.000%	99.999%	99.999%	99.999%	99.893%	-----
32.0 - 36.0	100.000%	100.000%	100.000%	100.000%	99.999%	-----
36.0 - 40.0	100.000%	100.000%	100.000%	100.000%	100.000%	-----
40.0 - 50.0	100.000%	100.000%	100.000%	100.000%	100.000%	-----

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	-----	-----	-----	-----	0.000%	0.000%
4.0 - 8.0	-----	-----	-----	-----	0.000%	0.000%
8.0 - 12.0	-----	-----	-----	-----	0.000%	0.000%
12.0 - 16.0	-----	-----	-----	-----	0.000%	0.000%
16.0 - 20.0	-----	-----	-----	-----	0.000%	37.219%
20.0 - 24.0	-----	-----	-----	-----	0.000%	88.153%
24.0 - 28.0	-----	-----	-----	-----	0.595%	98.571%
28.0 - 32.0	-----	-----	-----	-----	51.752%	99.874%
32.0 - 36.0	-----	-----	-----	-----	94.188%	99.994%
36.0 - 40.0	-----	-----	-----	-----	99.408%	100.000%
40.0 - 50.0	-----	-----	-----	-----	100.000%	100.000%

Uitsplitsingen bij significante golfhoogte 0.64 (m) en terugkeertijd 1 (jaar)

Uitsplitsingen naar windrichtingen
Uitsplitsingen naar meerpeilen
Uitsplitsingen naar windsnelheden
Uitsplitsingen naar windsnelheden en windrichtingen

Locatie = MM_3_hy19 (130694,486640)

```
Berekeningstype               = Significante golfhoogte
Significante golfhoogte       =     0.64 (m)
Terugkeertijd                 =        1 (jaar)
Overschrijdingsfrequentie     = 1.00E+00 (per jaar)
```

Uitsplitsingen over de windrichting onafhankelijk van de stormduur over alle gegevensblokken

richting	bijdrage
30.0	18.518%
60.0	65.407%
90.0	10.436%
120.0	0.610%
150.0	0.095%
180.0	0.004%
210.0	0.000%
240.0	0.000%
270.0	0.000%
300.0	0.000%
330.0	0.104%
360.0	4.826%
som	100.000%

```
Locatie                       = MM_3_hy19 (130694,486640)
Berekeningstype               = Significante golfhoogte
Significante golfhoogte       =     0.64 (m)
Terugkeertijd                 =        1 (jaar)
Overschrijdingsfrequentie     = 1.00E+00 (per jaar)
```

Percentielen van het meerpeil (m+NAP) over alle gegevensblokken

percentiel	waarde
5%	-0.32
10%	-0.29
25%	-0.26
50%	-0.21
75%	-0.15
90%	-0.08
95%	-0.02

Uitsplitsingen over de meerpeilen over alle gegevensblokken

meerp. (m+NAP)	bijdrage	cond. cumul.
-0.40 - -0.30	7.372%	7.372%
-0.30 - -0.20	49.903%	57.275%
-0.20 - -0.10	30.139%	87.413%
-0.10 - 0.00	8.605%	96.018%
0.00 - 0.10	2.856%	98.874%
0.10 - 0.20	1.126%	100.000%
0.20 - 0.30	0.000%	100.000%
0.30 - 0.40	0.000%	100.000%
0.40 - 0.50	0.000%	100.000%
0.50 - 0.60	0.000%	100.000%
0.60 - 0.70	0.000%	100.000%
0.70 - 0.80	0.000%	100.000%
0.80 - 0.90	0.000%	100.000%
0.90 - 1.00	0.000%	100.000%
1.00 - 1.10	0.000%	100.000%
1.10 - 1.20	0.000%	100.000%
1.20 - 1.30	0.000%	100.000%
1.30 - 1.40	0.000%	100.000%
1.40 - 1.80	0.000%	100.000%

som	100.000%

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 0.64 (m)
Terugkeertijd = 1 (jaar)
Overschrijdingsfrequentie = 1.00E+00 (per jaar)

Percentielen van de windsnelheid (m/s) over alle gegevensblokken

percentiel	waarde
5%	10.4
10%	10.7
25%	11.6
50%	12.6
75%	14.0
90%	15.8
95%	17.1

Uitsplitsingen over de windsnelheden over alle gegevensblokken

windsn. (m/s)	bijdrage	cond. cumul.
0.0 - 4.0	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%
8.0 - 12.0	34.861%	34.861%
12.0 - 16.0	56.280%	91.141%
16.0 - 20.0	7.874%	99.015%
20.0 - 24.0	0.820%	99.835%
24.0 - 28.0	0.131%	99.966%
28.0 - 32.0	0.030%	99.996%
32.0 - 36.0	0.004%	100.000%
36.0 - 40.0	0.000%	100.000%
40.0 - 50.0	0.000%	100.000%
som	100.000%	

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Significante golfhoogte
Significante golfhoogte = 0.64 (m)
Terugkeertijd = 1 (jaar)
Overschrijdingsfrequentie = 1.00E+00 (per jaar)

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	4.623%	27.507%	2.721%	0.010%	0.000%	0.000%
12.0 - 16.0	12.256%	35.460%	6.787%	0.474%	0.022%	0.000%
16.0 - 20.0	1.335%	2.766%	0.716%	0.098%	0.060%	0.000%
20.0 - 24.0	0.059%	0.166%	0.037%	0.004%	0.013%	0.001%
24.0 - 28.0	0.003%	0.010%	0.002%	0.000%	0.000%	0.002%
28.0 - 32.0	0.000%	0.001%	0.000%	0.000%	0.000%	0.001%
32.0 - 36.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
36.0 - 40.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
som	18.518%	65.407%	10.436%	0.610%	0.095%	0.004%

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.0 - 16.0	0.000%	0.000%	0.000%	0.000%	0.000%	1.281%
16.0 - 20.0	0.000%	0.000%	0.000%	0.000%	0.000%	2.899%
20.0 - 24.0	0.000%	0.000%	0.000%	0.000%	0.019%	0.521%
24.0 - 28.0	0.000%	0.000%	0.000%	0.000%	0.058%	0.055%
28.0 - 32.0	0.000%	0.000%	0.000%	0.000%	0.023%	0.006%
32.0 - 36.0	0.000%	0.000%	0.000%	0.000%	0.004%	0.001%
36.0 - 40.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
som	0.000%	0.000%	0.000%	0.000%	0.104%	4.826%

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	25.298%	41.734%	26.510%	1.772%	0.000%	0.000%
12.0 - 16.0	92.357%	95.534%	92.643%	82.644%	22.818%	0.000%
16.0 - 20.0	99.664%	99.731%	99.615%	99.348%	85.994%	0.000%
20.0 - 24.0	99.985%	99.984%	99.980%	99.981%	99.482%	23.227%
24.0 - 28.0	99.999%	99.999%	99.999%	99.999%	99.981%	79.760%
28.0 - 32.0	100.000%	100.000%	100.000%	100.000%	100.000%	98.159%
32.0 - 36.0	100.000%	100.000%	100.000%	100.000%	100.000%	99.937%
36.0 - 40.0	100.000%	100.000%	100.000%	100.000%	100.000%	99.999%
40.0 - 50.0	100.000%	100.000%	100.000%	100.000%	100.000%	100.000%

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	-----	-----	-----	-----	0.000%	0.000%
4.0 - 8.0	-----	-----	-----	-----	0.000%	0.000%
8.0 - 12.0	-----	-----	-----	-----	0.000%	0.000%
12.0 - 16.0	-----	-----	-----	-----	0.000%	26.897%
16.0 - 20.0	-----	-----	-----	-----	0.000%	87.779%
20.0 - 24.0	-----	-----	-----	-----	17.904%	98.718%
24.0 - 28.0	-----	-----	-----	-----	74.351%	99.870%
28.0 - 32.0	-----	-----	-----	-----	96.375%	99.989%
32.0 - 36.0	-----	-----	-----	-----	99.768%	99.999%
36.0 - 40.0	-----	-----	-----	-----	99.987%	100.000%
40.0 - 50.0	-----	-----	-----	-----	100.000%	100.000%

```
Hydra-NL              Versienummer: 2.7.1            november 2019
Berekeningsresultaten
Naam gebruiker                                         = marie
Gebruikersmodus                                        = Test
Datum berekening                                       = 25-09-2020 12:48:07

Invoerdatabase                                         = C:\MyPrograms\Hydra-
NL\werkmap\Kelvinwerkmap\Copy_Copy_WBI2017_Markermeer_aslocaties_v01.sqlite
Locatie                                                = MM_3_hy19
  X-coördinaat                                         =  130694 (m)
  Y-coördinaat                                         =  486640 (m)

De golfparameters uit de database zijn in de berekening gebruikt.


Berekeningstype                                        = Piekperiode

Bestand met transf. van potentiële naar open-water-wind = C:\MyPrograms\Hydra-
NL\data\invoer\Restant\Up2U\Up2U10.dat
Er is gerekend zonder extra steunpunten
Laagste piekwaarde meerpeiltrapezia                    =       -0.40 (m+NAP)
Hoogste piekwaarde meerpeiltrapezia                    =        1.80 (m+NAP)
Stapgrootte piekwaarde meerpeiltrapezia                =        0.05 (m)
Meerpeiltrapezia worden afgetopt bij bovengrens        =        0.10 (m+NAP)

Stijging meerpeil t.g.v. klimaatverandering            =        0.10 (m)

Discretisatiestap meerpeiltrapezia                     =       12.00 (uur)

Verhoging van de waterstand (b.v. als beheerruimte)    =        0.56 (m)

Bovengrens windsnelheid                                =       50.00 (m/s)

De waterstanden en (golf)belastingen zijn voor het meerpeil gerepareerd.

Berekening met onzekerheid in de waterstand en golfperioden.
De parameterwaarden van de modelonzekerheid zijn uit de database afkomstig.
  Verwachtingswaarde onzekerheid waterstand            =        0.00 (m)
  Standaarddeviatie onzekerheid waterstand             =        0.25 (m)
  Aantal gebruikte waarden onzekerheid waterstand      =          7
  Verwachtingswaarde onzekerheid spectrale golfperiode =        1.04 (-)
  Standaarddeviatie onzekerheid spectrale golfperiode  =        0.08 (-)
  Verwachtingswaarde voor onzekerheid piekperiode      =        0.96 (-)
  Standaarddeviatie voor onzekerheid piekperiode       =        0.05 (-)
  Aantal gebruikte waarden onzekerheden golfperioden   =          5

  Onzekerheid waterstand en/of golven in meerpeiltrapezia:
   percentage voor afhankelijke waterstandsblokken     =      100.00 (%)
   percentage voor onafhankelijke waterstandsblokken   =        0.00 (%)

1 gegevensblok
Som van de basisduren voor alle gegevensblokken        =      180.00 (dagen)
Totaal aantal trapezia                                 =          3

Gegevensblok 1
  Aantal keer dit gegevensblok                         =          3
  Bestand met overschrijdingskansen meerpeil           = C:\MyPrograms\Hydra-
NL\data\invoer\Meerpeil\Markermeer\Ovkans_Markermeer_piekmeerpeil_2017_metOnzHeid.txt
  Bestand met overschrijdingskansen windsnelheid       = C:\MyPrograms\Hydra-
NL\data\invoer\Windsnelheid\Schiphol\Ovkanswind_Schiphol_12sectoren_2017_metWindDrag_metOnzH
eid.txt
  Bestand met momentane kansen van de windrichting     = C:\MyPrograms\Hydra-
NL\data\invoer\Windrichting\Schiphol\Richtingskansen_Schiphol_12sectoren_2017.txt
  Bestand met kansen op de stormduren                  = C:\MyPrograms\Hydra-
NL\data\invoer\Restant\kansstormduur.txt

  Parametrische weergave van (geknikte) meerpeiltrapezia
```

Tabel met topduren van de meerpeiltrapezia = C:\MyPrograms\Hydra-NL\data\invoer\Topduur\Markermeer\Topduur_Markermeer_2017.txt

Basisduur trapezium = 60.00 (dagen)
Blokduur wind = 12.00 (uur)
Insnoeringsfactor hoogte meerpeiltrapezia = 100.00 (%)
Insnoeringsfactor horizontale breedte meerpeiltrapez. = 100.00 (%)

Berekeningsresultaten

Frequentie:	Piekperiode:		
1/ 830	4.432 (s)	Illustratiepunten	Uitsplitsingen
1/ 10	3.757 (s)	Illustratiepunten	Uitsplitsingen
1/ 1	3.004 (s)	Illustratiepunten	Uitsplitsingen

Terugkeertijd (jaren)	Piekperiode (s)
10	3.757
30	3.972
100	4.160
300	4.303
1000	4.455
3000	4.582
10000	4.705
30000	4.812
100000	4.901

Illustratiepunten voor de piekperiodes:

Waarschuwing: Er zijn illustratiepunten berekend in combinatie met aftoppen.
De berekeningsmethode hiervoor is niet geheel correct.
De illustratiepunten zijn daardoor niet altijd betrouwbaar.

Illustratiepunten bij piekperiode 4.43 (s) en terugkeertijd 830 (jaar)

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 4.43 (s)
Terugkeertijd = 830 (jaar)
Overschrijdingsfrequentie = 1.20E-03 (per jaar)

r	meerp. m+NAP	--	--	windsn. m/s	waterst. m+NAP	Tp s	ov. freq *0.001/whj	ov. freq %
30.0	-0.16	--	--	20.2	1.13	4.43	0.287	23.8
60.0	-0.18	--	--	20.4	1.07	4.43	0.734	60.9
90.0	-0.18	--	--	22.9	0.97	4.43	0.002	0.2
120.0	--	--	--	--	--	--	0.000	0.0
150.0	--	--	--	--	--	--	0.000	0.0
180.0	--	--	--	--	--	--	0.000	0.0
210.0	--	--	--	--	--	--	0.000	0.0
240.0	--	--	--	--	--	--	0.000	0.0
270.0	--	--	--	--	--	--	0.000	0.0
300.0	--	--	--	--	--	--	0.000	0.0
330.0	-0.17	--	--	32.1	1.42	4.43	0.002	0.2
360.0	-0.21	--	--	22.1	1.12	4.43	0.180	14.9
som							1.205	100.0

Onzekerheidswaarden (let op: deze zijn reeds verwerkt in de weergeven waterstanden/golfparameters)

r	h onz. m	f_Hm0 -	f_Tm-1,0 -	f_Tp -	ov. freq %

30.0	0.00	1.00	1.13	1.02	23.8
60.0	0.00	1.00	1.13	1.02	60.9
90.0	0.00	1.00	1.22	1.07	0.2
120.0	--	--	--	--	0.0
150.0	--	--	--	--	0.0
180.0	--	--	--	--	0.0
210.0	--	--	--	--	0.0
240.0	--	--	--	--	0.0
270.0	--	--	--	--	0.0
300.0	--	--	--	--	0.0
330.0	0.00	1.00	1.22	1.07	0.2
360.0	0.00	1.00	1.22	1.07	14.9

Betekenis van de gegevens:

- r = De windrichting
- meerp. = De ruimtelijk gemiddelde waterstand van het Markermeer in m+NAP
- windsn. = De potentiële windsnelheid van Schiphol in m/s
- waterst. = De waterstand op de HR-locatie in m+NAP
- Tp = De piekperiode op de HR-locatie in s
- ov.freq = De overschrijdingsfrequentie van de piekperiode voor de bijbehorende windrichting in gemiddeld aantal keer per winterhalfjaar en als percentage
- h onz. = De verhoging van de waterstand ten gevolge van de onzekerheid in de waterstand in m vóór een eventuele transformatie over een voorland
- f_Hm0 = De vermenigvuldigingsfactor van de golfhoogte als gevolg van de onzekerheid in de golfhoogte vóór een eventuele transformatie over een voorland
- f_Tm-1,0 = De vermenigvuldigingsfactor van de spectrale golfperiode als gevolg van de onzekerheid in de spectrale golfperiode vóór een eventuele transformatie over een voorland
- f_Tp = De vermenigvuldigingsfactor van de piekperiode als gevolg van de onzekerheid in de piekperiode vóór een eventuele transformatie over een voorland

Hoofdillustratiepunt bij piekperiode 4.43 (s) en terugkeertijd 830 (jaar)

windrichting r (bijdrage aan ov.freq)	60.0 (60.9%)
Markermeerpeil m [m+NAP]	-0.18
potentiële windsnelheid u [m/s]	20.4
lokale waterstand h [m+NAP]	1.07
piekperiode [s]	4.43
onz. lokale waterstand [m]	0.00
onz. piekperiode [-]	1.02

Illustratiepunten bij piekperiode 3.76 (s) en terugkeertijd 10 (jaar)

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 3.76 (s)
Terugkeertijd = 10 (jaar)
Overschrijdingsfrequentie = 1.00E-01 (per jaar)

r	meerp. m+NAP	--	--	windsn. m/s	waterst. m+NAP	Tp s	ov. freq *0.001/whj	ov. freq %
30.0	-0.19	--	--	14.4	0.73	3.76	28.046	28.0
60.0	-0.19	--	--	14.4	0.70	3.76	54.550	54.5
90.0	-0.19	--	--	17.3	0.69	3.76	1.790	1.8
120.0	-0.23	--	--	19.5	0.45	3.76	0.004	0.0
150.0	--	--	--	--	--	--	0.000	0.0
180.0	--	--	--	--	--	--	0.000	0.0
210.0	--	--	--	--	--	--	0.000	0.0
240.0	--	--	--	--	--	--	0.000	0.0
270.0	--	--	--	--	--	--	0.000	0.0
300.0	--	--	--	--	--	--	0.000	0.0

330.0	-0.22	--	--	24.1	0.89	3.76	1.619	1.6
360.0	-0.19	--	--	17.7	0.85	3.76	13.992	14.0
som							100.000	100.0

Onzekerheidswaarden (let op: deze zijn reeds verwerkt in de weergeven waterstanden/golfparameters)

r	h onz.	f_Hm0	f_Tm-1,0	f_Tp	ov. freq
	m	-	-	-	%
30.0	0.00	1.00	1.13	1.02	28.0
60.0	0.00	1.00	1.13	1.02	54.5
90.0	0.00	1.00	1.13	1.02	1.8
120.0	0.00	1.00	1.22	1.07	0.0
150.0	--	--	--	--	0.0
180.0	--	--	--	--	0.0
210.0	--	--	--	--	0.0
240.0	--	--	--	--	0.0
270.0	--	--	--	--	0.0
300.0	--	--	--	--	0.0
330.0	0.00	1.00	1.13	1.02	1.6
360.0	0.00	1.00	1.13	1.02	14.0

Betekenis van de gegevens:
- r = De windrichting
- meerp. = De ruimtelijk gemiddelde waterstand van het Markermeer in m+NAP
- windsn. = De potentiële windsnelheid van Schiphol in m/s
- waterst. = De waterstand op de HR-locatie in m+NAP
- Tp = De piekperiode op de HR-locatie in s
- ov.freq = De overschrijdingsfrequentie van de piekperiode voor de bijbehorende windrichting in gemiddeld aantal keer per winterhalfjaar en als percentage
- h onz. = De verhoging van de waterstand ten gevolge van de onzekerheid in de waterstand in m vóór een eventuele transformatie over een voorland
- f_Hm0 = De vermenigvuldigingsfactor van de golfhoogte als gevolg van de onzekerheid in de golfhoogte vóór een eventuele transformatie over een voorland
- f_Tm-1,0 = De vermenigvuldigingsfactor van de spectrale golfperiode als gevolg van de onzekerheid in de spectrale golfperiode vóór een eventuele transformatie over een voorland
- f_Tp = De vermenigvuldigingsfactor van de piekperiode als gevolg van de onzekerheid in de piekperiode vóór een eventuele transformatie over een voorland

Hoofdillustratiepunt bij piekperiode 3.76 (s) en terugkeertijd 10 (jaar)

windrichting r (bijdrage aan ov.freq)	60.0 (54.5%)
Markermeerpeil m [m+NAP]	-0.19
potentiële windsnelheid u [m/s]	14.4
lokale waterstand h [m+NAP]	0.70
piekperiode [s]	3.76
onz. lokale waterstand [m]	0.00
onz. piekperiode [-]	1.02

Illustratiepunten bij piekperiode 3.00 (s) en terugkeertijd 1 (jaar)

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 3.00 (s)
Terugkeertijd = 1 (jaar)
Overschrijdingsfrequentie = 1.00E+00 (per jaar)

r	meerp.	--	--	windsn.	waterst.	Tp	ov. freq	ov. freq
	m+NAP	--	--	m/s	m+NAP	s	*0.001/whj	%

30.0	-0.33	--	--	12.3	0.55	3.00	232.005	23.2
60.0	-0.33	--	--	12.3	0.53	3.00	471.925	47.2
90.0	-0.19	--	--	13.7	0.57	3.00	50.110	5.0
120.0	-0.19	--	--	13.8	0.43	3.00	5.252	0.5
150.0	-0.18	--	--	16.0	0.39	3.00	2.722	0.3
180.0	--	--	--	--	--	--	0.000	0.0
210.0	--	--	--	--	--	--	0.000	0.0
240.0	--	--	--	--	--	--	0.000	0.0
270.0	--	--	--	--	--	--	0.000	0.0
300.0	-0.23	--	--	21.9	0.35	3.00	10.318	1.0
330.0	-0.19	--	--	19.3	0.75	3.00	36.623	3.7
360.0	-0.33	--	--	13.7	0.53	3.00	191.043	19.1
som							1000.000	100.0

Onzekerheidswaarden (let op: deze zijn reeds verwerkt in de weergeven waterstanden/golfparameters)

r	h onz. m	f_Hm0 -	f_Tm-1,0 -	f_Tp -	ov. freq %
30.0	0.00	1.00	1.04	0.96	23.2
60.0	0.00	1.00	1.04	0.96	47.2
90.0	0.00	1.00	1.04	0.96	5.0
120.0	0.00	1.00	1.13	1.02	0.5
150.0	0.00	1.00	1.13	1.02	0.3
180.0	--	--	--	--	0.0
210.0	--	--	--	--	0.0
240.0	--	--	--	--	0.0
270.0	--	--	--	--	0.0
300.0	0.00	1.00	1.13	1.02	1.0
330.0	0.00	1.00	1.04	0.96	3.7
360.0	0.00	1.00	1.04	0.96	19.1

Betekenis van de gegevens:
- r = De windrichting
- meerp. = De ruimtelijk gemiddelde waterstand van het Markermeer in m+NAP
- windsn. = De potentiële windsnelheid van Schiphol in m/s
- waterst. = De waterstand op de HR-locatie in m+NAP
- Tp = De piekperiode op de HR-locatie in s
- ov.freq = De overschrijdingsfrequentie van de piekperiode voor de bijbehorende windrichting in gemiddeld aantal keer per winterhalfjaar en als percentage
- h onz. = De verhoging van de waterstand ten gevolge van de onzekerheid in de waterstand in m vóór een eventuele transformatie over een voorland
- f_Hm0 = De vermenigvuldigingsfactor van de golfhoogte als gevolg van de onzekerheid in de golfhoogte vóór een eventuele transformatie over een voorland
- f_Tm-1,0 = De vermenigvuldigingsfactor van de spectrale golfperiode als gevolg van de onzekerheid in de spectrale golfperiode vóór een eventuele transformatie over een voorland
- f_Tp = De vermenigvuldigingsfactor van de piekperiode als gevolg van de onzekerheid in de piekperiode vóór een eventuele transformatie over een voorland

Hoofdillustratiepunt bij piekperiode 3.00 (s) en terugkeertijd 1 (jaar)

windrichting r (bijdrage aan ov.freq)	60.0 (47.2%)
Markermeerpeil m [m+NAP]	-0.33
potentiële windsnelheid u [m/s]	12.3
lokale waterstand h [m+NAP]	0.53
piekperiode [s]	3.00
onz. lokale waterstand [m]	0.00
onz. piekperiode [-]	0.96

Uitsplitsingen van de overschrijdingsfrequentie bij opgegeven terugkeertijden:

Waarschuwing: Er zijn uitsplitsingen berekend in combinatie met aftoppen.
De berekeningsmethode hiervoor is niet geheel correct.
De uitsplitsingen zijn daardoor niet altijd betrouwbaar.

Uitsplitsingen bij piekperiode 4.43 (s) en terugkeertijd 830 (jaar)

Uitsplitsingen naar windrichtingen
Uitsplitsingen naar meerpeilen
Uitsplitsingen naar windsnelheden
Uitsplitsingen naar windsnelheden en windrichtingen

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 4.43 (s)
Terugkeertijd = 830 (jaar)
Overschrijdingsfrequentie = 1.20E-03 (per jaar)

Uitsplitsingen over de windrichting onafhankelijk van de stormduur over alle gegevensblokken

richting	bijdrage
30.0	23.783%
60.0	60.903%
90.0	0.185%
120.0	0.000%
150.0	0.000%
180.0	0.000%
210.0	0.000%
240.0	0.000%
270.0	0.000%
300.0	0.000%
330.0	0.192%
360.0	14.937%
som	100.000%

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 4.43 (s)
Terugkeertijd = 830 (jaar)
Overschrijdingsfrequentie = 1.20E-03 (per jaar)

Percentielen van het meerpeil (m+NAP) over alle gegevensblokken

percentiel	waarde
5%	-0.30
10%	-0.29
25%	-0.25
50%	-0.19
75%	-0.12
90%	-0.03
95%	0.04

Uitsplitsingen over de meerpeilen over alle gegevensblokken

meerp. (m+NAP)	bijdrage	cond. cumul.
-0.40 - -0.30	5.331%	5.331%
-0.30 - -0.20	42.378%	47.709%
-0.20 - -0.10	32.669%	80.378%
-0.10 - 0.00	12.057%	92.435%
0.00 - 0.10	5.104%	97.538%
0.10 - 0.20	2.462%	100.000%

0.20 - 0.30	0.000%	100.000%
0.30 - 0.40	0.000%	100.000%
0.40 - 0.50	0.000%	100.000%
0.50 - 0.60	0.000%	100.000%
0.60 - 0.70	0.000%	100.000%
0.70 - 0.80	0.000%	100.000%
0.80 - 0.90	0.000%	100.000%
0.90 - 1.00	0.000%	100.000%
1.00 - 1.10	0.000%	100.000%
1.10 - 1.20	0.000%	100.000%
1.20 - 1.30	0.000%	100.000%
1.30 - 1.40	0.000%	100.000%
1.40 - 1.80	0.000%	100.000%
som	100.000%	

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 4.43 (s)
Terugkeertijd = 830 (jaar)
Overschrijdingsfrequentie = 1.20E-03 (per jaar)

Percentielen van de windsnelheid (m/s) over alle gegevensblokken

percentiel	waarde
5%	18.1
10%	18.4
25%	19.3
50%	21.0
75%	22.7
90%	25.5
95%	27.0

Uitsplitsingen over de windsnelheden over alle gegevensblokken

windsn. (m/s)	bijdrage	cond. cumul.
0.0 - 4.0	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%
8.0 - 12.0	0.000%	0.000%
12.0 - 16.0	0.000%	0.000%
16.0 - 20.0	34.437%	34.437%
20.0 - 24.0	50.172%	84.609%
24.0 - 28.0	12.393%	97.002%
28.0 - 32.0	2.471%	99.473%
32.0 - 36.0	0.464%	99.937%
36.0 - 40.0	0.058%	99.995%
40.0 - 50.0	0.005%	100.000%
som	100.000%	

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 4.43 (s)
Terugkeertijd = 830 (jaar)
Overschrijdingsfrequentie = 1.20E-03 (per jaar)

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

8.0 - 12.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.0 - 16.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
16.0 - 20.0	10.401%	24.036%	0.000%	0.000%	0.000%	0.000%
20.0 - 24.0	11.708%	32.841%	0.084%	0.000%	0.000%	0.000%
24.0 - 28.0	1.293%	4.202%	0.080%	0.000%	0.000%	0.000%
28.0 - 32.0	0.088%	0.471%	0.017%	0.000%	0.000%	0.000%
32.0 - 36.0	0.004%	0.031%	0.003%	0.000%	0.000%	0.000%
36.0 - 40.0	0.000%	0.001%	0.000%	0.000%	0.000%	0.000%
40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
som	23.783%	60.903%	0.185%	0.000%	0.000%	0.000%

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.0 - 16.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
16.0 - 20.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
20.0 - 24.0	0.000%	0.000%	0.000%	0.000%	0.000%	5.539%
24.0 - 28.0	0.000%	0.000%	0.000%	0.000%	0.000%	6.817%
28.0 - 32.0	0.000%	0.000%	0.000%	0.000%	0.022%	1.873%
32.0 - 36.0	0.000%	0.000%	0.000%	0.000%	0.125%	0.302%
36.0 - 40.0	0.000%	0.000%	0.000%	0.000%	0.040%	0.017%
40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.004%	0.001%
som	0.000%	0.000%	0.000%	0.000%	0.192%	14.937%

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	-----	-----	-----
4.0 - 8.0	0.000%	0.000%	0.000%	-----	-----	-----
8.0 - 12.0	0.000%	0.000%	0.000%	-----	-----	-----
12.0 - 16.0	0.000%	0.000%	0.000%	-----	-----	-----
16.0 - 20.0	44.271%	39.031%	0.000%	-----	-----	-----
20.0 - 24.0	94.102%	92.360%	45.694%	-----	-----	-----
24.0 - 28.0	99.606%	99.184%	89.054%	-----	-----	-----
28.0 - 32.0	99.982%	99.949%	98.238%	-----	-----	-----
32.0 - 36.0	100.000%	99.999%	99.953%	-----	-----	-----
36.0 - 40.0	100.000%	100.000%	99.999%	-----	-----	-----
40.0 - 50.0	100.000%	100.000%	100.000%	-----	-----	-----

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	-----	-----	-----	-----	0.000%	0.000%
4.0 - 8.0	-----	-----	-----	-----	0.000%	0.000%
8.0 - 12.0	-----	-----	-----	-----	0.000%	0.000%
12.0 - 16.0	-----	-----	-----	-----	0.000%	0.000%
16.0 - 20.0	-----	-----	-----	-----	0.000%	0.000%
20.0 - 24.0	-----	-----	-----	-----	0.000%	38.070%
24.0 - 28.0	-----	-----	-----	-----	0.000%	84.928%
28.0 - 32.0	-----	-----	-----	-----	11.395%	97.802%
32.0 - 36.0	-----	-----	-----	-----	76.951%	99.875%
36.0 - 40.0	-----	-----	-----	-----	98.030%	99.995%
40.0 - 50.0	-----	-----	-----	-----	100.000%	100.000%

Uitsplitsingen bij piekperiode 3.76 (s) en terugkeertijd 10 (jaar)

Uitsplitsingen naar windrichtingen
Uitsplitsingen naar meerpeilen
Uitsplitsingen naar windsnelheden
Uitsplitsingen naar windsnelheden en windrichtingen

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 3.76 (s)
Terugkeertijd = 10 (jaar)
Overschrijdingsfrequentie = 1.00E-01 (per jaar)

Uitsplitsingen over de windrichting onafhankelijk van de stormduur over alle gegevensblokken

richting	bijdrage
30.0	28.046%
60.0	54.550%
90.0	1.790%
120.0	0.004%
150.0	0.000%
180.0	0.000%
210.0	0.000%
240.0	0.000%
270.0	0.000%
300.0	0.000%
330.0	1.619%
360.0	13.992%
som	100.000%

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 3.76 (s)
Terugkeertijd = 10 (jaar)
Overschrijdingsfrequentie = 1.00E-01 (per jaar)

Percentielen van het meerpeil (m+NAP) over alle gegevensblokken

percentiel	waarde
5%	-0.31
10%	-0.29
25%	-0.26
50%	-0.21
75%	-0.15
90%	-0.07
95%	-0.01

Uitsplitsingen over de meerpeilen over alle gegevensblokken

meerp. (m+NAP)	bijdrage	cond. cumul.
-0.40 - -0.30	7.123%	7.123%
-0.30 - -0.20	48.941%	56.064%
-0.20 - -0.10	30.465%	86.528%
-0.10 - 0.00	9.119%	95.648%
0.00 - 0.10	3.125%	98.773%
0.10 - 0.20	1.227%	100.000%
0.20 - 0.30	0.000%	100.000%
0.30 - 0.40	0.000%	100.000%
0.40 - 0.50	0.000%	100.000%
0.50 - 0.60	0.000%	100.000%
0.60 - 0.70	0.000%	100.000%
0.70 - 0.80	0.000%	100.000%

0.80 - 0.90	0.000%	100.000%
0.90 - 1.00	0.000%	100.000%
1.00 - 1.10	0.000%	100.000%
1.10 - 1.20	0.000%	100.000%
1.20 - 1.30	0.000%	100.000%
1.30 - 1.40	0.000%	100.000%
1.40 - 1.80	0.000%	100.000%
som	100.000%	

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 3.76 (s)
Terugkeertijd = 10 (jaar)
Overschrijdingsfrequentie = 1.00E-01 (per jaar)

Percentielen van de windsnelheid (m/s) over alle gegevensblokken

percentiel	waarde
5%	14.3
10%	14.6
25%	15.2
50%	16.2
75%	17.9
90%	20.1
95%	21.7

Uitsplitsingen over de windsnelheden over alle gegevensblokken

windsn. (m/s)	bijdrage	cond. cumul.
0.0 - 4.0	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%
8.0 - 12.0	0.000%	0.000%
12.0 - 16.0	43.687%	43.687%
16.0 - 20.0	46.078%	89.765%
20.0 - 24.0	8.175%	97.940%
24.0 - 28.0	1.643%	99.584%
28.0 - 32.0	0.368%	99.952%
32.0 - 36.0	0.045%	99.997%
36.0 - 40.0	0.003%	100.000%
40.0 - 50.0	0.000%	100.000%
som	100.000%	

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 3.76 (s)
Terugkeertijd = 10 (jaar)
Overschrijdingsfrequentie = 1.00E-01 (per jaar)

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.0 - 16.0	15.167%	27.767%	0.169%	0.000%	0.000%	0.000%
16.0 - 20.0	12.203%	24.865%	1.254%	0.001%	0.000%	0.000%
20.0 - 24.0	0.684%	1.931%	0.323%	0.002%	0.000%	0.000%
24.0 - 28.0	0.030%	0.120%	0.020%	0.000%	0.000%	0.000%
28.0 - 32.0	0.001%	0.007%	0.001%	0.000%	0.000%	0.000%

32.0 - 36.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
36.0 - 40.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
som	28.046%	54.550%	1.790%	0.004%	0.000%	0.000%

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.0 - 16.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.584%
16.0 - 20.0	0.000%	0.000%	0.000%	0.000%	0.000%	7.755%
20.0 - 24.0	0.000%	0.000%	0.000%	0.000%	0.420%	4.815%
24.0 - 28.0	0.000%	0.000%	0.000%	0.000%	0.839%	0.634%
28.0 - 32.0	0.000%	0.000%	0.000%	0.000%	0.290%	0.068%
32.0 - 36.0	0.000%	0.000%	0.000%	0.000%	0.038%	0.006%
36.0 - 40.0	0.000%	0.000%	0.000%	0.000%	0.003%	0.000%
40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
som	0.000%	0.000%	0.000%	0.000%	1.619%	13.992%

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	-----	-----
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	-----	-----
8.0 - 12.0	0.000%	0.000%	0.000%	0.000%	-----	-----
12.0 - 16.0	54.001%	50.771%	9.557%	0.000%	-----	-----
16.0 - 20.0	97.449%	96.235%	80.533%	36.332%	-----	-----
20.0 - 24.0	99.886%	99.766%	98.792%	95.693%	-----	-----
24.0 - 28.0	99.995%	99.986%	99.932%	99.812%	-----	-----
28.0 - 32.0	100.000%	99.999%	99.997%	99.995%	-----	-----
32.0 - 36.0	100.000%	100.000%	100.000%	100.000%	-----	-----
36.0 - 40.0	100.000%	100.000%	100.000%	100.000%	-----	-----
40.0 - 50.0	100.000%	100.000%	100.000%	100.000%	-----	-----

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	-----	-----	-----	-----	0.000%	0.000%
4.0 - 8.0	-----	-----	-----	-----	0.000%	0.000%
8.0 - 12.0	-----	-----	-----	-----	0.000%	0.000%
12.0 - 16.0	-----	-----	-----	-----	0.000%	4.215%
16.0 - 20.0	-----	-----	-----	-----	0.000%	60.159%
20.0 - 24.0	-----	-----	-----	-----	26.414%	94.891%
24.0 - 28.0	-----	-----	-----	-----	79.164%	99.462%
28.0 - 32.0	-----	-----	-----	-----	97.410%	99.954%
32.0 - 36.0	-----	-----	-----	-----	99.817%	99.998%
36.0 - 40.0	-----	-----	-----	-----	99.990%	100.000%
40.0 - 50.0	-----	-----	-----	-----	100.000%	100.000%

Uitsplitsingen bij piekperiode 3.00 (s) en terugkeertijd 1 (jaar)

Uitsplitsingen naar windrichtingen
Uitsplitsingen naar meerpeilen
Uitsplitsingen naar windsnelheden
Uitsplitsingen naar windsnelheden en windrichtingen

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 3.00 (s)
Terugkeertijd = 1 (jaar)
Overschrijdingsfrequentie = 1.00E+00 (per jaar)

Uitsplitsingen over de windrichting onafhankelijk van de stormduur over alle gegevensblokken

richting	bijdrage
30.0	23.201%
60.0	47.193%
90.0	5.011%
120.0	0.525%
150.0	0.272%
180.0	0.000%
210.0	0.000%
240.0	0.000%
270.0	0.000%
300.0	1.032%
330.0	3.662%
360.0	19.104%
som	100.000%

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 3.00 (s)
Terugkeertijd = 1 (jaar)
Overschrijdingsfrequentie = 1.00E+00 (per jaar)

Percentielen van het meerpeil (m+NAP) over alle gegevensblokken

percentiel	waarde
5%	-0.32
10%	-0.30
25%	-0.26
50%	-0.22
75%	-0.16
90%	-0.09
95%	-0.03

Uitsplitsingen over de meerpeilen over alle gegevensblokken

meerp. (m+NAP)	bijdrage	cond. cumul.
-0.40 - -0.30	7.861%	7.861%
-0.30 - -0.20	51.338%	59.199%
-0.20 - -0.10	29.427%	88.626%
-0.10 - 0.00	7.947%	96.572%
0.00 - 0.10	2.491%	99.063%
0.10 - 0.20	0.937%	100.000%
0.20 - 0.30	0.000%	100.000%
0.30 - 0.40	0.000%	100.000%
0.40 - 0.50	0.000%	100.000%
0.50 - 0.60	0.000%	100.000%
0.60 - 0.70	0.000%	100.000%
0.70 - 0.80	0.000%	100.000%
0.80 - 0.90	0.000%	100.000%
0.90 - 1.00	0.000%	100.000%
1.00 - 1.10	0.000%	100.000%
1.10 - 1.20	0.000%	100.000%
1.20 - 1.30	0.000%	100.000%
1.30 - 1.40	0.000%	100.000%

1.40 - 1.80	0.000%	100.000%
som	100.000%	

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 3.00 (s)
Terugkeertijd = 1 (jaar)
Overschrijdingsfrequentie = 1.00E+00 (per jaar)

Percentielen van de windsnelheid (m/s) over alle gegevensblokken

percentiel	waarde
5%	11.7
10%	12.0
25%	12.7
50%	13.7
75%	15.1
90%	17.3
95%	19.5

Uitsplitsingen over de windsnelheden over alle gegevensblokken

windsn. (m/s)	bijdrage	cond. cumul.
0.0 - 4.0	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%
8.0 - 12.0	9.995%	9.995%
12.0 - 16.0	73.579%	83.574%
16.0 - 20.0	12.255%	95.829%
20.0 - 24.0	3.346%	99.175%
24.0 - 28.0	0.674%	99.850%
28.0 - 32.0	0.131%	99.980%
32.0 - 36.0	0.018%	99.999%
36.0 - 40.0	0.001%	100.000%
40.0 - 50.0	0.000%	100.000%
som	100.000%	

Locatie = MM_3_hy19 (130694,486640)
Berekeningstype = Piekperiode
Piekperiode = 3.00 (s)
Terugkeertijd = 1 (jaar)
Overschrijdingsfrequentie = 1.00E+00 (per jaar)

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	3.093%	6.900%	0.002%	0.000%	0.000%	0.000%
12.0 - 16.0	18.705%	37.157%	4.222%	0.406%	0.113%	0.000%
16.0 - 20.0	1.428%	2.891%	0.769%	0.116%	0.153%	0.000%
20.0 - 24.0	0.060%	0.171%	0.039%	0.004%	0.011%	0.000%
24.0 - 28.0	0.003%	0.010%	0.002%	0.000%	0.000%	0.000%
28.0 - 32.0	0.000%	0.001%	0.000%	0.000%	0.000%	0.000%
32.0 - 36.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
36.0 - 40.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
som	23.201%	47.193%	5.011%	0.525%	0.272%	0.000%

Uitsplitsingen over de windsnelheid en de windrichting over alle gegevensblokken

r / windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.0 - 12.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.0 - 16.0	0.000%	0.000%	0.000%	0.000%	0.000%	12.976%
16.0 - 20.0	0.000%	0.000%	0.000%	0.000%	1.457%	5.442%
20.0 - 24.0	0.000%	0.000%	0.000%	0.591%	1.910%	0.560%
24.0 - 28.0	0.000%	0.000%	0.000%	0.334%	0.269%	0.056%
28.0 - 32.0	0.000%	0.000%	0.000%	0.089%	0.035%	0.006%
32.0 - 36.0	0.000%	0.000%	0.000%	0.014%	0.004%	0.001%
36.0 - 40.0	0.000%	0.000%	0.000%	0.001%	0.000%	0.000%
40.0 - 50.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
som	0.000%	0.000%	0.000%	1.032%	3.662%	19.104%

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r / windsn. (m/s)	30.0	60.0	90.0	120.0	150.0	180.0
0.0 - 4.0	0.000%	0.000%	0.000%	0.000%	0.000%	-----
4.0 - 8.0	0.000%	0.000%	0.000%	0.000%	0.000%	-----
8.0 - 12.0	13.283%	14.640%	0.041%	0.000%	0.000%	-----
12.0 - 16.0	93.597%	93.480%	83.921%	77.188%	40.779%	-----
16.0 - 20.0	99.729%	99.614%	99.194%	99.231%	95.796%	-----
20.0 - 24.0	99.988%	99.977%	99.959%	99.978%	99.859%	-----
24.0 - 28.0	99.999%	99.999%	99.998%	99.999%	99.996%	-----
28.0 - 32.0	100.000%	100.000%	100.000%	100.000%	100.000%	-----
32.0 - 36.0	100.000%	100.000%	100.000%	100.000%	100.000%	-----
36.0 - 40.0	100.000%	100.000%	100.000%	100.000%	100.000%	-----
40.0 - 50.0	100.000%	100.000%	100.000%	100.000%	100.000%	-----

Conditioneel cumulatieve bijdragen van de windsnelheid en de windrichting over alle gegevensblokken

r / windsn. (m/s)	210.0	240.0	270.0	300.0	330.0	360.0
0.0 - 4.0	-----	-----	-----	0.000%	0.000%	0.000%
4.0 - 8.0	-----	-----	-----	0.000%	0.000%	0.000%
8.0 - 12.0	-----	-----	-----	0.000%	0.000%	0.000%
12.0 - 16.0	-----	-----	-----	0.000%	0.000%	68.149%
16.0 - 20.0	-----	-----	-----	0.000%	39.640%	96.730%
20.0 - 24.0	-----	-----	-----	57.482%	91.609%	99.671%
24.0 - 28.0	-----	-----	-----	89.900%	98.933%	99.966%
28.0 - 32.0	-----	-----	-----	98.539%	99.887%	99.997%
32.0 - 36.0	-----	-----	-----	99.901%	99.993%	100.000%
36.0 - 40.0	-----	-----	-----	99.994%	100.000%	100.000%
40.0 - 50.0	-----	-----	-----	100.000%	100.000%	100.000%