Integrating stakeholders in a dike reinforcement project

Developing a methodology to efficiently integrate stakeholders in the design process of a dike reinforcement project

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UNIVERSITY OF TWENTE.

Witteveen + Bos

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Preface

In front of you lies my Bachelor thesis, “Integrating stakeholders within a dike reinforcement project”. This thesis is written to complete the Bachelor in Civil Engineering at the University of Twente. The last weeks provided me insight in working at a civil engineering firm, and the challenges that come with working with stakeholders and elaborate dike models.

I would like to thank Witteveen+Bos for the opportunity to conduct this research. I would like to thank Marinus Aalberts in particular, as we came up with this thesis subject together and while working from home was the standard the process still felt like an actual internship with weekly meetings, videoconferences and more. I would also like to thank my UT supervisor, Michiel Pezij, for his professional help and feedback, and always making time for videocalls whenever I got stuck.

I would also like to thank my fellow students for helping me when I needed a second opinion and for working together, preventing slacking whilst working from home.

Lastly, I would like to thank my father, Henk Wilms. We spent a lot of time figuring out how the elaborated dike model worked, and how the model could be adjusted for this research project. I could not have managed to finish this research without him.

Abstract

This research thesis presents a methodology to integrate stakeholders in the process of a dike reinforcement project. With the upcoming automatization of designing dikes, a high amount of dike configurations can be calculated at once. This improvement increases the amount of calculated possible dike parameter configurations. The parameter configuration determines the impact the dike has on the surrounding area. Integrating stakeholders within the dike design process is a challenge with mutual benefits for both the stakeholder and the contractor. The stakeholders understand the consequences of design choices better, which saves the contractor time explaining decisions made. Since the stakeholders themselves will be working with the model, the contractor can use its time for other activities. Therefore, there is no downside to the integration of stakeholders within the dike design process.

The first step of the methodology is to analyse the possible dike designs and the impact that the different parameters have on the amount of safe dikes and on the surrounding area. The impact of the dike design parameters on the dike designs is analysed to identify which parameter has the largest impact on the number of safe dike designs. This information can be used to efficiently reduce the large amount of dike design possibilities to a manageable number. The impact of parameters on the surrounding area is studied by defining six user functions (Living, Nature, Agriculture, Culture, Recreation and Transport). The sensitivity of each design parameter with respect to each user function is then analysed.. Three data sets should be set up for different users (Spence, 2014a):

- one for a stakeholder unfamiliar with dike design,
- one for a stakeholder familiar with dike design, and:
- one for the expert stakeholders regarding this topic.

These datasets have to be made considering the knowledge of the stakeholder. For the unfamiliar stakeholder dataset, parameters with low impact or which need extensive explanation are initially left out and in a later stage optimized by the automized model. For familiar stakeholders only low impact parameters are left out. Experts are provided with all parameters. When both the impact of the parameters and the knowledge level of the stakeholder are known, the stakeholder can be provided with their corresponding dataset, after which the parameters with the most impact on remaining safe solutions can be adjusted first. By performing this step, the stakeholder can experience the impact of certain design choices. Then, the leftover parameters are optimized for the chosen user functions by the model. In the end, the dike reinforcement generated by combining the stakeholders preferred parameters and the desired user functions is visualized together with the impact on the six user functions. A visual representation of this process is given in Figure 1

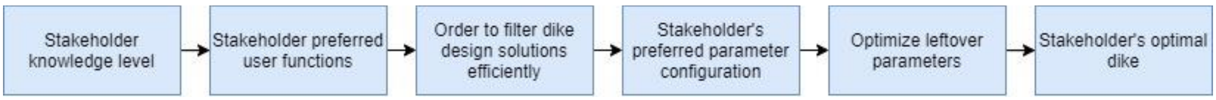

Figure 1: Simplified process

This methodology allows stakeholders to be integrated into a dike reinforcement project by not only having them look at the output, but also allowing them to experience the input side of a dike design process. This improvement allows them to easier understand design choices and more efficiently take part in discussions about the dike and decision making process.

Contents

1. Introduction

Witteveen+Bos was nominated for the water innovation prize in 2017 for their VR (Virtual Reality) dike technology (Witteveen+Bos, 2017). VR technology focuses on virtual environments in which you can move around. VR is an innovative method to involve stakeholders in the design process (Nova, 2018). Often, these stakeholders have little to no experience with dike design calculations. The VR-dike opened many doors towards stakeholder integration in design projects, because it made it possible to bridge the expertise gap between the stakeholder and the dike construction company. Examples of stakeholders are local residents, landscape architects, ecologists and licence providers. They are involved in the project but don't have the right prior knowledge . By having them work with VR dikes, they can instantly see what impact their choices have on other aspects of the design (Witteveen+Bos, 2017). The VR software did not work as intended, because the software was too complex for the stakeholder. The involving of stakeholders within early stages of design processes did show promising developments. This research thesis will focus on the involvement of stakeholders within a dike design process.

Many design parameters impact the design of a dike, see Figure 2 for an example. The design parameters can lead to different dike designs. Many different dike designs will meet the safety requirements of being resistant for failure mechanisms, although each of them has different design parameters. A few years ago, only a limited amount of dikes design would be calculated and adjusted until considered sufficient. Now, the increase in computational capacity enables us to calculate many different dike designs by means of, for instance, Microsoft Excel or Python. In this report, these dike designs will be referred to as outputs. Since these computer models generate many possible dike designs, it is easier to integrate stakeholders in the design process, as the calculations have already been executed. It is not possible, however, to show thousands of dike designs to a group of stakeholders and assume they select the same one. The goal of this research is to bridge the gap between stakeholder integration and efficient dike design. In the end, a stakeholder should be able to understand what impact design decisions have on the dimensions of the dike, and its impact on the surrounding area. A funnel system can filter out outputs to enable stakeholders to make proper decisions. Figure 3 is a visual representation of funnelling: many outputs (all possible dike designs) go in, and a manageable amount of outputs comes out.

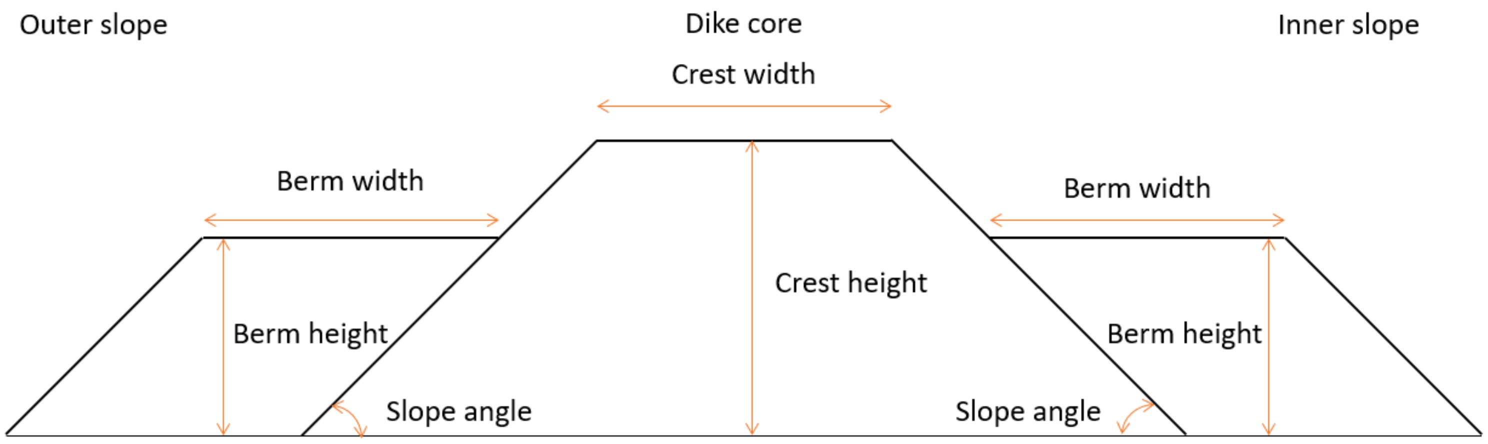

Figure 2: Dike parameters considered in this research project

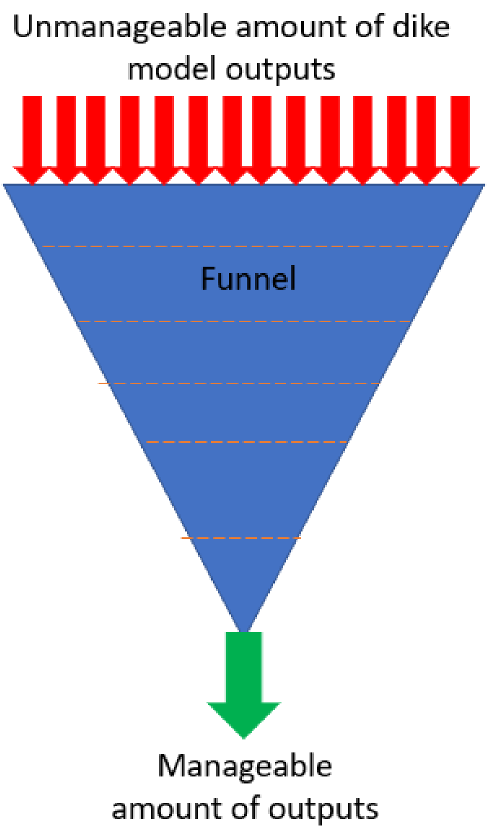

Figure 3: Visual representation of funnelling

1.1. Problem motivation

Though VR did not work as good as intended, the automatization in dike design processes increases the potential to integrate stakeholders in dike design. Because the calculations of the failure mechanisms are automatically performed, stakeholders do not need specific expertise to be integrated in the design process. However, a downside to this automatization is the large amount of possible dike designs which the models provide. Every potential dike that fits the safety norms can be calculated. Traditionally, the contractor would not integrate stakeholders into a design process because the knowledge gap is too big (Reed et al., 2009). When given a manageable and understandable number of dike design possibilities, the stakeholders can be integrated more efficiently within the decision making during the design process. If stakeholders have been involved more, the final design will meet design demands and design choices will be better understood by stakeholders. Integrating stakeholders within early stages of a design process is a rather new development for Civil Engineering. If the contractor can clearly show stakeholders which design choices have been made and what impact these decisions have on the final design and environment, the stakeholders will be more satisfied with the result. If the stakeholders can experience the impact of design choices themselves, and find that some parameters have more impact on for instance the recreational possibilities on a dike compared to other parameters, it is easier for the contractor to justify design choices made.

1.2. Problem description

A lot of work has to be done to properly integrate stakeholders within a dike design process. Morsing and Schultz (2008) built on the public relations model of Grunig and Hunt (1984) to suggest that organizations develop three distinct stakeholder integration strategies: informing, responding, and involving. Informing is a one-way communication flow towards stakeholders. Responding is a two-way information traffic, but asymmetrically with an imbalance in the favour of the company. Involving means trying to get stakeholders to participate in corporate processes. The first and second stakeholder strategy are usually used in dike design processes. The third strategy, involving, is a new trend in the dike designing. Because a large part of the design process is now automatized, stakeholder integration can potentially be pushed towards the second or third involvement strategy depending on the knowledge and skill of the stakeholder. An example of this stakeholder involvement is Joint Fact Finding (JFF), a fact finding method which is executed by multiple parties at the same time.(Ministerie van Infrastructuur en Waterstaat, 2020)

1.3. Research aim

The aim of this research is to develop a methodology which will filter a large amount of possible dike designs into a manageable amount of dikes to enhance stakeholder integration possibilities. In this context, manageable means that the stakeholder is able to understand the data provided, in this case possible dike configurations, and is not overwhelmed by the amount of data. The method aims to create a dataset which the stakeholder can work with themselves and clearly see what the consequences of design choices are.

1.4. Scope

Many design projects desire a more efficient stakeholder participation. Stakeholder participation ensures that the final product will be approved by all involved parties. A stakeholder integration tool is developed in this research. This report discusses the general methodology used to set up the stakeholder integration tool and applies the methodology for dike reinforcement project Wolferen-Sprok, a dike section in a rural area in the Netherlands. This reinforcement project has been chosen because this project was also used in Van den Berg (2018), a master thesis conducted for Witteveen+Bos regarding spatial integration of dike reinforcement. From this study, a dike design model has been developed for dike reinforcement project Wolferen-Sprok.

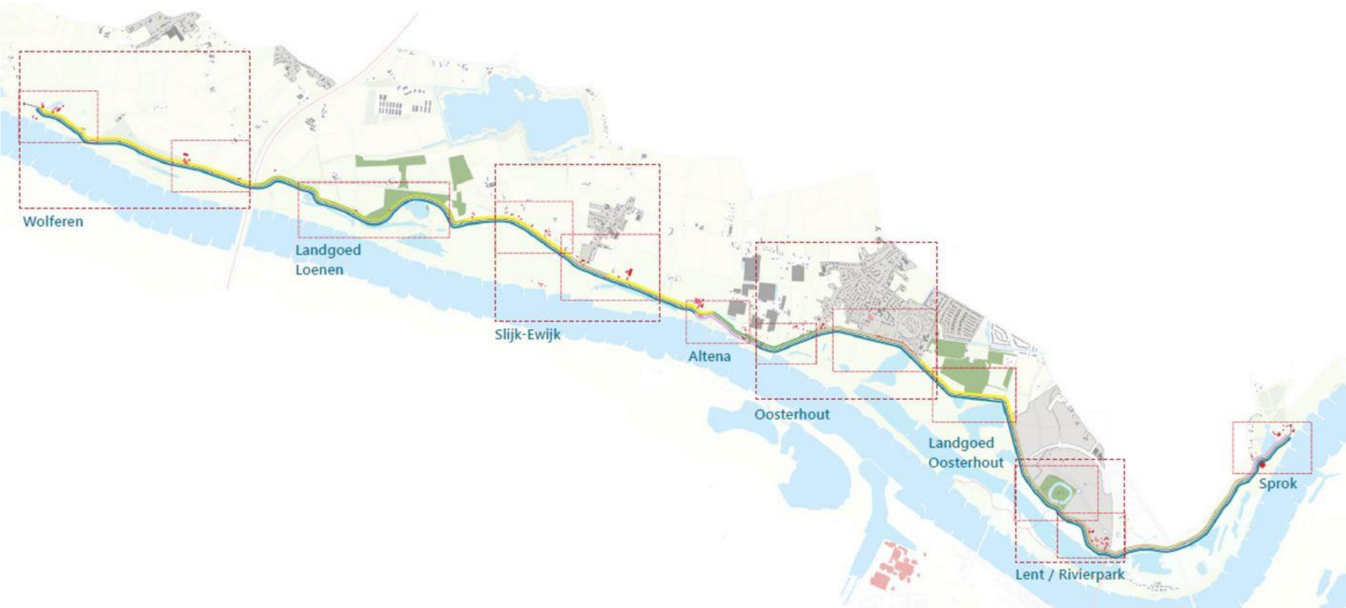

Figure 4: Overview of dike reinforcement Wolferen-Sprok. (Witteveen+Bos, 2017)

1.5. Research questions

The following main research question has been defined:

How can the outputs of a dike design model be made manageable and understandable for stakeholders to improve the integration of stakeholders in the design process?

To answer this main question, the following sub-questions will be answered.

1. .

The answer to this question will give insight in the complexity and amount of data that can be given to stakeholders whilst still being properly interpretable and not overwhelming.

2. What is the sensitivity of dike model parameters for filtering of the amount of dike design possibilities?

To develop a methodology that filters dike model outputs efficiently, we have to understand which parameters serve this purpose best.

3. What is the impact of dike design parameters considering important user functions?

The parameters not only impact the dimensions of the dike, but also its functionality for the users. Six user functions have been defined in Van den Berg (2018): Living, agriculture, nature, culture, recreation, and transportation. These user functions will be used in this research to show the impact of the dike on the surrounding area to the stakeholders.

1.6. Research method

In this section, the research methods for answering the sub-questions, introduced in section 1.5, are described. The relation between the main question, the sub-questions and the goal is given in Figure 5 :

1. When is dike design model input and output considered manageable?

A rubric will be developed to assess whether a data set consisting of a number of adjustable parameters is appropriate for a stakeholder. The stakeholders are divided into three groups: unfamiliar, familiar and expert. The unfamiliar stakeholder has never worked with a dike before and is not acquainted with scientific terms and units such as +NAP. Familiar stakeholders have not necessarily worked with dikes but do have knowledge of scientific terms and units such as +NAP. Experts are stakeholders who have worked with dikes or followed a course to learn about dikes. Several criteria will be defined using examples of other dike reinforcement projects, expert judgement, and assumptions. The answer to this question consists of two parts. First, a general explanation of when something is manageable is given. Then, a rubric will be set up regarding data manageability for dike design model input and output, considering the three stakeholder groups

2. What is the sensitivity of dike model parameters for filtering of the amount of dike design possibilities?

The impact of dike design model parameters regarding the reduction of possible dike designs will be determined by means of an sensitivity analysis. The result of this analysis will be a ranking of each parameter. The highest rank indicates a large reduction of the possible dike designs, whereas the lowest rank indicates a small reduction of possible dike designs. The analysis will be conducted with the input for the Python dike calculation model from Van den Berg (2018). The model input will be analysed in Microsoft Excel. The result is the number of safe dike designs for each parameter configuration. With that knowledge, a sensitivity analysis can be conducted for the following parameters: crest height, overtopping discharge, inner slope, outer slope, berm width and berm height. Then, the impact of each parameter on the dike width and height will be added because those are considered to be the most fundamental dimensions of a dike, and the easiest to show to stakeholders. Then, the rubric criteria from research question 1 and the rankings are used to select the parameters which must be presented to the three stakeholder groups.

3. What is the impact of dike design parameters considering important user functions?

The impact of dike model parameters regarding the six user functions will be determined by means of a sensitivity analysis conducted using the Python dike calculation model. The model finds the best performing dike parameter configuration regarding one of the user functions by checking the impact on the characteristics of the surrounding area. The impact of every safe parameter configuration on the criteria of the user functions will be analysed in Excel by means of a sensitivity analysis.. Finding the best performing parameter configuration for a distinct user functions will show the impact of the different parameters, which will be used to verify the results of the sensitivity analysis. The optimized parameter configurations will be used to validate the findings of the sensitivity analysis. The sensitivity analysis consists of finding the average, minimum and maximum value of the criteria for each possible value of a certain parameter. A total of 24 user function criteria, which can be found in Appendix B1, and seven parameters will be considered. The result of this analysis will be in the form of a table in which the parameters are ranked regarding the criteria of a user function, and a total ranking for each user function. An elaboration of the dike model is given in the next section.

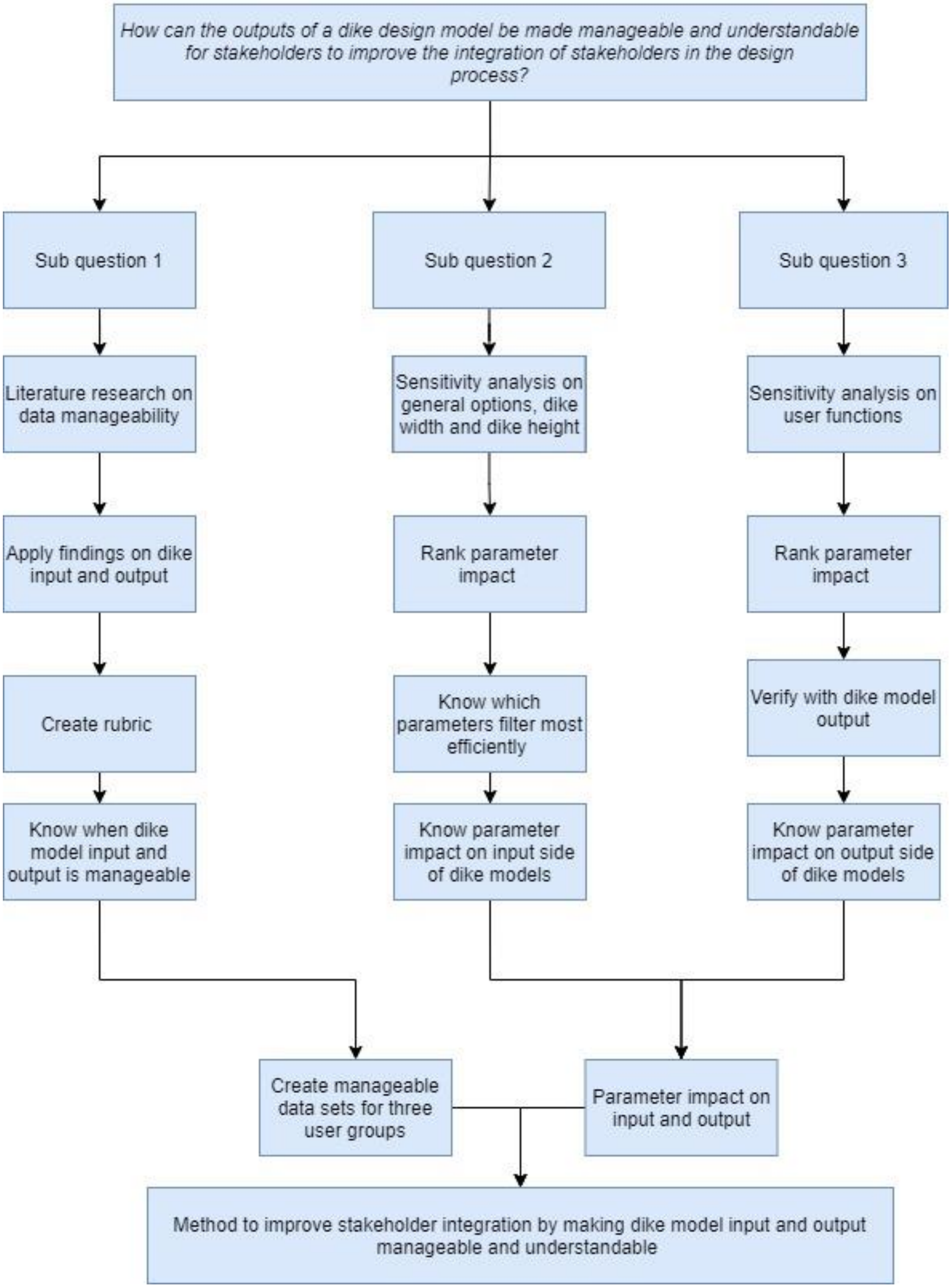

Figure 5: Relation between goal, research questions and research method

1.7. Dike design model

This section will explain how the dike model “Spatial quality model” works. One full model run takes about 20 minutes. Generating a visualization and impact plot takes 5 minutes. Figure 6 is a visual representation of how the dike model works.

The used dike model defines the geometries of all possible safe dike reinforcements, and considers the impact that these dikes have on the environment by means of a set of user functions. Then, the model generates a number of figures which show what the dike geometry looks like, and how it performs on the user functions compared to the other possible dikes. An example of these figures can be found in Figure 7. Lastly, the model can find the optimal parameter configuration for a certain user function.

To run the model, four elements must be given as input. First, the input parameters and possible configurations need to be added. Second, the geometries of the existing dike need to be added. Third, the shape files of the characteristics of the area need to be added. Examples of these characteristics could be the locations of the current houses, or the land that is currently being used for agricultural purposes. Lastly, the model needs the desired safety factor. The model does not calculate the safety factor for the parameter configurations. It needs a dataset which consists of input parameters and their corresponding safety factor, which can be calculated with for instance Deltares D-Geostability.

The model is used for two things: finding the impact that the parameters have on the total height and width of the dike, and evaluate how each dike reinforcement performs on the criteria of the user functions. The impact of the parameters on the height and width is simpler than the optimization process. The model evaluates all safe parameter configurations, after which two boxplots are created for each parameter. One of these boxplots indicates what impact a parameter has on the total width of the dike, and one shows the impact of a parameter on the height of the dike.

For the optimization process, the model first overlaps the shape files of the characteristics of the area with the geometries of all possible dikes. This way, the impact of all possible dikes on the user function criteria is known. When an optimization regarding a specific user function is desired, the model can search the database with impacts for the parameter configuration which scores best on the criteria of that user function compared to all other possible dikes. The model shows a chart with the scores for each criterium relative to the other dikes, and plots a top and side view of the dike reinforcement.

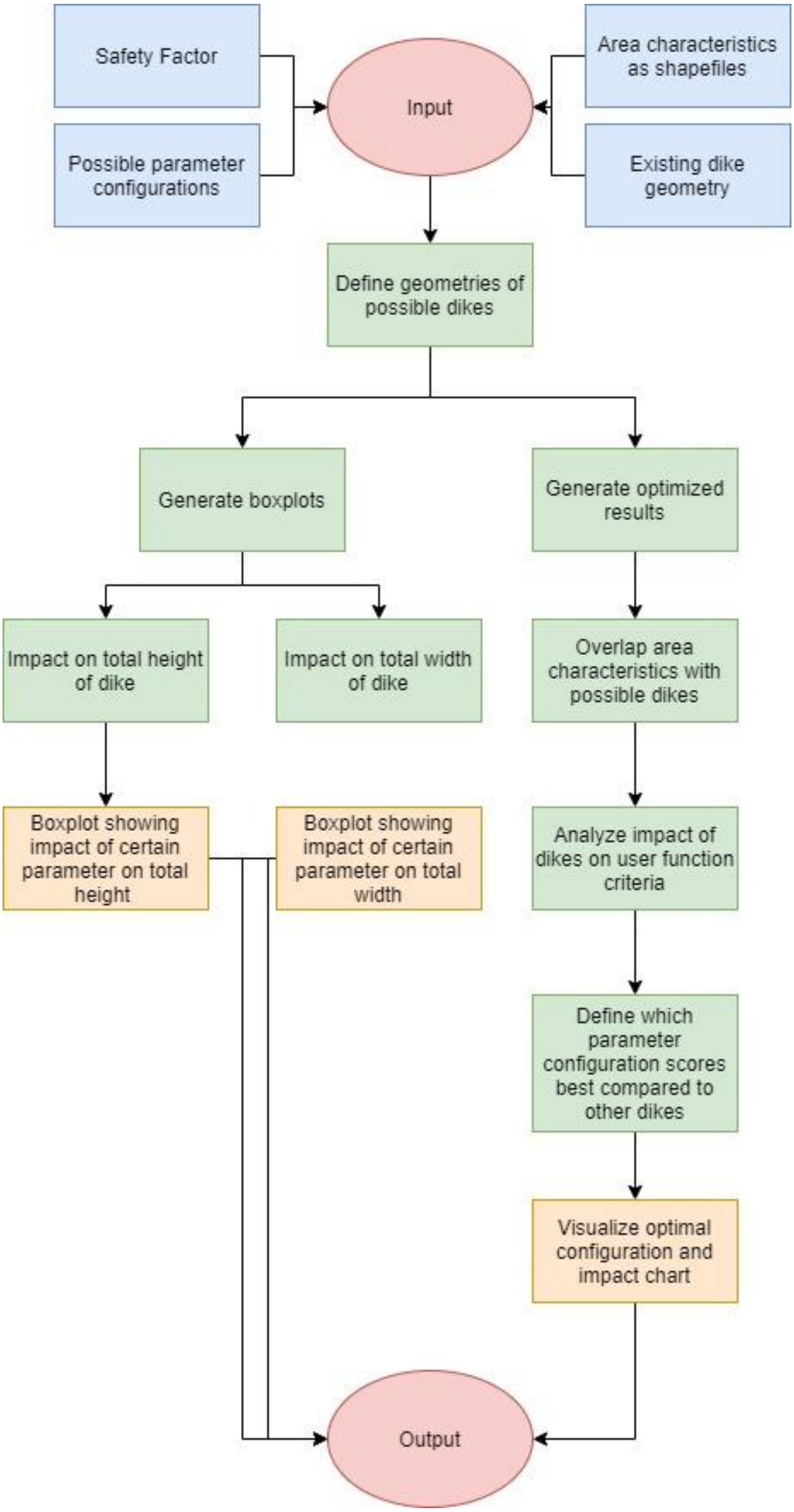

Figure 6: Dike model flowchart

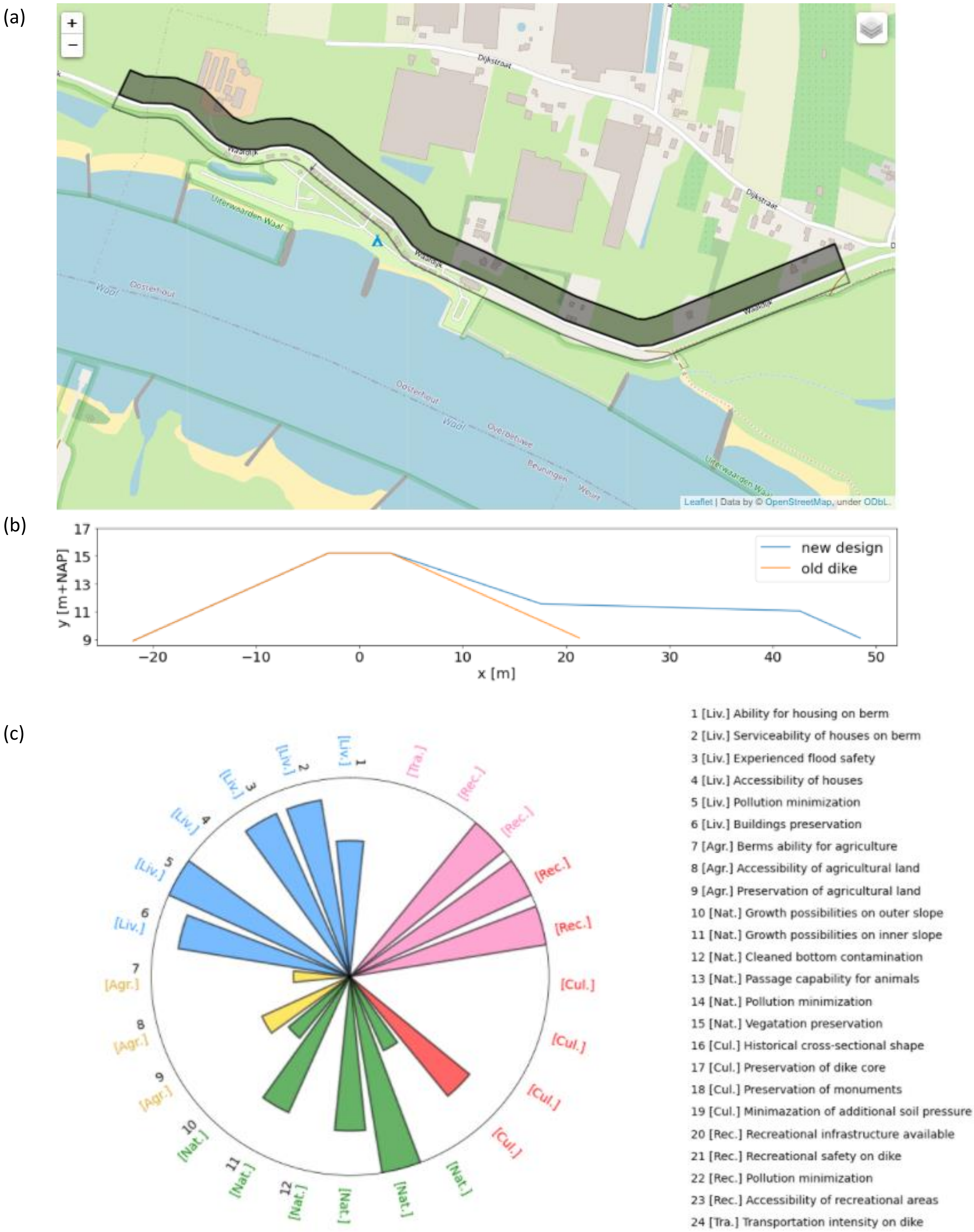

Figure 7: Optimization output. a: top view of dike reinforcement. b: side view of existing dike and reinforcement. c: Chart showing impact on each criterium

1.8. Application to dike segment Wolferen-Sprok

This research will develop a method to integrate stakeholders within a dike design process. This method will be applied to dike segment Wolferen-Sprok in the Netherland. Figure 4 shows a closed up top view of the study area. The red circle in Figure 8 shows the location of the study area. The dike reinforcement project of Wolferen-Sprok takes place in a rural area of the Netherlands close to Nijmegen. Wolferen-Sprok has sections both residential areas and non-residential areas consisting of for instance nature or agriculture. During the development of the method, the findings will be applied to the case study Wolferen-Sprok, and important findings during this application will be implemented in the general methodology which will be presented at the end of this research project. For the first sub-question of this research project, a general rubric will be developed. In a later stage, the findings of this rubric will be applied to the Wolferen-Sprok project. For the second and third sub-questions regarding the analyses of parameters efficiently filter the potential dike designs the input of the dike design model explained in section 1.7. The analyses will be explained generally both in the chapters conducting the analyses and in the general methodology.

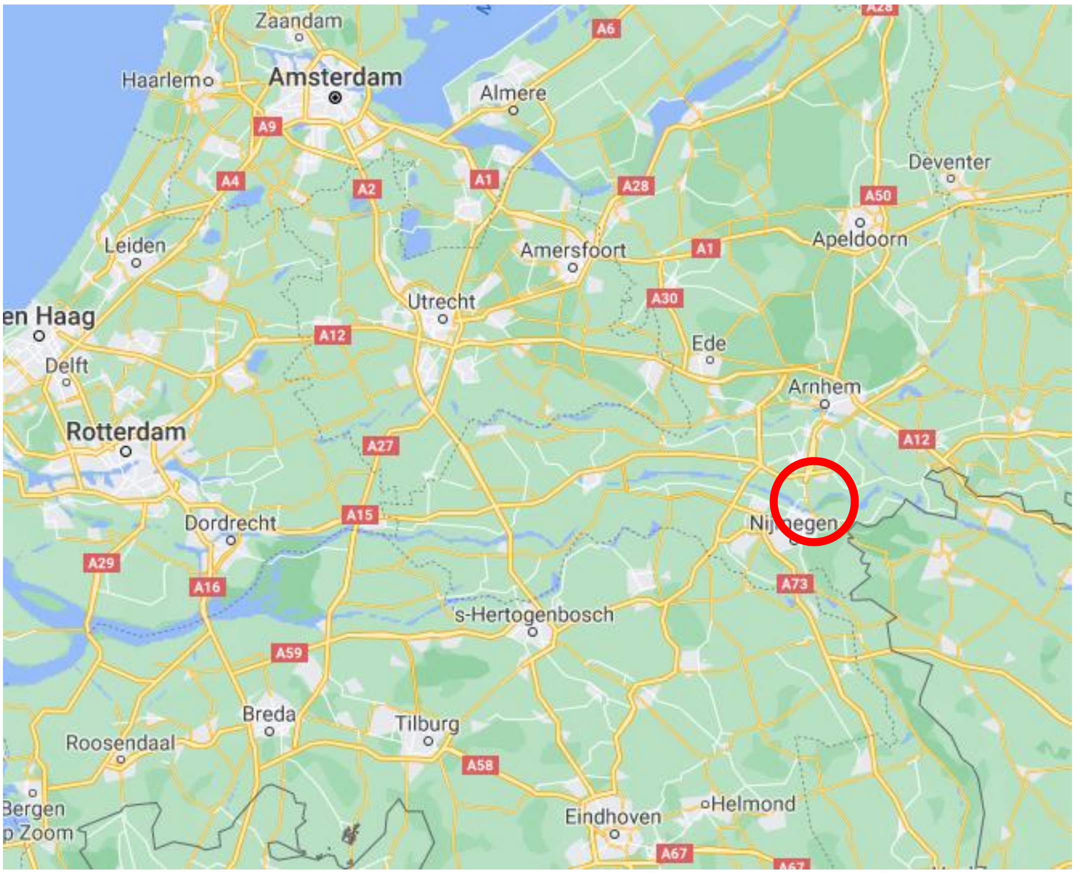

Figure 8: Location of Wolferen-Sprok

2. Manageability of information

In this section, the first sub question will be answered: When is dike design model input and output considered manageable? The section will explore data consideration and data management.

Stakeholders must be able to work with the provided data to ensure that stakeholder integration is possible. Therefore, we have to understand when data can be considered as manageable. This knowledge will then be applied to the output of the dike model. The Oxford Dictionary (2020) defines manageable as *able to be controlled or dealt with without difficulty*.

2.1. Understanding data

An important aspect to take into consideration when involving stakeholders into a design process is their lack of prior knowledge(Enserink, 2010). Results should be represented in a way that is suitable for these stakeholders. Stakeholders want to understand dike design model output. However, model output is usually presented in a way that is not easy to understand. The output may be in the form of numbers (Figure 9a), rankings or graphs (Figure 9b)(Spence, 2014a).

(a)

Soil type	ϕ_d [°]	c_d [kN/m^2]	γ_{dry} [kN/m^3]	γ_{sat} [kN/m^3]
Clay	19	2	15	15
Peat	14	4	2	10
Sand	28	0	18	20
anthropogenic sand	26	0	17	19

(b)

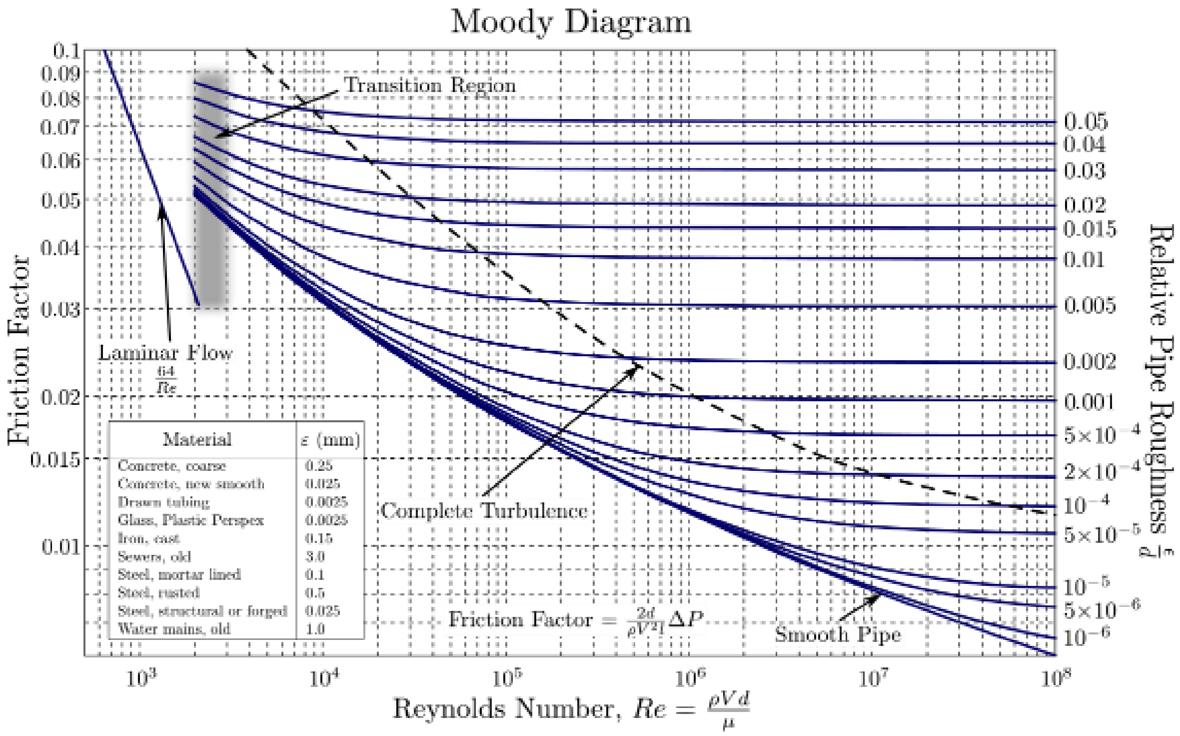

Figure 9: a: Data as numbers.(Warmink & Sterlini, 2015) b: Data as a figure (Fox, McDonald, Pritchard, Mitchell, & Leylegian, 2016)

Therefore, intermediate steps and results have to be shown to stakeholders in a manner that is understandable without the required expertise. If text does not work properly to depict a result, visualization is the go-to method of showcasing results (Wright, 2007). Spence (2014b) makes a distinction in three important principal concerns that should be identified when visualizing design results:

- The **type** of data: generally, data can be categorized as numerical (e.g. dimensions in meters), categorical (such as blood types) or ordinal (for instance on a scale of 1 to 5). Other data categories exist, such as relationships (e.g. marriage), textual data and unconventional forms, such as music notation.
- The **dimension** of the data: To what extent will the data be considered? Spence (2014b) states that the choice of which car to buy is much more difficult if about ten of its attributes must be considered than if only price is of concern. In the case of a dike design visualization, this means how many parameters will be taken into consideration.
- The **user** who must interpret a representation: which characteristics are important for the user? Different visualization methods can work for certain groups. However, every individual has its own perceptual and cognitive abilities.

These three principal concerns will be fundamental in this research. To state whether dike model in and output are considered manageable, it must first be known what **user** will be provided **which** type of data, and what its **dimension** is. The following section will develop a rubric regarding these three concerns.

2.2. Manageability of data

The Oxford Dictionary (2020) defines manageable as *able to be controlled or dealt with without difficulty*. This section will consider the manageability of data by developing a rubric. This rubric can be used to consider different data sets, and to state whether a set of data can be considered as manageable for the user. Whether the data set is considered as manageable will vary for different data users. Because it is not possible to generally quantify the manageability of data, as every stakeholder will desire a different set of data, the rubric will be made for three distinct types of data users, distinguished by their ability to interpret dike model input and output data. The three types of users will be unfamiliar, familiar and expert.

The rubric will consist of two parts: the interpretation of data, and the workability of the data. Each section has criteria, which are explained below. The criteria are used to identify the data type and data dimension. First, the criteria for interpreting the data are considered. The individual criteria of the rubric are considered in the next sections. The final rubric can be found in Table 9.

2.2.1. Rubric criteria considering data interpretation

The amount of data

The amount of data that will be distributed towards the stakeholders plays one of the most important roles regarding the manageability of the data set, as it defines the dimension of the data. If the set is too large, the stakeholder will not be able to find the information needed to interpret the data correctly. In such a case, the stakeholders cannot be integrated in the design process. The data amount should be tailor-made for the stakeholder so that the needed data can be found almost instantaneously. Distributing too little data will cause the stakeholder to believe that information is being withheld. For the data fit for stakeholders unfamiliar with dike design, only the important data is given, provided that it can be explained easily. Important data is for instance an explanation of the project, the location and the most impactful parameters. The set made for stakeholders familiar with dike design will have all important data, and the expert set has all data. In the case of a dike model, important data will be an explanation of the user functions and their criteria, the existing situation, and a description of possibilities regarding optimization of the dike considering user functions. The results for the amount of data are given in Table 1. The parameters are considered separately in the next section, as they play an important role in this research.

Table 1: Amount of data

Unfamiliar	Familiar	Expert
Important data is given if it can be explained without slang	Important data is given	All data is given

The number of parameters

The parameters will be fundamental for integrating the stakeholders within the design process, as they will be enabled to work with the different parameter configurations and see the impact of their decisions. How many parameters will be considered is part of the dimension of the data, and must be different for each stakeholder. By leaving out parameters with a small influence on the final design possibilities, stakeholders less acquainted with dike designs have less difficulty to understand what is happening in the model and what the impact of different parameters is. Leaving out input parameters which have little to no impact on the final product, makes the models easier to understand. A lot of these parameters, such as overtopping discharge, are usually fixed when the Environmental Effect Report is shown to the province. The new trend of involving stakeholders also leaves these parameters open for discussion. Therefore, the unfamiliar set consists of parameters that are both impactful and explainable without jargon. Experts or familiar stakeholders require more detailed information and therefore more parameters should be provided in their datasets. The results for the provided amount of parameters are depicted in Table 2.

Table 2: Number of parameters

Unfamiliar	Familiar	Expert
Only understandable and impactful parameters are provided	Impactful parameters are provided. Parameters with little impact or a small bandwidth are not provided.	All parameters are provided

The complexity of the data

The complexity of data is important to consider, especially for the stakeholders less familiar with dike design. The complexity of data is a part of the data type. When considering the slope of the dike, a 1:3 ratio is clear for anyone who is experienced with designing dike slopes. Someone unfamiliar with slopes would not know what the ratio means and possibly does not know which of 1:2 or 1:4 is steeper. Often, the parameter configurations can be simplified by means of examples and visualizing. If the data is presented too simple, experts may experience delay because the data could have been shown more efficiently. The data complexity is dependant on the amount of parameters, since parameters that are not provided don't need to be considered. For the expert, the model output can be provided. For the familiar stakeholders, the parameters can be accompanied by an explanation. The unfamiliar data user will be provided with limited amount of parameters. By adding an explanation to the provided parameters, the set can be used for a broader range of stakeholders. Some will be able to cope with the complexity instantly, while some may need extra explanation. The rubric for the complexity of the data is presented in Table 3.

Table 3: Complexity of the data

Unfamiliar	Familiar	Expert
The complexity of the data is minimized. More explanation is provided.	Model output is made less complex. More explanation and less jargon.	The model output is given.

Language of the data

The formulation and language use within the data set are also important when considering stakeholders with different expertises. The language is part of the data type principal. Jargon can be used for experts as they are experienced with dike design. The familiar group should only use language that is understandable with moderate knowledge of the subject: technical units and jargon are assumed to be understandable for a stakeholder familiar with the subject. The data set provided to the unfamiliar stakeholder should use no jargon at all, and may even need to simplify certain sections of the dataset. As an example, the interpretation of the dike slope, overtopping discharge and dike toe characteristics are understandable for experts, whereas local residents may not understand these characteristics. The results can be found in Table 4.

Table 4: Language of the data

Unfamiliar	Familiar	Expert
Simplified language	Language is understandable with moderate knowledge of the subject	Language level is expert, slang can be used.

The visualization of the data

The way that data should be visualized is a combination of the data type, dimension and user. (Spence, 2014a) Because the aim is to efficiently integrate stakeholders, visualizations play an important role in the data distribution. If the visualization is too complex for the stakeholder, the processing of the data can take longer than desired and consequently slow down the entire process. For visualization regarding unfamiliar stakeholders, only non-ambiguous figures should be used with a clear legend. Visualization for the familiar level can be a bit more technical, though some extra explanation could be added as stated in Table 3. The expert data visualization will be the model output. Table 5 shows the rubric criteria visualization for each data user.

Table 5: Visualization of the data

Unfamiliar	Familiar	Expert
Simple, non-ambiguous visualization, clear legend	Visualization with help/extra explanations	Model output

2.2.2. Rubric criteria considering data workability

This section will consider the workability of the data. In this context, workability means whether the stakeholder can use the data provided to find the influence of design choices and experience the design process by themselves. If the data will be shown to the stakeholder, but the stakeholder will not work with the data, these criteria do not need to be considered regarding the manageability of the data.

Needed software

To work with model output data, software will always be needed. There is a large variety in software. Flexibility, functionality, and code language can play a part in whether the stakeholder is able to use the software. If a stakeholder is already familiar with certain types of software, these software packages will more likely be considered manageable. For experts, the dike model used by the company in charge of designing the dike is generally useable. For both unfamiliar and familiar stakeholders, this software can be too complex. Simpler software then needs to be used, such as a forms or another type of website. The rubric criteria for software needed are given in Table 6. Experts are assumed to be able to work with the software provided to the unfamiliar stakeholder group, but not vice-versa.

Table 6: Needed software

Unfamiliar	Familiar	Expert
The software is easy to get accustomed to, or a clear guide is available	Software is understandable with moderate knowledge of the subject	All aspects of software are used.

The accessibility of software

If the software is easily accessible, stakeholders are more likely to install and use it. Since this aims to integrate all possible stakeholders in the design process, the accessibility of the software is the same for each stakeholder: the software should be open source, or the company should be able to provide the software. Though the accessibility of the software is the same for each data user, it is important regarding the integration of stakeholders and is therefore incorporated in the rubric.

Table 7: Software accessibility

Unfamiliar	Familiar	Expert
Open Source software, or the software must be provided	Open Source software, or the software must be provided	Open Source software, or the software must be provided

Specifications

If a stakeholder is not able to use the model because their hardware lacks the proper specifications, they cannot work with the data. Though each data user must be provided with software by the contractor, or make use of open source software, some computers may be unable to run large models within considerable time. A computer with internet must be enough for both the unfamiliar and the familiar data user. The expert can be provided with more elaborate models. If that is the case, they should have a computer capable of running dike calculation models. Otherwise, a computer with internet is sufficient. Table 8 shows the rubric input for the computer specifications

Table 8:Specifications

Unfamiliar	Familiar	Expert
Computer with internet	Computer with internet	Computer capable of running dike calculation models. If the software is the same as the software for the familiar group: Computer with internet

2.3. Remarks regarding the rubric

This rubric is made considering the amount of data that will be distributed towards stakeholders within a design process, which tries to integrate a larger group of stakeholders. In section 4.3, the output regarding six user functions will also be considered. With the explanation provided, stakeholders are assumed to understand the user functions and their corresponding criteria Therefore, these user functions are not included in the rubric.

2.3. Final rubric

Table 9: Final Rubric

Criterium	Unfamiliar	Familiar	Expert
Interpreting the data			
Amount of data	Important data is given if it can be explained without slang	Important data is given	All data is given
Number of parameters	Only understandable and impactful parameters are provided	Impactful parameters are provided. Parameters with little impact or a small bandwidth are not provided.	All parameters are provided
Complexity of the data	The complexity of the data is minimized. More explanation is provided.	Model output is made less complex. More explanation and less jargon.	The model output is given.
Language	Simplified language	Language is understandable with moderate knowledge of the subject	Language level is expert, slang can be used.
Visualization	Simple, non-ambiguous visualization, clear legend	Visualization with help/extra explanations	Model output
Working with the data			
Software	The software is easy to get accustomed to, or a clear guide is available	Software is understandable with moderate knowledge of the subject	All aspects of software are used.
Accessibility	Open Source software, or the software must be provided	Open Source software, or the software must be provided	Open Source software, or the software must be provided
Needed specifications	Computer with internet	Computer with internet	Computer capable of running dike calculation models.

3. Influence of different parameters

This chapter will consider the influence of the dike design parameters, specifically regarding the reduction of the number of safe dike design outputs.

3.1. General impact analysis

Because the goal of this research is to have stakeholders reduce possible dike model outputs efficiently, our aim is to find out which dike design parameters exclude the most design outputs. In general, finding the most impactful parameters and ranking them will allow the development of a framework which will reduce the amount of safe dike design possibilities efficiently (Wang & Fu, 2005). The framework should start with fixing or reducing the bandwidth of the most impactful parameter, since this parameter excludes the most outcomes.

3.2. Dike model impact

The possible parameter configurations that this dike model offered are shown in Table 10. These configurations are derived from Van den Berg (2018), in which a solution space is defined based on the geometric design parameters of a dike. The desired safety factor is 1.48 (Expertise Netwerk Waterveiligheid, 2017). For each parameter, the number of safe options for each value has been determined as well as the percentual value of the total amount of safe options. The results of this analysis have been depicted as clustered column charts. An example of such a chart is given in Figure 10. The results of each parameter can be found in Appendix A: General parameter impact.

Table 10: Parameter configurations for dike section Wolferen-Sprok

Parameter	Unit	Configurations
Crest height	(m + NAP)	14.7, 14.8, 14.9, 15.1 , 15.4
Crest width	(m)	3, 6, 10.4, 13.4
Overtopping discharge	(l/s/m)	1, 5, 10
Outer slope	(1:)	3, 4, 5
Inner slope	(1:)	3, 3.5, 4
Berm thickness	(m)	1.1, 1.2, 1.3, … 3.8, 3.9, 4.0
Berm width	(m)	20, 21, 22, … 36, 37, 38

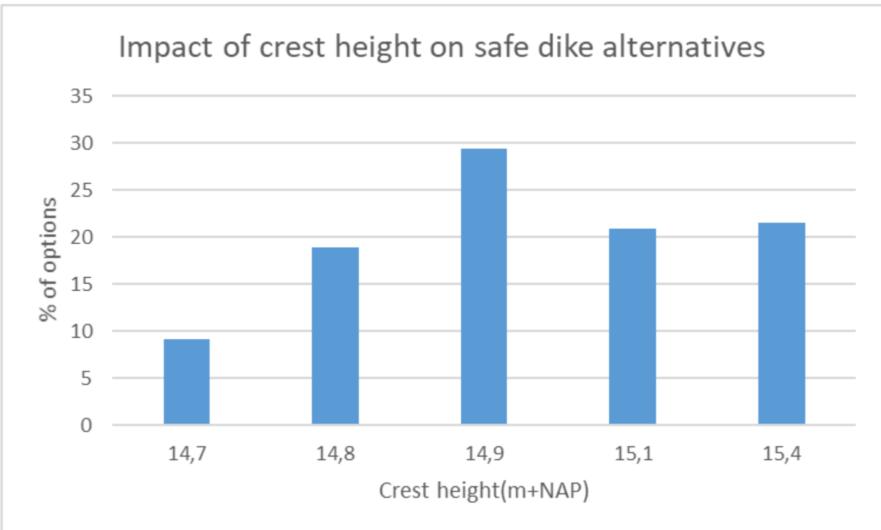

Figure 10: Impact of crest height on safe dike alternatives

Figure 10 shows that fixing the height reduces the alternatives with 71% for a crest height of 14.9 m +NAP up to a maximum value of 91% for a crest height of 14.7 m +NAP. For each parameter, the minimum and maximum values have been determined along with the range between these two values. To rank the parameters, a normalized version of the Kendall Tau distance method derived from Alvo and Yu (2014) has been used. The following formula has been used for finding the relative values:

$$Y = \frac{p_i - m^*}{M^* - m^*} \times N \qquad (1)$$

Using this formula, the performance of a single parameter compared to the other parameters could be determined. In this formula, Y [-] represents the relative value, p_i is the parameter value, m^* is the minimum score of all parameters and M^* is the maximum score of all parameters. The units of p_i, m^* and M^* are dependant on the unit of p_i. Since p_i, m^* and M^* are derived from the same set, their units are equal. Because some parameters have more configurations than others, the minimum and maximum amount of filtered dike design possibilities have been multiplied by the amount of configurations N [-]. When ranking data using different criteria, Eckenrode (1965) suggests to sum the scores of the criteria to find the overall performance. The following formula is used to find the total score:

$$Y_{overall} = \sum_{j=1}^{n} Y_j \qquad (2)$$

In this formula, Y_j is the result of formula 1 for criterium j, and n is the total amount of criteria. In this case, the criteria consist of minimum, maximum and range. The following section shows an example of this calculation regarding the score calculation of the Crest Height regarding the minimum amount of leftover safe dike designs.

The minimum amount of dike designs possibilities that are available is when the crest height is fixed on 14.7m + NAP. Fixing the crest height on 14.7m+ NAP leaves 8.68% of the total possible safe dike designs as potential dikes. The crest height has five different configurations. The minimum value considering the amount of configurations is therefore 8.68 * 5 = 43.4%. The performance of the parameters on this criterium is measured in %, and therefore the units of formula 1 are also in %. The next step is to find the score of the crest height relative to the other parameters. The following values have been filled into formula 1:

Symbol	Unit	Value
p_i	[%]	43.39
m^*	[%]	15.70 (minimum value of the set, in this case berm width)
M^*	[%]	100.00 (maximum of the set, in this case crest width)

The relative score of crest height regarding the minimal amount of filtered values can be calculated with the abovementioned values and is as follows:

$$Y = \frac{43.39 - 15.70}{100.00 - 15.70} = 0.33$$

For all parameters, the scores have been calculated regarding the minimum, maximum and range. To find the overall rank of a parameter, the relative scores of minimum, maximum and range have been multiplied with each other, and by a factor 100 to avoid unnecessary decimals. The parameter with the lowest overall score filters out the most parameters when fixed, and is therefore considered the most impactful parameter. Rank 1 indicates the best score. Table 11 shows the parameter values for minimum, maximum and range accompanied by the relative scores. The overall scores and ranks are also indicated in table 10.

Table 11: General parameter rankings

Parameter	Min	Y_{min}	Max	Y_{max}	Range	Y_{range}	$Y_{overall}$	Rank
Crest height	43,39	0,33	154,96	0,14	111,57	0,24	0,71	1
Crest width	100,00	1,00	100,00	0,00	0,00	0,00	1,00	3
Overtopping discharge	83,06	0,80	125,21	0,07	42,15	0,09	0,95	2
Outer slope	83,06	0,80	125,21	0,07	42,15	0,09	0,95	2
Inner slope	80,58	0,77	128,93	0,07	48,35	0,10	0,95	2
Berm thickness	25,62	0,12	281,82	0,47	256,20	0,54	1,13	4
Berm width	15,70	0,00	486,78	1,00	471,07	1,00	2,00	5

3.3. Dike width and dike height elaboration

The ranking has three parameters which have the same rank: the overtopping discharge, outer slope and inner slope. A distinction is made between these three parameters, because these parameters have a different effect on the total width and total height of the dike. The results for the overtopping discharge and outer slope parameters on the total width of the dike are also given in Figure 11a and Figure 11b. All model results are provided in Appendix A: General parameter impact. The boxplots represent the model output range regarding total width.

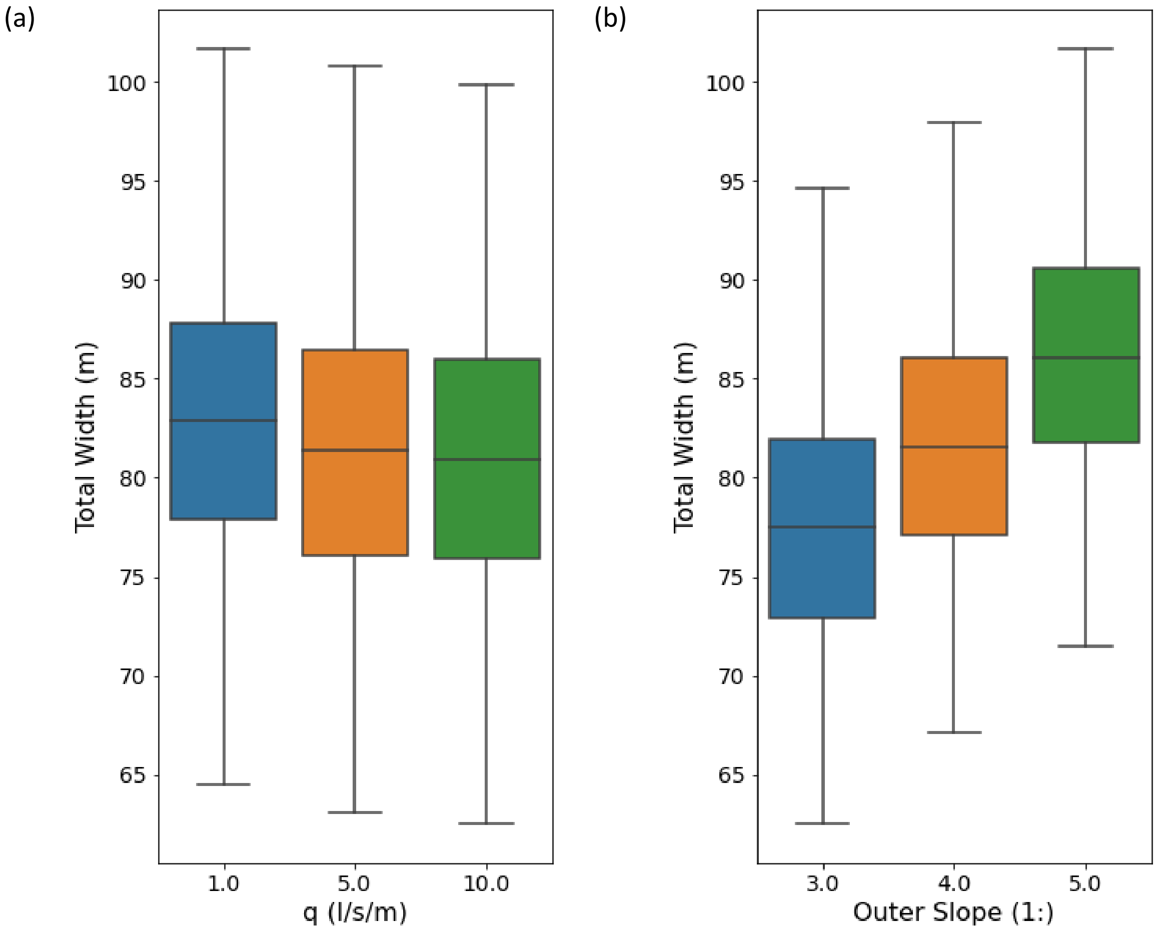

Figure 11: (a): Impact of overtopping discharge on total dike width. (b): Impact of outer slope on total dike width

The impact of each parameter on the total dike width has been considered and ranked. Because the minimum and maximum dike width and dike height are the same for all parameters, only the ranges that remain when fixing a parameter have been considered. As with the general safe dike design analysis, a normalized version of the Kendall Tau distance method has been used to determine how each parameter performed compared to the rest of the parameters. The tables showing the ranges for every parameter regarding dike width and dike height are given in Appendix A: General parameter impact. The total score of each parameter is calculated with formula 2 and combines the overall score, the score on dike width and the score on dike height. Table 12 below shows the results.

Table 12: Parameter ranking including impact on dike width and dike height

Parameter	$Y_{overall}$	Y_{width}	Y_{height}	Y_{total}	Rank
Crest height	0,71	0,20	0,00	0,91	**1**
Crest width	1,00	0,18	1,00	2,18	**3**
Overtopping discharge	0,95	0,86	0,44	2,26	**4**
Outer slope	0,95	0,36	0,39	1,70	**2**
Inner slope	0,95	0,74	1,00	2,69	**6**
Berm thickness	1,13	1,00	1,00	3,13	**7**
Berm width	2,00	0,00	0,56	2,56	**5**

3.4. Concluding remarks

This section has considered the impact of seven dike design parameters on the number of safe dike design possibilities. In the next chapter, these parameters will be linked to user functions. The results from this section have been derived from analysing the dike model input that has been used for the dike model for dike reinforcement project Wolferen-Sprok. The impact of each parameter will be combined with the impact on different user functions, which can change the rankings.

4. User function impact analysis

In this section, the third sub-question will be answered: What is the impact of dike design parameters considering important user functions? The impact of dike parameters on six predefined user functions will be analysed for dike reinforcement project Wolferen-Sprok. A general approach to the impact analysis of parameters on user functions will be provided, after which the analysis will be conducted for this study area.

4.1. User functions

Six user functions have been defined for a dike: living, agriculture, nature, culture, recreation, and transportation. Each of these user functions has been divided into user function criteria. All 24 criteria with an explanation can be found in Table 19 in Appendix B. The model considers how a dike design performs on the user function criteria and shows the score compared to the other dikes. An example can be found in Figure 7. The optimization finds the parameter configuration which scores best on a user function, such as living, and visualizes a top and side view of the dike. The sensitivity of each criterium regarding all parameters is checked and will be validated using the optimized parameter configurations.

4.2. General parameter impact

Every parameter of a dike design impacts some user function criteria. A large dataset of dike model outputs has been analysed to analyse these impacts. Because the impact of in- and decreasing the parameters needs to be found, a sensitivity analysis must be conducted (He & Fu, 2001). The input for this sensitivity analysis is a set of the parameters for which the impact on the user functions is desired, their possible safe configurations and the corresponding output. For this sensitivity analysis, the parameter impacts are compared to each other , which results in a ranking. The sensitivity analysis has been carried out by finding the average, minimum and maximum score of a parameter on each criterium. This time, as opposed to the analysis in chapter 3, the minimum, maximum and average score have been determined for each parameter configuration instead of for each parameter. This way, the impact of in- or decreasing the value of the parameter on each criterium can be defined, and the parameters can be ranked for each criterium.

4.3. Impact analysis of dike reinforcement project Wolferen-Sprok.

The impact analysis of parameters on the user functions has been conducted for each of the user functions separately. The parameter configurations have already been defined in section 3.2 and can be found in Table 10. Then, for each parameter configuration, the impact on each criterium has been derived from the dike model output, and the respective average, maximum and minimum value have been noted. These values can be used to derive the impact. For each user function, the results of the analysis are described in the next sections.

4.3.1. Living

The user function living consists of six criteria: available housing on the berm, serviceability options, experienced safety, accessibility, pollution minimization and demolished housing. For each criterium, the parameters have been ranked, and can be found in TABLE XXX. Rank 1 indicates the most impactful parameter. To find which parameter has most impact on living in general, the ranks for each criterium have been summed. If a parameter did not have any impact on a criterium at all, a maximum score of 7 is given for the summation. The parameter which has the lowest rank overall is considered most influential regarding the user function living.

Table 13: Impact of parameters on living criteria

Living	Crest height	Crest width	Outer slope	Overtopping discharge	Inner slope	Berm height	Berm width
Housing on berm	4	-	3	5	6	2	1
Serviceability	1	-	4	1	5	2	3
Experienced safety	1	-	4	1	5	2	3
Accessibility	-	1	-	-	-	-	-
Pollution minimization	-	1	-	-	-	-	-
Demolished housing	4	2	3	6	5	1	1
Sum	24	26	28	27	35	21	22
Final rank	3	4	6	5	7	1	2

4.3.2. Agriculture

The user function agriculture exists of three criteria: agriculture possibilities on the dike, accessibility of agriculture and demolished agriculture. Table 13 shows the results of the sensitivity analysis for agriculture. Both the berm height and berm width have rank 1, as their score is the same. The third most impactful parameter is crest width, followed by crest height, outer slope and inner slope. The least impactful parameter for agriculture is overtopping discharge.

Table 14: Impact of parameters on agriculture criteria

Agriculture	Crest height	Crest width	Outer slope	Overtopping discharge	Inner slope	Berm height	Berm width
Agriculture On dike	4	-	6	5	3	1	2
Accessibility	-	1	-	-	-	-	-
Demolished agriculture	5	4	3	7	6	2	1
Sum	16	12	16	19	16	10	10
Final rank	3	2	3	4	3	1	1

4.3.3. Nature

The user function nature consists out of six criteria: the growth possibilities on the inner and outer slope, cleaned bottom contamination, passage capability for animals, pollution minimization and preserved vegetation. The results of the sensitivity analysis regarding nature can be found in Table 14. The outer slope has most impact on nature, followed by crest height and crest width, which ranked equal. Berm height and berm width also ranked equal. Inner slope has the least impact on this user function. The passage capability and pollution minimization are only impacted by the crest width because that is the only parameter impacting the possibility of a road on top of the dike.

Table 15: Impact of parameters on nature criteria

Nature	Crest height	Crest width	Outer slope	Overtopping discharge	Inner slope	Berm height	Berm width
Growth possibilities outer	1	-	1	4	5	3	2
Growth possibilities inner	-	-	-	-	1	2	3
Cleaned bottom	5	3	4	1	6	2	7
Passage capability	-	1	-	-	-	-	-
Pollution minimization	-	1	-	-	-	-	-
Vegetation preservation	2	4	1	5	6	7	3
Growth possibilities outer	1	-	1	4	5	3	2
Sum	30	30	28	35	37	31	31
Final rank	2	2	1	4	5	3	3

4.4.4. Culture

The user function culture has four criteria: retaining of the historical cross sectional shape, preservation of the dike core, preservation of the monuments, and the minimization of additional soil pressure. Berm height and berm width are most impactful for culture, followed by crest height. The crest width and outer slope have the same score. The crest width is the only parameter that impacts the historical cross section.

Table 16: Impact of parameters on cultural criteria

Culture	Crest height	Crest width	Outer slope	Overtopping discharge	Inner slope	Berm height	Berm width
Historical cross section	-	1	-	-	-	-	-
preservation of dike core	3	5	4	6	7	1	2
Preservation of monuments	2	4	1	7	6	5	3
Minimization of additional pressure	3	-	5	4	6	1	2
Sum	15	17	17	24	26	14	14
Final rank	2	3	3	4	5	1	1

4.4.5. Recreation

The recreation user function has four criteria: possible infrastructure, recreational safety, minimized pollution and accessibility. The recreational infrastructure is reliant on the road on top. If there is no recreational infrastructure, there is also no recreational safety. The infrastructure and safety are therefore both only impacted by the crest width, which consequently has the highest rank regarding the recreation user function.

Table 17: Impact of parameters on recreational criteria

Recreation	Crest height	Crest width	Outer slope	Overtopping discharge	Inner slope	Berm height	Berm width
Infrastructure	-	1	-	-	-	-	-
Safety	-	1	-	-	-	-	-
Minimized pollution	2	4	1	7	6	5	3
Accessibility	1	-	1	4	5	3	2
Sum	17	13	16	25	20	22	19
Final rank	3	1	2	7	5	6	4

4.4.6. Transport

The transport user function consists of only one criterium: the possibility of a road on top of the dike crest. This criterium is only impacted by the crest width and can be either 1 (possibility for a road) or 0 (no possibility for a road). If the width of the dike exceeds the threshold for a road, the road possibility is therefore maxed.

4.5. Verification

The parameter rankings regarding the six user functions have been verified by having the dike design model optimize for one user function. For each of these optimizations, the dike dimensions have been noted. If a parameter was ranked high on a user function, the configuration for the optimized dike design was either a maximum or a minimum. Because the parameters most important for a certain user function have obtained an extreme value when optimizing the dike design regarding that user function, the results of this analysis are considered correct. The optimization outputs and the table with the parameter configurations for these optimizations are provided in Appendix B: Optimized dike model outputs.

4.6. Concluding remarks

Within the ranking of the criteria, all criteria are assumed to be equally important. For example, the possible agriculture has an overall average of 23.12 Ha. The demolished agriculture has a maximum value of 7.3 Ha. The impact of parameters on these values do not show that increasing the possible agriculture has more overall benefit on the amount of agriculture. The optimization model does take this into account.

5. Data provision

After the impact analysis of both the input and the output, the data needs to be provided to the stakeholder. This section will elaborate on what way of data provision shows most potential for this project. Three different groups of stakeholder have been considered in this research; unfamiliar, familiar and expert. A different data set has to be shown to these groups when cooperating in the design process of a dike. The proposed contents of the sets for each stakeholder type are provided in this chapter. The proposed contents are derived from the rubric and the impact analyses regarding total amount of safe options, height, width, and user functions.

5.1. Unfamiliar

The data set that should be provided to the unfamiliar stakeholder should consist of the following parts: a small introduction of the project, an explanation of how to work with the software, the user functions that have been considered and the parameters that can be modified by the unfamiliar stakeholder.

Introduction to the project

The introduction to the project should not be too detailed, but rather give a minor explanation of the goal of the project, the project location and how the stakeholder integration plan will work.

How to work with the software

The explanation of how to work with the software will give an insight of what is expected of the stakeholder and how the stakeholder can realise these expectations. The rubric criteria considering working with data in section 2.2.2. state that different software can be used for different data users. It is recommended, however, to use the same software for each data user. If each stakeholder makes use of the same software, the database will be a set of all stakeholder input. When all stakeholder are given the same software to work with, an internet page where choices can be registered is the optimal solution since it only requires an internet connection, potentially accompanied by a login, which can be provided to the stakeholders.

User functions

Properly defining the user functions is important for the unacquainted stakeholders. In particular, because it gives them the ability to state their preferences without specific knowledge of dike design. The user functions and their criteria must be provided, and the stakeholder can then choose to see a more elaborated explanation of the criteria. The explanation of criteria can be tailored for the stakeholder type by for instance reducing jargon or simplifying images.

Parameters subject to modification

The unacquainted stakeholder will only be able to fix parameters which are both important and explainable without use of jargon or technical terms. The other parameters will be fixed by optimizing them considering the preferences regarding the user functions. For example, the inner slope will not be stated as 1:3, or 1:4, but rather as steep, moderate, or gentle. The possible parameter configurations can be accompanied by their impact on the user functions.

5.2. Familiar

The data set provided to the familiar stakeholder is not much different from the unfamiliar stakeholders, but is more elaborate. It also consists of an introduction to the project, an explanation of the software, the explanation of the considered user functions and the parameters that can be fixed by this group of stakeholders.

Introduction to the project

As mentioned before, the data set for familiar stakeholders is similar to the dataset provided to unacquainted stakeholders. The introduction to the project can be more detailed regarding the existing dike, and give an explanation of the conducted impact analysis.

Software explanation

If the same software is being used for each stakeholder type, the explanation of the software will be the same for familiar and unacquainted stakeholders. Else, the software should be accompanied by a small stepwise manual. If different software is being used for stakeholder groups, the acquainted stakeholders will be provided a simplified version of the expert model, in which they can change the parameters which have the most impact, after which the model will fix the rest of the parameters considering the desired user functions.

User functions

An explanation of the user functions will be given to the familiar stakeholder. The explanations do not have to be simplified and could be presented in general or specified per criterium.

Parameters subject to modification

A stakeholder familiar with dike design will be able to change more parameters than an unfamiliar stakeholder. All impactful parameters will be subject to modification for this stakeholder group. Some jargon can be used for this data user, such as a slope with ratio 1:3, or a crest of 14.9 m +NAP. The impact of these parameters on the user functions should be provided. The stakeholder can also choose to leave a parameter blank. This will cause the model to optimize these parameters for the desired user functions. The model will automatically optimize the parameters that have not been marked as modifiable for the familiar data user.

5.3. Expert

The expert stakeholder group will gain all information needed to work with the dike design. The project goal, project description, information about the software and input variables accompanied by their impact on user functions.

Introduction to the project

The introduction to the project will be a description of the goal, project area, location and how the stakeholder integration is expected to work. The introduction for the expert can contain jargon and detailed images. The expert stakeholder is assumed to be familiar with this language and these types of images, and should not be overwhelmed by the amount of data. This way, the introduction does not have to be a large report, but rather an efficient explanation of the project.

Software explanation

The explanation of the software for experts depends on what is used. If simple software, such as mentioned in the software explanation of the unacquainted stakeholder, is being used, hardly any explanation will be necessary. If the proposed software is more in depth, an explanation or manual can be added. Since the stakeholder is an expert on the field of dike design, the manual of the software can be distributed.

User functions

With the detailed introduction provided to the expert, the user functions have already been presented. The specific criteria could be explained more elaborately in the same manner as they are explained for the familiar stakeholder.

Parameters subject to fixation

The expert will have freedom to work with all parameters. The order in which the parameters will be given is tailored to reduce the number of possibilities as efficiently as possible. The impact that the parameters have on user functions is given as well. The expert can choose to leave open certain parameters and have the model optimize these parameters for certain user functions.

6. General application of methodology

The methodology used in this research has been made general to make sure it can be implemented not only on the case study, but also on other dike design projects. The methodology follows 4 steps to integrate stakeholders within the dike design process. The method considers three main principles regarding data management, proposed by (Spence, 2014a): the data type, data dimension and data user. This methodology finds out when data is manageable, and executes two sensitivity analyses to find the most important parameters. One sensitivity analysis regards the potential of a parameter to filter out dike design options, and one sensitivity analysis regards the impact of a parameter on user functions.

Step 1: Data manageability

Whether the data is manageable or not is dependent on the amount of data that must be reduced initially. The rubric of chapter 2 can be considered for a project to find out whether the provided data can be considered as manageable. The rubric considers the manageability of data for 3 distinct users: The first set of data users are stakeholders unfamiliar with dike design. These have no experience with dike design and are not familiar with technical language. The second set of users are stakeholders familiar with dike design. These stakeholders do not necessarily have experience with dike design but do understand some technical language such as m+ NAP and slope 1:3. Finally, the third set of users are experts, which have experience with dike design. The criteria of the rubric will result in three data sets for the project, as can be seen in chapter 5.

Step 2: Data analysis regarding filtering

The second step of this methodology finds out which parameters are most impactful on the filtering of possible dike designs. By filtering the amount of dikes the stakeholder will not become overwhelmed by the amount of dikes provided. To find out which parameter is most impactful on filtering, the safe dike designs need to be analysed. First, for every parameter, the possible configurations need to be determined. For each parameter configuration, the percentage of safe dikes that have that configuration needs to be found. Then, for each parameter, find out which configuration filters out the most possible dikes, and which one filters out the least amount of possible dikes, and the range between the minimum and maximum value. To compare which parameter performs best in each of these three categories, minimum, maximum and range, formula 1 from chapter 3 needs to be filled in for each parameter and each of these three categories. To extend this analysis, the influence of each parameter on the total width and total height of the dike is also taken into account. The same formula should be applied. Once the score of each parameter on minimum, maximum, range, impact on width and impact on height has been determined, formula 2 can be filled in for each parameter, which will give a final score to each parameter. The parameter with the lowest score reduces the amount of possible dike designs the most and is therefore most impactful on the reduction of possibilities and should be ranked 1. The parameter with the highest score reduces the possible dike designs the least and should be ranked last.

Step 3: Data analysis regarding user functions

The third step in this methodology finds the impact that parameters have on a number of predefined user functions. To analyse the impact, the potential dike designs must be analysed by a model first. The model needs to find how much a user criterium is impacted by a dike design. In this case, the output of such a model has been exported to Excel, where the impact of each parameter configuration can be found for each criterium by means of a sensitivity analysis. To conduct this analysis, find out the average score on a criterium for each parameter configuration. The minimum and maximum impact on a criterium must be the same for each parameter as it spans all possible dikes. The average score of a parameter configuration on a criterium can be used to find the impact. The range between the highest and lowest average score of a parameter configuration shows the impact the parameter has on the criterium. For each parameter and each criterium, find this range. The largest range indicates the most impactful parameter on that user function criterium. For each user function criterium, the parameters can be ranked on impact. Concluding, these ranks can be summed up for each criterium of a certain user function, to find the overall score on the user function.

Step 4: Integration

When steps 1-3 have been executed, the rubric from step 1 and the rankings from steps 2 and 3 can be combined. Once a stakeholder states its preference regarding user functions, the importance of parameters on that user function can be combined with the overall impact on the filtering of dike design solutions. Along with the other criteria of the rubric, a tailor-made data set can be provided to each stakeholder, after which they can work with the possibilities and in a later stage better understand choices that have been made, and have been better integrated within the design process of a dike. Figure 12 below summarizes these steps as a flowchart.

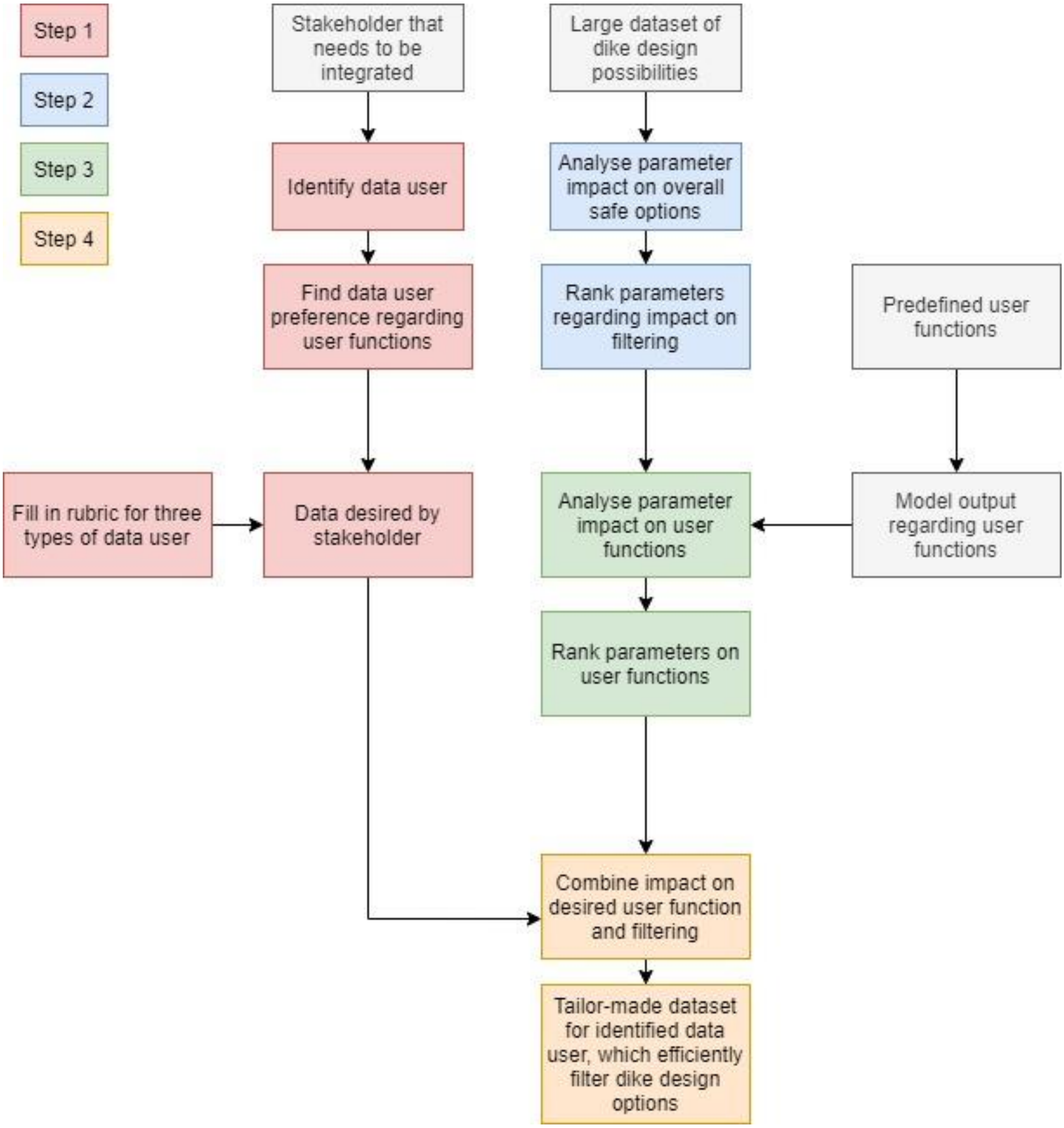

Figure 12: General method flowchart

7. Discussion

Rubric

The rubric is mostly substantiated by assumptions induced from literature and empirical findings. Moreover, the rubric is simplified by dividing all stakeholders into three groups. Further research should test this rubric on a large group of subjects with different backgrounds and also test this rubric in different projects where increased stakeholder integration is desired. The rubric can be extended by adding more groups or making a tool which has the data user identify themselves. The rubric only considers the input parameters because the user functions are assumed to be clear to all stakeholders. Whether all stakeholders indeed understand the output user functions should be tested as well.

Impact analysis on remaining dike solutions

The impact analysis on the remaining dike solutions resulted in knowledge on which parameters have most the largest impact on the reduction of safe dike options. The impact analysis considered six parameters when designing a dike. The results from this analysis have been executed for dike reinforcement project Wolferen-Sprok in the Netherlands. For further research, other design characteristics such as cover layer or piping solutions should be considered. In addition, this analysis could be conducted for different dike sections and projects to find if there are significant differences. Lastly, the rankings derived from this analysis could be combined with the user function impact, which may influence the final impact order.

Impact analysis on user functions

The impact analysis on user functions has been analysed by a model which imported shapefiles of user function criteria, and checked whether the dike reinforcement overlapped these areas. A sensitivity analysis has been conducted with the results to find the parameter influence on user functions. The shapefiles that have been used are the same ones that used by Van den Berg (2018), and are therefore over two years old. In these two years, a lot could have changed regarding the housing and nature in the area. Further studies should consider using more recent shapefiles for the dike model and adding more user functions such as costs. Finally, the criteria shown in the visualization of the impact show how a certain parameter configuration scores compared to other dike alternatives. This means that the impact of criteria compared to other criteria is unclear. As stated in chapter 4, demolished agricultural land is usually lower than new agricultural possibilities, but this is not visible in the generated polar plot.

Data provision

The datasets proposed in this chapter are developed for the dike reinforcement project of Wolferen-Sprok. Other project may have important information that needs to be stated within the data set. Some stakeholders can work with more difficult software which can increase the speed of the reduction process. Using the same programme for all stakeholders could save effort with analysing the results and distributing the data sets. The optimal way of distributing the data sets should be researched more. A tool could be made which, like a web shop, shows adjustable options and how much safe dike alternatives it leaves. An example of such a web shop is given in Appendix C

General methodology

This thesis has researched the impact of dike parameters in general and on user functions for dike reinforcement project Wolferen-Sprok. This is a rural area which has different characteristics than urban areas. Further research should focus on investigating whether the impacts in general for urban areas are in line with the impacts for rural areas. This research assumes that stakeholders will be involved after the impact analysis have been executed. It could be possible to integrate stakeholders in an earlier or later stage, and find out whether the timing of stakeholder integration influences decision making.

Limitations

This project has had a number of limitations which came forward due to three main reasons, being (1) the timespan of only 10 weeks to conduct this analysis, (2) the COVID-19 virus which reduced the opportunities for office working hours and face-to-face contacts where one could for instance walk by an employee or lecturers office for questions and (3) the limitations of to the dike model. The limitations of this research project are stated below.

- The rubric could not be tested in with a group of stakeholders which could state their preferences and commentaries on the outcome.
- The dike model had to be adjusted for this research project, which took more time than initially expected.
- The quantification of user function impact will often differ from what comes out of the model due to for instance emotional impacts. Taking everything into consideration when quantifying the impact of dike characteristics is not possible with current technology.
- Within this research project, not all failure mechanisms of a dike have been considered. The dike model is created to consider piping, inner slope erosion, inner slope stability and overflowing.
- The model assumes that the dike has a uniform cross section, which in reality will not be uniform when reinforcing a dike. Minor deviations will always occur with projects of such magnitude. These deviations have not been accounted for.

8. Conclusion and recommendations

8.1. Conclusion

The main question of this research thesis is:

How can the outputs of a dike design model be made manageable and understandable for stakeholders to improve the integration of stakeholders in the design process?

The research carried out resulted in a methodology to integrate stakeholders within the dike design process. The methodology has been performed for dike reinforcement project Wolferen-Sprok in the Netherlands.

The methodology starts with the main issue: the dataset with possible dike designs is too large to show to the stakeholders. Moreover, not every stakeholder desires the same data. Two paths should fix this issue. Firstly, the large dataset should be assessed to find the most efficient way of data filtering. When the designers understand how to reduce the large dataset efficiently, the stakeholders can funnel the number of options by stating their preferences. The assessment consists of two analyses ; a sensitivity analysis regarding the parameters and the total amount of safe options, finding what parameters reduce the total number of options the most, and a sensitivity analysis regarding different predefined user functions. In this case, seven parameters have been analysed and ranked for their general impact. The ranking is shown below. The results for Wolferen-Sprok are found in chapter 3.

Table 18: Final ranking

Parameter	Impact on reducing design options (1=highest, 6=lowest)
Crest height	1
Outer slope	2
Crest width	3
Overtopping discharge	4
Berm width	5
Inner slope	6
Berm thickness	7

The second analysis is a sensitivity analysis to find which parameters impact what criterium of the user function. The results for Wolferen-Sprok can be found in chapter 4. These results can be used to optimize the dike and show the stakeholder what the consequence of certain choices is.

When the two analyses have been executed, the next step is to find the stakeholders’ knowledge level regarding the subject. In this case, the subject is dike reinforcement projects. Three distinct knowledge levels are considered for this thesis: unfamiliar, familiar, and expert. The stakeholders have to select what their knowledge level is. If they find that their chosen level is too difficult or too easy, they should be able to change to another level.

When the knowledge level of the stakeholder is known, the dataset that should be distributed to the stakeholder can be defined. Combining the impact analysis and the knowledge level of the stakeholder, the amount of parameters that need to be fixed can be defined. If the knowledge level is unfamiliar, the parameters with little impact or parameters that are hard or time consuming to explain can be skipped and optimized by the model in a later stadium. A familiar stakeholder could take a look at some more in-depth parameters and the experts can consider all parameters. When the correct data set is distributed to the stakeholder, the filtering process can begin.

The first step of the filtering process will consist of finding the interests of the stakeholders regarding the user functions that have been proposed. The impact analysis can be combined with the user function analysis to find out which parameters are most influential on both the general filtering process and the user functions. The stakeholder then can fix the parameters in order from most influential to least influential, where only the parameters from the dataset are considered. The fixed parameters and the desired user functions are used as input for the dike calculation model. The dike design model optimizes the remaining parameters and visualizes the design in a top view, side view and impact chart. This way, the stakeholder is integrated in the design process and can experience the impact that certain decisions have on the geometry of the dike and its impact on the user functions, without being overwhelmed by the amount of data.

8.2. Recommendations

Forthcoming from the discussion in chapter 7 are the recommendations for further research and when using this methodology.

First of all, the rubric assumes that all stakeholders understand the meaning of the user functions, and can understand the criteria of each user function given that an explanation such as the one in Appendix B-1 is provided. It is recommended to research the understandability of the user functions defined in this project to make sure that all stakeholders indeed understand the meaning of these user functions and criteria. Moreover, it is highly recommended to test and validate the rubric. By providing a sample of subject stakeholders with a dataset tailor-made for their group of data users. If the dataset is considered manageable and understandable, the rubric is validated.

For further research, more design characteristics such as cover layer type or piping solutions could be researched. These can have significant impact on the safe dike designs, and the user functions. Additionally, it is recommended to add more failure mechanisms to the model. This potentially decreases the total amount of safe dike designs, which has an impact on the rankings. Most importantly, decreasing the amount of safe dike designs by adding more failure mechanisms is also a method to filter the amount of outputs and therefore make the dataset less overwhelming.

The shapefiles that have been used to find the impact of different dike designs on the user functions date back to 2018. Further research should consider using more recent shapefiles, for instance regarding the housing or land used for agricultural purposes.

Right now, the model used for assessing the impact of dike design alternatives on the user function criteria does not make a distinction between the impact of a criteria overall. An example could be the difference between the amount of houses that need to be demolished to build the dike, and the possibility to build houses on top of the dike. The amount of houses that can be built are on average more than the amount that need to be demolished. In the chart provided by the model, this difference can not be seen.

The most interesting recommendation is to create a tool to implement the findings of the methodology into a web shop type of application. An example of what this could look like can be seen in Appendix C. A stakeholder can then adjust the design characteristics of the dike and see the impact it has. Moreover, it allows the stakeholders that are interested in the functional characteristics (width and height) to adjust the parameters important to them, and the stakeholders interested in input (parameters) to adjust those. Lastly, stakeholders that are only interested in the output on user functions can also work with only the user functions. Stakeholders could even decide to work with a combination of these adjustable options. A web shop like tool would combine the principal concerns of data user, data type and data dimension, as it allows the users to tailor the dike with the options that interest them.

The final recommendation of this research is to find the integration possibilities in other stadia of the design process. This research is aimed to integrate all stakeholders in one of the first stages of the design process, but perhaps it is better to integrate some stakeholders later, for instance after the MER (Environmental effect report) stage. Integrating different stakeholders at other moments adds a new dimension to the integration process. Finding the optimal moment to integrate certain stakeholders would be interesting and valuable for dike design projects.

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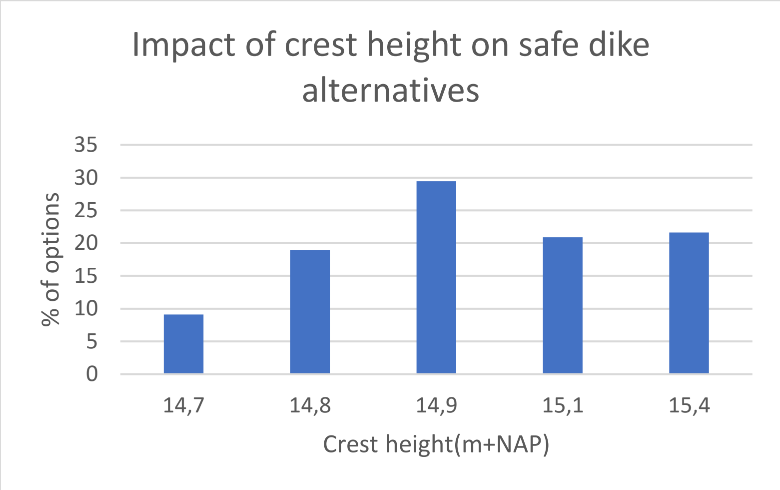
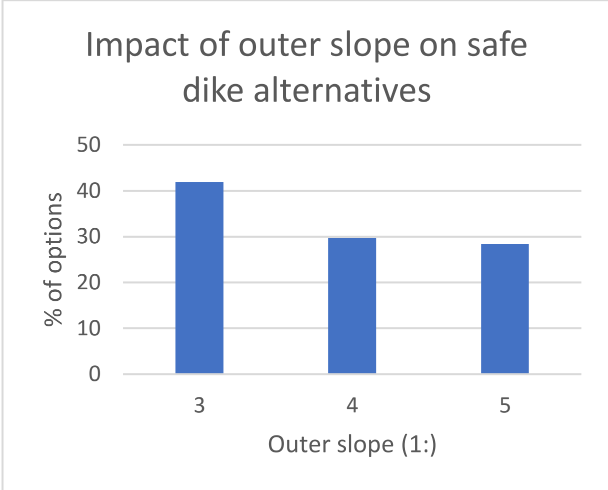
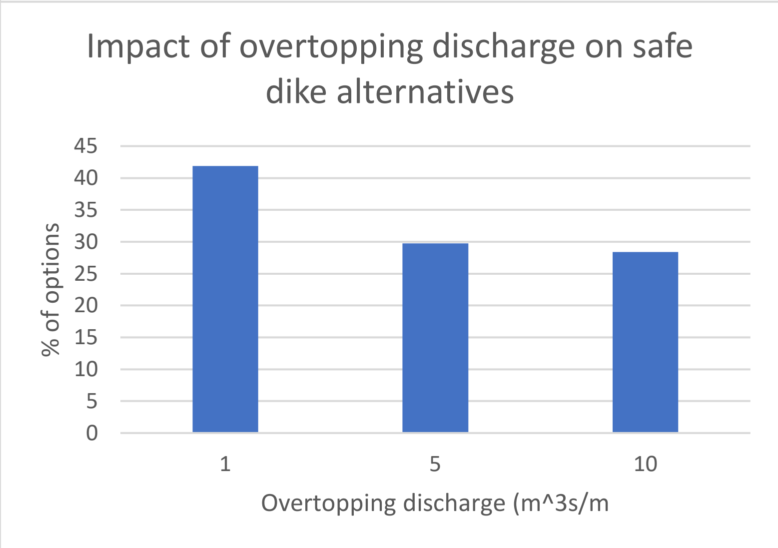
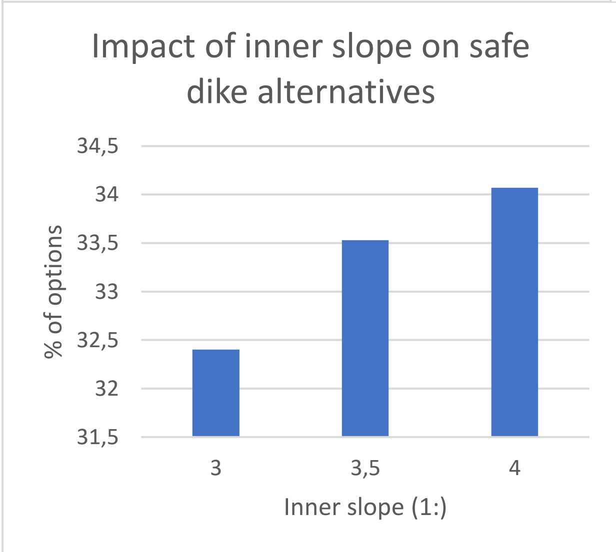
Appendix A: General parameter impact

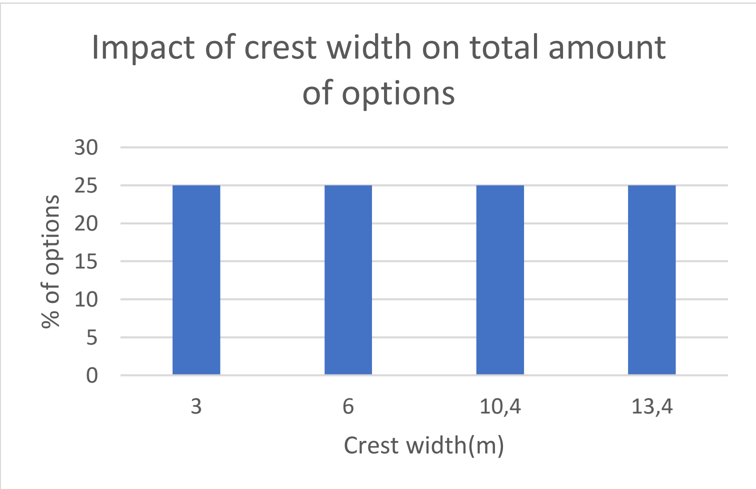
A-1: Impact on safe dike alternatives – charts

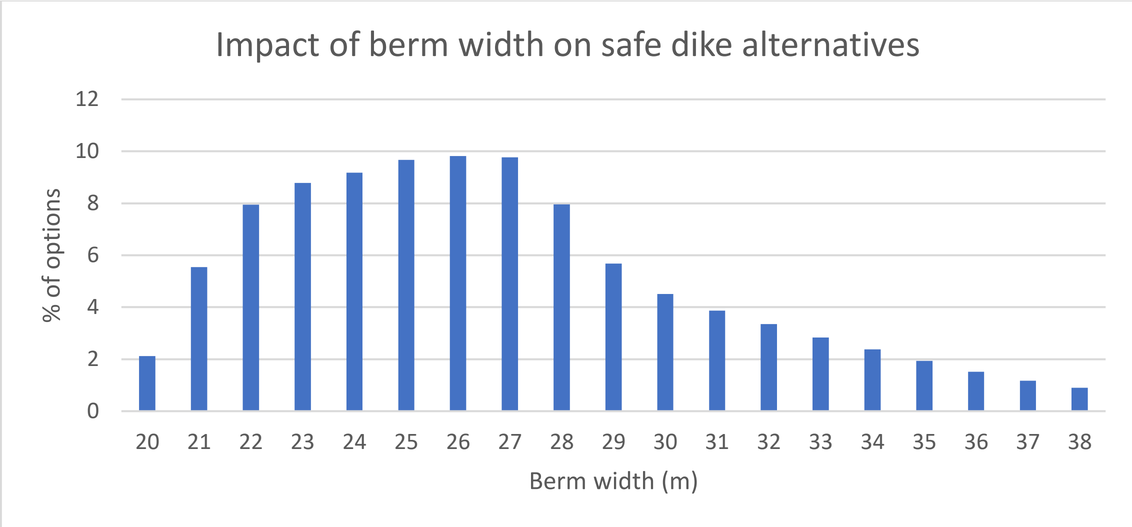


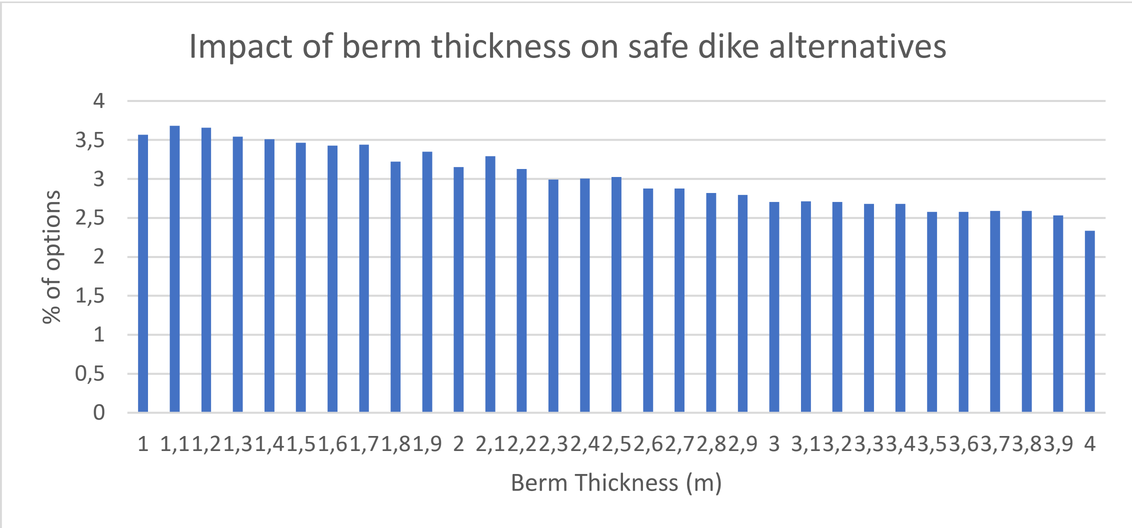




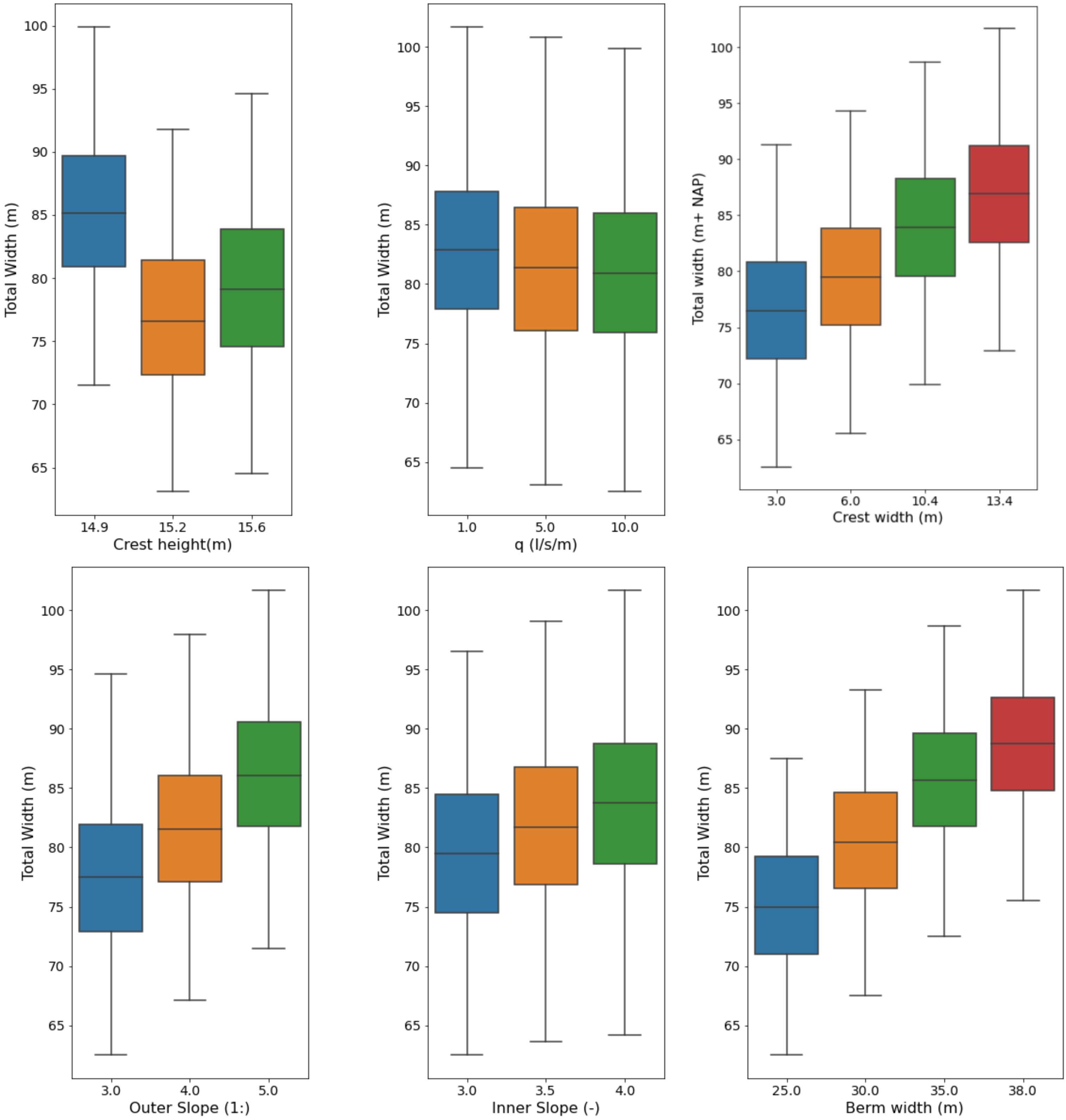





Impact of berm width on safe dike alternatives
% of options
0
2
4
6
8
10
12
20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38
Berm width (m)


Impact of berm thickness on safe dike alternatives
% of options
0
0,5
1
1,5
2
2,5
3
3,5
4
1 1,11,21,31,41,51,61,71,81,9 2 2,12,22,32,42,52,62,72,82,9 3 3,13,23,33,43,53,63,73,83,9 4
Berm Thickness (m)

A-2: Impact on total dike width – boxplots

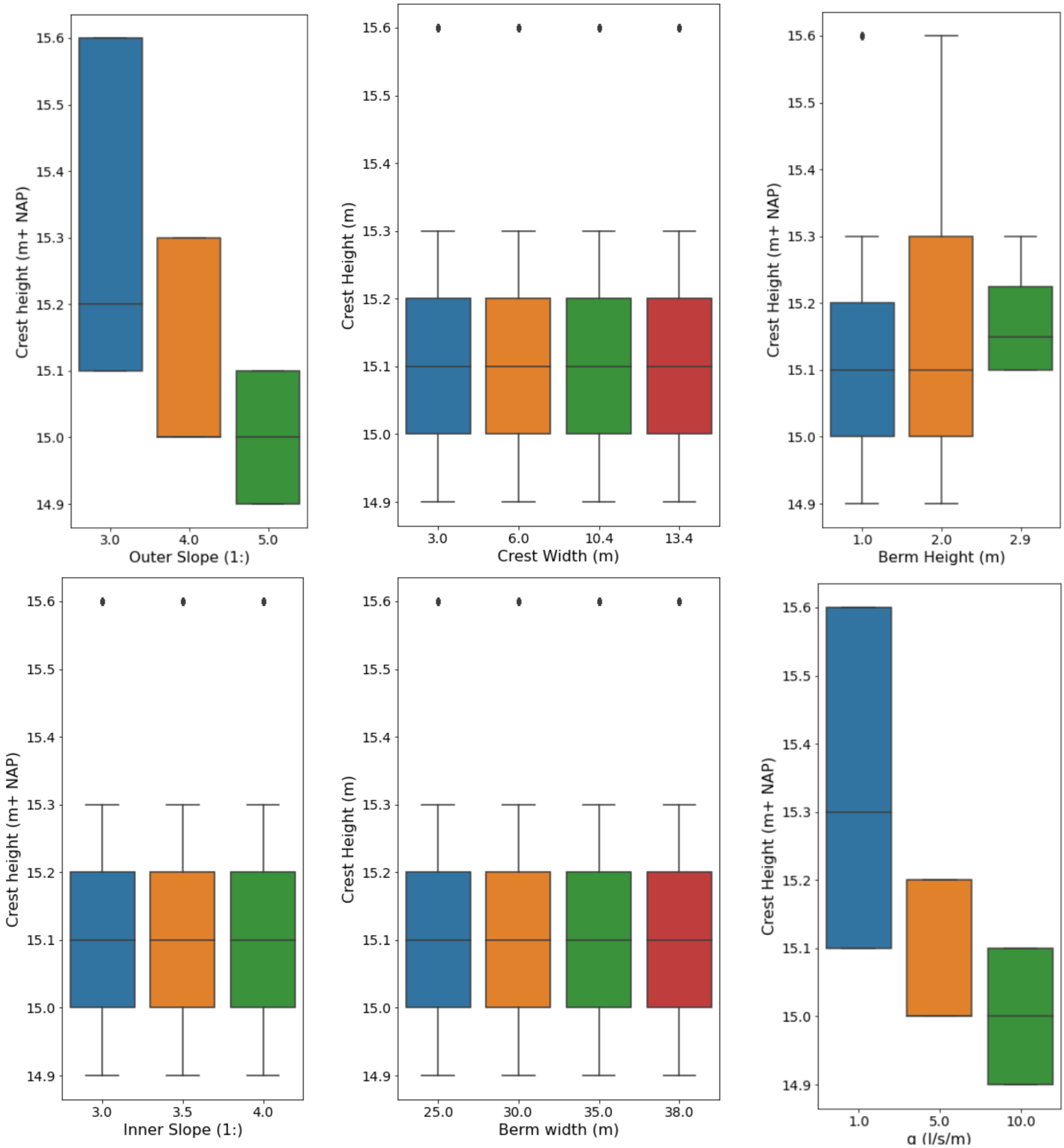


A-3: Impact on total dike width – table

Parameter	Total range	Range1	Range2	Range3	Average	Score	Rank
Crest height	39.2	28.4	28.7	30.1	29.1	0.20	3
Crest width		28.8	28.8	28.8	28.8	0.18	2
Overtopping discharge		37.2	37.7	37.4	37.4	0.86	6
Outer slope		32.1	30.9	30.2	31.1	0.36	4
Inner slope		33.9	36.4	37.5	35.9	0.74	5
Berm thickness		39.2	39.2	39.2	39.2	1.00	7
Berm width		25.0	25.8	28.8*	26.5	0.10	1

*For the berm width, 4 ranges had been considered because the parameter itself had a large range as well. Range 3 (35,0m) and range 4(38,0m) had the same value of 28,8. For the average value, range 3 has been multiplied by 2.

A-4: Impact on total dike height– boxplots



A-5: Impact on total dike height– table

Parameter	Total range	Range1	Range2	Range3	Average	Score	Rank
Crest height	0.70	0.10	0.10	0.10	0.10	0.10	1
Overtopping discharge		0.70	0.20	0.20	0.37	0.44	3
Outer slope		0.50	0.30	0.20	0.33	0.39	2
Inner slope		0.70	0.70	0.70	0.70	1.00	5
Berm thickness		0.70	0.70	0.70	0.70	1.00	5
Berm width		0.40	0.70	0.20	0.43	0.56	4
Crest width		0.70	0.70	0.70	0.70	1.00	5

Appendix B: Optimized dike model outputs

B-1: Table with user functions and explanation

Table 19: User function criteria explanation

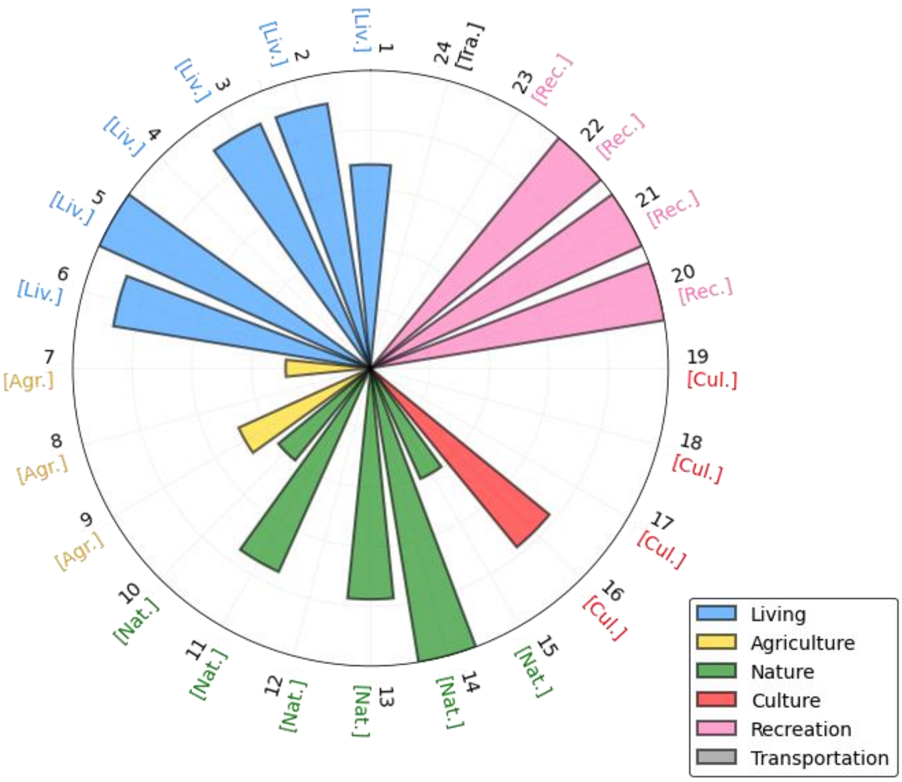
User function criterium	Explanation
Living	
Ability for housing on berm	The ability of housing on the berm defines whether there is living on the dike in the first place.
Serviceability of houses on berm	If houses are built on the cross section of the dike, there should be accounted for the limited serviceability during storm conditions.
Experienced flood safety	The experienced flood safety regards the feeling of safety rather than a calculation showing that the resident is safe. This is dependant of the dimensions of the dike.
Accessibility of houses	Visser and Van Dam (2006)states that the accessibility of the houses highly impact the value of the houses, but this criterium is set apart from the transport criterium as roads are not the only access method.
Pollution minimization	The pollution minimization regards noise- and air pollution, as they lower the quality of living in the area of a rural dike.
Agriculture	
Berms ability for agriculture	This criterium checks whether the berm allows for agriculture in the form of crops or animals. Crops are vulnerable to height differences due to moisture differences in the soil (Huinink, 2011). Animals are not fit for steep slopes.
Accessibility of agricultural land	The agricultural land needs to accessible for farmers to be able to work with the crops or animals.
Preservation of agricultural land	The preservation of agricultural land considers whether the existing agricultural land can stay or has to be removed to construct the reinforcement
Nature	
Growth possibilities on inner slope	This criterium considers the possibility to grow plants on the inner slope of the dike and is mainly impacted by the inner slope and the subsoil. The subsoil, however, is the same for each possible dike in this case.
Growth possibilities on outer slope	This criterium considers the possibility to grow plants on the outer slope of the dike and is impacted by the outer slope.
Passage capability for animals	The passage capability for animals is focussed on the crest of the dike and the activity that takes place on it. A busy road, for instance, negatively impacts the passage capability for animals
Vegetation preservation	This criterium considers whether the vegetation currently on the dike has to be removed or not.

Cleaned bottom contamination	Governmental regulations don't allow a decrease in bottom quality (Rijkswaterstaat, 2013). When future use of an area can increase health issues, contamination needs to be cleaned. The excavation during the construction of the reinforcement allows for the cleaning of contaminated soil.
Culture	
Historical cross-sectional shape	The trace of the dike is from cultural historical perspective more important than the cross section of the dike, because cross sectional properties are time dependant (Technische Adviescommissie voor de Waterkeringen (TAW), 1996).
Preservation of dike core	A good readable soil composition forms over years. When excavating a dike core, the archaeological value will become lost.
Preservation of monuments	This criterium considers whether existing monuments must be removed for the dike reinforcement.
Minimization of additional soil pressure	Changes in soil pressure impact the archaeological values of a dike, because of the same reason mentioned in "preservation of dike core".
Recreation	
Recreational infrastructure available	The recreational infrastructure consists of for instance a watch tower, picknick benches or a special walking route.
Recreational safety on dike	The recreational safety depends on the traffic intensity, as recreation on a dike mainly consists of walking and cycling, and is therefore negatively impacted by motorized traffic.
Pollution minimization	The pollution for recreation mainly consists of other user functions that are implemented instead of recreation.
Accessibility of recreational areas	The recreational areas need to be accessible to be used. It often shows that recreational areas are easily accessible since they are roads/walking paths or next to these. The recreational accessibility does not regard a large road for cars, since the road is already considered in the available infrastructure criterium.
Transport	
Transportation intensity on the dike	A road on a dike in a rural area is usually located on the crest of the dike when possible. Dike reinforcement project allow re-evaluation of such roads. Waterschap Hollandse Delta (2011) states that low traffic intensities require fewer wide roads compared to high traffic intensity roads.

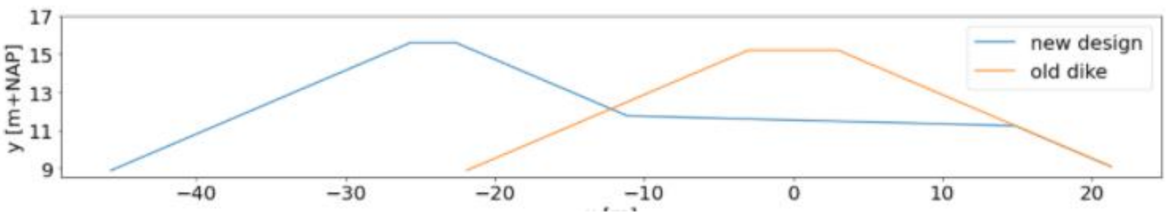
B-2: Sensitivity analysis user function criteria

	Crest height	Crest width	Outer slope	Overtopping	Inner slope	Berm height	Berm width
Living							
Housing on berm	4	-	3	5	6	2	1
Serviceability	1	-	4	1	5	2	3
Experienced safety	1	-	4	1	5	2	3
Accessibility	-	1	-	-	-	-	-
Pollution minimization	-	1	-	-	-	-	-
Demolished housing	4	2	3	6	5	1	1
Agriculture							
Agriculture On dike	4	-	6	5	3	1	2
Accessibility	-	1	-	-	-	-	-
Demolished agriculture	5	4	3	7	6	2	1
Recreation							
Infrastructure	-	1	-	-	-	-	-
Safety	-	1	-	-	-	-	-
Minimized pollution	2	4	1	7	6	5	3
Accessibility	1	-	1	4	5	3	2
Nature							
Growth possibilities outer	1	-	1	4	5	3	2
Growth possibilities inner	-	-	-	-	1	2	3
Cleaned bottom	5	3	4	1	6	2	7
Passage capability		1					
Pollution minimization		1					
Vegetation preservation	2	4	1	5	6	7	3
Transport							
Available transport		1					
Culture							
Historical cross section	-	1	-	-	-	-	-
preservation of dike core	3	5	4	6	7	1	2
Preservation of monuments	2	4	1	7	6	5	3
Minimization of additional pressure	3		5	4	6	1	2

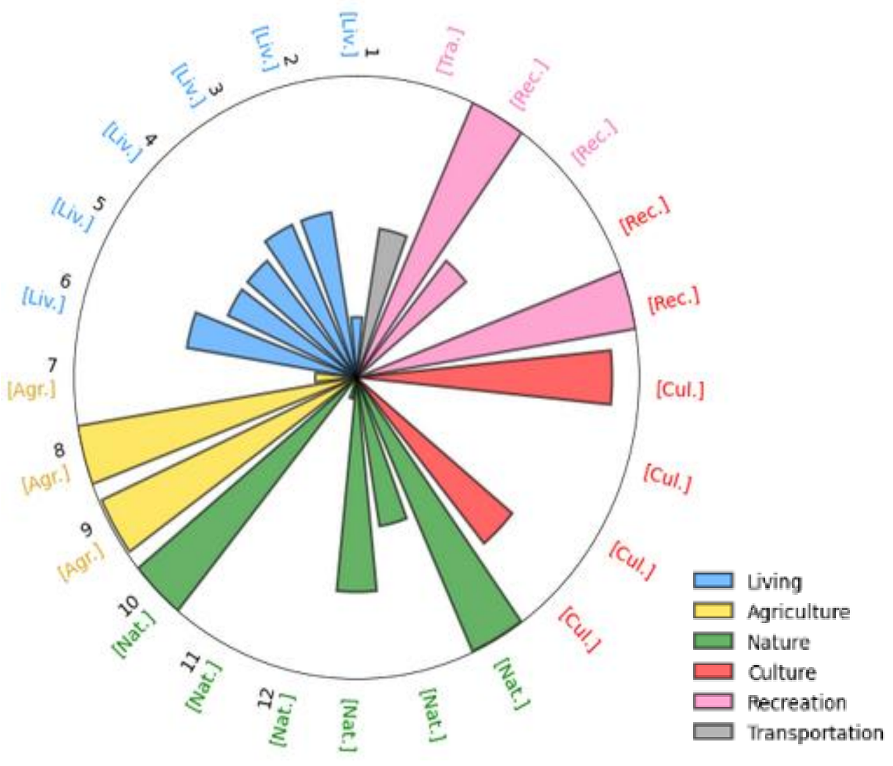
B-3: Living optimization



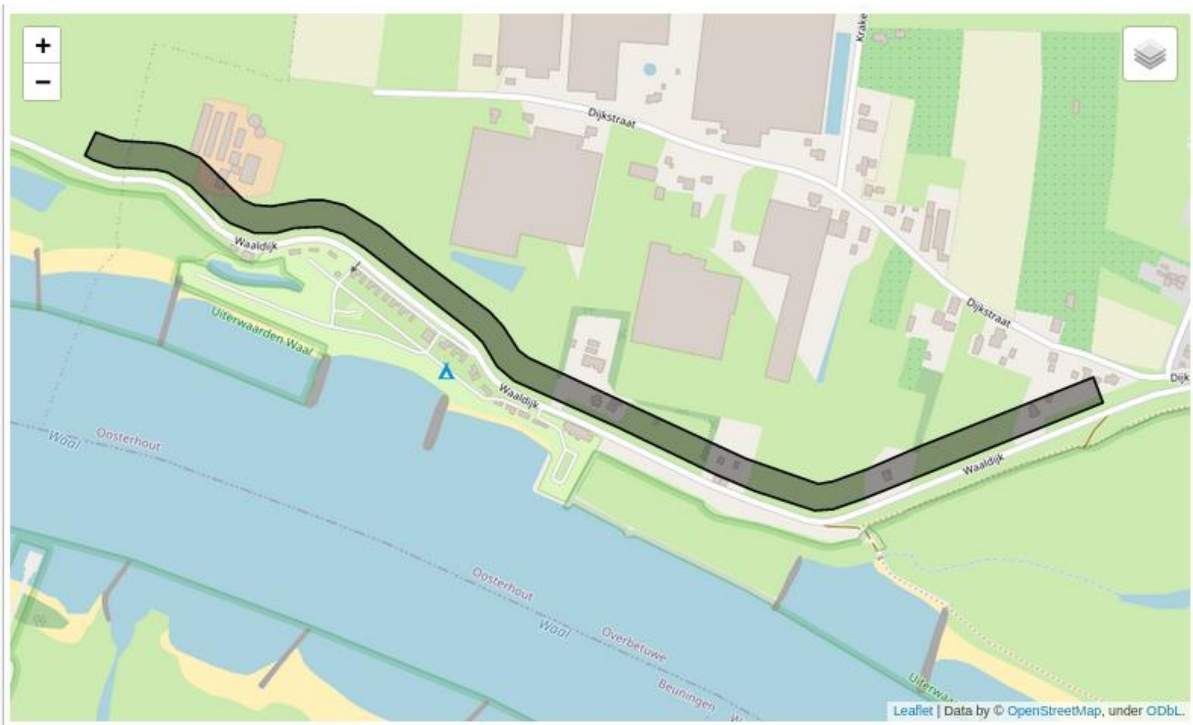
1 [Liv.] Ability for housing on berm
2 [Liv.] Serviceability of houses on berm
3 [Liv.] Experienced flood safety
4 [Liv.] Accessibility of houses
5 [Liv.] Pollution minimization
6 [Liv.] Buildings preservation
7 [Agr.] Berms ability for agriculture
8 [Agr.] Accessibility of agricultural land
9 [Agr.] Preservation of agricultural land
10 [Nat.] Growth possibilities on outer slope
11 [Nat.] Growth possibilities on inner slope
12 [Nat.] Cleaned bottom contamination
13 [Nat.] Passage capability for animals
14 [Nat.] Pollution minimization
15 [Nat.] Vegatation preservation
16 [Cul.] Historical cross-sectional shape
17 [Cul.] Preservation of dike core
18 [Cul.] Preservation of monuments
19 [Cul.] Minimazation of additional soil pressure
20 [Rec.] Recreational infrastructure available
21 [Rec.] Recreational safety on dike
22 [Rec.] Pollution minimization
23 [Rec.] Accessibility of recreational areas
24 [Tra.] Transportation intensity on dike

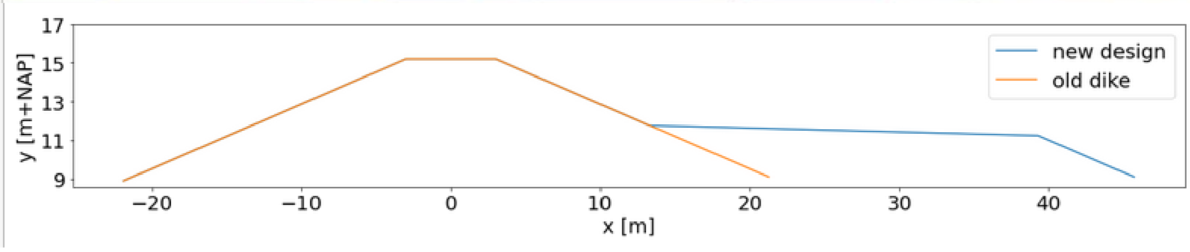


B-4: Agriculture optimization

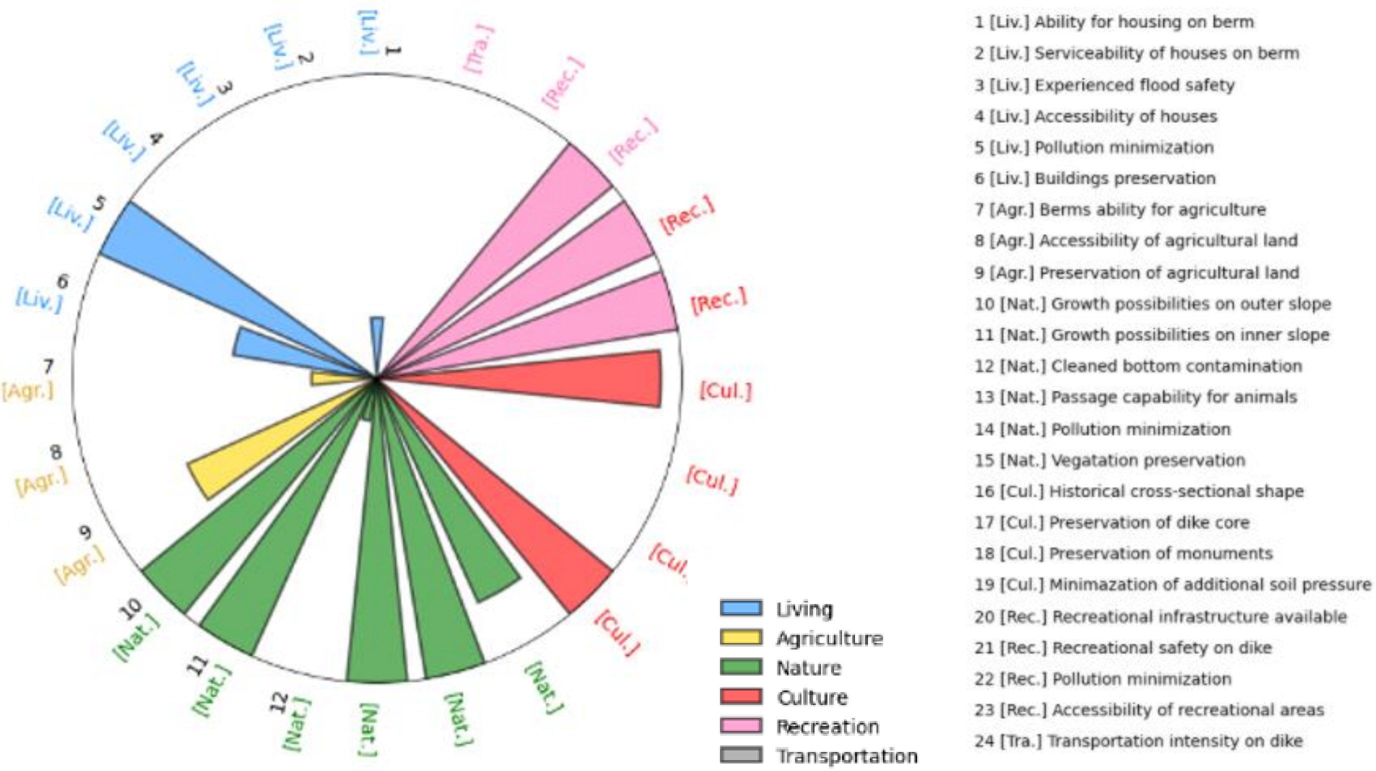


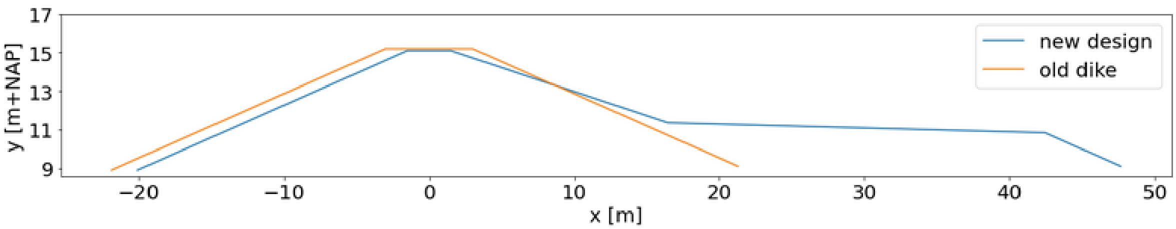
1 [Liv.] Ability for housing on berm
2 [Liv.] Serviceability of houses on berm
3 [Liv.] Experienced flood safety
4 [Liv.] Accessibility of houses
5 [Liv.] Pollution minimization
6 [Liv.] Buildings preservation
7 [Agr.] Berms ability for agriculture
8 [Agr.] Accessibility of agricultural land
9 [Agr.] Preservation of agricultural land
10 [Nat.] Growth possibilities on outer slope
11 [Nat.] Growth possibilities on inner slope
12 [Nat.] Cleaned bottom contamination
13 [Nat.] Passage capability for animals
14 [Nat.] Pollution minimization
15 [Nat.] Vegatation preservation
16 [Cul.] Historical cross-sectional shape
17 [Cul.] Preservation of dike core
18 [Cul.] Preservation of monuments
19 [Cul.] Minimazation of additional soil pressure
20 [Rec.] Recreational infrastructure available
21 [Rec.] Recreational safety on dike
22 [Rec.] Pollution minimization
23 [Rec.] Accessibility of recreational areas
24 [Tra.] Transportation intensity on dike



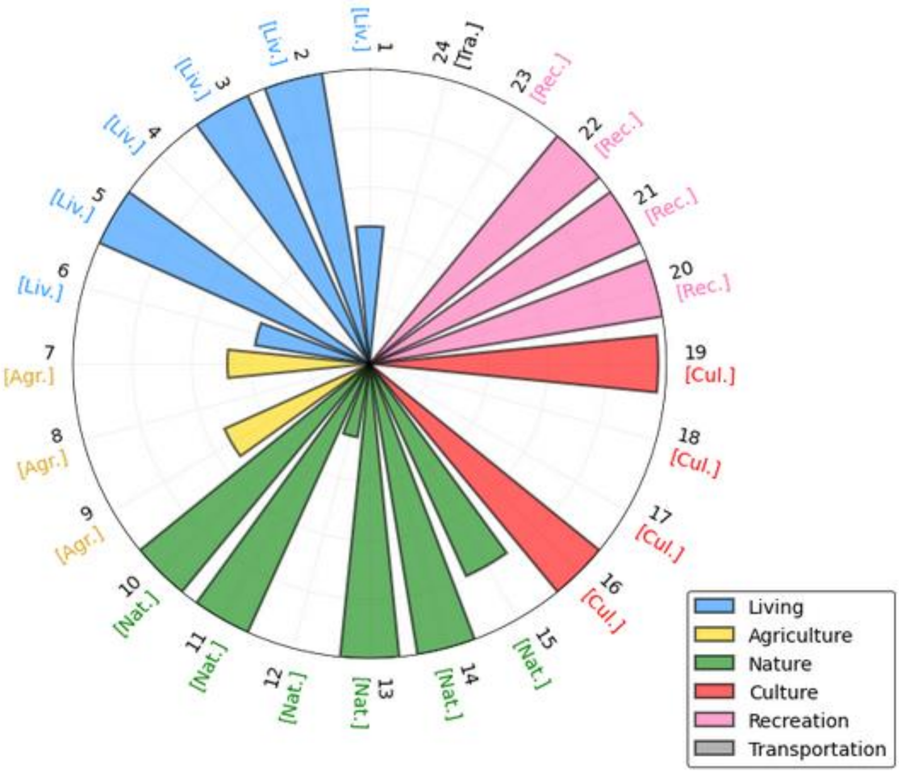


B-5: Nature optimization

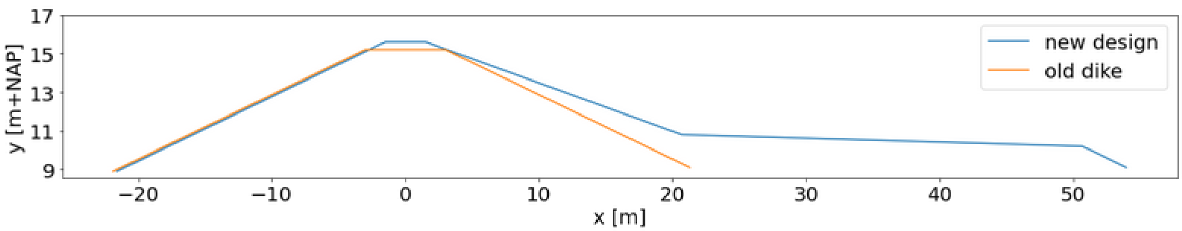




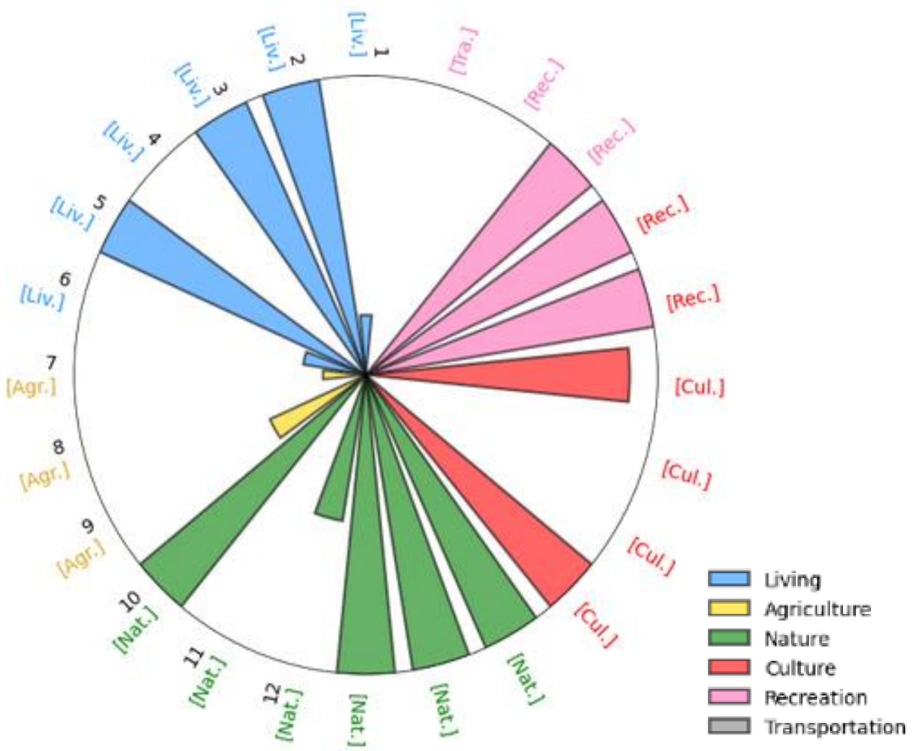
B-6: Culture optimization



1 [Liv.] Ability for housing on berm
2 [Liv.] Serviceability of houses on berm
3 [Liv.] Experienced flood safety
4 [Liv.] Accessibility of houses
5 [Liv.] Pollution minimization
6 [Liv.] Buildings preservation
7 [Agr.] Berms ability for agriculture
8 [Agr.] Accessibility of agricultural land
9 [Agr.] Preservation of agricultural land
10 [Nat.] Growth possibilities on outer slope
11 [Nat.] Growth possibilities on inner slope
12 [Nat.] Cleaned bottom contamination
13 [Nat.] Passage capability for animals
14 [Nat.] Pollution minimization
15 [Nat.] Vegatation preservation
16 [Cul.] Historical cross-sectional shape
17 [Cul.] Preservation of dike core
18 [Cul.] Preservation of monuments
19 [Cul.] Minimazation of additional soil pressure
20 [Rec.] Recreational infrastructure available
21 [Rec.] Recreational safety on dike
22 [Rec.] Pollution minimization
23 [Rec.] Accessibility of recreational areas
24 [Tra.] Transportation intensity on dike



B-7: Recreation optimization



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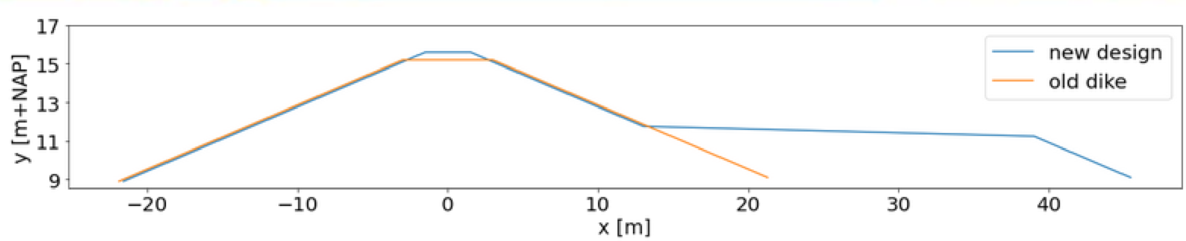
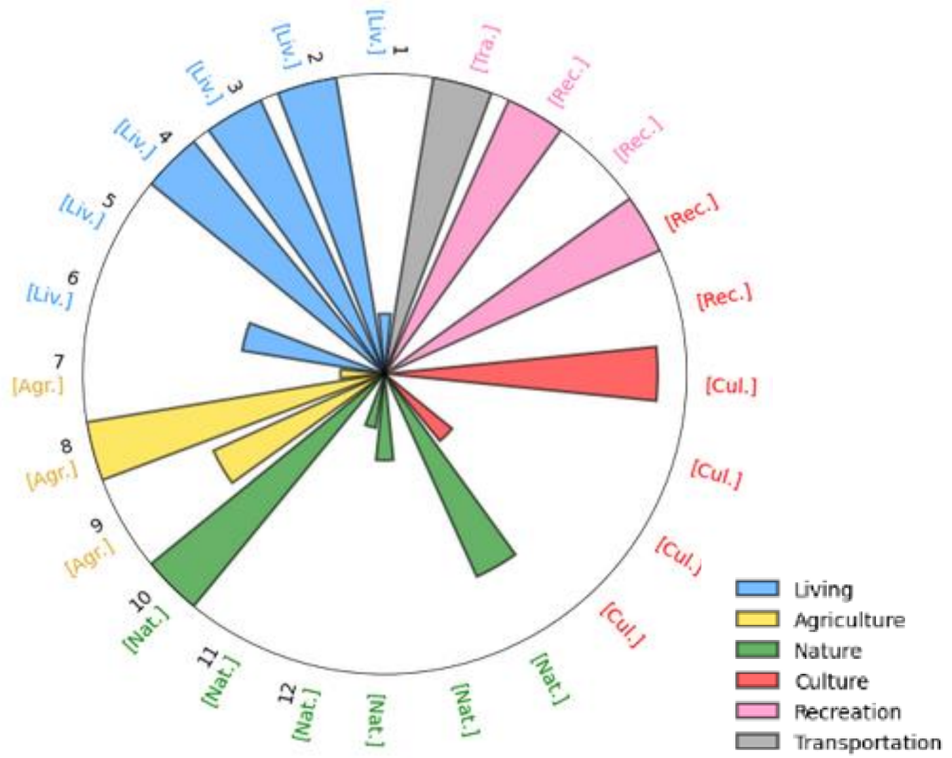
19 [Cul.] Minimazation of additional soil pressure
20 [Rec.] Recreational infrastructure available
21 [Rec.] Recreational safety on dike
22 [Rec.] Pollution minimization
23 [Rec.] Accessibility of recreational areas
24 [Tra.] Transportation intensity on dike



B-8: Transport optimization



1 [Liv.] Ability for housing on berm
2 [Liv.] Serviceability of houses on berm
3 [Liv.] Experienced flood safety
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5 [Liv.] Pollution minimization
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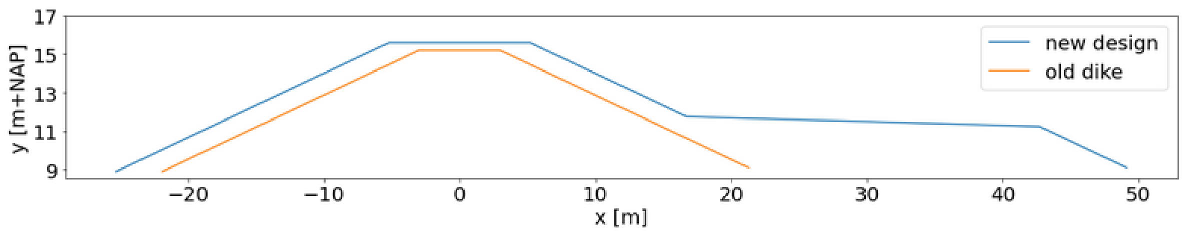
18 [Cul.] Preservation of monuments
19 [Cul.] Minimazation of additional soil pressure
20 [Rec.] Recreational infrastructure available
21 [Rec.] Recreational safety on dike
22 [Rec.] Pollution minimization
23 [Rec.] Accessibility of recreational areas
24 [Tra.] Transportation intensity on dike



B-9: Optimized parameter configurations

	Crest height[m+NAP]	Crest width[m]	Outer slope[1:]	Overtopping discharge[l/s/m]	Inner slope[1:]	Berm thickness[m]	Berm width[m]
Living	15.6	3	3	1	3.5	1	37
Agriculture	15.3	10.4	4	1	3	1	37
Recreation	15.2	3	3	5	3.5	3.3	24
Nature	15.2	6	3	5	4	2	26
Transport	15,6	10,4	3	1	4	2,7	23
Culture	15,6	3	3	1	4	2,7	23

Appendix C: Example of web shop

Welkom | Dike Geometries | Contact

Dike Geometries

Dike geometries

User Functions

In this tab, you can select your desired user funtcions.

Options are:

Living

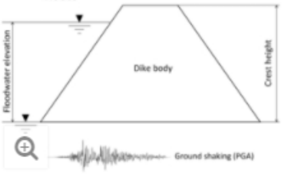
Agriculture,

Recreation,

Transport,

Nature,

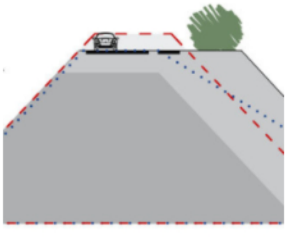
Culture.



Crest Height

The crest height is measured in m+ NAP. Increasing the crest height reduces the dike reinforcements performance on Living, Agriculture, Recreation and Nature. A higher crest is positive for the Culture user function

· 14.7 : 21...

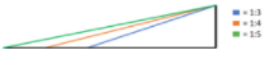


Crest Width

The crest width impacts the possibility of a road on top of the dike. Increasing the width is positive for the following user functions:

Recreation, Nature, Transport

Increasing the width is negative for the following user...



Outer Slope

The outer slope regards the slope on the water side of the dike. A steeper slope corresponds with:

Increase of culture

Decrease of living, recreation and nature

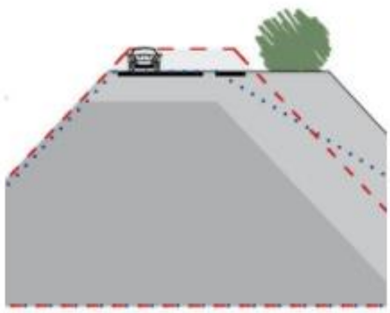
Options:

· 1:3(steep); 101 safe options
· 1:4(moderate); 74...

Welkom | Dike Geometries | Contact

Crest Width

Artikel 3 van 4



Overzicht

The crest width impacts the possibility of a road on top of the dike. Increasing the width is positive for the following user functio

Recreation, Nature, Transport

Increasing the width is negative for the following user functions:

Living, Agriculture, Culture

Options:

- 3m : 60 safe options
- 6m : 60 safe options
- 10.4m : 60 safe options
- 13.4m : 60 safe options