RESEARCH TO INCREASE BIODIVERSITY POSSIBILITIES ON THE INNER SLOPE OF THE DIKE SECTIONS FLEVOPOLDER AND NOORDOOSTPOLDER

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THESIS

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Summary

This research explores possibilities to enlarge biodiversity on the landward slope of the dike sections Flevopolder and Noordoostpolder. The dikes are owned by the Waterboard Zuiderzeeland, which wants to promote biodiversity; this goal is part of its agenda and also is part of the sustainable development goals proposed by the United Nations.

Currently, on the dikes' landward slope, a grass cover is used to prevent erosion in case of overtopping. In the past, the research has been focused on grass and the contribution of its roots to provide erosion resistance to the dikes. Nonetheless, this limitation of information related to other plant species in dike covers represents a problem for the enlargement of biodiversity. This research investigated a scenario where no erosion resistance might be needed because of null or low overtopping. Additionally, not all the plants might be implemented on the dike because they might be dangerous for their structure; thus, which types of plants are suitable for the implementation are also investigated.

The methods used to carry out this research can be divided into three main methods: wave overtopping calculation, literature research, and expert interview. The wave overtopping calculations was done using the Riskeer software in which the dike sections and hydraulic loads of the dikes were used. The literature research was focused on journal articles, technical reports, and law documentation to get more information about the investigated topics. Finally, the expert interview was carried out using a structured format for experts that were selected based on specific criteria depending on the type of interview; three types of interviews were carried out, one for the criteria to select pilot locations, one for the criteria to select types of plants, and last one for evaluating selected plants based on the criteria.

The Flevopolder and Noordoostpolder dikes have a length span of approximately 200 km along the Flevoland region; the results showed that nearly 172 km are functional to implement pilot projects in terms of biodiversity because they might be exposed to overtopping discharge of less than 5 l/m/s, while about 17 km might be considered depending on other conditions, and about 11 km cannot be used for implementation of projects on the landward slope of the dikes with species-rich vegetation. These results were reached considering the calculated overtopping for the dike sections of the dikes and the criteria of overtopping discharge that must be met. In terms of the plant species, the criteria that the plants should meet are that they are no trees or shrubs, grow currently in Flevoland, do not attract burrowing animals, and the root depth should not be more profound than the clay layer of the dike, the spreading velocity should not lead to a dominative specie, the mowing should not be highly frequent, and the plant should be able to grow in harmony with grass. Seven out of eight plants that were evaluated with the criteria met all the requirements; these species are the *Centaurea jacea* (Brown knapweed), *Leucanthemum vulgare* (Marguerite), *Plantago lanceolata* (Narrowleaf), *Rumex acetosa* (Sorrel), *Silene dioica* (Red campion), *Centaurea cyanus* (Cornflower), and *Galium odoratum* (Sweet woodruff).

Overall, the results show that in specific locations on the dikes Flevopolder and Noordoostpolder, there are high possibilities to implement projects to enlarge biodiversity by introducing a variety of plants on the landward slope of the dikes.

Table of Contents

List of figures

List of tables

1 Introduction

The following research project aims to investigate the possibilities of enlarging biodiversity on the landward slope of the Flevopolder and Noordoostpolder dikes. The introduction is divided into background information about the problem (section 1.1), defining the problem statement (section 1.2), the research objectives and questions (section 1.3), and the outline of this report (section 1.4).

1.1 Problem context

The Waterboard Zuiderzeeland is a regional water authority which manages the water in the polders of Eastern and Southern Flevoland and the Northeast polder (Waterschap Zuiderzeeland, n.d.-b). The Waterboard is the owner and responsible for the maintenance and operation of the dikes that cover that area known as Flevopolder and Noordoostpolder. The primary dikes are marked with blue lines in figure 1; they protect these areas from possible flooding from the lake.

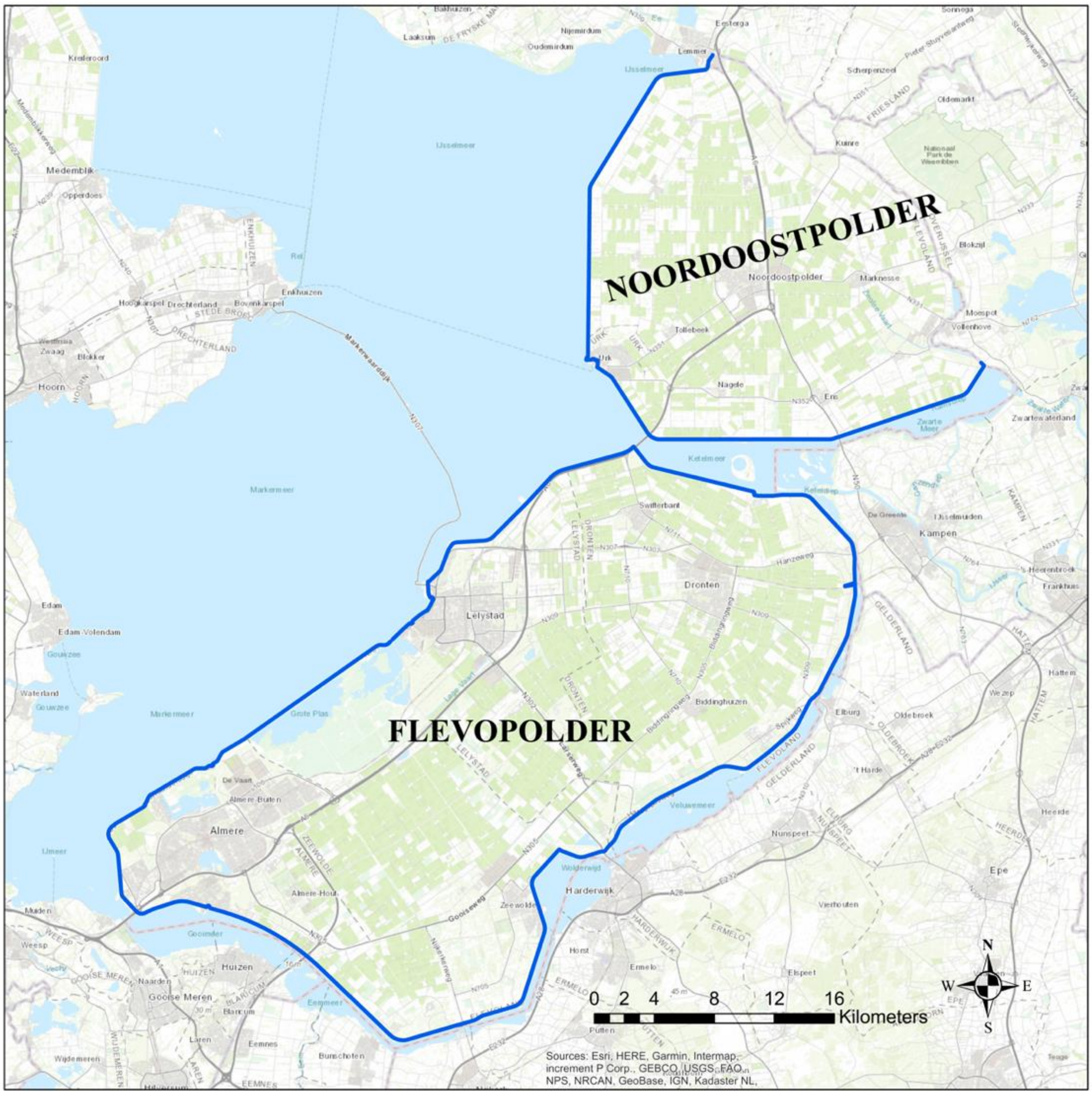

Figure 1 Study area of the project, Flevopolder and Noordoostpolder dikes marked with blue (ArcGIS, 2020).

Life on land preservation is the 15th of the Sustainable Development Goals (SDGs) promoted by the United Nations (n.d.). The goal is “Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss,” with the specific target to take urgent and significant action to halt the loss of biodiversity.

Biodiversity has become a world issue, recognized by politicians and publicists, non-government organizations, and concerned people (Frankel et al., 1995). On the margin of the SDGs and the increasing awareness of biodiversity by several groups, the Waterboard Zuiderzeeland wants to investigate possibilities to enlarge biodiversity in their dikes to contribute toward more environmentally sustainable dikes. The Waterboard has implemented this goal in its biodiversity agenda, considering that changing behavior and strengthening biodiversity is also necessary for its area (Waterschap Zuiderzeeland, 2021). In that sense, the Waterboard Zuiderzeeland wants to explore options to integrate as much as possible variety of plant species in the landward slope of its dikes.

At this point, the limitation to solo use of grass to protect dikes from erosion is that it has proved to be good enough for its purpose. No other research or tests have been made for another type of species but grass. Therefore, implementing other types of plants comes with uncertainties about their contribution to erosion protection on the landward slope.

1.2 Problem statement

The encountered problem is that in order to enlarge biodiversity on the landward slope of the dikes, the grass revetment that offers erosion protection should be removed partially or entirely to introduce a new variety of plants. Removing the grass revetment will weaken the dike in case of erosion by wave overtopping, which might cause the dike to breach and make the protected area prone to flooding.

Currently, there is unknown which segments of the dike Noordoostpolder are prone to overtopping discharge and how large it might be in each section; moreover, there is no definition of which amount of discharge defines an area that is prone to overtopping or not. Additionally, a limited amount of studies investigate the implementation of different plant species on the landward slope of the dikes because they are mainly focused on grass species.

The problem related to the variety of plant species is that some of them might threaten the structure; their roots can affect the stability of the dike and might make it prone to water infiltration. Aside from that, the type of root might reduce the erosion resistance of the cover.

1.3 Research objective and questions

The research objective of this project is to determine which sections of the dikes Noordoostpolder and Flevopolder are not prone to overtopping; and if there are sections that are not risky to overtopping, investigate which types of plants (based on their resistance to local weather, type of roots) can be implemented in these segments of the dikes to enlarge biodiversity. The segments in which biodiversity will be implemented will be considered pilot locations for the project.

The Waterboard Zuiderzeeland has already calculated the probabilities of wave overtopping for the Flevopolder area. Thus, for this project, the calculation for wave overtopping failure will be made just for the dike area of Noordoostpolder.

Further, based on the results from the overtopping analysis, this project will be focused on researching new types of plants that are likely to grow in the dikes and not represent a threat to their structure; it will enlarge biodiversity in the Flevopolder and Noordoostpolder dike pilot locations with a variety of plants and likely attracting different types of insects.

Two main research questions are derived from the presented research objective. They are as follows:

1) Where are the segments of the dike Flevopolder and Noordoostpolder in which plant biodiversity can be implemented without risking erosion due to overtopping?

From this main research question, there are derived two sub-questions that lead to answering the main questions.

1.1) Which parameters need to be met (overtopping discharge, failure probability) to consider that the dike section is not risky for erosion as a result of overtopping, assuming the new cover has negligible strength to prevent wave overtopping erosion?

1.2) What segments of the dike Flevopolder and Noordoostpolder can be considered pilot locations[1] considering the parameters obtained in the research question 1.1?

2) What are the options to enlarge plant biodiversity on the landward slope of the dikes?

To solve this main question, three sub-questions are proposed that will help answer it.

2.1) What are the regulations[2] (national-regional) regarding what can be planted on the landward slope of a dike?

2.2) Which plants are suitable under the regulations and resistant to the local weather[3]?

2.3) Which plants are most appropriate to be planted on the landward slope of the dike?

1.4 Thesis outline

The outline of this report starts with the theoretical background related to grass covers and wave overtopping in section 2; then, the methodology used to answer the research questions is explained in section 3, which explains the wave overtopping calculation, literature research, and the expert interviews. Further, the selection of the pilot locations and the results of the

[1] Pilot locations are considered the places where it is not risky to implement new types of plants on the inner slope of the dike because they meet specific overtopping discharge, wave height, and failure probability conditions.
[2] The legally binding regulations in terms of what can be planted in the dike.
[3] Local weather is considered to have the four seasons (fall-winter-spring-summer)

overtopping calculations and interviews are presented in section 4. In section 5, the biodiversity implementation results are presented based on the research and the interviews. It is followed in section 6, by a discussion about the results obtained, and section 7 presents the conclusion reached from this research. Finally, in section 8, a set of recommendations about the project are given. The last two sections, 9 and 10, contain the list of references and the appendices which support the main text.

2 Theoretical background

2.1 Grass cover functionality

Bare soil might offer residual strength to erosion, but it is not durable; when water flowing over the surface takes the minimum hold, the formation of a gulley will be rapid. The gulley will increase turbulence and channel flow, which will cause a higher rate of erosion (Young, 2005). Therefore, bare soil is not enough to prevent erosion in dikes; for that reason, grass mats are used as a sustainable solution to minimize erosion.

The grass cover on the dikes is an effective and simultaneously sustainable surface protection against erosion on dikes (Scheres & Schüttrumpf, 2019). The high erosion resistance provided is mainly due to the structure of the root layer. According to Verheij et al. (1997), the reason is that the root hairs and symbiotic fungal threads in the soil keep the fine aggregate closely because they are anchored within the substrate, creating a sort of network underground. This network makes the sod layer firm, springy, and flexible that can deform without tearing. Moreover, it is also water-permeable, which gives water-limited space to hold onto and therefore causes erosion. A schematization of the underground network created by the roots is shown in figure 2.

In terms of erosion, Young (2005) mentioned that based on centrifuge tests carried out in the Netherlands to investigate surface erosion, it was concluded that root density offers erosion resistance in the top layer while both rooting density and soil composition influence deeper layers preventing erosion.

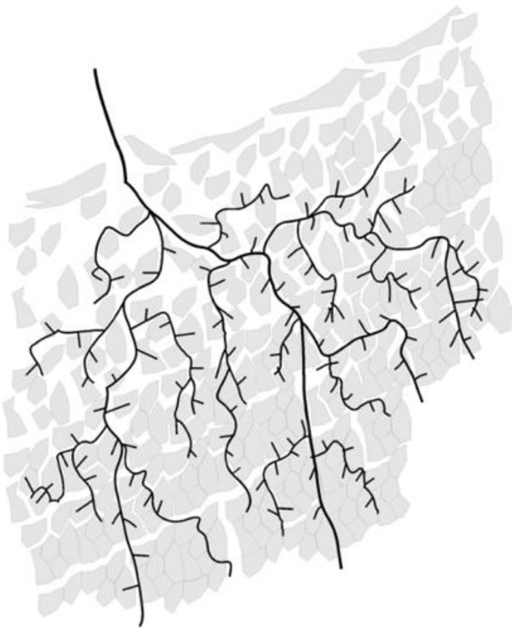

Figure 2 The structure of the sod (Verheij et al., 1997).

Additionally, grass revetments provide the flood defenses additional benefits on the ground and underground, as shown in figure 3. In the Flevopolder and Noordoostpolder dikes, the grass cover is explicitly used to prevent and minimize erosion in the inner slope under wave overtopping.

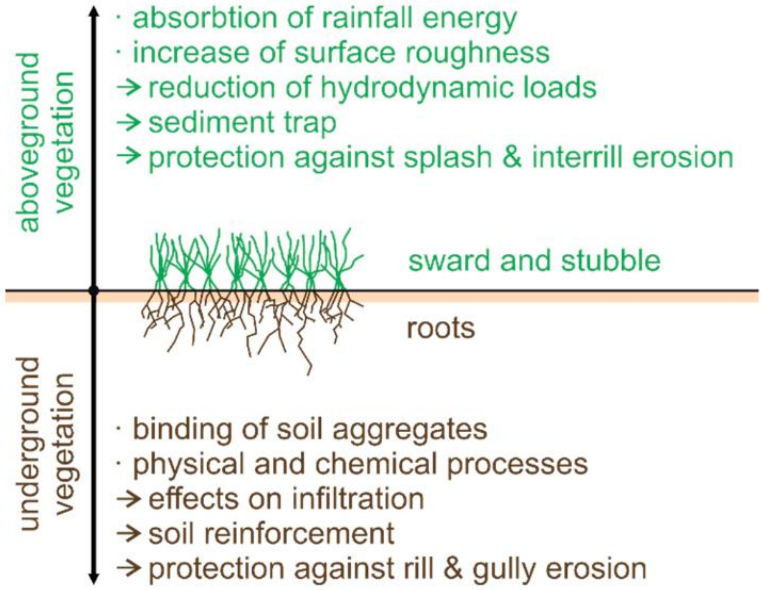

Figure 3 Structure and physical effects of a grass cover (Gaston & Spicer, 2013).

Research has been made by Verheij et al. (1997) to determine the average density of roots per specie of grass. The grass roots depth reaches a maximum layer of 40-50 cm with a lower density compared to the first three layers 0-10cm, 10-20cm, and 20-30 cm. The average root density per depth per specie type is shown in figure 4. A further study by Young (2005) shows that the stability provided by the grass roots is marginal below 30cm. Therefore, the primary erosion protection is given in the layer within 0-30cm; nevertheless, the roots might be expected to grow up to 50 cm depth in the soil layer. Moreover, a recent study from Vannoppen et al. (2017) in sandy soils showed that the effectiveness of plant roots in handling flow erosion rates depended on the soil cohesion; the effect relies on the type of roots: fine root systems were most effective in non-cohesive soils while tap root systems were most effective in cohesive soils.

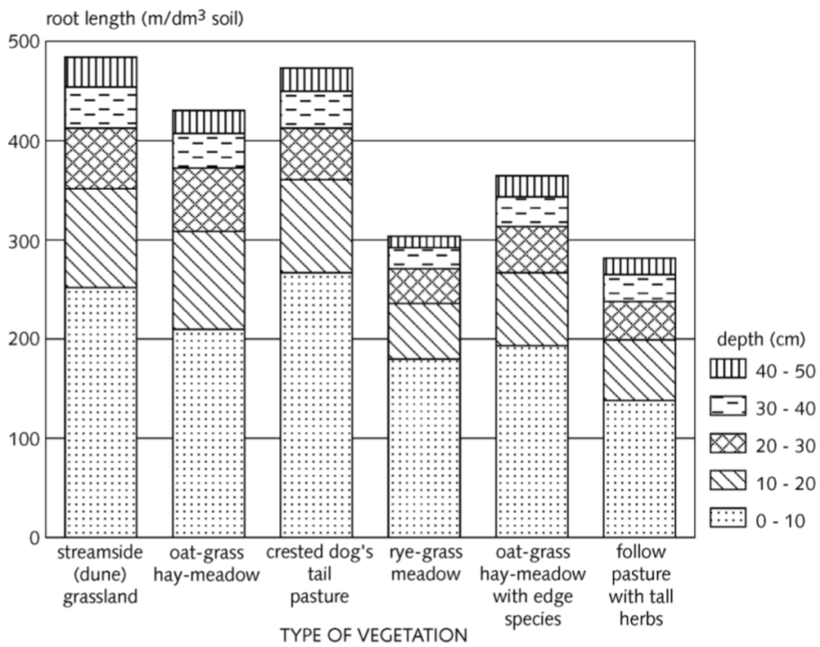

Figure 4 Average density of roots per specie type (Verheij et al., 1997).

2.2 Wave overtopping

There are several failure mechanisms that dikes might encounter. The most relevant for the inner slope of the dikes is wave overtopping. Fast wave overtopping might cause damage to the grass cover, and if erosion happens, it may likely lead to a dike breach because it may penetrate the material layers beneath (Trung, 2014). It is essential to mention that overtopping does not only occur due to high water levels but as an effect of meteorologic phenomena. According to van Bergeijk et al. (2021), high waves are capable of overtopping the dike and flowing down the inner slope with significant erosive action during a storm. This failure mechanism is schematized in figure 5. Wave overtopping failure is defined as the exceedance of a peak acceptable overtopping discharge that ranges between 0.1 and 10 l/s/m (Bergeijk et al., 2021). This probability of failure due to wave overtopping is determined considering the average overtopping discharge.

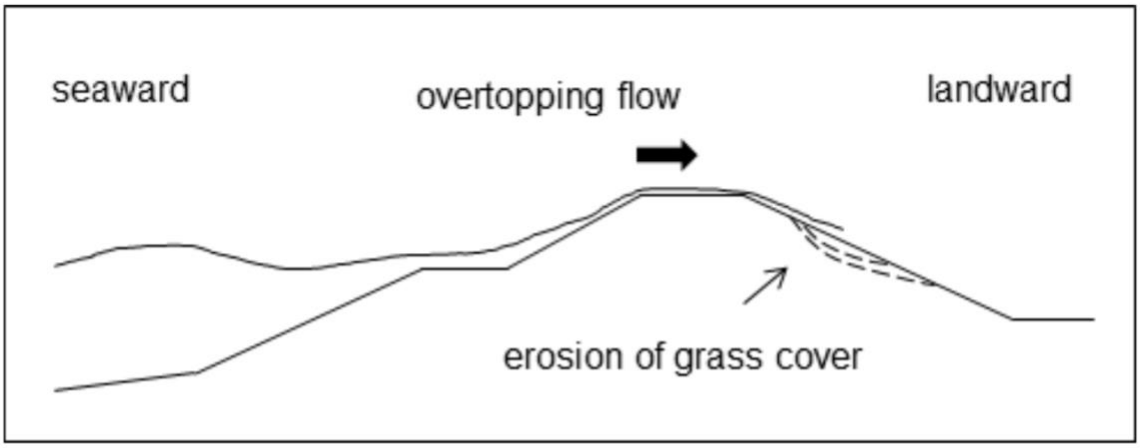

Figure 5 Erosion by wave overtopping (Trung, 2014).

Wave overtopping depends on the freeboard R_C; freeboard is defined as the vertical difference between the still water level (SWL) and the crest height. This fact is important because wave overtopping increases for decreasing freeboard height (EurOtop, 2007). Empirical formulas have been fitted to determine average overtopping discharge which sometimes obey one of the expressions shown in equation 1.

Equation 1 Empirical formula to calculate the average overtopping discharge for specific dike and wave conditions (EurOtop, 2007).

$$Q_* = Q_0(1 - R_*)^b \text{ or } Q_* = Q_0 \exp(-bR_*)$$

where:

$Q_* = dimensionless\ overtopping\ discharge$

$b = coeficient\ which\ describes\ the\ specific\ behaviour\ of\ wave\ overtopping$
$for\ a\ certain\ structure$

$R_* = dimensionless\ freeboard\ height$

$Q_0 = wave\ overtopping\ for\ zero\ freeboard$

The average wave overtopping can be further calculated considering the ratio between the freeboard height and the wave run-up height ($\frac{R_C}{R_u}$) and its relationship with the breaker parameter $\xi_{m-1,0}$ which is used to differentiate between breaker types given by the combination of the structure slope and wave steepness (EurOtop, 2007).

For calculation purposes, there have been set formulas to make a probabilistic design that describes average overtopping discharge; nonetheless, for deterministic calculations, the average discharge is increased by about one standard deviation. EurOtop (2018) describes a formula based on the wave run-up height and the freeboard height for breaking and non-breaking waves for a deterministic design or safety assessment shown in equation 2. This equation is valid for a breaker parameter lower than 5.

Equation 2 Deterministic formula for average wave overtopping for breaker parameter lower than 5 (EurOtop, 2018).

$$\frac{q}{\sqrt{gH^3{}_{m0}}} = \frac{0.023}{\tan(a)}\gamma_b \xi_{m-1,0} \exp\left(-4.75\frac{R_c}{\xi_{m-1,0}H_{m0}\gamma_b\gamma_f\gamma_\beta\gamma_v}\right)$$

$$with\ a\ maximum\ of{:}\ \frac{q}{\sqrt{gH^3{}_{m0}}} = 0.2\exp\left(-2.6\frac{R_c}{H_{m0}\gamma_f\gamma_\beta\gamma_v}\right)$$

where:

$q = average\ wave\ overtopping$

$g\ = gravity$

$H_{m0} = incident\ significant\ height$

$R_c = crest\ freeboard$

$a = slope\ of\ the\ front\ face\ surface$

$\xi_{m-1,0} = breaker\ parameter$

$\gamma_b = influence\ factor\ for\ a\ berm$

$\gamma_f = influece\ factor\ for\ roughness\ elements\ on\ a\ slope$

γ_v = influence factor of a wave wall

$\gamma_\beta = influence\ factor\ for\ oblique\ wave\ attack$

The results from this formula are used to determine wave overtopping failure in a dike. Regarding Dutch guidelines described in Young (2005), the values should be 0.1 l/s per m for sandy soil with a poor turf, 1 l/s per m for clayey soil with relatively good grass, and 10 l/s per m with a clay protective layer and grass mat in line with the requirements for the outer slope.

The equations mentioned above are helpful in order to determining the discharge for average wave overtopping. Nevertheless, to obtain the failure probability by overtopping, it needs to be evaluated in each segment within the dike because they have different cross-section profiles and are exposed to different hydraulic conditions. Furthermore, there is uncertainty while calculating failure probability, given that the hydraulic conditions are based on probabilities gathered from statistics. According to Rijkswaterstaat (2012), for calculating the overall failure probability of flood defenses, all combinations of loads and strengths are considered at which the defense will fail. Nevertheless, the loads and strengths are assigned in terms of probabilities which are estimated based on statistics and expert judgment.

The calculation approach is based on conditional failure probabilities in software calculations of wave overtopping (Hydra-Ring/Riskeer), specifically for grass erosion in crest and landward slope. The approach for the calculation considers the cumulative overload method linked to a grass erosion model; the formula for its calculation is shown in equation 3.

Equation 3 Cumulative overload method with grass erosion model (van Hoven and Boers, 2019).

$$D = \sum_{i=1}^{N} \max\left[(\alpha_M(\alpha_a U_i)^2 - \alpha_S U_c^2); 0\right]$$

where:

$D = cumulative\ overload, also\ known\ as\ damage\ number\ \left(\frac{m^2}{s^2}\right)$

$N = number\ of\ skipped\ waves\ (-)$

$\alpha_M = factor\ for\ discounting\ increases\ at\ transitions\ (-)$

$\alpha_a = acceleration\ factor\ depending\ on\ slope\ and\ length\ (-)$

$\alpha_S = factor\ for\ discounting\ strength\ reduction\ at\ transitions\ (-)$

$U_i = maximum\ depth\ mean\ flow\ velocity\ during\ the\ i\ (time), overtopping$
$wave\ at\ the\ crest\ (\frac{m}{s})$

$U_C = critical\ flow\ rate\ (\frac{m}{s})$

For equation 3, the water level and wave conditions are considered stationary for periods of 2, 5, and 12 hours. The stationary load is assumed to be characteristic for an actual course of water level and wave conditions over time (van Hoven and Boers, 2019). According to van Hoven and Boers (2019), the modelling software uses a deterministic value of $\alpha_M = 1.8$ and $\alpha_S = 0.9$, the combination of this values allows a neat transition and is theoretically the most unfavorable; additionally, to differentiate within the crest and the slope, the acceleration factor (α_a) is 1 and 1.4 respectively. The erosion resistance of the grass cover is expressed in the critical flow velocity U_C which is based on the lognormal distributions of grass resistance.

This modeling approach is useful to investigate the effects of overtopping on the landward slope of the dike by the accumulation of load over time with the different wave heights, flow rates, and slopes. The software of Hydra-Ring and Riskeer contains this model of overload and grass erosion, which can be used to determine overtopping discharge, failure probabilities, and wave height in a critical situation for a determined location and dike cross-section profile.

The probability of dike failure has been calculated according to the VNK2 project, which aims to analyze the current flood risk in the Netherlands. The VNK2 project determines the risk using an innovative method, considering flood loading, probabilities, and dike performance probabilities which are linked to the consequences of flooding as economic damage and casualty numbers (Rijksoverheid, n.d.). In terms of the dikes of Noordoostpolder and Flevopolder, the probability of dike failure by overflow and overtopping have been calculated in Vergouwe (2016); this probability is shown per dike in table 1. According to ENW (2017), the standards in the Water Act consider a reference period of one year which means that the probability of flooding must be sufficiently low in each individual year. Therefore, the probabilities shown in table 1 refer to a reference period of one year.

Table 1 Probability of dike failure by overflow and overtopping in Noordoostpolder and Flevopolder (Vergouwe, 2016).

Dike section	**Probability of dike failure by overflow and overtopping (annual)**
Noordoostpolder	1/1200
Flevopolder	1/770

It is essential to mention that from 2017, new standards have been applied to dikes, dams, and dunes in the Netherlands, which not only consider the probability of flooding but also take a close look at the possible consequences based on the principle that everyone should receive the same level of protection from flooding (ENW, 2017).

The new standards approach is based on the probability of a loss of *flood defense capacity* (resulting in flooding) which differs from the old safety standard established on the principle that the design water level must be safely withstood, the design rules in the old system were based on criteria concerning the beginnings of levee failure, such as damage to the revetment. The new standards are stricter because they take into account the length effect, which considers that the longer a levee, the greater the chance that there will be a weak spot somewhere; therefore, the probability that a long stretch of the levee will fail at some point is higher than the probability that a section will fail at one specific point (ENW, 2017). Therefore, the failure probability shown in table 1 might not be in line with the new standards; still, it gives an impression of how likely it is to have failure by overflow and overtopping.

The introduction of empirical equations and software, together with the failure probability, shows that there are methods to approach the problem of erosion by wave overtopping in dikes. These methods are helpful to guarantee the safety of the people protected by the dikes. The presented information about the failure probability of overtopping and its influence on the landward slope is essential to understanding this project's problem and research objective that were presented in section 1.3. The methods used for this project will be further explained in the next section.

3 Methodology

The methodology used to answer the research questions is divided into three sections. The first section is the wave overtopping calculation for the Noordoostpolder dike; it is done using Riskeer software. The following section is the identification of pilot locations in the Flevopolder and Noordoostpolder dikes; it is done by combining the results obtained from the calculations and expert interviews to determine the most suitable locations. These two methods help to answer question 1 and sub-questions 1.1 and 1.2 of the research questions.

The last section is the research on increasing plant biodiversity; this research is supported by expert interviews and literature research about regulations and plants. These methods help to answer question 2 and sub-questions 2.1, 2.2, and 2.3.

Based on the division of sections, the workflow with the methods used for each section to answer the research questions is shown in figure 6. This workflow presents an overview of how the different methods are linked to each other and their inter-relationship within sections.

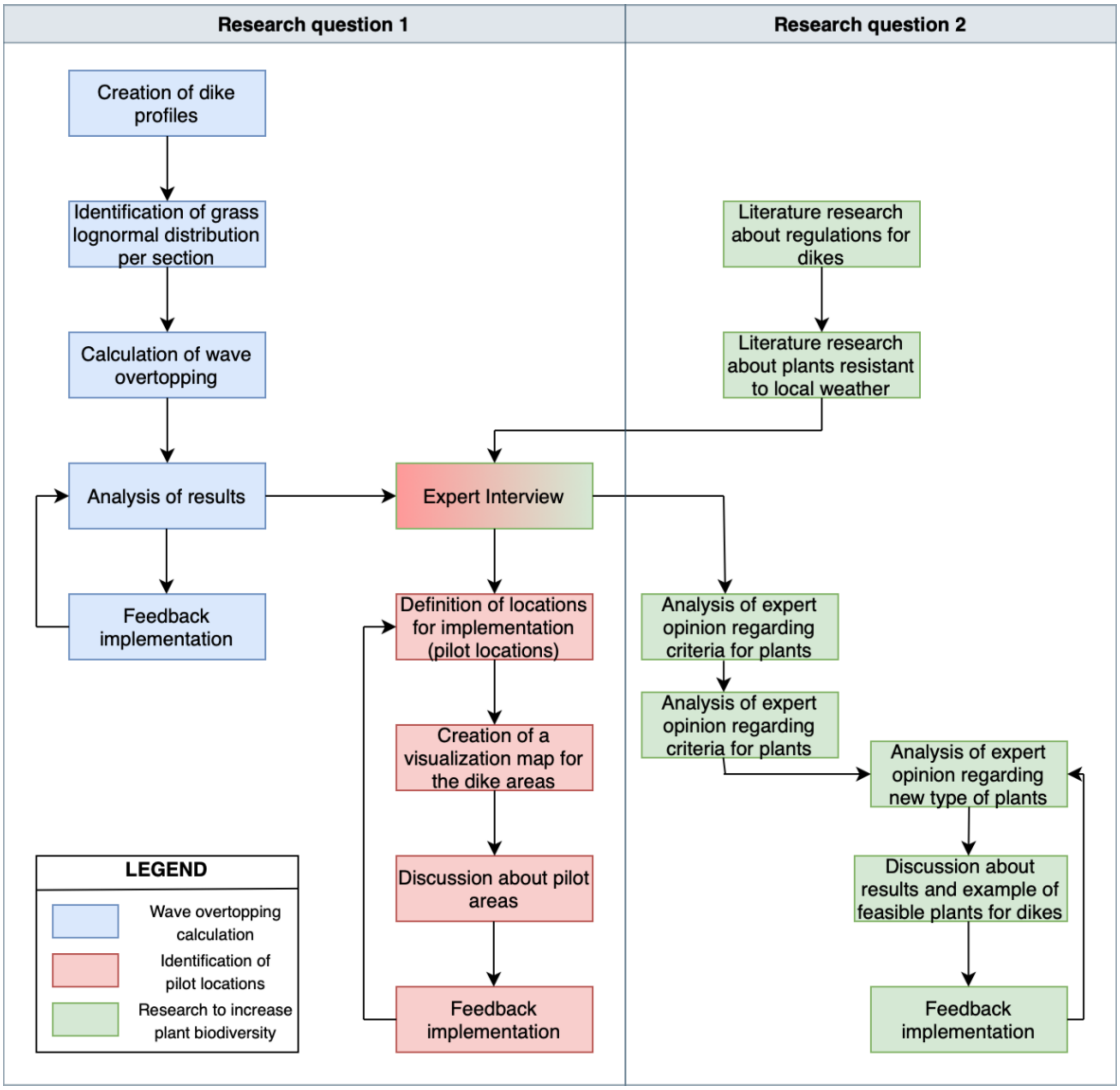

Figure 6 Methodology workflow of the project.

The rest of this section provides an in-depth explanation of the wave overtopping calculation, the literature research, and the expert interview.

3.1 Wave overtopping calculation

The wave overtopping calculation for Noordoostpolder is carried out using the GEKB approach, which is an abbreviation for "Grass Erosie Kruin en Binnentalud" which translates to "Grass erosion of the crest and inner slope." This approach is one of the failure modes for dikes that considers overtopping, and it is related to HBN, an abbreviation for "Hydraulisch Belasting Niveau" (Guus, 2020). The HBN is a vertical distance quantity used to express the dike height required for support overflow and overtopping. The GEKB method is used because it interconnects wave overtopping and grass revetment protection to make its calculations. Thus, it is considered an appropriate method to calculate overtopping and its effect on the landward slope of the dike.

The software used for the GEKB calculations is Riskeer. Riskeer is a software that allows primary flood defenses to be assessed according to the Assessment and Design Instruments and supports the design process of dikes (Helpdesk Water, n.d.). This software is intended for the use of flood defense managers such as Waterboards and Rijkswaterstaat that carry out the assessment or design for primary flood defense systems. Significantly, the version software of Riskeer 21.1.1 offers supporting calculations with scenarios for dikes and dams in terms of grass cover erosion of crest and inner slope (see section 2.2, equation 3) (Helpdesk Water, n.d.).

The failure probability in Riskeer is based on slow random variables such as discharge and fast stochastics such as wind and seawater level. The grass revetment damage at one level on the slope is calculated, giving the failure probability for a specific revetment quality in the dike. Riskeer software's requires as input the hydraulic loads, the dike profile, and the grass-cover quality. In depth description of the input is provided in Appendix A in section 10.1.1.

To calculate wave overtopping in Noordoostpolder, the dike profiles (see section 10.1.1.2) and the lognormal grass distribution (see section 10.1.1.3) are added to Riskeer. Additionally, the hydraulic loads such as winds, precipitations, and so for, for the Noordoostpolder area are added to the software (see section 10.1.1.1). The hydraulic loads conditions database is retrieved from Rijkswaterstaat and was provided by the Waterboard Zuiderzeeland.

The calculations are performed per dike section with different dike profiles. The main outputs of the calculations are the failure probability in 1/years and the overtopping discharge in l/m/s. These outputs are used to analyze the results further.

3.2 Literature research

The literature research provides the theoretical background to increase the comprehensiveness of the grass-cover resistance, the current regulations for dikes, and the plants that grow in the Netherlands, especially in Flevoland. According to Snyder (2019), by integrating findings and perspectives from empirical studies, a literature review can address research questions with a power that no single study has. Therefore, the combination of theories from previous studies is essential to increase the quality of the project outcome. The literature research uses journal articles, technical reports, and law documentation.

Literature reviews can serve as a basis for knowledge development, provide evidence of an effect, and, if well conducted, engender new ideas and directions for a particular field (Snyder, 2019). In that sense, the theory background (section 2) is used to support further research about regulations and key features required in plants and provide a better understanding of the wave-overtopping phenomena, which leads to a better comprehensiveness of the results. Research about biodiversity implementation (biodiversity possibilities, key features, types of plants) is detailed in section 5.1.

3.3 Expert interview

Experts' knowledge is invaluable to better understanding the problem and analysing possible solutions. For this research, three types of expert interviews were conducted with different experts; the interviews were focused on criteria to define pilot locations, criteria to select plants to be implemented on the landward slope of the dike, and evaluating the criteria with different types of plants.

The expert interview method retrieves information from professionals and experienced people in the interest field. The interviews are carried out in a structured way. The structured interview allows the possibility to compare the opinions of the people interviewed (Susan, 2007). Therefore, it is helpful to interpret and relate the answers from the participants and identify consensus within their answers. Additionally, according to Aamodt et al.t (2006), it has been recognized that biases have a small but significant effect on structured interviews and a larger effect on unstructured interviews; therefore, bias is less likely using a structured format. To avoid biases within experts, the interviews are conducted individually. The interviews are recorded (upon interviewers' permission) for further analysis. Additionally, if possible, the interviews were done face-to-face; otherwise, they were conducted online.

Different considerations are made for the interviews, depending on the interview's topic and aim. The interview focused on criteria to define the pilot location's objective is to obtain insights about what requirements (overtopping discharge, failure probability) the experts consider appropriate to establish a pilot location; the interview contains a total of 11 questions and sub-questions, and it was made to five experts. The interview related to the criteria to select plants to be implemented on the landward slope aims to determine the characteristics that the plants should have to be planted on the landward slope of the dikes; three experts of different backgrounds were interviewed, answering five questions related to the topic. Finally, in the interview about the evaluation of the criteria with different types of plants goal is to determine the types of plants that can be planted on the landward slope of the dikes for biodiversity enlargement; in this interview, the questions were focused on the types of plants analyzed in this study.

Regarding the experts, it is essential to consider that the results of an expert interview study are sensitive to the selection of the experts from which the estimates/opinions are gathered (Warmink et al., 2011). Therefore, the experts were selected based on expertise, experience, and background criteria. The experts for the criteria for the pilot locations most had worked on projects related to dikes and flood safety; for the criteria to select the type of plants, experts had to have experience related to dike maintenance and grass-cover maintenance and mowing, preferably in a Waterboard context, and the experts to evaluate the plants must have an ecologist background and had worked on vegetation-related topics. It is essential to mention that the Waterboard Zuiderzeeland has experts on these topics; however, to avoid inter-organizational biases, it is preferable to have at least one expert external to the organization.

The interviews regarding pilot locations are in-depth explained in Appendix B in section 10.2.2, and the interviews regarding the criteria to select the type of plants and the type of plants are in-depth explained in Appendix C in sections 10.3.1 and 10.3.3; the explanation contains the type of experts and the questionnaire that is used.

4 Results selection of pilot locations

4.1 Wave overtopping results for Noordoostpolder

The results of wave overtopping for Noordoostpolder are detailed in Appendix B, section 10.2.1. The calculations are made per dike section with its respective length span in km; the output contains the overtopping discharge and failure probability.

The calculations were made for the norm probability and the cross-section requirement probability which are 1/3000 and 1/37500 years for Noordoostpolder. The cross-section requirement differs from the norm because required failure probabilities for a specific failure mechanism at the cross-section level are determined by dividing a flood probability norm over different failure mechanisms (ENW, 2017). This approach is known as the failure probability budget; according to the standard failure probability budget, the failure probability in a segment due to overflow and overtopping is 24% and the damage to the revetment and erosion is 10%, therefore, the failure probability must be no greater than 34% (ENW, 2017). In that sense, the cross-section probability is derived from the norm failure probability of the whole dike translated to its representative cross-section probability.

In the calculations for the norm, the maximum overtopping expected is in the segment 22.95-24.20 km from the dike starting point in Lemmer, which is nearly 102 l/m/s, and the average overtopping from all segments is approximately 4 l/m/s. In the cross-section calculations, its maximum discharge is in the section 38.00-38.30 km from the dike starting point in Lemmer, which is approximately 623 l/m/s and its average is about 41 l/m/s. The results from the cross-section requirement represent the worst situation in terms of safety, but at the same time, this is less unlikely to happen in real life, given that its probability is 12.5 times higher than the norm. Hence, for practical reasons, the rest of the project works with the results based on the norm probability. These results are used to determine where pilot locations can be established for biodiversity implementation along the dike.

4.2 Expert elicitation results

This section analyzes and synthesizes the output from the pilot locations interview. The structure and output from each interview are given in Appendix B, sections 10.2.2 and 10.2.3, respectively. In total, five experts were interviewed, two of them work at the Waterboard Zuiderzeeland, and three of them work in external organizations; the experience of the experts varies within theoretical research and practical experience from working in maintenance and supervision of dikes, their expertise provides valuable insights that are synthesized in the following paragraphs.

Regarding the safety of a dike section without grass cover from overtopping, it might be considered safe but just for specific situations because it depends on some facts such as the composition of the soil, slope of the dike, and the amount of wave overtopping. Moreover, there is an emphasis on analyzing what is considered a failure and how much the clay layer is allowed to erode. Therefore, the safety of a dike section for overtopping depends on the context in which it is exposed.

In terms of the failure probability of overtopping and how it represents the flood risk, there is a consensus among the experts that the failure probability of overtopping does not represent the flood risk properly. It is because flood risk includes much more than just overtopping, given that failure probability is just a tiny part of flood risk, and failure probability is also calculated for several failure mechanisms.

Concerning the overtopping discharge and failure probability as indicators to change the cover of the inner slope of a dike, all interviewees agreed that overtopping discharge is an appropriate indicator, but that might be better if combined with other indicators. Additional indicators that experts consider appropriate to determine pilot locations are wave characteristics, the maximum overtopping volume of a wave, wave height, the dike's slope, and the dike's material. Nonetheless, all the interviews agree that the failure probability is not appropriate for this purpose; therefore, it is not used to determine the pilot locations.

The range of overtopping discharge that experts considered most safe to implement a project where grass erosion resistance might be negligible ranges within 0 to 5 l/m/s, while one of them expresses a conservative value that ranges within 0 to 0.1 l/m/s, another expert considers that for clay dikes it is within 0 to 1 l/m/s. The other expert considers most safe a discharge within 0 to 5 l/m/s. Additionally, one of the experts stated that other factors should be considered but did not give any value because it is not its expertise field. Based on these values, the lower and the intermediate range are considered the *most safe* to implement pilot locations, which is within 0 to 1 l/m/s, while the upper range is considered *safe* from 1 to 5 l/m/s.

In terms of a neutral range to implement a project where grass erosion resistance might be negligible, two of three experts agree that a range of 5 to 10 l/m/s can be considered *neutral*[4] to implement a pilot location. Finally, three of the five agree that everything larger than 10 l/m/s is considered *unsafe* to implement pilot locations, while one of them considers as not safe a discharge over 50 l/m/s for clay dikes.

Finally, regarding biodiversity and flood protection by implementing new types of plants but grass on the landward slope of the dikes, the experts agree that it will enlarge biodiversity increasing types of vegetation and insects. Experts believe that a variety of species on the cover can help in flood protection in case of droughts and heavy rain, given that the seeds used for grass cover were not prepared to handle the current climate conditions; two experts pointed out that it is currently being researched in the Future Dikes project. Finally, an important idea given by an expert is that monotype grass covers are uniform and will have lower erosion resistance than a combination of plant species.

This section has synthesized the input received by the experts. Its content is further used to define the criteria to select pilot locations for biodiversity implementation in the following section.

[4] *Neutral* is the range in which there is not enough certainty to declare it safe, but that can be considered to implement pilot locations if proper measures are taken or if it is analyzed with other indicators.

4.3 Criteria to select pilot locations for biodiversity implementation

The criteria to select pilot locations for biodiversity implementation in Flevopolder and Noordoostpolder dikes is based on the overtopping discharge. The range values in which biodiversity might be implemented are based on expert's judgement which was explained in detail in the previous section.

The range in which it is safe to implement new types of plants in the dike is within 0 to 5 l/m/s, separating from 0 to 1 as *most safe* and from 1 to 5 as *safe*, while a *neutral* range is given within 5 to 10 l/m/s. Calculated overtopping discharge above 10 l/m/s is considered unsafe, a differentiation is made within *unsafe* in a range of 10 to 100 l/m/s and *high-risk* area which is all the discharge over 100 l/m/s. The criteria to select pilot locations for biodiversity implementation based on the expert interview is shown in table 2.

Table 2 Criteria to select pilot locations considering the overtopping discharge based on the expert interview.

Overtopping discharge [l/m/s]	Condition
0 – 1	Most safe
1 - 5	Safe
5 – 10	Neutral
10 -100	Unsafe
>100	High-risk

4.4 Pilot locations in Flevopolder and Noordoostpolder

The Flevopolder and Noordoostpolder dikes have a length span of nearly 200 km along the Flevoland region. Based on the criteria presented in the previous section, it can be considered that a condition of most safe and safe could be certainly used for biodiversity implementation. The most safe and safe length is approximately 138 and 34 km, respectively; thus, there is a total of about 172 km to implement pilot projects in terms of biodiversity.

In terms of a neutral situation, the length is around 17 km, mainly in the Flevopolder dike; however, considering the total length of a most safe and safe situation, it is significantly better to start a biodiversity project in these zones. However, the neutral dike sections can be further explored by analyzing other indicators such as wave height, the maximum overtopping volume of a wave, the dike's slope, or the dike's material.

The unsafe sections span a length of roughly 11 km, which is relatively low compared to the safe sections; it provides a clear perspective that the Flevopolder and Noordoostpolder are potential structures where a project about biodiversity can be implemented and evaluated safely without risking erosion due to overtopping.

The zones of each condition are marked in the map shown in figure 7. The green lines show the safe, the yellow, the neutral, and the red indicate the unsafe sections. There are black lines on the map; they represent the town of the Urk and a harbor that does not have an inner slope because they have dam-type structures.

It is essential to point out that the map shown in figure 7 only shows the locations based on its calculated overtopping discharge where a pilot project for biodiversity could be implemented. However, the map does not consider any other facts such as other indicators or the Waterboard Zuiderzeeland's use for its dikes sections such as rent to farmers.

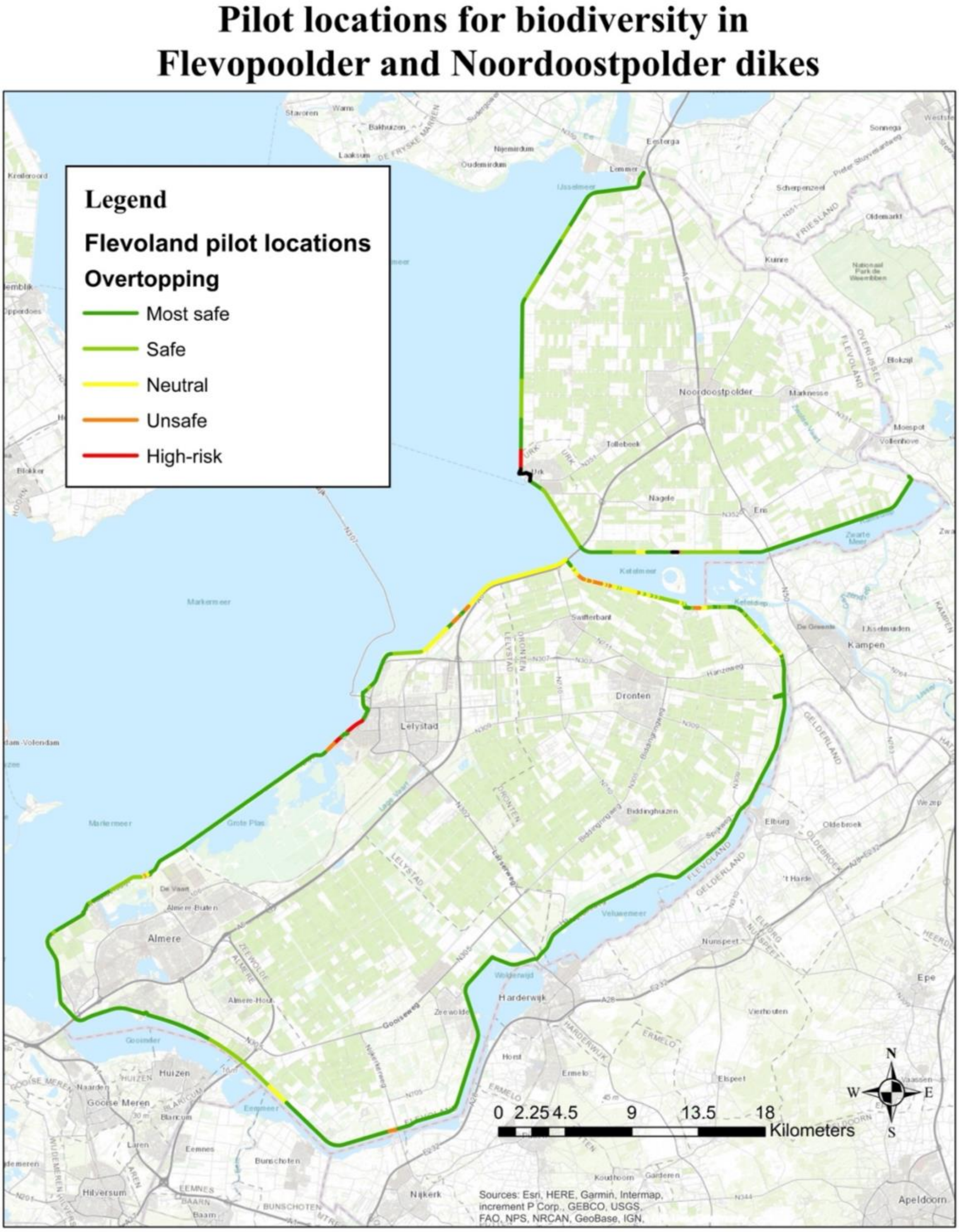

Figure 7 Pilot locations for biodiversity implementation in Flevoland.

5 Results of the biodiversity possibilities

Biodiversity is the variability among living organisms that encompasses all forms and combinations of natural variation (Gaston & Spicer, 2013). This variability among living organisms carries out certain benefits for life; according to the World Health Organization (2015), biodiversity provides goods and services elemental to life on earth. Additionally, it reinforces economic opportunities and recreational activities that support overall wellbeing.

In environmental terms, biodiversity loss might represent an ecosystem collapse, threat humanity will face in the next decade. Regarding the economic and social cost of inaction, it is estimated that the world lost 3.5-18.5 trillion euros per year in ecosystem services from 1997 to 2011 (European Commission, 2020). Additionally, it is essential to point out that biodiversity implementation represents the creation of direct and indirect local jobs for nature restoration.

This section explores the possibilities to implement biodiversity in terms of plants in the landward slope of the dikes in Flevopolder and Noordoostpolder. Firstly, there is a research of biodiversity possibilities based on literature and a set of criteria is defined to select new type of plants (section 5.1), then, the options and the criteria are analyzed based on expert opinion (section 5.2), and finally, a summary of some plants that might be implemented in the pilot locations is presented (section 5.3).

5.1 Research of biodiversity possibilities

Currently, the inner slope of the dikes managed by the Waterboard Zuiderzeeland is mainly revested by grass. For this project, the enlargement of biodiversity is focused only on increasing the variety of plants on the landward slope of the Flevopolder and Noordoospolder dikes. It in principle, might also foster attraction to insects, increasing the biodiversity in the area.

Aside from the enlargement of biodiversity on the landward slope of the dikes, the diversity of plant species might increase the erosion resistance on the slope. According to Berendse et al. (2015), it has been shown that loss of plant species diversity reduces erosion resistance on the dike's slopes. In that sense, restoring diverse plant communities on embankments could be essential to minimize soil erosion and increase safety from overtopping; the primary mechanism explaining the strong effects of plant species variety on soil erosion is the compensation effect, which is the capacity of various communities to supply species to take over the positions of species that went extinct because of fluctuating environmental conditions (Berendse et al., 2015). The flow contribution of plants species diversity to increase soil erosion resistance is shown in figure 8.

To further analyze the types of plants that might be implemented in the dike to increase the biodiversity, the theoretical background of the functionality of the grass cover in the soil was explored to identify the key elements that the turf offers to the soil (section 2.1). Based on this theoretical background, key features for the new types of plants are considered, summarized and further investigated (section 5.1.1), and finally, it is identified endemic[5] plants of Flevoland (area of Flevopolder and Noordoospolder) that are analyzed based on this criteria (section 5.1.2).

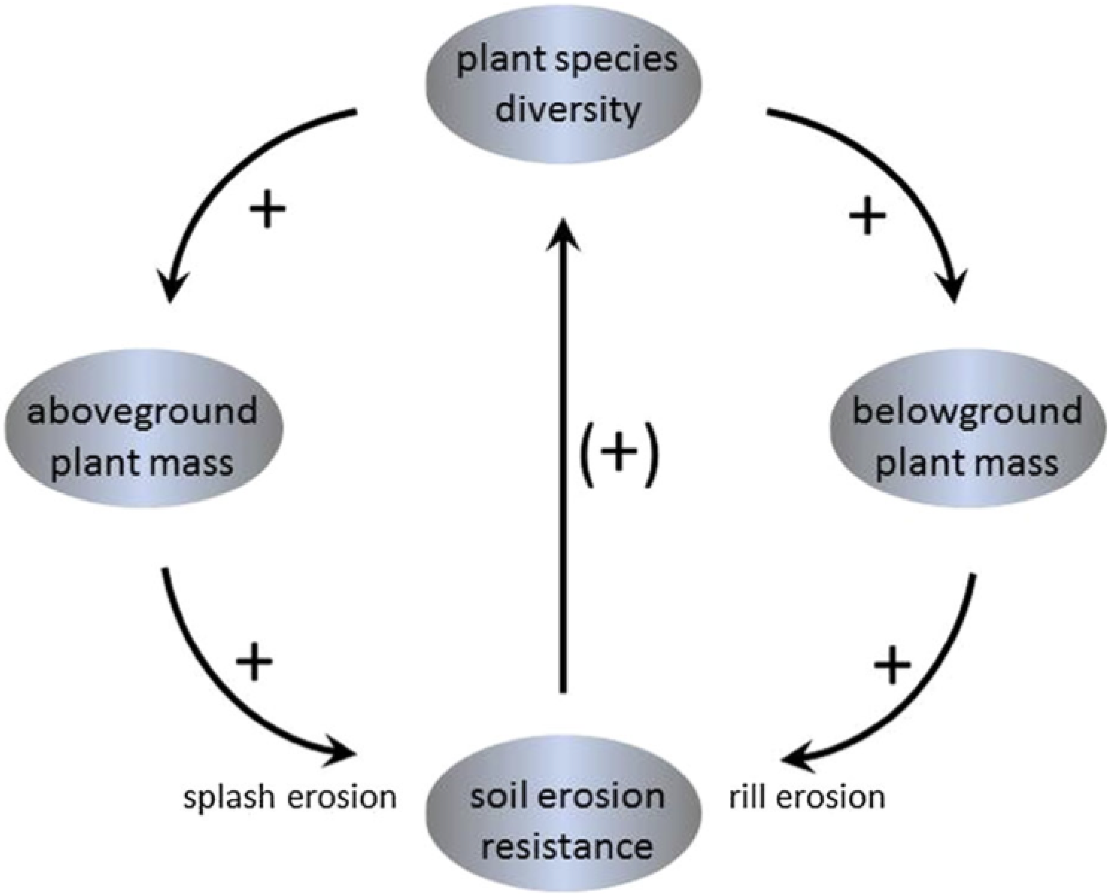

Figure 8 Effects of the restoration of plant species diversity on aboveground and belowground plant mass leading to higher soil erosion resistance (Berendse et al., 2015).

5.1.1 Key features required in plants

In terms of legislation regarding flood defenses in the Netherlands, it has been established The Flood Defences Act. According to Muijs (1999), The Flood Defences Act requires that other functions of the flood defense be considered and encouraged when placing or altering a flood defense. Additionally, it is stated that a flood defense can have values in terms of nature, the environment, landscape, and culture-history (abbreviated in Dutch as LNC). Therefore, implementing new types of plants on the landward slope of the dike proposes values in terms of nature and the environment while partially contributing to erosion protection. Thus, adding new types of plants to the landward slope of the dike is allowed; however, erosion protection should be considered while implementing it. Additionally, the regulations by the Waterboard establish that the cover of the dikes on the landward slope must have grass along its span. For

[5] Endemic plants are referred to the plants that grow in the area of Flevoland. The consideration of plants that can be found in Flevoland is because they are resistant to the local weather.

that reason, plants with similar features to grass (root depth, root type) and that can grow along with it might contribute to erosion protection and biodiversity enlargement.

Explore options such as woody and shrub vegetation is not feasible due to its deep and extensive roots. According to Zanetti et al. (2011), woody vegetation induces several risks which are not compatible with dike safety; some of those risks are low visibility of dike slopes, the attraction of burrowing animals, risk of piping due to root growth through the dike, dike weakening by tree uprooting and creation of sinkholes with stumps decomposition. The risks are that large roots cross right through the dike body or might softly dike materials and cause internal erosion risk (Zanetti et al., 2011). Hence, short roots are most appropriate than long roots that might represent a risk for the dike; therefore, trees and shrubs cannot be considered for implementation in the dikes. In terms of root depth, based on the average root depth of the grass species, it might reach a maximum of 50 cm depending on the clay layer; thus, introduced plants should have a similar threshold regarding its root length.

Another fact to consider is the spreading speed of the introduced plants; it is not wanted that just one type of plant spread faster and do not let the chance to other species because it will reduce biodiversity. According to Vavra et al. (2007) and Levine et al. (2006), exotic plant species' invasion of natural ecosystems is a significant threat to biodiversity and economic and environmental impacts. Furthermore, disruption to native plant communities is a primary element contributing to a successful invasion by exotic plant species (Vavra et al., 2007). Therefore, it is essential to consider plants growing in ecosystems in the Flevoland area to avoid the threat to biodiversity and because it is guaranteed that these plants can withstand local weather.

Introducing different types of plants on the landward slope might attract animals which will enlarge biodiversity. However, it is essential to be aware that certain animals are unwanted on dikes. Bayoumi & Meguid (2011) reported that burrowing animals usually dig tunnels and holes inside earth structures and flatten the external slopes in search of food; most of these dangerous activities modify earthen structures' external and internal geometry. Moreover, damage caused by wildlife in earthen hydraulic structures is commonly associated with internal and external erosion (Bayoumi & Meguid, 2011). Thus, the plants must not attract burrowing animals to the dikes.

On the other hand, insects will enlarge biodiversity without harming the dike structure. Planting floral colors enable insects to recognize appropriate food sources more readily; it serves the plant by encouraging consistency of visitor type or individual and thus aids appropriate pollen transfer; therefore, many kinds of insects can be found on flowers (Kevan & Baker, 1983). Therefore, flowers on dikes will attract insects and enlarge biodiversity along the dikes. Hence, animal attraction should be carefully explored while deciding on a particular plant to be implemented.

Regarding mowing and maintenance of the vegetation in the dike, increasing frequencies of it will represent higher costs; thus, it could be something to consider while implementing new types of plants. Nevertheless, Socher et al. (2013) claim that mowing may initially increase light availability, encouraging subdominant species and germination paces. Nonetheless, at higher cutting frequencies, just a few species can manage with such a degree of disruption, and thus diversity declines. Therefore, the mowing frequency might be inspected while deciding the type of plants that will be implemented; it will help reach a frequency of mowing where various plants form a biodiverse ecosystem.

In summary, the identified key features that should be analyzed in plants are related to their root depth, the animals they attract, the spreading velocity (invasive or not), if they can grow along with grass, and if they grow in Flevoland, and the mowing frequency they require. These features will be corroborated and contrasted with experts (see section 5.2) working on supervision and maintenance of dikes in the Waterboards to explore if they are appropriate or if there are any criteria to select plants missing. It is essential to mention that the increase in biodiversity will not just attract specific species that are attracted by the plants but all the species that fit in the habitat that will be formed around the dike, enlarging the biodiversity.

In the next section, a list of plants will be selected; they will be analyzed based on these criteria (if it is appropriate based on expert opinion), and the ones that meet them will be used as examples of types of plants that might be implemented on the landward slope of the dikes.

5.1.2 Analysed plants of Flevoland

In terms of using the criteria previously mentioned to select different types of plants, some plants are selected and further evaluated to determine if they are suitable or not for implementation on the dikes.

As previously mentioned, it is essential that the plants grow in the Flevoland area; therefore, selected plants are found in this area. For determining which plants grow there, the database of iNaturalist (iNaturalist, n.d.), which is a joint initiative of the California Academy of Sciences and the National Geographic Society, together with the database of the Global Biodiversity Information Facility (GBIF, 2018) are used to find plant species that are growing in Flevoland.

Eight types of plants are selected for analysis of the plant species with the criteria. Four of them are selected from the study of Berendse et al. (2015), in which the species proved to increase erosion resistance to fluctuating environmental conditions; they are Centaurea jacea, Leucanthemum vulgare, Plantago lanceolata, and Rumex acetosa. The other four species were randomly selected from the databases considering that they are not trees or shrubs; the species are Silene dioica, Lapsana communis, Centaurea cyanus, and Galium odoratum.

The list of plants is compared with the criteria by an expert interview and literature research, and if they meet the criteria, they will be examples of plants that can be further implemented on dikes for enlarging biodiversity.

5.2 Expert elicitation results

The outcomes from the interviews of the criteria to select type of plants and the investigated plants from the list are analyzed in this section, explained details of the interviews and its output are given in in Appendix C.

5.2.1 Criteria to select type of plants

This section analyzes and synthesizes the output from the criteria to select type of plants interview. The structure and output from each interview are given in Appendix C, sections 10.3.1 and 10.3.2, respectively. Three experts were interviewed to define the criteria to select the type of plants; two of them work at the Waterboard Zuiderzeeland, they have experience in maintenance and supervision of flood defense's structure, and one works at the Waterboard Vallei en Veluwe with experience in research related to water safety.

Concerning the root depth, the experts agree that the maximum depth of the roots depends on the clay layer; for the dikes of Flevopolder and Noordoostpolder, it varies from 60 to 80 cm depth. Additionally, it is not essential to aim for deeper roots in all plants but for a combination of roots depths that create a more robust network.

In the case of animals unwanted in the dikes, the experts focused on burrowing animals because the holes they make will damage the integrity of the dike structure. Moreover, there is a specific focus on underground species, which might help vegetation develop better. However, it is mentioned that grubs attract burrowing animals to dikes. Additionally, while eating the plants, some animals remove the roots of the plants, for instance, cows. An essential point mentioned by an expert is that individual plant species do not attract a specific type of animals but a combination of them that create an environment suitable for those animals. Therefore, it is essential to carefully analyze which types of animals will be attracted to the biodiverse environment in order to take proper measures to avoid unwanted animals.

The spreading velocity of plants indeed represent a problem for the dike's biodiversity, but mainly because species that are likely to spread faster than other might invade the space of the others to become the dominant species. A dominant specie is not wanted for biodiversity; thus, there are solutions to avoid the spreading such as mowing before the plants get flowers, but it will be mainly in the early stages of the implementation. Moreover, it is argued that the spreading of a plant might not represent a problem for the dike but for the neighboring farmers, who might not want other species on their land. In that sense, the spreading of a plant is something essential to be considered to mitigate its impact by mowing or by avoiding a specific specie that is likely to spread quickly.

Regarding the frequency of maintenance or mowing of a plant, experts agree that there is no problem meaning that it is possible; however, it is essential to consider that it represents economic costs to the Waterboard. An expert mentioned that in the Waterboard Zuiderzeeland, currently, they are doing 2 to 3 mowing per year but increasing it to 10 times is potentially a problem. Nevertheless, one of the experts mentioned that higher mowing would be expected in the development phase of the cover until it reaches a stable vegetation status, where required mowing will be 1 to 2 times per year.

In the case of the importance that the plant can grow along with grass, the experts agreed that it is essential that the plants grow along with grass. Additionally, it was mentioned that there are specific problems related to growing herbs and grass, such as higher herbs that cover the grass leaving a blind spot in the cover; however, one expert argues that if there is no overtopping expected, then the grass cover might not be necessary, but still, a plant cover with herbs should be implemented.

5.2.2 Selected plants of Flevoland analysis

This section analyzes and synthesizes the output from the type of plants interview. The structure and output from each interview are given in Appendix C, sections 10.3.3 and 10.3.4, respectively. The eight analyzed plants were the Centaurea jacea, Leucanthemum vulgare, Plantago lanceolata, Rumex acetosa, Silene dioica, Lapsana communis, Centaurea cyanus, and Galium odoratum.

From the eight species, the criteria were evaluated by expert opinion and, if possible, with literature research; nonetheless, for certain species, the expert was not sure about the characteristics and made an educated evaluation about the specie. Additionally, specific information about certain plants was not found in the literature. Nevertheless, the information provided by the expert and found in literature coincide with the species characteristics, and therefore, the educated evaluation of the expert is considered correct.

Overall, all the analyzed plants meet the criteria to be implemented on the dikes in the pilot locations; from none, the roots are more profound than 50 cm, and they do not attract specific animals but insects. Additionally, based on the definition of biodiversity, that is, the variety of species, all the species implemented will contribute towards a biodiverse environment. The spreading of the plants from the list might not be considered a problem for the outer slope of the dike, and the maintenance and mowing will depend on the vegetation conditions that are wanted in the dike; though regarding flowering plants, not frequent mowing will be better for them. Finally, just one specie has not been proved that can grow along with grass; it is the Lapsana communis; therefore, this plant does not meet these criteria and cannot be implemented in the pilot locations.

In summary, seven out of the eight plant species are examples of plants that can be implemented on the landwards slope of the dikes to enlarge biodiversity in the pilot locations; more species can be analyzed considering the criteria defined in section 5.3. Hence, the analyzed plant species that can be used to promote biodiversity are the Centaurea jacea, Leucanthemum vulgare, Plantago lanceolata, Rumex acetosa, Silene dioica, Centaurea cyanus, and Galium odoratum.

5.3 Type of plants suitable for implementation

The type of suitable plants for its implementation is selected based on criteria that assure that the new plants will not be a danger to the dike structure and contribute to enlarging biodiversity.

The criteria that the plants should meet are that they are no trees or shrubs, grow currently in Flevoland, do not attract burrowing animals, the root depth should not be more profound than the clay layer of the dike, the spreading velocity should not lead to a dominative specie, the mowing should not be highly frequent, and the plant should be able to grow in harmony with grass. A critical remark is that the root depth can be higher than 50 cm depending on the clay layer, but the value is used as an average reference value for the criteria while analyzing the plant species.

The criteria previously mentioned can be considered a framework to evaluate plants that can be implemented in the dike without risking the functionality of the dike structure and that do not represent a problem for the maintenance of the dikes. Therefore, more plants can be selected and evaluated using the criteria to broaden the list and make a more robust mix of species that will enlarge biodiversity in dikes.

In this research, eight species were evaluated using the criteria. Of the eight species, seven met all the aspects. They are the *Centaurea jacea*, better known as Brown knapweed, *Leucanthemum vulgare*, better known as Marguerite, *Plantago lanceolata*, better known as Narrowleaf, *Rumex acetosa*, better known as Sorrel, *Silene dioica*, better known as Red campion, *Centaurea cyanus* better known as Cornflower, and *Galium odoratum*, better known as Sweet woodruff. All these plants are examples of plants that can be successfully implemented on the landward slope of the dikes to enlarge biodiversity in dikes.

6 Discussion

This research project can best be treated under two main fields: selection of pilot locations and investigation of plants biodiversity on the landward slope of dikes. Thus, the discussion for each topic will be treated in a different section. Section 6.1 is about the selection of pilot locations, and section 6.2 is about the investigation of plant biodiversity.

6.1 Selection of pilot locations

The objective related to the pilot locations was to find a location that is not prone to overtopping and, therefore, it might not require the grass cover protection fully. In that sense, the research sub-questions that followed that objective were to find parameters to consider a dike section not risky for erosion due to overtopping and which segments from these parameters can be considered for pilot locations. Combining the results from the former sub-questions, the main question could be answered which was to identify where in the dikes Flevopolder and Noordoostpolder the pilot locations are.

Following the results from this research, the parameter that should be met to have a *most safe* and *safe* location is to expect an overtopping discharge lower than 5 l/m/s. A division is also made within *neutral* locations for implementation (overtopping discharge between 5 to 10 l/m/s) and *unsafe* and *high-risk* locations (overtopping discharge higher than 10 l/m/s). From those parameters, the segments that can be considered for pilot locations are the *most safe* and *safe* sections. These sections to implement pilot locations can be seen on the map from the dikes shown in figure 7.

The results show that roughly 172 km along the dikes can be used for biodiversity-related projects. It shows that in the dikes of Flevopolder and Noordoostpolder there is a high potential to carry out pilot projects that increase biodiversity, not just on the dikes but in the Flevoland region. Nevertheless, not all the locations classified as *most safe* and *safe* can be currently used for biodiversity implementation because the Waterboard Zuiderzeeland rents sections of their dikes to farmers for agriculture (see Appendix D, figure 14) and for feeding their animals. The rented sections represent an economic income for the Waterboard. Therefore, it should be something to decide whether to keep renting the sections, progress with biodiversity implementation projects or a possible combination of both.

It is essential to point out that this research project focuses on finding parameters that can be considered safe where erosion resistance might be negligible. However, experts were emphatic that various roots might form a root network leading to erosion resistance. In this thesis, the worst situation of not having a cover was assumed, but in practice, there will be erosion resistance with the plants implemented. Therefore, considering that a scenario where no erosion resistance was considered, the *neutral* sections might also be taken into account for biodiversity implementation; nonetheless, this sections should be further explored to minimize possible risks.

The findings of this study suggest that there are locations where a diversity of plants can be planted without needing the protection of a grass cover. The expert interviews were focused on a scenario where grass erosion resistance is negligible. Thus, the results gathered from the experts show that to some extent, it is feasible to use a variety of other species of plants than grass, mainly because it was argued that overtopping discharge lower than 5 l/m/s can be handled by only the clay cover without a root network to provide erosion resistance; however, the current regulations by the Waterboard require the landward slope to have a grass cover limiting the possibilities to explore scenarios of landward slope covers without grass. In the past years, grass has proved to be an optimal option to provide erosion resistance on the dikes, but experts suggest that climate change and extreme weather conditions might require a diversity of plants to withstand the erosion due to overtopping in dikes. Promising segments to introduce a variety of species in Flevopolder are located near Zeewolde and Almere (see Appendix D, figures 15 and 16); the Waterboard Zuiderzeeland does not currently rent these sections, and its environment seems appropriate for implementing the first pilot projects.

There are certain limitations in the results presented. Firstly, due to the scope of the project and the time limit, the only parameters analyzed were related to overtopping discharge and overtopping failure; nonetheless, experts provided an overview of other criteria that could also be considered to reach robust results. Secondly, the Riskeer software does not allow modeling of two berms next to each other; thus, the berms were generalized into one; this changes the actual cross-sections of the dikes into a simplified one which also leads to not precise results. Finally, the hydraulic conditions used for the calculations are close to the calculated sections, but they are not precisely taken in the location of the section; thus, results might differ if there are hydraulic loads in the precise locations which have a different dike segment.

The limitations might represent that the calculated overtopping discharge underestimates or overestimates the hydraulic conditions at a specific point, which results in a lower or higher overtopping. However, considering that the criteria for most safe and safe locations are lower than 5 l/m/s, a slight deviation from the results might not represent a problem, given that the combination of new plants might still provide erosion resistance on the landward slope.

Essential points that could have been addressed in this research were how to combine different indicators to create more robust criteria. For instance, combining wave overtopping discharge with the maximum discharge volume might add more reliability while deciding which segments could be safe without a cover to provide erosion resistance.

To conclude, in this section, the first research question proposed in this project has been answered, showing where the segments of the dike Flevopolder and Noordoostpolder in which plant biodiversity can be implemented on the landward slope are. Nonetheless, essential limitation points related to the criteria and the software used must be considered while using the results presented for the pilot locations, especially if the *neutral* locations are planned to be used in future projects; indicators that could be considered for this purpose are wave height, landward slope, and maximum discharge volume. Moreover, software such as Hydra-NL can be used to calculate the overtopping discharge and compare the results gathered from Riskeer; it will provide more certainty about the expected overtopping discharge. Additionally, this research focuses mainly on finding the locations where projects for biodiversity can be implemented on the landward slope of the dike, considering overtopping discharge from an engineering perspective. However, it did not cover administrative or economic aspects that the Waterboard Zuiderzeeland might have to carry out in relation to implementing biodiversity projects.

6.2 Investigation of plant biodiversity on the landward slope of dikes

Plant biodiversity aims to identify plants that can be planted on the landward slope of the dikes safely without risking damage to the dike structure. For that purpose, the proposed research sub-questions to identify the options to enlarge plant biodiversity support the answer to the main research question.

Regarding the sub-questions, the regulations regarding what can be planted in the dike were something essential; the answer is that in order to plant on the dike it must enlarge values such as environmental and nature (national regulation), and it should be planted along with grass (Waterboard regulation). Regarding plants resistant to the local weather, it was proposed to select plants that grow in Flevoland, as they proved to withstand the weather conditions. Finally, the plants that are most appropriate to be planted on the landward slope of the dike are the plants that meet the criteria that was proposed based on literature and expert interviews.

Combining the results from the sub-questions leads to answering the main research question about the options to enlarge biodiversity on the landward slope of the dikes. The options of plants that can be used to enlarge biodiversity on dikes are all the plants that meet the criteria presented in the list provided in figure 9. These criteria represent a framework to analyze plants and identify whether they meet the conditions to be implemented on the dikes for biodiversity enlargement.

Root not deeper than the clay layer
- Approximately 50 cm (depends on the dike)
- No trees or shrubs

Plants that does not attract unwanted animals
- Especially burrowing animals

Not invasive especies
- Spreading quickly and do not allow grass to grow

Grow along with grass
- Provide a combination of root depths and networks

Withstand weather conditions
- Grow in Flevoland

Figure 9 Criteria framework to select plants for biodiversity implementation on the landward slope of dikes.

Based on the definition of biodiversity provided by Gaston & Spicer (2013), biodiversity is the variability among living organisms that encompasses all forms and combinations of natural variation; thus, different type of grass species also represents biodiversity. However, this project aimed to increase the biodiversity possibilities by exploring other plant species than grass. Thus, in this project, eight plants were analyzed based on the criteria framework. Of the eight plants, seven met the criteria to be implemented on the dikes; the seven plants are the Centaurea jacea, Leucanthemum vulgare, Plantago lanceolata, Rumex acetosa, Silene dioica, Centaurea cyanus, and Galium odoratum. These plants are examples of plants that will enlarge biodiversity on dikes, creating a diversity of plant species and attracting other species such as insects.

These results indicate that a variety of plant species can be implemented on the landward slope of the dike to enlarge biodiversity. Even though not all the plants suit the criteria requirements, four of the analyzed plants were randomly selected, and just one out of four did not meet the criteria; hence, there is a high chance that several plants will meet the conditions to be implemented on the dikes. Furthermore, various plants can already be found in the Noordoostpolder dike (see Appendix D, figures 17 and 18); these plants might have adapted to the environmental conditions and grown there naturally. Thus, it might be necessary to analyze the existing type of plants with the criteria framework to determine if those plants do not represent a risk for the dike structure.

It is essential to consider the study from Berendse et al. (2015), which argues about the compensation effect; it affirms that having diverse species that can take over the positions of species that went extinct because of fluctuating environmental conditions contributes to erosion resistance. In that sense, the contribution of biodiversity reducing erodibility in fluctuating environmental conditions might represent that diverse plant species have to be implemented in sections with high overtopping; however, it is necessary to study further the erosion resistance contribution of other types of plants and the functionality of the compensation effect in different environmental conditions.

An essential point that was not considered in the criteria because it might vary by plant species is the type of the root. According to Zanetti et al. (2011), large taproots can create sinkholes in dikes which will affect their structure; some herbs might have taproots, but they might not be large and might not affect the structure. Moreover, a study from Vannoppen et al. (2017) shows that fibrous root species are more effective in protecting the topsoil against concentrated flow erosion than tap root species; therefore, fibrous roots might be preferred in that regard even if small tap roots do not affect the structure. Experts suggest reviewing the Handreiking grasbekleding (translated as Grass cover guide), which contains information about unwanted situations on the grass covers; the guide was not explored in this report because the guide was not available in the research period. Thus, it is an information source to review while analyzing the plants. Thus, there are extra points to take into account while analyzing the plants.

The results from this part were limited to an engineering background knowledge that was focused on the structure safety and did not have broad knowledge about plants; thus, the framework might be limited to options that can be considered safe from an engineer's point of view. However, more options about the criteria, type of roots, or plant limitations might be considered by an ecologist or environmentalist background. Still, this research presents an initial solution to the implementation of plants diversity on the landward slope of dikes that might be further explored in future studies.

Another limitation was the lack of interviews on the type of plants for implementation. The fact that only one expert provided their input does not let room to compare or corroborate with another expert knowledge. Some of the results were corroborated by literature, but it was limited and not possible for all the plants. Finally, this study focused on the criteria to select plants to implement biodiversity on the dikes. However, it does not explore the status of the soil on the dikes nor the weather periods (to identify which season is better to plant) or the dike directions towards sunrise or sunset that might affect the plants; thus, there are points that can be more investigated to create the best possible scenario for biodiversity enlargement.

Moreover, the idea of using plants that grow in Flevoland because they are resistant to local weather is limited to actual weather conditions. However, it will be significant to focus on plants for the future, species that are resilient to climate change, rainy and drought periods, and extreme weather conditions. Those considerations can be further made while selecting the species, increasing the resilience of the landward slope dike covers over time, making them more resistant to climate change.

It is essential to mention that the criteria framework to select the plant species is a guide that might be further expanded by making other considerations such as the dike direction towards the sunrise and sunset, resistance to drought and rainy periods, the type of the roots, the environment created by different plants, and so on. Adding this type of consideration to the criteria might help to decide better which plant species are most appropriate for implementation and in which location they suit better. In that sense, these criteria to select the type of plant species for the landward slope of the dike is appropriate from an engineer's point of view to avoid any damage to the dike structure; however, it can be further developed to make it resilient and location-driven.

In summary, a criteria framework to select suitable plants to be implemented on the landward slope of the dikes has been provided. The former is focused on an engineering perspective that might be broadened by analyzing it from a different focus; in that sense, some focus points were given based on the acknowledged limitations of this research field. Overall, a variety of plants are suitable for implementation on the landward slope of the dikes, seven were presented as examples, but much more can be explored in future studies using the framework criteria previously introduced as a reference.

7 Conclusion

This research project was carried out to define if it is possible to enlarge biodiversity on the landward slope of the dikes Flevopolder and Noordoostpolder. The landward slope of the dikes is covered by grass which, through its roots, offers erosion resistance in case of overtopping flow. In that sense, the literature on plant covers in dikes is mainly related to grass species.

Due to the limited information available about other plant species' potential for erosion resistance, this research investigates locations that are not prone to overtopping on the dikes Flevopolder and Noordoostpolder, assuming that if not or low overtopping is expected, the sections could be used as pilot locations for a project related to biodiversity implementation. Based on the calculated overtopping discharge, a set of locations where biodiversity projects can be implemented was presented in figure 10. The length of the dikes where the projects can be implemented is approximately 172 km which is about 86% of the total length; this value is relatively high, meaning that there are many locations where biodiversity projects can be implemented.

Nonetheless, even if the locations are not prone to overtopping, not all types of plants can be introduced on the landward slope of dikes because their root might represent a risk to the structure of the dikes or could be against current regulations. Therefore, a criteria framework to select the appropriate species to be planted on the dike and that contributes towards biodiversity enlargement was introduced in figure 9. In this research, eight plant species were analyzed under the criteria framework, and seven met the criteria. The plants are the Centaurea jacea, Leucanthemum vulgare, Plantago lanceolata, Rumex acetosa, Silene dioica, Centaurea cyanus, and Galium odoratum.

In conclusion, no empirical research has been previously made to determine the contribution of different plant species to the erosion resistance on the landward slope of the dikes; therefore, an alternative scenario in which erosion resistance might not be required was proposed. This scenario helps to investigate which amount of overtopping discharge requires erosion resistance on the landward slope cover of the dikes. Therefore, locations that do not face this problem are assumed not to require the erosion resistance from the grass covers fully, and thus, a variety of plant species can be implemented in these locations landward slope. Finally, not all types of plants can be introduced, but they need to meet certain conditions, which were introduced as a framework to decide which plants are suitable for implementation on the landward slope of the Flevopolder and Noordoostpolder dikes.

8 Recommendations

The results presented in this report, the discussion, and the conclusion led to introduce a few recommendations for further studies and projects.

The first recommendation is about the pilot locations for biodiversity in Flevopolder and Noordoostpolder dikes, considering that the Waterboard Zuiderzeeland had rented about 70% of the segments. Therefore, to avoid economic losses while implementing pilot projects related to biodiversity, projects can be started in locations that are not rented. A visualization of the no rented locations and the classification based on the overtopping is shown in figure10. Thus, the initial projects for biodiversity can be potentially implemented in the *most safe* and *safe zones* shown on the map. The other sections that met the criteria of *most safe* and *safe* could be used in the future after the expiration date of the rented agreement, in which negotiations regarding biodiversity with the renting parties could also be discussed.

The following recommendation related to the pilot locations is to explore further the *neutral* locations in combination with other parameters such as wave height, landward slope, and maximum discharge volume. Therefore, these locations can be further assessed to determine whether they can also be used for biodiversity implementation. Along with that recommendation, it is recommended to use small *neutral* segments in the early projects; thus, *neutral* sections with a length between 0 to 0.5 km are suggested. These locations are shown in figure 11.

Regarding the types of plants, a recommendation about an appropriate set of plants to start analyzing is the plants that can be found growing along the dikes. Therefore, if the plant meets the criteria, its seed can be collected from the area where it was found, and then it can be planted, and its expansion can be fomented on the landward slope of the dikes. Additionally, it is recommended to use the *most safe* locations as segments to study the implementation of a variety of species than grass; it will help to study the effects of no grass on the landward slope of dikes related to erodibility without representing a substantial risk for erosion given that in these segments less than 1 l/m/s of overtopping discharge is expected.

After the implementation of different types of plants on the landward slope of the dikes, it is recommended to monitor the effects of the diversity of the plants in the environment, for instance, the attraction of insects to the dike or the growth of other plant species. Moreover, after a few years of implementing the plants in the pilot locations, it is recommended to evaluate the erosion resistance that the combination of diversity of plant species provides to the landward slope of the dike. The recommended method to carry out this evaluation is the extraction of a piece of soil to visualize the root networks formed by the different types of plants; this method has been previously used at the Waterboard Zuiderzeeland to evaluate the strength of the root network.

The final recommendation is to study further the type of plants that can be implemented on the dikes. The given criteria framework is a helpful basis for deciding which type of plants are suitable for implementation on the dikes. However, other considerations might be made while selecting a plant; several facts, such as the dike direction towards the sunrise and sunset, the type of the roots, the environment created by different plants, and so on. A specialist in ecology and environment can better explore those aspects; thus, studying this aspect further with an expert in the area is recommended.

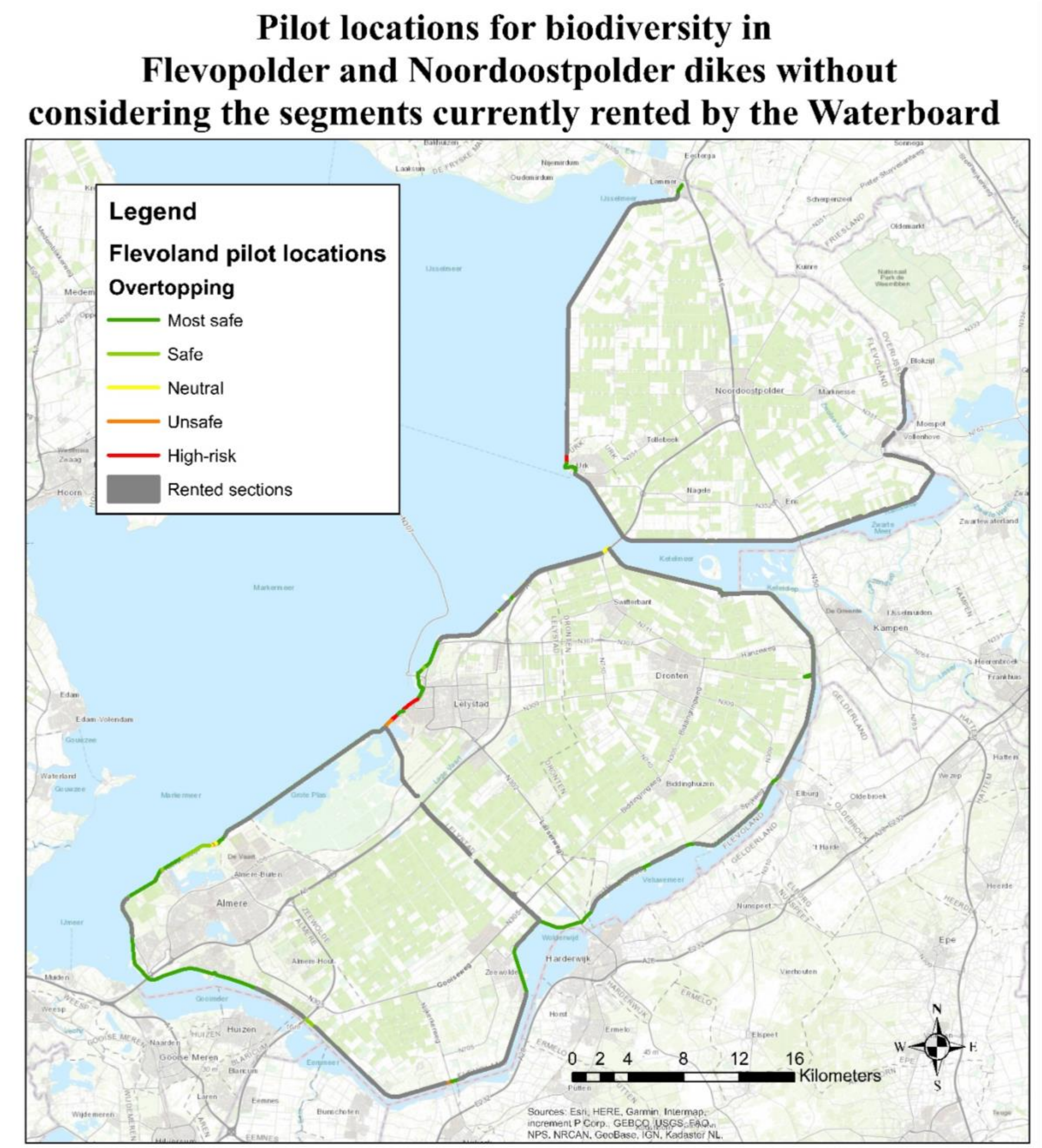

Figure 10 Pilot locations for biodiversity implementation in Flevopolder and Noordoostpolder dikes without considering the segments currently rented by the Waterboard.

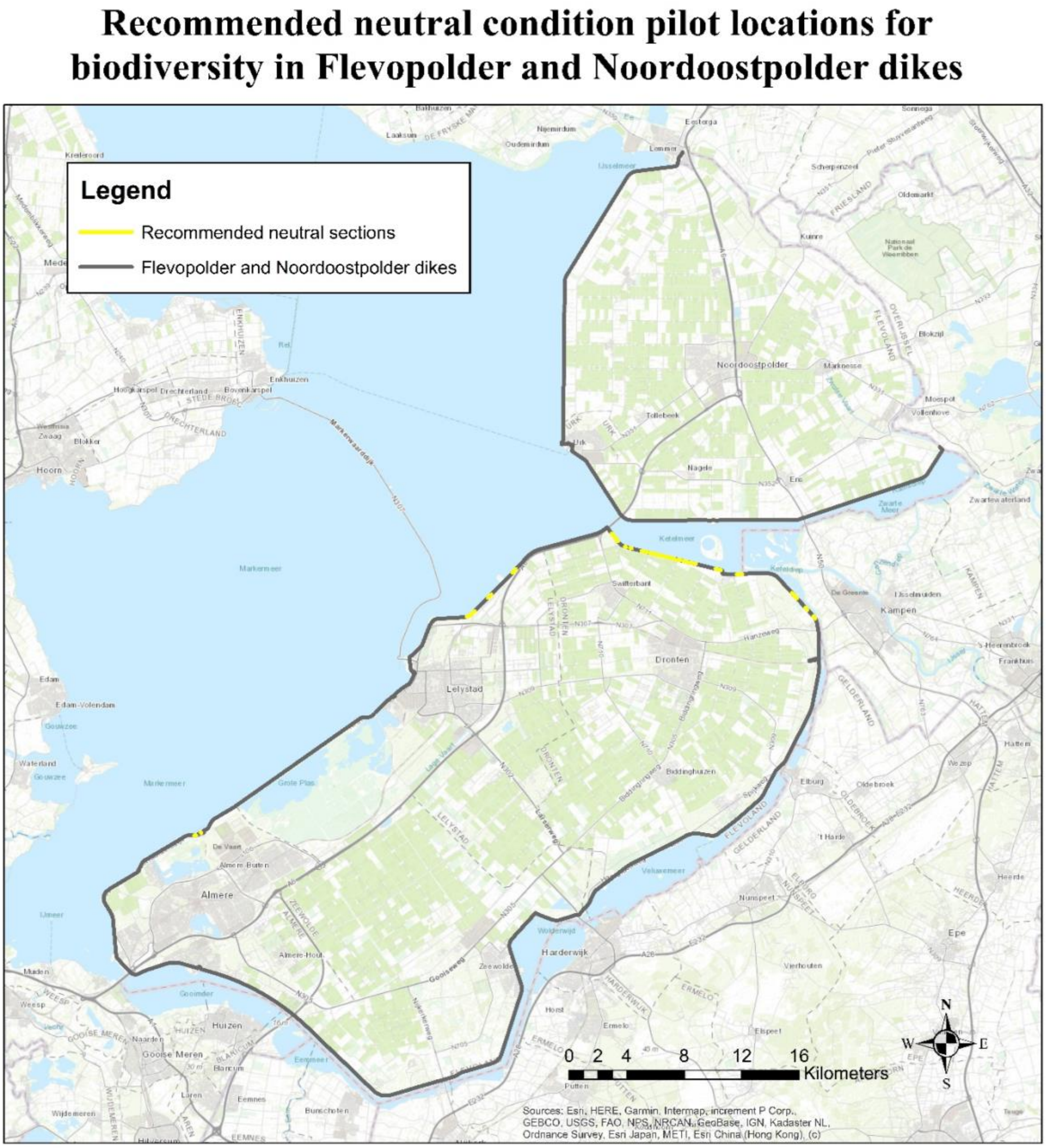

Figure 11 Recommended neutral condition pilot locations for biodiversity implementation in Flevopolder and Noordoostpolder dikes.

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10 Appendices
10.1 Appendix A

A detailed description of the input for Riskeer is provided in this section. The section that introduces and discusses the content of Appendix A is the section on the methodology of wave overtopping calculation (see section 3.1).

10.1.1 Riskeer input

10.1.1.1 Hydraulic loads

The database of the hydraulic loads (combination of water level and waves) is an essential input for calculating the overtopping discharge and failure probability. Riskeer uses an HDR database; it contains the water levels per dike location and information regarding the translation from basic stochastics to hydraulic loads; moreover, the calculations and model uncertainties on water level and wave conditions are stored in the database (Rijkswaterstaat, 2017). The magnitude of a load on a flood defence over a particular period of time is uncertain. The uncertainty regarding the natural variability in sea levels, river discharge rates, wind speeds and the unevenness of riverbeds and the relationship between wind speed and wave height, mean that in practice, loads are only referred in terms of probabilities (ENW, 2017).

For the database of hydraulic loads, the basic stochastics are the wind direction and speed, the discharge of the river, the sea level, the interaction of design with the tide, the lake level, the prediction accuracy of the closure of the storm surge barriers, and the condition (being open or closed) of the storm surge barriers (Overheid.nl, 2017). As the basic stochastics vary per area, the databases are created specifically for the water system of Noordoostpolder.

According to Overheid.nl (2017), the hydraulic loads that follow Riskeer are topwater levels and wave maxima from the hydrodynamic calculations, and the time dependence has been worked out for each test track in the water level trends. Additionally, for each combination of load parameters, it is known how great the probability of occurrence of that combination is; based on this, the most probable combination of parameters leading to the hydraulic loads can also be determined for the semi-probabilistic test per dike. Therefore, the hydraulic loads used for the calculations in Riskeer estimate an unlikely scenario of topwater levels, which have a low chance of occurrence in the dikes.

10.1.1.2 Dike profiles

In order to perform a GEKB calculation using Riskeer, the "Legger-profiles" of the Noordoostpolder dikes are required. The profiles are an essential input for the software; it should be a shapefile containing the ID, the X0, and the name (Deltares, 2021).

For creating the shapefiles for the Noordoostpolder dike area, the drawings of the Waterboard Zuiderzeeland will be retrieved from ArcGIS (2020); in figure 12 , an example of a dike profile of Noordoostpolder is shown. Additionally, the drawings contain the dikes, canals, urban water, and structures the Waterboard manages and where they are located (Waterschap Zuiderzeeland, n.d.-a).

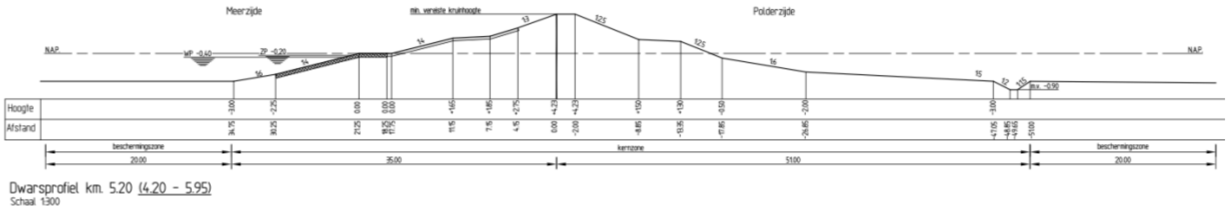

Figure 12 Dike profile of Noordoostpolder, section 4.20 - 5.95 km (ArcGIS, 2020).

The input required to create a dike profile for Riskeer is shown in figure 13; it is an example of the requirements for the shapefile. It needs to be added the version, the ID, the direction, the type of dam it contains, the dam height relative to the NAP, the use of a sheet pile in the dike or not, the foreland coordinates, the crop height, the dike profile coordinates, and the memo which is simply the comments of the file.

```
VERSIE        4.0
ID            01200
RICHTING      62
DAM           3
DAMHOOGTE     0.5

DAMWAND       0

VOORLAND      3
-150.000      -9.000     1.000
-100.000      -6.000     1.000
-18.000       -6.000     1.000

KRUINHOOGTE   6

DIJK          4
-18.000       -6.000     1.000
-2.000        -0.100     0.500
2.000         0.100      1.000
18.000        6.000      1.000

MEMO
dam:  havendam
voorland
talud met (ruwe) berm
```

Figure 13 Example of inputs required to create a dike profile for Riskeer (Deltares, 2021).

The shapefiles will be created for the dike drawings of Noordoostpolder, which have a different cross-section profile; the ones with a similar profile will be linked to the first similar shapefile.

10.1.1.3 Grass quality

The grass quality for calculation purposes is classified as ‘closed,’ ‘open,’ or ‘fragmentary.’ From the ‘open’ and ‘closed’ classification, there have been set probability distributions that represent the erosion resistance of the crest and the inner slope during wave overtopping (Rijkswaterstaat, 2021). These values are calculated for different wave height categories and will be used in the Riskeer calculations; the values are shown in table 3.

Table 3 Lognormal distribution probability of the critical overtopping discharge at different wave height classed and sod quality of the l expected value (μ) and standard deviation (σ) for the probability of failure of the grass mat (Rijkswaterstaat, 2021).

	Close sod		Open sod	
Wave height category	$\mu[m^3/s/m]$	$\sigma[m^3/s/m]$	$\mu[m^3/s/m]$	$\sigma[m^3/s/m]$
0 m – 1 m	0.225	0.250	0.100	0.120
1 m – 2 m	0.100	0.120	0.070	0.080
2 m – 3 m	0.070	0.080	0.040	0.050

It is essential to point out that the wave height category cannot be determined before proceeding with the calculations. However, the maximum wave height is an output of the Riskeer GEKB calculation; therefore, an iterative process to determine the correct distribution and wave height needs to be made for each dike profile and section. For the calculations, the close sod distribution is used given the current status of the grass cover in the Noordoostpolder dike.

Nevertheless, the grass quality distribution does not contribute to the results of the overtopping discharge that might occur in the dike nor the failure probability by overtopping, but it is related to the strength of the dike and its failure probability.

10.2 Appendix B

10.2.1 Noordoostpolder overtopping results

The results presented in this section are elaborated in section 4.1. The results are given for a dike section with its length span, and the calculated values are the overtopping flow and failure probability. The results were calculated in Riskeer for the norm and the cross-section requirement probability; they are presented in table 4 for the norm and table 5 for the cross-section probability.

Table 4 Overtopping results for Noordoostpolder calculated by the norm (probability of failure of 1/3000) in Riskeer.

Dike ID	Segment (km)	Overtopping flow [l/m/s]	Calculated failure [1/year]
DP00039	(0-1.1)	0	0.000282885
DP00140	(1.10-1.60)	0	0.000332116
DP00270	(2.25-3.15)	0.03	0.000334001
DP00520	(4.20-5.95)	0.42	0.000333222
DP00650	(5.95-7.00)	0.32	0.00033456
DP00750	(7-8.10)	1.43	0.000334113
DP00950	(9.10-10.85)	0.68	0.000333111
DP01200	(10.85-12.95)	1.17	0.000332668
DP01320	(4.20-5.95)	0.54	0.000334448
DP01460	(12.95-15.20)	1	0.000334113
DP01740	(16.00-18.20)	0.79	0.000333556
DP01910	(18.20-19.50)	1.49	0.000332889
DP02000	(19.50-20.85)	1.46	0.00033389
DP02170	(20.85-22.95)	0.91	0.000333778
DP02360	(22.95-24.20)	102.18	0.000336814
DP02620	(25.60-26.65)	0.39	0.000333111
DP02680	(26.65-27.00)	1.5	0.000333444
DP02750	(27.00-28.15)	2.7	0.000333778
DP02870	(28.15-29.00)	1.96	0.000333778
DP02920	(29.00-29.80)	2.6	0.000333222
DP03050	(29.00-31.30)(A-6)	1.71	0.000333444
DP03170	(31.30-31.90)(A-6)	0.46	0.00033389
DP03270	(31.90-33.65)	0.02	0.000332668
DP03430	(33.65-35.25)	1.63	0.000332226
DP03575	(35.25-35.90)	9.19	0.000333333
DP03670	(36.25-37.34)	0.89	0.000334001
DP03744	(37.34-37.60)	0.58	0.000286287
DP03790	(37.70-38.00)	0.02	0.000333111
DP03825	(38.00-38.30)	42.49	0.000334113
DP03880	(38.40-39.10)	4.11	0.000334225
DP03970	(39.10-40.10)	2.73	0.000332668
DP04100	(40.10-42.25)	1.73	0.000333778
DP04330	(42.25-43.65)	0.06	0.000333667

Dike ID	Segment (km)	Overtopping flow [l/m/s]	Calculated failure [1/year]
DP04380	(43.65-44.00)	0.02	0.000334225
DP04420	(44.00-Ramspolbrug)	0.29	0.000332557
DP04560	(44.30-46.22)	0	0.000372301
DP04740	(46.22-49.16)	0	0.000329924
DP05000	(49.16-50.66)	0	0.000332226
DP05190	(50.66-53.10)	0	0.000334336
DP05370	(53.10-54.30)	0	0.000185736
DP05450	(54.30-54.65)	0	0.00012955
DP05500	(54.65.55.30)	0	0.000182116
DP05540	(55.30-55.55)	0	0.000332447

Table 5 Overtopping results for Noordoostpolder calculated by the cross-section requirement (probability of failure of 1/37500) in Riskeer.

Dike ID	Segment (km)	Overtopping flow [l/m/s]	Calculated failure [1/year]
DP00039	0.63	0.06	1/37614
DP00140	(1.10-1.60)	0.52	1/37457
DP00270	(2.25-3.15)	2.85	1/37494
DP00520	(4.20-5.95)	3.41	1/37544
DP00650	(5.95-7.00)	2.77	1/37363
DP00750	(7-8.10)	9.71	1/37507
DP00950	(9.10-10.85)	5.45	1/37489
DP01200	(10.85-12.95)	6.57	1/37347
DP01320	(4.20-5.95)	3.59	1/37467
DP01460	(12.95-15.20)	5.99	1/37393
DP01740	(16.00-18.20)	5.52	1/37497
DP01910	(18.20-19.50)	8.84	1/37462
DP02000	(19.50-20.85)	8.34	1/37382
DP02170	(20.85-22.95)	5.48	1/37542
DP02360	(22.95-24.20)	237.13	1/37507
DP02620	(25.60-26.65)	3.79	1/37448
DP02680	(26.65-27.00)	12.46	1/37572
DP02750	(27.00-28.15)	20.13	1/37488
DP02870	(28.15-29.00)	16.24	1/37603
DP02920	(29.00-29.80)	21.74	1/37462
DP03050	(29.00-31.30)(A-6)	15.71	1/37476
DP03170	(31.30-31.90)(A-6)	9.76	1/37366
DP03270	(31.90-33.65)	1.65	1/37438
DP03430	(33.65-35.25)	29.43	1/37435
DP03575	(35.25-35.90)	135.75	1/37435
DP03670	(36.25-37.34)	22.99	1/37467
DP03744	(37.34-37.60)	26.4	1/37616

Dike ID	Segment (km)	Overtopping flow [l/m/s]	Calculated failure [1/year]
DP03790	(37.70-38.00)	27.92	1/37518
DP03825	(38.00-38.30)	622.61	1/36312
DP03880	(38.40-39.10)	91.69	1/37395
DP03970	(39.10-40.10)	96.87	1/37564
DP04100	(40.10-42.25)	65.21	1/37584
DP04330	(42.25-43.65)	18.19	1/37368
DP04380	(43.65-44.00)	16.61	1/37600
DP04420	(44.00-Ramspolbrug)	204.69	1/37381
DP04560	(44.30-46.22)	0	1/41384
DP04740	(46.22-49.16)	0	1/36716
DP05000	(49.16-50.66)	0	1/37580
DP05190	(50.66-53.10)	0	1/37972
DP05370	(53.10-54.30)	0	1/37389
DP05450	(54.30-54.65)	0	1/37462
DP05500	(54.65.55.30)	0	1/37516
DP05540	(55.30-55.55)	0	1/37494

10.2.2 Interview structure regarding pilot locations

The expert interview regarding pilot locations aims to determine a criterion to select pilot locations for biodiversity implementation on the inner slope of the dikes, therefore, the goal is to obtain insights about what requirements (overtopping discharge, failure probability) the experts consider appropriate to establish a pilot location. The criteria are mainly related to the overtopping discharge and the failure probability by overtopping in a determined section of the dike. Hence, the interview will be structured to drive the experts to provide this input. The results are summarized in section 10.2.3 and analyzed in section 4.2.

The experts will be interviewed alone; however, if they do not speak English, they might be accompanied by a translator; this is to avoid biases in the answers by other experts. The interview session will be voice-recorded upon the expert's permission; otherwise, notes of the answers will be taken. For the processing of the information, the expert will be asked for permission to allow the use of its input in the research; the input will be transcribed and summarized after the session. Then the information that will be used in the project will be sent to the expert for final approval. The voice-recorded audio will be deleted after the project is finished.

For the interview, firstly, a presentation of background information about the project and a study area map will be presented to the interviewers. After the introduction, the interviewers will be asked the structured questionnaire (section 10.2.2.2); the questions are defined based on the results from the overtopping calculations in Riskeer and on the theory of flood safety and grass erosion. The interview will be supported with slides to present information and to show the interviewer the questions. The agenda for the pilot locations interview will be as follows:

1. Opening and welcome to the expert
2. Presentation of background information about the project
3. Presentation of the study area map
4. Interview expert (see questionnaire, section 10.2.2.2)
5. Closure

In the opening and welcome section, I will briefly introduce my background and ask for the expert’s background. Then, in the presentation of background information about the project section, the project and its aim will be introduced. In the presentation of the study area map, the map of Flevoland and its dike will be shown. Further, the interview expert section will be carried out by asking the questions from the questionnaire. Finally, the expert will be thanked for their time and input on the project in the closure section; together with asking for permission to use expert’s name in the report.

10.2.2.1 Experts

There are some considerations regarding selecting the experts for the pilot locations interview. The selection will be made based on their education level (graduated or doctoral degree) and the research/projects they have worked on; for the determination of the research/projects, it should be related to dikes and flood safety. There are experts from the Waterboard Zuiderzeeland; however, at least one expert should be from outside the organization to avoid inter-organizational biases.

The experts' profiles and backgrounds are listed in table 6, the experts will be listed based on the interview date, Thus, the first will be expert pilot locations #1, the second will be expert pilot locations #2, and so forth. In the results in section 10.2.3, the experts will be listed based on their number.

Table 6 Experts for the pilot location interview.

<table>
<tr><th colspan="2">Expert pilot locations #1</th></tr>
<tr><th>Name</th><th>Education level and organization</th></tr>
<tr><td rowspan="3">Jord Warmink</td><td>PhD at the University of Twente.
Associate professor in hydraulic engineering related projects at the University of Twente.</td></tr>
<tr><th>Projects/research</th></tr>
<tr><td>Guided PhD students who did research about stability of dikes (piping stabilities) related to the soft soil, wave overtopping (numerical model to determine effect of erode in top of a dike)
• Other projects mainly related to wave overtopping (data analysis about experiments) and numerical models about the effect of overtopping in the landward slope of dikes.</td></tr>
<tr><th colspan="2">Expert pilot locations #2</th></tr>
<tr><th>Name</th><th>Education level and organization</th></tr>
<tr><td rowspan="3">Vera van Bergeijk</td><td>Master of Sciences in Meteorology, Physical Oceanography and Climate in Utrecht University.
PhD at University of Twente.
Currently working at Deltares (Coastal structures and waves group).</td></tr>
<tr><th>Projects/research</th></tr>
<tr><td>• Modelling wave-overtopping flow and dike cover erosion on the crest and landward slope (PhD thesis).
Overtopping flow and wave generation, wave breaking and run-off in dunes and dikes.</td></tr>
<tr><th colspan="2">Expert pilot locations #3</th></tr>
<tr><th>Name</th><th>Education level and organization</th></tr>
<tr><td rowspan="3">Peter Boone</td><td>Maintenance policy work for Waterboard Vallei en Veluwe</td></tr>
<tr><th>Projects/research</th></tr>
<tr><td>Connection within research done for water safety. For instance, grass covers on dikes</td></tr>
</table>

	and its connection with the maintenance people.
Expert pilot locations #4	
Name	**Education level and organization**
Gerrit Kiers	Professional engineer water management, in flood protection and inland water control 20 years' experience as Geotechnical engineer and technical designer in VIZITERV Consult Ktf. Consultant flood risk management at Waterboard Zuiderzeeland
	Projects/research
	Advisor of flood safety structure in Budapest and Netherlands.
Expert pilot locations #5	
Name	**Education level and organization**
Bernd Fetlaar	Studied Land and Water Management Specialist in Water Safety in the Waterboard Zuiderzeeland
	Projects/research
	Working several years on maintenance and supervision of the flood defenses structure.

10.2.2.2 Questionnaire

The questions aim to retrieve a yes/no answer; however, to understand the background of the answer, they are followed by a why (not)? question. The following questionnaire will be used for the interviews:

1. Will you consider that a dike section without a grass cover will be safe from wave overtopping failure in the inner slope? Why (not)?
2. Does the failure probability of overtopping properly represent the flood risk? Why (not)?
3. Are overtopping discharge and failure probability appropriate indicators to make a change in the cover of the inner slope of a dike? Why (not)?

If question 3 was answered positively that they are good indicators, then continue with question 3.1 to 3.7.

3.1. Which range of overtopping discharge will you consider most safe to implement a project where grass erosion resistance might be negligible?
3.2. Which range of overtopping discharge will you consider neutral to implement a project where grass erosion resistance might be negligible?
3.3. Which range of overtopping discharge will you consider not safe to implement a project where grass erosion resistance might be negligible?
3.4. Considering the probability failure norm of the dikes, will you consider a higher recurrence period (lower probability of occurrence) appropriate to implement a project where grass erosion resistance might be negligible?

3.5. Considering the probability failure norm of the dikes, will you consider a lower recurrence period (higher probability of occurrence) not appropriate to implement a project where grass erosion resistance might be negligible?

3.6. Is there a combination of the overtopping discharge and failure probability that you consider highly suitable for implementing a pilot project where grass erosion resistance might be negligible?

If question 3 was answered negatively, then skip question 3.1. to 3.6.

3.7. Which indicators will you use to make a change in the inner slope of a dike implementing a project where grass erosion resistance might be negligible?

4. Do you consider that implementing new types of plants but grass on the landward slope of the dikes can increase biodiversity and flood protection? Why (not)?

10.2.3 Interview outcomes for pilot locations interviews

The input provided by each interviewee is summarized in table 7; it is listed based on the questionnaire established in section 10.2.2.2. The input from the experts is analysed in section 4.2; it is used to answer the research questions of this project.

Table 7 Expert outcome from the pilot location interviews.

Question	Expert pilot locations #1 outcome	Expert pilot locations #2 outcome	Expert pilot locations #3 outcome	Expert pilot locations #4 outcome	Expert pilot locations #5 outcome
1. Will you consider that a dike section without a grass cover will be safe from wave overtopping failure on the inner slope? Why (not)?	It depends on the amount of wave overtopping, but it has been seen in an experiment of erosion resistance of clay only, thus, it depends a lot on the composition of the soil itself. Therefore, it will depend on the particular circumstances of each section.	It depends on what is considered as failure. If it is looked failure as in flooding, it can be allowed to the clay underneath the grass to erode a bit more.	It is safe, but it depends of course on the amount of wave overtopping and the slope of the dike. Slope of 1:3 or less, then, grass cover is very strong. And it is not only for grasses, but the combination of grass and other plants. However, there are several plants that are not good for erosion resistance. Recommend to check “handreiking grasbekleding".	It will not be safe, because erosion will work on the ground particles, it is a risk that the soil gets saturated, and particles of soil start to float.	It depends on the clay layer, because if it is very good it can withstand up to 10 l/m/s.

Question	Expert pilot locations #1 outcome	Expert pilot locations #2 outcome	Expert pilot locations #3 outcome	Expert pilot locations #4 outcome	Expert pilot locations #5 outcome
2. Does the failure probability of overtopping properly represent the flood risk? Why (not)?	For flood risk, it is needed to consider not just overtopping but other types of failures. In flood risk, there is also the consequences of flood included. Therefore, it is impossible to relate them, because failure probability is just a small part of flood risk.	The current definition of failure by erosion by wave overtopping is 20 cm erosion depth. But in terms of flooding, it can be allowed much more erosion. Probably until the dike crest is lower. Therefore, based on the current definition it might not be representative but an easy way to calculate it.	It depends on what is the main load and the impact of the waves, height water level and the water resistance through the dike. Which of them is causing the worst problem for the dike, and if it is overtopping then it will properly represent it. But it depends on how the dike is built and the type of dike it is.	It does not represent the flood risk because failure probability is a combination of several failure mechanisms. In reality, there is no idea how overtopping or stability are actually contributing to the failure probability.	It is one of the mechanisms, however, it is theoretically because our dikes are prepared to withstand a unlikely situation that theoretically exists, but it can be difficult to happen in reality.
3. Are overtopping discharge and failure probability appropriate indicators to make a change in the cover of the inner slope of a dike? Why (not)?	Overtopping discharge is not always the best indicator, but it said something about the amount of water. But erosion also depend on the wave characteristics, thus, it can be used but needs to be complemented. Failure probability depends on how it was calculated. Therefore, roughly they give a sense of indication but not in detail.	It is needed more than overtopping discharge as an indicator, because wave volume also influences what will happen. But still it can be used as an indicator.	It is depending on what slope is in the dike and which is the material on which the dike is built on. It influences if the dike is likely to erosion or not. Therefore, a combination with other indicators is better.	Overtopping discharge is a very important indicator. Failure probability of overtopping is actually related to overflow related situations and not so much related to change on the cover and new type of vegetation.	Yes, overtopping is an appropriate indicator; if there is no overtopping then it clearly shows that something can be done on the landward slope of the dike.

Question	Expert pilot locations #1 outcome	Expert pilot locations #2 outcome	Expert pilot locations #3 outcome	Expert pilot locations #4 outcome	Expert pilot locations #5 outcome
3.1. Which range of overtopping discharge will you consider most safe to implement a project where grass erosion resistance might be negligible?	Within 0 to 0.1 l/m/s	For clay, within 0 to 1 l/m/s discharge	Really safe will be under 5 l/m/s (It is important that the dike can be properly inspected, which will help to guarantee that the structure is safer under this value)	Factors that should be taken in consideration, such as the duration of overtopping, slope of the inner slope, the time of the year and so for. Therefore, it is not a threshold value from my experience.	It is something that is being explored in the Future Dikes project. In dikes without berms or slope changes, erosion is less likely because the point of change is a weak spot for erosion.
3.2. Which range of overtopping discharge will you consider neutral to implement a project where grass erosion resistance might be negligible?	Within 0.1 to 5 l/m/s	Within 1 to 10 l/m/s	5 to 10 l/m/s	Answered in 3.1.	Answered in 3.1.
3.3. Which range of overtopping discharge will you consider not safe to implement a project where grass erosion resistance might be negligible?	Larger than 5 l/m/s (maybe even 10 l/m/s but it depends a lot on the conditions)	Everything above 10 l/m/s	Not safe will be over 50 l/m/s for most clay dikes.	Answered in 3.1.	Everything above 10 l/m/s.

Question	Expert pilot locations #1 outcome	Expert pilot locations #2 outcome	Expert pilot locations #3 outcome	Expert pilot locations #4 outcome	Expert pilot locations #5 outcome
3.4. Considering the probability failure norm of the dikes, will you consider a higher recurrence period (lower probability of occurrence) appropriate to implement a project where grass erosion resistance might be negligible?	I consider failure probability is a really complicated number which is dominated by a lot of effects. But it depends on how it is calculated; however, it will not be my first choice.	If the probability of failure is lower than the norm, it might be safe.	For most of the overtopping problems, a grass cover will be good enough. But the dike should be strong enough with a good clay cover where the cover with grass and herbs is growing.	In general, a higher recurrence period represents a safer dike against failure. Unfortunately, it does not provide any information related to how risk it is for grass erosion.	It is a difficult question, but mainly if there is no overtopping; then it is possible.
3.5. Considering the probability failure norm of the dikes, will you consider a lower recurrence period (higher probability of occurrence) not appropriate to implement a project where grass erosion resistance might be negligible?	Answered in 3.4.	It depends on what is defined as failure. If it is allowed for more erosion and repair, then, it will be fine. But for that it will be required manteinace and inspection.	Already answered in 3.4.	Answered in 3.4.	Answered in 3.4.

Question	Expert pilot locations #1 outcome	Expert pilot locations #2 outcome	Expert pilot locations #3 outcome	Expert pilot locations #4 outcome	Expert pilot locations #5 outcome
3.6. Is there a combination of the overtopping discharge and failure probability that you consider highly suitable for implementing a pilot project where grass erosion resistance might be negligible?	If it is below 1 l/m/s and below the norm, then it can be suitable. However, this is a very conservative estimate. Dike slopes will probably be sufficiently strong above these values, but I cannot be sure, therefore the conservative estimates.	Considering that the failure probability is based on the overtopping discharge, then, there is no need on combination of both indicators.	Already answered in 3.1 and 3.4.	I will not consider any combination of this both for implementing a pilot project.	Answered in 3.4.
3.7. Which indicators will you use to make a change on the cover of the inner slope of a dike implementing a project where grass erosion resistance might be negligible?	Wave characteristics	Indicators such as maximum overtopping volume of a wave and wave height might make overtopping discharge more reliable. Focus might be in the erosion of clay rather than erosion of grass.	The slope, the material the dike is built and the type of grass cover (how good is the root network).	Not my expertise.	Not creating problem for the neighbors, new species should not be protected by law because maintenance will require permission from the Province.

Question	Expert pilot locations #1 outcome	Expert pilot locations #2 outcome	Expert pilot locations #3 outcome	Expert pilot locations #4 outcome	Expert pilot locations #5 outcome
4. Do you consider that implementing new types of plants but grass on the landward slope of the dikes can increase biodiversity and flood protection? Why (not)?	It can increase biodiversity; it has been seen that there increase biodiversity of vegetation and insects. Flood protection, currently we are studying it in the "Future dikes" project; however, they are more resilient in draught and more biodiverse probably will stay healthier and help flood protection.	Definitely it will increase biodiversity, also a good option given the amount of dikes in the Netherlands. For flood protection, a lot of research is going on, but they might be better for flood protection in draughts and heavy rain.	The seeds used nowadays for making grass cover are made of in 1960, but currently there are more draughts than before. Therefore, a combination of grasses and herbs is stronger than only grass, and also it increases biodiversity. For biodiversity, is important a large variety of plants and through the season let the vegetation produce flowers and seeds, thus, it will give food for insects.	It certainly will increase biodiversity by its basic definition of variety of species. In terms of flood protection, it might increase, because some species have bigger roots, and it can make dike stronger against erosion. Additionally, monotype grass covers, are really uniform and they have lower erosion resistance. However, it is not my expertise area, so it is mainly based on my opinion.	Yes, it will increase biodiversity. In terms of flood protection, it will be explored in the Future Dikes project.

10.3 Appendix C
10.3.1 Interview structure for criteria to select type of plants

The expert interview regarding the criteria to select the type of plants aims to determine the characteristics that the plants should have to be planted in the landward slope of the dikes. The questions are aimed to provide insights in how good the criteria defined in section 5.1.1 is. Hence, the interview will be structured to drive the experts to provide their opinion for the key features and requirements expected in the plants. The results are summarized in section 10.3.2 and analyzed in section 5.2.

The experts will be interviewed alone; however, if they do not speak English, they might be accompanied by a translator; this is to avoid biases in the answers by other experts. The interview session will be voice-recorded upon the expert's permission; otherwise, notes of the answers will be taken. For the processing of the information, the expert will be asked for permission to allow the use of its input in the research; the input will be transcribed and summarized after the session. Then the information that will be used in the project will be sent to the expert for final approval. The voice-recorded audio will be deleted after the project is finished.

Firstly, a presentation of background information about the project and a study area map will be presented to the interviewers. After the introduction, the interviewers will be asked the structured questionnaire (section 10.3.1.2); the questions are defined based on the research about regulations and grass cover theory. The interview will be supported with slides to present information and to show the interviewer the questions. The agenda for the criteria to select type of plants interview will be as follows:

1. Opening and welcome to the expert
2. Presentation of background information about the project
3. Presentation of the study area map
4. Interview expert (see questionnaire, section 10.3.1.2)
5. Closure

In the opening and welcome section, I will briefly introduce my background and ask for the expert's background. Then, in the presentation of background information about the project section, the project and its aim will be introduced. In the presentation of the study area map, the map of Flevoland and its dike will be shown. Further, the interview expert section will be carried out by asking the questions from the questionnaire. Finally, the expert will be thanked for their time and input on the project in the closure section; together with asking for permission to use expert's name in the report.

10.3.1.1 Experts
There are some considerations regarding selecting the experts for the criteria to select type of plants interview. The selection will be made based on their experience and the research/projects

they have worked on; for the determination of the research/projects, it should be related to dike maintenance and grass-cover maintenance and mowing, preferable with experience in a Waterboard context. There are experts from the Waterboard Zuiderzeeland; however, at least one expert is from outside the organization to avoid inter-organizational biases.

The experts' profiles and backgrounds are listed in table 8, the experts will be listed based on the interview date. Thus, the first will be expert types of plants #1, the second will be expert types of plants #2, and so forth. In the results in section 10.3.2, the experts will be listed based on their number.

Table 8 Experts for the criteria to select type of plants interview.

Expert criteria to select type of plants #1	
Name	**Education level and organization**
Peter Boone	Maintenance policy work for Waterboard Vallei en Veluwe
	Projects/research
	Connection within research done for water safety. For instance, grass covers on dikes and its connection with the maintenance people.
Expert criteria to select type of plants #2	
Name	**Education level and organization**
Benjamin Wijma	Senior supervisor of flood defenses in the Waterboard Zuiderzeeland
	Projects/research
	Working on maintenance and supervision of the flood defenses structure.
Expert criteria to select type of plants #3	
Name	**Education level and organization**
Bernd Fetlaar	Studied Land and Water Management Specialist in Water Safety in the Waterboard Zuiderzeeland
	Projects/research
	Working several years on maintenance and supervision of the flood defenses structure.

10.3.1.2 Questionnaire

The questions aim to retrieve background and technical information related to the criteria to select new type of plants which was introduced in section 5.1.1. The following questionnaire will be used for the interviews:

1. Do the root depth of a plant might be higher than 50 cm?
2. Is any type of animal which is not wanted in dikes?
3. Do you think the spreading velocity of a plant represent a problem for the landward and outer slope of a dike?
4. Do you think that if a plant requires frequent maintenance or mowing it will be a problem?
5. Is it important that the plant can grow along with grass?

10.3.2 Interview outcomes for criteria to select type of plants

The input provided by each interviewee is summarized in table 9; it is listed based on the questionnaire established in section 10.3.1.2. The input from the experts is analysed in section 5.2; it is used to answer the research questions of this project.

Table 9 Expert outcome from the criteria to select type of plants interview.

Question	Expert pilot locations #1 outcome	Expert pilot locations #2 outcome	Expert pilot locations #3 outcome
1. Do the root depth of a plant might be higher than 50 cm?	It is important to have a combination of root depth. The grasses with the root make a really strong net in the surface and it is held in the top layer of the clay, but then the deeper roots come in to create a net in deeper slope as well. Additionally, piping might not be a problem if the root is higher than 50 cm, but trees and shrubs are not appropriate. Therefore, grass and herbs can be used even with deeper roots.	It's not wise to have the clay layer completely fill with roots, it's good to have some amount without roots. Moreover, it depends on the clay layer thickness because the roots should stay there. Also, they shouldn't grow till the drain of the dike. The clay layer is about 20 cm for the upper layer and a lower layer of 40 to 60 cm.	It does not matter, if it is very deep or not so deep; the diversity of roots makes the resistance stronger. Comparing dikes with just two type of grass species, a combination with more plants will increase erosion resistance. Regarding root depth, it depends on the clay layer.
2. Is any type of animal which is not wanted at the dikes?	There are several problems, but it is not directly for some plant, but there are animals that like roots for instance. Additionally, there are grubs that is living underground and eat the roots of the plants, moreover, these grubs attract other type of animals that eat them and make holes in the dike. Therefore, there are animals that harm the dike, but it is not about a specific plant but a combination of plants that attract the animals. Finally, it is essential to consider	The underground species are good and help to develop the vegetation better. In terms of other animals such as foxes, rabbits, mice and so for. Mainly, animals that make holes on the clay layer are not wanted in dikes.	Regarding animals no burrowing animals, but also animals that while eating the grass remove the roots of the plants like cows.

Question	Expert pilot locations #1 outcome	Expert pilot locations #2 outcome	Expert pilot locations #3 outcome
	that there are certain plants that are toxic for animals such as sheep's and cows, which represent a problem if the grass cover is used as food for animals.		
3. Do you think the spreading velocity of a plant represent a problem for the landward and outer slope of a dike?	Most of the time it is good that the plants spread because the diversity is wanted in the grass cover to be less vulnerable to draught. But if there are unwanted species, then it is better not to let them spread by mowing (not allowing the plants to making flowers and seeds) but the wanted species are good to let them spread.	There is not good to have just one type of species, therefore, if their spreading is dominant then it's not good for the vegetation along the dike. For that, it main be important to do maintenance to keep the plants in the place they are wanted to avoid them to spread.	It will not be a problem for the dike, but for the neighbors' farmers because the plant species will spread to the land of farmers, and they might not want it.
4. Do you think that if a plant requires frequent maintenance or mowing it will be a problem?	It depends on how stable the vegetation is, if the grass cover developing is vulnerable, then it is needed to mow and remove biomass, thus, it will remove nutrients because herbs are growing in circumstances with less nutrients compared with the species that are unwanted. Clay is very rich in nutrients; therefore, it is needed to remove as much as nutrients as you can;	It is a bit of a choice, if it strength biodiversity, then frequent maintenance and mowing might be okay; however, it is essential to be aware that it will cost more money for the Waterboard.	No, it is not a problem; normally we are doing 2 to 3 times per year, however, if they are plants that have to be mowed 10 times per year, it is potentially a problem.

Question	Expert pilot locations #1 outcome	Expert pilot locations #2 outcome	Expert pilot locations #3 outcome
	and when the grass cover is good and reach a stable vegetation, then the maintenance and mowing will be less frequent. Roughly at the beginning it will require 3-4 times per year to mow but when it reaches a stable situation it will be within 1-2 years.		
5. Is it important that the plant can grow along with grass?	There are certain problems related to herbs and grass cover explained in Handreiking Grasblekeding. For instance, if the herb is growing faster than the grass, and it got cover by the herbs, then it will be a blind spot underneath the higher herbs (it will be potentially a problem because it will reduce erosion resistance).	Yes, because it is essential to have a combination with grass and other species. It is a difference within a flowering dike which is biodiverse, but it could also be a dike with a lot of type of species of grass in the dike.	Even if there is no overtopping, I consider it should be a small cover to protect the soil from eroding. The most usual is the grass; however, if there are no overtopping just other types of plants can be implemented, nonetheless, a cover is necessary to avoid soil from blowing away.

10.3.3 Interview structure regarding types of plants

The expert interview regarding types of plants aims to determine the types of plants that can be planted in the landward slope of the dikes for biodiversity enlargement. The plants need to meet certain requirements related to the roots and they might foster biodiversity attracting other type of animals. The types of animals that plants might attract will enlarge biodiversity, however, it is important to prevent the dike areas from undesirable species such as gooses. Hence, the interview will be structured to drive the experts to provide their opinion for selected types of plants. The results are summarized in section 10.3.4 and analyzed in section 5.2.

The experts will be interviewed alone; however, if they do not speak English, they might be accompanied by a translator; this is to avoid biases in the answers by other experts. The interview session will be voice-recorded upon the expert's permission; otherwise, notes of the answers will be taken. For the processing of the information, the expert will be asked for permission to allow the use of its input in the research; the input will be transcribed and summarized after the session. Then the information that will be used in the project will be sent to the expert for final approval. The voice-recorded audio will be deleted after the project is finished.

Firstly, a presentation of background information about the project and a study area map will be presented to the interviewers. After the introduction, the interviewers will be asked the structured questionnaire (section 10.3.3.2); the questions are defined based on the research about regulations and types of plants suitable for the study area. The interview will be supported with slides to present information and to show the interviewer the questions. The agenda for the types of plants interview will be as follows:

6. Opening and welcome to the expert
7. Presentation of background information about the project
8. Presentation of the study area map
9. Interview expert (see questionnaire, section 10.3.3.2)
10. Closure

In the opening and welcome section, I will briefly introduce my background and ask for the expert's background. Then, in the presentation of background information about the project section, the project and its aim will be introduced. In the presentation of the study area map, the map of Flevoland and its dike will be shown. Further, the interview expert section will be carried out by asking the questions from the questionnaire. Finally, the expert will be thanked for their time and input on the project in the closure section; together with asking for permission to use expert's name in the report.

10.3.3.1 Experts

There are some considerations regarding selecting the expert for the type of plants interview. The selection is made based on their education level (graduated or doctoral degree) and the research/projects they have worked on; for the determination of the research/projects, it should be related to flood safety and vegetation-related projects, preferable with an ecologist background.

As just one expert was available for the interview, and it is from the Waterboard Zuiderzeeland, avoiding organizational biases will be made, if possible, by answering the questions with literature.

The expert's profile and background are listed in table 10. In the results in section 10.3.4, the expert input and the literature research is summarized.

Table 10 Experts for the types of plants interview.

Expert types of plants #1	
Name	**Education level and organization**
Marianne Wolfs	Ecologist (master's in resource ecology in Wageningen University)
	Projects/research
	Working on topics about fish migration, handling exotic species of fish and plants in the Waterboard Zuiderzeeland.

10.3.3.2 Questionnaire

The questions aim to retrieve a yes/no response; in some cases, the questions are followed by an additional question to gather more information in relation to the original question. The questions are based on the key features introduced in section 5.1.1 and the list of plants presented in section 5.1.2. The following questionnaire will be used for the interviews:

1. Do you estimate that the root depth of this plant will be higher than 50 cm?
2. Does this plant attract any types of animals? If yes, which types of animals?
3. Does this plant spread quickly? If yes, how likely it is that it will spread to the outer slope of the dike?
4. Does this plant require frequent maintenance or mowing? If yes, how often?
5. Do you think this plant will enlarge biodiversity on the dikes?
6. Does this plant can grow along with grass?

The above listed questions will be asked for all the plants in the list described in section 5.1.2.

7. Do you have any suggestions regarding plants that will enlarge biodiversity on the dikes in Flevoland which have a root depth of maximum 50 cm?

10.3.4 Interview outcomes for types of plants interviews

The input provided by each interviewee and the literature review is summarized in table 11; it is listed based on the questionnaire established in section 10.3.3.2. The input from the experts is analysed in section 5.2; it is used to answer the research questions of this project.

Table 11 Expert outcomes of the types of plants interviews.

Question		Expert types of plants #1 outcome	Literature research outcome
Marguerite (Margriet)	1. Do you estimate that the root depth of this plant will be higher than 50 cm?	No, I do not think that the roots reach 50 cm deep	Relatively shallow root system (Clements et al., 2004).
Leucanthemum vulgare	2. Does this plant attract any types of animals? If yes, which types of animals?	It will attract insects, given that it is a flowery plant.	The flowers attract beneficial insects (Clements et al., 2004).
	3. Does this plant spread quickly? If yes, how likely it is that it will spread to the outer slope of the dike?	It does spread, but it might not be considered a problem specie.	It occasionally spread a short distance into adjacent cropped areas (Clements et al., 2004).
	4. Does this plant require frequent maintenance or mowing? If yes, how often?	It does not because flowering species do not benefit from mowing.	Recommended mowing meadows as soon as the first flowers appear, to prevent further spread of seeds. (Clements et al., 2004).
	5. Do you think this plant will enlarge biodiversity on the dikes?	Yes, biodiversity is the amount of species. Thus, more species more biodiversity. Therefore, a combination of more plants will enlarge biodiversity in the system.	Specie commonly sown as a means of maintaining biodiversity within agricultural land (Clements et al., 2004).
Photo: Hugo (2007)	6. Does this plant can grow along with grass?	Yes, it is currently growing on some places in the dikes.	Yes, it grows in grasslands (Clements et al., 2004).

Question		Expert types of plants #1 outcome	Literature research outcome
Sorrel (Veldzuring)	1. Do you estimate that the root depth of this plant will be higher than 50 cm?	No, it is a very small plant.	Root about 9 cm long, grow horizontally (Klimeš & Klimešová, 1999).
Rumex acetosa	2. Does this plant attract any types of animals? If yes, which types of animals?	This plant is quite edible; thus, I think it attract animals.	It develops properly in absence of grazing animals (Moore, 1954).
	3. Does this plant spread quickly? If yes, how likely it is that it will spread to the outer slope of the dike?	I have not heard any problems related to spreading for this plant.	Spread rapidly if grass is removed (Putwain & Harper, 1970).
	4. Does this plant require frequent maintenance or mowing? If yes, how often?	It does not require often mowing, because it is really small. But this plant might affect the vegetation underneath.	Not found in literature.
	5. Do you think this plant will enlarge biodiversity on the dikes?	Yes	Not found in literature.
Photo: Descounens (2021)	6. Does this plant can grow along with grass?	This plant is very common in grass areas.	Populations of Rumex acetosa grow along grasslands (Putwain & Harper, 1970).

Question		Expert types of plants #1 outcome	Literature research outcome
Narrowleaf (Smalle weegbree)	1. Do you estimate that the root depth of this plant will be higher than 50 cm?	No, I do not think so.	Roots not deeper than 20 cm (Cranston et al., 2016).
Plantago lanceolata	2. Does this plant attract any types of animals? If yes, which types of animals?	I do not know if it specially attracts certain types of animals. However, dike managers do not want it to attract rabbits because they make holes in the dike.	Attract some insects and grazing animals (Stewart, 1996).
	3. Does this plant spread quickly? If yes, how likely it is that it will spread to the outer slope of the dike?	No, it is a plant that grow well along the road. But it is not big spreader.	Not found in literature.
	4. Does this plant require frequent maintenance or mowing? If yes, how often?	No, I think it grows along with the grass.	Mowing homogeneous to grasslands (Gáspár et al., 2019).
	5. Do you think this plant will enlarge biodiversity on the dikes?	Yes	Yes, it is a common specie in the Biodiversity Exploratorie (Gáspár et al., 2019).
Photo: Sannse (2004)	6. Does this plant can grow along with grass?	Yes	It has a successful adaptation in grasslands (Stewart, 1996).

Question		Expert types of plants #1 outcome	Literature research outcome
Brown knapweed (Knoopkruid)	1. Do you estimate that the root depth of this plant will be higher than 50 cm?	I do not know it very much. But because it looks really small, I do not think so.	Not found in literature.
Centaurea jacea	2. Does this plant attract any types of animals? If yes, which types of animals?	It has flowers, and its pink and visible. Visible flowers help to attract more insects.	Popular plant species among honeybees and bumblebees (Eschen et al., 2009).
	3. Does this plant spread quickly? If yes, how likely it is that it will spread to the outer slope of the dike?	Not sure about this one.	From a seed mixture it tends to become a dominant specie (Eschen et al., 2009).
	4. Does this plant require frequent maintenance or mowing? If yes, how often?	Not sure about this one.	Not found in literature.
	5. Do you think this plant will enlarge biodiversity on the dikes?	Yes	Sown with meadow seed mixture can support agrobiodiversity and maintain a high level of biodiversity. (Eschen et al., 2009).
Photo: Planther.nl (n.d.)	6. Does this plant can grow along with grass?	Yes, it seems like it.	Yes, it grows in grasslands (Eschen et al., 2009).

Question		Expert types of plants #1 outcome	Literature research outcome
Red campion (Dagkoekoeksbloem)	1. Do you estimate that the root depth of this plant will be higher than 50 cm?	Not sure about this one. It is not very common.	5 to 10 cm length (Falkengren-Grerup, 1998).
Silene dioica	2. Does this plant attract any types of animals? If yes, which types of animals?	Insect most likely.	Not found in literature.
	3. Does this plant spread quickly? If yes, how likely it is that it will spread to the outer slope of the dike?	I do not think this plant will be a problem, it is not really common.	Disperse widely and spreading germination over several years (Matlack, 1987).
	4. Does this plant require frequent maintenance or mowing? If yes, how often?	This one might benefit from less mowing.	Easily tolerates mowing (Matlack, 1987).
	5. Do you think this plant will enlarge biodiversity on the dikes?	Yes	Not found in literature.
Photo: Jane (2020)	6. Does this plant can grow along with grass?	Yes, it seems like it.	Not found in literature.

Question		Expert types of plants #1 outcome	Literature research outcome
Nipplewort (Akkerkool)	1. Do you estimate that the root depth of this plant will be higher than 50 cm?	I do not think so, given the Akker (in the name) it gives a consideration that it is growing in the field along the vegetables, and they are hardly growing along with grass.	Not found in literature.
Lapsana communis	2. Does this plant attract any types of animals? If yes, which types of animals?	Yes, most likely.	Insects observed near this plant (Francis et al., 2011).
	3. Does this plant spread quickly? If yes, how likely it is that it will spread to the outer slope of the dike?	It might spread quickly, because this type of plants tends to spread a lot. However, if grass is already grown it will unlikely grow.	It is likely to spread to neighboring areas, but it is really low (Francis et al., 2011).
	4. Does this plant require frequent maintenance or mowing? If yes, how often?	No, it will not benefit from frequent mowing.	Not found in literature.
	5. Do you think this plant will enlarge biodiversity on the dikes?	Yes	Attracts insects (Francis et al., 2011).
Photo: Zell (2009)	6. Does this plant can grow along with grass?	Not sure about it.	Not found in literature.

Question		Expert types of plants #1 outcome	Literature research outcome
Cornflower (Korenbloem)	1. Do you estimate that the root depth of this plant will be higher than 50 cm?	Not known, it is known to grow in the wheat fields.	Root length varies from 30 to 55 cm depending on treatment (Yang & Zhang, 2022).
Centaurea cyanus	2. Does this plant attract any types of animals? If yes, which types of animals?	Yes, most likely insects.	Not found in literature.
	3. Does this plant spread quickly? If yes, how likely it is that it will spread to the outer slope of the dike?	I do not think its spreading will be a problem for the outer slope of the dike.	Not found in literature.
	4. Does this plant require frequent maintenance or mowing? If yes, how often?	No, it will not benefit from frequent mowing.	Not found in literature.
	5. Do you think this plant will enlarge biodiversity on the dikes?	Yes	Not found in literature.
Photo: Bykova (2020)	6. Does this plant can grow along with grass?	Yes, very well I consider.	Not found in literature.

Question		Expert types of plants #1 outcome	Literature research outcome
Sweet woodruff (Lievevrouwebedstro)	1. Do you estimate that the root depth of this plant will be higher than 50 cm?	No, definitely no.	4 to 7 cm below the ground surface (Falkengren-Grerup, 1994).
Galium odoratum	2. Does this plant attract any types of animals? If yes, which types of animals?	Yes, most likely. Not specific species are attracted to it, but most likely.	It attracts pollination insects because its specie is insect pollinated (Rawlik & Jagodziński, 2020).
	3. Does this plant spread quickly? If yes, how likely it is that it will spread to the outer slope of the dike?	No, I do not think so.	It spread by clonal growth, and it is slower than seed spreading species (Petersen & Philipp, 2001).
	4. Does this plant require frequent maintenance or mowing? If yes, how often?	This plant does not require frequent mowing or maintenance.	From periodic mowing, it benefits significantly reducing vole presence compared to other cover crops (Wiman et al., 2009).
	5. Do you think this plant will enlarge biodiversity on the dikes?	Yes, definitely.	Insect pollinated specie (Rawlik & Jagodziński, 2020).
Photo: Tanne (2008)	6. Does this plant can grow along with grass?	Not sure about it.	It was studied with grasses in Falkengren-Grerup (1994).

Question	Expert types of plants #1 outcome	Literature research outcome
7. Do you have any suggestions regarding plants that will enlarge biodiversity on the dikes in Flevoland which have a root depth of maximum 50 cm?	Dike managers use a list of seeds to spread in the dike, there might be a list of grass and herbs that grow in the dikes.	Cannot be answered by literature.

10.4 Appendix D

10.4.1 Field research

This section presents recent photos of locations in the dike that were taken as part of a field research. The pictures are used to better visualize the scenario in the dikes which are introduced in the discussion section (section 6).

Figure 14 Landward slope on the Noordoostpolder dike used by farmers (picture location shown in red).

Figure 15 Promising non-rented location for biodiversity projects near Zeewolde (picture location shown in red).

Figure 16 Promising non-rented location for biodiversity projects near Almere (picture location shown in red).

Figure 17 Diversity of plants in the landward slope of the Noordoostpolder dike (picture location shown in red).

Figure 18 Diversity of plants in the landward slope of the Flevopolder dike (picture location shown in red).