A research in the usefulness of a Quantitative CO2 emission framework in the preliminary design phase of a dike reinforcement project.

Olof Baltus
S1819437
o.baltus@student.utwente.nl

Content

Title	A research in the usefulness of a quantitative CO_2 emission framework in the preliminary design phase of a dike reinforcement project.
Subtitle	Implementing a quick scan assessment framework in the preliminary design Phase of a dike reinforcement project
Date	September 2019

Involved people

Student	Olof Baltus
Student number	s1819437
Address	Soendastraat 36
Postal code/City	7512 DW/ Enschede
Telephone	(+31) (0)6 81 62 95 48
Email address	o.baltus@student.utwente.nl

External organisation	Infram-Hydren
Address	Amersfoortseweg 9
Postal code/City	3951 LA/ Maarn

External supervisor	Ir. Rinse Joustra
Telephone	(+31) (0) 6 53841724
Email Address	rinse.joustra@infram-hydren.nl

University	University of Twente
Address	Drienerlolaan 5
Postal code/City	7500 AE/ Enschede
Faculty	Engineering Technology
Program	Civil Engineering

Supervisor University	Dr. Ir. H.L. ter Huerne
Email address	h.l.terhuerne@utwente.nl

Second supervisor	Msc. M. Pezij
Email address	m.pezij@utwente.nl

INFRAM HYDREN
Waterbouw, Innovatie en Onderzoek

UNIVERSITY OF TWENTE.

Pre-Ambule

The past three months I have been busy researching the sustainability of different dike reinforcements. I have done my research at Infram a consultancy firm located in Maarn. I want to thank Infram for giving me the opportunity to research this awesome and challenging topic. Also, want to thank all the people at Infram who helped me during my research. When I had a question there was always somebody that could help.

I want to thank especially Rinse Joustra who helped me shape my research as it is written in this report. We began with a question on how to improve the sustainability of a dike reinforcement project and ended with this report including an assessment framework to assess sustainability of different dike reinforcements. Also, the useful feedback he gave me multiple times helped me to perform this research and get this result.

Also want to thank Meinke Schouten for inviting me to the Dubocalc sessions where I got a lot of information to fulfil this research. These sessions also gave me the chance to meet people who have a lot of experience in the sustainability of dike reinforcements. Some of which I couldn't have done this research without. This is why I also want to thank Michiel Wolbers from Royal HaskoningDHV for inviting me to the working sessions to make standard objects in Dubocalc. Also, Michiel Wolbers gave me feedback about how to improve my calculations, this was very helpful for the total process of my research.

To answer my last research question, I had to find two technical managers from waterboards in the Netherlands with experience in dike reinforcement projects. With the help of Rinse, I found two technical managers which were able to tell me a lot about the daily practice of dike reinforcements and especially about how sustainability is now implemented in dike reinforcement project. I want to the Marco Weijland from waterboard Schieland Krimpenerwaard and Gerjan Westerhof from waterboard Rivierenland for the interesting interviews and their opinion about my assessment framework.

At last I want to thank Dr. Ir. ter Huerne for the feedback he gave on my reports. Also, the time he took to help me bring this research to a good end.

I hope my research is an eyeopener for everyone who reads my report, on how much more CO_2 emission reduction there can be achieved when implementing more sustainable alternatives in dike reinforcement projects.

Olof Baltus

Enschede, 15-9-2019

List with abbreviations

Abbreviation	In full
Dubocalc	Duurzaam bouwen calculator
MKI	Milieu kosten indicator
CO_2	Carbon Dioxide
LCA	Life Cycle Analysis
HDPE	Hard Polyetheen
MIRT	Meerjarenprogramma Infrastructuur, Ruimte en Transport
GWW	Grond-, Weg- en Waterbouw
POV	Project overstijgende verkenning

Table 1 List with Abbreviations

Table of Content

Summary

Everywhere in the news there is spoken about the climate change and how to reduce it. Also, it is a very hot topic in the different political parties in the Netherlands. This awareness followed to a goal set in the climate agreement in Paris, the goal is to Reduce the CO_2 emission by 50 percent before 2030. This directly has influence on the civil engineering working field, that is why Rijkswaterstaat has made its own agreement, the 'Green deal duurzaam GWW'. In this Green Deal they have spoken out the ambition to make sustainability one of the focus points in civil engineering projects.

In the Netherlands every primary dike needs a required failing probability. To see if dikes full fil this failing probability the government tests dikes every couple of years. In the last testing round 540 Km of the 900 Km tested dikes was rejected due to the failure mechanism of piping. With the ambitions set by Rijkswaterstaat, the dike reinforcement projects also need to take sustainability into account. Furthermore, there can be found a vicious circle in this process when a dike is in need of reinforcements due to the rising sea levels this project will emit CO_2. The CO_2 emitted during the dike reinforcement will cause more rising of the sea level, which will make the just reinforced dike unsafe again. Which causes that the dike needs reinforcements again.

In the first phases of a project the big decisions are made for example, which kind of reinforcement will be used. The problem there is present is that the different options for reinforcements are not quantitatively compared before the decision is made. This results in very subjective analysis of the different options which may result in choosing an option which is environmentally a bad decision. A possible solution for this problem is to make a quantitatively environmental assessment framework with the different measures and their environmental impact.

Because the failure mechanism of piping is at this moment one of the bigger problems in the Netherlands, the quantitatively assessment framework will be tested on the fail mechanism of piping. To design the assessment framework there will be made calculations in Dubocalc, which is a software to calculate the environmental impact of a civil engineering project. First there is done research on the different measures to prevent piping and how these measures can be implemented in Dubocalc.

To make a location independent assessment framework, some assumptions needed to be made. The most important assumption is the seepage length shortage, which is assumed at 10 m. With the assumed needed extra seepage length, the dimensions of the different measures can be calculated. With this dimension the impact on the environment and the CO_2 emission of the different measures can be calculated. The calculations showed that the impact on the environment of the different measures are far apart from little impact on the environment to very big impact.

With the calculated CO_2 emissions of the different measures there can be made a better decision in the preliminary design phase of a project. But it is also interesting to know where there can be made more improvements in later phases to bring down the CO_2 emission of a project. This is done with analysing the dominant factors of the different measures to see what influence they have on the total environmental impact. After analysing the factors, it can be seen that the most measures have one factor that has 50% or more influence on the total environmental impact.

Now that the quantitative assessment framework is made, it is important to test if the assessment framework will be used in the civil engineering working field. To achieve this there are done interviews with technical managers of two water boards. The interviews were structured to get the answer on the question of the assessment framework is applicable.

1. Introduction

To introduce the subject of the research and explain more about the problem and the aim of the research this first introduction is written. Within this introduction there will be started with explaining the motive to do this research, followed by defining the problem. When the problem is defined the aim of the research will be explained with the questions that need to be answered to reach the aim. At last, the methods and the data that will be used during the research will be explained.

1.1. Motive

Climate change including sea level rises and extreme weathers is becoming one of the biggest targets the coming years to counteract. The Dutch government already made the first steps with the Climate agreement which was made in Paris. Furthermore, the Dutch government has the ambition to reduce the greenhouse gases with 49 to 55 percent by 2030 (Milieudefensie, 2018). This directly has influence in the Civil Engineering working field, because of the CO_2 gasses which are emitted in civil engineering projects.

In the green deal 'duurzaam GWW' is noted that by 2020 all big civil engineering projects are going to be assessed on sustainability (Green Deal, 2019). A typical Dutch civil engineering construction project is a dike reinforcement project. Many dikes in the Netherlands will be reinforced as result of a national flood risk assessment. Most of these dikes due to the failure mechanism piping. In 2013 already 200 Kilometres of the dikes in the Netherlands were rejected because of the chance on dike failure due to piping. After this event the water boards did research in 940 Kilometres of dikes from which 540 Kilometres got rejected due to piping. (Huijsmans, 2013)

The subject of environmental change already had my interest before this research. The reason behind this is that scientist have answers on almost every question there is about nature, also on environmental change and how to reduce the environmental change. But although the answers to reduce the change is already there, the environment is still changing. Furthermore, as said earlier to counteract the environmental change is one of the biggest challenges and definitely a challenge where I am interested in. So, when I heard there was an opportunity to do research in the field of CO_2 reduction this got me motivated to take this challenge and see what is possible.

1.2. Problem definition

In the preliminary design phase, the different alternatives of dike reinforcement projects are assessed and there is chosen a preferred alternative which is worked out in the plan elaboration phase. There can be assumed that the different alternatives have different CO_2 emissions. At the moment there are done little to nonenvironmental assessments in the preliminary design phase of a project. The assessments that are done in the preliminary design phase are often very subjective, so not really trustworthy.

1.3. Research Aim/Questions & Research Methods

The aim of this research is to find out if a quantitative assessment framework can help with the choice that is made during the preliminary design phase. This is done to see if there can be made choices in the preliminary design phase to reduce the CO_2 emission of a dike reinforcement project. In the research there is focussed on the measures to reduce the problem of piping, but if the research is successful there is room to expand this also to other measures.

With this research aim there can be a main question:

1. Can a quantitative environmental assessment framework make a difference in preference choice in the preliminary design phase for dike reinforcements due to the failure mechanism of piping?

With this main question there can be formed some sub questions that support answering the main question.

1.1. How are environmental aspects now assessed in the MIRT project phases?
To Answers this question there will be done literature research in finding how environmental aspects are now assessed in the MIRT project phases. The union of waterboards also has regular meetings to discuss the problem of assessing the environmental aspects in the MIRT project phases. To get more information about the current situation I will go to these meetings and get more information about the current situation.

1.2. What are the commonly used reinforcements against piping?
For answering this question there will be done literature research in the common measures to prevent piping, within Infram there are multiple persons working in the field of piping. So, the outcome of the literature research will also be checked with this people.

1.3. How can the MKI for the different reinforcements be calculated?
Within the civil engineering working field there is developed a software to calculate the MKI of civil engineering projects. This software is called Dubocalc and will be used to calculate the MKI of the different measures. There will also be done literature research to see how the different measures are normally build up and what materials are used. At last there will be done literature research to see how the dimensions of the different measures can be calculated after which they will be calculated.

1.4. What are the CO_2 emissions for the different alternatives?
Using the software of Dubocalc the MKI of the different measures will be calculated after which the CO_2 emission of the different measures can be calculated with Dubocalc.

1.5. Which parameters have the biggest influence on the CO_2 emission for the different alternatives?
With the calculations made in the previous questions the MKI was calculated. Within these calculations different factors have influence on the total outcome of the MKI. To answer this question the different Dubocalc calculations will be analysed and the influence of the different operations and factors will be calculated.

1.6. Using the assessment framework made in the previous questions, is it applicable and will it be used in dike reinforcement projects?
As validation of the assessment framework made in the previous questions, the applicability of the assessment framework will be tested by taken two interviews. The two interviews will be done with two technical managers from waterboards in the Netherlands.

1.4. Data

The data that will be used in this research is mostly literature research data and Dubocalc data. The literature data is used to see how the different measures are build up and how they can be dimensioned. The other part is data to calculate the MKI of the different measure, this data is imported in Dubocalc from the 'milieu database'. The data consists of numbers for MKI values, which followed from a lifecycle analysis. The data that is in the 'milieu database' is checked with established procedures written by the environmental databank.

1.5. Reading guide

To understand how the design of the assessment framework is done the next chapters will explain what is done to make the assessment framework. In chapter 2 the current situation is analysed and the current innovations in the field of sustainability in dike reinforcements will be researched. After the current situation is analysed, the different measures to prevent piping will be described in chapter 3. When there is known which measures there are to prevent piping in dikes, the sustainability of these measures can be calculated. This will be done in chapter 4, where first the different measures will be dimensioned after which the environmental cost indicator and the CO_2 emission will be calculated. When the assessment of the different alternatives is done, the influence of the different parts within the alternatives will be researched this can be found in chapter 5. The assessment framework can be made after the factors are research, the assessment framework can also be found in chapter 5. In chapter 7 the assessment framework will be validated, to see if it is applicable in the working field of dike reinforcements. This will be done by taking interviews with two technical members of waterboards in the Netherlands. In chapter 8 the conclusion for the research and the answers to the research questions can be found. Followed by chapter 9 in which the recommendations for future research can be found. And in the last chapter, chapter 10, there will be a discussion about the research.

2. Current situation

As described in the introduction Rijkswaterstaat has set the ambition to improve the sustainability of their projects. By 2030 they have the ambition to have reduced the CO_2 emission of their projects with 50%. To find out where the research of improving the sustainability of dike reinforcement projects is at the moment, there will be done research to see the current situation. This will start with explaining the Green Deal 'Duurzaam GWW', this is the agreement a lot of civil engineering companies made to improve the sustainability of their projects. This explanation is followed by the current innovations in the working field of sustainability in dike reinforcements.

2.1. Green Deal 'Duurzaam GWW'

The Green deal is a practical method to implement sustainability in GWW projects. The method is based on five basic principles. Three of these principles are interesting for this research, the first one is that sustainability of a project must be measured uniform over different projects. The second principle is that sustainability needs to be taken into account in an early project phase because there the environmental profit can be the highest. The third and last interesting principle is that there need to be focussed on the parts where the most profit can be reached. (Duurzaam GWW, 2019)

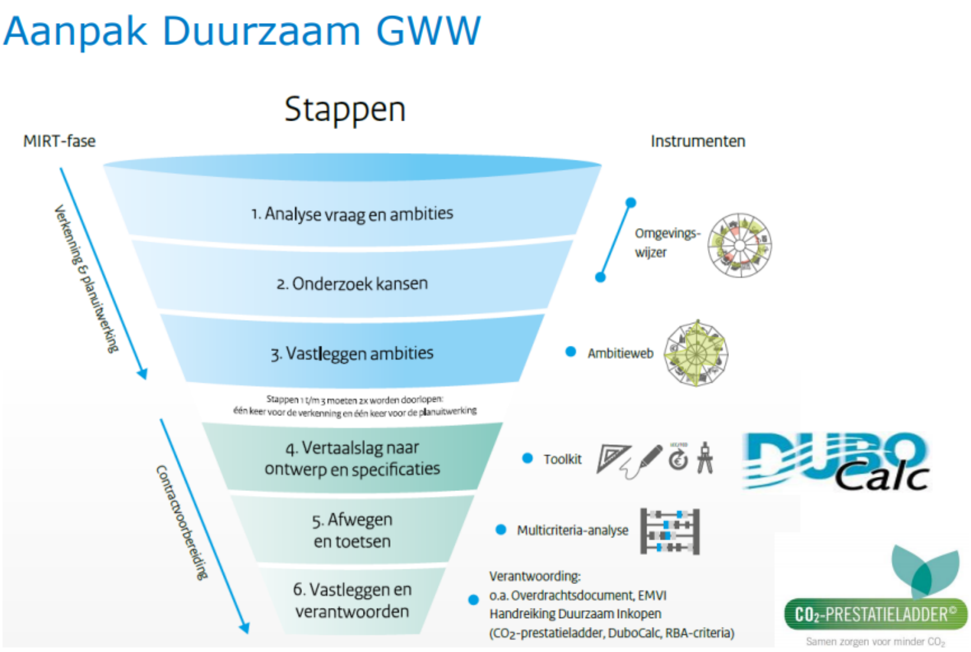


Figure 1 Aanpak Duurzaam GWW (Schweitzer, 2018)

Figure 1 shows the 'aanpak duurzaam GWW' with the corresponding steps. These steps are linked to the MIRT project phases which are often used in Civil Engineering projects in the Netherlands. To give better insight in the MIRT project phases these will be described below shortly. Figure 2 gives the different phases of the MIRT process.

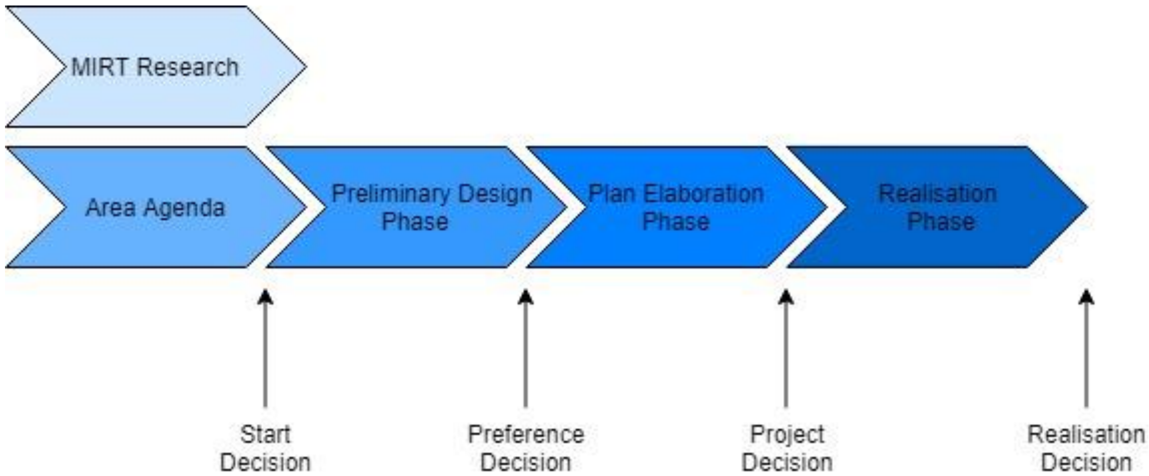


Figure 2 MIRT project phases (Ministerie van Infrastructuur en Milieu, 2016)

In the 'Gebiedsagenda' or in English area agenda the ambitions of the Dutch government are gathered. Also, in the area agenda the tasks to reach these ambitions are noted. The area agenda is formed through combining the ambitions of the government and the region. After the area agenda the 'MIRT Verkenning' in English MIRT Reconnaissance starts. In this phase a deep and careful problem analysis is done to come to a smart, sustainable and climate proof solution. Sustainable aspects, cultural heritage and area information of the ground are taken into consideration in the problem analysis. In the preliminary design phase multiple options are considered and from these options one preference solution is chosen. This preference solution is worked out in the next phase. This phase is called the 'MIRT Planuitwerking', in English MIRT Plan Elaboration. In the Plan Elaboration phase the preference decision is elaborated to reach a concrete solution that is executable and financial reachable. The last phase is the realisation phase of the project, this is where the project is really realised.

what is remarkable when looking at figure 1 is that there isn't done a quantitively environmental assessment in the preliminary design phase. With the principle that every project needs to be assessed in the same way, it is in contradiction with the principle of the Green deal that the different options for a dike reinforcement project are not assessed quantitatively. When looking at old reports which are made in the preliminary design phase there can be seen, that sustainability is now often assessed with plusses and minuses, which is very subjective in comparison with a quantitative analysis. This can be seen in the Table 1 below, where the use of sustainable materials and energy use is assessed, but it isn't done quantitatively so it is hard to check if the different options are assessed with the same method.

Alternatives	1	2	3
	Reinforcement in Ground	Construction on the landside of the dike	Construction on the in- and outside of the dike
Climate adaptation	0	-	-
Fall of water level	--	--	0
Need ground replacement (1.000 m^3)	16	16	8
Ground water	0	-	-
Working Function	-	0	0
Use of sustainable materials	--	-	-

Table 1 Assessment table (Soepboer, 2018)

So, the different alternatives that are now presented in the preliminary are not assessed with calculations but just with not quantified results.

2.2. Other innovations

Within the field of dike reinforcements there are made some innovations to already reduce the CO_2 emission of the projects. One example of this is the Project-wide exploration 'gebiedseigengrond' or in short 'POV gebiedseigengrond' where there is done research to see if there can be used location own ground in dike reinforcement projects, this to reduce transport lengths of materials (HWBP, 2017). Also, in the realisation phase of the project there can be taken measures to reduce CO_2 emission, for example use bio diesel instead of normal diesel.

Another innovative POV is the POV piping which did research in innovative solutions to prevent piping. There are two of these innovative solutions which are already accepted in the working field of dike reinforcements. These two solutions are a drainage solution to the problem of piping, which means that the solutions do not stop the water from flowing under the dike. Instead of stopping the water from flowing underneath the dike it stops the water from transporting sand with the water and the formation of a pipe. The innovative solutions are the vertical geotextile and the coarse sand barrier. Both solutions have the functions of holding the sand in place and let the water float through. For the vertical geotextile it is assumed that it has little environmental impact, this will be investigated later on in the research.

There can be assumed that the different alternatives have different influences on the environment so the choices that are made during the preliminary design phase are very important for the overall CO_2 emission of the project. In a meeting organised by the 'Unie van Waterschappen' about the use of a quantitative assessment in the preliminary design phase all the above described were confirmed. At the meeting there were a dozen waterboard sustainability advisers who recognised the problem and already had set the first steps in the past year. In the past year three pilot projects were executed to see if there can be used a quantitative environmental assessment in the preliminary design phase of the project. These projects are 'Meanderende Maas', 'Grebbedijk' and Hansweert.

From these three projects there followed two things and the overall conclusion that a quantitative environmental assessment in the preliminary design phase can be useful. As mentioned, there followed two things from these three pilot projects. The first, when the different design options are put into Dubocalc there are big differences between them but there is still missing information in Dubocalc to make very accurate calculations. The second, is that a calculation in the preliminary design phase probably can give insight in what factors within a project have big influence on the environmental impact of the project.

To elaborate more on the missing objects in Dubocalc which were mentioned in the meeting. Dubocalc is already very up to date for the use in infrastructural projects and the database which is connected to Dubocalc is filled with objects and materials that are used in infrastructural projects. For dike reinforcement projects in contrast with infrastructural project the database in Dubocalc is very empty. Therefor it is sometimes hard to find the right materials to design certain measures, in these cases there needed to be found alternatives that have the same characteristics as the original material. But the Dubocalc database is continuously under construction and the database is growing so the expectation is that in a couple years the database is filled with materials for dike reinforcements.

2.3. Sub-Conclusion

The current situation is there is made an agreement called Green deal 'Duurzaam GWW'. But within this agreement there is not done any quantitively assessment in an early project phase. This is in contradiction with some of the ambitions of the Green deal. But at the same time there are already three pilot projects running where there is made use of a quantitative assessment in the preliminary design phase. From these three pilot projects can be concluded that different alternatives have different influences on the environment and following from this a quantitative assessment in the preliminary design phase can help a lot to improve the sustainability of the project.

Above of all that, the sector is also innovating to come with new solutions to improve the sustainability of dike reinforcement projects for example, POV Piping and POV 'gebiedseigengrond'. These innovations can also help at improving the sustainability of dike reinforcement projects.

3. Different measures to prevent piping

After the current situation is analysed, the next step will be made. Experts have shown that an environmental assessment framework can make a difference in the preliminary design phase so such a framework will be made. The framework will be made for the failure mechanism of piping because at the moment this is the most common failure mechanism, so first this failure mechanism will be explained. After this step there will be looked into the different reinforcements against piping and how they are built up. This is needed to eventually be able to calculate the CO_2 emission of the different reinforcements.

3.1. Failure mechanism piping

In Figure 3 below the failure possibility of piping is shown, the problem will be explained using this figure.

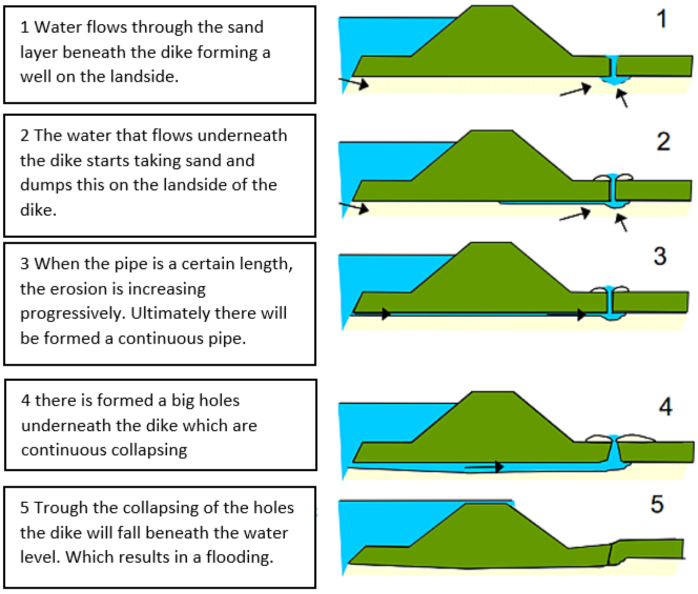


Figure 3 5 steps of piping (Blinde, 2019)

Due to water pressure on the river side of the dike the water will start flowing in the sand layer beneath the dike. This flow will start to form a well on the landside of the dike, this phenomenon will always form at the border of a clay and a sand layer. This is because water can flow through sand and cannot flow that easily through a clay layer, so the water can't go up into the clay layer very easy so the water will go up to the surface where the clay layer is thinnest which is at the landside of the dike. After the well is formed at the landside of the dike the waterflow will start transporting sand and dropping this in the well. This process has as result that there will be formed a continuous connection under the clay layer this can be seen in picture 3. After this connection is formed it will start to expand the connection progressively which can be seen in picture 4. Following from this the dike will collapse and there will be a dike breach where the water can flow into the dike ring which can be seen in picture 5. (Blinde, 2019)

There are also options to prevent piping from happening. These are listed below:

- Piping Bank
- Steel Seepage screen
- Plastic seepage screen

- Gravel Chest
- Sand-tight permeable to water geotextile
- Water pressure reliever
- Rough sand barrier

These options will be explained in sub-chapter 3.2. To last two will not be taken into account in the rest of the research. For the water pressure reliever, the reason is that this solution is a new and not a common solution and not yet accepted as real solution. The Rough sand barrier is also a new solution for the failure mechanism piping and exactly functions the same as the gravel, for this reason there is chosen to only take one into account in this research.

When a dike is tested on its strength the dike will be rejected if the head is bigger than the critical head which is allowed. The head is determined by the pressure difference between the river side of the dike and the landside of the dike this is shown in figure 4 where the H is the head.

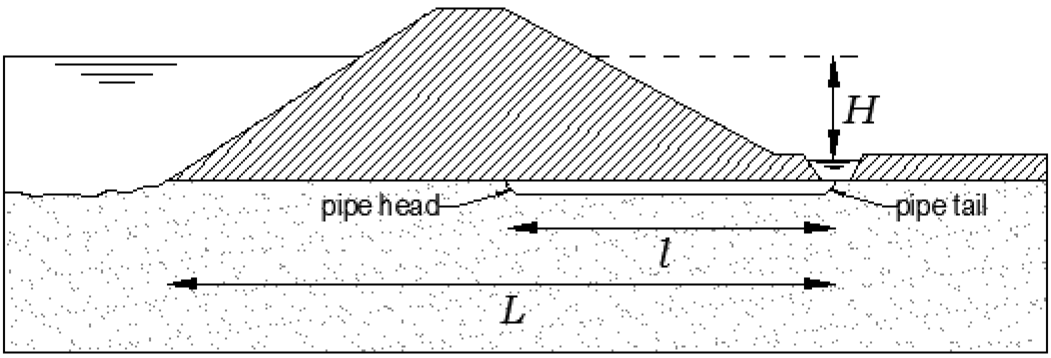


Figure 4 Head difference piping (Bersan, Koelewijn, & Simonini, 2015)

The maximum allowed head is called the critical head and this head can be calculated with the formula of Bligh.

$$\Delta H_{CRIT} = \frac{L}{C_{CREEP}}$$

Equation 1 Formula of Bligh (Kramer, 2014)

In which is:

ΔH_{CRIT}	(m)	The critical head difference (maximum permitted)
L	(m)	The minimum seepage length (sum of horizontal and vertical seepage). When there is placed a seepage screen the length alongside this screen is twice the screen length.
C_{CREEP}	(-)	the creep factor that depends on the median grain diameter of the sand

The formula was formulated in 1918, The formula of lane followed the empirical approach of Bligh but there were some differences in the horizontal and vertical seepage length. Lane argued that vertical seepage length should weigh 3 times more than the horizontal. So, when there is made use of a vertical seepage screen the formula of Lane can be used. (Kramer, 2014)

$$\Delta H_{CRIT} = \frac{\frac{1}{3}L_H + L_V}{C_{W\_CREEP}}$$

Equation 2 Formula of Lane (Kramer, 2014)

In which is:

ΔH_{CRIT}	(m)	the critical head difference
L_H	(m)	The total minimum horizontal seepage length
L_V	(m)	the total minimum vertical seepage length
C_{W_CREEP}	(-)	the weighted creep factor that depends on the median grain diameter these are listed in the list below

Type of sand	**Median size [μ m][1]**	**C_{CREEP} (Bligh)**	**C_{W_CREEP} (Lane)**
The finest grain	< 105	-	8.5
Very fine grain	105-150	18	-
Very fine grain (mica)		18	7
Moderate fine grain (quarts)	150-210	15	7
Moderate coarse grain	210-300	-	6
Very coarse grain	300-2000	12	5
Fine gravel	2000-5600	9	4
Moderate coarse gravel	5600-16000		3.5
Very coarse gravel	> 16000	4	3

Table 2 Creep factors Bligh and Lane (TAW, 1999)

When a dike need reinforcement due to the problem of piping these formulas can be used to calculate the needed dimensions of the reinforcements. But between the two formulas there is a contradiction. When the vertical seepage length equals zero there can be assumed that the critical head of the two formulas should be the same, but this is not the case. This can be explained by the difference in the creep factors of the both formulas. From the formula of Sellmeijer which is not taken into account in this research there can be found that the creep factor is influenced by the grain size distribution and aquifer thickness. This can cause the difference in creep factors, for example when one took the aquifer thickness into account and the other did not. Furthermore, for some grain one them, Bligh or Lane, did not report the creep factor. (Kramer, 2014)

To be able to compare the different measures correctly there will be made use of one formula, this will be the formula of Lane. There is chosen to use the formula of Lane because some of the solutions include a seepage screen and for this the formula of lane is more useful than the formula of Bligh.

There is explicitly not chosen to use the commonly used formula, the formula of Sellmeijer. This is done because the application of the used formula is to give dimensions to different dike reinforcements for the problem of piping. The formula of Sellmeijer is in this application to detailed and when using this formula there need to be made to much assumptions.

3.2. Reinforcements to prevent piping

There are a lot of different options for dike reinforcements which are used in the Netherlands (figure 5). There are two main groups in the options these are reinforcements in the soil and the other group is reinforcement through construction.

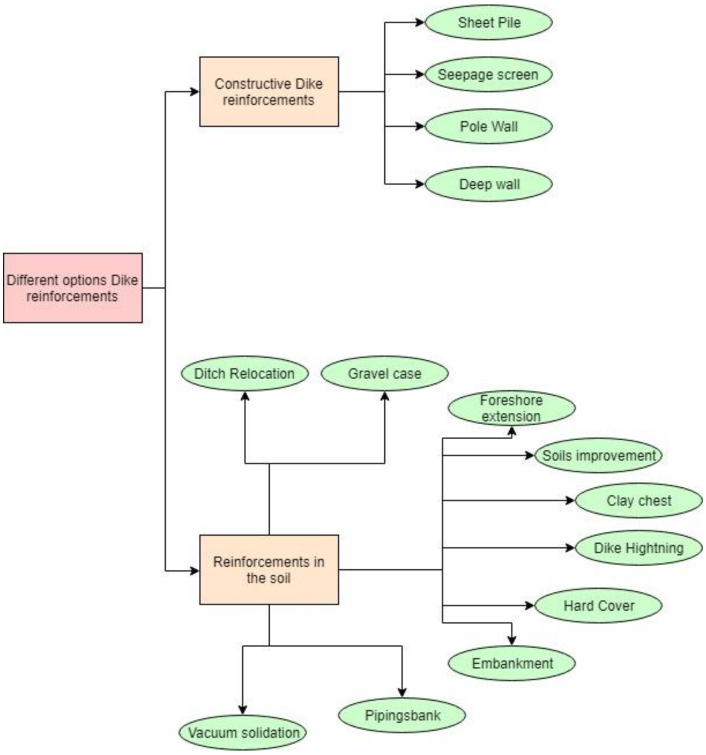


Figure 5 Options dike reinforcements

For the dike failure due to piping not every reinforcement noted above is applicable. Therefore, the dike reinforcements which are applicable to prevent piping will be listed below with some more explanation what every reinforcement exactly does. Also, there will be explained how the measure prevents piping.

3.2.1. Seepage screen

This is a well-known measure to reduce the chance of dike failure due to piping. With this measure a screen is placed vertically in both the clay and sand layer a figure of this measure can be found in the Appendix A The screen has as influence that it stops water and sand transportation between the river side of the dike and the landside. Because the water needs to go around the screens the seepage length becomes longer and the chance that piping appears grows smaller. Seepage screens are mostly made of one of the following materials. The first material is plastic the second bentonite mixed with cement and the last is steel (Jasper van Gestel, 2013). When looking at the formula of lane, the improvement of the vertical seepage length weighs three times more the improvement of the horizontal seepage length. This is one of the reasons the vertical seepage screen is an often-used improvement.

3.2.2. Gravel Chest

The gravel chest is located beneath the lowest point on the landside of the dike, where normally the well will be formed a figure of the gravel chest can be found in the Appendix A. The influence that the gravel chest has on the water flow is that the water can go through the gravel, but the sand stays in place because the creep factor of the gravel is smaller which has the influence that the critical head can be bigger. (Meurs, Niemeijer, Meerten, Langhorst, & Meuwese, 2018)

3.2.3. Piping bank

A piping bank is a bank of sand on the landside of the dike, a figure can be found in appendix A. With this measure the horizontal seepage length of the dike is enlarged because the seepage stream has to go to the weakest point to reach ground level and this is after the piping bank. If there is already formed a seepage stream the piping bank has as benefit that it holds the sand in place and lets the water through. (Jasper van Gestel, 2013)

3.2.4. Vertical sand proof and permeable to water geotextile

With this measure a screen of sand proof and permeable to water geotextile is brought in vertical on the landside of the dike. It is important that the screen is placed in the sand layer as well as in the clay layer, because the border of these two is the most sensitive to piping. The screen allows water to flow through but holds the sand beneath the dike and prevents with this way piping. In appendix A a figure of this measure can be found. (Jasper van Gestel, 2013)

3.2.5. water pressure reliever

In the appendix A a figure of the water timer can be found. The water timer is a system to release the pressure in the sand layer beneath the dike. In the construction of the water timer a deep hole will be made from the surface direct into the sand layer this is done every 10 to 20 meters alongside the dike at the landside of the dike. After this hole is made a strong pipe will be shoved into this hole, this has as function to bring the water to the surface in case of piping. At the surface it will be transported through a system of pipes to the nearest surface water where it will be dropped off. The system has as function to release the water pressure in the sand layer so there can't be formed a well at the landside of the dike. (Kroon, 2014)

3.3. Subconclusion

In this chapter the different alternatives for the prevention of piping are explained. These are the seepage screen which can be made of three materials: Betonite, Steel and Plastic. Followed by the Gravel chest, Piping Bank, Vertical sand proof Geotextile and the water pressure reliever. Also, in this chapter the failure mechanism of piping is explained with the formula to calculate the critical head. There are three different formulas; Bligh, Lane and Sellmeijer. After explanation there is chosen to use the formula of Lane to calculate the dimensions of the different alternatives.

4. Calculate the Environmental impact of the alternatives

Now there is known what the different reinforcements are to prevent piping, the environmental impact of the different alternatives can be calculated. To be able to do this, first of all the different alternatives need to be dimensioned. After the dimensions of the different alternatives are made, the environmental impact of the different alternatives can be calculated in Dubocalc. These environmental impacts will be transformed to CO_2 emission, to give an impression on what the impact is of the different alternatives. Dubocalc calculates different materials in different units, in the calculations below the unit is used which is also used in Dubocalc.

4.1 Dimensions of the Alternatives

For the calculation there is chosen to design an example dike with a length of one Kilometre. This is done so the different measures can eventually be compared to each other. The example dike can be found in figure 6 below.

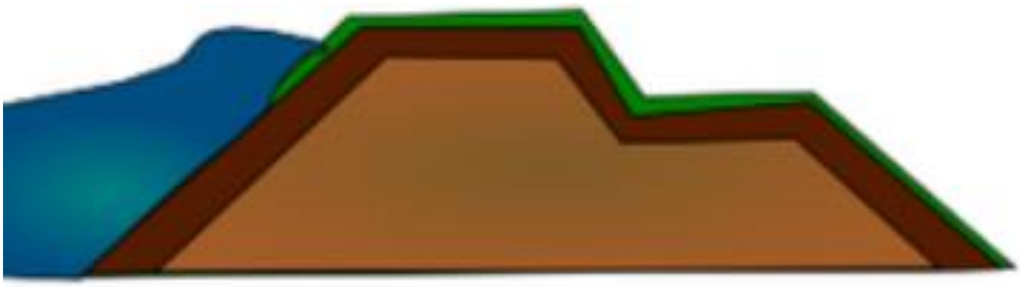


Figure 6 Example dike

The example dike is a normal river dike as can be seen in the figure. The dike has a width of 20 meter at the bottom where the pipe is formed. There is chosen to take a ten-metre seepage length shortage, this is done to be able to compare the different alternatives. A seepage length shortage of 10 metres means the seepage length need to be enlarged with the minimum of 10 meter. With knowing the seepage length shortage and the assumption of that the sand seize in the dike is Moderate coarse grain, the head can be calculated.

$$\Delta H_{crit} = \frac{\frac{1}{3} * 30}{6} = 1{,}667\ m$$

Equation 3 Critical head

This means that with a critical had of 1,667 meter the seepage length under the dike need the be at least 30 meters. The relation between the critical head and the seepage length shortage is linear as can be seen in the figure 7 below.

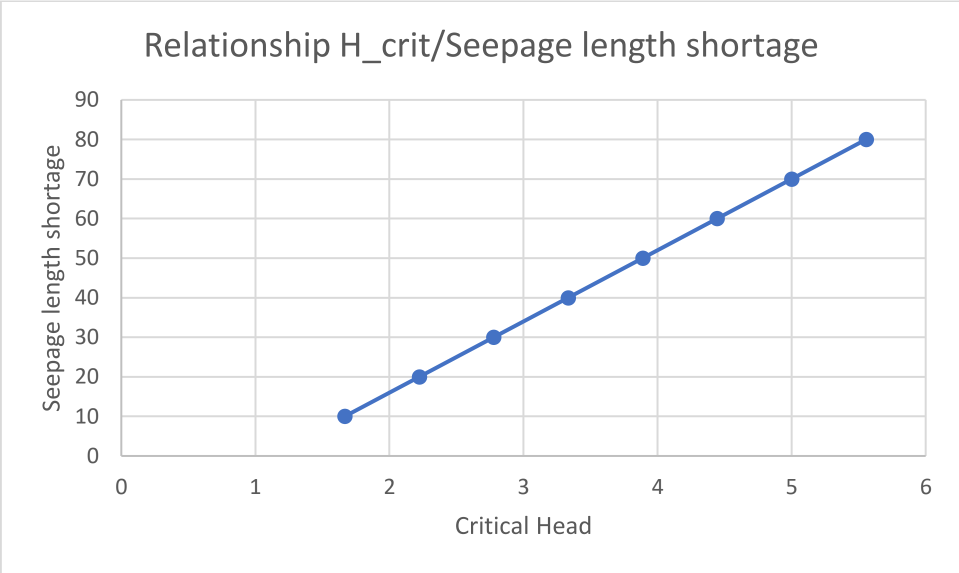


Figure 7 relationship H_crit/seepage lenght shortage

4.1.1. Steel seepage screen

For the calculation of the MKI of a steel seepage screen there is used a steel sheet pile in Dubocalc. The transport in Dubocalc of this material in Dubocalc is standard 50 kilometres, and this cannot be changed in Dubocalc. For the construction of the seepage screen there is made use of the technique of driving. The lifecycle of the material in Dubocalc is 50 years and the recycling in Dubocalc is 95% of the total used steel. The other 5% is dumped, when comparing this recycling to sources on the internet it seems that the value is pretty accurate. The following source says that normally 93 % of the steel can be re-used (SteelConstruction.info).

The depth of the seepage screen in a dike is normally 1/3 of the seepage length shortage, in our example we assumed the seepage length at 10 metres (Jasper van Gestel, 2013). The factor 1/3 is formed through the different old layers that are horizontally in the ground, for water is harder to penetrate these different layers than to follow a layer. Following from this factor the minimum depth of the seepage screen needs to be:

$$Depth\ (m) = \frac{1}{3} * Seepage\ length(m) = \frac{1}{3} * 10 = 3{,}33\ m$$

Equation 4 depth of a seepage screen

This depth is needed over the whole dike which means that in total there is needed 3330 m^2 of steel sheet pile. In Dubocalc there are made calculations in weight of steel, so the amount of the material needs to be put in in tons. In the description of the material is noted that 1 m^2 is 0,19 ton. So, the amount of material is:

$$Amount\ (ton) = 3330 * 0{,}19 = 632{,}7\ ton\ steel$$

Equation 5 Ton of steel

4.1.2. Plastic seepage screen

For the calculation of the of the plastic seepage screen, is used a plastic sheet pile in Dubocalc. In Dubocalc is not specified how much Kilograms 1 m^2 of the plastic material is. For the depth of the plastic sheet pile the same calculation as the depth of steel sheet pile can be used, this means that the amount of plastic needed is 3300 m^2. The amount of the sheet pile needs to be filled in in Tons, and with the missing specific gravity this means that there need to be done some more research on the amount of plastic needed.

Following from this research there can be found that the common used plastic seepage screen is the Geolock which is built by Cofra BV (Cofra BV., 2014). This sheet pile built by Cofra BV. is built with the material of 'Hard Polyetheen' and has a width of 2 mm (Cofra BV.). The specific gravity of this material is 0,95 Gram/cm^3 (Killian, 2000).

With this information the amount of plastic sheet pile can be calculated.

$$Amount(kg) \; = depth(m) * length(m) * width(m) * specific\ gravity\ (\frac{kg}{m^3})$$
$$Amount = 3{,}33 * 1000 * 0.002 * 950 = 6327\ kg\ plastic$$

Equation 6 Kg plastic

4.1.3. Gravel Chest

A gravel chest is mostly built up with two things, these are a geotextile and river gravel (Niemeijer & Langhorst, 2018). The geotextile has as function to prevent the filter from silting up, the river gravel to let water through but hold sand particles in place.

The dimensions of the gravel chest are not influenced by the seepage length shortage because the gravel chest has not as goal to lengthen the seepage length under the dike. The gravel chest has as goal to let the water through and hold the sand in place, this is also why it is placed in the family of drainage. The dimensions are based on the following figure:

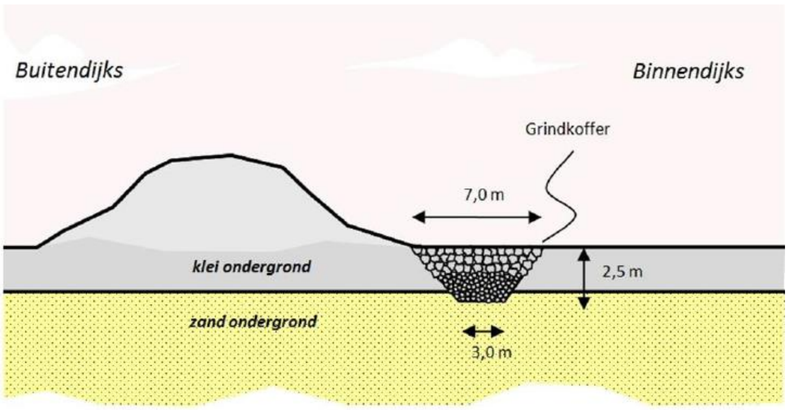
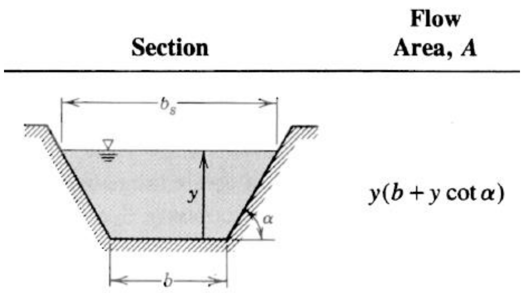


Figure 8 Dimensions Gravel Chest (Niemeijer H. , 2017)

As can be seen in figure 8 the gravel chest is displayed as a trapezoidal. To calculate the area of the gravel chest the following formula will be used:



Equation 7 Area trapezoidal (Fox, MCdonald, Pritchard, & Mitchell, Eighth Editions)

$Area = 2{,}5(3 + 2{,}5 * \cot(51{,}35)) = 12{,}49$ m^2

For calculating the piping bank there are needed their different operations. These are the sand excavation, the construction of the geotextile and the construction of the river gravel. The first step is to remove the sand, in total there need to be 12,49 m^2 sand removed over a length of 1000 meter.

$$Sand\ removed = 12{,}49 * 1000 = 12.490\ m^3\ sand$$

Equation 8 Sand removed

In Dubocalc is assumed that the sand removed can be dumped within 25 kilometres from the project sight. For the geotextile the surrounding of the gravel chests needs to be calculated. The only unknown side is the slanted side, which can be easily calculated with the formula of Pythagoras:

$$A^2 + B^2 = C^2$$
$$C = \sqrt{2^2 + 2{,}5^2} = 3{,}2 \text{ m}$$

Equation 9 Pythagoras

So, the total sides are 3,2 + 3,2 + 3 = 9,4 m. So, the total area of geotextile needed is 9,4 m * 1000 m = 9400 m^2.

The Dubocalc software calculates the amount of river gravel in tons, so for the calculation of the amount of river gravel some extra calculations need to be made. For the river gravel the same amount of m^3 is needed as the sand. To calculate the amount of tons of river gravel needed there first need to know what the specific gravity of the river gravel is, this is 1600 KG per m^3 (Grind.be, 2019). So, with the formula below the amount of river gravel can be calculated.

$$Amount = \frac{12.490 * 1600}{1000} = 19.984\ ton\ river\ gravel$$

Equation 10 Ton river gravel

With these three amounts of material the MKI of the gravel chest can be calculated in Dubocalc

4.1.4. Piping Bank

A normal Piping bank is built up from two different materials, first of all the sand to make the piping bank. Secondly, a piping bank is built up from a geotextile layer to prevent the sand from washing out. In the calculation of the environmental impact of a piping bank there will be made a distinction between sand that is transported by ship and sand that is transported by truck. This will be done because this difference will make a difference in the environmental impact the piping bank has. This is caused by the amount of sand that needs transporting, with this amount the transport is one of the big influencers of the total MKI value.

Dimensions:

For the example dike with a seepage length shortage the piping bank will have the following dimensions. The normal height of a piping bank is one meter, and the width on the inside of a dike is equal to the shortage in seepage length (Deltares, 2018). In this case that means that the sand in the piping bank have the following dimensions H*W*L = 1*10*1000 = 10.000 m^3. The geotextile is placed under the sand of the piping bank, this means that for the geotextile 10.000 m^2 material is needed.

4.1.5. Vertical Sand-tight Geotextile

A vertical sand-tight geotextile is not standard in Dubocalc, but to approach the MKI as best as possible there can be used 'Polypropyleen vlies gewapend' (Jutte, Mentink, & Timmerman, 2019). This is the geotextile with the highest MKI value in Dubocalc so this gives the highest MKI value. Also, the placement of the geotextile is not standard in Dubocalc so this have to be done apart from the geotextile component.

For the dimension of the geotextile, the Polypropyleen vlies gewapend has a width of 3,9 meter and a length of 75 meters. The total length needed is 1000 meter, so there are 14 pieces of geotextile needed for the project. This gives a needed area of geotextile of the following:

$$Area = 14 * 3{,}9 * 75 = 4095\ m^3\ Geotextile$$

Equation 11 Amount of Geotextile

In a talk with a project manager from the waterboard Rijnland, it became clear that to place the vertical geotextile there first need to be made an excavation with the dimension of the geotextile and with a width of 30 cm. The amount of ground that need to be excavated is calculated below:

$$Volume = 0{,}3 * 3{,}9 * 1000 = 1170\ m^3$$

Equation 12 Volume excavation

This volume of sand will be first excavated then stored on the project site. After the geotextile is placed the sand will be placed in the excavation again. So, in Dubocalc this is done in two different operations first the excavation and after that the replacement.

4.2. Results MKI Calculations

Now the dimensions of the different alternatives are known, the impact on the environment can be calculated. This will be done in this sub-chapter. The calculations are made in the software program 'Dubocalc', this program is mostly used in the civil engineering sector to calculate the sustainability of projects. The software calculates the sustainability of a project using the Environmental Cost Indicator or in short, the 'MKI'. The MKI gives a good insight in what the influence of the different alternatives has on the environment. Also, the MKI is the most used factor the find out the sustainability of a project. To understand the software and how it calculates the sustainability, first the environmental cost indicator will be explained after which Dubocalc will be explained a bit more. After these two explanations the Dubocalc calculations will be made and the results will be presented.

4.2.1. Environmental Cost indicator

Within civil engineering projects it is common to calculate the environmental value and the CO_2 emission with the in Dutch called 'Milieu Kosten Indicator' or in English the environmental cost indicator.

The MKI value is a group of different values noted in one value (Bouw Circulair, 2018). With this value different environmental impacts can be considered. The value displays the impact on the environment in social costs in euros. So, for example a dike needs to be heightened due to changing environment the costs for heightening this dike are implemented in the MKI. The MKI can be calculated with a lot of different software, for example Dubocalc or Dubomat (Dubocalc light) which are developed by Rijkswaterstaat and Royal Haskoning DHV. The MKI is calculated with the life cyclus analysis (LCA) of different materials. The life cycle analysis is an analysis on the environmental impact of materials, from the making of the material till the demolition. In the LCA two main steps are normally taken these are, the Life Cycle Inventory and the Life Cycle Impact Assessment. In the LCI there is looked at the dangerous fabrics that are emitted during the life cycle and the raw materials that are used during the life cycle. In the LCIA the LCI results are assessed followed by an environmental value of the material. (RIVM, 2018)

As said in the paragraph above the MKI is a value for the environmental costs of a project or part of a project. This means that how smaller this value how more environmentally friendly the project is, with this value there can be compared the environmental impact of different alternatives for dike reinforcement project.

The eleven factors which are included in the MKI can be found in table 3 below.

Environment effect category	**Equivalent unit**	**Weighing factor (€/KG EQ)**
Depletion of abiotic raw materials	Sb eq	€ 0,16
Depletion of fossil energy carriers	Sb eq	€ 0,16
Climate Change	CO_2 eq	€ 0,05
Ozone layer degradation	CFK-11 eq	€ 30
Photochemical oxidant formation	C_2H_4 eq	€ 2
Acidification	SO_2 eq	€ 4
Eutrophication	PO_4 eq	€ 9
Human toxicity	1,4-DCB eq	€ 0,09
Freshwater aquatic ecotoxicity	1,4-DCB eq	€ 0,03
Marine aquatic ecotoxicity	1,4-DCB eq	€ 0,0001
Terrestrial ecotoxicity	1,4-DCB eq	€ 0,06

Table 3 Factors Environmental cost indicator (Schweitzer, 2018)

What can be seen in the figure is that all the different factors within the MKI are weighted different. The first column displays the category, the second column the equivalent chemical element which is emitted. The last column is the weighing factor, this is combined with the harmfulness of the element. When the element is more harmful the weighing factor is also higher. In the 1,4-DCB eq there is made a difference in where the element ends to determine the weighing factor.

4.2.2. Dubocalc Software

Within Dubocalc four phases of a project are taken into account. These are the building phase, the using phase, the maintenance phase and at last the demolition phase. Within the building phase there are four factors considered, the choice of the materials, the amount of materials, the transport distance for bulk materials and at last the removal of extra materials (for example extra ground which came free in the building phase). In the using phase the amount of electricity and fuel used for example for pumps are considered. In the maintenance phase are the technical duration of life for the different materials and the duration of life for the whole project. With these two the amount of maintenances for the different materials can be calculated. In the end phase of the project the factors that are needed for demolition, removal and processing of the materials. (Vroonhof, 2016)

4.2.3. MKI values

After there is explained how the environmental cost indicator is build up and how the Dubocalc software works. The calculations of the different alternatives can be made. This is done by putting in the values which are calculated in Chapter 3 in the Dubocalc software. The software then calculates automatically the MKI of the different materials. When the different materials for an alternative are combined the software automatically calculates the MKI of the alternative. The results of the calculations can be found in figure 9 and the alternatives are listed from a small MKI to a big MKI.

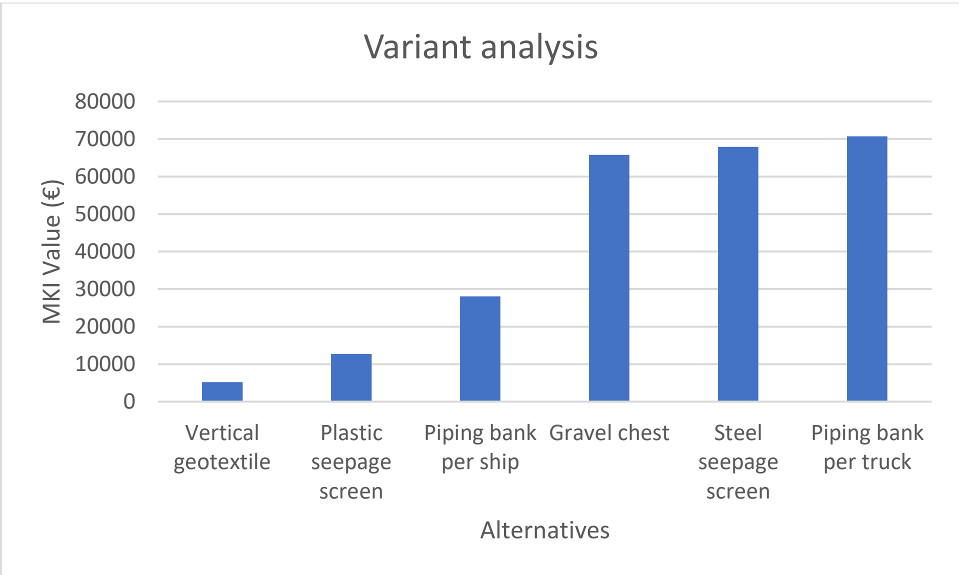


Figure 9 MKI values of different alternatives

When comparing these values there can be easily seen which measure is environmentally the best option. This is the vertical geotextile, so this has a very low MKI. After the vertical geotextile the Plastic seepage screen is the best option, far better than the piping bank where the sand is transported with a ship. The piping bank where the sand and gravel are transported per ship is the third best option. After the piping bank per ship the MKI value make a big step to the next options which are closer together, in which the following order can be made: Steel seepage scree, Gravel chest and pipings bank where the sand and gravel are transported per truck.

In the table the different alternatives presented in the previous are ordered on increasing MKI values can be seen with the corresponding MKI values.

4.3. CO_2 Emission Calculations

In Dubocalc there is also a possibility to calculate the CO_2 emissions of the different materials, Dubocalc then gives the Kilogram CO_2 equivalents of a measure. This can be done by using the calculations of the MKI value and only changing a few settings.

When this is done the following values follow from this.

Measure	**MKI Value (€)**	**CO_2 emission (KG eq.)**
Vertical Geotextile	5.196	43.391
Plastic Seepage screen	12.739	71.980
Piping bank per ship	28.102	243.260
Gravel chest	65.737	504.282
Steel seepage screen	67.885	747.080
Piping bank per truck	70.710	614.680

Table 3 MKI values and CO2 emissions

When comparing the MKI values with the CO_2 Kg equivalents, there can be seen that the order is the same except for the Gravel chest, this one is lower than the steel seepage screen. This is because for calculating the CO_2 emissions there is looked at the environmental impact and not on the MKI with all its corresponding factors. The making of steel has a bigger influence on the environment than the transport of river gravel that is why the CO_2 emission of the steel seepage screen is bigger than the gravel chest.

To give an insight how much the CO_2 emission is compared to other businesses in table 5 below the CO_2 of some other businesses are given.

Operation	**CO_2 emission (KG eq.)**
One Hour Flight of a Boeing 747-400	92
Average emission of a person car during a year	4.600
Average household during a year	23.000

Table 4 (Carbon Independent, 2015)

In comparison with the CO_2 emission of the steel seepage screen there can be flown 8120 hours with a Boeing 747-400, 162 cars can drive a whole year and 32 average households can be kept running.

4.4. Sub-Conclusion

In this chapter the different dimensions of the alternatives are calculated. With these dimensions the environmental impact of the alternatives is calculated after which this is transformed to the CO_2 emissions of the different materials. With this CO_2 emissions the different alternatives can be compared on its sustainability

5. Which parameters have the biggest influence on the CO_2

A possible other big advantage of using Dubocalc in the preliminary design phase is the identification of the different factors that build up the MKI value of a project. With identifying factors that have huge influence on the MKI value of a project, there can be focussed in a later phase on improving these factors. To find out if this is possible with Dubocalc and if the different measures have factors that have a significant huge influence on the total MKI value, this will be checked in Dubocalc.

For every measure there will be look independent what the important factors are and how much influence they have on the total MKI of a measure. Within Dubocalc it is possible to analyse the different factors with looking in to how the different parts of a measure are build up. So, for every operation there will be looked at what the important factors are and how much influence they have on the total MKI of the measure. When there is only one operation/product in a measure, Dubocalc directly gives the contribution of the factors an example can be found in table 6 below. When there are multiple operations/products in a measure, there need to be done some calculation this will be explained at the measures that have multiple operations.

The influence of the import factors is displayed in percentages. This is done to give a quick view of what influence the factor has on the total measure. In this chapter the factors that have the most influence on the measure are identified to get insight in what parts of the measure it is feasible to improve. For the design of the assessment framework the factors with small influence will not be taken into account, so the factors displayed in the framework and in this chapter will not add up to 100% because the factors with small influence are left out.

Name	Quantity	Unit	Phase	MKI	Contribution (%)
Steel	1	Ton	Building	68,35	67,53
Pile Driving	0,4211	h	Building	7.33	7.42
Aggregate Hydraulic	0,4211	h	Building	14,55	14,73
Thrive Block	0,3759	h	End of Life	0,02	0,02
Hydraulic thrive hammer	0,4211	h	Building	2,83	2,87
Crane Hydraulic	0,4211	h	Building	2,63	2,67
Dragline	0,3759	h	End of Life	2,35	2,38
Transport Steel	1	Ton.km	Building	1,55	1,57

Table 6 Factors in Dubocalc

These are the factors of the steel seepage screen and immediately the first measure we will analyse. As can be seen in the table, that Dubocalc immediately gives the contribution of a factor to the whole measure.

5.1. Steel seepage screen

When there is looked at the factors that have influence on the MKI of the steel seepage screen, there can be seen that the biggest contribution is the construction of steel with 67,53 %. So, if there are made improvements in a later phase this best can be focussed on the construction of the steel plates. After the construction of the steel plates, the aggregate has the biggest influence with 14,55 %. Next to these two the other parts have less influence and improving these in a later phase will not be very helpful.

5.2. Plastic seepage screen

The plastic seepage screen only consists of one product which is the plastic sheet pile. So, for analysing this measure there is only looked at the plastic sheet pile. For the plastic sheet pile there is one factor dominant for the MKI, and this is the fiberglass used to make the sheet pile. This fiberglass has an influence of 95 % of the total MKI. So, when the MKI need improvement in a later stage there can be best focussed on the reducing of the MKI of the fiberglass.

5.3. Vertical Geotextile

The vertical geotextile has three operations/products in Dubocalc to calculate the MKI, these are the sand excavation the geotextile itself and the sand replacement. So, for analysing the dominant factors, there have to be done some more calculations. First there will be checked what influence the different operations of the vertical geotextile have on the total MKI. This can be found in the table below.

Operation	**Influence on total MKI (%)**
Geotextile	51,08
Sand replacement	39,12
Sand removal	9,8

Table 7 Influence operations Geotextile

Now the influence of the operations/products on the measure is analysed the next step is to analyse the dominant factors within the three operations/products. The dominant factors within the different operations and products give an influence on the total operation or product and not on the total measure. For analysing the dominant factors on the whole measure, the influence of the different factors on the total MKI need to be calculated. This can be done with the following formula:

$$Influence\ factor\ on\ total\ MKI\ measure = \frac{operation\ (\%)}{100} * factor(\%)$$

Equation 13 Influence factor on total MKI

Within the different operations the dominant factors are as follows, within the operation of the geotextile there are three dominant factors. These are the polypropylene material, excavator for building and the excavator for demolishing. Within the sand replacement the dominant factor are the transport of the sand and the sand as material itself. For the sand removal the dominant factors are the same as for the sand replacement. After Calculation with the formula the dominant factors have the following influence on the total MKI of the vertical Geotextile.

Operation	**Factor**	**Influence on total MKI (%)**
Geotextile	Polypropylene	21,8
Geotextile	Excavator building	19,47
Geotextile	Excavator end of life	9,73

Sand Replacement	Transport	33,61
Sand Replacement	Sand	3,44
Sand Removal	Transport	8,42
Sand Removal	Sand	0,8624

Table 8 Influence factors Geotextile

So, the factors with the most influence on the MKI are the Transport of the sand replacement, the polypropylene as material and the excavator for placing the Geotextile. The biggest two will be taken into account for the assessment framework, these are the transport of sand replacement and the Polypropylene as a product.

5.4. Gravel Chest

The gravel chest also has three operations the same as for the Geotextile. First there will be looked at the influence that the different operations have on the total MKI of the measure, with this the influence of the individual factors on the total MKI of the measure can be calculated.

The three operations included in the MKI calculation of the gravel chest are: Gravel construction, construction of the enclosure and the sand excavation. The influence of the different operations is ordered as can be seen in table 2.

Operations	**Influence (%)**
Gravel construction	81.85
Construction of enclosure	16.73
Sand excavation	1.41

Table 9 Influence operations Gravel Chest

For calculation of the influence of the individual factors on the total MKI of the measure the same formula as for the geotextile can be used:

$$Influence\ factor\ on\ total\ MKI\ measure = \frac{operation\ (\%)}{100} * factor(\%)$$

Equation 13

First there will be looked at the factors that have influence on the construction of the gravel. Within this operation there are two dominant factors, the gravel dumping and the needed work fleet. The gravel dumping has an influence of 65.67 % in the operation and the work fleet 11.80 %. For the construction of the enclosure there are also two dominant factors, these are the material of the enclosure, geotextile, and the excavation to place the geotextile. The geotextile has an influence of 77.5 % in the operation and the excavation 11.51 %. As last operation the sand excavation has very small influence on the total measure that the factors in this operation will not be taken into account in the calculation.

The influence of the different factors can be calculated with equation 13. The results of this calculations can be found below.

Operation	Factor	Influence on total MKI (%)
Gravel construction	Gravel dump	53.75
Gravel construction	Work fleet	9.66
Construction of enclosure	Geotextile	12.96
Construction of enclosure	Excavator	1.92

Table 10 Influence factors gravel chest

In this table can be seen that the best thing to focus on to accomplish reduction of the MKI value is to focus on the Gravel construction because this has a 53.75 % influence on the total measure. The rest is significantly smaller so the other factors will not be taken into account.

5.5. Piping bank per truck

The piping bank is calculated in Dubocalc with two components, the sand that is needed to build the piping bank and the geotextile that prevent heaving of the sand. The sand has the biggest influence on the total MKI with 96.42 % of the total MKI. Because the sand is so dominant there is chosen to only calculate the sand and skip the calculation of the geotextile.

The sand has two major factors that have influence on the MKI of the sand, these are the Transport of the sand and the MKI the sand has on its own. The transport has the biggest influence and causes 85.93 % of the total MKI of the sand, the MKI of the river sand itself has 8.8 % influence on the total MKI. When calculating the influence of these two factors in the whole measure the equation 4 will be used. The results of this calculation can be found in the table below.

Operation	Factor	Influence on total MKI (%)
Sand	Sand transport	82.85
Sand	Land sand	8.48

Table 11 Influence factors Piping Bank per Truck

5.6. Piping bank per ship

The piping bank per ship is calculated the same way as the piping bank per truck. The only difference between the two is that the sand is transported per ship instead of per truck. This makes a little difference in the influence the two components have on the total MKI. The sand still has major influence, 90.98 % of the total MKI and the geotextile 9.02 percent. Because of the major influence of the sand, only the influence of the sand will be calculated. This calculation will be done with equation 4, which is also used in the previous influence calculations.

Operation	Factor	Influence on total MKI (%)
Sand	Sand transport	48,93
Sand	Land sand	25,79

Table 125 Influence factors piping bank per ship

6. Environmental Assessment framework

In the previous chapters there where done calculations to finally make a quantitative assessment framework to be able to choose the most environmentally friendly alternative in the preliminary design phase. Also, the dominant factors are identified to see when a choice for a measure is made, where there can be made more improvements to reduce the environmental impact of the alternative.

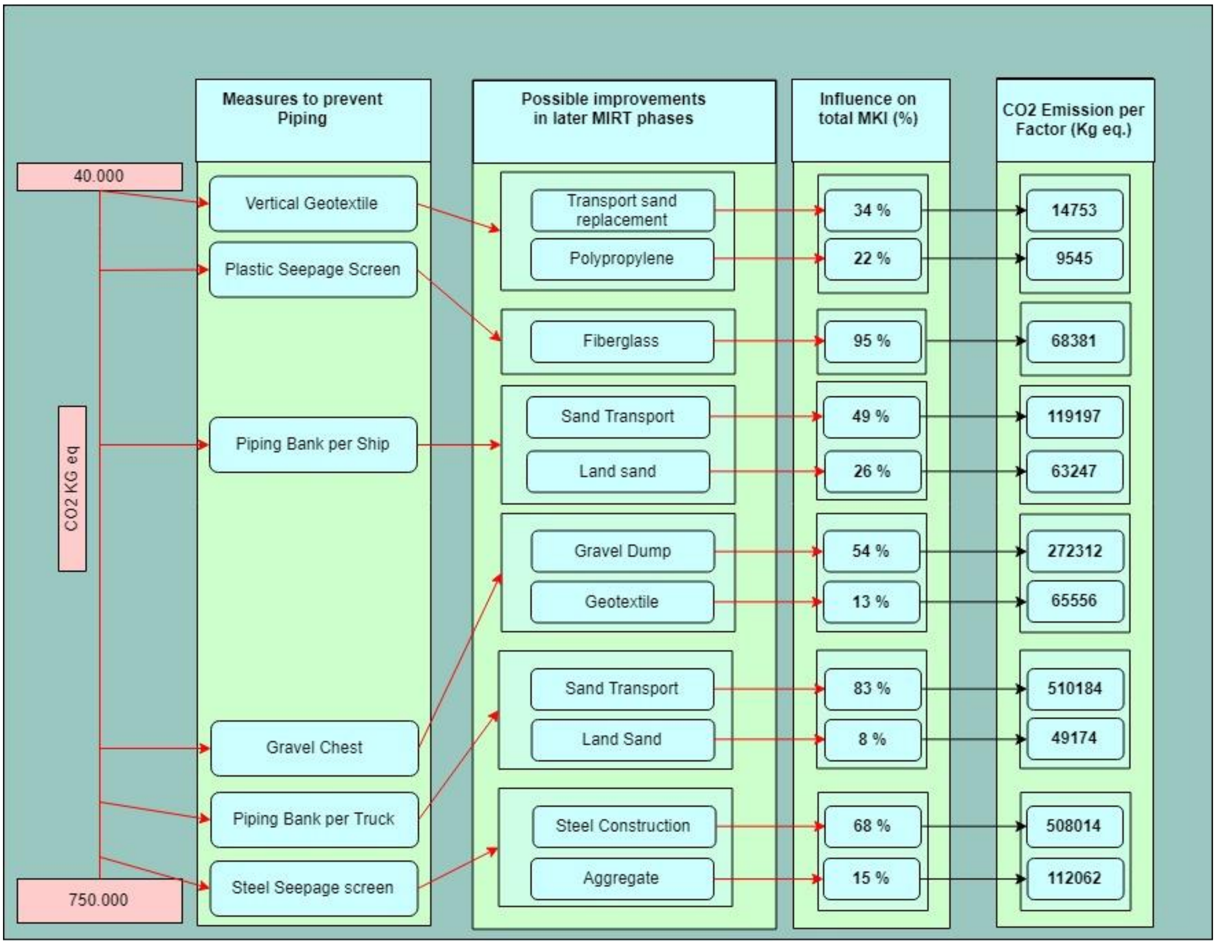


Figure 10 Environmental assessment framework

In the figure 10 the different measures are ordered from Low CO_2 emission to high CO_2 emission. The CO_2 emission values are calculated in chapter 4. In addition to the CO_2 values also the dominant factors of the measures are analysed and calculated. The dominant factors can be found in the column of possible improvements, next to it is the influence of the independent factors on the total MKI. As can be seen in the figure the influence values will not add up to 100%, this is because only the dominant factors are shown and the factors with little influence are not shown. The influence of the different factors does not change with change in the amount of material, this is tested in Dubocalc for all the factors. In the column on the right the CO_2 emission of the different factors is shown, this is done so it can be easily compared to for example fly hours.

7. Validation of the assessment framework

After the research steps that already done, from analysing the current situation till researching the important factors that have a high CO_2 emission. Finally, the assessment framework could be made, this framework can be found in chapter 6. Now the assessment framework is made it is important to test if it is applicable in the working field of dike reinforcements in the Netherlands. That is why there is chosen to interview two technical managers from waterboards in the Netherlands.

First of all, the interview questions will be explained, which questions will be asked and why these questions will be asked. After these are explained two summaries of both interviews will be made. At last there will be made a conclusion of both interviews. The full transcripts of the interviews can be found in appendix B and C.

7.1. Interview Questions

The interview is built up to validate some parts of our research. First of all, the interview starts with asking some questions about the interviewee to get to know more about his working experience and to know on what projects he is working at the moment. After this is done, there are fabricated two questions to find out if the change in the importance of sustainability that is found in literature is also recognised in the working field.

After these questions are done, the assessment framework made in this research will be explained. After which the interviewee will be asked four questions about the applicability of the assessment framework in dike reinforcements. These questions are made to check if the assessment framework is applicable and if the interviewee has something to add to the assessment framework.

Below the translated list with questions can be found:

- **How long are you already working in the dike reinforcement sector? And have you encountered the failure mechanism of piping in the present or in the past?**

- **Within your work in the dike reinforcement sector what was your role when looking especially to the preliminary design phase?**

- **At the moment Rijkswaterstaat and the Dutch government are improving the requirements around sustainability for example by the climate agreement which was made in Paris and the Green Deal 'Duurzaam GWW 2.0'. Do you also see this change in the working field of dike reinforcements?**

- **Do you have within your present project or projects in the past taken sustainability as an ambition/requirement? If the answers are yes, how did you have taken as an ambition, quantitative or qualitative? And did you take it into account in the preliminary design phase?**

In between these questions there will be explained how the assessment framework is build up. Also, there will be explained why there is chosen to make the assessment framework for dike reinforcements and the failure mechanism of piping. At last there will be explained why there is chosen to calculate the CO_2 emission and not the environmental cost indicator.

- **What do you see as benefits and what do see as disadvantages of the assessment framework?**

- **Can the environmental assessment framework help you with make a better substantiated decision in the preliminary design phase? If the answers are yes, how would it help you?**

- **Do you have any improvements for this assessment framework to improve it even further?**

- **Would you use the assessment framework in your projects? If the answers are no, what should be changed to make the framework applicable?**

7.2. Interview Marco Weijland

The full transcript can be found in Dutch in appendix B. The most important answers and conclusions from the interview with Marco will be described in this chapter. This summary is made to be able to compare it to the second interview and to be able to take conclusions out of it.

Marco is a technical manager of the waterboard 'Schieland en Krimpenerwaard'. Marco has at the moment 4 years of work experience in the primary dike reinforcements. Currently he is working on the dike reinforcement KIJK where the dike is rejected on the failure mechanism of macro stability. Before Marco started working on the primary dikes in the Netherlands he has worked on regional dikes.

When asked about the new challenge of implementing sustainability in dike reinforcement projects, Marco acknowledged the challenge. Furthermore, with their current project they made an multicriteria analysis to choose an alternative. Within this project the different alternatives scored pretty much the same, so the factor of sustainability was not the leading factor. But in the project, there was not set a goal to reach for sustainability.

To get more insight in the way of measuring the sustainability of a project there was asked how the sustainability of a project was measured. Marco told that the sustainability is qualitatively measured in the preliminary design phase, at this time the project is in the plan elaboration phase and there will be probably chosen to test the different design options quantitively. But Marco also marks that he thinks that it is important to also do this in the preliminary design phase because in the plan elaboration phase they are working on the details and the big decisions are made before this phase.

After explaining the assessment framework why and how the assessment framework was designed, there was asked what the benefits and disadvantages of the assessment framework are. For the benefits Marco explained that the assessment framework makes it very insightful that the different alternatives also have different influences on the environment. As disadvantage, the assessment framework gives a number of CO_2 emission but its hard to estimate the value of this number. So, to make it even more insightful the number of CO_2 emission need to be compared with the emission of a household for example.

At last the question was asked if Marco thought the assessment framework is applicable in the dike reinforcements. Marco said that the assessment framework made the step to take sustainability into account in the preliminary design phase a very small step. With promising alternatives this assessment framework can assess the different alternatives on sustainability without making the calculations yourself. The calculation maybe is not precise for the dike you are assessing, but then you get qualitive assessment with quantitative substantiated calculations.

At the end of the interview Marco made the note that waterboards are often asked to make a strong and inexpensive solution to strengthen a dike. When the most sustainable option is also very expensive there is still little chance that this option will be chosen. So, there need to be made an optimal solution between inexpensive and sustainable.

7.3. Interview Gerjan Westerhof

The full transcript can be found in Dutch in appendix C. The most important answers and conclusions from the interview with Gerjan will be described in this chapter.

Gerjan is a technical manager for the Waterboard Rivierenland. He has ten years of experience in the dike reinforcement sector. The last 4 years he got acquainted with the failure mechanism of piping. Currently he is working on the dike reinforcement at Wolveren-Sprok which is a dike reinforcement from Nijmegen till the A50. The whole dike is rejected on the failure mechanism of piping.

Gerjan did acknowledge the new challenge of implementing sustainability in dike reinforcement projects when asked about it. But he did also say that it sometimes seems that sustainability is a totally new thing, but the truth is that it already existed but currently we are putting it on the foreground. The only new thing is that in the past it was voluntary if you did something with sustainability in your project, but now it is sometimes obligated to do something with sustainability in your project.

At their current project sustainability is not a goal on its own, but it has influence on other goals of the project. Within the preliminary design phase Gerjan told that the different options were not assessed on sustainability. But the waterboard always prefers to do all dike reinforcements in ground and not in construction. The reason for this is that if you put a piece of ground in place, over 100 years that same piece of ground will still be there. So, for the waterboard this is a very sustainable way because the solution will not rot away. Within our research is found that the construction of ground reinforcements is not sustainable when looking at CO_2 emission, but Gerjan told they are at the moment not looking at the sustainability of the construction of an alternative.

Gerjan told that for the biggest part of the dike there will be made solutions with ground. But on sections where this is not possible there need to be made a construction inside the dike, these constructions will be assessed quantitively on their sustainability. But with the sidenote that sustainability is one of the factors that will be assessed and is not the most important. The dike safety is the most important factor, after which costs are also very important so sustainability then comes on a lower level.

After explaining the assessment framework why and how the assessment framework was designed, there was asked what the benefits of the assessment framework are and what the disadvantages are. Also, an advantage is that the number give more meaning to the sustainability then words. Gerjan reacted that a big advantage of the assessment framework that it makes the CO_2 emission of the different alternatives insightful. But there are also disadvantages, for example the vertical sand tight geotextile has a very low amount of CO_2 emission. Behind the scenes there are probably more emissions because it is not yet known how well the geotextile functions in real conditions.

7.4. Sub-Conlusion

Both the technical managers acknowledge the new challenge to implement sustainability in their projects. Both the technical managers also already looked at sustainability in their projects. But Gerjan also made the side note that people do if sustainability is a totally new thing, while this is not true. The only thing that changed drastically the last years is that we put a label on sustainability. Although, both the technical managers see the challenge of implementing sustainability in dike reinforcement project it is not taken as goals in their projects. Furthermore, when asked about the way of assessing sustainability they both gave as answer they did it qualitive and not quantitative. When comparing this to the green deal, this is remarkable because one of the statements of the green deal that sustainability must be measured uniform over different projects. When assessing sustainability qualitative can be uniform but mostly it will be of the interpretation of the assessor.

When asked about the preliminary design phase, where this research is focussed on. Both technical managers say that they did not assess their alternatives on sustainability in the preliminary design phase, so this confirms that there is a lot to win in this phase. Marco even confirmed that the big decisions are made in this phase so that assessing the alternatives in this phase should improve the sustainability of the project al lot.

After explaining the assessment framework, both the technical managers had as benefit that it makes the difference between the alternatives insightful. Although it is not accurate for every specific dike, it gives a good estimation what influence the different alternatives have on the environment. As downside Gerjan told that Dubocalc works with standard values and for example for the vertical geotextile there are probably more emissions because it is not yet known how well the geotextile functions.

For the improvements to the assessment framework, both the technical managers think it is handy to expand the assessment framework also to other failure mechanisms. Also, Marco said that is was handy to compare the CO_2 emission to things that people can estimate, for example with the CO_2 emission of household.

Overall there can be concluded that both the technical managers see benefits but also some negative points in the assessment framework. Through the time limit for the research it was not possible to interview more technical managers. For the validation of the assessment framework it would be better if there were taken more interviews with technical managers. Also, both the interviews went totally different, which made it harder to compare the interviews and take conclusions out of it. Another option to validate the assessment framework is to use it in the preliminary design phase of a real dike reinforcement project, this would be valuable for future research.

8. Conclusion and answer sub-questions

This chapter is split up in two parts, first of all the overall conclusion on the main research questions. In the second part the sub-questions will be answered shortly.

8.1. Conclusion research

The overall question was if an environmental assessment framework can make a difference in choosing the preference alternative in the preliminary design phase of a dike reinforcement.

When there is looked back at the current situation, which was researched by literature, meetings with sustainability advisors and the question in the interviews. There can be found that there is not done a quantitative sustainability assessment in the preliminary design phase, this was confirmed within the interviews.

When designing the assessment framework there were made calculations on the sustainability of different alternatives for the failure mechanism of piping. The results show that there is a big difference in emission and impact on the environment between the different alternatives. From this can be concluded that the choice of a measure in the preliminary design phase has major influence on the total environmental impact of the project. Knowing that currently there is not done any quantitative sustainability assessments in the preliminary design phase, there can be concluded that there can be made a lot of improvements here.

Also, with the factors within the different the alternatives there can be seen that by almost all the alternatives one or two factors have the major influence on the environmental impact. This means that in the preliminary design phase there can be chosen an option with already knowing where the focus points need to be to improve the sustainability of the alternative even further.

Within the interviews the above-mentioned point was confirmed. Both the technical managers had the idea that the assessment framework gave insight in the influence of alternatives on the environment and that the assessment framework can change a preference choice if sustainability becomes an important factor in civil engineering projects.

So, the answer to the overall research question is; The assessment framework can make a difference in choosing a preference alternative if sustainability becomes an important factor within civil engineering projects.

8.2. Answer to sub-questions

In this sub-chapter the sub questions of this research will be answered in short.

8.2.1. How are environmental aspects now assessed in the MIRT project phases?

The environmental aspects are now assessed different in every phase. Within the preliminary design phase, the environmental aspects are assessed qualitative currently. Within the plan elaboration phase there is a mix between qualitative assessment and quantitative.

8.2.2. What are the commonly used reinforcements against piping?

The Commonly used reinforcements against piping are; Steel seepage screen, Plastic Seepage screen, Vertical Geotextile, Gravel Chest and the Piping bank

8.2.3. How can the MKI for the different reinforcements be calculated?

First the materials needed for the reinforcement need to be known and their dimensions. After this the MKI of the different materials can be calculated within the software of Dubocalc.

8.2.4. What are the CO_2 emissions for the different alternatives against piping?

The CO_2 emissions of the different alternatives can be found in the table below.

Measure	**MKI Value (€)**	**CO_2 emission (KG eq.)**
Vertical Geotextile	5.196	43.391
Plastic Seepage screen	12.739	71.980
Piping bank per ship	28.102	243.260
Gravel chest	65.737	504.282
Steel seepage screen	67.885	747.080
Piping bank per truck	70.710	614.680

The CO_2 are calculated with the software of Dubocalc, which first calculated the MKI of different measures after which the CO_2 values of the different measures could be calculated with changing some settings in Dubocalc.

8.2.5. Which parameters have the biggest influence on the CO_2 emission for the different alternatives?

The parameters that have the biggest influence on the different alternatives can be found in the assessment framework (figure 10) on page 33. The dominant factors are analysed with the software of Dubocalc. The software directly gives the influence of factors in a single product/process in percentages. When there is only one product/process in a measure the influence on the single product/process is directly the influence on the whole measure. When there are more then one product/process in the measure the influence of the product/process first need to be analysed after which the factors within de product can be analysed. The influence of the factor on the whole MKI value can then be calculated with the following formula:

$$Influence\ factor\ on\ total\ MKI\ measure = \frac{operation\ (\%)}{100} * factor(\%)$$

Equation 13 Influence on total MKI

8.2.6. Using the assessment framework made in the previous questions, is it applicable and will it be used in dike reinforcement projects?

To answer this question there were conducted interviews with two waterboard members. The assessment framework is applicable in the preliminary design phase of a dike reinforcement project. The assessment framework will most certainly also be used, but if it will be decisive for the choosing of a preference decision is dependent on the importance sustainability has in the project.

9. Recommendations future research

- For future research it would be helpful to also research to other failure possibilities and make an assessment framework of these reinforcements. This because a dike is often rejected on multiple failure mechanisms.

- Also, for future research it would be interesting to see if the calculations can be made dependent on the seepage length shortage. So, the assessment framework can be functional for every seepage length.

- For the reinforcements that have drainage functions, the water that need to be relocated is now not taken into account in the calculations, for future research it can be interesting to see how much influence this has on the environmental impact of the alternative.

- In this research there is only looked at the sustainability of the different measures. When choosing a preference alternative there are more criteria which can influence the assessment. For future research it is therefore handy to do research in other criteria of the different measures for example safety.

10. Discussion

In this chapter the uncertainties that may cause discussion within this research. The uncertainties mostly are caused by the short time there was to do this research, for this reason some assumptions needed to be made.

First of all, for the because the assessment framework was not made on one specific dike, the seepage length shortage needed to be assumed. So, all the alternatives and their dimensions are now based on this assumption, but this does not make a huge difference in the result. Because this assumption was made for every alternative and in the end the alternatives are compared with each other.

Within Dubocalc not every material was available to calculate the different alternatives. When there was a material not available, a material with the same environmental impact was selected to calculate the alternatives. In the end the alternative should have the same environmental impact.

At last for the interviews, through the short time available it was only possible to conduct two interviews with technical members from waterboard. If there was more time available it would be better to conduct more interviews, to be able to better validate the assessment framework. The two interviews both went different which makes it hard to compare both interviews to each other. Through this problem, the validation is not as strong as hoped but it gives a first image what the opinion of waterboards is towards the assessment framework

References

Bersan, S., Koelewijn, A. R., & Simonini, P. (2015). *Backward ersosion under a dike*. Retrieved from researchgate: https://www.researchgate.net/figure/Backward-erosion-piping-under-a-dike-adapted-from-ICOLD-2015_fig1_312256040

Blinde, U. F. (2019, Mei 22). *Piping*. Retrieved from Joost de Vree: http://www.joostdevree.nl/shtmls/piping.shtml

Bouw Circulair. (2018, January 24). *Microsoft Word - BouwCirculair_actieblad_LCA_MKI_waarde_24012018.* Retrieved from bouw circulair: http://www.bouwcirculair.nl/static/files/tinymce/uploads/BouwCirculair_infoblad_LCA_MKI_waarde_24012018.pdf

Bureau ruimtewerk. (2018, July 2). *Innovatie bij dijkversterking Twentekanaal - Waterschap Rijn en IJssel*. Retrieved from Bureau ruimtewerk: https://www.bureauruimtewerk.nl/innovatie-dijkversterking-twentekanaal-waterschap-rijn-en-ijssel/

Carbon Independent. (2015, January 29). *Aviation Sources*. Retrieved from Carbon Independent: https://www.carbonindependent.org/sources_aviation.html

Cofra BV. (2014, Augustus). *Geolock Kwelschermen.* Retrieved from Cofra: http://cofra.com/wp-content/uploads/2014/08/Geolock-NL-V0.pdf

Cofra BV. (n.d.). *Cofra Folieconstructies.* Retrieved from Joost de Vree: http://www.joostdevree.nl/bouwkunde2/jpgf/folieconstructie_4_brochure_folieconstructies_www_cofra_nl.pdf

Deltares. (2018, September 11). *Pipingberm aanbrengen*. Retrieved from Wiki Noodmaatregelen: http://v-web002.deltares.nl/sterktenoodmaatregelen/index.php/Pipingberm_aanbrengen

Duurzaam GWW. (2019, May 15). *De aanpak*. Retrieved from Duurzaam GWW: https://www.duurzaamgww.nl/de-aanpak/

Fox, MCdonald, Pritchard, & Mitchell. (Eighth Editions). Flow in open channels. Wiley.

Green Deal. (2019, May 16). *Duurzaam GWW 2.0*. Retrieved from Green Deal: https://www.greendeals.nl/green-deals/duurzaam-gww-20

Grind.be. (2019). *Soortelijk gewicht en inoud*. Retrieved from Grind.be: https://www.grind.be/soortelijk-gewicht-en-inhoud

Huijsmans, A. (2013, December 6). *Pipingprobleem landelijk aangepakt*. Retrieved from Hoogwaterbeschermingsprogramma: https://www.hoogwaterbeschermingsprogramma.nl/actueel/nieuws-actueel/239021.aspx?t=pipingprobleem+landelijk+aangepakt+

HWBP. (2017, December). *De gebiedseigendijk: Een prachtige kans!* . Retrieved from Hoogwater bescherming: http://hoogwaterbescherming.nl/nieuwsbrieven/december-2017/artikel-5.html

Jasper van Gestel, H. T. (2013). *De Werkmethode Tegen Piping.* Opheusden: GMB.

Jutte, J. B., Mentink, B., & Timmerman, W. (2019). *Circulaire objecten.* Amersfoort: Haskoning Nederland B.V.

Killian, F. (2000, September). *Dichtheid kunststof.* Retrieved from Newsroom: https://newsroom.nvon.nl/files/default/M13_bepaling-dichtheid-kunststof.pdf

Kramer, R. (2014). *erosion under dikes.* Enschede: University of Twente.

Kroon, R. v. (2014, October 6). *Slimme oplossing voor instabiele rivierdijk*. Retrieved from Heijmans: https://www.heijmans.nl/nl/verhalen/het-idee-waterontspanners/

Meurs, D. i., Niemeijer, I. J., Meerten, I. J., Langhorst, I. O., & Meuwese, I. H. (2018). *POV Drainagetechnieken.* POV Macrostabiliteit en de Pov-Piping.

Milieudefensie. (2018). *Eerlijk Klimaatakkoord*. Retrieved from Milieudefensie: https://milieudefensie.nl/klimaatakkoord?gclid=CjwKCAjwycfkBRAFEiwAnLX5Ie1BqknNd8wq3G3kyExzdSeg_FkDL7hzhgCy1GaxOHAM9419bqo6-xoCk5UQAvD_BwE

Ministerie van Infrastructuur en Milieu. (2016). *Spelregels van het Meerjarenprogramma Infrastructuur, Ruimte en Transport (MIRT).* Den Haag: Ministerie van Infrastructuur en Milieu.

Movares. (2015, November 10). *Dijkvesterking zonder ruimtebeslag*. Retrieved from Waterontspanner: https://waterontspanner.nl/

Niemeijer, H. (2017). Technische Richtlijn Drainagetechnieken. *Technische Richtlijn Drainagetechnieken* (p. 10). Pov Piping.

Niemeijer, i. J., & Langhorst, I. O. (2018, March). *publicatie_POV-Drainagetechnieken.* Retrieved from Pov Macrostabiliteit: https://www.povmacrostabiliteit.nl/wp-content/uploads/2015/03/publicatie_POV-Drainagetechnieken.pdf

Oldhoff, R. (2013). *Meetkwantiteit versus toetsingskwaliteit.* Deventer: BZ Innovatiemanagement.

RIVM. (2018, November 2). *Wat is LCA?* Retrieved from Rijksinstituut voor volksgezondheid: https://www.rivm.nl/life-cycle-assessment-lca/wat-is-lca

Schweitzer, G. (2018, September 4). *Schaduwprijzen sessie 2.* Retrieved from Piano: https://www.pianoo.nl/sites/default/files/media/documents/Schaduwprijzen_sessie2_4sep2018.pdf

Soepboer, m. d. (2018). *Integrale verkenning Dijkversterking Wolferen-Sprok en Dijkteruglegging Oosterhout.* Deventer: Witteveen + Bos Raadgevende ingenieurs B.V.

SteelConstruction.info. (n.d.). *Recycling and reuse.* Retrieved from SteelConstruction.info: https://www.steelconstruction.info/Recycling_and_reuse

TAW. (1999). *Technisch Rapport Zandmeevoerende wellen.* Delft: Technische Adviescommissie voor de Waterkeringen.

Vroonhof, J. (2016). *DuboCalc-light voor kleinere GWW.* Bussum: vroonhof milieu advies.

Waterschap Rivierenland. (2019, January 3). *Gameren*. Retrieved from Waterschap Rivierenland: http://www.dijkverbetering.waterschaprivierenland.nl/common/projecten/gameren/gameren.html

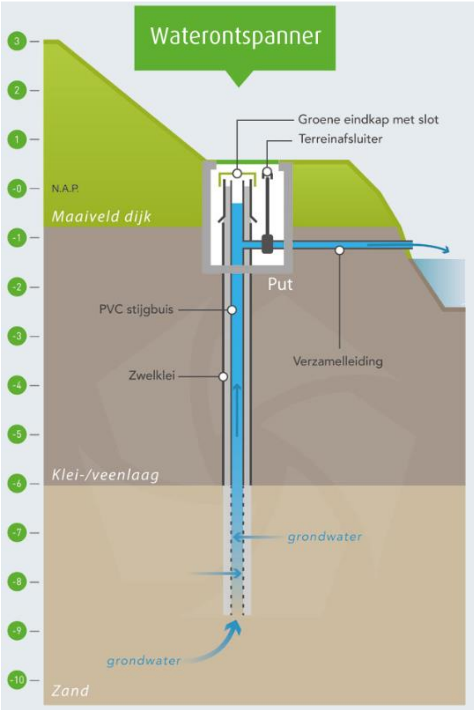
Appendices

In the appendices extra information and figures can be found in addition to the main text.

Appendix A: Figures different measures

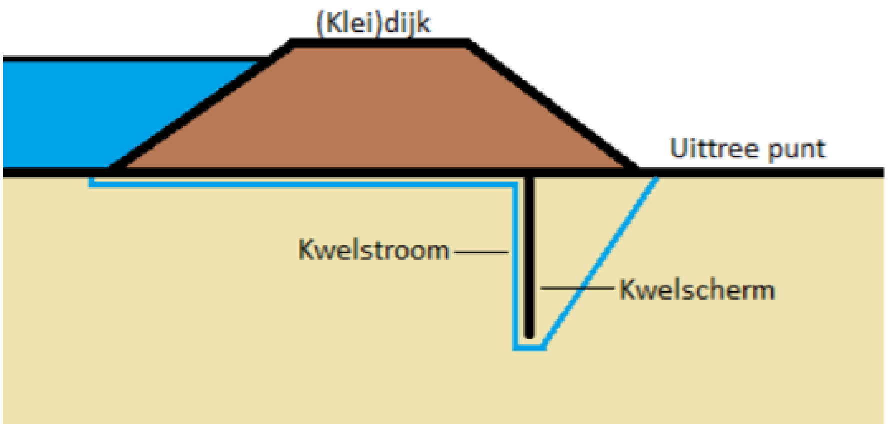
In this appendix the pictures of the measures against piping will be displayed.

Water timer:



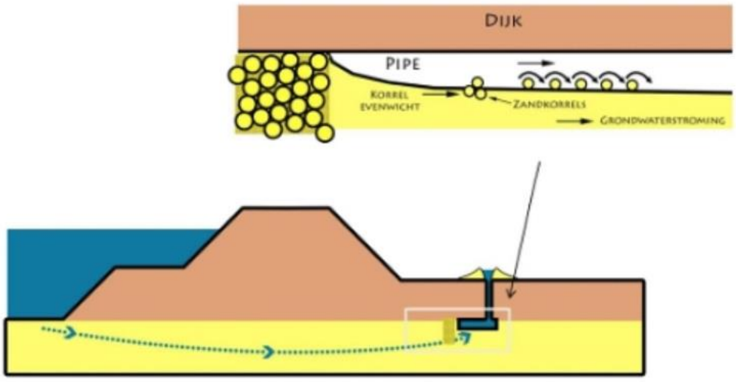
Water timer (Movares, 2015)

Seepage screen:



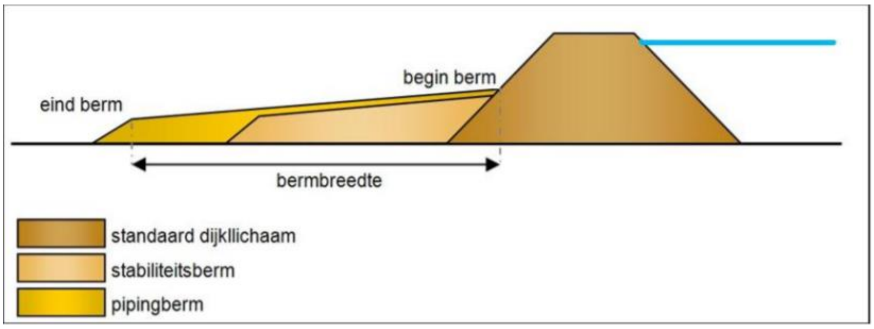
seepage screen (Oldhoff, 2013)

Gravel chest:



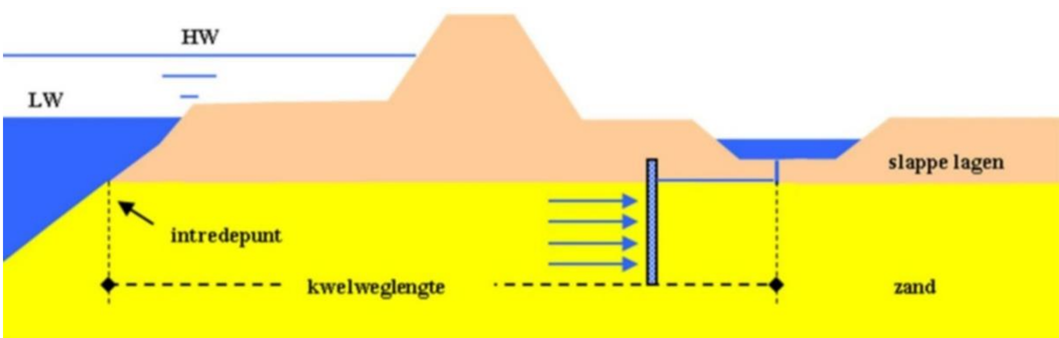
Gravel chest (Waterschap Rivierenland, 2019)

Piping bank:



Piping bank (Jasper van Gestel, 2013)

Vertical sand-proof geotextile:



Vertical sand-proof geotextile (Bureau ruimtewerk, 2018)

Appendix B: Transcript interview Hoog heemraadschap Schieland Krimpenerwaard

The interview will be with Marco Weijland a technical manager from the Water Board Schieland Krimpenerwaard with the office located in the City of Rotterdam. The interview will be in Dutch, but the most important captures will also be translated into English.

Doel: Het doel van het interview is ten eerste erachter komen of de trend die in mijn onderzoek beschreven wordt, het belangrijker worden van duurzaamheid, in de praktijk ook zo ervaren wordt. Dit is belangrijk om erachter te komen of het probleem waar mijn afwegingskader een oplossing voor bied ook in de praktijk gebruikt zou gaan worden. Daarnaast wil ik door het uitleggen van mijn afwegingskader, kijken of dit in de werkelijkheid op dijkversterkingsprojecten toepasbaar is.

De vragen die ik graag aan de technisch managers zou willen stellen zijn de volgende:

- **Hoelang bent u al werkzaam in de dijkversterkingen? En heeft u nu of in het verleden te maken gehad met grote dijkversterkingen die afgekeurd zijn door het faalmechanisme van piping?**

Marco: Ik ben nu vier jaar actief bij de primaire keringen. Ik werk momenteel aan de dijkversterking bij Kijk, daar zit geen piping probleem in dus dat hebben we in een vroeg stadium kunnen afschrijven. De dijk bij Kijk is vooral afgekeurd of macrostabiliteit en hoogte. Daarvoor ben ik ook bezig geweest met regionale dijken, waar niet persé piping optreedt maar wel opdrijven van Veenkades.

Olof: Maar u heeft wel kennis van het faalmechanisme piping?

Marco: Ja zeker!

- **U heeft al verteld dat u momenteel al vier jaar aan het project Kijk werkt. Wat was u rol daarin en dan vooral kijken naar de verkenningsfase?**

Marco: In de verkenningsfase ben ik vanuit de afdeling dijken en wegen toegevoegd aan het projectteam, ik assisteerde de technisch manager in die tijd. De technisch specialisten zaten ook wel bij de afdeling waterkeringen en wegen. Na drie jaar ben ik aan de slag gegaan als technisch manager in het project, op dit moment waren we aan het einde van de verkenningsfase waar we de kansrijke alternatieven hadden uitgewerkt. Voor het voorkeursalternatief (VKA) hebben we toen een afweging gemaakt op 54 aspecten. Bij duurzaamheid zaten niet onderscheidende verschillen, deze zaten vooral bij de technische haalbaarheid. Wel hebben we ook naar de milieu effecten gekeken maar ook daar zaten niet de grote verschillenen tussen de verschillende varianten.

- **Op het moment stelt Rijkswaterstaat steeds meer eisen aan duurzaamheid o.a. door het klimaatakkoord gesloten in parijs, dit is bijvoorbeeld terug te zien in het akkoord duurzaam GWW 2.0. Hoe ziet u dit terug in de praktijk bij dijkversterkingen?**

Marco: Ja wij zien daar als waterschap zelf ook een opgave, wij hebben dezelfde ambitie en zijn ook akkoord gegaan met deze deal. Ons bestuur vind duurzaamheid ook erg belangrijk. Binnen het project KIJK wat vier jaar geleden al is begonnen hebben we nu al een voorkeursalternatief. Bij ons project vinden veel constructies in de kruin van de dijk plaats, dus hier is nog wel veel mogelijk als hij gaat om materiaalkeuze waar we dan bijvoorbeeld een duurzaamheidsscore aan kunnen hangen. We kijken in de planuitwerking wel naar duurzaamheid in de omgeving en bijvoorbeeld het opleveren van een bloemrijke dijk. Daarnaast kijken we ook naar ruimte voor natuur ontwikkeling en ecologie.

Olof: Dus dat zijn meer maatregelen om uitstoot te compenseren in plaats van te reduceren?

Marco: Ja dat klopt inderdaad.
Olof: Want project KIJK is inmiddels aanbesteed? Of zit het nog in de aanbestedingsfase?

Marco: We staan nu op het punt om aan te besteden, dus we zijn op zoek naar een partner om het plan verder uit te werken. In het verder uitwerken van het project zijn we ook van plan om de verschillende alternatieven naast elkaar te leggen en te testen op duurzaamheid. Waar we zullen beginnen met een variantenstudie waar we de verschillende varianten van de verschillende dijkvakken naast elkaar zullen leggen. Verder zijn we niet heel expliciet hoe we de verschillende varianten willen gaan testen, hier willen we samen met de partner naar gaan kijken. Dubocalc zou hier een van de mogelijkheden zijn maar dat staat nog niet vast. Maar dit gaat dan alleen over het materiaalgebruik en de uitstoot van de verschillende varianten, daarnaast zal er ook naar andere compensatie mogelijkheden gekeken worden.

- **Heeft u bij uw huidige projecten of bij projecten in het verleden duurzaamheid als doelstelling meegenomen? Zo ja op wat voor manier kwalitatief of kwantitatief en hoe heeft u dat dan gedaan? En heeft u dit al meegenomen in de verkenningsfase van het project?**

Marco: We hebben geen specifieke doelstelling op het verminderen van CO_2 uitstoot op dit moment. Als we erachter komen dat er een groot verschil is in varianten met betrekking tot CO_2 uitstoot dan zal er op dat moment een beslissing worden genomen. Hierin zal een kosten baten analyse worden gemaakt, om te kijken of het waard is om meer uit te geven voor een duurzamere dijk. Het project zelf is best wel complex dus is ons beeld dat we op dit moment nog geen doelstelling/ambitie kunnen stellen omdat we het moeilijk vinden in te schatten of deze ambitie dan ook daadwerkelijk haalbaar is.

Olof: dus eigenlijk hangt het erg af van wat de partij waarmee jullie samen gaan werken gaat doen in de planuitwerkingsfase?

Marco: Ja klopt inderdaad, als zij berekeningen gaan maken op duurzaamheid dan zullen die meegenomen worden om uiteindelijk compromis te vinden tussen een Duurzaam, Maakbaar, betaalbaar en veilig ontwerp.

Olof: In jullie project wegen jullie duurzaamheid dus vooral kwalitatief af en mogelijk ook kwantitatief?

Marco: Ja klopt we gaan het in net als in de verkenningsfase kwalitatief afwegen, maar ik verwacht om dat we het ook wel kwantitatief zullen gaan afwegen. Laatst was ook de uitspraak over het stikstof programma, dus zou het mogelijk zijn dat we het kwantitatief moeten gaan maken om te kunnen bewijzen dat we aan de norm voldoen. In een volgende MER studie zullen we hier ook aandacht aangeven om te kijken of we het kunnen reduceren en anders compenseren. Bij compensatie spelen die kosten ook wel mee, het kan natuurlijk niet zo zijn dat het compenseren duurder wordt dan het project zelf. Maar het laaghangend fruit moet je hier zeker aanpakken. Bijvoorbeeld letten op het materieel wat je inzet, het mixen van diesel met biodiesel.

Maar het lijkt mij nuttig om in de verkenningsfase dit al aan te pakken, hier maak je namelijk de echte grote keuzes en nu zijn we vooral met detail dingen bezig. Hier boek je waarschijnlijk niet de meeste winst, ten opzichte van de verkenningsfase. Als je het hier kwantitatief maakt dan kan je hier ook een afgewogen keuzen in maken, gaan we enerzijds voor de duurzame dijk of gaan we anderzijds voor de meest betaalbare dijk.

Olof: Ik merk dat je eigenlijk zegt dat het in project KIJK vooral kwalitatief is meegenomen en in dat er in de planuitwerking waarschijnlijk wel kwantitatieve berekeningen gaan worden uitgevoerd. Ook zeg je dat je verwacht dat de grote slagen qua CO_2 reductie te halen vallen in de verkenningsfase van projecten omdat hier de grote beslissingen worden gemaakt.

Marco: Ja dat klopt inderdaad.

Uitleggen van het afwegingskader waarin ik de volgende dingen wil verwerken. Waarom dijkversterkingen? Omdat binnen de dijkversterkingen ze echt achterlopen op het gebied van duurzaamheid in vergelijking met andere velden binnen de civiele techniek. Piping is gekozen omdat het een veel voorkomend probleem is en er recent ook veel nieuwe oplossingen zijn voor piping en deze ook goed te modeleren waren in Dubocalc. Dubocalc rekent met de MKI waarin weer 11 factoren zijn meegenomen, omdat de MKI bij mensen weinig zegt is dit omgerekend naar CO2 uitstoot. De verschillende maatregelen die zijn gekozen is eigenlijk elke losse maatregel voor piping uitgezonderd van de grofzand barrière en de waterontspanner, deze zijn niet meegenomen omdat deze lastig op dit moment nog niet te modeleren zijn in Dubocalc.

- **Wat ziet u als voordelen van het afwegingskader en wat ziet u als nadelen?**

Marco: Ik denk dat het heel goed is voor het besef, dat de keus van een oplossing een heel verschillend invloed kan hebben op het milieu. Bijvoorbeeld een verticaal geotextiel stoot twintig keer minder uit dan een stalen damwand, dat is een behoorlijk verschil. Dus voor het besef is het heel erg nuttig, daar in tegen is het nog wel erg abstract omdat de waarde van zoveel CO_2 lastig te schatten is. Dus dat zou je dan in het afwegingskader moeten vertalen naar, dat is zoveel uur moet je auto rijden of zoveel uren vliegen. Dat zou naar mijn mening heel nuttig zijn om het nog inzichtelijker te maken en om het perspectief te hebben. Dus als je dan de afweging zou moeten maken dan zou de ene echt -- scoren en de ander misschien wel ++. Dus in het kort het voordeel is dat het inzichtelijk maakt wat het verschil is tussen beide opties. Een nadeel of een punt van aandacht is dat je er op moet letten dat de uitstoot ook op waarde wordt geschat. Als ik specifiek kijk naar het project KIJK dan zie je het voordeel van het zand per schip aanvoeren in plaats van per vrachtwagen, dus daar mag ook wel iets tegenover staan.

- **Zou het afwegingskader wat zojuist is uitgelegd u helpen om een beter afgewogen keuze te maken. Zo ja, hoe zou het u helpen?**

Marco: Zoals eerder besproken maakt het inzichtelijk wat de invloed op de CO_2 uitstoot van de verschillende maatregelen is ten opzichte van elkaar. Daarnaast maken de factoren duidelijk waar nog meer winst te behalen valt. Bijvoorbeeld voor staal, daar hoef je niet meer aan te rekenen, je weet gewoon dat je de hoeveelheid staal in je project wilt verminderen.

Olof: Dit afwegingskader is gericht op de maatregelen tegen piping, zou je ook toekomst zien om dit voor andere faalmechanismes te ontwerpen?

Marco: Ja, als ik bijvoorbeeld kijk naar het faalmechanisme macrostabiliteit, ben ik bijvoorbeeld benieuwd hoe vernageling zou scoren ten opzichte van een traditionele steun berm. Als we bijvoorbeeld zand niet uit ons eigen gebied aanvoeren per vrachtwagen dan zit het ongeveer op dezelfde uitstoot als een stalen scherm en dan zou duurzaamheid dus de doorslag kunnen geven om toch voor vernageling te kiezen. Daarnaast lijken mij de bekledingen van het buitentalud ook nuttig om af te wegen, om hier bijvoorbeeld te kijken naar het hergebruik van materialen, ook al kost dat iets meer effort. Waarschijnlijk zal dit zich dan uitbetalen in duurzaamheid, met zo'n afwegingskader kan je het dan inzichtelijk maken waarom je dan toch voor deze optie zou kiezen.

- **Wat is er volgens u nodig om het afwegingskader verder te verbeteren?**

Marco: Ja zoals eerder gezegd is het echt wel een aandachtspunt om de waarde goed te kunnen schatten, dat het vergeleken wordt met andere dingen in de praktijk bijvoorbeeld het aantal vlieguren of het aantal huishoudens. Het zal lastig zijn om het echt op waarde te schatten, maar dat is wel nodig om mensen te kunnen motiveren om niet voor de sobere en doelmatige variant te gaan maar ook kijken naar een duurzame variant.

- **Zou u het afwegingskader toepassen in de praktijk? Zo nee, wat zou er voor u moeten veranderen om het wel toepasbaar te maken?**

Marco: Ja dat zou de drempel heel laag maken om het toe te passen in de verkenningsfase. Hoe wij het nu hebben aangepakt in de verkenningsfase is dat wij van mogelijke alternatieven naar kansrijke alternatieven gegaan. Bij de kansrijke alternatieven zou je met dit afwegingskaders al de verschillende alternatieven af kunnen wegen op duurzaamheid. Met dit afwegingskader kan het heel inzichtelijk worden om de verschillende alternatieven op een rijtje te zetten gebaseerd op uitstoot van CO_2. Dan is het misschien nog niet helemaal doorgerekend voor de constructie maar je ziet dat als het verschil een factor twintig is dat je daar wel al uitspraken over kunt doen. Je zou dan bijvoorbeeld kunnen zeggen deze twee zijn even slecht, dus daar is duurzaamheid niet een onderscheidend criterium. Maar omdat er veel aannames zijn gemaakt blijft het kwalitatief onderbouwd ook omdat je werkt met ordegrootte. Dus het is een kwantitatief onderbouwde kwalitatieve score.

Marco: Misschien nog een aandachtspunt, misschien niet helemaal aansluitend op dit onderzoek. Wij krijgen vaak de opgave om een sober en doelmatige oplossing te ontwerpen. Duurzaamheid wordt daar in tegen altijd gekoppeld aan duur, dus zijn mensen vaak bang om te kiezen voor een duurzame oplossing omdat iedereen denkt dat hier ook meer kosten mee gemoeid zijn. Dus als je voor een duurzame dijk kiest dan zou het zo maar eens kunnen zijn dat je als waterschap veel zelf zal gaan moeten betalen, dan lopen de kosten toch al snel op. Dus het is moeilijk om van de voorkant te zien wat levert een duurzame dijk mij op ten opzichte van de kosten. Maar met dit wordt het wel al een stukje inzichtelijker.

Appendix C: Transcript interview Water board Riverland

The interview will be with Gerjan Westerhof a technical manager from the Water Board Rivierenland with the office located in the City of Tiel. The interview will be in Dutch, but the most important captures will also be translated into English.

- **Hoelang bent u al werkzaam in de dijkversterkingen? En heeft u nu of in het verleden te maken gehad met grote dijkversterkingen die afgekeurd zijn door het faalmechanisme van piping?**

Gerjan: Ik ben al tien jaar werkzaam in het veld van dijkversterkingen en ik heb eigenlijk pas de afgelopen vier jaar te maken met dijken die zijn afgekeurd door het faalmechanisme van piping. Momenteel ben ik werkzaam aan het project wolveren sprok van Nijmegen tot aan de A50.

Olof: Is er een groot gedeelte van dit project afgekeurd op piping?

Gerjan: Het project is honderd procent afgekeurd op piping, dus eigenlijk over het hele stuk is het afgekeurd op piping.

Olof: in welke fase zit dit project op dit moment?

Gerjan: Dat zit een beetje ingewikkeld, we hebben eigenlijk vier fases. We gaan eerst de dijk toetsen, dat is eigenlijk een voorverkenning. Dan worden dijken wel of niet afgekeurd en dan starten we eigenlijk de verkenning, waar we eigenlijk nog beter gaan kijken. Vervolgens gaan we naar de planuitwerking fase en uiteindelijk de uitvoering. We zitten voor het project nu in de planuitwerking fase, in de vorige fases is elke keer gezegd ja hij is op piping afgekeurd maar er zit ook een ontwerpopgave, maar met het nieuwe ontwerp instrumentarium wisten we niet hoe we dat moesten aanpakken. Bij piping kwamen er namelijk zulke grote tekorten uit, dat we er zo erg aan twijfelde dat we het vooruit hebben geschoven. We hebben ervoor gekozen om voor piping niet hele grote grondbermen aan te leggen, wat we vroeger altijd deden. Maar we lossen het op met een verticale voorziening, we zitten nu in de planuitwerkingsfase waar we een ontwerpteam hebben samen met een aannemers combinatie en een inginieursbureau. We hebben nu dus heel veel knappe koppen bij elkaar om dit probleem eens goed vast te pakken. Wat we nu eigenlijk eerst zijn gaan doen is meer grond onderzoek met nieuwe technieken om te kijken zit er nou echt een piping opgave. We verwachten dat we daar al een reductie van minimaal 50% van de totale opgave krijgen. En van die overige 50% proberen we meer duidelijk te krijgen wat hebben we nou tekort. Als je het over duurzaamheid hebt dan is dat wat mij betreft de duurzaamste methode.

En hieruit volgt dan de piping opgave maar hoe we die opgave gaan invullen hebben we nog niet duidelijk. Maar die beslissing komt wel erg snel, binnen twee drie maanden willen we wel duidelijk hebben hoe we de piping opgave gaan aanpakken. Dus eigenlijk is het voorkeursalternatief al gekozen maar de manier waarop we het gaan doen wordt dat uitgezocht. We maken in de verkenningsfase namelijk een hoogoverkeuze dat was in dit geval de verticale voorziening en pas in de planuitwerkingsfase gaan we dat uitwerken.

Olof: Verschilt dat dan nog erg tussen verschillende waterschappen? Want ik heb ook wel eens gehoord dat in de verkenningsfase al een hele oplossing uitgewerkt was.

Gerjan: Dat is eigenlijk per project verschillend, we hebben bij dit project die keuze niet gemaakt omdat we de opgave nog niet goed genoeg wisten en omdat we de planuitwerkingsfase samen met een aannemerscombinatie en een ingenieursbureau gingen doen. Als je dan niets meer te kiezen hebt dan is dat eigenlijk onzin dus hebben we het zo open mogelijk gelaten.

- **Binnen deze dijkversterkingen. Wat was u rol daarin en dan vooral kijkend naar de verkenningsfase?**

Gerjan: Ik heb vooral de pet van de beheerder van het waterschap op in het ontwerpteam. Er zit binnen het ontwerpteam ook nog een technisch manager van de aannemerscombinatie, die trekt vooral het ontwerpspoor en ik zorg er eigenlijk vooral voor dat als het project straks klaar is dat het waterschap eigenlijk ook vind dat het een goede oplossing is. Dus als de technisch manager bijvoorbeeld komt met een oplossing met drainage buizen en een pomp die je aan moet zetten als het hoogwater is. Dan hou ik de aannemer daarin tegen omdat dit vanuit het beheerderperspectief erg onderhoud behoevend is.

- **Op het moment stelt Rijkswaterstaat steeds meer eisen aan duurzaamheid o.a. door het klimaatakkoord gesloten in parijs, dit is bijvoorbeeld terug te zien in het akkoord duurzaam GWW 2.0. Hoe ziet u dit terug in de praktijk bij dijkversterkingen?**

Gerjan: Allereerst ben je bij de goede persoon om dit te vragen omdat ik het duurzaamheid spoor van het project trek. Dat zie je inderdaad wel terug, soms lijkt het wel opnieuw uitgevonden te worden. Ik doe ook nog een andere dijkversterking bij de kinderdijk schoonhoogseveer, dat bevind zich nu in de fase van het schrijven van een overdracht rapportage. Maar daar hebben wij bijvoorbeeld ook al het asfalt wat vrij komt bij het project proberen her te gebruiken en ook als je kijkt naar klei, al het klei wat vrij komt proberen we weer opnieuw te gebruiken in het project. Dat is in feite niet nieuw maar nu hang je er een label duurzaamheid aan, momenteel is er dus wel meer aandacht voor. Vroeger was het vrijblijvend maar met huidige projecten ben je vaak verplicht het te doen, je moet het in het project een plek geven.

Olof: Bij uw huidige project wordt daar dan ook ruimte voor gecreëerd en wordt het als doelstelling meegenomen bij de eisen?

Gerjan: Nee het is geen doelstelling op zichzelf maar het draagt wel bij aan onze doelstellingen. Bij onze duurzaamheidsambitie hebben we onder andere gewerkt met de omgevingswijzer en de input vanuit duurzaam GWW. Hier hebben wij dan een hele concrete invulling aan gegeven van wat we willen bereiken.

Olof: Als we naar de verkenningsfase kijken, hebben jullie de verschillende alternatieven dan al afgewogen op duurzaamheid?

Gerjan: Nee we hebben in de verkenningsfase de verschillende alternatieven niet echt op duurzaamheid gescoord. Wat bij ons heel belangrijk is dat we dijkversterkingen eigenlijk altijd in grond willen uitvoeren, vanuit ons is dat namelijk erg duurzaam. Want als je op een locatie een schep grond neergooit dan ligt die schep grond er over honderd jaar nog steeds. Als je dit vergelijkt met een stalen damwand en dit bekijkt over honderd jaar dan zie je dat deze zo goed als weg is.

Olof: Oke dus grond staat voorop bij het waterschap omdat dit qua levensduur heel duurzaam is, maar misschien is dit qua aanleg wel niet zo. Kijken jullie daarnaar op dit moment?

Gerjan: Nee daar kijken we op het moment niet naar.

Olof: Voor alle faalmechanisme zit het project al in de planuitwerking fase behalve op die van piping. Wordt er in deze fase wel gerekend aan duurzaamheid?

Gerjan: Bij wolveren-sprok hebben we uberhaupt maar weinig alternatieven, we kunnen het meeste in grond doen. Dit past dan natuurlijk perfect bij het beleid van het waterschap om zo veel mogelijk projecten in grond uit te voeren. Op plekken waar we met grond niet uitkomen dan zul je iets anders moeten bedenken en daar hebben we dan voor gekozen om een constructie te maken. Nu we voor deze plekken in de planuitwerking fase zitten moeten we gaan bedenken wat voor constructie dat gaat worden. Voor het kiezen van deze constructie willen we wel duurzaamheid gaan meenemen. Waarschijnlijk zullen we hier gebruik gaan maken van dubocalc. Dit betekend dus dat we in de planuitwerking fase wel kwantitatief aan de verschillende oplossingen gaan rekenen.

Maar wat dan in dit geval lastig is, is dat duurzaamheid een van de parameters is. Binnen deze parameters is dan duurzaamheid niet de belangrijkste.

Olof: Dat is interessant want duurzaamheid gaat als het aan Rijkswaterstaat ligt steeds zwaarder wegen. Ze hebben onder andere uitgesproken de CO_2 uitstoot drastisch te willen verminderen voor 2030. Denk je dat duurzaamheid dan meer gaat opspelen?

Gerjan: Bij dijkversterkingen blijft de allerbelangrijkste parameter dat een dijk veilig is.

Olof: Dat snap ik, maar als twee oplossingen even veilig zijn en de ene is heel duur maar heel duurzaam. De ander is daar in tegen heel milieu onvriendelijk maar wel goedkoop. Denk je dat hier dan de duurzaamheid een belangrijke factor gaat spelen?

Gerjan: Zolang het niet in de wet verankerd in dan denk ik dat dit vies zal tegen vallen. Als je het vergelijkt met natura2000 gebieden, wij mogen niets meer van deze gebieden afsnoepen dan noodzakelijk voor dijkveiligheid. Als duurzaamheid op hetzelfde nivieau komt te staat dan is het net zo belangrijk, maar dit zie ik nog niet gebeuren.

- **Heeft u bij uw huidige projecten of bij projecten in het verleden duurzaamheid als doelstelling meegenomen? Zo ja op wat voor manier kwalitatief of kwantitatief en hoe heeft u dat dan gedaan? En heeft u dit al meegenomen in de verkenningsfase van het project?**

- **Wat ziet u als voordelen van het afwegingskader en wat ziet u als nadelen?**

Gerjan: Nadelen die ik zie zijn dat vzg er hier heel gunstig uit lijkt te komen maar dat er meer uitstoot bij komt kijken dan je nu zou denken. Een voordeel is dat het heel makkelijk inzicht geeft in wat een duurzame en wat een minder duurzame oplossing qua CO_2 uitstoot. Dit wordt op dit moment alleen nog niet meegenomen in de verkenningsfase van een project. Mocht dit wel het geval zijn de komende jaren dan is dit afwegingskader erg makkelijk te gebruiken om de afweging te maken in de verkenningsfase. En in een latere fase kan je de percentages gebruiken om een beter ontwerp te maken in de planuitwerkingsfase.

Olof: Een denkbeeldige situatie waar u verschillende opties om het faalmechanisme piping te voorkomen moet afwegen. Zou u dit kwantitatief doen met dit afwegingskader of kwalitatief met woorden?

Gerjan: Nou getallen maken het vaak wel erg inzichtelijk dus zou ik gebruik maken van getallen. Aan de andere kant zou ik het soms ook in woorden doen, een voorbeeld daarvan is bijvoorbeeld versterkingen met zand. Deze komen heel slecht uit op CO_2 score, maar zijn aan de andere kant heel duurzaam omdat ze niet vergaan. Dit is dan weer moeilijk uit te drukken in een getal.

- **Wat is er volgens u nodig om het afwegingskader verder te verbeteren?**

Gerjan: Je zou het nog kunnen verbeteren door het ook voor andere faalmechanismen beschikbaar te maken.

- **Zou u het afwegingskader toepassen in de praktijk? Zo nee, wat zou er voor u moeten veranderen om het wel toepasbaar te maken?**

Gerjan: Als duurzaamheid belangrijker wordt dan zou ik het inderdaad toepassen, om het mee te kunnen wegen in een multicriteria analyse.