Improving the work instructions of emergency measures against piping

Mark Castelijns

20 July 2018, final report

Preface

This report is the final version of my master thesis on the improvement of the work instructions of emergency measures against piping and the effectiveness of the measures. This thesis will conclude my Master of Science in Civil Engineering and Management at the University of Twente. This research was requested by the Wiki Noodmaatregelen work group and is conducted in collaboration with Deltares.

I want to thank the members of the work group, with whom I had contact during the meeting and workshops, for their input and feedback on my progress. In particular I want to thank Eric Huijskes and Ulrich Förster, for all their support and help during the duration of this research. I also want to thank Wijnand Evers and Freddie Schutte of the waterboard Drents Overijsselse Delta for their help and opportunities to observe the workings of a water board in practice during training exercises and during a real high water situation in January 2018.

Finally I want to thank the other member of my graduation commission: Andre Doree, Jord Warmink. Their knowledge and feedback helped me at times when I was stuck and gave me a positive impulse to finish the research.

Summary

Almost 60% of the Netherlands is at risk of flooding due to high water or extreme weather and almost 3800 kilometres of levees are in place to protect against this. These levees can fail due to different failure mechanisms, and piping is one of the most important ones. Piping can occur during high water; due to the water head difference water can start to flow underneath the levee. This flow of water can result in particle transport and if this is not stopped eventually a pipe can form and finally the levee can fail. Several emergency measures are possible to combat piping, three of which will be discussed in this research: the creation of an impoundment, raising the water level in the ditch behind a levee, and the construction of a filter. Whether these emergency measures are effective or not is dependent on three aspects: the detection of a failure, the design of the emergency measure and the implementation of the measure. If the detection is done timely, the correct emergency measures is chosen and designed, and this measure is implemented correctly and stops the sand transport, the emergency measure is deemed effective.

Currently there is no method to determine the effectiveness of an emergency measure and to determine the effect they have on the safety of levees. However, some water boards have indicated that the presence of work instructions during the implementation positively affect the quality of the emergency measure. Not all water boards use work instructions and the work instructions that are used are not uniform. This research’s objective is to give recommendations for the adjustment of the work instructions for the three emergency measures. This research will also try to give an indication of the effect the adjustments have on the effectiveness of the three emergency measures. The research goal is defined as: *To assess, evaluate, and improve the work instructions for the implementation phase of the three emergency measures against piping.*

The process surrounding the implementation of an emergency measure is divided into three phases: detection, design, and implementation. These three phases are affected by many different factors which can be placed into two categories: factors that can be influenced by the water boards and factors that cannot be influenced. The work instructions must include information on how to deal with all these factors. The work instructions need to support decisions concerning the design and the implementation of emergency measures. They must be user friendly and help the executing party (a contractor, the waterboards, or a combination of the two) to construct the measure quickly and safely and to minimize the probability of failure of the emergency measure. Currently the existing work instructions only give an indication on the needed materials and address some of the factors that can be influenced, but they lack in some areas. They also address the steps that need to be taken to construct an impoundment and a filter construction, but the steps necessary for raising the water level are not stated. The instructions also do not mention the non-influenceable factors and how to deal with them. To make the work instructions more complete, data is gathered in three different instances: observations at WDOD during the training exercise Deining en Doorbraak, interviews with contractors from two different water boards, and a workshop conducted with experts from six different water boards and calamiteitenteam waterkeringen (CTW).

Based on the gathered information, and the information gaps in the current work instructions, recommendations are made to adjust the work instructions. The indication of the needed materials should be adjusted to comply with the minimum standards found in the literature. Other additions that must be made to the work instructions are: a quality check for the used materials, a checklist for the mobilisation, a division of tasks for the construction, clear instructions how to handle sandbags, the addition of an additional step for the construction of an impoundment and a filter, all the necessary steps to construct a dam to raise the water level

in the ditch behind a levee, and an overview of the biggest risks during construction for each of these emergency measures. The step that must be added to the work instructions of the impoundment and filter construction is the removal of excess sand surrounding the damage.

The implementation phase can be separated into two sub-phases: the mobilisation and the construction. Both these sub-phases will have a probability of failure of about $1e^{-3}$ when the adjustments are implemented. The adjustments comply with the method to mitigate the probability of human error stated in the literature (the procedures are well organized and documented and not excessively complex, and training for normal and abnormal conditions). This probability of failure is based on the human performance in the implementation phase. There are also factors that do not dependent on human actions, however, there is no method to determine how much effect they have on the probability of failure of the emergency measures available at the moment.

Another method to reduce the probability of failure of the implementation phase is to train the mobilisation sub-phase more realistically. At the moment the mobilisation, as it would be in real high water situations, is not a part of the current training exercises. By including the mobilisation it will become a more routine task and therefore the probability of failure could be lower. It is also important that the lessons learnt from training exercises are continuously being used to improve the entire process. Mistakes that are made during exercises must be documented and communicated to the participants in order to learn form them and prevent them from happening in other training exercises.

The water boards would like the work instructions to be more uniform between all water boards. To reach that goal three steps have to be taken. First of all, the presented adjustments should be included in the work instructions. Secondly, members from different water boards should discuss these work instructions to see if there are still shortcomings to them. Thirdly, if everybody is satisfied they should be tested during training exercises at different water boards. If step two and three are completed successfully the work instructions can be distributed, if further changes have to be made the steps have gone through again.

Contents

1 Introduction 1
1.1 Background 1
1.1.1 Definition of effectiveness 2
1.2 Problem description 4
1.3 Research scope 4
1.4 Research goal 5
1.5 Methodology 5
1.5.1 Theoretical background 5
1.5.2 Initial framework 5
1.5.3 Adjustments to work instructions 7
1.6 Reading guideline 7

2 Theoretical background 8
2.1 General 8
2.2 Piping process 8
2.3 Emergency measures 9
2.3.1 Constructing an impoundment 10
2.3.2 Raising water level 13
2.3.3 Constructing a filter construction 14
2.4 Probability of failure of emergency measures 16
2.5 Initial framework 19
2.5.1 Event trees 19
2.5.2 Influence diagram 20
2.6 Requirements for work instructions 23
2.7 Conclusions 24

3 Data gathering 26
3.1 Deining & Doorbraak 26
3.2 Interviews with contractors 29
3.3 Workshop 30
3.3.1 Detection 31
3.3.2 Prioritizing 31
3.3.3 Implementation 32
3.4 Overview of the collected data 32

4 Adjustment of work instructions 35
4.1 Users 35
4.2 Materials 35
4.3 Personnel 36
4.4 Mobilisation checklist 37
4.5 Instructions way of working 37
4.6 Instructions emergency measures 39
4.6.1 Impoundment 39
4.6.2 Raising water level 40
4.6.3 Filter construction 40
4.7 Validation of adjustments 40
4.7.1 Mobilisation 41
4.7.2 Construction 42
4.7.3 Probability of failure emergency measures 43

5 Discussion **44**
5.1 Data gathering 44
5.1.1 Observations 44
5.1.2 Interviews 44
5.1.3 Workshops 44
5.2 Interpretation results 45

6 Conclusions & recommendations **47**
6.1 Conclusion 47
6.2 Recommendations 49
6.3 Options for further research 50

7 Bibliography **51**

Appendix A: Deining & Doorbraak **54**

Appendix B: Interviews contractor **57**

Appendix C Results workshop **62**

List of figures

Figure 1.1: Failure mechanisms of a levee (STOWA, 2012) ... 1
Figure 1.2: The process (“Trits”) (Wiki Noodmaatregelen, 2017) ... 2
Figure 1.3: Reduced probability of failure (Dupuits, 2011) ... 2
Figure 1.4: Event tree of the process concerning emergency measures ... 3
Figure 1.5: Methodology ... 7
Figure 2.1: Stages of the piping process (Schweckendiek et al., 2014) ... 9
Figure 2.2: Impoundment on land (left) and in a ditch (right) ... 10
Figure 2.3: Examples of introduction presented in work instructions by WSRL ... 11
Figure 2.4: Placement of first layer of sandbags (Waterschap Rivierenland, 2017) ... 12
Figure 2.5: placement of additional layers of sandbags (Waterschap Rivierenland, 2017) ... 12
Figure 2.6: Securing the sandbags (Waterschap Rivierenland, 2017) ... 13
Figure 2.7: Raised water level (Wiki Noodmaatregelen, 2017) ... 14
Figure 2.8: Filter construction (Waterschap Rivierenland, 2017) ... 14
Figure 2.9: Event tree for flood fighting (Jonkman, Dupuits, & Havinga, 2013) ... 16
Figure 2.10: Nominal human task performance reliability (Bea, 2002) ... 17
Figure 2.11: Relation human error probabilities and performance level ... 18
Figure 2.12: Event tree detection phase ... 19
Figure 2.13: Event tree design phase ... 19
Figure 2.14: Event tree implementation phase ... 20
Figure 2.15: Influence diagram emergency measure ... 21
Figure 2.16: Part of the process covered by the work instructions ... 23
Figure 3.1: Percentage of found incidents (left) percentage of notifications about placed incident (right) ... 27
Figure 3.2: Percentage of found piping incidents (right) and percentage of found remaining incidents (left) ... 28
Figure 3.3: Percentage of found incidents ... 28
Figure 3.4: Prioritizing events ... 32
Figure 4.1: Example of positioning while passing sandbags. ... 38
Figure 4.2: Examples of stacking sandbags. A – cross section, example of neatly stacking sandbags. B – cross section, example of stable base. C – front view, example of ‘kont op stik’. D – front view, example of staggered stacking. ... 39
Figure 4.3: Failure tree implementation phase ... 41
Figure 4.4: Example of construction of an impoundment at WDOD (left) and WSRL (right) ... 42
Figure 5.1: Estimation of PoF for all the phases by experts form the water boards ... 45

List of tables

Table 2-1: Needed sandbags for given height and length (Waterschap Rivierenland, 2017) .11

Table 2-2: Information in work instruction for impoundment 13

Table 2-3: Needed amount of sandbags per surface area geotextile (Waterschap Rivierenland, 2017) 15

Table 2-4: Needed amount of gravel (m^3) per surface area geotextile (Waterschap Rivierenland, 2017) 15

Table 2-5: Information in work instructions for a filter construction 15

Table 2-6: Description influence diagram 21

Table 3-1: Information gathered during D&D 26

Table 3-2: Information gathered from interviews 29

Table 3-3: Information gathered during workshops 30

Table 3-4: Overview of information in the work instruction and gathered data 33

Table 4-1: Mobilisation checklist current work instructions vs. adjustments 37

Table 4-2: Overview of adjustments to the work instructions 40

Table A-1: Observations Deining & Doorbraak 54

Table A-2: Reported incidents by dike watch 55

1 Introduction

1.1 Background

In the Netherlands almost 60% of the country is at risk to floods from the sea, rivers, or lakes due to high water or extreme weather. Almost 3800 kilometres of levees are in place to defend the low lying areas against this. These levees can fail due to different mechanisms, see Figure 1.1.

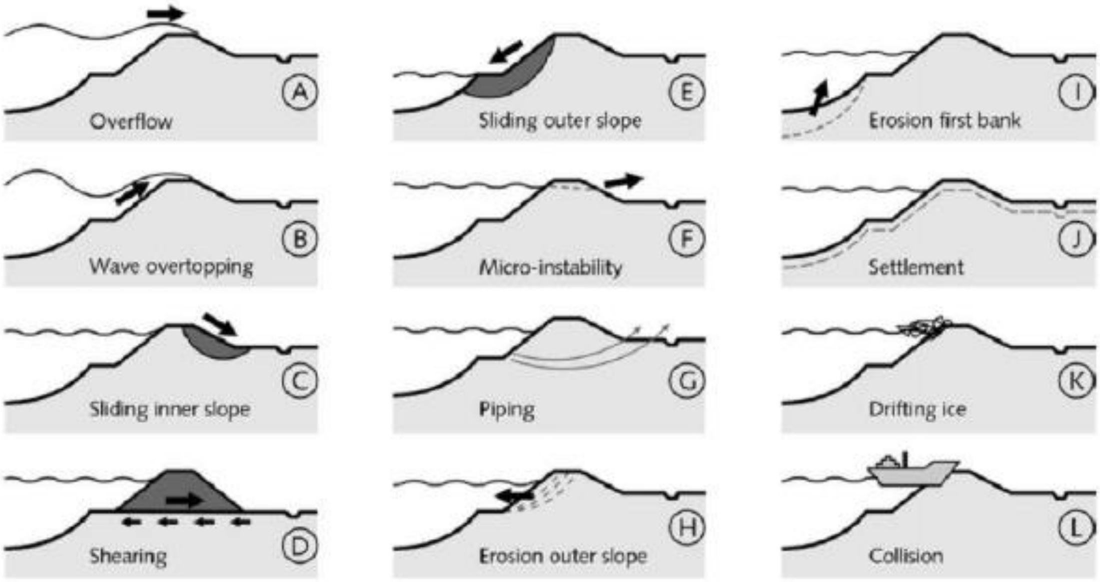


Figure 1.1: Failure mechanisms of a levee (STOWA, 2012)

Piping is one of the most important failure mechanisms of the Dutch levees (Schweckendiek et al., 2014). It can occur during high water situations. Water will start to flow underneath the levee if there is a high water head difference. This water flow can result in the transport of sand particles and this can eventually result in the creation of literally a "pipe" underneath the levee. If this pipe reaches the entry point of the water, it is possible that the levee will fail completely. To combat piping several emergency measures are possible. The Dutch working group "Wiki Noodmaatregelen" was created as a Community of Practice to share knowledge and experience on failure mechanisms and emergency measures for levees, such as for piping. One of the products of the working group is a website (http://v-web002.deltares.nl/sterktenoodmaatregelen/index.php/Wiki_Noodmaatregelen_Waterkeringen_-_homepage). On this website water boards, Rijkswaterstaat, and other organizations can find open source information regarding emergency response measures. Deltares acts as the administrator and host of this site. The working group used the process (in Dutch the 'trits'), Figure 1.2, which covers all steps from detecting damage to a levee, to executing an emergency measure as a means to map knowledge, experience and tools. For each category in this process the different options are defined and provided with examples and tools.

Observed damage *Failure mechanism* *Emergency measure* *Design* *Implementation*

Figure 1.2: The process ("Trits") (Wiki Noodmaatregelen, 2017)

The water board Drents Overijsselse Delta (WDOD) and water board Rivierenland (WSRL) are two members of the working group. These two water boards, besides others, want to get more insight in the effectiveness of the emergency measures against piping. Besides, they would like uniform work instructions for the implementation of the measures that can be used by all the water boards. To answer these questions the University of Twente conducts this research in collaboration with Deltares for the Wiki Noodmaatregelen Working Group as final client.

1.1.1 Definition of effectiveness

Emergency measures have a certain level of effectiveness. This level can be determined in different ways. Both Lendering (2014) and Dupuits (2011) define the effectiveness of an emergency measure as a reduced probability of failure of a levee. Lendering determines the effectiveness based on the reliability of the detection, design phases and the reliability of the actual construction of an emergency measure. These reliabilities lead to a reduced probability of failure for the levee. By dividing the reduced probability of failure with the initial probability of failure a factor is calculated for the effectiveness. Dupuits (2011) determines the effectiveness in a similar manner; the only difference is that he combines the probabilities for piping with a failed and a successful measure to get a reduced probability of failure, as can be seen in Figure 1.3. The effectiveness itself is expressed in a percentage of reduction of probability of failure.

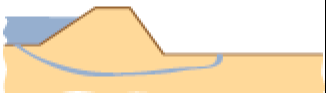
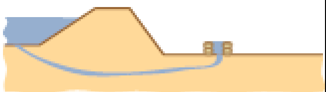
Situatie	Verval	Faalkans dijk piping	Faalkans opkisten	Totaal
Niet (succesvol) opkisten 	h	$P_{piping\ zonder\ kist}$	$P_{opkisten\ faalt}$	$P_{piping\ zonder\ kist} \cdot P_{opkisten\ faalt}$
Met opkisten 	$h - h_{kist}$	$P_{piping\ met\ kist}$	$P_{opkisten\ succes}$	$P_{piping\ met\ kist} \cdot P_{opkisten\ succes}$
Gecombineerde faalkans dijk door piping met opkisten				$\sum totaal$

Figure 1.3: Reduced probability of failure (Dupuits, 2011)

Even if an emergency measure is successfully implemented it is possible that the levee could fail (Figure 1.4). This can happen if another weak spot was missed during detection or due to adverse side effects of the emergency measure itself. An impoundment, for example, can cause another exit point of water to emerge if it is built to high and too much counter pressure is added by this.

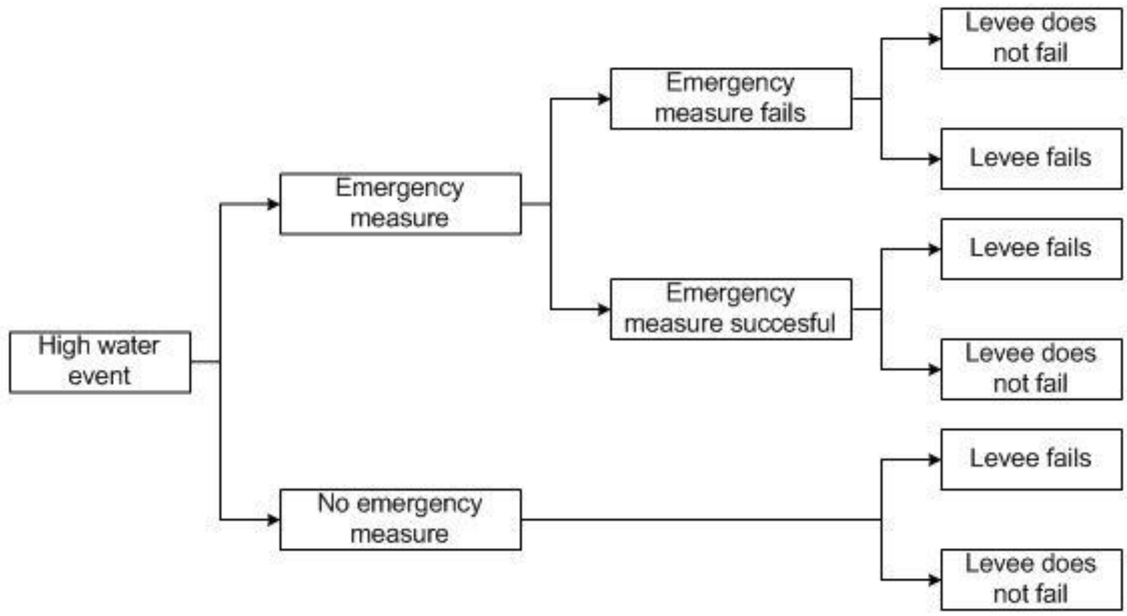


Figure 1.4: Event tree of the process concerning emergency measures

Three aspects are important for the effectiveness of an emergency measure (Lendering et al., 2014). The detection of the failure (1), the design of an emergency measure (2), and the implementation of the designed emergency measure (3). In this research the detection also includes the communication of the findings. Implementation is defined as the mobilisation of personnel, materials and machinery and the construction of the emergency measure. All of these aspects determine if an emergency measure functions or not. If all these aspects are done correctly according to instructions and sand transport is stopped, it can be concluded that this emergency measure is successful, but if one (or more) of these aspects are not executed properly the emergency measure may not work as required. However, it is difficult to determine if all aspects are executed properly, as there are no certified methods available for the execution of the 3 phases at this moment. All water boards use a slightly different approach for executing an emergency measure.

If these aspects are translated to the whole process from damage to a levee to execution of an emergency measure, as defined by the Wiki Noodmaatregelen work group, it can be said that observed damage (schadebeelden) and failure mechanisms (faalmechanismes) are part of the detection, while the choice of emergency measures (noodmaatregelen) and dimensioning (dimensionering) are part of the design. The construction (uitvoering) is part of the implementation.

In summary, the following definition of effectiveness is used in this research:

An emergency measure is deemed to be effective if the detection of a damage is done timely and communicated properly, the correct emergency measure is chosen based on the findings of the detection, and the emergency measure is properly designed and is implemented correctly conform the instructions. The implemented emergency measure has to stop the sand transport so that the levee including the emergency measure cannot fail.

1.2 Problem description

In January 2017 new safety standards for flood defences in the Netherlands were introduced. These new standards are based on the probability of flooding due to multiple failure mechanisms, instead of the probability of exceedance of a certain water level (ENW, 2017). With the introduction of these new standards various levees do not meet the assessment criteria anymore. These standards apply to the flood defences as they are at present, i.e. without any additional measures (emergency or control measures) that could be implemented to enhance their strength. The current Dutch safety standards do not provide any guidelines how such additional measures can be assessed. However, it is possible to treat the emergency measures as part of the flood defence in the safety assessment (VNK Office, 2012).

In order to include the emergency measures in the safety assessment, the probability of failure of these measures should be determined. The probability of failure for emergency measures depends on many different factors, such as: visibility during inspection, available materials and personnel, and the experience of personnel. What these factors exactly are and what the influence of these factors is on the probability of failure is not known yet.

Besides the aforementioned factors, the water boards have indicated that presence and use of work instructions for the construction of an emergency measure positively affects the quality of the measure. Based on meeting with the working group it can be said that not all waterboards have work instructions for emergency measures at the moment, and all water boards have slightly different ways of constructing them. The water boards want to create explicit and uniform work instructions for all the emergency measures, so that they can be assessed as effective.

1.3 Research scope

In this research the processes concerning the emergency measures will be divided into three phases: detection-, design-, and implementation phase. Although this research will touch on all the three phases, it will focus on the implementation phase; this phase consists of the mobilisation and the construction of an emergency measure. This choice is made because it is the most interesting one for the client and it is an important step in the failure of emergency measures. Besides, this choice confines the scope of the research and enables meaningful tests and observations. Three emergency measures are selected to be assessed, as there are too many emergency measures to do them all in the limited time frame of this master thesis. These three emergency measures are: the construction of an impoundment, raising the water level in the ditch behind a levee, and the placement of a filter construction. These measures were selected in a meeting with WDOD and in a meeting with the Wiki Noodmaatregelen Working Group. Both indicated these measures to be most interesting; especially raising the water level and the filter construction, for WDOD and WSRL respectively.

As mentioned above, the focus of the research is on the implementation phase, but the other two phases will be described as well. This has two reasons: first of all, the Wiki Noodmaatregelen Working Group expects the whole process to be covered by the research. The second reason is that the implementation phase is influenced by the detection and design phases, as the choice and design of an emergency measures is based on the findings of the detection phase. Because of this, the detection and design phases will be assessed during ‘Deining & Doorbraak’ (a national training exercise that simulates a high water event in 2017; this exercise will be explained further on in this report) and the subsequent workshops. This enables the possibility to assess the influence of detection and design on the implementation and it will satisfy the requests of the client.

Besides this, there are also some assumptions to be made to help creating a clear boundary for the research:

- When a sand boil is detected, it is assumed that this will grow up to a full pipe if no measure is taken.
- An emergency measure will be considered as failed when it is not constructed correctly, according to the instructions, and timely.

In practice these assumptions are not necessarily true, it can be the case that a pipe collapses due to the weight of the levee so that the piping process stops. But to be able to determine if a pipe will grow or not it is necessary to schematize detailed cross sections of levees; therefore many ground samples are needed. In most cases this is not financially feasible (Dupuits, 2011). It might also be possible that an incorrect constructed emergency measure still stops the sand transport, but this will create too many possibilities to consider in the timeframe of this research.

1.4 Research goal

This research focuses on the assessment of the effectiveness of emergency measures against piping and translating the findings of the assessment into recommendations for more robust work instructions to implement such measures. These recommendations may be seen as a first step to make work instructions uniform.

Based on the scope the goals of the research can be defined as:

"To assess, evaluate and improve work instructions for the implementation of three emergency measures against piping"

To properly reach that goal the following steps are defined:
1. Analysis of the current process of implementation based on existing work instructions.
2. Analysis and evaluation of the observed mobilisation process of the emergency measures.
3. Analysis and evaluation of the observed construction process of the emergency measures.
4. Analysis of possible weak spots in the processes and translation of these weak spots into recommendations to improve the work instructions.
5. Analysis of the effect of the improved work instructions on the probability of failure.

1.5 Methodology

This research is divided into several steps (Figure 1.5). In this section the different parts of the research will be further explained.

1.5.1 Theoretical background

The first step of the research is to form a theoretical background. This consist of three parts: an overview of the piping process, an explanation of the three emergency measures that will be discussed in this report with their current work instructions, and a description of the calculation of the probability of failure for levees. These theoretical background serves as a base for the initial framework.

1.5.2 Initial framework

The three phases that are defined in the definition of effectiveness (detection, design and implementation) must be executed properly for an emergency measures to be effective. These three phases are influenced by many different factors and the reliability of these factors is either dependent on human actions or not. In the initial framework these three phases will be further divided in the sequence of events that make up the process concerning the emergency measures. This will be visualised using event trees. All the factors influencing these events will be divided in two categories: factors that can, and factors that cannot be influenced by the water boards.

The data gathered in the observations during D&D and a training day at WDOD, interviews with contractors, and a workshop with 6 water boards and the “crisisteam waterkeringen” (CTW) will provide an insight on the importance of the identified factors. During D&D and the training day the actions of the personnel in the field were observed. Participants of the workshop were experts in water safety. Their input can also be used to update the framework and make it more accurate. The initial framework will be used to come to requirements for work instructions. These requirements will be used to analyse the current work instructions and make adjustments to them.

1.5.2.1 Deining & Doorbraak (D&D)

D&D was a national exercise in 2017 in which six water boards simulate a high water event to test their crisis organisations, including emergency response. During this exercise the detection of failure mechanisms and the construction of emergency measures against piping, among other emergency measures, were observed. To collect data from these observations, two observation forms were developed in collaboration with Guido van Rinsum, a master student from TU Delft who conducted a research on the effectiveness of emergency measures against erosion of grass revetments for the same Wiki Working Group. The observations are used to collect data concerning the detection, design and implementation phases and were used to detect weak spots in the process.

Besides the data collected during the observations, data from the application used by the dike watch to report findings is also used as input for the analysis of the detection. The data give an indication how effective the current way of inspecting the levees is, as it shows how many incidents were found and how many were missed by the dike watch.

1.5.2.2 Interviews

To get a better understanding of the mobilisation of materials, machinery and personnel, and the construction of emergency measures, interviews with four contractors were conducted. From within WSRL the contractors Tromp BV and BV Koek, and from within WDOD Mulder-Eykelkamp and Netjes Kampen are contacted.

The questions that are asked to the contractors are annexed in appendix II. The questions focus on the processes concerning the mobilisation and construction of the emergency measures and the answers will help to identify factors that influence the process and their importance. The importance of factors give an indication of which factors should get a priority over other factors.

1.5.2.3 Workshops

The different water boards have different approaches to the processes concerning emergency measures. To get a better understanding of these different approaches and to get expert opinions on the importance of the different factors of the framework two workshops were conducted. These workshops were held with participants of six different water boards and CTW. During these workshops the whole process from detection to implementation of an emergency measure was covered by means of several questions. Some questions focussed on factors that influence a part of the process and how important these factors are, other questions focussed on a more in-depth analysis for a specific part of the process within the water boards. The answers to these questions help to determine the importance of several factors influencing the processes concerning the emergency measures. It will also show the different approaches the water boards have and to assess if and how processes can be improved.

1.5.3 Adjustments to work instructions

The current work instructions will be analysed with the help of the requirements of the work instructions. The requirements are based on the gathered data from the previous steps. With these requirements information gaps in the work instructions will be identified. Possible adjustments to fill these gaps will be discussed as well as the effects these adjustments will have on the reliability of the work instructions.

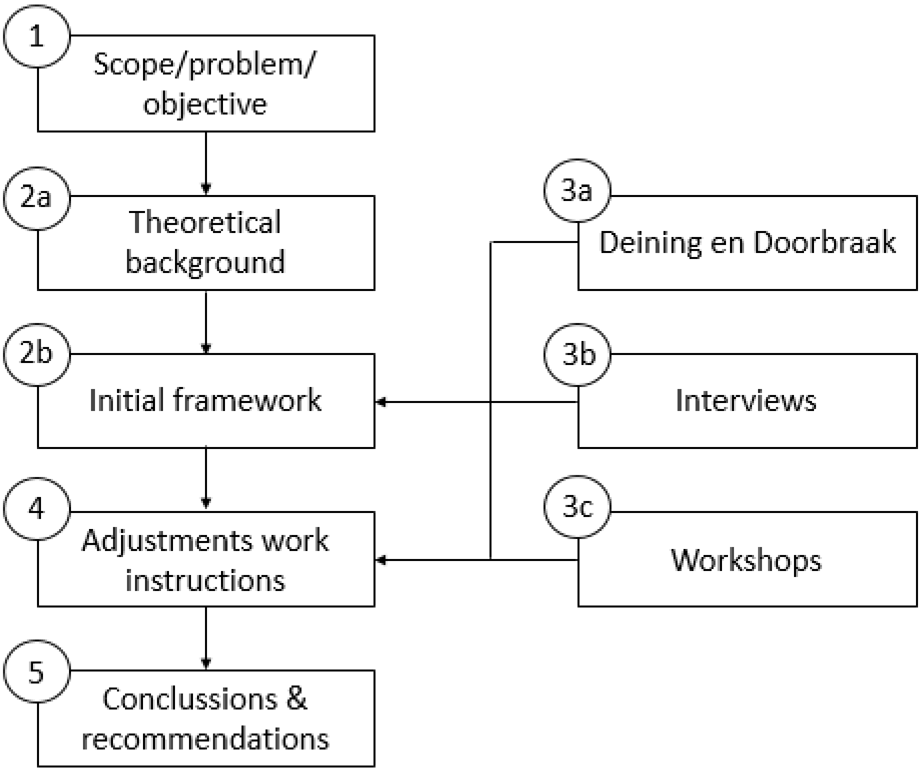


Figure 1.5: Methodology

1.6 Reading guideline

In Figure 1.5 the general structure of this research report is given. The first chapter is an introduction to the problem and the scope of the research. In chapter two a theoretical background is given and an initial framework is constructed. This framework is based on the theoretical background and the observations during Deining & Doorbraak. In chapter three the results of the data gathering are discussed and based on this data. Chapter four will address the adjustments to the work instructions and the effect the adjustments have on the probability of failure Chapter five and six will cover the discussion, conclusions and recommendations of this research. The contents of the different parts of the research will be further explained in the following sections.

2 Theoretical background

2.1 General

To get a better overview of what has been done already in this field of research a literature study has been conducted. This study focuses on three aspects: (1) a clear overview of the piping process, (2) an overview of the possible emergency measures against piping and of appropriate work instructions, and (3) a description of how the probability of failure of a levee is currently calculated in the Netherlands and how this can be done for emergency measures. Besides the literature study an initial framework will be constructed in this chapter. Based on the literature and the initial framework, requirements for work instructions will be made.

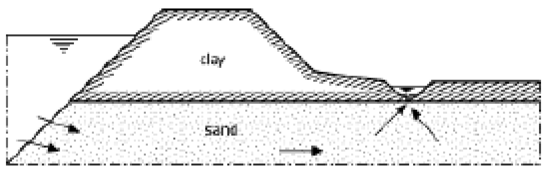
2.2 Piping process

Piping is a failure mechanism for levees and for other hard hydraulic structures. It is a form of internal erosion created by a water flow in the sand layer underneath the impermeable layer of a levee. The water flow can take away sand particles under the levee creating a pipe. Piping can occur when the following criteria are met:

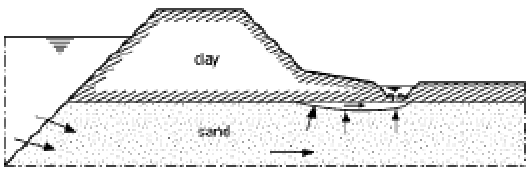
1) There has to be a sufficiently large difference in water level between the river, lake, or sea and the hinterland of the levee.
2) Piping can only occur in granular, permeable layers. Erosion in clay or peat layers are not called piping but are categorized as other forms of internal erosion.
3) Piping can only occur when there is also uplift and/or heave.

Piping does not occur spontaneously, but it is a process of several stages before the actual pipe forms and eventually leads to levee failure (de Bruijn, 2013), (Schweckendiek et al., 2014). The first stage is the rising of the water level; this creates a water pressure difference between the water outside the levee and the polder water level, which in turn creates a groundwater flow. If a levee is not directly founded on sand but on top of a (semi)impermeable layer, the flow might be difficult to detect. If the water pressure under an impermeable layer is higher than the weight of the top layer itself, the impermeable layer will be lifted up from the sand layer, this process is called uplift. The pressure causes the impermeable layer to crack open, creating an exit point for the water. Water will start to flow upwards through this crack in the impermeable layer. If there is no cohesive layer on top of the aquifer (the water bearing sand layer) the upward flow of water can decrease the contact forces between the granular materials, a kind of quicksand can be created if the contact forces approach 0. This process is called 'heave' (Förster et al., 2012).

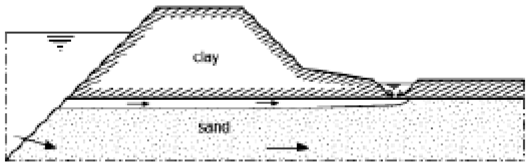
In the second stage the water pressure rises even further, sand boils can become visible at the point where the water exits the impermeable layer. This is the start of the creation of pipes; these pipes will form on top of the sand layer, directly underneath the cover layer and will start to grow towards the outside of the levee. This is called piping. If the water level outside the levee does not subside and the pipe does not encounter any obstacles, the pipe will eventually reach the outside of the levee. This is stage three. From that point on that the pipe reaches the entry point of the pipe hydraulic short-circuit occurs. At this point there is a full pipe underneath the levee and this will start growing wider from the outside toward the inside of the levee. The time it takes to form the entire pipe and to widen it so that the levee will fail is not known exactly. This is because it is highly dependent on the cross section of the levee and changes in the water level (de Bruijn, 2013). In Figure 2.1 below a schematized view is given for all the stages of piping.



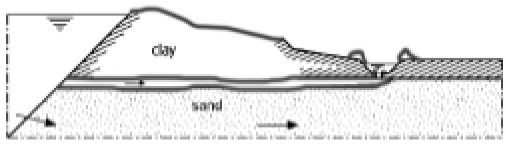
1. Blanket cracks and water starts to flow out.



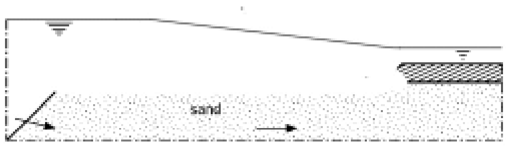
2. Sand starts to wash out.



3. The piping channel forms from inner to outer side.



4. The levee starts to collapse due to the piping channel.



5. The levee is breached.

Figure 2.1: Stages of the piping process (Schweckendiek et al., 2014)

2.3 Emergency measures

In order to check the flood defenses regarding possible failure, onsite inspections are performed. This is done prior to the storm seasons, and in the days before and during a peak discharge the inspections are intensified. In case of piping in river dikes water boards have about 96 hours to detect a possible failure and to place an emergency measure. This assumption is made based on interviews with water boards for the report of (Lendering et al. 2014). The water boards in the Netherland in general have three options for the inspection of dikes; a group of volunteers called the ‘dike watch’, the ‘district’ who is responsible for the maintenance of a certain area of the water board, or the ‘supervisors’ who are responsible for the monitoring and maintenance of the whole water board area (Lendering et al., 2014). For each of the water boards it is different which of these options is used and when the different parties are involved, thus the skills and expertise for detecting piping will differ between water boards.

When field observations show a weak spot in a flood defense, such as seepage or a sand boil, emergency measures can be implemented to stop the transport of sand. Emergency measures against piping in general have two possible functions: (1) to provide a counterweight on the inner side of the levee to prevent uplift or (2) to provide counter pressure by reducing the hydraulic head to prevent heave and backward erosion (Lendering et al., 2014)

The effectiveness of the measures depends on when the sand boil is detected, if the measures are placed in time to prevent further degradation, and if the measure is constructed correctly. If only one of these elements fails the whole emergency measure will fail (Schweckendiek et al., 2014). As mentioned in the scope of the research three emergency measures are selected. These emergency measures will be explained in more detail in the following subsections.

2.3.1 Constructing an impoundment

When a sand boil is detected it is possible to place sandbags around it ("opkisten" in Dutch). The sandbags will create an impoundment, in this impoundment the water level will rise. When the water level rises, the hydraulic head difference across the levee is reduced for this particular pipe and the flow of water will be reduced as well. The reduced flow of water will also prevent sand from being transported and thus will prevent the pipe from growing larger. It is also possible to place a geotextile on top of the sand boil before placing the sandbags. The geotextile will stop the sand transport but will allow water to pass. Whether a geotextile must be used or not is still a point discussion. The geotextile will stop sand transport, but it also will block the sight on the damage and it also possible that the sand will flow out from underneath the geotextile. By not making use of a geotextile it will be possible to actually see when the sand transport is stops. The best option still has to be examined.

It is also possible to build an impoundment in the ditch behind the levee if a sand boils occurs there. The water level in a part of the water way will be set up to create a counter pressure, but the water will still be able to flow through the ditch. (Waterschap Rivierenland, 2017)

Some difficulties with this measure are:

- If the sandbags are stacked too high it is possible to increase the counter pressure too much and create new sand boils outside the impoundment.
- It is very difficult to use this technique in wooded areas as the water will easily find another route due to all the roots.

Figure 2.2: Impoundment on land (Wiki Noodmaatregelen, 2017)(left) and in a ditch (Waterschap Rivierenland, 2017) (right)

Work Instructions for constructing an impoundment

Work instructions for constructing an impoundment are released by WSRL and available at the Wiki website. They are mainly focused on the way sandbags are placed. They also give an indication on how many sandbags are needed to create an impoundment. The steps in these instructions are stated below (Waterschap Rivierenland, 2017).

Before the steps to construct the different emergency measures are explained the work instructions give a small explanation on the cause and effect of piping, possible damages and corresponding choices for emergency measures. This is shown in Figure 2.3.

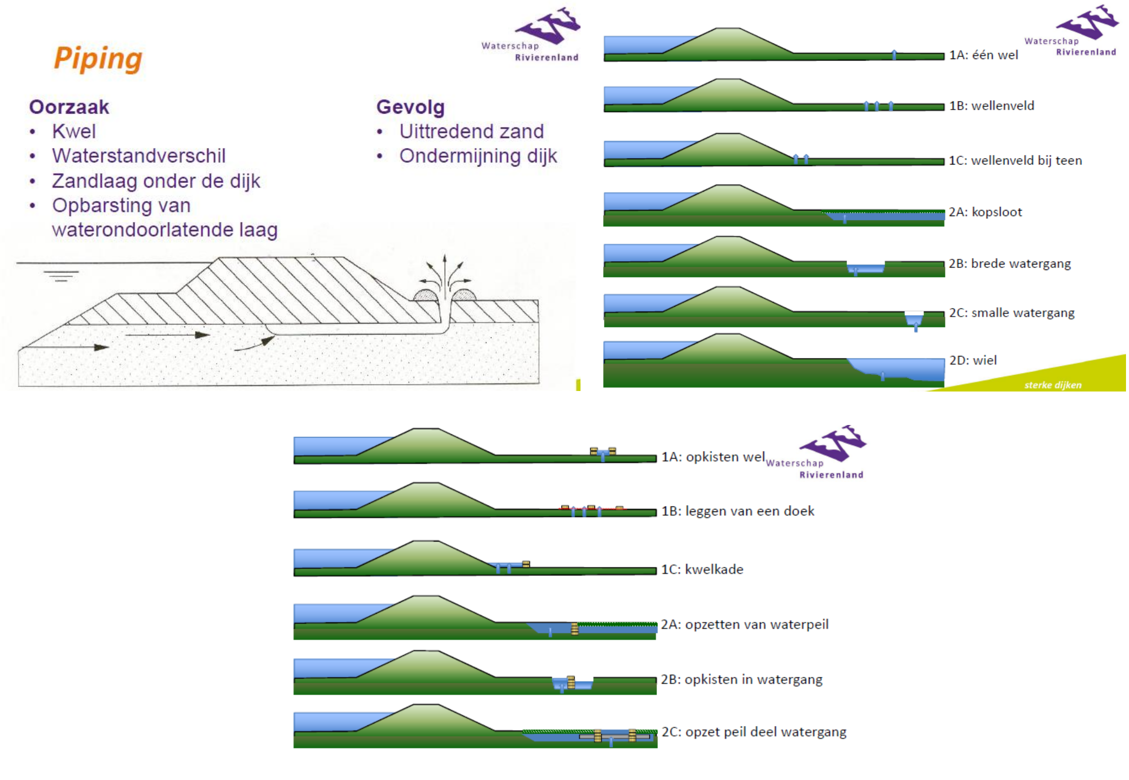


Figure 2.3: Examples of introduction presented in work instructions by WSRL

In the following section the steps in the work instructions for the construction of an impoundment are discussed in more detail.

1 Determine the needed number of sandbags for the emergency measure: Table 2-1. Based on the length and height of the needed structure it can be determined how many sandbags are needed to construct the measure.

Table 2-1: Needed sandbags for given height and length (Waterschap Rivierenland, 2017)

hoogte [zakken]	Hoogte [m]	1	2	3	4	5	6	7	8	9	10
		<= lengte van de zandzak constructie [m] =>									
1	0,15	10	20	30	40	50	60	70	80	90	100
2	0,3	15	30	45	60	75	90	105	120	135	150
3	0,45	20	40	60	80	100	120	140	160	180	200
4	0,6	25	50	75	100	125	150	175	200	225	250
5	0,75	30	60	90	120	150	180	210	240	270	300
6	0,9	45	90	135	180	225	270	315	360	405	450
7	1,05	55	110	165	220	275	330	385	440	495	550
8	1,2	65	130	195	260	325	390	455	520	585	650
9	1,35	75	150	225	300	375	450	525	600	675	750
10	1,5	95	190	285	380	475	570	665	760	855	950
11	1,65	105	210	315	420	525	630	735	840	945	1050
12	1,8	115	230	345	460	575	690	805	920	1035	1150
13	1,95	125	250	375	500	625	750	875	1000	1125	1250

<= hoogte van de zandzak constructie =>

The height of the impoundment will differ from case to case; an initial estimation can be made based on the expected water level that is needed to provide the counter pressure. The actual height of an impoundment is determined in the field and is based on the flow of sand.

2 Placement of the first layer of sandbags: Figure 2.4. The bottom layer of an impoundment should be at least two sandbags wide, to prevent water passing underneath the sandbags and to create a stable foundation for other layers. The sandbags in this layer should overlap each other, just like roof tiles.

Figure 2.4: Placement of first layer of sandbags (Waterschap Rivierenland, 2017)

3 Placement of the additional layers of sandbags: Figure 2.5. The sandbags in these layers should be placed in a brick pattern on top of the first layer, this creates a stable connection between the sandbags in the layer. The number of layers has to be increased until the sand transport is stopped.

Figure 2.5: placement of additional layers of sandbags (Waterschap Rivierenland, 2017)

4 Securing the sandbags: Figure 2.6. Every layer of sandbags should be secured to create a stable construction; this can be done by putting a load on the sandbags (for example by stamping on them).

Figure 2.6: Securing the sandbags (Waterschap Rivierenland, 2017)

If these work instructions are coupled with the steps in the process it can be determined what information is used in which step. This is shown in Table 2-2.

Table 2-2: Information in work instruction for impoundment

Damage	Failure mechanism	Emergency measure	Design	Implementation
Brief overview of different damages	General effects of damages	Choices of emergency measure for different damages	Needed amount of sandbags for given height and length (given in a table) Cross-sections of stacked sandbags for different heights	Points of interest for mobilisation in form of question that need to be answered by personnel Steps to construct impoundment Points of interest during construction (staggered stacking of sandbags and 'kont op stik')

2.3.2 Raising water level

By building a dam in the ditch behind the levee the water level inside this ditch will raise, Figure 2.7. This measure is used when a sand boil, or multiple sand boils, in a ditch occurs (Waterschap Rivierenland, 2017). This emergency measure has the same effect as placing sandbags around a sand boil on land, but the scale of the effect is larger, as it will raise the water pressure along the whole length of the ditch. The added water pressure will reduce the water flow underneath the levee and thus will reduce the transport of sand or prevent it from happening. This measure can also be used as a control measure, by raising the water level before the high water arrives and preventing any sand boils from occurring.

Figure 2.7: Raised water level (Wiki Noodmaatregelen, 2017)

Work instructions for raising the water level.

The work instructions for raising the water level in ditch are also provided by WSRL. The level of detail of the instructions differs from that of the other instructions. They simply state: stack sandbags as is described in the instructions for an impoundment. However, the actual execution of the measure is not as simple as the instructions describe because they do not account for the water. Water in a ditch affects the visibility and thus how sandbags are being stacked.

2.3.3 Constructing a filter construction

A filter construction has the same effect as the placement of a geotextile that can be used with an impoundment, only in this case there is no use of water pressure to stop the flow. It is possible to use this measure when multiple sand boils occur close to each other. A piece of geotextile is placed over the sand boils and this is held down with sandbags, on top of the geotextile a layer gravel is placed. Water will be able to pass through this filter, but the transport of sand is prevented (RWS, Deltares, Blueland Consultancy, 2015).

Figure 2.8: Filter construction (Waterschap Rivierenland, 2017)

Work instructions for constructing a filter construction

Instructions for this measure are also released by WSRL. They consist of the steps that need to be taken to construct the measure and give some indication on how much material is needed dependent on the required size of the filter.

1 Determine the needed surface of the geotextile, the needed number of sandbags and needed amount of gravel. Both the number of sandbags and the needed amount of gravel are dependent of the surface area of the geotextile, as can be seen in the tables below.

Table 2-3: Needed amount of sandbags per surface area geotextile (Waterschap Rivierenland, 2017)

Aantal zandzakken		<= lengte van het doek [m] =>											
		4	6	8	10	12	14	16	18	20	22	24	26
<= breedte van het doek [m] =>	2	34	48	62	76	90	104	118	132	146	160	174	188
	3	45	63	81	99	117	135	153	171	189	207	225	243
	4	56	78	100	122	144	166	188	210	232	254	276	298
	5	67	93	119	145	171	197	223	249	275	301	327	353
	6	78	108	138	168	198	228	258	288	318	348	378	408
	7	89	123	157	191	225	259	293	327	361	395	429	463
	8	100	138	176	214	252	290	328	366	404	442	480	518
	9	111	153	195	237	279	321	363	405	447	489	531	573
	10	122	168	214	260	306	352	398	444	490	536	582	628
	11	133	183	233	283	333	383	433	483	533	583	633	683
	12	144	198	252	306	360	414	468	522	576	630	684	738

Table 2-4: Needed amount of gravel (m^3) per surface area geotextile (Waterschap Rivierenland, 2017)

m3 grind		<= lengte van het doek [m] =>											
		4	6	8	10	12	14	16	18	20	22	24	26
<= breedte van het doek [m] =>	2	0,9	1,4	1,8	2,3	2,7	3,2	3,6	4,1	4,5	5,0	5,4	5,9
	3	1,4	2,0	2,7	3,4	4,1	4,7	5,4	6,1	6,8	7,4	8,1	8,8
	4	1,8	2,7	3,6	4,5	5,4	6,3	7,2	8,1	9,0	9,9	10,8	11,7
	5	2,3	3,4	4,5	5,6	6,8	7,9	9,0	10,1	11,3	12,4	13,5	14,6
	6	2,7	4,1	5,4	6,8	8,1	9,5	10,8	12,2	13,5	14,9	16,2	17,6
	7	3,2	4,7	6,3	7,9	9,5	11,0	12,6	14,2	15,8	17,3	18,9	20,5
	8	3,6	5,4	7,2	9,0	10,8	12,6	14,4	16,2	18,0	19,8	21,6	23,4
	9	4,1	6,1	8,1	10,1	12,2	14,2	16,2	18,2	20,3	22,3	24,3	26,3
	10	4,5	6,8	9,0	11,3	13,5	15,8	18,0	20,3	22,5	24,8	27,0	29,3
	11	5,0	7,4	9,9	12,4	14,9	17,3	19,8	22,3	24,8	27,2	29,7	32,2
	12	5,4	8,1	10,8	13,5	16,2	18,9	21,6	24,3	27,0	29,7	32,4	35,1

2 Place a roll of geotextile on the ground and put a load over the width of the geotextile with sandbags in such a way that no wind can come underneath it.
3 Unroll the geotextile and place sandbags over the length of the cloth in such a way that no wind can come underneath it.
4 Place sandbags on the end of the geotextile.
5 Create squares of 3 × 3 metre with sandbags on the geotextile.
6 Fill the squares with gravel to create a load on the entire geotextile.

Similar to the construction of an impoundment a table can be made to link the information of the work instructions to the process of implementing an emergency measure, as can be seen in Table 2-5. The first three columns are the same, as both work instructions come from the same document.

Table 2-5: Information in work instructions for a filter construction

Damage	Failure mechanism	Emergency measure	Design	Implementation
Examples of different damages	Effects of damages	Choices of emergency measure for different damages	Needed amount of sandbags for given dimension of geotextile Needed amount of gravel for given areas of geotextile	Points of interest for mobilisation in form of question that need to be answered by personnel Steps to construct filter

				Points of interest during construction (unroll geotextile downwind)

2.4 Probability of failure of emergency measures

The probabilities of failure (PoF) for all the levees in the Netherlands are assessed regularly by law. Within these probabilities the influence of emergency measures is not taken into account. For taking emergency measures into account when assessing a levee two criteria have to be met: (1) there have to be procedures for human interventions with a minimum level of reliability and these procedures have to be followed, (2) the emergency measures themselves have to be checked in the same way as other elements of the levee (Vrijling et al., 2010).

The emergency measures themselves also have a PoF and can fail because of issues in process of detection, design or implementation of the measure. This can be seen as a series system: if the detection fails, the emergency measure will fail regardless of design and implementation, as can be seen in Figure 2.9 (Jonkman, Dupuits, & Havinga, 2013). This can be linked back to the definition of the effectiveness given in the introduction. If the detection is not done properly the emergency measure will fail and thus will not be effective, the same can be said about the implementation. The design of the emergency measure can be placed between the detection and placement, although Jonkman et al. (2013) do not include this in their analysis it is also a phase where the emergency measure can fail, for example when the wrong emergency measure is chosen, or when the dimensions are determined incorrectly.

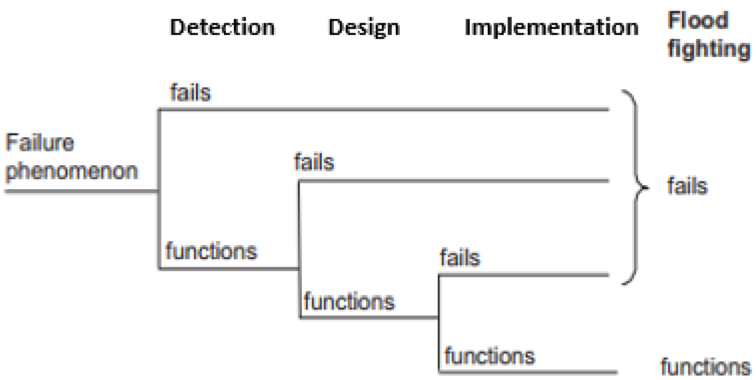


Figure 2.9: Event tree for flood fighting (Jonkman, Dupuits, & Havinga, 2013)

The PoF of an emergency measure can be calculated with the following formula (Jonkman et al., 2013):

$$P_{EM} = 1 - (1 - P_D)(1 - P_{Ds})(1 - P_I)$$

With:
$P_{EM} = probabilty\ of\ failure\ of\ the\ emergency\ measure$
$P_D = probability\ of\ failure\ of\ detection$
$P_{Ds} = probability\ of\ failure\ of\ design$
$P_I = probability\ of\ failure\ of\ implemtation$

The flood defences have an initial PoF and the addition of an emergency measure lowers this probability. This means that a levee can still fail even if a measure is applied. The probability of failure of a flood defence with a measure can be calculated with the following formula.

$$P_f = P_{EM} \cdot P_{f|no\ EM} + (1 - P_{EM}) \cdot P_{f|EM}$$

With:
$P_f = Probability\ of\ failure\ levee$
$P_{EM} = Probability\ of\ failure\ of\ emergency\ measure$
$P_{f|no\ EM} = Probability\ of\ failure\ of\ levee\ without\ emergency\ measure$
$P_{f|EM} = Probability\ of\ failure\ of\ levee\ with\ emergency\ measure$

As can be seen in this formula the PoF of a levee consists of two components. The first component ($P_{EM} \cdot P_{f|no\ EM}$) is the probability given that the implementation of an emergency measure is unsuccessful combined with the probability that the levee fails. The second component ($(1 - P_{EM}) \cdot P_{f|EM}$) is the probability that the implementation of an emergency measures was done successfully combined with the probability the levee fails. In this research only the PoF of the emergency measure (P_{EM}) itself will be discussed, the effect the emergency measure has on the safety of the flood defence will not be regarded.

The PoF of an emergency measure is influenced by many different factors. These factors can be categorized in two categories: factors that can or cannot be influenced by the water boards. The factors that can be influenced by the water boards are largely dependent on human performance. A more detailed description of the different factors is given in chapter 2.5.

For the factors that are dependent on human performance the probability of doing the correct actions of the personnel must be quantified, this is difficult however as it will differ from person to person. However, it is possible to estimate the probability of failure of human performance using the bandwidths from (Bea, 2002), shown in Figure 2.10. This method of quantifying human errors is crude, as it gives a range for a PoF, and the actual probability might differ in practice.

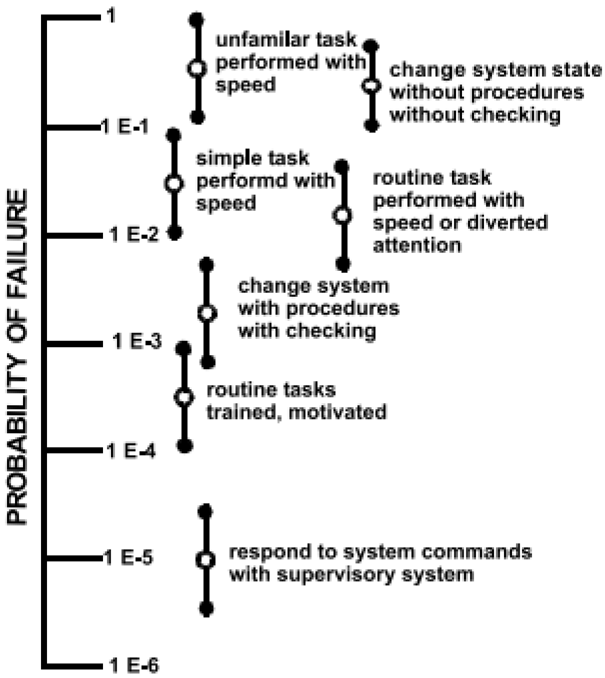


Figure 2.10: Nominal human task performance reliability (Bea, 2002)

According to Rasmussen (1983) human tasks can be divided into three categories. Each of these categories can also be quantified using bandwidths (Bea, 2010). The three categories are: knowledge based tasks, rule based tasks, and skill based tasks. This is shown in Figure 2.11. Knowledge based tasks are the most cognitive demanding; these tasks are performed in new situations with no pre planned actions available. Rule based tasks respond to a familiar situation with standardized rules to follow. Skill based tasks are the least cognitive demanding; they are performed often so that knowledge retrieval and actions are done almost automatically.

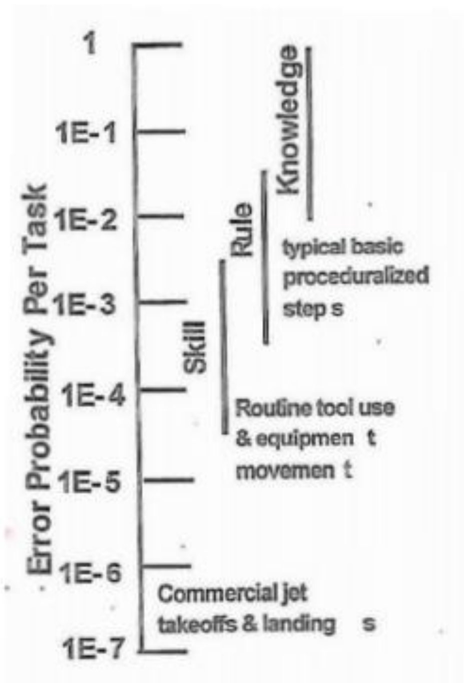


Figure 2.11: Relation human error probabilities and performance level by Watson end Collins (Lendering et al. 2014)

It is possible for organizations to mitigate the probability of human errors by using the following steps as stated by Bea (in Lendering et al., 2013):

- Command by exception or negation to push authority to the lower levels of the organization;
- Procedures and rules that are correct, complete, well organized and documented, and not excessively complex;
- Training for normal and abnormal conditions;
- Appropriate rewards and punishments;
- Ability of management to see the big picture to perceive the important developing situations.

As already mentioned, emergency measures can also fail due to factors that are not dependent on human influence, such as the quality of materials, the accessibility of the site for heavy machinery, availability of personnel, the use of damage registration forms or application and many others. Some of these factors, such as the accessibility of the site, may differ from case to case, and from water board to water board, other factors may themselves be depended on other factors. The availability of personnel, for example, can be influenced by sickness or evacuations. It is difficult to quantify the probability of failure for these factors in a similar manner as factors that are depended on human reliability. In the current literature nothing is written about it.

2.5 Initial framework

Based on the definition of effectiveness, the literature and observations during D&D an initial framework is constructed. In the framework all the steps concerning the process of placing an emergency measure are visualized in event trees. The three phases that are stated in the definition of effectiveness (detection, design, and implementation) are further divided into events. All the factors that influence these steps are also visualised in an influence diagram. The influence diagram shows the interrelationship between the different factors and the steps in the event tree. These factors can be placed into two categories: factors that are influenced by human performance and factors that are not.

2.5.1 Event trees

In Figure 2.12 the event tree of the detection phase is shown. Within this section there are four events that are affecting the effectiveness of the emergency measures: whether or not an inspection of the levee is done, if there are any damages observed during this inspection, how the initial assessment of the damage is done, and how these findings are communicated.

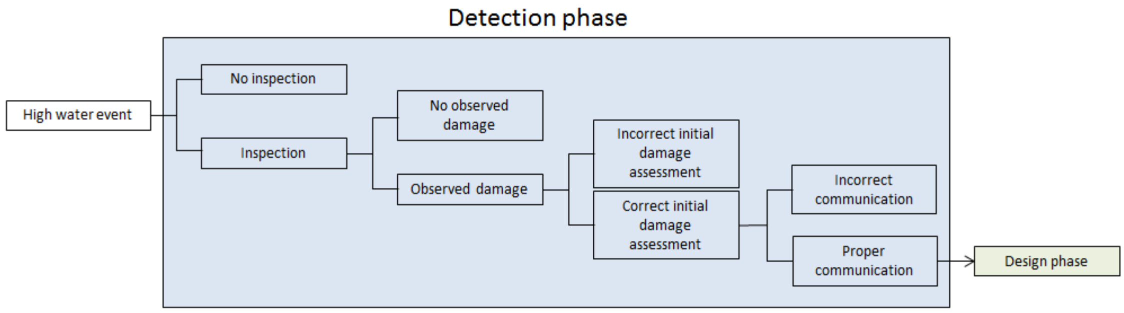


Figure 2.12: Event tree detection phase

After the detection phase the design phase is started, this phase also consists of four events, Figure 2.13. The way the information, obtained during the inspection, is interpreted. This interpretation includes matching the right failure mechanism with the observed damage and determining how severe the found damage is. The other events are: the correct choice of an emergency measure, based on the provided information and if the correct dimensions are determined, and the manner in which the design of the chosen emergency measure is communicated to the executing party.

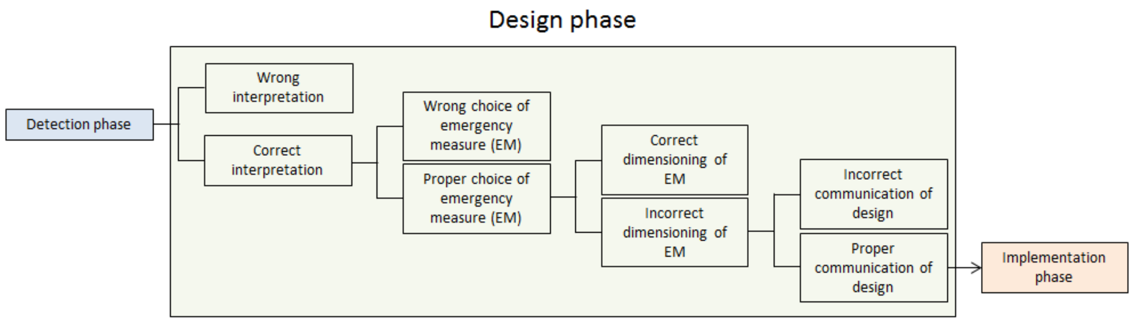


Figure 2.13: Event tree design phase

The last phase is the implementation phase; the event tree of this phase can be seen in Figure 2.14. This phase can be further divided into two sub-phases; the mobilisation and the construction. The mobilisation consists of the mobilisation of materials, machinery and personnel, and gaining access to the site of the damage. The placement of the emergency measure falls in the sub-phase construction. For this sub-phase it is possible to expand the event tree further for each specific emergency measure, this are the steps in the work instructions.

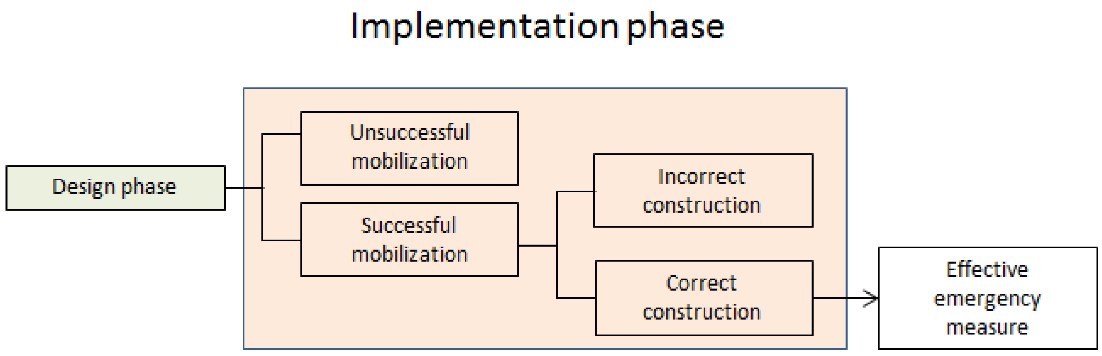


Figure 2.14: Event tree implementation phase

2.5.2 Influence diagram

The use of event trees is a simple method to describe the whole process concerning the emergency measures. They only allow two options; an event is executed successfully or not, in reality this will not be the case as is explained in the scope of this research. Besides, event trees will grow rapidly if more factors are taken into account. To get a more realistic view of the occurring process an influence diagram is made, see Figure 2.15. The red aspects are environmental factors and cannot be influenced by the water boards or other parties. The blue circled factors, however, can be directly influenced by the water board. The factors in black are different for every situation, for example the location and severity of the damage and the available materials at the moment the damage is detected. The square nodes correspond with the events in the event trees.

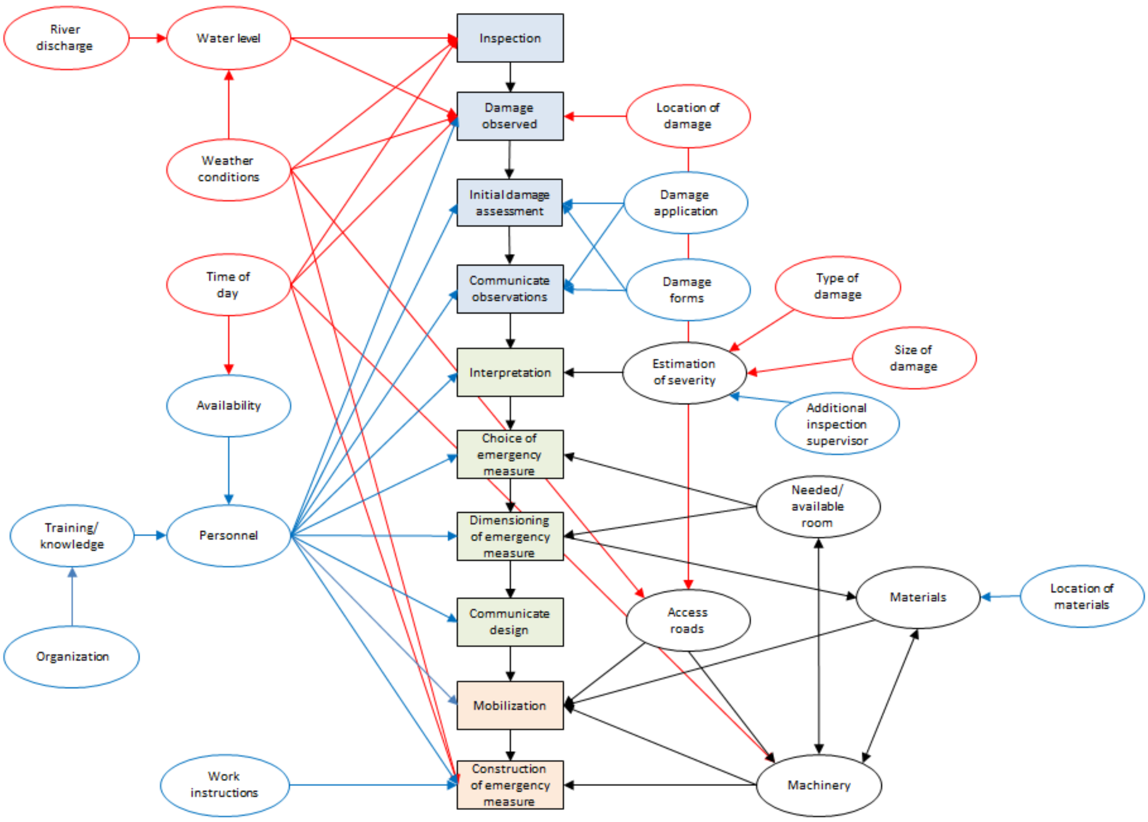


Figure 2.15: Influence diagram emergency measure

From this influence diagram follows that environmental factors play an important role in the process; they influence the detection of a possible failure and the execution of the emergency measure. This is also confirmed by the observations from the D&D exercise; it was almost impossible to detect anything during the patrols at night. However, it is not possible for the water board to change anything about the environmental factors. An important factor that the water boards can influence is the personnel they mobilise. Well trained personnel are more likely to detect possible failures and construct emergency measures properly even if environmental conditions are bad. In below Table 2-6 all the nodes in the influence diagram are explained.

Table 2-6: Description influence diagram

	Node name	Description
Sub-events		
	Inspection	Is an inspection of the levee done?
	Damage observed	Is there any damage to the levee observed during this inspection?
	Initial damage assessment	What is the initial assessment of the detected damage by the dike watch?
	Communicate observations	How much and what information is passed on by the inspection teams to the 'Actie Centrum Water' (ACW)?
	Interpretation	How is the available information interpreted?
	Choice of emergency measure	Which emergency measure is chosen?

	Dimensions of emergency measure	What dimensions for the chosen emergency measure are needed, based on the provided information.
	Communicate design	The way and extend the design is communicated to the executing party.
	Mobilization	The collection of materials, machinery and personnel needed for the construction of the designed emergency measure.
	Construction of the emergency measure	The way the emergency measure is constructed.

	Node name	**Description**
Non -influenceable factor		
	River discharge	The discharge of the river.
	Water level	The water level in the river.
	Time of day	The time of day the inspection of an levee or the construction of an emergency measure takes place.
	Weather conditions	The weather conditions during the inspection or construction.
	Location of damage	Is the damage easily detected or not?
	Type of damage	What type of damage is observed during the inspections?
	Size of damage	How big is the observed damage?
	Needed/available space	The amount of space that is needed to unload the materials and construct the emergency measure versus the amount of space that is available at the location of the damage.
	Access roads	What is the condition of the roads that are needed to access the location of the damage?
Influenceable factors		
	Damage forms	Do the inspection teams have any damage forms with them during the inspection?
	Damage application	Do the inspections teams have digital means of reporting their findings?
	Additional inspection supervisor	Is there an additional inspection of the reported damage by a supervisor to get an expert opinion?
	Availability	Is there sufficient personnel available for the inspections or implementation?
	Training/knowledge	How much training and knowledge do the parties have?
	Organization	From which organization is the personnel?
	Personnel	How much experience and knowledge do the involved parties have?
	Work instructions	Are work instructions used during the construction of the emergency measure?

	Location of materials	The location were the needed materials are stored.
	Estimation of severity	How severe is the reported damage?
	Materials	What materials are needed for the implementation of the emergency measure?
	Machinery	What machinery is needed to unload the materials and construct the emergency measure?

2.6 Requirements for work instructions

Using the initial framework, the literature, and observations during D&D, requirements for work instructions can be made. With these requirements it becomes clear which parts of the work instructions are sufficient and which parts of the instructions should be altered. The work instructions need to support decisions concerning the design and implementation of emergency measures. The requirements consist of two aspects: (1) the actual content of the work instructions and (2) the design of the work instructions. In this section the requirements will be explained.

Before the requirements can be made it is important to determine what part of the process the work instructions should cover. Looking at the process different users for different phases can be identified. The identification of damages and corresponding failure mechanisms is done by personnel of the water boards in the field. The choice of emergency measure is either done by personnel of the water boards at the office or at the dike post. The dimensioning is done by the water boards at the office, or by the executing personnel in the field, if conditions have changed when they arrive, and the construction is done by contractors or personnel from the water boards or a combination of the two. The work instructions are intended for the last two steps, the dimensioning and the implementation of the emergency measures (Figure 2.16). Although only two steps of the process are covered by the work instructions, it is important that the information passed on from the first three steps is correct. If the information is not verified by the executing party an emergency measure might be constructed that is not suitable for the situation.

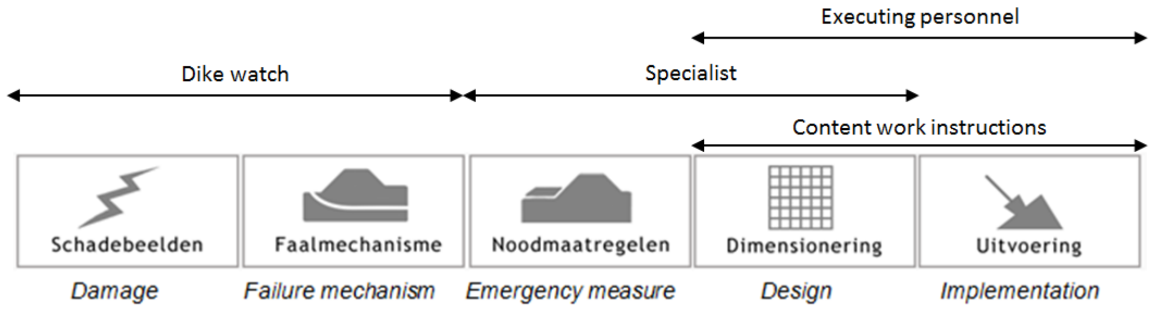


Figure 2.16: Part of the process covered by the work instructions

The work instructions should help the executing party to construct an emergency measure quickly and safely, and it should minimize the probability of failure of the emergency measure. It is important that the instructions are understandable and user friendly so that they can be used quickly regardless of the knowledge and experience of the user (2). This can be achieved by using explanatory images instead of a lot of text.

Looking at the initial framework and the steps that must be covered by the work instructions, the following four sub-events must be included in the work instructions (1): dimensioning of the emergency measure, communicating the design, mobilisation, and construction of the emergency measure. Besides the above-mentioned conditions there are also some requirements for the content of the work instructions. All the factors that influence the aforementioned steps of the process should be included in the work instructions and it should be clear how they must be dealt with as these factors influence the probability of failure of the emergency measure. These requirements can be seen in textbox 2-1. The content stated in this textbox relate to the (non)-inluenceable factors with are explained in paragraph 2.5.2. For example; the sub event mobilisation is influenced by the factors access roads, machinery, materials, and personnel. The access roads and machinery themselves are influenced by the weather conditions and time of day respectively. The work instructions should include information on how to deal with this sub event and its influencing factors. A checklist will make sure that all the necessary information about these factors is communicated to the contractor.

Textbox 2-1: Content requirements work instructions:

- A list of all the materials needed to construct a certain emergency measure.
- An indication of the amount of materials needed for certain dimensions.
- The amount of people needed to construct the emergency measures with and without any machinery and their tasks.
- A checklist for the mobilisation:
  - Materials + needed amount,
  - Needed personnel,
  - Needed machinery,
  - Access routes.
- Instructions for working safely and neatly.
- Step by step instructions how to construct the emergency measures, both written and depicted.

2.7 Conclusions

To combat the piping failure mechanism several emergency measures are possible, in this research three measures were investigated; an impoundment, raising the water level in the ditch behind the levee, and a filter construction. The emergency measures stop the piping process by either reducing the water pressures and thereby the sediment transport, or by stopping the sand flow with some kind of filter and thereby making sure sediment cannot leave the levee.

For the emergency measures against piping some work instructions are available. These are made by WSRL and consist of visual aids concerning the different steps that are needed to construct a certain measure and indications of the amount of materials that are needed. The current work instructions do differ in the level of detail per measure, and the indication of needed materials are not based on any tests at the moment.

At the moment emergency measures are not included in the safety assessment of levees. To be able to be included in the assessment, the emergency measures must be checked in a similar manner as the levees themselves. The probability of failure of the measures is depended on the tree aspects that are defined in the definition of effectiveness; detection, design and implementation. These three aspects themselves are dependent on many other factors, some of which can be influenced by the water boards and some of which cannot be influenced. The reliability of many of these factors is related to the level of human reliability of the personnel. An estimation of the quantification of these factors can be made using the bandwidths of Bea (2002). There are factors such as the quality of materials and the accessibility of the site for machinery that cannot be quantified with human reliability. At the moment there are no methods available to quantify these kinds of factors to be found in the literature. Not all these steps are relevant for work instructions. The steps that should be included in the work instructions are: dimensioning of emergency measure, communication of the design, mobilisation, and construction of an emergency measure. All the work instructions should consist of lists of needed materials, machinery and personnel, a checklist of information that needs to be communicated regarding the mobilisation, instructions on how to work, and step by step instructions on how to construct a certain emergency measure. The instructions themselves must be clear and user friendly so they can be used quickly regardless of the knowledge and experience of the user.

3 Data gathering

In this chapter the gathered data is discussed. The data were collected in 5 different instances: during D&D, in interviews with contractors, with a workshop with water boards, during a training day for personnel of WDOD and during high water in 2018 at WDOD. The data that is collected is placed in the same tables as is done with the information from the current work instructions. By doing so, a clear overview is created of what information is gathered for the steps of the process and it also shows if some steps are lacking information. This overview can be used to adapt and improve the current work instructions.

The collected data can be categorized as soft data as it is based on qualitative observations and expert judgement.

3.1 Deining & Doorbraak

During the D&D exercise observations were done at WDOD and WSRL. For these observations two forms were developed; one for the detection process and one for the construction process. These forms are annexed in Appendix A**.** At WDOD the detection and the consrtuction were observed and in case of WSRL only the construction of emergency measures was looked at. The results of these observations are given in this section of the report; the remarks are divided between the observations of the detection and the placements.

Important to keep in mind is that these observations were done during an exercise, which means that there are some aspects that do not correspond with real life situation. There was almost no time pressure for the dike watch. Furthermore, the dike watch knew it was an exercise they were primarily focussed on looking for pictures. This was the way the water board placed damages during previous exercises, although during this exercise the water board tried to simulate them more realistically. In Appendix A the observations made during D&D can be found. In Table 3-1 the gathered information is summarized and placed in the part of the process that it relates to. A further explanation of the summarized data will also be given in this section.

Table 3-1: Information gathered during D&D

Damage	**Failure mechanism**	**Emergency measure**	**Design**	**Implementation**
Identifying damages	Interpreting damages			Quality and type of materials Transportation of materials Way of stacking sandbags

Detection

As mentioned above, the observations of the inspection of the levees were solely done at WDOD; other water boards might have other ways of executing the inspection than this water board. From the observations the following remarks can be made:

- The inspecting personnel had a lack of knowledge, about the levees that they inspect and about the material they use during the inspection. They were not always able to name the exact spot in the levee were they found something and not all of them could operate the radio they used to communicate with the dike post.

- The dike watch, at WDOD, did not have any forms to report the damages they found or make notes. If questions about a certain observation were asked after they continued with their patrol, they could not answer it properly.
- There was no clear division of tasks within the inspection team. Therefore the way the dike watch inspected the levees was not consistent. They did not inspect all parts of the levee, the focus was on the ditch but the inner slope and the crown of the levee were barely covered.

During this exercise numerous notifications were made by the patrols. Using the log of the application the dike watch used to register these notifications and the list of placed incidents for the exercise, it is possible to see how many of the placed incidents were found. As can be seen in Figure 3.1, 47% of the incidents that were placed were reported and entered in the application and only 15% of the incoming reports were about the placed incidents. The other notification varied between real damages to the levees to objects in the flood plaines that would not be there in real high water situations.

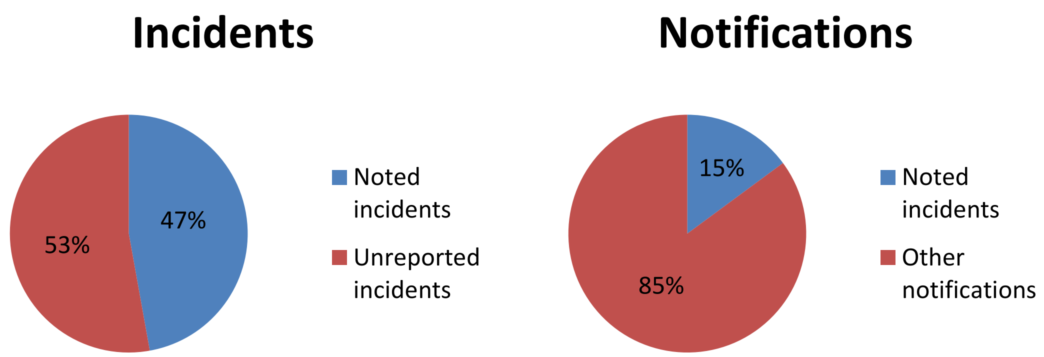


Figure 3.1: Percentage of found incidents (left) percentage of notifications about placed incident (right)

Regarding the piping incidents 22 different incidents were placed, 64% of the placed damage indicators were found. 32 incidents other than piping were also placed during D&D, of which only 34% were reported (Figure 3.2). In total there were ten different types of incidents placed by the water board, the percentage of each type of incident that was reported can be seen in Figure 3.3. The incident types damage (due) to structure, liquefaction, crack in the levee crest, and outflowing water are not present in this graph. This means that not one of these incidents of this type were found. These incidents, however, only form a small part, 7 out of 54, of the total amount of incidents.

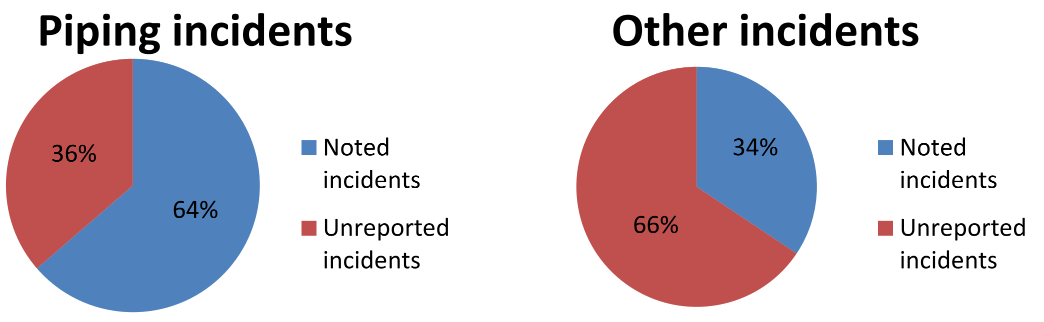


Figure 3.2: Percentage of found piping incidents (right) and percentage of found remaining incidents (left)

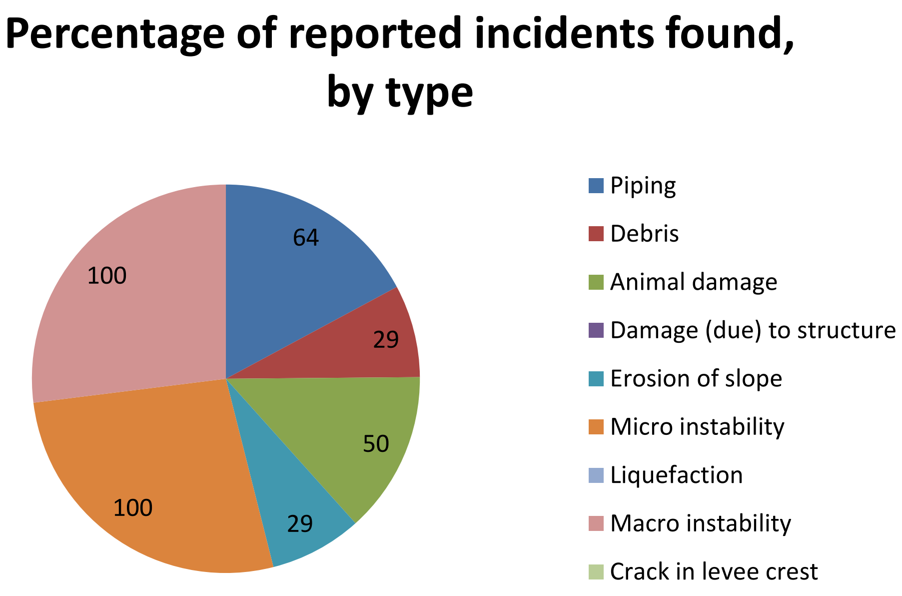


Figure 3.3: Percentage of found incidents

Placement

The observations of the construction of emergency measures were done at two water boards. At WDOD a construction of an impoundment was observed and at WSRL the construction of an impoundment and a dam to raise the water level in a ditch were observed. Based on these observations the following remarks can be made:

- It is important to pay attention to the kind and the quality of the materials that are used. For example; for the creation of a dam in the ditch polyester sandbags were used by a contractor at WSRL, these sandbags slipped off during the placement. Also, a lot of sandbags that were used at WDOD to keep a geotextile in place were leaking. If these sandbags are used during actual high water the water flow can cause the bags to empty out.
- During the exercise WSRL carried out the construction of emergency measures with contractors, at WDOD this was done with its own employees. At WSRL a work instruction and a supervisor from the water board were present during the placement, this was not the case at WDOD. These different approaches resulted in a quality difference between the water boards.

In all the observed cases more than enough sandbags were present. At WSRL they were brought at location on pallets by a truck, WDOD used a trailer to transport the materials. Mobilisation was not part of the training exercise, in actual high water situations it will be done differently and/or by different parties than during D&D. It is important to know for what kind of vehicles the location is accessible; a heavy truck might not be able to access the levee during high water without damaging it, this was not simulated during D&D.

3.2 Interviews with contractors

Four contractors were interviewed during this research. These interviews were held to get a better understanding of the experience of the contractors with the execution of emergency measures, the use of work instructions, and the mobilisation of materials and personnel. For the interviews two contractors from within WDOD and two from within WSRL were selected, these two water boards have different approaches concerning the use of contractors for emergency measures. The complete interviews can be found in Appendix B, in Table 3-2 the summarized data is given for each step of the process and a further explanation of the data is given in this section.

The questions of the interviews were mainly focussed on how the contractors deal with the implementation of emergency measures when they are called upon by the water boards and their experience with work instructions. This was done because the inspection of the levees and the choice of emergency measure lies with the water boards. Questions about these parts of the process would therefore not be relevant for the contractors.

Table 3-2: Information gathered from interviews

Damage	Failure mechanism	Emergency measure	Design	Implementation
(not questioned)	*(not questioned)*	*(not questioned)*	*(not questioned)*	Mobilisation of personnel, machinery and materials Material storage Supervision during construction

There is a large difference in what the water boards are expecting from the contractors. At WDOD the contractors are only required to transport the materials and machinery to a specific location, the construction of the emergency measures is done by personnel of the water board itself. At WSRL however construction of emergency measures is done by personnel of contractors with supervision by someone from the water board. Although WSRL has work instructions only one of the contractors that were interviewed has knowledge of them. The difference in tasks that are required of the contractors is also reflected in the amount of training exercises the contractors participate in. The contractors at WSRL practice with a different emergency measure every year. The contractors at WDOD are not as regularly involved in exercises at the water board, as a contractor from this water board stated.

Another difference between the water boards is the type of contract the contractors have. At WDOD the contractors have contracts with durations of one year. They need to be renewed every year and there is a chance that the contract will go to somebody else every year. Contractors at WSRL get a so called ‘waakvlam’ contract, which has a duration of multiple years. The advantage of having the same contractor for multiple years is that no knowledge is lost. The contractors from WDOD stated that it takes some time to get to know the area.

At WDOD the contractors do not get any updates regarding incoming high water prior to a discharge wave. This does not seem to be any problem for big companies who have enough personnel. However, the contractors at WSRL and one of the contractors at WDOD state that updates prior to a high water event help to make sure enough personnel is available if needed.

None of the contractors that were interviewed have any materials in their own storage, they all have to collect the materials at a depot from the water board. However, both the water boards do rely on third parties like contractors for materials if they have any shortage during a high water event.

3.3 Workshop

A workshop was organised to get input from five different water boards. During the workshop the participants were given a fictitious case and were asked to go through the entire process, from inspection to implementation, give an expert opinion on the importance of factors influencing the process and come up with an emergency measure. In total 21 people participated in the workshop, divided into 9 teams over 2 days. Most of the participants are dike supervisors and have practical experience with emergency measures. The following parties participated in the workshop:

Wednesday 17 January 2018 (at Deltares, Utrecht)

- Hoogheemraadschap Stichte Rijnlanden – 5 persons
- Hoogheemraadschap Rijnland – 2 persons
- Calamiteiten Team Waterkeringen (CTW) – 5 persons
- Water board Vallei en Veluwe – 2 persons
- Water board Drents Overijsselse Delta – 1 person

Wednesday 24 January 2018 (at WSRL, Tiel)

- Water board Rivierenland – 3 persons
- Water board Aa en Maas – 3 persons

The complete results of the workshop can be found in Appendix C, in Table 3-3 the data of the workshops is summarized and placed in their respective place in the process.

Table 3-3: Information gathered during workshops

Damage	Failure mechanism	Emergency measure	Design	Implementation
Importance of factors influencing detection of damages Indication of probability of failure of this part of the process	Prioritizing of different damages Importance of factors influencing prioritizing Indication of probability of failure of this part of the process	Importance of factors influencing the choice of emergency measure Indication of probability of failure of this part of the process	Indication of probability of failure of this part of the process	Importance of factors influencing the implementation of an emergency measure Material storage, indication of quantities

				Mobilisation of executing personnel Supervision during construction Amount of personnel needed to construct an impoundment + tasks of personnel Indication of risks of the emergency measures Indication of probability of failure of this part of the process

3.3.1 Detection

The workshops gave a lot of data regarding the factors for different parts of the process. Notable was that the answers of the different groups were very different and a lot of factors were named. This means that the different water boards and their experts are not unanimous on what the most important factors are.

3.3.2 Prioritizing

During the workshop the groups were asked to prioritize four events of a fictional case:

1. Water is flowing from the foot of the levee, no sand is visible and the flow appears to constant
2. In the ditch behind the levee a sand boil is observed. The boil has a diameter of 80 centimetre and a flow of clouded water is visible.
3. Within 30 metres of the levee 4 sand boils are detected. One, at the foot of the levee, has a diameter of 30 centimetre and clear water is flowing from this exit point. The other three sand boils were found in the ditch, they all have a diameter between 20 and 30 centimetres. The water is the ditch is clouded.
4. Near an impoundment in the hinterland three new sand boils are found. The boils are within an area of 4 by 5 metres and have a diameter of about 20 centimetres. Sand is flowing out of two of the sand boils, from the third only water is flowing.

The results of this prioritizing can be seen in Figure 3.4. This figure shows that the groups are divided in their prioritizing, this is remarkable as the reasoning behind the prioritizing was similar for each group: the size of the damage and the amount of sand coming out with the water flow are the most important factors. This indicates that there are other factors that influence the prioritization that were not explicitly mentioned. With follow-up questions it became clear that knowledge of the levee and the area are crucial to prioritize events.

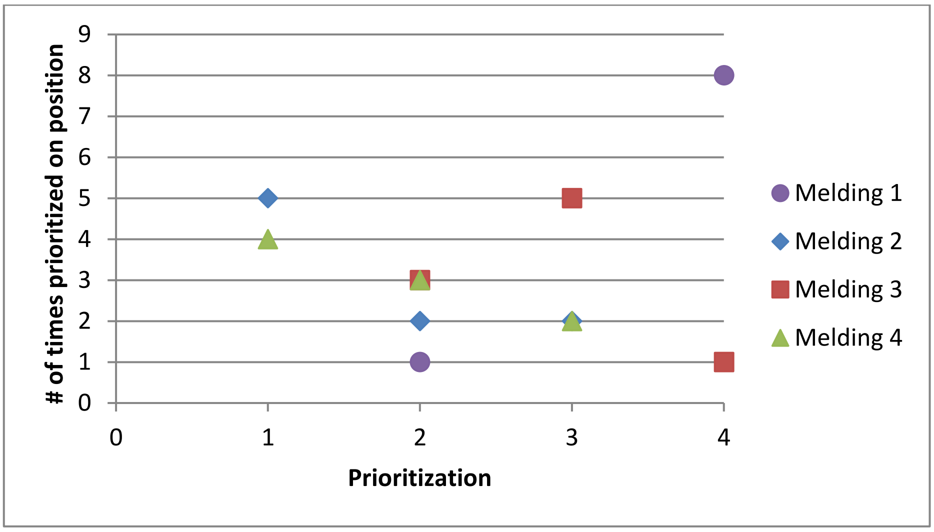


Figure 3.4: Prioritizing events

3.3.3 Implementation

Based on the answers on the question about the construction of an emergency measure the following can be stated. In general there are 6 people needed to place an emergency measure; 1 driver/crane operator, 1 supervisor, and 4 people to construct the measure. The activities are being done based on experience, only 3 water boards indicated that they use work instructions during the implementation of an emergency measure.

The following risks were identified, by the experts, for the construction of the three emergency measures that are discussed in this research:

Impoundment

- Emergency measure to small
- Impoundment build to steep so the construction becomes unstable
- Sandbags stacked carelessly so construction becomes unstable
- Too much water pressure can cause other sand boils to emerge

Raising water level in the ditch behind the levee

- Unstable construction (to steep, careless construction)
- Raised water level can introduce other problems in the area

Filter construction

- The emergency measure restricts the sight on the damage

3.4 Overview of the collected data

The tables for each instance of data gathering and the table for the current work instructions is combined into one table. This creates an overview of the data that is gathered and shows where there are gaps in the collected information. This is done in table 3-4, the blue text is the information from the current work instructions. The black text are the subjects of the information that is gathered. Not all this information is new as some of the subjects are already present in the current work instructions, the information about these subjects may be used to check the current work instructions.

This table shows that there is no new data regarding the design of emergency measures, besides and indication about the probability of failure of this part of the process. Therefore it will not be possible to check if the indications of the needed materials in the current work instructions are reasonable based on the gathered data. The other parts of the process do get covered by the data and it will be possible to adapt the current work instructions based on this.

The data gathered regarding the implementation phase can be used to adapt the current work instructions to the format discussed in paragraph 2.6. As the work instructions only cover design and implementation, the information gathered about first three steps cannot be used for the adaption of the instructions. However, the information gathered about these steps can be used for an indication of the probability of failure.

Table 3-4: Overview of information in the work instruction and gathered data

Observed Damage	Failure mechanism	Emergency measure	Design	Implementation
Examples of different damages Identifying damages Identifying damages Importance of factors influencing detection of damages Indication of probability of failure of this part of the process	Effects of damages Interpreting damages Interpreting damages Prioritizing of different damages Importance of factors influencing prioritizing Indication of probability of failure of this part of the process	Choices of emergency measure for different damages Importance of factors influencing the choice of emergency measure Indication of probability of failure of this part of the process	Needed amount of sandbags for given height and length (given in a table) Cross-sections of stacked sandbags for different heights Needed amount of sandbags for given dimension of geotextile Needed amount of gravel for given areas of geotextile Indication of probability of failure of this part of the process	Points of interest for mobilisation in form of question that need to be answered by personnel Steps to construct impoundment Points of interest during construction (staggered stacking of sandbags and 'kont op stik') Points of interest for mobilisation in form of question that need to be answered by personnel Steps to construct filter Points of interest during construction (placing geotextile downwind) Quality and type of materials

				Transportation of materials Way of stacking sandbags Mobilisation of personnel, machinery and materials Supervision during construction Importance of factors influencing the implementation of an emergency measure Material storage, indication of quantities Amount of personnel needed to construct an impoundment + tasks of personnel Indication of risks of the emergency measures Indication of probability of failure of this part of the process

4 Adjustment of work instructions

This chapter will elaborate on the content requirements, as seen in textbox 2-1, for the work instructions of the three emergency measures; constructing an impoundment, raising the water level in the ditch behind the levee, and the construction of a filter. This will be done by addressing two objectives. First, missing information will be identified by comparing the gathered information and the information already present in the current work instructions with the requirements. Secondly, the quality of the information will be discussed, both old and new.

4.1 Users

Within the whole process there are three different parties in general: the dike watch that inspects the levees, the specialists who decide which emergency measure will be used and designs the measures and the executing personnel who place the measure (Figure 2.16). The current work instructions touch all the steps of the process in some way, but as there are different users for the different steps not all of the information will be relevant for every user. Ideally there would be different instructions for each user with all the relevant information. The work instructions for the implementation of emergency measures should include information about the dimensioning of a measure and about the actual implementation. The choice of which emergency measure will be used is already made by specialists of the water board, therefore information about how to assess damage to a levee and what emergency measures are appropriate for the situation is not relevant for the executing party and can be excluded from the work instructions. It is important however that the executing personnel check the provided information from the previous steps, such as the size and location of the damage, to check if the provided design needs to be adjusted to the situation.

4.2 Materials

The three emergency measures need different materials to construct them. An overview of the needed materials should be included in the work instructions as is stated in the requirements. This is not the case in the current work instructions. Besides the materials for the construction possible aids to help with the construction or transportation can also be listed. This is based on observations and conversations with executing personnel. For example: some kind of tube to slide sandbags of a levee or a wading suit when the emergency measure needs to be constructed in water, a generator and lights if it is night time.

Quantity

Besides the needed materials for the construction of an emergency measure the needed quantities of these materials are also important. In the current work instructions there are some indications on how much materials are needed to build the emergency measures. The gathered data lacks in this area, but in the literature there are some assumptions how sandbags have to be stacked. With this it is possible to see if the indications in the current work instructions are viable. In Lendering et al. (2014) it is stated that the width of the base must be a minimum of 1.1 times the height of the construction. The United States Army Core of Engineers has a more conservative method that states that the width must be a minimum of 1.5 times the height of the construction (USACE, 2017). The German national fire brigade even has a higher minimum as they state that the base of the construction should has as many sandbags as the number of sandbags the construction is in height, which gives a ratio of 2 times the height of the construction (Schmidt, 2014). Sandbags generally have a size of 30 x 60 x 15 cm when they are stacked, with these dimensions it is possible to check if the stated amount of sandbags in the work instructions are correct. In Table 4-1 the examples that are given in the current work instruction are stated with their corresponding width/height ratio. Only three of these examples have a ratio over the smallest provided ratio, which is stated by Lendering et al. (2014).

Table 4-1: Width – height ratio examples work instructions

# of layers of sandbags	Height (cm)	Width (cm)	Width/Height
1	15	60	4.0
2	30	60	2.0
3	45	60	1.3
4	60	60	1.0
5	75	60	0.8
6	90	90	1.0
7	105	90	0.9
8	120	90	0.8
9	135	90	0.7
10	150	120	0.8
11	165	120	0.7
12	180	120	0.7
13	195	120	0.6

Quality
The quantities of the materials explain what materials to use for certain emergency measures, but they should also give an indication on what materials not to use. The workshops indicate that the quality of the materials is an important factor and give an average PoF of 25% to this factor. So once out of four times an emergency measure is constructed with the use of materials with a bad quality. Therefore it is important that the quality of the materials is checked prior and during the construction of the measure. Three examples of quality requirements are given below:

1. Not every type of material is suitable for every measure. For example, polyester sandbags are more durable than the regular ones but are to slippery for measures like raising the water level.
2. Sandbags should be ⅔ filled, if the sandbags are too full they cannot be shaped properly and will become too heavy (Wiki Noodmaatregelen, 2018). Besides that, if sandbags are used that are too full or too empty it will be difficult to stack them properly and the construction will become crooked, as was observed during an exercise at WDOD.
3. During observations at WDOD it was observed that a lot of sandbags have holes in them these should be discarded when constructing any emergency measure. The holes will allow the sand to flow out and this will weaken the construction.

4.3 Personnel
The following item in the requirements is the needed personnel for the construction of an emergency measure and the tasks they have. Based on the data from the workshop and interviews the following tasks are identified independent of the different emergency measures:

- Supervisor – 1 person
- Construction – 4 persons
- Crane operator – 1 person

The amount of people needed for the task depends on the accessibility of the site. The crane operator, for example, is optional, not all the emergency measures require a crane to be present and not all the locations will be accessible with heavy machinery. If the location cannot be accessed by heavy machinery more people might be necessary to carry the materials needed for the construction of the emergency measure.

The task 'construction' will differ for the three emergency measures; this will be further explained in the individual instruction for the measures.

4.4 Mobilisation checklist

Prior to the construction of a measure all the personnel, materials, and machinery need to be gathered. In the current work instructions the following list is present (Table 4-1). The information of this list must adjusted to ensure that everything is communicated to the contractor and no information is forgotten.

Two points should be added to this list based on the gathered information: first of all, calling the depot. During the interviews all the contractors said that they need to pick up the materials at a depot. If a call is made to the nearest depot the materials can be prepared to be picked up which may shorten the time needed for the mobilisation. Secondly, the access route to the damage. The contractor will need to know the exact location and the easiest way to access the site. During high water it might be possible that some roads are not accessible for heavy machinery. The communication of access routes got an average PoF of 37.5% during the workshops, so more than 1/3 of the times accessibility of the site is not communicated (properly) to the contractors. Therefore it is important that all the relevant information is communicated to the contractor.

Table 4-1: Mobilisation checklist current work instructions vs. adjustments

Current work instructions	Adjusted work instructions
Stap 1 analyse vragen **Vervolgens:** • Kies welke maatregel geschikt is (zie volgende sheets) • Bepaal welke materialen en materieel de aannemer moet meenemen. • Bepaal hoeveel personeel er nodig is. • Denk na over de route naar de locatie, heb je extra materieel nodig? • Let op veilig werken: welke verkeersmaatregelen moet je nemen? • Bel de aannemer. • Leg de 0-situatie vast met een foto: locatie waar gewerkt wordt + aanvoerroute waar schade kan ontstaan.	Determine needed materials
	Determine needed machinery
	Determine needed personnel
	Call contractor for: • Materials, machinery, personnel • Location of the depot the materials need to be picked up • Access routes • Time they need to be present
	Call depot for: • Materials • Time the materials are picked up

4.5 Instructions way of working

The current work instructions lack an overview of how the work should be executed, based on the observations and answers to the workshop it seems that this is important to guard the quality of the emergency measures and the health and safety of the executing personnel. These factors got awarded a high level of importance by the experts of the water boards. Some of these instructions seem obvious but can be easily forgotten or overlooked during the implementation of an emergency measure as was observed at an exercise at WDOD.

Handling sandbags:
For all emergency measures sandbags are used. It is not always possible to place the sandbags close to the location and therefore they sometimes will have to be carried. If enough personnel are available it will be possible to form a sort of chain and pass the sandbags to one another. To do this with the least amount of effort the bags should be given to one another instead of thrown and the people passing the bags should stand alternately as is depicted in Figure 4.1. This way of passing sandbags to one another minimises the amount of turning required and therefore requires less effort for the personnel.

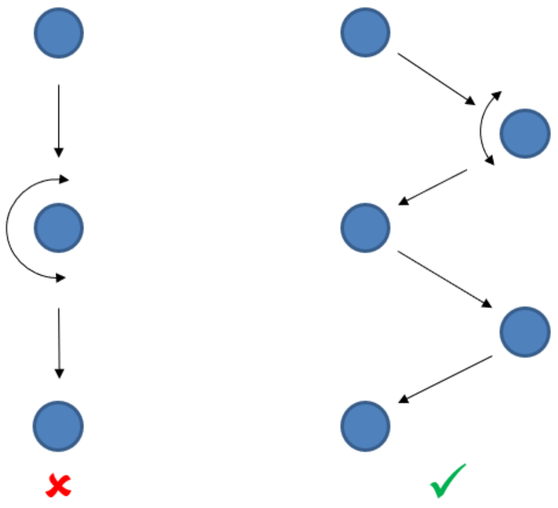


Figure 4.1: Example of positioning while passing sandbags.

Placing sandbags:
In the current work instructions there are some pointers on how to stack the sandbags in the instructions for the impoundment, but they are also important for other emergency measures. In Figure 4.2 four examples are given on how the sandbags should be placed. They should be placed neatly on top of each other (A) to prevent the construction from becoming crooked. The base of the construction should be broad (B), so the construction is stable. The first layer of sandbags must be placed ‘kont op stik’ (C) which means that the opening of the sandbags is covered by the bag next to it. This prevents sand from flushing out. The rest of the sandbags must be placed staggered on of top each other (D), to increase the stability of the construction. Besides these four points of interest it is also important that the sandbags are placed on to the construction and not thrown down.

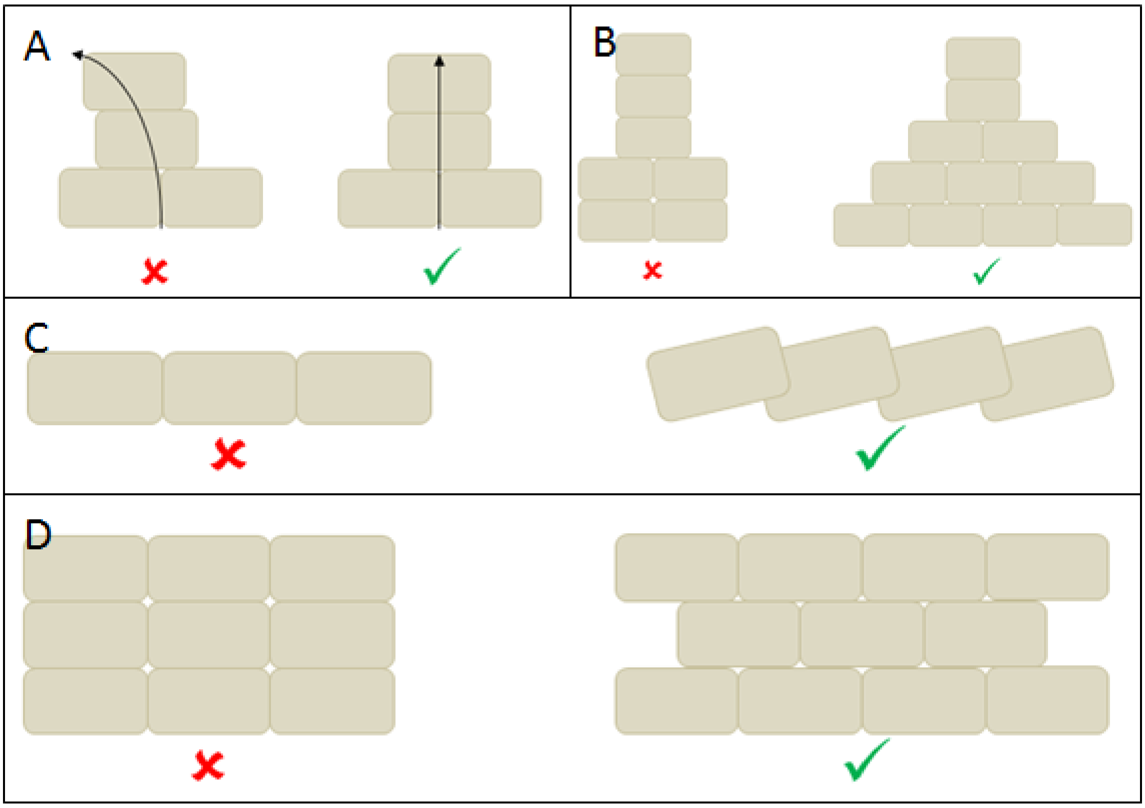


Figure 4.2: Examples of stacking sandbags. A – cross section, example of neatly stacking sandbags. B – cross section, example of stable base. C – front view, example of 'kont op stik'. D – front view, example of staggered stacking.

4.6 Instructions emergency measures

The current work instructions show the steps to construct the emergency measures. In this section these steps will be analysed and any missing steps, based on the observations, interviews and workshops, will be stated. Besides the steps, points of interest for each emergency measure should be stated in the work instructions. If the executing personnel have an overview of the things that go wrong most often it can help to prevent these things during the construction.

4.6.1 Impoundment

Based on the observations at the WDOD and the data from the workshop one step can be added to the current work instruction for an impoundment: the removal of sand prior to the construction of the impoundment (Knotter, 2018). If the excess sand is not removed and the impoundment is built on top of it, it is possible that piping start to occur underneath the impoundment itself.

Points of interest for this emergency measures are:

- Impoundment is built too small
- Impoundment is built too steep
- The sandbags are stacked messy

4.6.2 Raising water level

The current work instructions do not show any steps for the raising the water level in a ditch but simply states “place sandbags as is stated in the work instructions for placing sandbags”. However, there are some steps that must be specified to create this emergency measure.

1. Check how much the water can be raised. If the water is raised to much it might cause problems in the surrounding area.
2. Start the dam in the deepest point in the ditch and work your way up from there, create a solid base.
3. Stack the sandbags to the required height.

The main point of interest is the stability of the dam; if the dam is built to steep or the work is messy the dam could topple.

4.6.3 Filter construction

For the work instructions for the filter construction the same addition can be made as for the construction of the impoundment: the removal of sand prior to the placement.

The point of interest with this emergency measure is:

- Size of the filter construction, the filter should cover the whole damages area
- The filter will obstruct the visibility on the damage, which makes it hard to monitor the situation.

4.7 Validation of adjustments

When the current work instructions and the requirements from chapter 2.6 are put together an overview is created of missing information. The aforementioned adjustments should fill these gaps or add to the current information. An overview of the missing information and what is added by the adjustments is given in Table 4-2. The impoundment is represented as EM 1, raising the water level as EM 2 and the filter construction as EM 3.

Table 4-2: Overview of adjustments to the work instructions

Required content work instructions	**Current work instructions**			Adjustments
	EM 1	EM 2	EM 3	
Needed materials + machinery	+	+	+	The needed number of sandbags checked Instructions to check quality added
Needed personnel + tasks	-	-	-	Specification of tasks added
Mobilisation personnel	+	+	+	
Mobilisation materials + machinery	+	+	+	Call to depot added to mobilisation checklist

Access routes (+ handling non influenceable factors)	+	+	+	Call contractor for specification of access route added to mobilisation checklist
Instruction safety/neatness	+	-	+	Instructions for handling and placing sandbags added
Steps for construction	+	-	+	Added step 'remove excess sand' to the instructions of the impoundment and filter Added steps for raising the water level in the ditch behind a levee Added points of concern for measures

As can be seen in the table, the adjustments fill all the information gaps and verify some of the current information and are conform to the steps to minimize the probability of human errors that is found in the literature (Bea, 2002). The two steps that apply to the adjustments are: *"Procedures and rules that are correct, complete, well organized and documented, and not excessively complex"* and *"training for normal and abnormal conditions"*. However, at this moment it cannot be said that the adjustments are actually better than the original work instructions. To determine if the adjustments are an actual improvement the probability of failure of the implementation phase is looked at. For this the data from the workshop and the literature by Bea (2002) will be used.

The implementation can fail due to the mobilisation (a), or the construction of the emergency measure (b). The mobilisation further depends on the access route to the location and the available personnel, materials and machinery. The construction is dependent on the experience of the personnel, the supervision during the construction and environmental factors.

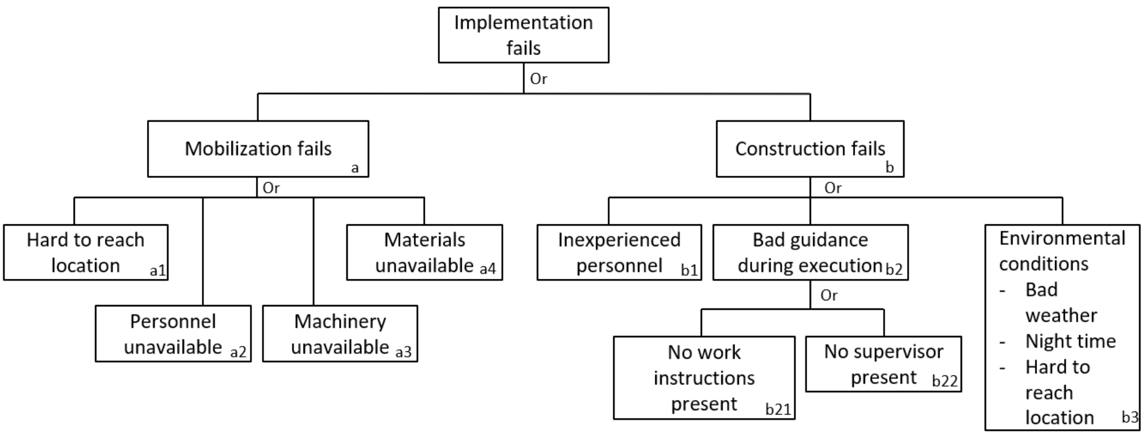


Figure 4.3: Failure tree implementation phase

4.7.1 Mobilisation

The mobilisation of materials, machinery and personnel, is done by third parties. The PoF of this aspect depends on the time the party has to mobilize the personnel and the amount of materials that is available at the depots. The availability of materials will not be a problem at the beginning of a high river discharge, but if the high water continues over a longer period of time the stock will dwindle. The data from the workshops shows that the amount of materials differs from water board to water board. For example: the smallest number of sandbags that is said to be held in storage at the depots is 8500, while the largest amount is 20000. It also differs, of course, how many piping incidents occur for each of the water boards, but the amount of materials in the depots is based on nothing. The water boards do not state how many emergency measures they wish to be able to construct during a high water event. Therefore it is difficult to make an estimation of the PoF of this aspect. However, an estimation can be made using the provided literature for the factors that are dependent on human actions. Figure 2.10 shows several categories for human performance of tasks. Every action taken in the implementation phase can be placed in one of these categories. The adjustments that influence the mobilisation are the additions to the mobilisation check list and the instruction to call ahead to the depot and/or contractor. At the moment the mobilisation, as it would be during real high water situations, is not practiced during exercises at every water board, therefore the mobilisation can be placed in the *"Simple tasks performed with speed"* category. The adjustments will remove the 'with speed' component and add an extra check to the checklist, this places this action in the *"change system with procedures with checking"* category. For the mobilisation to become a routine task more realistic exercises are required. At the moment this is not the case and therefore it will not be a routine task when it has to be done during a high water event.

4.7.2 Construction

The construction of the emergency measures themselves can also be placed into one of the categories of Figure 2.10. This figure shows that unfamiliar tasks that are performed with speed have the largest probability of failure. This can be confirmed with the observations from D&D, at WDOD an impoundment was built without supervision and very quickly, at WSRL a impoundment was built with supervision by the water board and not as rushed. The results of these two exercises can be seen in Figure 4.4.

Figure 4.4: Example of construction of an impoundment at WDOD (left) and WSRL (right)

This figure shows that the way the construction of an emergency measure is being lead has quite a big impact on the PoF of the construction. This can also be verified with the data from the workshop. If the construction is being lead based on experience of personnel of the water board the PoF is estimated about 20%, if work instructions are being used, the PoF is estimated about 10%. Looking at the categories from Bea (2002) this estimation seems rather high as it places the implementation in either the category "*unfamiliar task performed with speed"* or "*change system state without procedures, without checking"*. The current work instructions already give a procedure to construct the different measures. Therefore it can be said that the construction of emergency falls within the category *"change systems with procedures and* *checking"* if the construction is not rushed. It must be placed in the upper bound of this category however, as the constructions is not always checked. The adjustments add some steps to the instructions to build the measures and include the most common mistakes that are made during previous constructions and/or other points of interest. To decrease the probability of failure for the construction of the emergency measures it must be made sure that the construction is always checked, during the construction and afterwards. The division of tasks that is added to the work instruction can make sure that there is always someone who has supervision during the construction and thus can make sure that the instructions are followed.

4.7.3 Probability of failure emergency measures

The three emergency measures will each have a different PoF, as they require different (amount of) steps to be constructed and each of these steps will have its own PoF. The filter construction can be used in the same situations as an impoundment; therefore it would be interesting to know which of these emergency measures is the most reliable.

Looking at the sequence of steps and the most common mistakes during the construction of these measures the filter construction seems to be the most reliable. The filter requires more steps: remove excess sand, place geotextile, place sandbags, and place counter pressure with gravel. For the construction of an impoundment only the sand has to be removed and the sandbags need to be placed. But during the construction of an impoundment more mistakes can be made, every layer of sandbags needs to be placed with care to ensure the stability of the emergency measure. With the filter construction neatness is not really a problem as no sandbags need to be stacked on top of each other. The construction of a filter can therefore be placed in the category "*simple task performed with speed"* based on this. A big difference between the two emergency measures, however, is the amount they are practiced and used. An impoundment is a measure that is quite often used during exercises and real high water events, while the filter construction is not used during these instances as was stated by an expert of WSRL. The construction of an impoundment can therefore be seen as a routine task, placing it in the category *"routine task performed with speed or diverted attention"* in the most unfavourable situations. Raising the water level in a ditch can be placed in the same category, for the same reasons as for the impoundment.

5 Discussion

In this section the research and its results are discussed. This is done in two sections, in the first section the data and the way that it was gathered are discussed, as will the effect this might have had on the results. In the second section the results themselves will be discussed and how these results can be interpreted looking at the whole process.

5.1 Data gathering

For the gathering of data three different methods were used: observations, interviews, and workshops. These methods provided the necessary information to come to the provided results but were not perfect. For each of the methods it will be discussed how they could have been improved and what implications these improvements would have.

5.1.1 Observations

For this research three observations were done, the national training exercise D&D at WDOD and WRSL, a training for its own personnel at WDOD, and the inspection of levees during high water in January 2018 at WDOD. These observations provided insight how the water boards operate during high water, but they also had some shortcomings:

- During D&D all the events happened on the same day. This meant that there was little time to implement a lot of measures. At the WDOD this might have resulted in the rushed execution of the impoundment that was observed by the author. The tight schedule also caused that only one implementation was observed at the WDOD, where originally more observations were planned.
- The mobilisation of materials during D&D at WDOD was done by the water board itself. This does not correspond with real high water situations where the mobilisation is done by contractors.
- Most of the observations were done at WDOD, however not every water board operates in the same way. The lessons learnt from these observations may therefore not be applicable for all water boards.

The above-mentioned comments mean that the data that is gathered through the observations can only serve as an indication on how the water boards operate during high water events. For a more detailed analysis more observations at different water boards are required.

5.1.2 Interviews

Four contractors from two different water boards were contacted for the interviews. The questions were focussed on the mobilisation and construction of emergency measures. Some of the answers contradicted the information provided by the water boards. For example, all the contractors indicated that they do not have their own supply of materials for the construction of emergency measures while the water boards state contractors as one of their sources for materials. It is possible, of course, that other contractors do have their own stockpile, but this has to be verified by more interviews.

5.1.3 Workshops

The workshops were conducted with experts from 6 different water boards and CTW, therefore the information gained from these workshops can be seen as reliable. There is a point to note regarding the workshops: the time required to conduct the workshops. During the two sessions it became clear that more time was required to complete the workshops than was estimated.

This resulted in some missing explanations to answered questions and less comprehensive answers than hoped for.

5.2 Interpretation results

During the workshops the groups were asked to assign probability of failures to several factors. A lot of these probabilities that were given were very high (50-90%). It is not very probable that these probabilities are realistic and therefore they cannot be interpreted as normal probabilities of failures. A possible explanation for the high probabilities is the expertise of the workshop participant. The participants have a lot of knowledge about water safety but are not familiar with working with PoFs and what order of magnitude they might have.

The estimation given by the water boards can be used as a reference of how important they think the implementation is compared to the other parts of the process. During the workshops the experts from the water boards were asked to give an estimation of the PoF for every phase, this estimation is given in Figure 5.1. This shows that the water boards believe that the determination of the failure mechanism is the largest obstacle within the process and the implementation the smallest. The PoF do not sum up to 100% but are an indication how much of the times that the process is gone through the phase is not done correctly. **Error! Reference source not found.**

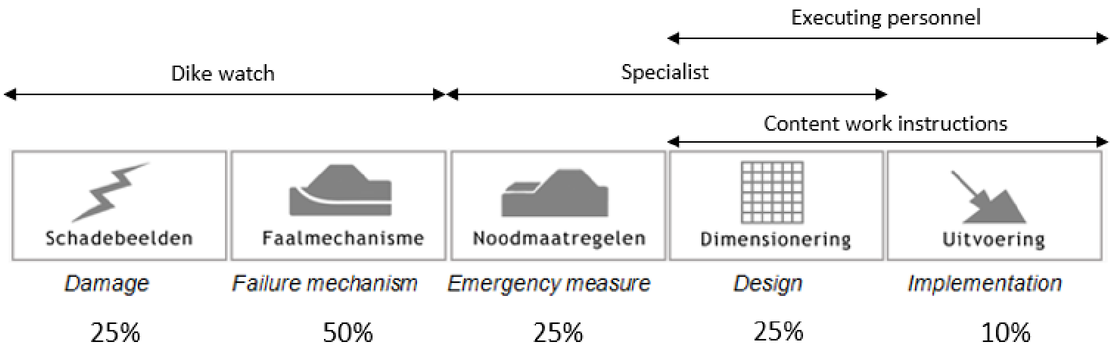


Figure 5.1: Estimation of PoF for all the phases by experts form the water boards

The estimation of the PoF of the detection phase contradicts the report of Lendering et al. (2014), which gives the detection of a damage the largest probability (86%), which can be supported by the observations of D&D, where about 33% of the placed incidents was not found. This still means that the inspection is an important part of the process, without a thorough inspection no damages will be found and there will not be an emergency measure to implement in the first place. The adjustments made to the work instructions that are discussed in chapter 4 help to improve the design and implementation phase, which is the part that already has the lowest probability of failure. However, this does not mean that the improvements are not important, the levee can still fail due to an incorrect implementation even if the detection and design were done perfectly. As can be seen in chapter 4, a large part of the PoF of the implementation can be appointed to human performance. Regular training can thus help to improve the reliability of the emergency measures.

5.2.1 Sequence of steps of work instructions

The adjusted work instructions assume that an emergency measure is chosen and then a step by step process can be followed to construct this measure. In reality the process is more iterative than a sequence of steps. Between the point that an emergency measure is chosen by the water board and the construction starts some time expires. The situation for which the emergency measure was chosen might be changed in that time. Therefore, the provided information and design of the measure must be checked to see if they are still applicable to the current situation. If this is not the case another emergency measure must be chosen or the design must be adjusted. Another possibility is that the designed measure is constructed but not effective. In that case the design must be adapted in such a way that the emergency measures works. Both possibilities require iterative steps until a working emergency measure is constructed.

6 Conclusions & recommendations

The main goal of this research was: *"To assess, evaluate and improve work instructions for the implementation of three emergency measures against piping".* In this section the conclusions of the findings will be given. After that recommendations for the water boards will be given on what to do following this research, followed by options for further research.

6.1 Conclusion

The current work instructions cover the whole process from the different damages that indicate piping to the implementation of different emergency measures. The process has three different parties that are involved in general: the dike watch for the inspections, specialist from the water board for the choice and design of an emergency measure, and executing personnel for the implementation of the measure. Not all the information is relevant for all the parties and in some areas information is missing. In order to improve the work instruction the instructions must be separated for each of the parties and all the relevant information must be included.

The instructions for the implementation of emergency measures can be improved by making the following adjustments.

1. Add instructions to check quality of materials. A lot of sandbags have holes in them or are not filled correctly, these sandbags should not be used during the construction of emergency measures.
2. Add minimum needed personnel and specification of their tasks. In general 6 people are needed to construct an emergency measure, a supervisor, four people to construct the measure, and one crane operator. The number of people can change based on the size or location of the needed measure.
3. Extend mobilisation checklist by adding "call contractor for access routes" and "call depot". By extending the mobilisation checklist with these two points the mobilisation time can be reduced. By disclosing the access route, the contractor does not have to look for a route himself and avoids possible problems if roads are closed. By calling the depot the needed materials can be prepared for pick up by the contractor.
4. Add instructions for handling and placing sandbags. If the sandbags need to be transported by hand to get to the construction site, the sandbags should be passed to each other while standing alternately along a line. This requires less of an effort than standing in straight line behind each other. Besides instructions for handling sandbags, clear instructions on how to place them also need to be added to the work instructions in order to minimize mistakes that are made during the construction of an emergency measure.
5. Add step "remove excess sand" to the sequence of steps to construct the impoundment and filter. This is a crucial step that is not present in the current work instructions. If the excess sand is not removed the water can find a new route through this sand after the emergency measure is constructed.
6. Add the sequence of steps raise water level in a ditch. Currently there are no instructions to raise the water level in a ditch behind a levee. In order to create complete work instructions the steps for this emergency measures must be added.
7. Add most common mistakes during construction for each of the emergency measures. The participants off the workshop identified some common mistakes for each of the emergency measures. These mistakes must be added to the work instructions, they can function as a reminder or as warning during the construction of a measure to minimize the change that these mistakes occur.

In the table below an overview is given of the requirements for the work instructions, the provided and missing information in the current work instructions, the adjustments for the different categories of the requirements, and the effect the adjustments have on the PoF. EM 1 corresponds with the instructions for an impoundment, EM 2 with the instructions for raising the water level in a ditch behind a levee, and EM 3 with the instructions for a filter. The + indicates that some information about a certain subject is available in the current work instructions, the – indicates a lack of information about a certain subject.

Required content work instructions	**Current work instructions**			Adjustments (#)
	EM 1	EM 2	EM 3	
Needed materials + machinery	+	+	+	1
Needed personnel + tasks	-	-	-	2
Mobilisation personnel	+	+	+	
Mobilisation materials + machinery	+	+	+	3
Access routes (+ handling non influenceable factors)	+	+	+	3
Instruction safety/neatness	+	-	+	4
Steps for construction	+	-	+	5, 6, 7

All the adjustments that are made to the work instructions seem straight forward and quite simple. However, they are quite important to increase the reliability of the emergency measures. The adjustments are made to lower the PoF of the implantation phase. The implementation phase is separated in two sub-phases: the mobilisation of materials, machinery, and personnel, and the construction of the emergency measure. The mobilisation, as it would be in real high water situations, is currently not a regular part of any training exercises. Therefore it can be placed in the category “*simple tasks performed with speed”* on the scale for human performance reliability, which corresponds with a PoF between $1e^{-1}$ – $1\ e^{-2}$. With the adjustments and training this can be improved to a PoF between $1e^{-2}$ and $1e^{-3}$. The construction phase currently has a PoF about $1e^{-2}$ looking at the categories for human performance reliability. With the adjustments, training, and supervisions during and after the constructions this can be improved to about $1e^{-3}$.

The effects that the adjustments have on the PoF are roughly the same for all the emergency measures, when looked at them quantitatively. But the effect the adjustments have on the executing of the emergency measures will differ in practice. The quality check will have a larger effect on the impoundment and raising of the water level than on the filter construction. Simply because the needed amount of materials is larger. The same can be said of the instructions for placing the sandbags, more sandbags will have to be placed with the construction of an impoundment and a dam to raise the water level than with a filter construction. Therefore, the instructions to place the sandbags correctly will have a larger effect on the execution of the emergency measure.

Based on the required steps and the most common mistakes during the implementation the filter construction seems as a viable replacement for the impoundment. However, the filter construction has not been tested often and has not been implemented during high water so it hard to say if this measure has the desired effect.

6.2 Recommendations

Several recommendations can be made to the water boards, which will help to improve the reliability of the emergency measures. In this section these recommendations will be explained.

Test work instructions

The water boards wish to have uniform work instructions. To reach that goal, several steps will have to be taken:

1. The first step is to implement all the adjustments that are presented in this report for the work instructions of the three emergency measures.
2. The second step is a discussion meeting with experts from the water boards. In this meeting the adjusted work instructions must be discussed to see if they are satisfactory for all the water boards. It is possible to add additional changes to the work instructions.
3. The third step is to test the work instructions, for example during training exercises like D&D. During these training exercises it will be possible to see if the adjustments help the personnel execute the emergency measures more meticulously. These tests of the work instructions must be done by several water boards. If the results of these tests are all positive the work instructions can be used during actual high water situations.

Even when the work instructions are used across the water boards they will continuedly need to be kept up to date.

Update needed materials

The current indication on the needed amount of materials for the emergency measures is inaccurate for the three emergency measures that are discussed in this report. Different indications for width/height ratios can be found in the literature. It will be beneficial for the water boards to investigate the optimal way to construct the emergency measures. By doing so the indication in the work instruction can be updated properly.

Add instructions for detection and design phases

One of the adjustments is to separate the work instruction for the different users and the adjustments for the implementation phase are given in this report. In order to improve the detection and design phases work instruction can be made for these phases as well. A lot of factors that influence these phases have already been identified in this report, these can be used to make (adjustments for) the work instruction of these phases.

Improve the training exercises

The training exercise that was observed during this research was not very realistic. In order to improve the overall probability of failure or the entire process the training exercises need to be done more realistically, for example by including the mobilisation in the training exercises. To be able to do this it might be necessary to set certain goals for the organisation, like the minimum amount of emergency measures they want to be able to implement. During exercises it will be possible to see if these goals can be met.

The lessons learnt from these exercises also need to be fed back into the organisation, at the moment a lot of data is collected but not a lot is done with it. The data can be used to improve the implementation process and train the personnel.

6.3 Options for further research

Apply framework to other measures

In this research three measures against piping are discussed. The water boards do have more emergency measures they implement during high water situations. Measures against piping and other failure mechanisms. The method used in this research can be applied to these measures to update their respective work instruction and make the whole crisis organisation more reliable. Besides, the framework can be extended to cover not only the implementation but also the detection and design in more detail. This can help to improve the entire process for all the emergency measures.

Analyse Probability of Failure

In this report a very rough indication of the PoF for the implementation of the three emergency measures is given. A detailed analysis of the PoF of the three discussed emergency measures, or other measures, will give a better insight in the critical parts of the process and might help to improve it further.

7 Bibliography

Bea, R. (2002). Human and organizational factors in reliability assessment and management of offshore structures. *Risk Analysis, vol 22*, 29-45.

Ben-Gal, I. (2007). Bayesian Networks. In F. Ruggeri , F. Faltin, & R. Kenett, *Encyclopedia of Statistics in Quality and Reliability.* Wiley & Sons.

Casteleijn, A., & van Bree, B. (2017). *Analyse geacanceerde betrouwbaarheidsanayses voor Betrouwbaarheid Sluiten.* WVL RWS.

Casteleijn, A., & van Bree, B. (2017). *Werkwijze bepalen kans op niet sluiten per sluitvraag met scoretabellen.* RWS-WVL.

de Bruijn, H. (2013). *Het pipingproces in stripvorm.* Delft: Deltares.

Dupuits, E. (2011). *Opkisten van wellen: een onderzoek naar de invloed van noodmaatregelen op de faalkans van dijken door piping.* MSc thesis. Delft: Delft University of Technology.

ENW. (2017). *Fundamentals in Flood Protection.* Den Haag: Ministry of Infrastructure and the Environment.

Förster, U., van den Ham, G., Calle, E., & Kruse, G. (2012). *Onderzoeksrapport Zandmeevoerende Wellen.* Delft: Deltares.

Jonkman, S., Dupuits, E., & Havinga, F. (2013). The effects of flood fighting and emergency measures on the reliability of flood defences. *Comprehensive Flood Risk Management*, 1583-1590.

Lendering, K., Jonkman, S., & Kok, M. (2014). *Effectiveness and reliability of emergency measures for flood prevention.* Delft: Delft University of Technology .

McClave, J. T., Benson, P. G., Sinich, T., & Knypstra, S. (2011). *Statistiek - Een inleiding.* Pearson Education.

Ministerie van Infrastructuur en Milieu. (2016). *Regeling veiligheid primaire waterkering 2017 - Bijlage III Sterkte en veiligheid.* Den Haag: Ministerie van Infrastructuur en Milieu.

Morales Napoles, O., Worm, D., van den Haak, P., Hanea, A., Courage, W., & Miraglia, S. (2013). *Introduction to Bayesian Networks.* Delft: TNO.

Niemeijer, J. (2016). *WTI 2017 Kunstwerken - Achtergrondrapport toetsspoor betrouwbaarheid sluiting I, verbeteren gedetaileerde toets.* Delft: Deltares.

Rijkswaterstaat. (2006). *Hoogwater op de Rijn en de Maas.* Ministerie van Verkeer en Waterstaat.

Rijkswaterstaat. (2012). *Onderzoeksrapport Zandmeevoerende Wellen.* 1202123-003 Den Haag: Ministry of Infrastructure and Environment.

Rijkswaterstaat, Deltares, Blueland Consultancy. (2015). *Omgaan met piping.* Rijkswaterstaat.

Schmidt, K. (2014). *Hinweise zum Einsatz von Sandsacken bei Hochwasser.* Bruchsal: Landesfeuerwehrschule Baden-Wyrttemberg.

Schweckendiek, T., Kanning, W., & Jonkman, S. (2014). *Advances in reliability analysis of the piping failure mechanism of flood defences in the Netherlands.* Delft: Deltares.

STOWA. (2012). *Inspectiewijzers waterkeringen.* Amersfoort: STOWA.

USACE. (2017). *Emergency Flood Fighting and Flood Protection - Appendix K.*

van Bree, B., & Casteleijn, A. (2017). *Kwantificering scoretabellen niet sluiten.* RWS.

VNK Office. (2012). *The national flood risk analysis for the Netherlands.* Den Haag: Rijkswaterstaat VNK project office.

VNK2. (2012). *Flood risk in the Netherlands - VNK2: The method in brief.* VNK2 project office.

Vrijling, J., Kok, M., Calle, E., Epema, W., van der Meer, M., van den Berg, P., & Schweckendiek, T. (2010). *Piping: realiteit of rekenfout.* Utrecht: Expertisenetwerk waterveiligheid.

Waterschap Rivierenland. (2017). *Werkinstructie stabiliseren zandmeevoerende wellen.* Waterschap Rivierenland.

Weisstein, E. W. (n.d.). *Normal Distribution*. Retrieved from WolframMathworld: http://mathworld.wolfram.com/NormalDistribution.html

Wiki Noodmaatregelen. (2017). *Piping*. Retrieved 07 13, 2017, from Wiki Noodmaatregelen: http://v-web002.deltares.nl/sterktenoodmaatregelen/index.php/Piping

Wiki Noodmaatregelen. (2018). *Hoe om te gaan met zandzakken*. Retrieved from Wiki Noodmaatregelen: http://v-web002.deltares.nl/sterktenoodmaatregelen/index.php/Hoe_om_te_gaan_met_zandzakken

Appendices

A) Observation D&D
B) Interviews with contractors
C) Results workshops 17/24 January

Appendix A: Deining & Doorbraak

Table A-1: Observations Deining & Doorbraak

Location	Wijhe (WDOD)	Wijhe (WDOD)	Sleeuwijk (WSRL)	Langerak (WSRL)
Time	04:00-07:30	08:00-13:40	11:08-12:00	19:45-20:35
Concerning	Detection	Detection + Implementation	Implementation	Implementation
Description	Inspection by dike watch consisting of volunteers. Time of day and weather conditions resulted in poor sight. The placed sand boil was not found.	Inspection by dike watch consisting of volunteers, the placement of the impoundment done by employees of the water board. Two sand boils that were found during the inspection were impounded. Mobilisation took a long time and the construction was done without any instructions or supervisor present.	Placement of the impoundment done by contractor with 'waakvlam' contract. Instructions and supervisors both present. Water flow simulated by garden hose.	Placement of dam in a ditch, constructed by contractor with 'waakvlam' contract. Dam was about two meters long and one meter in height. Supervisor and work instructions present.
Remarks	The dike watch did not inspect the dike consistent and in some cases they lacked knowledge of what they were doing. Clear instructions at the dike post might improve the quality of the inspections. Although there were flashlights it was very difficult to see anything in the dark.	The inspection lacked consistency. The damage indicators that were found were placed in unrealistic locations, therefore the dike watch did not take them seriously. There were more than enough sandbags present and also enough people to place them. However without any instructions or supervision the	Both work instructions and a supervisor were present, and the contractor was experienced with the construction. The placement itself went routinely and carefully. There were more than enough materials present, brought to the site by a truck with a crane	There was a supervisor from the water board present and the employees from the contractor had a clear division of tasks. Because of the time of day lights were needed for visibility, these were placed on tripod. This was a viable solution in this situation, but with higher wind speeds they will be unstable.

	placement of the emergency measure was sloppy.	attached to it. During actual high water it might not be possible to get so close to the location with the truck.	The sandbags were made of polyester, this makes them insusceptible for mold and reusable but it also makes them slick. During the construction of the dam a couple of sandbags slipped off the construction. The work instructions for constructing a dam were not followed. The first sandbags were placed with a crane and this makes it impossible to place the bags staggered. Besides that was the dam not constructed in a pyramid shape.

Table 0-2: Reported incidents by dike watch

Dijkpost	Number of notifications	Placed incidents	Reported incidents	Not noted incidents
RWZI Deventer	38	5	3	Debris, leaking pumping station
Café Ripperda	12	6	4	Tree on levee, debris
Accountant Smit	9	4	2	2x Piping
Dorpshuis Herxermarke	10	8	6	Piping, animal damage
RWZI Zwolle	13	2	0	Piping, debris
Café Zalkerveer	16	5	3	2x piping
Café IJsselzicht	6	2	1	Piping
Depot Zendijk	13	3	1	2x erosion
Van Dorp	7	2	0	Animal damage, liquefaction
Camping Haven-sevenigen	7	2	1	Liquefaction
Ons Erf	17	2	2	

Loonbedrijk Buijert	5	3	0	Animal damage, debris, erosion
De Riete	5	2	0	Liquefaction, animal damage
MFC Zalk	7	5	1	Piping, erosion outer slope, 2x crack in the crest of the levee
Ten Hove	3	2	1	Outflowing water inner berm
Total	168	53	25	

Appendix B: Interviews contractor

The reactions of the different contractors are given in this appendix. The following contractors were contacted: Tromp B.V. (T), Koek B.V. (K), Mulder-Eykelkamp (ME), and Netjes Kampen (NK). The first two are located within WSRL, the other two within WDOD.

The interviews were done in Dutch, so the answers to the questions are also given in Dutch.

Vragenlijst aannemer

1. **Wat moeten jullie leveren aan het waterschap volgens het waakvlam contract?**

   (T): Het is een klein bedrijf (1 mans bedrijf), het bedrijf moet materieel en personeel leveren voor de uitvoer van kleinere opdrachten aan de dijken in de omgeving. Ook dingen zoals het aanvullen van materiaal zoals zandzakken wordt bij de aannemer neergelegd. Grote opdrachten zijn lastig omdat hij (dhr. Tromp) het kapitaal niet heeft om tegen grotere bedrijven te competeren. D.m.v. een waakvlam contract kan hij toch werkzaam blijven voor het waterschap.

   (K): De aannemer moet enkel personeel leveren bij calamiteiten, voor de rest hebben ze geen overeenkomst voor onderhoud o.i.d.

   (ME): Het bedrijf heeft al 6 a 7 jaar een raamovereenkomst met het WDOD dat elk jaar opnieuw gewonnen moet worden. Volgens dit contract herstellen ze 2x per jaar de schades die gevonden zijn bij de schouw. Daarnaast doen ze klein onder aan de waterkeringen zoals maaien en assisteren ze bij het aanbrengen van noodmaatregelen.

   (NK): De aannemer heeft 2 contracten lopen bij het WDOD, 1 voor het leveren van personeel en materieel voor onderhoudswerkzaamheden aan de dijken (verwijderen daak, dierschade herstellen e.d.). En 1 contract voor het leveren van materieel voor maaiwerkzaamheden van watergangen. Het bedrijf heeft daarnaast ook een contract lopen bij waterschap Vallei en Veluwe voor onderhoud aan de dijken.

   Het plaatsen van de noodmaatregelen valt onder het onderhouds contract.

2. **Zijn jullie toegewezen aan bepaalde dijkvakken, of kunnen jullie in het gehele waterschap worden ingezet?**

   (T): Een specifiek gebied is niet toegewezen, echter krijgen ze vooral opdrachten in de buurt. Het is nog nooit voorgekomen dat hij bv naar de andere kant van het waterschap moest voor een opdracht.

   (K): Er is geen specifiek gebied toegekend, echter worden ze alleen ingezet in de omgeving waar ze gevestigd zijn (Werkendam)

   (ME): Ze worden ingezet in het gebied tussen Deventer en Zwolle.

   (NK): De aannemer kan worden ingezet in het gebied rondom Kampen en Ommen.

3. **In hoeverre zijn jullie bekend met de toegewezen gebieden? Weten jullie welke plekken moeilijk bereikbaar zijn en waar je je materieel wel of niet kan gebruiken en wordt er vanuit het waterschap doorgegeven als er toegangswegen niet te gebruiken zijn?**

   (T): De aannemer is bekend in de omgeving doordat hij er al jaren werkzaam is en ook in het gebied woont. De aannemer dient slechts als verlengstuk van het waterschap, en de toegangswegen e.d. worden dus ook geregeld door het waterschap.

   (K): Het personeel is bekend in het gebied doordat ze er gevestigd zijn en ook jaarlijks meedoen met oefeningen van het waterschap.

   (ME): Goed bekend in het gebied, het bedrijf is in Zwolle gevestigd en door dat ze al meerdere jaren een overeenkomst hebben met het waterschap is de kennis van hoe ze op bepaalde stukken van waterkeringen moeten komen aanwezig binnen het bedrijf.

   (NK): De aannemer is gevestigd in Kampen, en hierdoor zijn ze ook goed bekend in het gebied. Door onderhouds werkzaamheden is de toegankelijkheid van de dijken ook bekend op dit moment, dit was minder het geval aan het begin van de contractperiode.

4. **Hoe wordt er door het waterschap gespecificeerd wat jullie moeten doen (type maatregelen, afmetingen, etc.) en waar jullie precies heen moeten?**

   (T): De aannemer heeft een vast contactpersoon bij het waterschap die doorgeeft wat ze moeten doen en waar ze moeten zijn. Hele specifieke ontwerpen krijgen ze niet, maar er wordt verteld wat voor maatregel er geplaatst moet worden en hoe groot deze ongeveer moet zijn. Dit contactpersoon is ook op de locatie aanwezig tijdens de uitvoer

   (K): De wachtcommandant belt de aannemer dat ze een x aantal mensen moeten leveren. Hierbij wordt de locatie gemeld en hoe laat ze er moeten zijn, ook krijgen ze een uitleg wat voor maatregel er geplaatst moet worden.

   (ME): Vast contact persoon bij het waterschap, deze geeft aan wat en waar er precies gedaan moet worden.

   (NK): Als er een melding voor een noodmaatregel binnenkomt krijgen ze te horen wat ze moeten leveren (personeel en machines) en de locatie waar ze heen moeten, op de locatie wordt verdere uitleg gegeven.

5. **Worden jullie door het waterschap op de hoogte gehouden over aankomend hoogwater?**

   (T): Ja~~/nee~~
   (K): Ja~~/nee~~
   (ME): ~~Ja/~~nee
   (NK): ~~Ja/~~nee

   Indien ja ga verder met vraag 6. Indien nee ga verder met vraag 7.

6. **Zijn deze updates over het hoogwater nuttig voor bv voorbereiding?**

(T): Ja/~~nee~~, want:

Ongeveer een week van te voren wordt de aannemer op de hoogte gebracht van aankomend hoogwater. Dit is nuttig, aangezien het een eenmansbedrijf is moet extra personeel ingehuurd worden, hier heeft hij wel vaste mensen voor. Door de melding van het waterschap heeft de aannemer voldoende tijd om deze mensen ook op de hoogte te stellen dan ze eventueel opgeroepen kunnen worden.

(K): Ja/~~nee~~, want:

Bij hogere afvoeren worden ze soms tot 5 dagen van te voren op de hoogte gehouden, dit verschilt per situatie. Het kan helpen bij het regelen van genoeg personeel maar over het algemeen is dat geen probleem.

(ME): ~~Ja/~~nee, want:

Updates niet per se nodig, het bedrijf heeft een grote (±50 man) flexibele organisatie waardoor er altijd wel genoeg personeel beschikbaar is. Er is daarnaast bijna wel dagelijks contact met het waterschap waardoor ze wel op de hoogte worden gehouden.

(NK): Ja/~~nee~~, want:

De melding dat er iets gedaan moet worden komt meestal last minute of de dag van te voren. Als er van te voren wordt gewaarschuwd voor hoogwater en mogelijke werkzaamheden zou dit helpen met de mobilisatie. Het materieel staat namelijk verspreid over het gebied bij verschillende werkzaamheden, als er van te voren gewaarschuwd wordt kunnen er machines worden klaargezet en dit zou tijd schelen.

7. **Hoeveel materiaal hebben jullie standaard op voorraad liggen en indien er meer nodig is, waar moeten jullie dit ophalen?**

(T): De aannemer heeft zelf geen materiaal op voorraad liggen, maar heeft alleen materieel dat hij zelf mee moet nemen (graver e.d.). Materiaal dat nodig is voor de uitvoer van de maatregelen moet worden opgehaald bij het dijkmagazijn. De aannemer weet niet precies hoeveel er van alles op voorraad ligt, maar naar zijn inzicht is het wel ruim voldoende.

(K): De aannemer hoeft alleen personeel te leveren, ze hebben dus zelf geen materiaal op voorraad liggen en het hoeven het zelf ook niet op te halen.

(ME): Niets, moet worden opgehaald in depots

(NK): De aannemer heeft zelf geen materiaal op voorraad liggen, al het materiaal moet worden opgehaald bij het dijkdepot

8. **Wordt er bij de uitvoer van de noodmaatregelen gebruik gemaakt van werkinstructies?**

(T): ~~Ja/~~nee
(K): Ja/~~nee~~
(ME): ~~Ja/~~nee
(NK): ~~Ja/~~nee

Indien ja: ga verder bij vraag 10. Indien nee: ga verder bij vraag 9.

9. Op welke manier wordt de uitvoer van de noodmaatregelen geleid en gecontroleerd?

(T): Tijdens de uitvoer van de maatregelen is er een vast contactpersoon van het waterschap aanwezig voor verdere instructies en controle van de maatregel.

(K): O.b.v. de werkinstructies, daarnaast is er ter plekke ook iemand van het waterschap aanwezig die mondelinge instructies geeft.

(ME): De aannemer moet vooral assisteren bij de uitvoer van de maatregelen, vooral het vervoeren van materiaal en leveren van materieel. De uitvoer zelf wordt gedaan door personeel van het waterschap. Hierdoor is er geen bekendheid van de werkinstructies of hoe de maatregelen precies worden uitgevoerd.

(NK): Op de locatie is iemand van het waterschap aanwezig die instructies geeft wat er precies moet gebeuren en de maatregel ook controleert. Binnen het bedrijf zijn er wel iets van werkinstructies aanwezig, maar als er echt nood aan de man is wordt de uitvoer op de ervaring van het personeel gedaan.

10. ***Alleen beantwoorden als het antwoord op vraag 9 'ja' is.***
Op wat voor manier worden de werkinstructies gebruikt? (vooraf instructies/leidraad bij de uitvoer/achterafcontrole/etc.)

(T): n.v.t.
(K): Voor de aannemer als leidraad bij de uitvoer, wordt vooraf gekeken hoe het gedaan moet worden.
(ME): n.v.t.
(NK): n.v.t.

11. *Alleen beantwoorden als het antwoord op vraag 9 'ja' is.*
Zijn er punten waarop de werkinstructies verbeterd zouden kunnen worden, zowel inhoudelijk als vormgeving?

(T): n.v.t.
(K): Nee, is aan het waterschap om dat aan te passen.
(ME): n.v.t.
(NK): n.v.t.

12. Met welke van de volgende drie maatregelen zijn jullie bekend, en hoe vaak hebben jullie deze maatregelen als eens moeten aanbrengen of hebben jullie geoefend met de uitvoer?

Opkisten
Opzetten waterpeil in de sloot:
Filterconstructie

(T): Elk jaar is er een oefening vanuit het waterschap waar de aannemer aan mee doet, hierbij wordt elk jaar een andere maatregel geoefend. Daarnaast heeft de aannemer veel ervaring doordat hij al jaren actief is en ook tijdens het hoogwater van 1995 heeft hij veel ervaring opgedaan. Hij heeft alle maatregelen geoefend en uitgevoerd.

(K): Elk jaar wordt er een andere maatregel geoefend met het waterschap, hierdoor zijn dus bekend met de uitvoer van alle maatregelen. Als de maatregelen vaker zouden worden geoefend zou dat voordelig zijn, dan wordt de uitvoer ervan meer een routine taak voor het personeel.

(ME): De aannemer wordt af en toe wel gevraagd voor het helpen bij oefeningen, maar ook hier wordt de uitvoer van de maatregelen gedaan door het personeel van het waterschap.

(NK): Vooral door werkzaamheden bij Vallei en Veluwe heeft de aannemer ervaring met het plaatsen van de maatregelen. Ze worden echter niet betrokken bij de oefeningen.

Scenario:
Vanuit het waterschap komt de melding binnen van een wel die opgekist moet worden. De kist moet 70cm hoog worden met een diameter van 1.5m. Hoe gaat uw bedrijf met een dergelijke inkomende melding om, wat is de procedure, en wat moet er geregeld worden, ect.?

(T): Als een dergelijke melding binnen komt wordt het extra personeel gecontacteerd hierna gaan we met het benodigde materieel naar het dijkmagazijn om de zandzakken op te halen. Vervolgens gaan we naar de locatie waar de wel wordt opgekist. Hierbij is het belangrijk te letten op de manier waarop de zandzakken gestapeld worden.

(K): Zie antwoord vraag 4

(ME): Personeel wordt opgeroepen en de benodigde materialen worden opgehaald op het depot, het materiaal en materieel wordt naar de locatie gebracht, hier wordt het uitvoerend personeel van het waterschap geassisteerd waar dat nodig is.

(NK): Als de melding binnenkomt wordt zo snel mogelijk het benodigde personeel gebeld. Deze gaan met de benodigde machines naar het dijkmagazijn om de materialen op te halen. Ondertussen gaat de hoofduitvoerder naar de locatie toe. Hier overlegd hij met de persoon van het waterschap wat er precies moet gebeuren. Zodra het overige personeel er is kan er begonnen worden met de constructie en kan er goed leiding gegeven worden.

Appendix C Results workshop

In this appendix the results of the workshops are given, 7 groups from 6 different water boards and 2 teams from CTW participated in the workshop. As the workshop was held in Dutch, the results are also displayed in Dutch.

Vraag 1: Hoe wordt het extra personeel voor de inspecties gemobiliseerd?
De manier waarop extra personeel wordt opgeroepen is verschillend (mail, whatsapp, bellen), maar dit staat over het algemeen wel beschreven een draaiboek of calamiteitenplan. Personeel voor inspecties komt veelal uit de eigen organisatie, 3 groepen gebruiken vrijwilligers als dijkwacht of als aanvulling op eigen personeel.

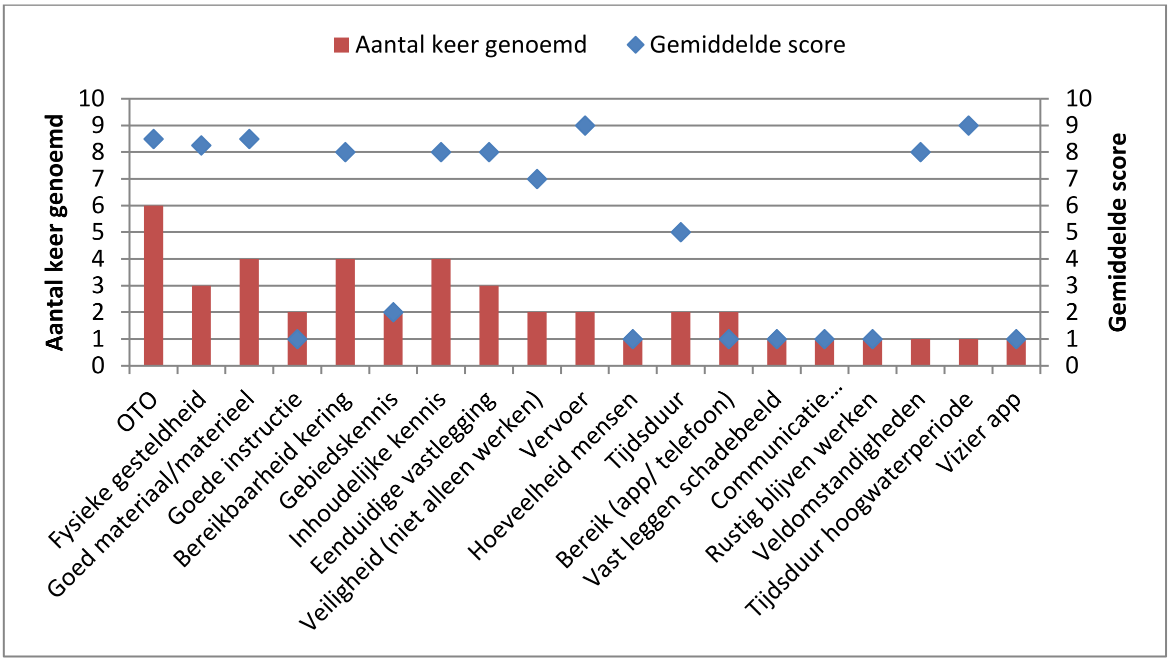
Vraag 2: Wat is de kans dat de mobilisatie niet gaat zoals gewenst en hoe kan dit worden opgevangen?
De kans dat de mobilisatie mis gaat is volgens alle partijen erg klein. Defensie, aannemers met waakvlamovereenkomsten of meer mensen inplannen dan eigenlijk nodig is zijn opties om eventuele te korten op te vangen.

Vraag 3 tm 5: Welke factoren spelen een rol met betrekking tot de kwaliteit van de inspecties, hoe belangrijk zijn deze factoren en wat is de kans dat deze uitvallen?
In Tabel 1 zijn de gemiddelde waarden en de standaard deviatie van de factoren gegeven die al ingevuld waren vooraf aan de workshop. In Figuur 1 zijn de factoren gegeven die aangevuld zijn door de groepen met de gemiddelde score erbij. De spreiding van de factoren die genoemd zijn is erg groot, de factoren met de gemiddelde score van 1 zijn slechts door 1 groep genoemd en hebben geen waarde toegekend gekregen door deze groep.

Van de factoren die al genoemd waren blijken de beschikbaarheid van het personeel en de communicatie middelen het belangrijkste. De faalkans die aan de communicatie middelen wordt toegewezen is ook opvallend, voor een factor die belangrijk blijkt te zijn is de faalkans erg hoog. Door de groepen zelf worden de opleiding, bereikbaarheid en inhoudelijke kennis het meeste genoemd, deze factoren krijgen ook een hoge score.

Tabel 1: Factoren inspectie

Factoren	Score	Standard afwijking	Faalkans
Weer	6,39	2,71	-
Tijdstip dag	6,78	2,22	-
Waterstanden	6,72	2,28	-
Beschikbaarheid dijkwachten	8,44	1,59	5-30%
Beschikbaarheid dijkpostleider	8,44	1,59	5-30%
Eten en drinken	7,00	1,12	1-90%
Communicatie middelen	8,78	1,09	20-90%
Schaderegistratie formulieren	7,00	2,40	0-90%
Computers dijkposten	7,22	2,17	20-90%



Figuur 1: Genoemde factoren door waterschappen

Vraag 6 en 7: Wat wordt er aan de dijkwachten meegegeven voorafgaand aan een inspectie, hoe belangrijk zijn deze punten en wat is de kans dat ze alsnog fout gaan.
De focus ligt vooral op de aandachtpunten voor de dijkwacht en de dingen die al eerder gemeld zijn. Dit wordt 6 keer genoemd krijgt ook een hoge score van alle groepen (8.5 gemiddeld). Slechts 4 partijen geven instructies/aandachtspunten mee over de communicatie dit wordt echter wel belangrijk bevonden (8 gemiddeld). Eigen veiligheid wordt 5 keer genoemd er krijgt een hoge score toegekend (9.4 gemiddeld)

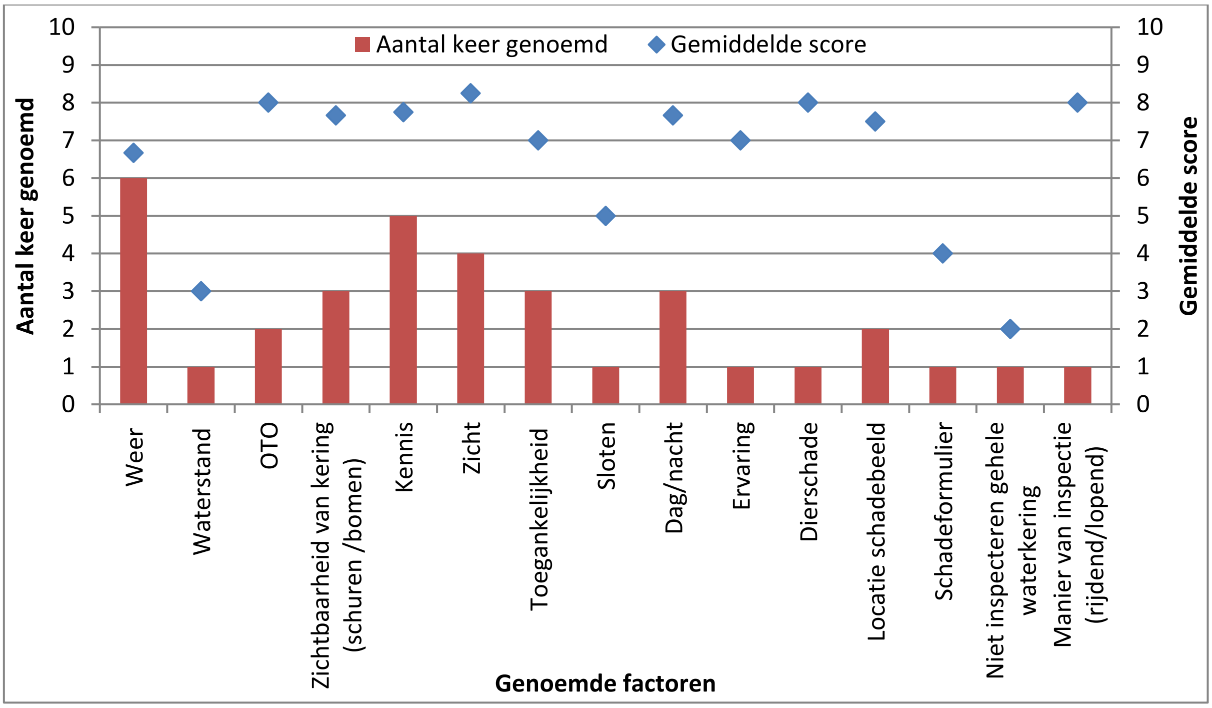
Vraag 8: Welke factoren hebben invloed op het wel of niet vinden van een zwakke plek en hoe belangrijk zijn deze factoren?
De factoren die door de groepen genoemd zijn, zijn weergegeven in Figuur 2. In Tabel 2 staan de gemiddelde scores van de factoren met de spreiding tussen de groepen. De factoren zonder standaard afwijking zijn maar 1x genoemd.

Het weer wordt door 6 van de 9 groepen genoemd met een gemiddelde score van 6.7, deze factor is dus wel van invloed maar niet uitermate belangrijk volgens de groepen. Kennis en zicht worden respectievelijk door 5 en 4 groepen genoemd, beide factoren krijgen een hoge gemiddelde score en een kleine standaard afwijking. Deze factoren kunnen dus als belangrijk worden beschouwd.

Tabel 2: Factoren vinden zwakke plek

Factoren	Gemiddelde score	Standaard afwijking
Weer	6,7	0,75
Waterstand	3,0	
OTO	8,0	
Zichtbaarheid van kering (schuren /bomen)	7,7	1,25
Kennis	7,8	0,43
Zicht	8,3	0,43

Toegankelijkheid	7,0	2,94
Sloten	5,0	
Dag/nacht	7,7	2,05
Ervaring	7,0	
Dierschade	8,0	
Locatie schadebeeld	7,5	0,50
Schadeformulier	4,0	
Niet inspecteren gehele waterkering	2,0	
Manier van inspectie (rijdend/lopend)	8,0	



Figuur 2: Factoren vinden zwakke plek

Vraag 9: Op welke manier worden de gevonden schadebeelden doorgeven?

Tabel 3: Communicatie middelen

	A01	A02	A03	A04	A05	A06	A07	B01	B02
Portofoon	X		X		X Back up 2	X		X	
Schadeformulieren				X	X Back up 1			X	X backup
Schade registratie applicatie	x	X	X	X	x	x	x	X	X
Anders		Telefonisch		Mobile telefoon	Satelliet telefoon tussen dijkpost				

					en kantoor				

Vraag 10: Communicatie niveau

In Tabel 4 zijn de communicatie niveaus weergegeven die de groepen aan hun organisatie geven. Over het algemeen gaan de groepen ervan uit dat het grootste deel van hun communicatie perfect is.

Tabel 4: communicatie niveau

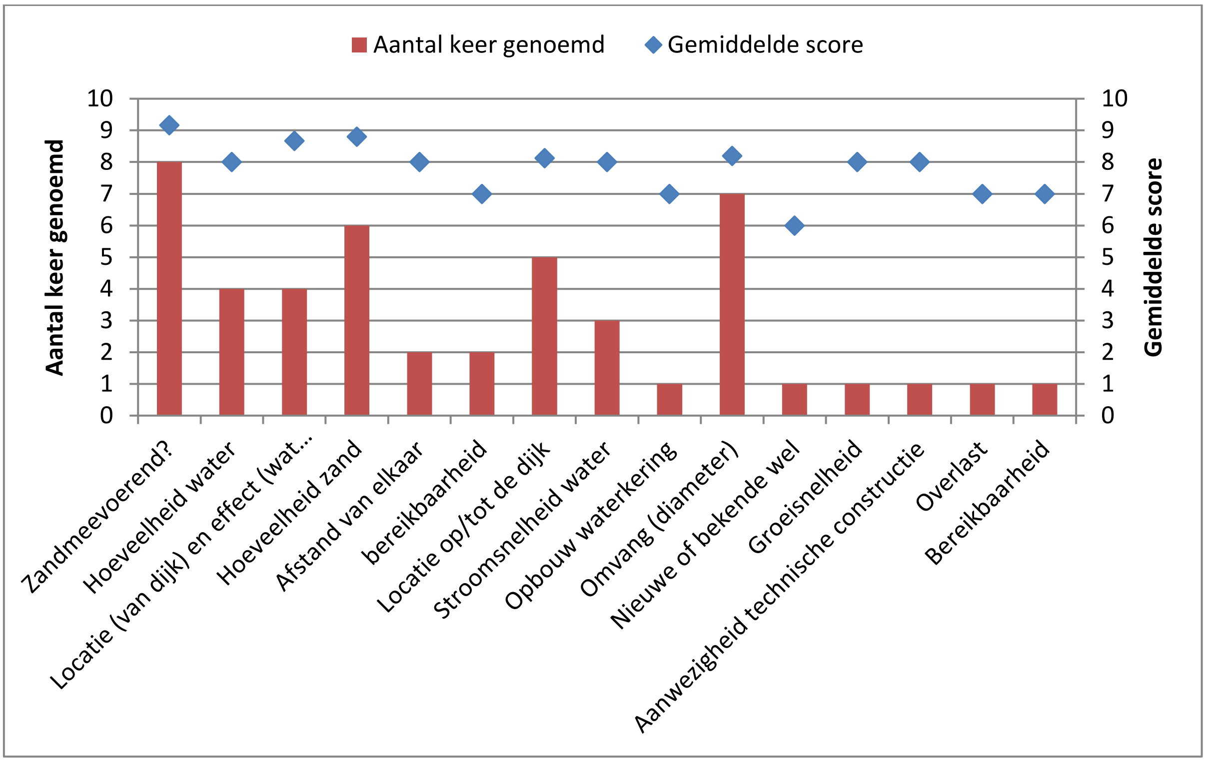
	A01	A02	A03	A04	A05	A06	A07	B01	B02
Communcatie niveau	% van de gevallen								
Perfecte communicatie (geheel volledig, geen missende gegevens)	50	80	-	10-30	75	70	60	95	45
Onvolledige communicatie (bv afmetingen schade vergeten)	25	10	-	30-60	10	30	20	0	20
Onjuiste communicatie (bv verkeerd schadebeeld, verkeerde locatie)	25	10	-	30-40	10	20	10	10	30
Geen communicatie (schadebeeld gemist)	Weten we dan niet	5	-	10-30	5	10	10	20	5

Vraag 11: Welke aspecten spelen een rol bij het vaststellen van de prioritering van verschillende meldingen?

De belangrijkste factor blijkt het wel of niet zandmeevoerend zijn van een wel, dit krijgt de hoogste score en heeft de kleinste standaard afwijking. Daarnaast worden de hoeveelheid zand, de locatie t.o.v. de dijk en de omvang van de krater belangrijk geacht. Deze factoren worden ook het meeste genoemd door de groepen.

Tabel 5: Factoren prioritering

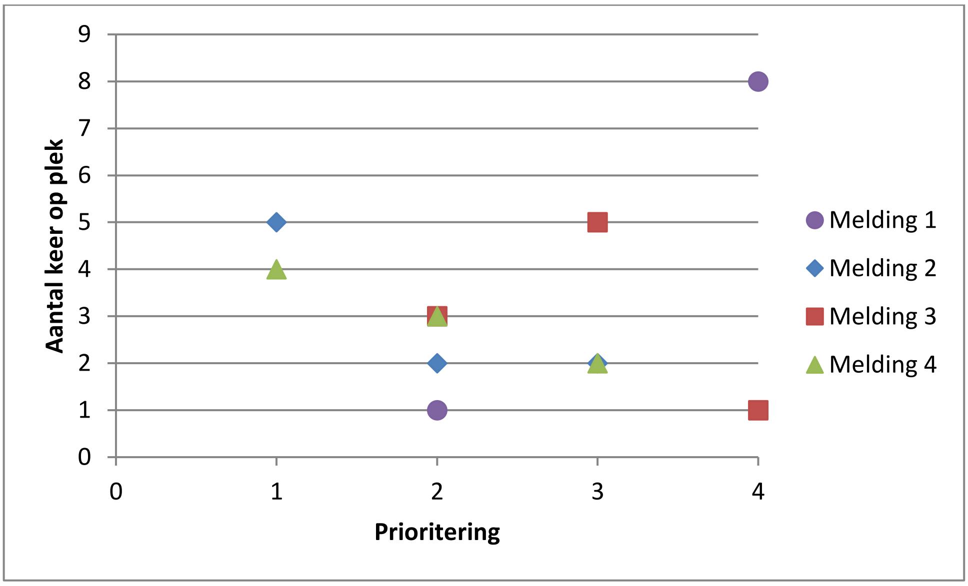
Factoren	Gemiddelde score	Standaard afwijking
Zandmeevoerend?	9,1	0,69
Hoeveelheid water	8	2
Locatie (van dijk) en effect (wat voor achterland)	8,7	1,89
Hoeveelheid zand	8,8	1,6
Afstand van elkaar	8	
bereikbaarheid	7	
Locatie op/tot de dijk	8,1	0,74
Stroomsnelheid water	8	
Opbouw waterkering	7	
Omvang (diameter)	8,2	0,98
Nieuwe of bekende wel	6	
Groeisnelheid	8	
Aanwezigheid technische constructie	8	
Overlast	7	
Bereikbaarheid	7	



Figuur 3: Genoemde factoren prioritering

Vraag 12 en 13: Maak een prioritering en motiveer uw keuze.

In Figuur 4 is de prioritering van de 4 meldingen te zien. De horizontale as geeft de prioritering weer en de verticale as hoe vaak een melding op die plek in de prioritering geplaatst is. Hieruit blijk er nog veel verschillen zijn in de prioritering, maar dat vooral melding 2 en 4 belangrijk worden geacht. Opvallend is wel dat de motivatie achter de prioritering wel bij de groepen op hetzelfde neer komt. De omvang van de schade en de hoeveelheid uitstromend zand in bepalend voor de prioriteit van een melding. Daarnaast wordt de afstand tot de kering ook genoemd als indicator



Figuur 4: Prioritering

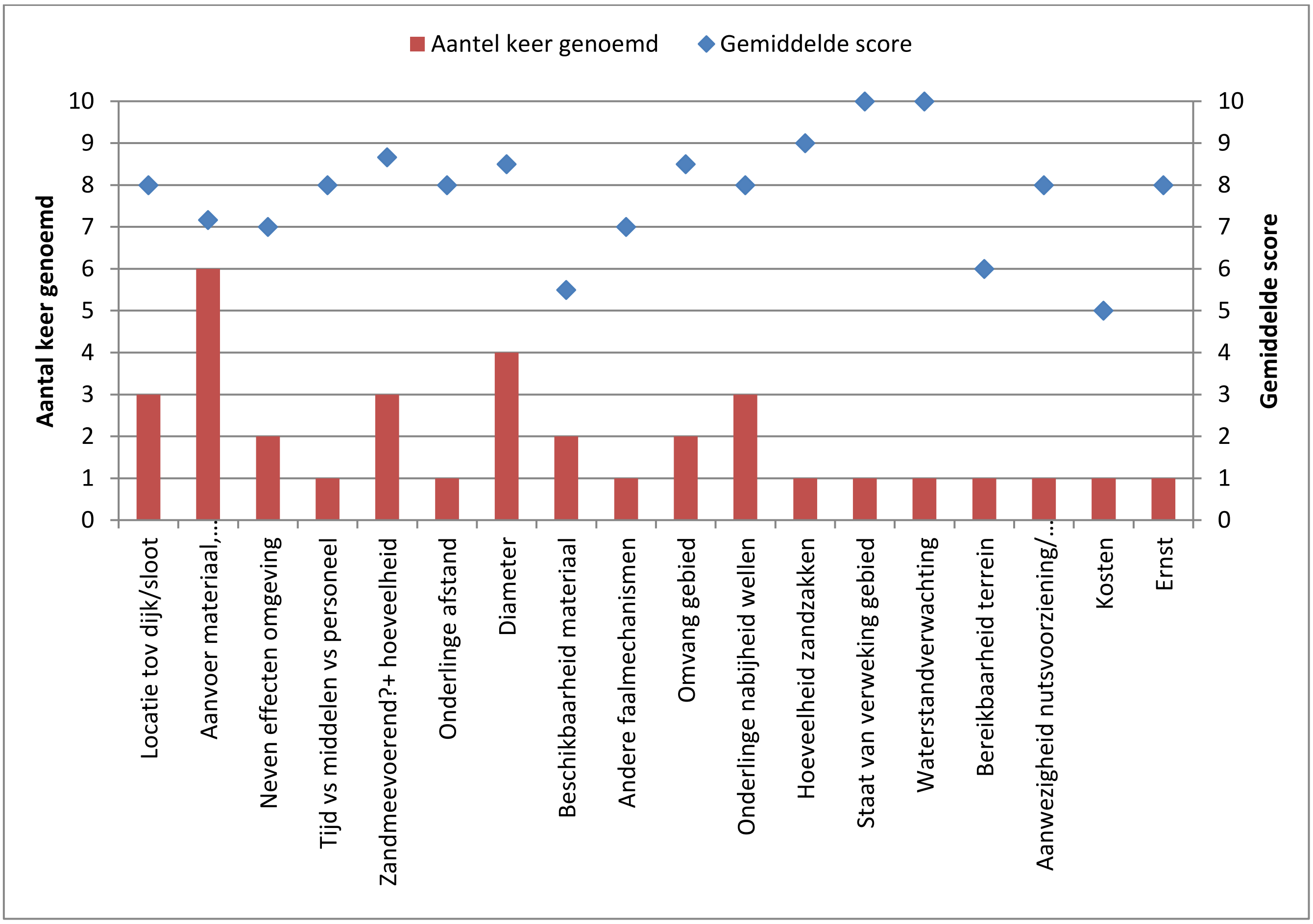
Vraag 14: Leg uit hoe je zeker weet dat je het juiste schadebeeld en faalmechanisme hebt vastgesteld.
Veelal gebruik van beeldmateriaal, 5 groepen laten ook nog een extra inspectie plaatsvinden door specialist.

Vraag 15 welke factoren spelen een rol om er voor te zorgen dat de juiste maatregel wordt vastgesteld?
De spreiding van factoren ligt weer veel uit elkaar bij de verschillende groepen, de scores van de meeste factoren die door meerdere groepen genoemd zijn liggen wel dicht bij elkaar (standaard afwijking <1) en de groepen zijn het dus eens over het belang van deze factoren. De bereikbaarheid en de diameter worden respectievelijk door 5 en 4 groepen genoemd en krijgen een hoge score toegewezen. Deze factoren kunnen dus als het belangrijkste worden geacht.

Tabel 6: Factoren keuze maatregel

Factoren	Gemiddelde score	Standaard afwijking
Locatie tov dijk/sloot	8	0,82
Aanvoer materiaal, bereikbaarheid locatie/zwaar materieel	7,2	1,67
Neven effecten omgeving	7	
Tijd vs middelen vs personeel	8	
Zandmeevoerend?+ hoeveelheid	8,7	0,94
Onderlinge afstand	8	
Diameter	8,5	0,5
Beschikbaarheid materiaal	5,5	2,5
Andere faalmechanismen	7	
Omvang gebied	8,5	0,5
Onderlinge nabijheid wellen	8	
Hoeveelheid zandzakken	9	

Staat van verweking gebied	10	
Waterstandverwachting	10	
Bereikbaarheid terrein	6	
Aanwezigheid nutsvoorziening/ bebouwing	8	
Kosten	5	
Ernst	8	



Figuur 5: Genoemde factoren keuze maatregel

Vraag 16: Kies een maatregel, welke factoren spelen een rol om er voor te zorgen dat deze snel en effectief wordt ingezet.

6 van de 7 groepen die een maatregel gekozen hebben kiezen voor opkisten van de wellen. De manier waarop verschilt wel, allen in 1 kist of apart. 1 groep kist voor het toepassen van een filterconstructie. De aanwezigheid van voldoende materiaal wordt het meeste genoemd als belangrijk voor een snelle en efficiënte inzet van de maatregel.

Tabel 7: Keuze maatregel

Groep	Maatregel	Factoren
A01	Opkisten wellen 1e 2x zand meevoerend 2e 1x niet zand voerend monitoren	Afstand tot elkaar 2 wellen in 1 kist indien te dicht bij elkaar
A02	Opkisten	Bereikbaarheid

		Benodigd materiaal/materieel Kennis medewerkers Aanvalsplan/ beschrijving werkwijze
A03	Zand voerende wellen opkisten	Beschikbaarheid materialen Beschikbaarheid personeel (aannemer) en materieel
A04	-	-
A05	-	Beheer maatregel voor handen? Van te voren bedacht → aanvalsplan Getrainde mensen Noodmaterialen voorhanden?
A06	Opkisten van wel	Bereikbaarheid Voorraad in dijkmagazijn Kennis van het personeel dat werkzaamheden uitvoert Hoeveelheid personeel Werkinstructies
A07	Per stuk opkisten, beginnend met zand voerende	Precieze locatie Materiaal 'boodschappen lijstje' Iemand die de leiding neemt + werkinstructie
B01	Gelet op afmetingen wellen monitoren, eventueel aanbrengen waterdoorlatend doek + grind	Bereikbaarheid Bodemgesteldheid Uitbreidbaarheid maatregel Kosten
B02	Opkisten, 1 grote kist (granulair filter zie je niet)	Bereikbaarheid Beschikbaarheid materiaal, materieel, mensen Ervaring, kennis

Vraag 17 en 18: Er zijn een aantal factoren genoemd die invloed hebben op de efficiënte inzet van de maatregel, geef voor elk hiervan het belang aan en de kans dat ze uitvallen (als ze beïnvloedbaar zijn).

Tabel 8: Factoren keuze maatregel

Factoren	Gemiddelde score	Standaard afwijking	Faalkans (%)
Invloed op ander faalmechanismen	7,4	2,57	
Beschikbare ruimte	6,2	2,10	
Beschikbaarheid van de maatregel	7,1	2,59	0-40
Verwachte behoefte mbt maatregel	6,8	1,94	
Bereikbaarheid	7,7	1,70	10-70
Tijd (beschikbaar vs nodig)	7,8	1,13	20-80
Beschikbaarheid en kwaliteit materiaal	7,6	2,18	10-80
werkinstructies	6,6	1,64	5-70

Vraag 19 en 20: Hoe stel je vast welke materialen en materieel je nodig hebt voor de maatregel, en hoeveel? Wat zijn de voor en nadelen van deze aanpak?
De methodes verschillen erg per groep, werkinstructies en ervaring worden een aantal keer genoemd als basis voor de afmetingen.

Vraag 21: Op welke manier is de opslag van materiaal geregeld binnen uw waterschap?

Tabel 9: Opslag materiaal

	A01	A02	A03	A04	A05	A06	A07	B01	B02
Depots	X		X	X	X	x	X	x	x
Bij aannemers	x			X	X		x	x	X
anders		Waakvlam overeenkomsten	handel		Enorme beschikbaarheid zand				leveranciers

Vraag 21 en 23: Wat ligt er op deze locaties op voorraad en hoe worden eventuele tekorten van materiaal tijdens hoogwater opgelost?

Een deel van de groepen vertrouwt op leveranciers indien er tekorten zijn tijden hoogwater. De vraag is of dit wenselijk is, de kans is dan namelijk aanwezig dat leveranciers de benodigde materialen ook niet op voorraad hebben.

Tabel 10: Hoeveelheid materiaal + oplossing eventuele tekorten

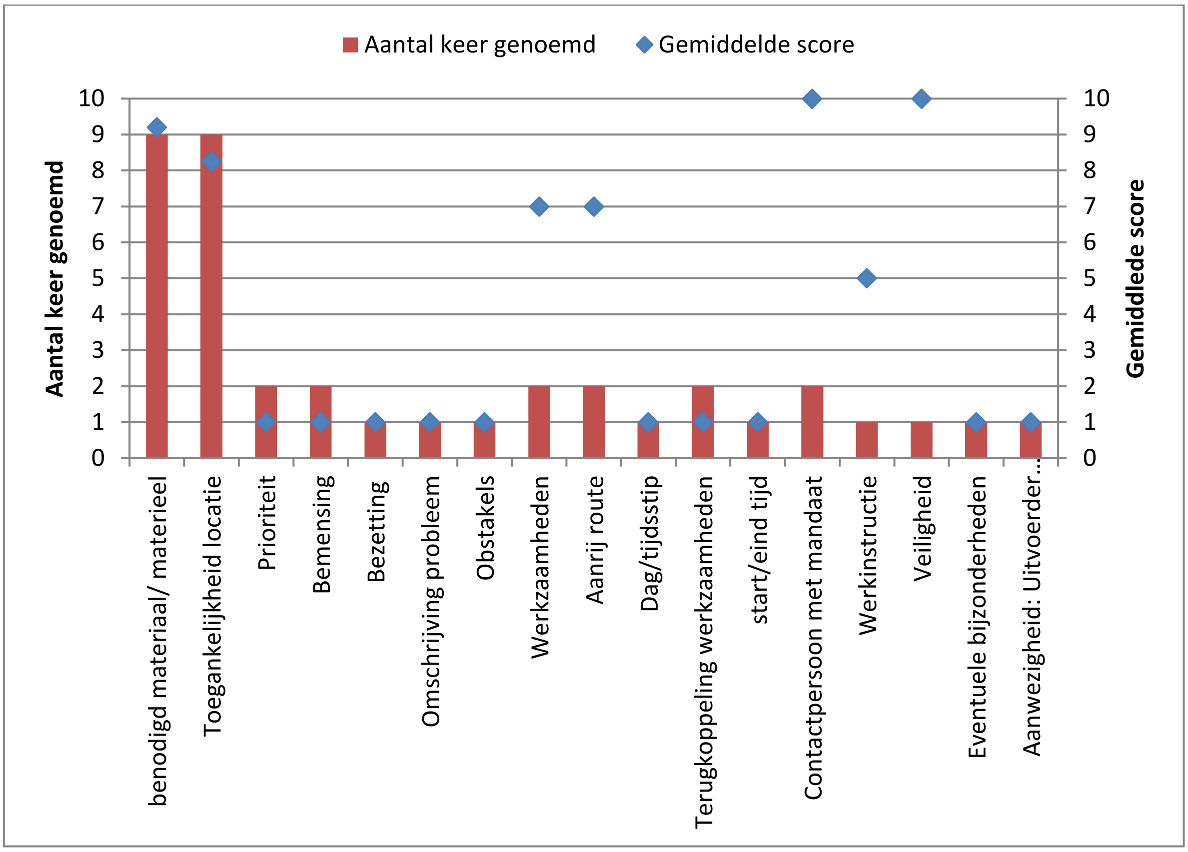
Groep	Voorraad	Oplossing tekorten.
A01	Geotextiel 30/35 rollen Zandzakken leeg jute 10000 → waakvlam ook nog 10000 Krammen 7 x 5000 kabels/ palen Plastic landbouw folie 3 rollen	Platform crisisbeheersing, collega waterschappen Aannemers defensie
A02	Zandzakken ongevuld 8000 Zandzakken gevuld 500 Doek/ geotextiel	Nvt
A03	Zandzakken Doek (waterdoorlatend) Krammen Bigbags (alles behalve zand)	Waakvlam overeenkomsten voor zandzakken Doek door leveranciers
A04	Zand zakken 300000 Schotbalken bij bijna iedere sluis Stortsteen in grote hoeveelheden Noodpompen	Aannemers/ waterschappen in de omgeving improviseren
A05	Geotextiel 9 x 500m Bigbags 1000 Zandzakken 20000 Jutte 12 x 100m Aanlijnmiddelen 2 Pennen veel	Bellen leveranciers Evt andere waterschappen
A06	Zandzakken 10000 Vulmachine Zand 100m^3 Klei 100m^3 Rollen grond doek	Overeenkomsten met leveranciers
A07	Zandzakken 10000 Vulmachine	Link met andere waterschappen Aannemers met waakvlam overeenkomst

	Zand 100m^3 Klei 100m^3 Rollen grond doek	
B01	Zie lijst dijkposten (zandzakken, doek, pennen, zeilen, bigbags, zandzak vulmachine, enz)	Waakvlamovereenkomsten, markt, defensie, evt andere waterschappen
B02	Genoeg voor een paar wellen Miljoenen m^3 zand, klei en puin, 100000 zandzakken bij leveranciers 10000 eigen voorraad	Bellen

Vraag 24 en 25: Door welke partij wordt de maatregel binnen uw waterschap uitgevoerd, hoe wordt deze partij op de hoogte gebracht?
Bij de 6 van de 9 groepen worden noodmaatregels uitgevoerd door eigen personeel, 4 daarvan met hulp van aannemers. Bij de overige 3 groepen worden de werkzaamheden uitgevoerd door enkel aannemers.

Vraag 26: Worden de uitvoerders op de hoogte gehouden van de ontwikkelingen in waterstanden?
Bij slechts 2 van de 9 groepen worden de uitvoerders niet op de hoogte gehouden. Beschikbaarheid van materiaal en personeel wordt als reden gegeven om dit wel te doen. Reden om dit niet te doen is dat de informatie op dat moment nog niet relevant is.

Vraag 27 en 28: Welke informatie wordt er naar de uitvoerende partij gecommuniceerd, hoe belangrijk is dit en wat is de kans dat deze dingen alsnog niet goed worden uitgevoerd?
In Figuur 6 zijn de factoren te zien die naar de uitvoerende partij worden gecommuniceerd. De eerste 2 factoren in deze figuur waren al genoemd en slecht door een enkele groep is er een score aan deze factoren gehangen.

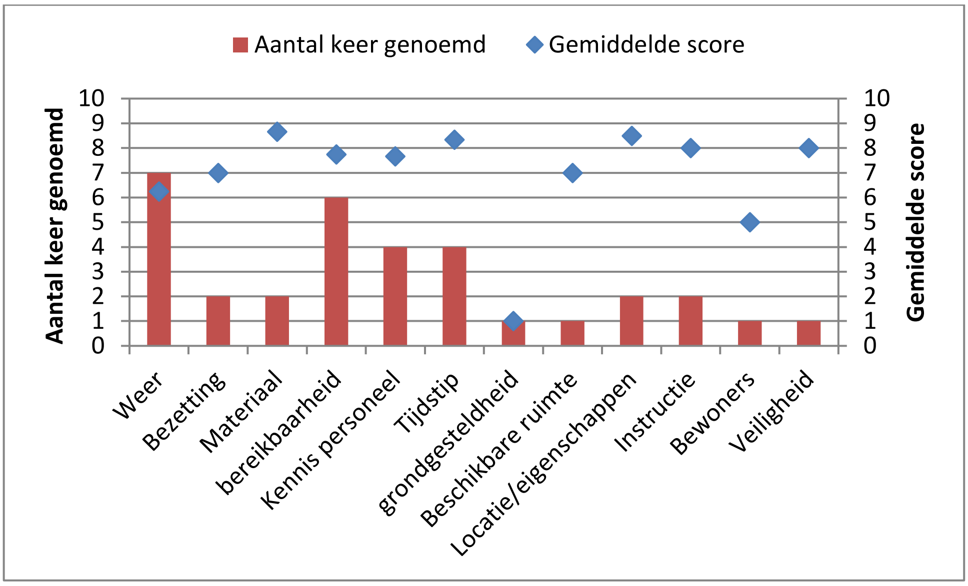


Figuur 6: Communicatie naar uitvoeder

Vraag 29: Welke factoren hebben invloed op de uitvoer van de noodmaatregelen?
Bereikbaarheid, kennis van het personeel en het tijdstip worden het meeste genoemd en krijgen de hoogste gemiddelde score. De kennis van het personeel heeft wel een grote standaard afwijking, de groepen zijn het dus niet eens over het belang van deze factor.

Tabel 11: Factoren uitvoer noodmaatregelen

Factoren	Gemiddelde score	Standard afwijking	Faalkans (%)
Weer	6,3	2,94	
Bezetting	7	1	10
Materiaal	8,7	0,94	
bereikbaarheid	7,8	0,43	15-30
Kennis personeel	7,7	2,05	30-90
Tijdstip	8,3	0,47	
grondgesteldheid	1		
Beschikbare ruimte	7		10-50
Locatie/eigenschappen	8,5	0,5	30-90
Instructie	8		25
Bewoners	5		
Veiligheid	8		10



Figuur 7: Genoemde factoren uitvoer noodmaatregelen

Vraag 30 en 31: Op welke manier wordt de maatregel geleid en wat is de kans dat het op deze manier niet goed uitgevoerd wordt?
De uitvoering van de maatregelen wordt veelal (6 van de 9) geleid op basis van de ervaring van de leiding gevende. Van deze 6 groepen wordt er daarnaast bij 2 ook gebruik gemaakt van werkinstructies. Er zijn 2 partijen die enkel gebruik maken van de werkinstructies ipv werkervaring. De faalkans die aan de uitvoering wordt toegekend heeft nog wel een grote spreiding, van 0 - 40%.

Tabel 12: Begeleiding uitvoering maatregelen

	A01	A02	A03	A04	A05	A06	A07	B01	B02
instructies op basis van ervaring door intern personeel	x	X	x	30%	X	x		X	
werkinstructies in handen van intern personeel		X		40-50%			X (+ ervaring)	X	X
Instructies op basis van ervaring van een externe leidinggevende				40-50%				X	
Werkinstructies in handen van externe leidinggevende				60-95%					X
Anders, namelijk….				Op gevoel 50-80%					

Kans niet goed uitvoeren	10%	-	40%		20%	10%	5%	20%	<5%

Vraag 32: Door wie wordt de uitgevoerde maatregel gecontroleerd?
Bij alle groepen wordt de maatregel gecontroleerd, ofwel door een wachtcommandant, of door dijkwachters. Slecht 1 groep geeft aan dat dit gebeurt op basis van werkinstructies.

Vraag 33: Wat is de kans dat uitgevoerde maatregel niet goed wordt bevonden? Wat wordt er gedaan als dit het geval is?
De kans dat dit het geval is ligt redelijk ver uit elkaar (5-40%). Herstel werkzaamheden worden niet gespecificeerd.

Vraag 34: Beschrijf welke stappen gedaan moeten worden om de noodmaatregel te plaatsen. Geef hierbij aan hoeveel personen er minimaal nodig zijn en wat de belangrijkste aandachtspunten zijn.
De werkwijze wordt niet specifiek uitgewerkt, gemiddeld zijn er 5 personen nodig om de maatregel op te bouwen.

Vraag 35: Geef voor de volgende 3 noodmaatregelen aan wat de struikelpunten zijn, hoe vaak deze punten fout gaan, en hoe ernstig dit is.
De punten die het meeste fout gaan/ het vaak genoemd zijn, zijn hieronder weergegeven. Het belang van de punten is niet vaak genoeg toegewezen om er een score aan te hangen.

- Opkisten
    - Te kleine kist
    - Te steile kist (instabiel)
    - Slordig stapelen
    - Wel of geen doek gebruiken?
- Opzetten waterpeil
    - Instabiel stapelen
    - Andere faalmechanismen introduceren door verhoogd waterpeil
- Filter constructie
    - Geen zicht meer op wat er gebeurt
    - Te dicht doek/te veel materiaal kan te veel druk opbouwen waardoor nieuwe wellen ontstaan.