# Effectiveness and reliability of emergency measures for flood prevention

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# Summary

Floods in the summer of 2013 in Central Europe demonstrated once again that floods account for a large part of damage and loss of life caused by natural disasters. During flood threats emergency measures, such as sand bags and big bags, are often applied to strengthen the flood defences and attempt to prevent breaches. Although these measures are often used there is limited insight in the actual reliability of the measures and their effectiveness in increasing the safety of the flood defences.

*The objective of this research is to develop methods to determine the reliability and effectiveness of emergency measures for flood defences. Attention will be paid to the quantification of the reliability of emergency measures through an extensive risk analysis.*

The investigation is limited to emergency measures used to prevent initiation of failure mechanisms of the flood defence, Measures to limit growth and/or close breaches are beyond the scope of this report, see (Joore, 2004; van Gerven, 2004). The approaches developed in this report are applied to a case study at Water board Groot Salland.

### Flood defences and emergency measures

Flood defences are part of the primary flood defence system. They can be divided in two sub categories: permanent defences and temporary / moveable defences. Emergency measures do not form part of the primary flood defence system. They can be divided in 'control' measures, which are prepared beforehand for a specific situation, and 'emergency' measures which are unprepared and site specific. The results found in the assessment of flood defences and project VNK found that piping is the dominant failure mechanism for river dikes in the Netherlands (Dijk & Plicht, 2013).

Emergency measures for piping reduce the hydraulic head over the flood defense: either locally with containments around sand boils or over a larger area by increasing the inner groundwater level. Other measures are water berms and piping berms. For overtopped dike sections measures are used to temporarily increase the height of the flood defense. Sand bags are still widely used for these purposes and although new products are being developed the water boards still rely on the use of the 'classical' sand bag.

### Event tree for emergency measures

When including emergency measures in the reliability analysis of flood defences failure is defined as failure of both the emergency measure as well as the flood defence. To determine the failure probability of flood defences with emergency measures two assessments are made: 1) First the probability of failure of the emergency measure is determined and 2) second the effect of the emergency measures on the failure probability of the dike section. So even when emergency measures are successfully applied the dike could still fail (!). The reliability of emergency measures is determined with event and fault tree analyses.

The framework is based on the Dutch situation, which has specific government organizations that manage the flood defences in different parts of the country. However, it is also applicable in other areas and systems subject to flooding.

### 1) The reliability of emergency measures

The probability of a correct functioning control and/or emergency measure depends on the completion of three phases: Detection – Placement – Construction. The system is modelled in an event tree: it forms a series system which functions when each event is completed on time and correctly (Figure 1).

1) **Detection**: in this phase the water boards monitor the upcoming high water and perform inspections of the flood defences to find possible weak spots.
2) **Placement**: if weak spots are found a diagnosis is required to determine whether or not measures are required after which these are placed.
3) **Construction**: the operational phase of the 'control' and/or emergency measure where it needs to function correctly to withstand flood loads.

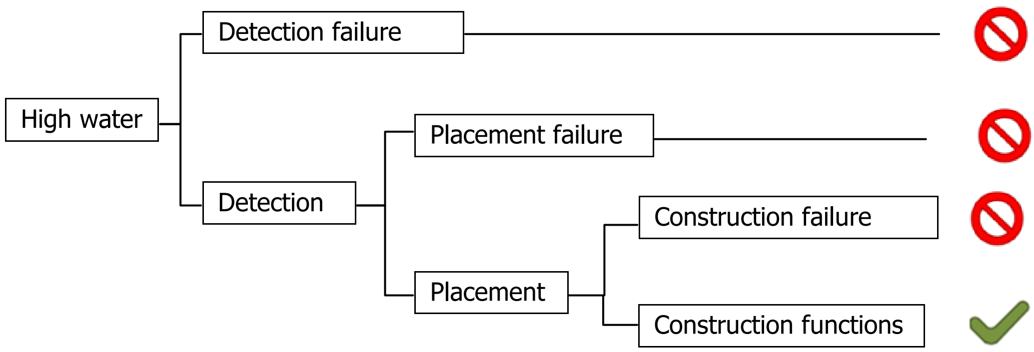


**Figure 1: Event tree control and/or emergency measures**

### 2) The effectiveness of emergency measures

During the operational phase, when emergency measures are placed correctly, these will reduce the failure probability of the dike section. This reduction is determined with sensitivity analyses together with project VNK. For piping the effect of reducing the hydraulic head over the flood defence is calculated in steps of 0.5 meter. For overtopping the effect of filling up local 'dents' (i.e. spots with less elevation than the surrounding flood defence) in the flood defence height is determined.

Overtopping measures only effectively reduce the failure probability of the dike section for water levels close to the crest while piping measures could potentially reduce the failure probability at lower levels compared to the crest height.

### Length effect

An important aspect in the reliability assessment is the length effect; the longer the flood defence the higher the probability of it having a weak spot. In this report two types of length effect are treated: (1) The length effect of the flood defence (failure mechanism) and (2) the length effect of the emergency measure.

**Ad 1) The length effect of the flood defence** is modelled as a series system, which divides the dike in different dike sections each with its own strength characteristics. Distinction is made between the failure mechanisms of the flood defence. Due to large uncertainties and irregularities in the subsoil piping has a large length effect.

**Ad 2) The length effect of the emergency measures** is also modelled as a series system. It depends on the amount of weak spots along the flood defence (in the dike ring). Longer flood defences have higher probabilities of misses during the detection or too late placement.

With increasing amounts of weak spots along a flood defence the contribution of a system of 'control' and/or emergency measures to the reliability will then decrease. The length effect determines to a large extent the feasibility and type of emergency measure.

### Results case study dike ring 53: 'Salland'

The framework developed is applied to a case study at the Dutch water board Groot Salland, for dike ring 53. According to VNK this dike ring has a high probability of flooding (>1/100 per year) as a result of a high vulnerability for piping (Piping probability of 1/63 per year) (Dijk & Plicht, 2013). The water board acknowledges the problems with piping as it is known that along several parts of the dike sand boils occur during high water on the river. Sometimes even boils occur at locations not known beforehand.

The data sheet is used to determine the failure probability of such a system of 'control' or emergency measures. The failure probability for piping measures in dike ring 53 is estimated at 1/3 per event. Taking the effectiveness of the measures in to account this resulted in a decrease of the failure probability of the section with a factor 1.2 to 2.7. At dike ring level the failure probability is reduced to 1/120 per year, a factor 1.9.

This validates the statement made that with increasing length (number of weak spots) the contribution of a system of emergency measures to the reliability of the flood defence decreases. The failure probability of the system depends largely on the probability of detecting weak spots in the dike, see Figure 2. The reliability of the detection phase is influenced by the knowledge and experience of the detection personnel, but also by the weather conditions and visibility.

The overtopping failure probability of the dike ring is estimated by VNK at 1/610 per year (Dijk & Plicht, 2013). The contribution of increasing local 'dents' in the dike is also determined. For these sections a failure probability is found of 1/9 per event. Together with the effectiveness this resulted in a reduction of the failure probabilities of the dike sections with a factor 2 to 6. This resulted in a failure probability of the dike ring with emergency measures of 1/3000 per year, a reduction with a factor 3.6.

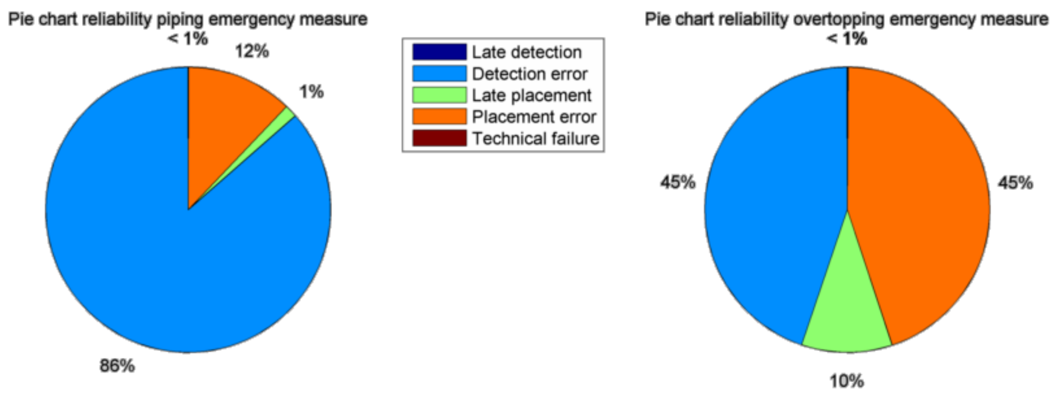


**Figure 2: Distribution of reliability of overtopping emergency measures for dike section 11 (left) and piping emergency measures for dike section 29 (right)**

The failure probability of measures against overtopping is determined largely by the probability of detection of weak spots and the probability of correct placement of the emergency measure (sand bags). Both analyses show that overtopping measures are more reliable than piping measures, which is explained by the fact that it is easier to detect overtopping than piping.

## Comparison of strategies

In the Netherlands about one thirds (1225km of total 3780km) of the flood defences currently do not meet the safety standards required for flooding. Besides reinforcements other options could be considered to improve the safety of the flood defence, each with their own effect on safety and costs. The question is what effect a system of emergency (or control) measures could have on the total cost, which consists of investments, operational cost and risk. On dike ring level dike reinforcements reduce the failure probability with a factor 10, compared to the factor 1.5 ~ 2 of emergency measures. Which strategy is preferred depends on the specifications of the dike ring.

| | **Activity** | **Reduction of risk** | **Cost [€]** |
|---|---|---|---|
| **Not approved dike** | Nothing | High | 0 |
| | Soil investigations | Unknown | ~100,000 |
| | Emergency measure | Factor 1.5~2 | ~ 3 mln $yr^{-1}$ |
| | Dike reinforcements | Factor 10 | ~ 5 mln $km^{-1}$ |

**Figure 3: Scheme of actions for a dike which does not meet the safety requirements**

For typical dike rings along the Dutch rivers, with initial failure probabilities of 1/100, the increase in safety of a system of emergency measures (factor 2) is insufficient to be an alternative for dike reinforcements (factor 10), because the failure probability is limited to 1/1,250 by law. Dike reinforcements are more cost effective than a system of emergency measures. But, a system of emergency measures could be an interesting interim solution if investments in dike reinforcements take years (or decades).

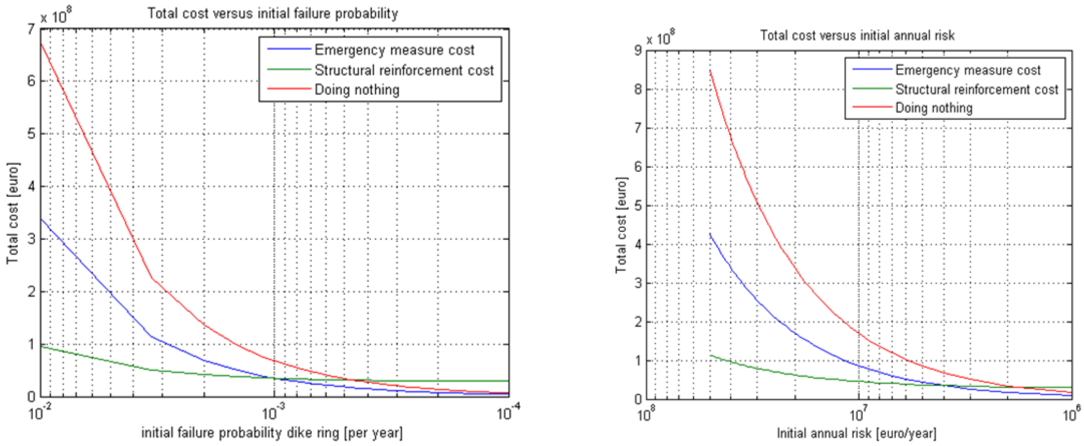


**Figure 4: Total cost versus initial failure probability (left) and annual risk (right)**

The total cost of all strategies depends largely on the initial failure probability (or annual risk) of the dike ring. For dike ring 53, where 33% of the dike required reinforcement / emergency measures, dike reinforcement is the best option for initial failure probabilities of 1/100 ~ 1/1,000. This corresponds with an annual risk of flooding of 4 million euro (with an average damage cost during a flood of 2~10 billion euro). For initial failure probabilities below 1/1,000 a system of emergency measures becomes more cost effective. It is expected this is more or less the optimal safety level for flood defences in this type of dike ring, which can be investigated with (Brekelmans, Hertog, Roos, & Eijgenraam, 2012).

## Conclusions and recommendations

A comparison of emergency measures and dike reinforcements showed that both strategies contribute to a reduction of the probability of flooding. Emergency measures could reduce the failure probability of a dike with a factor 2 ~ 5, depending on the failure mechanism, organizational reliability and the length effect of the emergency measure. Dike reinforcements could achieve higher reductions of the failure probability. Looking at the stringent safety standards for flood defenses it is concluded that dike reinforcements are the only option to achieve the required safety levels (higher than 1/1,000 per year).

If emergency measures are included in the assessment of flood defenses safety standards are required for their reliability. In other areas where temporary/moveable defenses are applied, for example in hydraulic structures, the probability of non-closure may not exceed 10% of the safety standard. For Dutch rivers, with a safety standard of 1/1,250 per year, this corresponds with a probability of 1/12,500 per year. Human failure is included in these methods. Taking the results of this research in to account it seems similar criteria for emergency measures are not feasible.

## Reliability of emergency measures

The reliability of a system of emergency measures depends to a large extent on human performance during the detection and placement phase. For piping specifically investments in the personnel responsible for finding sand boils, are very effective as the failure probability of the emergency measures for piping depends largely on the probability of finding sand boils. Increasing the reliability of the organization is only effective up to a certain level, when other factors such as the reliability in time and effectiveness become dominant. Reductions up to a failure probability of 1/100 are effective, which corresponds with the level at which districts operate. Further reduction can be achieved by investing in logistics (placement speed).

The feasibility in time has failure probabilities of one order lower than the organizational failure probabilities. It becomes dominant when the available time is around 24 hours. River systems have prediction times of 2 to 4 days, but coastal systems have much shorter available time (order 12 hours). It is expected that a system of emergency measures will have little effect on the reliability of a dike ring in a coastal system.

The emergency measures treated (dikes of sand bags, sand boil containments and piping berms) proved to have technical failure probabilities (order $10^{-5}$ per demand) which are negligible compared to the failure probabilities of humans and/or the feasibility in time.

### Recommendations for further research

The reliability of the emergency measures depends largely on the reliability of human actions. The assignment of error rates to the different employees of the water boards is based on expert judgement of the author, which was quite accurate when compared to observations in the field. However, further investigation (possibly with Bayesian networking, (Jager, 2013)) could provide more insights in human performance during floods.

The framework is simulated with an event tree, which only allows for an analysis in binary sense (probability of 'yes or no', 'correct or incorrect'). An analysis using Bayesian networks with distributions may give more accurate reliabilities and insight in the interdepencies and common factors such as weather and visibility. Due to a lack of data for distributions of organizational reliability and effectiveness of the emergency measures this method requires further investigation.

Research in the use of alternative (innovative) emergency measures is recommended, as a lot of products are currently being developed for flood fighting. The main disadvantage of sand bags is the required time for placement, which is rather high. Several new products are being tested which could be an alternative for the classical sand bag, yet these products have technical reliabilities which are lower than sand bags.

### Recommendations for water boards

For dike rings with failure probabilities of ~1/100 water boards are advised to choose a system of emergency measures to temporarily increase the safety of the flood defenses, in anticipation of dike reinforcements. A prioritization of dike sections suitable for emergency measures is advised to determine where emergency measures have the largest effect. To determine these dike sections similar sensitivity analyses are required such as those made for dike ring 53 by VNK2, for both piping (head reductions) and overtopping (dents) sections.

Control and/or emergency measures are advised to be included in the calamity plans of the water boards, including water levels where each phase (detection, placement and construction) need to start. Water boards are recommended to invest in the training and knowledge of the employees with high failure probabilities such as the dike watch for detection and contractors/military for placement. Especially in the river systems where piping is dominant investments in the detection personnel (dike watch) responsible for finding sand boils could be very effective.

Each dike watch is assigned a specific dike section and receives procedures and tools to perform the inspection. These tools, such as the 'Handboek dijkbewaking', could be further improved using site-specific information. When given specific information on dominant failure mechanism and corresponding observations the detection phase will be more reliable.

During every exercise water boards are advised to collect (historical) data regarding human performance and time required for placement of all emergency measures. For example during 'Conecto' it was concluded that the time estimated by the water board for placement of the emergency measures was optimistic, resulting in the recommendation to revise the data sheet used to determine the required time for each emergency measure.

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# 1. Introduction

## 1.1 Background

Recent floods in Central Europe, Canada and India demonstrated once again that floods account for a large part of damage and loss of life caused by natural disasters. During flood threats (on a river or at sea) emergency measures, such as sand bags and big bags, are often applied to protect the flood defences and attempt to prevent breaches. In the Netherlands, but also in foreign countries, various stakeholders have gained experience in the detection of weak spots in flood defences and placement of the necessary emergency measures to prevent these from growing.

In 2013 large rainfalls occurred in Central Europe resulting in high water levels on the Elbe and Donau rivers in Germany, the Czech Republic and Austria. The high waters had return periods between 50 and 500 years depending on the locations. Several dike breaches occurred flooding large parts of Central Europe. Local authorities, civilians and the army worked together to place tens of thousands of sand bags attempting to prevent large breaches in the flood defences.

**Figure 5: Dutch army placing sand bags along the Elbe in Germany (right) [ANP]**

During the 2011 floods in Thailand a lot of emergency measures were placed to prevent the water from entering Bangkok. The King Dike, which surrounds Bangkok, was not finished so over a length of several kilometres an attempt was made to close the dike with big bags to prevent the flood from entering Bangkok.

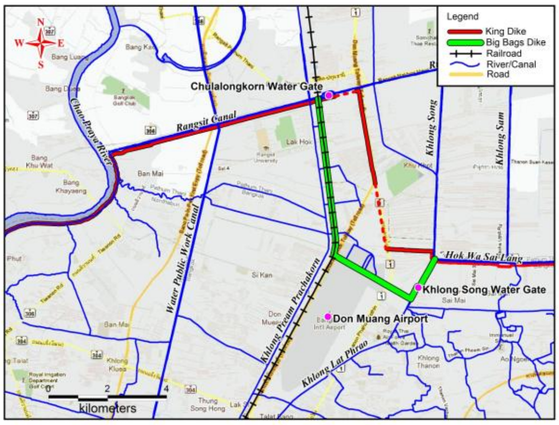


**Figure 6: King dike Bangkok (left) and placement of big bags in gaps (right) [Jonkman]**

In the Netherlands water boards are responsible for the flood defences. Large parts of the flood defences do not comply with the current safety standards. Most of these parts lay along the rivers in the Netherlands. These water boards are faced with a problem, as flood defence reinforcement is a costly task which takes time. During this period the flood defences are not safe and water boards may require emergency measures to increase the safety of the flood defences during river floods.

Although emergency measures are used often there is limited insight in the actual reliability of the measures and the effectiveness on increasing the safety of the flood defences. This is why these measures do not form part of the assessment of flood defences (VTV) and/or reliability analyses, such as Veiligheid Nederland in Kaart (short: VNK2) (Rijkswaterstaat, 2005).

This report investigated the reliability and effectiveness of emergency measures and the role these could have in preventing floods from happening. Whether or not emergency measures could be included in the assessment of flood defences is beyond the scope of this report.

## 1.2 Problem description

In the Netherlands there are three systems which could cause flooding, extreme water levels on the North Sea, high waters on the three main rivers Rhine, Meuse and Scheldt and extreme rainfall. From the last assessment of the flood defences was concluded that about one thirds (1225km of total 3780km) currently do not meet the safety standards. Most of the flood defences which did not pass the assessment lay along the rivers in the Netherlands (Figure 7), so river flooding will be the main focus of investigation in this report.

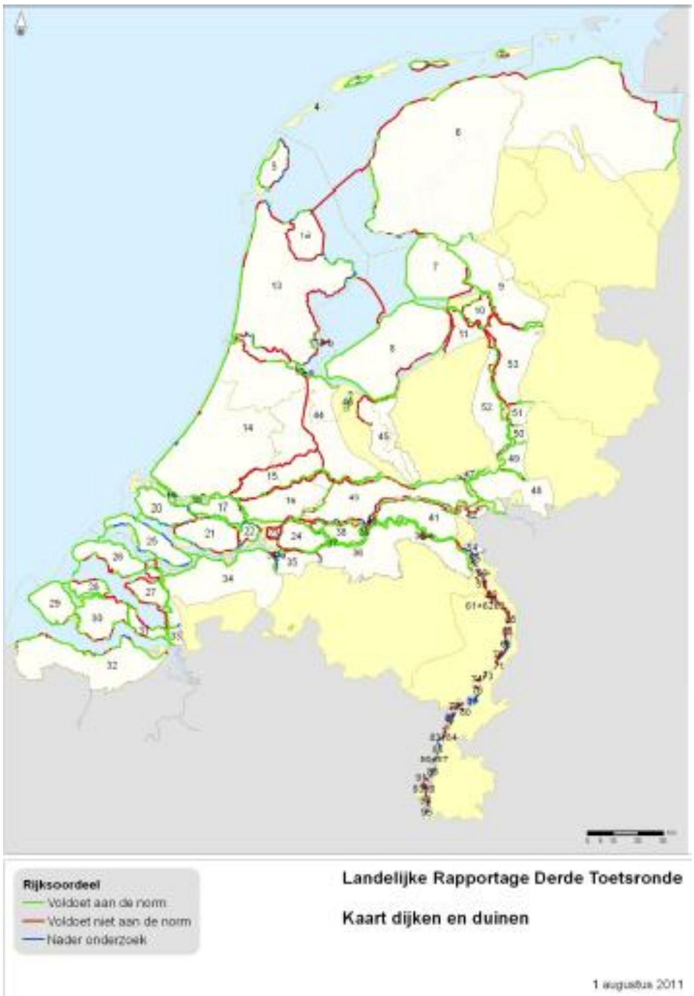



**Figure 7: Result of assessment of flood defences [VNK]**

During high waters on the Dutch rivers (or the North Sea) the water boards inspect the flood defences thoroughly to find weak spots. If weak spots are found emergency measures are applied to limit the probability of failure of the flood defence and thus prevent breaches from occurring. The conditions occurring during a flood could influence the placement of emergency measures (rain, wind, waves). In other areas (temporary flood defences and flood barriers) methods have been developed to take these factors in to account (TAW, 2003).

Previous research on both the safety of flood defences and emergency measures have concluded that the organisational and logistics side requires more investigation (Dupuits, 2011; Leeuw, Vis, & Jonkman, 2012). The effectiveness of emergency measures is investigated in a master thesis in 2007 which assumes that the measures are placed in time and correctly.  The report concluded that the logistics will determine to a large extent the reliability of the emergency measure. It was therefore recommended to do more research on this subject (Boon, 2007).

Dupuits investigated the effectiveness of emergency measures against piping for sand boils and suggested a framework containing a series of steps which need to be successfully fulfilled ('detection, placement and construction') for emergency measures to function correctly (Dupuits, 2011). In his report a simple method is explained to include human reliability in the reliability analysis of emergency measures, as these measures depend on the performance of the people involved in both inspecting the flood defence and placing the emergency measure.

A similar analysis of emergency measures is made by (Corn & Inkabi, 2013) in a paper which describes a more thorough method to include human intervention in the reliability analysis of flood defences. An event tree is used to model the steps taken when emergency measures are applied to increase the safety of flood defences. This report will build on these models, and further elaborate on the human reliability aspects and feasibility in time of emergency measures. Further, the effect emergency measures could have on increasing the safety of the dike is also investigated.

## 1.3 Research objective

The objective of this research is to develop methods to determine the reliability and effectiveness of emergency measures for flood defences. Attention will be paid to a quantification of the reliability of emergency measures through an extensive risk (failure probability) analysis.

The investigation is limited to emergency measures used to prevent initiation of failure mechanisms of the flood defence. Measures to limit growth and/or close breaches which have developed are considered beyond the scope of this report, these are treated in previous reports (Joore, 2004; van Gerven, 2004). The approaches developed in this report are applied to a case study at the water board Groot Salland in the Netherlands.

### Research questions

The following research questions will be investigated:

- What type of emergency measures exist?
    - When are these measures used, for which failure mechanism of the dike?
    - What are the failure mechanisms of the emergency measures?
    - What is their effect on the safety of the dike?
- How do the organisations and logistics regarding emergency measures work?
- What is the reliability of emergency measures?
    - How can the reliability be determined, what methods can be used?
    - How can the reliability be increased?
    - Could (if yes: how) emergency measures be included in the reliability analyses of flood defences in general?

## 1.4 Research methodology

The problem requires a multidisciplinary approach combining technical aspects as well as organisational and logistics aspects. Knowledge of different stakeholders is obtained through meetings and interviews with all parties involved in the use of emergency measures; a logbook is included in the appendices. Further, during the extent of the project the TU Delft collaborated with Deltares who is also investigating emergency measures. The focus of Deltares is to develop a decision based program for the use of emergency measures based on the observations during inspection of the flood defences.

The project was divided in several phases as explained below:

I. **Literature study**: Investigating existing literature and previous research.

II. **Framework**: Developing a framework used to determine the reliability of emergency measures.

III. **Case study:** Together with water boards and other stakeholders a case study will be made to apply the framework on a practical case. The Dutch water board Waterschap Groot Salland is used.

IV. **Testsite Floodproof Holland**: Different emergency measures were tested in a controlled testing facility in Delft to gain insight in the technical failure mechanisms of emergency measures. A 'management summary' is added in the appendices.

V. **Analyses:** All findings will be analysed to make conclusions and recommendations regarding the research questions explained in the last paragraph.

## 1.5 Report lay out

Chapter one contains an introduction in the subject treated in this report, the problem is described and research objectives are treated. In chapter two a description of the reliability analyses of flood defences in the Netherlands is given, providing the required background information/context in which the emergency measures are applied.

In chapter three a general framework is described used to determine the reliability of emergency measures. The different stages required for correct application of an emergency measure are explained. This framework is treated in more detail in chapter four which links the different phases to the organisation, logistics and technical reliability.

Chapter five treats the application of the framework to a case study at Waterschap Groot Salland. In chapter 6 the cost of a system of emergency measures is compared with the cost of dike reinforcements for the flood defence sections which did not pass the assessment. A discussion of the results found and broader applications of this framework are treated in chapter 7 after which chapter 8 gives conclusions and recommendations for further research.

# 2. Reliability analyses of flood defences

## 2.1 Introduction

In this chapter relevant background information is given on the reliability analyses of flood defences in the Netherlands. A short overview of flood defences and emergency measures is given after which failure mechanisms of flood defences are treated. Past and present risk assessment methods are explained followed by the conclusions and recommendations relevant for this report.

## 2.2 Terminology used in this report

Flood defences structures are built to retain outside water (from rivers or sea) and as such prevent flooding of the hinterland; they can consist of hydraulic structures and/or embankments. This paragraph explains different definitions used in this report.

### 2.2.1 Flood defences

Flood defences in the the primary flood defence system can be divided in two sub categories.

**1a) Permanent defences** are structures that are permanently present along the flood defences trace and as such permanently retain water. These are part of the Dutch assessment of flood defences, an example are river dykes along the Ijssel.

**1b) Temporary / moveable defences** are structures which are only temporarily part of the primary flood defence system, they need to be closed when the water levels exceed a certain 'critical level'. As with the permanent structures these are also part of the Dutch assessment of flood defences. In this assessment methods are included to determine the reliability of the closing procedure, examples are storm surge barriers and stop logs.

### 2.2.2 Emergency measures

Emergency measures do not form part of the primary flood defence system and form no part of the Dutch assessment of safety of the flood defences. They are used to provide additional safety during flood threats. These measures are divided in two groups.

**2a) 'Control' measures** are measures applied at locations of which is known there is a shortage of safety, for example after the results of the assessment. The required measure, location and placement procedures are prepared in advance. These measures are not part of the primary water system and thus not evaluated in the assessment of flood defences.

Examples are sandbags on a dike which has insufficient height (overtopping) or raising the water levels behind a dike section to reduce the hydraulic head and limit the probability of piping.

**2b) Emergency measures** are measures applied after in situ inspection of the flood defence system reveals weak spots. The location and type of measure depend on the specific situation; these are unknown beforehand so no operations are prepared. Emergency measures do not form part of the evaluation of the flood defences in the assessment; examples are containing sand boils within boxes or placing sand bags on an overtopped dike.

*Weak spots are defined as damages in the flood defence (visual or non-visual) where it is expected failure of the flood defence will occur during the expected river flood if no measures are taken which prevent failure and improve the strength of the weak spot.*

This report is limited to 'control' and emergency measures that prevent breaches. When a breach occurs further breach growth is almost inevitable, as was also seen during the flood in Germany in 2013. The main problems occurring are the high current velocities and relatively short time available to apply emergency measures against breach growth. This subject was investigated thoroughly in a master thesis (van Gerven, 2004).

**Summary**

Flood defences are considered part of a 'safe system'; emergency measures are not. The objective of this report is to determine the effectiveness and reliability of these emergency measures, both the 'control' and emergency measures.

| Type | Prepared | Failure by | Assessment | Example |
|---|---|---|---|---|
| **1a) Permanent defence** | Yes | Technical failure | Yes | Dikes |
| **1b) Temporary / moveable defence** | Yes | Human and technical failure | Yes | Storm surge barriers, stop logs |
| **2a) 'Control' measure** | Yes | Human and technical failure | No | Raising the inside water level against piping failure |
| **2b) Emergency measure** | No | Human and technical failure | No | Sand bags against overtopping |

**Table 1: Flood defence terminology**

## 2.3 Failure mechanisms flood defences

Flood defences could consist of dikes or hydraulic structures. For both options different failure mechanisms could lead to breaching of the flood defence. This report will focus mainly on the contribution of control and/or emergency measures to the reliability of river dikes. The definitions of failure mechanisms used stem from 'Veiligheid Nederland in Kaart 2' (VNK2) (Rijkswaterstaat, 2005), a short overview is given in this paragraph.

**Failure mechanisms of dike sections**

The following failure mechanisms are taken in to account for dike sections: overtopping, inner slope sliding, uplift and/or piping and outer slope erosion. An illustration of the failure mechanisms is given in Figure 8.

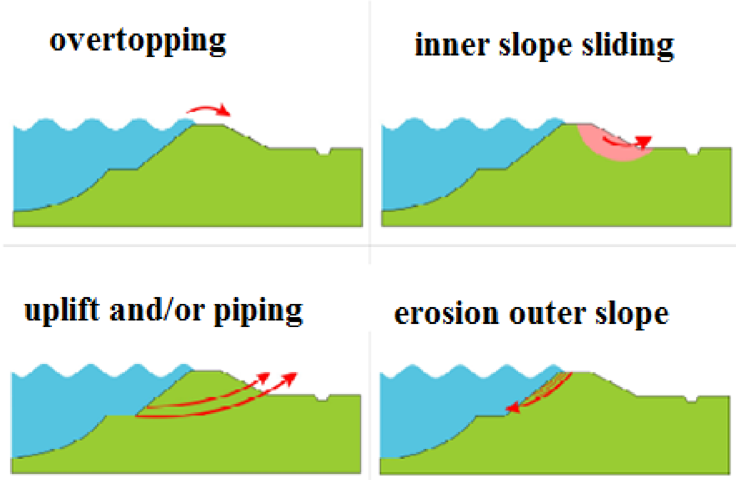



**Figure 8: Failure mechanisms dikes** (Rijkswaterstaat, 2005)

Other failure mechanisms such as foreshore instability, sliding of outer slope and micro instability are not taken in to account in VNK 2, mainly because their contribution to the failure probability of the dike sections is negligible. According to the results of the assessment of flood defences and studies of project VNK2 piping contributes to almost 80% (!) of the failure probability of dikes in the eastern parts of the Netherlands. It is therefore expected that the majority of control and/or emergency measures are required against piping. The next section will elaborate further on this failure mechanism.

### 2.3.1 Piping

Piping occurs when the head difference over a flood defence causes uplift of the impermeable layer on the inland side after which erosion of the subsoil can grow such that a channel or pipe is formed. These channels can grow to connect the inside and outside water level of a flood defence undermining the flood defence, which leads to breaching. The different phases of piping are explained with Figure 9.

When the permeable layer under a dike is in contact with the outside water groundwater starts flowing in the direction of the inner side. Water pressure develops in the permeable layer, which will result in uplift of the impermeable layer if the weight of this layer is insufficient to counteract upward water pressure (step 2). When the flow velocities from the permeable layer to the surface are high enough heave will occur. This is the phenomenon where particles flow out of the permeable layer creating a crater of sand next to the boils: sand boils (step 3).

If the erosion continues in the direction of the dike a channel is formed which is called backwards erosion (step 4). This process stops when the flow velocities reduce with increasing length of the pipe. However, in some situations the hydraulic head exceeds the critical hydraulic head (step 5), which will cause progressive growth of the pipe and lead to instability of the dike and breaching (step 6).

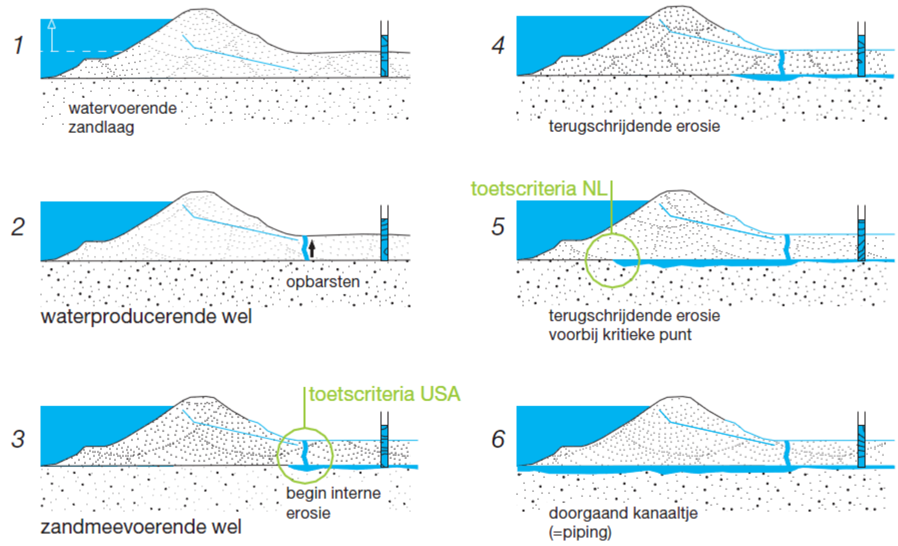



**Figure 9: Development of piping** (J. K. Vrijling et al., 2010)

In short piping has three phases: uplift (2), heave (3) and piping (5).

### Design rules piping: Netherlands versus U.S. approach

The criterion for piping used in the U.S. is fundamentally different from the criterion in the Netherlands: in the U.S. the criterion is based on not allowing boils to develop. This leads to a maximum gradient of 0.5 preventing heave (step 2 in Figure 9). In the Netherlands the criterion is based on preventing piping, uplift and heave are allowed. As a result levees will be rejected more often with the U.S. criterion than with the Dutch criterion. The Dutch criterion is much closer to actual failure, allowing sand boils to occur as long as the head difference does not exceed the 'critical head difference'. In practice this results in a minimum L/dH value for the Dutch criterion of 18 (for Bligh) and the U.S. criterion of 44 (J. K. Vrijling et al., 2010).

Analyzing these differences one could expect that the observation of sand boils behind a Dutch dike is a normal and 'safe' observation, as long as the critical head difference is not exceeded. However, there were situations in the U.S. were breaches occurred for L/dH ratios considered safe according to the assessment in the Netherlands with Bligh (<18).

### Conclusions

The main difference in both approaches is the phase of piping which is considered critical; the U.S. approach does not allow boils to develop while the Dutch approach allows boils as long as the seepage length does not exceed the critical seepage length. This was investigated by (Ammerlaan, 2007) in a master thesis. The difference between both approaches suggest a certain redundancy between the observation of sand boils and the actual breach due to piping, which in practice is not always experienced.

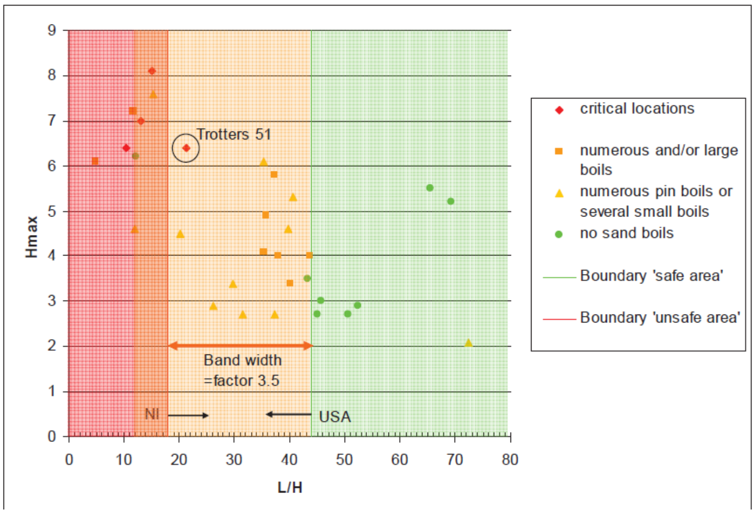



**Figure 10: Critical boil locations with L/H estimates** (J. K. Vrijling et al., 2010)

***Approach water boards***

In (Schweckendiek, Vrouwenvelder, & Calle, 2014) a method is explained to update the failure probability of a dike section based on observations. It shows that observations of sand boils increase the probability of failure of the dike section with a factor 4. Taking the before mentioned uncertainty about the growth of sand boils and the results in (Schweckendiek et al., 2014) in to account water boards are advised to treat every sand boil as critical

## 2.4 Types of emergency measures

Currently there are a lot of products available that could serve as a 'control' or emergency measure for flooding, each with its own advantages and disadvantages. This paragraph gives a brief overview of the possibilities, the effectiveness of these measures is treated in chapter 4. Distinction is made between the measures applicable for the different failure mechanisms of dikes. The overview is taken partly from the master thesis of R.A. van der Eijk (Eijk, 2002), M.J.J. Boon (Boon, 2007) and the report 'Keuzemodel tijdelijke en demontabele waterkeringen' by STOWA (STOWA, 2008).

Currently Deltares is doing research on emergency measures. The focus lies on developing a tool that determines the required emergency measure based on an observed weak spot in a dike. For this tool the link between weak spots, failure mechanisms and corresponding emergency measures is investigated together with several water boards (see Appendix I).

### 2.4.1 Overtopping

During overtopping the purpose of the 'control' or emergency measure is to increase the height of the dike over a certain length and (or) protect the inner slope from erosion. For measures placed on top of the dike one should check whether or not the stability of the dike will be threatened due to the higher load on top of the dike and possible higher freatic line inside the dike.

To increase the height of the dike several measures could be used such as: straw bales, sand bags, big bags, box barrier or other innovative products (see Table 1). To protect the inner slope from erosion water boards often place geo textiles over the damaged top layer.

Next to the products already mentioned a lot of 'innovative temporary flood defences' exist, which are summarized in the following table. Due to lack of experience with these products they are not used often (yet) by Dutch water boards, research in the effectiveness of these product is therefore advised, as they could be alternatives to the labour intensive sand bags.

| Type of measure | Product | Source |
|---|---|---|
| **Fill containers** | Green soil bags | J.P. de Garde |
| | Garbage bags | ENW report of Thailand floods |
| | Dura-Bell Barricade | (STOWA, 2008) |
| | Hesco container bastion | (STOWA, 2008) |
| | MRP systems modular shielding | (STOWA, 2008) |
| | Quickdam dam flood safety system | (STOWA, 2008) |
| **Systems filled with water or air** | Twin Flex Barrier | (Boon, 2007) |
| | Waterfront Block | (Boon, 2007) |
| | Aqua levee | (Boon, 2007) |
| | Box Barrier | Bam Infra and GMB |
| | Aquadam | (STOWA, 2008) (Boon, 2007) |
| | Aquatube | (STOWA, 2008) |
| | FloodMaster barrier | (STOWA, 2008) |
| | Mobile Dam | (STOWA, 2008) |
| | NOAQ tubewall / boxwall | (STOWA, 2008) |
| **Other self retaining products** | Water-gate | Benelux Flood Defence Systems |
| | Richardson flood control panel barriers | (STOWA, 2008) |
| | Rapidam | (STOWA, 2008) |
| | Portadam | (STOWA, 2008) |
| | Pallet Barrier | (STOWA, 2008) |
| | Concrete blocks | (STOWA, 2008) |
| | Aquastopdam | (STOWA, 2008) |

**Table 1: Emergency measure for overtopping. For a more thorough list reference is made to the research project currently undergoing at Deltares.**

**Figure 11: Overtopping measures [ANP]**

***Flood Proof Holland***

*For this project research was done by bachelor students of the TU Delft at Flood Proof Holland, a test site for emergency measures. The classical sand bags, Box Barrier and the Water Gate have been tested under circumstances similar to those present during river floods, see Figure 12. A summary of the work done is given in appendix XIV. The tests provided insight in the technical failure mechanisms of various emergency measures.*

**Figure 12: Box barrier (left) and Water gate (right) testing**

### 2.4.2 Uplift and/or piping

Obervations of piping start with seepage water on the inner side of the dike, if locally the impermeable layer tears a sand boil is formed. Measures to prevent piping could have two functions: (1) To provide counterweight on the inner top layer preventing uplift and heave, (2) Providing counter pressure by reducing the hydraulic head over the flood defence.

Water boards often increase the inside water levels of the polders in anticipation of a river flood, which decreases the hydraulic head over the flood defence. Depending on the density of boils along the dike a choice is made to treat every sand boil individually or place large-scale measures. Individual measures consist of placing sand bags around a sand boil to reduce the hydraulic head locally or geotextiles to prevent further erosion. Large-scale measures could be soil berms which provide extra ballast to avoid uplift or water berms to reduce the hydraulic head.


Figure 13: Containing sand boils (left) and constructing a soil berm (right)

### 2.4.3 Inner slope sliding

Measures to prevent inner slope sliding consist of applying counter weight at the toe of the dike to avoid further sliding. This counter balance can be provided several ways: with soil berms, sand bags, big bags, or any other type of heavy material. Traffic on the crest of the dike should be restricted. To prevent further infiltration of the dike geo textiles or foils could be placed on the outer slopes of the dike.

Figure 14: Emergency measures during 1995 river floods in the Netherlands

During the floods in Germany in 2013 mistakes were made in the placement of counter weight at the toe of the dike. The counter weight was placed on the inner slope causing sliding of the inner slope, see Figure 15.

Figure 15: Placement error (E.J.C. Dupuits)

### 2.4.4 Outer slope erosion

Outer slope erosion can have several causes. A distinction is made between smaller and larger damages. As a start it is advised to remove all debris on the outer slopes at all times. For smaller damages no direct action is required during the flood wave on the river. For larger damages (over square meters) it is advised to place a 'bekramming' of geotextile to protect the area. Holes are filled with sandbags before also closing these off with geotextiles.

## 2.5 Risk assessment of flood defences

After the large floods in the Netherlands in 1953, where 1836 people were killed and 1800 $km^2$ was flooded, the Delta plan was set up. It consisted of a reduction of the exposed coastline with about 700 kilometres by closure of the estuaries with dams and storm surge barriers and new safety standards based on cost-benefit analysis of flood defences.

### 2.5.1 General risk assessment

This section gives a short summary of how the risk of flooding is determined as these methods also form the basis of the risk analyses of 'control' and emergency measures. For more details reference is made to appendix II. The annual risk of flooding [R] is determined by a probability of failure [Pf] multiplied by the corresponding damage (economical or loss of life) [S]. When this is divided by the discount rate [r '] one obtains the Net Present Value of the risk, see equation 2-1.

$$R = \frac{P_f * S}{r'} \qquad (2\text{-}1)$$

The failure probability of a system can be determined using different techniques; most common are the fault tree analysis and event trees. For each system it should be determined if the system can be modelled as a series or parallel system, which has large effects on the resulting probability of failure.

After determining the risk of a certain system one could compare the cost of several risk reduction methods in a cost benefit analysis to determine which method is most cost effective. Such cost benefit analyses have long been used in the Netherlands to inform policy debates about the safety of flood defences (Jongejan, Jonkman, & Vrijling, 2012)(Eijgenraam, 2006).

### 2.5.2 Economic optimization of flood defences

In the approach used by the Delta Committee in 1960 the required flood defence level was determined through a cost benefit analysis (van Dantzig, 1956). The exceedance frequency of a certain water level was theoretically determined through an economic optimization: the optimum between on one hand the investments (I) required to raise the flood defence (h) and on the other the corresponding reduction of the risk (R) due to the lower probability of exceedance ($P_f$). The probability of exceedance was determined by extrapolating observed water levels to levels never seen before.

A disadvantage of the approach used is the fact that the probability of flooding is assumed to be equal to the probability of exceedance of a certain water level, implying that overtopping is the only failure mechanism which could cause flooding. Recent work has proved that other failure mechanisms could also result in dike breaching long before it is overtopped.

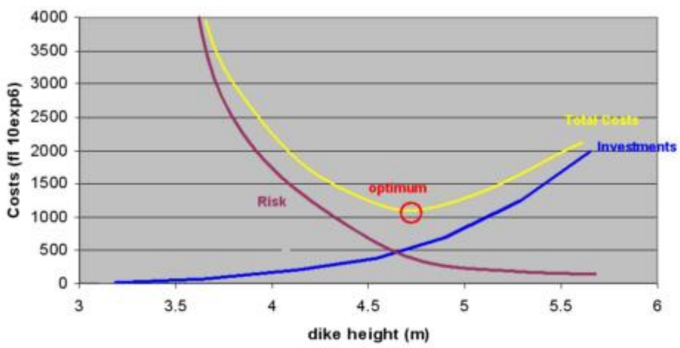



**Figure 16: Economic optimisation for determining the required flood defence level by Van Dantzig** (Jonkman & Kok, 2008)

### 2.5.3 Flood protection act

The current standards for the flood defences in the Netherlands are still based on the levels determined through the approach used by the Delta Committee in 1960. This approach to flood protection is laid down in the flood protection act of 1996. The Netherlands was divided in a total of 53 dike rings each with their own safety standard, see Figure 17. The standards were determined according to the (economic) value of the area and the source of flooding; riverine or coastal.

For coastal areas design water levels have been chosen with exceedance frequencies of 1/4,000 per year and 1/10,000 per year. For the Dutch river area the safety standards were set at 1/1,250 per year and 1/2,000 per year. Some smaller dike ring areas bordering the river Meuse in the south of the country have a safety standard of 1/250 per year (Jonkman & Kok, 2008).

The management and maintenance of the flood defences is done by Dutch Water boards, which are decentralized local governmental agencies responsible for the flood defences in these areas (Leeuw et al., 2012). The Water Boards have three main responsibilities:

1. Ensuring fresh water quality
2. Managing drainage and irrigation systems
3. Managing and maintaining the flood defences in the area.

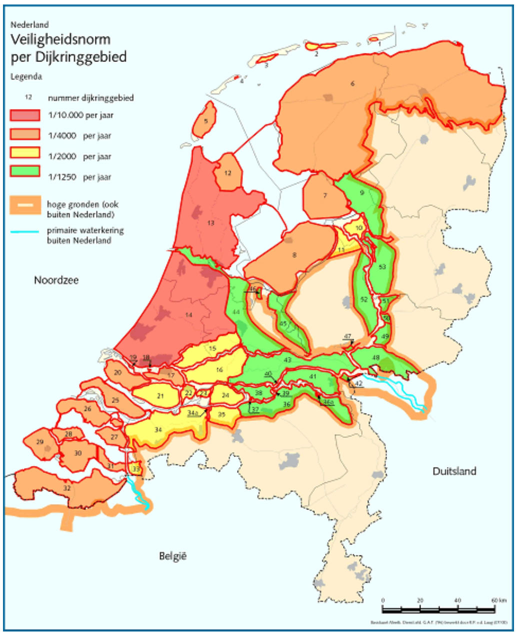



**Figure 17: Dike rings and safety standards in the Netherlands. (source: Dutch ministry of Public Works and Water Management)**

As part of task three the Dutch water boards perform an assessment of the flood defences every six years to determine whether or not they still comply with the current safety standards. Further, the Dutch water boards are responsible for the flood defences and safety of the area during river floods.

### Reliability analysis of flood defences (Leidraad Kunstwerken)

According to the flood protection act the flood defences need to fulfil their water retaining function with a certain reliability (TAW, 2003). The requirements are split up in requirements for:

- Retaining height; based on a maximum allowed inflow through a closed flood defence. This is called the standard (example: 1/1,250 per year for river dikes)
- Reliability of closures of temporary flood defences; based on a maximum allowed inflow through a non-closed flood defence (non-closure); 0.1* standard (example: 1/12,500 (!) per year for river dikes)
- Structural instability; 0.01 * standard (example: 1/125,000 per year for river dikes)

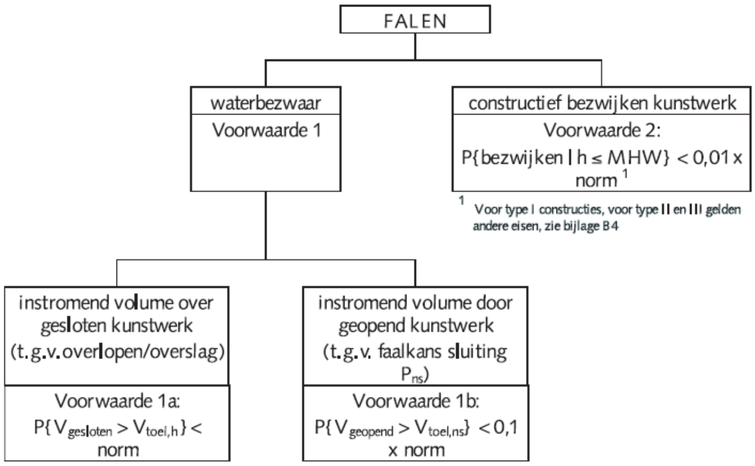



**Figure 18: Functional reliability of flood defences** (TAW, 2003)

### Reliability of closures of temporary flood defences

The flood protection act concerns all permanent flood defences as well as the temporary / moveable flood defences. 'Control' and/or emergency measures as defined in paragraph 2.2 are not included in the flood protection act or in the assessment of flood defences. To determine the reliability of closure of the temporary flood defences a method is described in 'Leidraad Kunstwerken' which includes failure probabilities for human actions. The probability of non-closure may not exceed 10% of the probability of exceedance of the flood defence (!). For emergency measures similar methods are developed in chapter 4, the reliability of non closure could be compared to the reliability of a system of 'control' measures when used as a structural measure against flooding.

This probability is determined by the multiplication of the probability of failure of the closure process ($P_{ns}$ in 1/attempt) and the frequency of exceedance of the maximum allowable inflow through a non-closed flood defence ($n_j$ in attempts/year).

$$P_{fa} = P_{ns} * n_j < 0.1 * \text{standard}$$

Different methods (simple, detailed and advanced) are described in 'Leidraad Kunstwerken' to quantify the reliability of human actions and the tasks which are required to close the flood defences. The quantification used is based on work done by Swain and Guttman in 1983 (TAW, 2003).

## 2.5.4 Project VNK2

A disadvantage of using the probability of exceedance to model the flood probability of a flood prone area is the fact that other failure mechanisms next to overtopping are not taken in to account. Recent events, such as the floods in New Orleans, have shown that dikes could also fail before they are overtopped. Mechanisms such as piping and slope instability have also led to dike breaching which resulted in lower probability of failures as were expected according to the flood protection act. Project VNK2 has the objective of determining the flood probabilities and corresponding economic damage and loss of life of all dike rings in the Netherlands providing insight in the actual flood risk of the country.

Project VNK2 uses a method to determine the probability of flooding taking in to account that different failure mechanisms could lead to breaching of a flood defence section which could result in flooding of a dike ring. Each failure mechanism contributes to the total probability of flooding. To determine the consequences of a flood different flood scenarios are modelled in a dike ring. When looking at a dike ring it can be divided in different sections; dikes, structures and/or dunes. Project VNK2 determines the probability of flooding for each section and their contribution to the total probability of flooding of the dike ring.

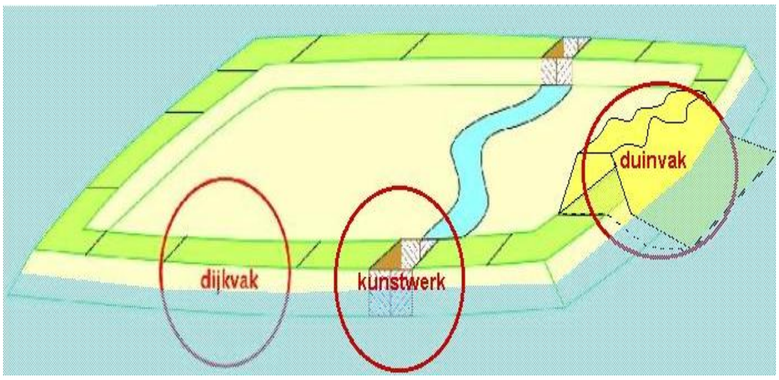



**Figure 19: Dike ring schematization** (Rijkswaterstaat, 2005)

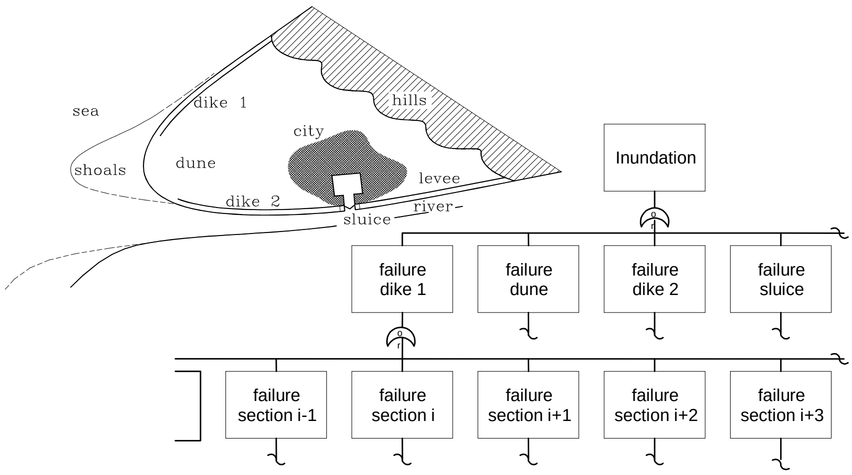



**Figure 20: Failure tree of a dike ring** (J. Vrijling, 2001)

According to VNK2 the probability of a flood due to overtopping is very small due to the extreme safety and residual strength (0.5 meter of freeboard) of the flood defence. Calculations show that the probability of uplifting and/or piping for dikes and non-closure of a structure are dominant. This project worked closely together with VNK2 who determined the prior failure probabilities for dike ring 53 (withouth emergency measures) and the posterior failure probabilities with correctly functioning emergency measures.

### Length effect

An important aspect in a reliability assessment is the length effect; the longer the flood defence the higher the probability of it having a weak spot. Thus, longer flood defences generally have higher probabilities of flooding than shorter (similar) flood defences. In this report two types of length effect are treated: (1) The length effect of the flood defence (failure mechanism) and (2) the length effect of the emergency measure.

**Ad 1) The length effect of a flood defence** can best be modelled as a series system, which divides the dike in different dike sections each with its own strength characteristics. Distinction is made between the failure mechanisms of the flood defence. Sections subject to overtopping have no length effect as these sections are modelled dependent: if one section overtopped it is likely that the next will also overtop. Sections subject to piping are modelled independent resulting in a large length effect. The sections are independent because the subsoil parameters can be very different between sections.

**Ad 2) The length effect of the emergency measures,** which is dependent on the length of emergency measure to be placed. This is also modelled as a series system; longer flood defences have higher probabilities of having weak spots. Thus it depends on the amount of weak spots found along the flood defence (in the dike ring). Due to large uncertainties and irregularities in the subsoil piping has a large length effect; an example is given of the amount of sand boils which occurred along the 'river 'Waal' during a river flood of 2011:

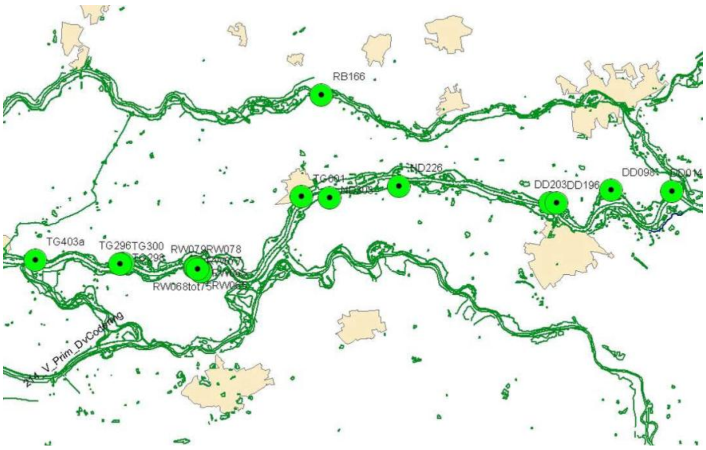



**Figure 21: Sand boils at Water board Rivierenland during the 2011 river flood** (Arcadis, 2011)

If along large parts of a flood defence emergency measures are required it is questionable whether this is a realistic option considering logistics and the effectiveness of the emergency measures. During the river flood of 1993 on the Rhine 120 sand boils were found: 40 along the Rhine, 30 along the Ijssel and 10 along the Meuse. In 1995 even more boils were found, 180. A lot of the boils found in 1993 returned, but there were also situations were boils did not return or developed for the first time (J. K. Vrijling et al., 2010).

*When all weak spots are modelled independent a system of emergency measures will have a large length effect. With increasing amounts of weak spots along a flood defence the contribution of a system of 'control' and/or emergency measures to the reliability will then decrease. The length effect determines to a large extent the feasibility and type of emergency measure.*

## 2.5 Current situation in the Netherlands

The results of the last assessment of flood defences show that a large part (1225km of total 3780km) does not comply with the required safety standards, requiring large investments for dike reinforcements. This is mainly because the failure mechanism piping results in higher failure probabilities than expected beforehand. Especially in the river systems piping accounts for about 80% of the total flood probability of the dikes rings.

Besides the classical option of dike reinforcements it is possible to choose a system of emergency measures to increase the safety of flood defences. Because 'classical' reinforcement of the flood defences is a costly operation which takes a lot of time water boards started investigating this system of 'control' or emergency measures for the dike sections which do not meet the safety standards.

According to the 'Expertise Netwerk Waterveiligheid ' (ENW) it is (currently) unrealistic to take such measures ('control' / emergency measures) in to account as part of the assessment of flood defences (J. K. Vrijling et al., 2010). If considered an option they should meet certain strict requirements:

1. Procedures for human reliability need to be determined with a minimal safety level yet to be determined;
2. The reliability of the measures (structures) needs to be determined in compliance with the methods used to determine the reliability of other parts of the flood defences (e.g. temporary defences according to 'Leidraad Kunstwerken').

## 2.6 Conclusions and recommendations

Flood defences are part of the primary flood defence system and are therefore part of the assessment of flood defences (VTV). This category can be divided in two sub categories: permanent defences and temporary / moveable defences.

Emergency measures do not form part of the primary flood defence system and are not tested in the assessment of flood defences. These can be divided in 'control' measures, which are prepared beforehand for a specific situation, and emergency measures which are unprepared and site specific. This report will focus mainly on control and/or emergency measures used to prevent breaches in dikes.

The main failure mechanisms of dikes are overtopping, piping, inner slope instability and outer slope erosion. This report will focus mainly on piping failures, because this proved to be the dominant failure mechanism for river dikes in the Netherlands. The approach to determine piping safety used in the Netherlands is less strict than in the U.S. Sand boils have been seen in the U.S. which were safe according to the Dutch approach, but still lead to a breach in the dike. This shows that the growth of sand boils is not completely understood, which is why it is recommended to perform further research on this phenomenon.

Different control and/or emergency measures exist for each failure mechanism of a dike. An overview of 'control' and/or emergency measures used for the failure mechanisms overtopping, piping, inner slope sliding and outer slope erosion is given.

An important aspect in a reliability assessment is the length effect; the longer the flood defence the higher the probability of it having a weak spot. In this report two types of length effect are treated: (1) The length effect of the flood defence (failure mechanism) and (2) the length effect of the emergency measure. Both are modelled as a series system.

For emergency measures the length effect determined to a large extent the feasibility and type of emergency measure required. With increasing amounts of weak spots along a flood defence the contribution of a system of 'control' and/or emergency measures to the reliability will decrease.

About one third of the flood defences in the Netherlands do not comply with the required safety standards, resulting in large investments required for dike reinforcements. Emergency measures could play an important role in improving the safety of the flood defences. Taking in to account that these measures are often less costly than structural dike reinforcements some say that they could even be an alternative to dike reinforcements.

A framework will be developed which can be used to compare the different strategies to increase the safety against piping. To determine the reliability of control and/or emergency measures insight is required in human and organizational reliability, logistics and the technical reliability of the measures.

# 3. Framework for reliability of a system of emergency measures

## 3.1 Introduction

To determine the reliability of the emergency measures first an analysis is made of the organization responsible for the system. The different phases, which need to be passed before emergency measures are placed and operational, are modelled using event and fault tree analyses.

## 3.2 Event tree analysis of emergency measures

Engineering practice for flood defences generally does not take control and/or emergency measures in to account as these are considered to be a last resort. When including emergency measures (human intervention) in the reliability analysis failures happen when both the flood defence and the emergency measure fails, as shown in Figure 22.

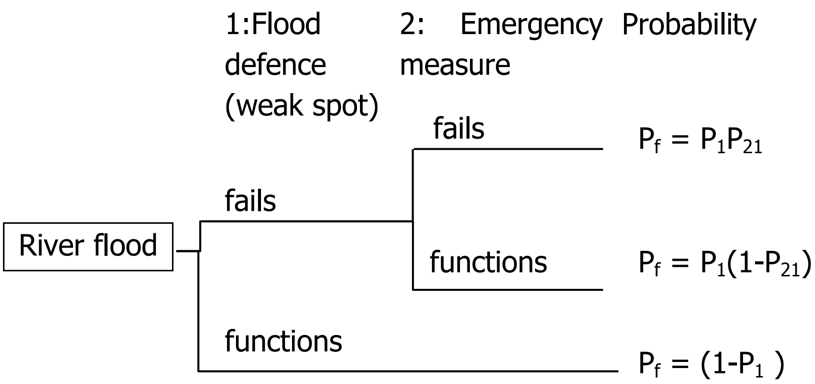



**Figure 22: Event tree failure of flood defense with emergency measure**

In his master thesis W. Ter Horst suggested an approach to take emergency measures in to account when considering the failure probability of a dike ring area, he proposed two steps (ter Horst, 2005):

1. Determine the **reliability** of a system of emergency measures, which will be investigated with the framework developed in this chapter and the next.
2. Determine the reduction of the failure probability of the dike section due to a good working emergency measure, which is labelled as the **effectiveness** of the emergency measure. *This will be investigated partly together with VNK2 who will*

*make sensitivity analyses of the effect of emergency measures on the probabilities of failure of dike sections and dike rings; this is treated in chapter 4.*

### 3.2.1 Event tree of emergency measures

To determine the reliability of emergency measures it is necessary to fully understand all phases in the process of placing emergency measures and to analyse how these interact with the physical system (Corn & Inkabi, 2013). All phases will be captured in one simple event tree which will be further elaborated during the course of this report.

For a 'control' and/or an emergency measure to function correctly different phases need to be passed successfully: from the moment a weak spot is found in a dike to the moment the measure is placed and functioning. The procedures followed more or less resemble those followed for a temporary / moveable flood defence, see appendix III.

Dupuits investigated the effectiveness of emergency measures against piping for sand boils and suggested a framework containing a series of steps which need to be successfully fulfilled ('detection, placement and construction') for emergency measures to function correctly (Dupuits, 2011).

1) Detection: in this phase the water boards monitor the upcoming high water and perform inspections of the flood defences (either through an assessment or by in field inspections on the defences). If weak spots are found these are reported to assess whether or not a 'control' or emergency measure is required.
2) Placement: after weak spots are found a diagnosis is made whether or not measures are required taking the expected water levels and severity of the weak spot in to account. Relevant parties are informed to place the measures on the flood defence.
3) Construction: this is the actual operational phase of the 'control' and/or emergency measure where it needs to function correctly to effectively prevent further damage to the flood defence.

The first phase, detection, starts at a similar moment as the warning phase starts for temporary/moveable flood defences, after a certain water level is exceeded. The different phases are modelled in an event tree as follows:

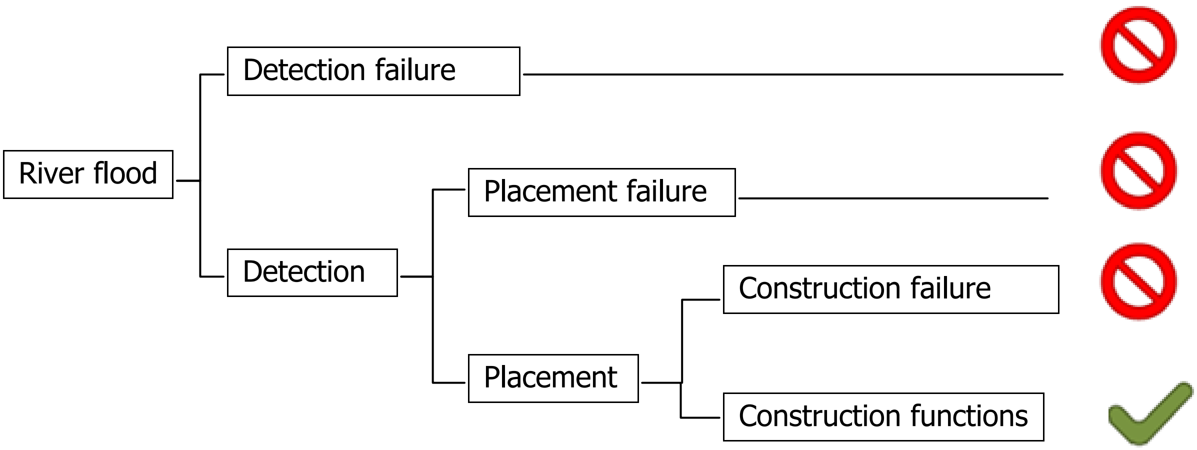



**Figure 23: Event tree control and/or emergency measures**

### System reliability

The system is modelled as a series system: for a successful measure all phases need to function correctly. To determine the reliability of the system the probability of failure of each phase needs to be determined as well as the correlations of the phases.

The reliability of each phase depends on the people performing each individual task as well as the feasibility of complete placement in time (time available versus time required). Therefore, distinction is made between the 'organizational reliability' (human reliability) and the 'feasibility in time' (time available versus time required). The technical reliability completes the total reliability:

- The people performing each individual task; → Organization
- The available time versus the required time; → Time
- The technical reliability of the measure. → Technical

This distinction will be used in the remainder of this report, the relations between these three reliability aspects and the different phases of the event tree is shown in Table 2.

| | Organisation | Time | Technical |
|---|---|---|---|
| **Detection** | | | |
| **Placement** | | | |
| **Construction** | | | |

Table 2: Relations reliability emergency measures

Each phase is further elaborated in the following sections, based on the organizations of the Dutch water boards. However, it is thought that the proposed framework is also applicable to international cases where different organizations are used for flood fighting.

## 3.3 Task analysis 'Detection'

High waters on river in the Netherlands can be predicted, depending on the system, days in advance. For the Rhine Rivers a time span of 2 to 4 days is available before the predicted water levels reach the area. Dutch water boards constantly monitor the forecasted water levels on the river to judge whether or not an inspection of the flood defences is necessary. The framework for emergency measures starts playing a role when this decision is made.

### 3.3.1 Sub tasks 'detection'

The detection phase can be divided in different sub phases:

1. The signal to inspect the flood defences;
2. The inspection of the flood defences;
3. The detection of a weak spot in the flood defence;
4. The report of the weak spot in the flood defence.

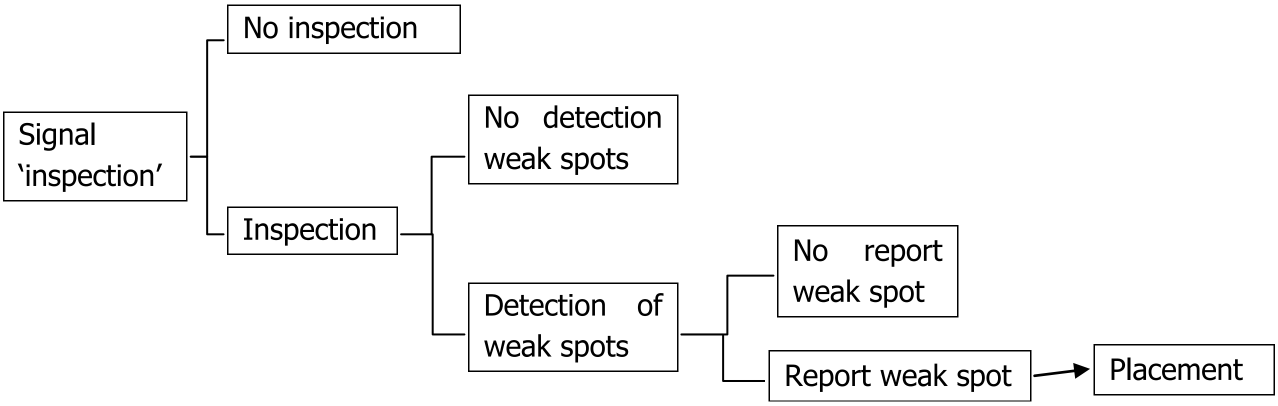



**Figure 24: Sub tasks of 'Detection'**

The event tree suggests that each phase is binary (correct or incorrect); however an inspection can be done partially or completely which also holds for the detection of all weak spots. For now it is assumed a binary representation is correct.

### 3.3.2 Organizations involved in 'Detection'

Water boards in the Netherlands generally have a choice between three organizations to perform the in situ inspections of the flood defences:

1. The **'dike watch'**, which is a group of volunteers (Example: 650 volunteers at Groot Salland Water Board) who received course in flood defence inspection. This group has low experience, as they only receive training incidentally (once every year / two years depending on the water board).
2. The **'districts'**, who are each responsible for the execution of all works / maintenance of the flood defences within a certain area of a Water Board. It can be expected that the employees of these districts are more experienced then the 'dike watch' as they work with flood defences daily.
3. The **'supervisors'** of the water boards, who are responsible for the maintenance and monitoring of the flood defences within the water board. These are well trained experienced professionals who work daily in the field (example: Groot Salland Water Board has 4 supervisors).

During every high water, when the river floods its banks, the supervisors inspect the flood defences in search of potential weak spots. Usually first the areas are inspected which are known to be vulnerable to assess whether or not 'control' measures are required.

When water levels reach critical levels and the supervisors cannot cover the full length of the flood defences in the area the dike watch is ordered to perform the inspections. When weak spots are found these are reported to the relevant teams of the Water Board.

## 3.4 Task analysis 'Placement'

After the 'Detection' phase the placement phase starts, specifically when weak spots are reported. These are then analysed to assess whether or not a measure is required, when no measures are required the weak spots will be monitored to see how these develop.

### 3.4.1 Sub tasks 'placement'

The placement phase can be divided in different sub phases:

1. Diagnostics: to analyse which type of control/emergency measure is required;
2. Mobilization: the mobilization of the personnel, equipment and material to the weak spot (s);
3. Placement: the actual placement of the emergency measure.

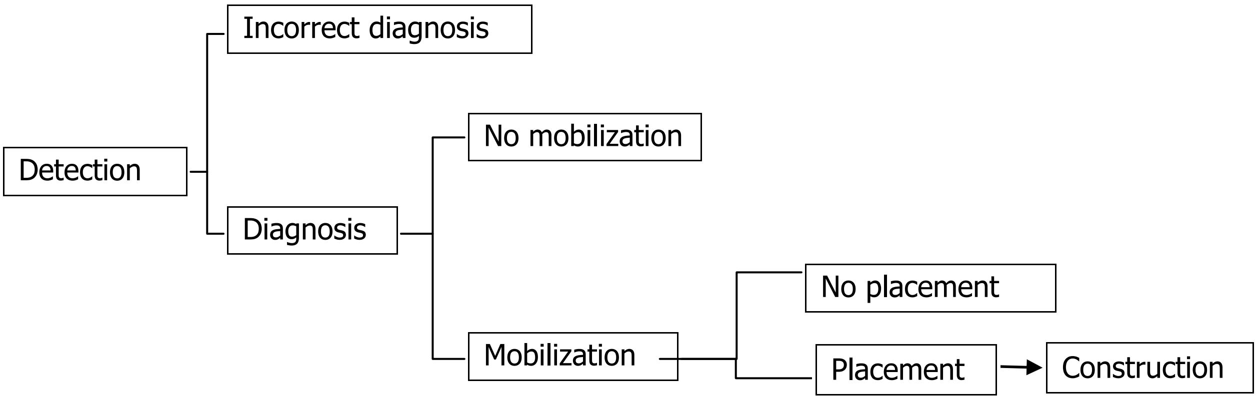



**Figure 25: Sub task 'placement'**

After reporting a weak spot the Water Board needs to decide whether or not a 'control' and/or emergency measure is necessary. If a measure is deemed necessary it should be dimensioned according to the site-specific conditions. This depends on the failure mechanism occurring at the weak spot. A tool to determine which measure to apply could be the 'Dashboard', which Deltares is developing for emergency measures, see appendix I.

Whether or not a certain weak spot will result in a breach in the dike is uncertain and depends to a large extent on the corresponding failure mechanism. For overtopping one could easily state that the dike is failing. For sand boils it is not certain whether or not this will lead to piping failure. For these weak spots Water Boards need to decide whether or not they will monitor the weak spot or apply an emergency measure. The supervisors together with the Water board Action Team make this decision. Three choices could be made, depending on the severity of the damage (weak spot), illustrated in Figure 26.

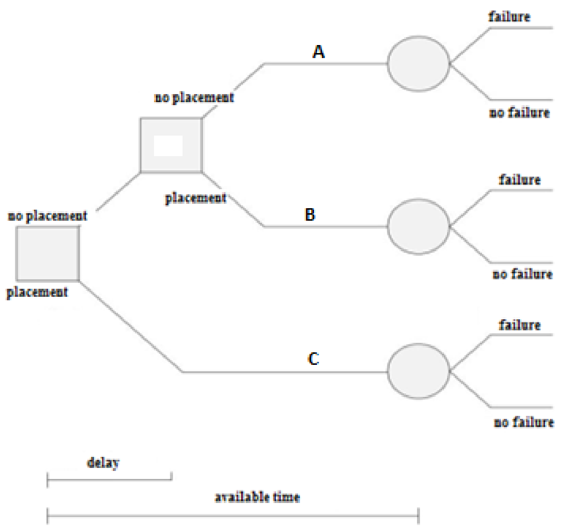



**Figure 26: Delay in placement** (Arkel, 2013)

*Note: During a critical situation Water Boards will treat every weak spot as a threat to dike safety, measures are always placed immediately according to supervisor W. Evers of Water board Groot Salland.*

### 3.4.2 Organizations involved in 'Placement'

The teams responsible for the placement of 'control' and/or emergency measures are summed up below starting with the teams responsible for dimensioning of the measures:

- **Dike post**: the dike post coordinates the dike watchers and registers all incoming reports of the dike watch. They are qualified to decide for the placement of routine 'control' measures.
- **Water board Action Team (WAT):** The WAT controls the dike posts and decide upon more extensive control and/or emergency measures, depending on the situation various experts are consulted.
- **Water board Operational Team (WOT):** focuses on tactics and deals with decision making during the threat of a calamity.
- **Water board Policy Team (WBT):** focuses on a strategic level and deals with decision making during the threat of a calamity.

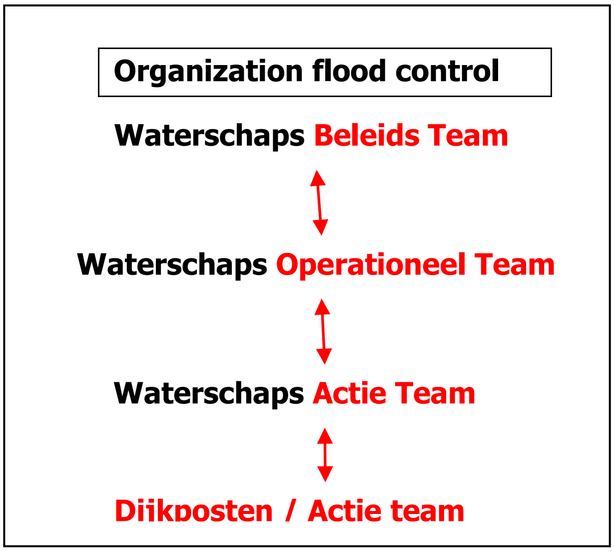



**Figure 27: Organization  dike monitoring [handboek dijkbewaking]**

In short, the dike post and the WAT are responsible for dimensioning 'control' and/or emergency measures. Three parties do the actual placement of the measures:

- **Districts:** As explained the districts of a water board are responsible for the execution of all works / maintenance of the flood defences within a certain area of a Water Board;
- **Contractors / Military:** When the districts do not have sufficient capacity water boards rely on third parties such as contractors or the military to place the 'control' and/or emergency measures;
- **Volunteers:** Past floods have shown that a large amount of volunteers want to help placing emergency measures along the flood defences to keep them from breaching.

Water boards have prepared instructions and procedures for most emergency measures, which should be followed by the districts and contractors during placement. The supervisors perform checks on the work carried out and correct them where necessary.

## 3.5 Task analysis 'Construction'

After the placement of the measures the operational phase starts which in the framework is called the 'Construction' phase. Because of the different types of emergency measures a general event/fault tree for the construction phase cannot be made. Instead the reliability of the measures is treated separately for each failure mechanism of the dike.

### 3.4.3 Reliability of overtopping measures

Measures to prevent overtopping consist of small water retaining structures which can be modelled as gravity structures. The forces acting on the structure are shown in Figure 29.

- The own weight of the system (W [kN/m]);

- The horizontal water pressure ($F_{w;h}$ [kN/m]);
- The vertical water pressure (if present) ($F_{w;v}$ [kN/m]);

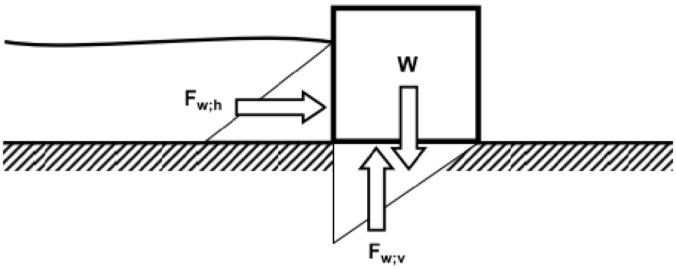



**Figure 28: Pressure and acting forces on an overtopping measure**(Boon, 2007)

Whether or not the vertical water pressure develops like it is illustrated in the figure depends on the subsoil and the loading time (the water pressure requires a certain amount of time to infiltrate the subsoil), see (Boon, 2007). These structures are subject to the following failure mechanisms, illustrated in Figure 29.

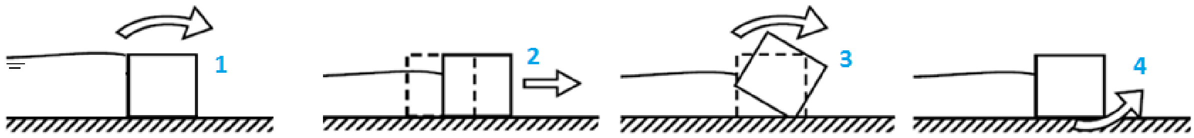



**Figure 29: Overtopping (1), Sliding (2), Rotation (3) and piping (4)** (Boon, 2007)

1. Overtopping, insufficient retaining height
2. Sliding, horizontal sliding of the structure due to the horizontal water forces
3. Rotation, tipping over of the structure due to the horizontal water forces
4. Piping, under seepage or piping under the structure due to the head difference over the structure causing instability

Depending on the measure (sand bags, box barriers etc) applied different reliabilities can be found. In a master thesis made by M.J.J. Boon calculations were made of the safety of several retaining measures against sliding, rotation and piping. (Overtopping was not taken in to account because this would simply require a higher structure). The results are presented in detail in appendix IV.

The calculations show that when the design rules are followed the emergency measures perform quite well on peat and clayey subsoil that are mostly found on dikes. On permeable subsoil the measures prove to be unstable for piping failure. Sliding proved to be the dominant failure mechanism. Probabilistic calculations of the sliding stability of a dike of sand bags are made in chapter 4 to obtain the failure probabilities of these structures.

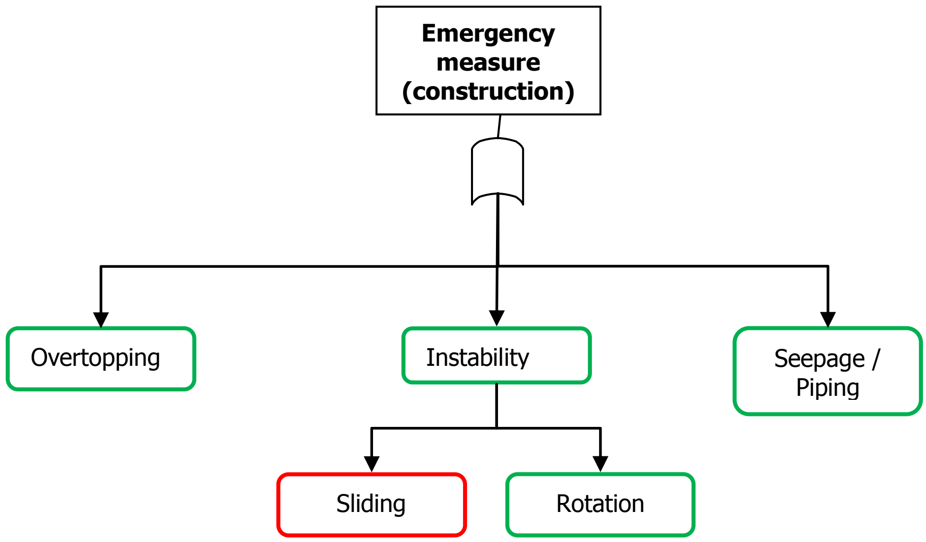



**Figure 30: Failure tree of overtopping measures**

***Sand bags at Flood Proof Holland***

*Investigations in the stability of a retaining wall of sand bags were made in the bachelor thesis of B. Stoop in 2013. According to the guidelines of various water boards the width of a dike of sand bags should be twice the height, which requires a lot of sand bags. In her Bachelor Thesis Bianca investigated the feasibility of lower ratios and found that a minimum width of 1.1 times the height is required(Stoop, 2013). A dike of sand bags proved to fail due to insufficient friction between the sand bags (plastic material), as shown in Figure 31. The friction with the subsoil (peat) proved sufficient to avoid shear failure between the bags and the sub soil.*


***Figure 31: failure of a dike of sand bags*** (Stoop, 2013)

### 3.4.4 Reliability of uplift and piping measures

Containments of sand boils and water berms at the toe of the dike are constructed with water retaining structures such as those used against overtopping. These structures are therefore subject to the same failure mechanisms as overtopping measures. To determine the reliability of these measures reference is made to the last section.

**Figure 32: Containment of a sand boil (left:Dupuits) and filling a ditch at the toe of the dike {right: Waterschap Groot Salland)**

For the other measures against piping: raising the inside water levels, constructing berms with soil and placing geotextiles to prevent further erosion, it is assumed that the technical failure probabilities of these measures are negligible (when placed correctly). The (un) reliability is expected to be dominated by organizational failure (placement errors) or the feasibility of complete placement in time. An example could be placing a piping (soil) berm on the inner slope of the dike instead of at the toe, see Figure 15.

### 3.4.5 Reliability of inner slope stability measures

Measures applied to prevent inner slope sliding consist of placing counterweight at the toe of the dike and keeping heavy equipment from driving on top of the dike. It is assumed these measures do not have technical failure mechanisms once they are placed correctly. Errors could be made during placement, which are considered organizational failures and thus are not part of the technical reliability.

### 3.4.6 Reliability of outer slope erosion measures

Measures used for damages of the protective layer of the dike consist of 'bekrammingen', placing geotextiles on the outside slope of the dike, and/or using sand bags to fill holes in the dike. Such measures delay further erosion of the protective layer, but may itself be washed away under the influence of waves or water pressure, see Figure 14.

Geotextiles will fail when insufficient anchors have been placed causing the textiles to wash away. Sand bags will fail when they are subject to large forces due to the water pressures and waves, as explained in 'Overtopping measures'. These failures are considered to be organizational failures, the technical failure probabilities are assumed negligible.

## 3.6 Conclusions & recommendations

Engineering practice for flood defences generally does not take control and/or emergency measures in to account as these are considered to be a last resort. When including emergency measures (human intervention) in the reliability analysis failures happen when both the flood defence and the emergency measure fails.

To determine the contribution these measures could have to the reliability of a dike system two assessments need to be made. Firstly the probability of a correct functioning emergency measure needs to be determined taking organisational, logistics and technical factors in to account. Secondly the reduction of the failure probability of a dike ring due to an emergency measure needs to be determined; this will be done together with VNK2. A framework is used which divides the use of a measure in a series of tasks:

1) Detection: in this phase the water boards monitor the upcoming high water and perform inspections of the flood defences find weak spots.
2) Placement: after weak spots are found a diagnosis is required whether or not measures are required after which these are placed.
3) Construction: this is the actual operational phase of the 'control' and/or emergency measure where it needs to function correctly.

The reliability of each phase is dependent on the people performing each individual task as well as the feasibility of complete placement in time. Distinction is made between the organizational reliability and the feasibility in time. Finally the constructions also have a certain reliability or probability of failure which is the technical failure. Figure 33 gives a representation of the reliability aspects which influence the different steps in the event tree of control and/or emergency measures.

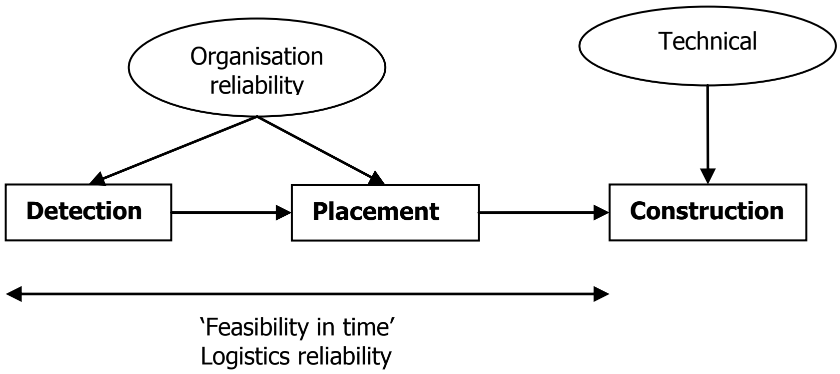



**Figure 33: Network representation of reliability framework**

The tools required to determine the reliability of the organization, the feasibility in time and the technical reliability are developed in the next chapter.

# 4. Reliability of sub phases in the framework of emergency measures

## 4.1 Introduction

In this chapter the quantification of the reliability framework developed in the last chapter will be investigated further. As was concluded in that chapter the organizational reliability, feasibility in time and technical aspects will determine the total reliability of the emergency measures.

This chapter will discuss the theory of an organizational reliability analysis and apply these to the different phases detection – placement. Further, an analysis is made of the available time for emergency measures and compared to the required time. The technical reliability is determined through probabilistic calculations.

## 4.2 Organisational reliability

Human and organizational factors (HOFs) contribute to approximately 80% of major engineered system failures and although HOFs have been incorporated in the reliability evaluation of a variety of engineered they continue to be commonly omitted in flood protection conceptual models and reliability valuations (Corn & Inkabi, 2013).

In the last chapter it became clear that the organization plays an important role in the reliability of the emergency measures. In particular whether or not the weak spots are found and evaluated correctly and if the corresponding control and/or emergency measure are placed correctly. To assess the reliability of these tasks a Human Reliability Analysis is made. The theory of an HRA is treated in appendix V.

### 4.2.1 Methods to analyze the organizational reliability

Event and fault tree analyses are used in an HRA to determine what types of errors can be made and how these errors interact with the other components of the system. An event tree analysis is made in chapter 3 about the system of emergency measures. The next step is to quantify the probabilities of errors. For the quantification of human errors the THERP method will be used (see appendix V). A similar approach is used in 'Leidraad Kunstwerken' to determine the 'Reliability of non-closure', where human errors also play an important role.

**Human error quantification: Mean error rates**

A Human and Organizational Error is a deviation from acceptable or desirable practice on the part of an individual (human error) or group of individuals (organizational error) that can result in unanticipated and/or undesirable results (Stamler, 1993).

Human reliability practitioners have had to rely on expert judgment in combination with limited numerical data due to a lack of a successful database of human error probabilities. This database is then manipulated by the assessor to find probabilities of errors for the specific tasks to be performed within the system. The analysis of reliability in the engineering/technology vocations typically seek only orders of magnitude of estimations of errors rather than exact descriptions (R Bea, 2010).

The most important aspect is the qualitative analysis of the system, rather than the quantitative results, where numerical values are assigned to the probabilities of human errors, based on the judgment of the assessor (Rasmussen, 1982).

The methods of Rasmussen are used to describe the typical human errors for emergency measures. Rasmussen uses a generic psychological classification of human errors which can be applied to specific task performances (Rasmussen, 1982). In his model distinction is made between three levels of behaviour: skill based, rule based and knowledge based (Rasmussen, 1983).

- **Knowledge based** performance is the most cognitively demanding level, at this stage there are no pre-planned actions which can be called upon because of the novelty of the situation. The assessor is required to analyse the unfamiliar situation, develop alternative (conceptual) plans and choose the plan which is considered to be the best alternative (Rasmussen, 1983).The error rates vary between 0.5 and 5 e-3 (1 in 20 – 1 in 2,00) per task.
- **Rule based** performance is the next cognitive level; this class involves responding to a familiar problem according to standardized rules. The rule to be applied is selected from previous successful experiences (Rasmussen, 1983). The error rates vary between 5 e-2 and 5 e-4 (1 in 20 – 1 in 2,000) per task.
- **Skill based** performance is the least cognitively demanding level; at this level the calling conditions occur so often that knowledge retrieval and action are virtually automatic. Normally, skill based performance occurs without conscious attention or control (Rasmussen 1983). The error rates vary between 5 e-3 and 5 e-5 (1 in 200 – 1 in 20,000) per task.

The relation between common error probabilities and the three performance levels is show in Figure 34. Watson (1986) and Collins (1995) have addressed the human performance reliabilities associated with skill-, rule- and knowledge based tasks. Onsite examination of tasks, interviews and expert judgment are used to identify the evaluation of human performance levels. To increase human performance levels training people with the specific repertoire of (unexpected) possible behaviour of the system proved to be highly effective (Rasmussen, 1983).

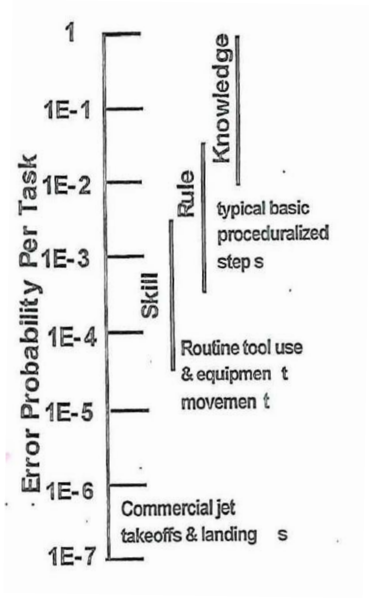



**Figure 34:Relation human error probabilities and performance levels by Watson and Collins (R. Bea, 2010)**

## Human error quantification: Performance shaping factors

Performance shaping factors (PSF) are used to model an engineered system in different components and are useful in helping develop quantification of the potential effects of changes in seven categories (Williams, 1988; Swain & Guttman, 1983): operators, organization, procedures, hardware, structures, environments and interfaces. Reference is made to appendix V.

In practice assessors rarely use PSF to change mean error rates, because these are considered highly subjective. Instead assessors more often only use the factor stress to determine the spread around the mean base rates of human errors. This is not how it is meant to be used by THERP but is considered applicable (Kirwan, 1996). To compare the following figure shows the mean error rates as determined by Williams.

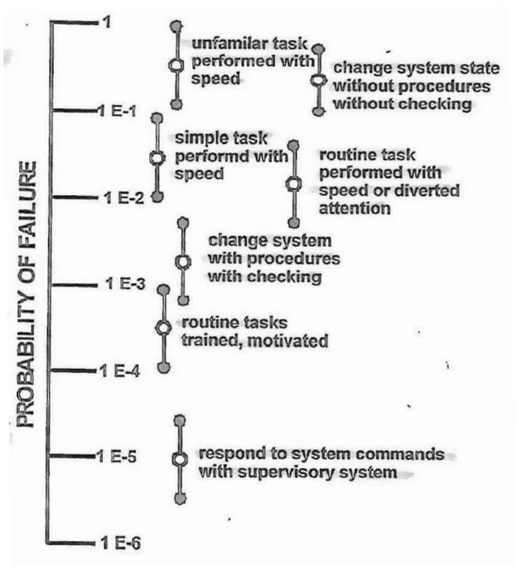



**Figure 35: Normal human task performance reliability by Williams (1988)**

### Conclusion

To determine the human and organizational reliability for emergency measures the steps followed in a Human Reliability Analysis are followed. The qualitative description of the system is the most important aspect, as it is used to identify all possible errors and how these can be avoided. For the quantification of the mean error rates the methods proposed by Rasmussen are used which divide the performance of humans in three categories. Knowledge based, Rule based or Skill based performance.

Specific aspects which influence the reliability of the organisation are the familiarity with the system, the novelty of each task to the assessor and knowledge and experience with the system. Other aspects which influence the reliability are the availability of documented procedures, the stress level of the assessor, fatigue and weather conditions.

Methods to increase human performance are explained in the appendix. In short, options used often consist of documenting procedures and rules and training of the personnel during normal and abnormal conditions. The proposed methods are widely used in man-machine interactions and have not been used in flood fighting.

#### *Bayesian network for organizational reliability*

For a more thorough investigation based on expert judgement W. Jager proposed a model to ellicitate expert judgment for probabilistic hazards in engineering systems (Jager, 2013a), see the appendix. This assessment is based on the Classical model which has been developed for the European Space Agency for risk assessment applications, it's objective is to properly ellicitate expert judgment for probabilistic hazards. For this project it seems unreasonable to use this model due the lack of data and time constraints.

## 4.2.2 Reliability of 'Detection' task

Three organizations are involved in the detection phase; the dike watch, the districts and the dike supervisors. Tools used to perform the inspections are summed up below:

- Current and predicted weather, water levels and river discharges;
- Results of last assessment of the flood defences (especially for the supervisors);
- Reports of inspections in the past (especially for the supervisors);
- Damage forms (especially for the dike watch).

Water Boards acknowledge that there is a lot of subjectivity of the inspections done by the dike watch: "volunteers are only helpful for relatively simple tasks, because most of the work requires extensive training." (Leeuw et al., 2012). These are the people who they need to rely on during the most critical situations to perform the inspections.

Depending on who performs the inspections, weak spots can be evaluated as critical or not critical. 'Suspicious' spots are always found; it is up to the person who does the inspection to evaluate whether or not these spots need to be reported. It can be assumed that the 'supervisors' and 'districts' evaluate each weak spot correctly; this cannot be said of the dike watch because of their lack of experience. Water boards are aware of this subjectivity and therefore always instruct the supervisors to check the observations of the dike watch.

To gain understanding of the levels (skill, rule or knowledge based) at which the different parties act systematic interviews were taken and workshops given, see appendix V. Table 3 gives an overview of the expected human error probabilities of the three parties involved per task, which coincide largely with the probabilities found in (Corn, Inkabi, 2013). As shown in the table ranges of error probabilities are given, these are further assessed in case studies with the different water boards.

| Group | Knowledge | Experience | Performance level | Error probability per task |
|---|---|---|---|---|
| **Dike watch with low training** | Low | Low | Knowledge based (dike watch uses damage forms) | ~ 1/10 – 1/20 |
| **Dike watch with high training** | Relatively low | Relatively low | Rule based (dike watch uses damage forms) | ~ 1/20 – 1/100 |
| **District** | Relatively high | High | Rule based | ~ 1/200 – 1/2,000 |
| **Supervisors** | High | High | Skill based | ~ 1/2,000 – 1/20,000 |

**Table 3 Human / organizational error probabilities for detection**

### 4.2.3 Reliability of 'Placement' task

The actual placement of the measures can be performed by three parties: the districts, contractors / military or volunteers. Regarding these parties it can be assumed that the reliability of their actions decrease from the districts to the volunteers due to a lack of applied knowledge and experience in the field. Table 4 gives an overview of the expected human error probabilities per task of all parties involved.

| Group | Knowledge | Experience | Performance level | Error probability per task |
|---|---|---|---|---|
| **Dike post** | High | High | Skill based | ~ 1/2,000 – 1/20,000 |
| **WAT** | High | High | Skill based | ~ 1/2,000 – 1/20,000 |
| **Volunteers** | Low | Low | Knowledge based | ~ 1/10 – 1/20 |
| **Contractors** | Low | High | Rule based: contractors follow procedures during placement of the measures | ~ 1/20 – 1/200 |
| **Districts** | Relatively high | High | Rule based: districts follow procedures during placement of the measures | ~ 1/200 – 1/2,000 |

**Table 4 Human / organizational error probabilities for placement**

Note that for the dike post and the WAT high reliabilities (low error probabilities) are given, mainly because the dike post is only allowed to decide upon routine control measures and the WAT decides upon more drastic measures. As this is laid down in the organization it is expected that these procedures have low error probabilities.

After interviews with contractors it became clear that these do not exercise more frequent than the dike watchers which would imply the same error probabilities as the dike watch. However the contractors have a large experience in water construction, which results in lower expected error probabilities than the dike watch.

**Outsourcing: capacity and performance reliability**

From the analyses became clear that water boards rely on third parties during critical situations (military, contractors and/or volunteers). These parties have relatively low experience with the work that need to be done. Supervisors are instructed to coordinate the work, but are lacking in capacity to oversee all work done during a critical situation.

Regarding availability it is recommended to make contracts with the third parties in which their availability during high waters is arranged. Similar contracts exist for the temporary / moveable flood defences, so called 'waakvlam' contracts. In the 'waakvlam' contracts a certain amount of equipment and personnel are made available to the water board at every given moment. Response times and consequences when not showing up are also part of these contracts (STOWA, 2008).

Another problem with outsourcing is that the third party is responsible for safety instead of the water board itself. This could result in lower reliabilities because an extra step in the chain is introduced: the third party could be less preoccupied with safety then water board (more interested in profits), see also (RG Bea, 1998).

### 4.2.4 Discussion

The approach in this study generally followed the HRA / THERP process. In the next chapter a case study will be made of a water board in the Netherlands in which the error probabilities determined would be assessed in more detail for the specific situations. The error probabilities found are based on expert judgment. It is advised to do more onsite examinations in the case studies to validate the error probabilities, see chapter 5.

## 4.3 Feasibility in time

The reliability of emergency measures depends to a large extent on the feasibility of complete placement in time, which is influenced by the logistics. The reliability of logistics depends on the capacity of the organization (personnel, equipment and material), the distance to the site, weather conditions and the placement speed. This paragraph will deal with the time line for placement of the emergency measures and how this effects the reliability of emergency measures.

As heavy rains usually precede high river discharges or storm surges can be predicted in advance. Depending on the system considered the water levels can be predicted hours in advance (storm surge / rain) to days in advance (river flood). This implies that there is always a certain 'available time' to prepare for the hazard (Leeuw et al., 2012), see Table 6.

| Prediction lead time | Type of hazard |
|---|---|
| 0 to seconds | Explosion, fire, airplane crash, car crash |
| Minutes | Earthquake, tsunami |
| Hours | Storm surge at sea |
| Days | Hurricane, volcanic eruption, river floods |

Table 5: Prediction times of hazards (Frieser, 2004)

### 4.3.1 Reliability in time

The available time is defined as the prediction lead-time, the time between the moment the hazard is predicted until it arrives. This window is available to detect and place emergency measures. The required time is the time required for the correct placement of the emergency measure. The different phases of Detection – Placement – Construction are illustrated in a time line in Figure 36, which shows the available/required time for completion of every phase before the arrival of the peak of the river flood.

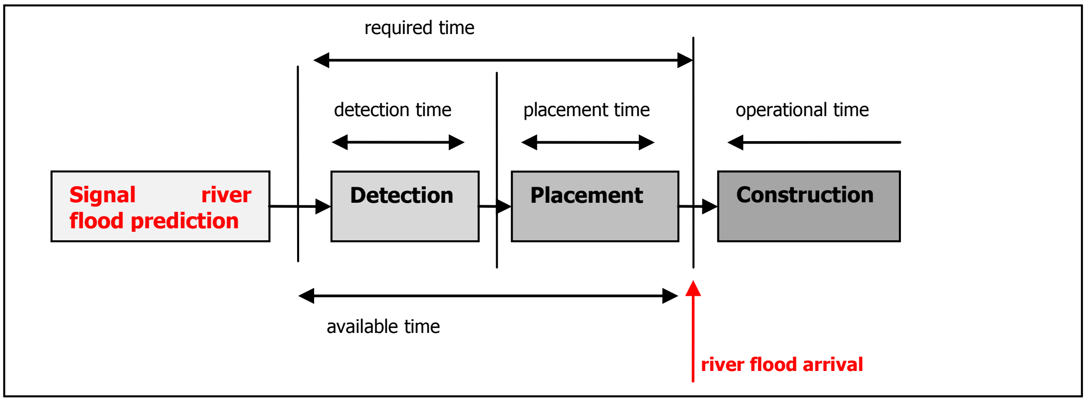



Figure 36: Time line control / emergency measures

#### Probabilistic calculation

Naturally for a correct functioning measure the available time must exceed the required time. To determine the reliability in time a reliability function is made, normal distributions are used for the different sub phases.

$$Z = T_{available} - T_{required} \quad (4\text{-}1)$$

$$T_{available} = \text{river flood prediction lead time} \quad (4\text{-}2)$$

$$T_{required} = T_{detection} + T_{placement} \quad (4\text{-}3)$$

$$Z = T_{available} - T_{detection} - T_{placement} \quad (4\text{-}4)$$

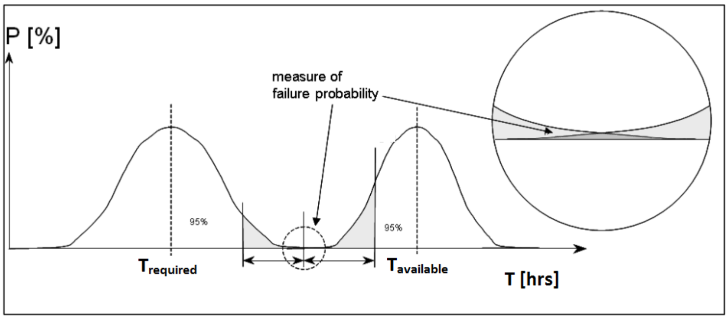



**Figure 37: Required versus available time**

The required time for both the detection and placement is treated in the following paragraphs. Conditions that will influence the detection and placement are day or night-time, visibility, the weather, the subsoil (paved subsoil versus unpaved) and manpower. Two categories will be given: normal and extreme conditions:

- **Extreme conditions**: little visibility (extreme weather or night time) together with strong winds and rain. This also influences the unpaved subsoil, which will be muddy resulting in slower walking, speeds.
- **Normal conditions**: good visibility (daytime), clear weather with little wind. This makes walking easier because no heavy rains are expected.

### 4.3.2 The available time [$T_{available}$]

In the Netherlands there are two models that predict the water level on the river Rhine, which are FloRIJN and Lobith. Both models are able to predict the water levels in the Rhine 4 days in advance, with the FloRIJN model being more accurate (Frieser, 2004). Table 6 shows the accuracy of the prediction in relation to the prediction time, which increases as the prediction time decreases.

| Prediction lead time [days] | Accuracy [deviation forecast from measures water level] |
|---|---|
| 4 | +/- 40cm |
| 3 | +/- 30cm |
| 2 | +/- 20cm |
| 1 | +/- 10cm |

**Table 6: Accuracy of prediction times(Frieser, 2004)**

**Approach for temporary flood defences**

For temporary flood defences the water levels are laid down in the closing procedures. In 'Keuzemodel tijdelijke en demontabele keringen' a description is given of the effects of choosing a warning level too low or too high. In short; choosing a level too low results in more uncertainty about the predictions and a higher probability of unnecessary closures while choosing a warning level too high increases the probability of not having sufficient time to close the defence (STOWA, 2008).

In the report a tool is explained used to determine the average available time for closures including the probabilities of these times. A similar instrument could be used to determine the levels at which the inspection and placement should start for emergency measures.

### Approach Dutch water boards

For Water Boards a certain water level at Lobith will result in the decision to start the calamity control program; some water boards have laid this down in their 'Calamiteit bestrijdingsplan' (ex: Rivierenland (Knotter, 2013)). The water level at which the dike watch starts inspecting determines the time available for detection and placement of an emergency measure. Water board Rivierenland prepared procedures for when the dike watch starts inspection, depending on the water levels. For Groot Salland a different approach is used, based on the experience with past river floods.

To determine the available time for placement of the emergency measures it is assumed the same time is available as for closures of temporary flood defences, the distributions are shown in Table 7 (STOWA, 2008). The table shows the mean and standard deviations for a normal distribution based on the data in (STOWA, 2008).

| River system | Closure water level (+m NAP) | Average duration (50%) [hrs] | Minimum duration (5%) [hrs] | Minimum duration (1%) [hrs] | Mean [hrs] | Standard deviation [hrs] 5% | Standard deviation [hrs] 1% |
|---|---|---|---|---|---|---|---|
| Rhine | 12.5 | 94 | 48 | 40 | 94 | 28 | 23 |
| Rhine | 13 | 128 | 65 | 54 | 128 | 32 | 38 |
| Meuse | 19.25 | 51 | 23 | 19 | 51 | 17 | 14 |
| Meuse | 20 | 86 | 41 | 34 | 86 | 27 | 22 |

**Table 7: Distributions of available time for different river systems depending on closure water level** (STOWA, 2008)

***Experiences from past river floods***

During the river floods in 1993 the water levels of the Rhine increased from an annual average winter level of +11m NAP at Lobith to a top level of +16.39m NAP in 4 days (between December 20 and 24 1993). The water levels remained above a level of +11m NAP until February 12$^{th}$ 1994. The water levels on the Meuse increased from an annual average level of +42.9m NAP at Borgharen to a peak level of +45.9m NAP in 3 (!) days (between December 19 and 22 1993) and stayed above the average level until January 12$^{th}$ 1994 (TAW 1992). This illustrates the speed at which the water levels can reach peak levels.

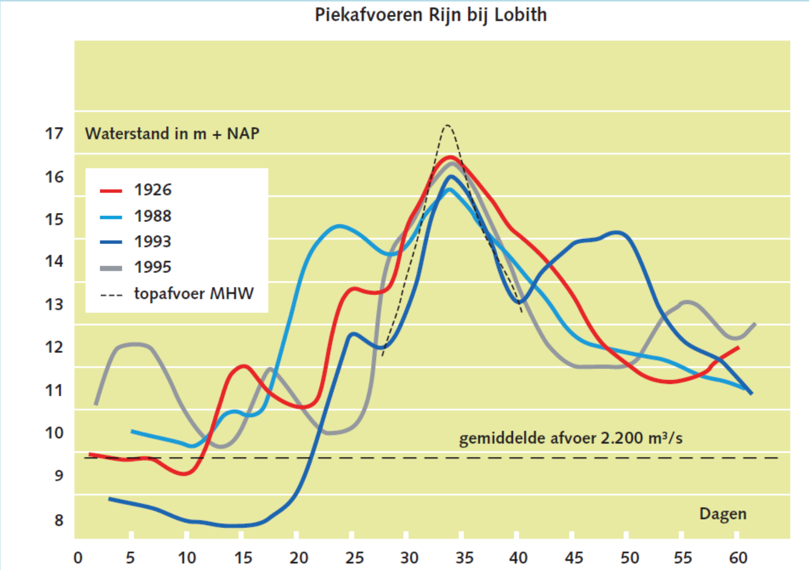



**Figure 38: Water level at Lobith for different river floods (http://www.ruimtevoorderivier.nl/media/75812/hoog-en-laagwaterboekje_1_.pdf)**

**Conclusion: available time for emergency measures**

Based on the experiences of 1993 and 1995 and observations of the water boards Rivierenland and Groot Salland assumptions are made regarding the available time:

***Overtopping***

Overtopping only occurs when the water levels exceed the dike height, which will only happen during the peak of the river flood. The accuracy of the predicted water levels increases with decreasing time to the arrival of the peak of the river flood. As water boards are expected to have up to date information on the height of their flood defences it is assumed that the available time for placement of overtopping measures is 48 hours with a standard deviation of 12 hours.

***Piping***

Dike sections vulnerable for piping failure will be inspected days before the peak of a river flood is expected, opposed to those sections vulnerable for overtopping. Piping could potentially occur before the arrival of the peak of the river flood, but also after as a certain time is necessary to develop a complete pipe under the dike. Based on interviews with the water boards and the aforementioned aspects it is assumed the available time to detect and place piping measures is 96 hours with a standard deviation of 24 hours. Note that if sand boils are found the available time will decrease, because the piping process has already started. This is also seen from experiences with past piping breaches.

### 4.3.3 The required time for detection [$T_{detection}$]

The required time for detection can be divided in different sub phases, see Figure 24:

**Decision time**

The decision time is the time between the signal of a river flood and the decision to inspect the dike. During the 1995 high water in The Netherlands the decision was made to evacuate several areas along the River Rhine, which took 4 hours (Boon, 2007). Because of the big impact of an evacuation it is expected less time is required to decide upon inspection of the flood defences, a decision time of 2 hours is assumed with a deviation of 0.25 hours, which results in a 95% confidence interval between 1.5 and 2.5 hours.

#### Mobilization time

No data was found on the mobilization time of the dike watchers. It is known that the mobilization of all volunteers of the high water brigade of the temporary flood defence in Kampen Midden takes 4 hours. This is a comparable situation so the same time will be assumed with a deviation of 0.5 hours. This results in a distribution where 95% of the cases the mobilization takes between 3 and 5 hours.

#### Inspection time

The required time of the actual inspection of the flood defences not only depends on the type of measure (control / emergency) and the conditions (normal versus extreme) but also on the people performing the inspection. The inspection time of a supervisor is considered to be faster than that of the dike watch because supervisors are more experienced. The inspection time is summarized in the following table for the combinations possible.

| Who | Measure type | Condition | Inspection time mean | Inspection time deviation |
|---|---|---|---|---|
| Supervisor/district | Control measure | Favourable | 3.5 km/hr | 0.25 km/hr |
| Supervisor/district | Control measure | Unfavourable | 2.5 km/hr | 0.25 km/hr |
| Dike watch | Emergency measure | Favourable | 2.5 km/hr | 0.25 km/hr |
| Dike watch | Emergency measure | Unfavourable | 1.5 km/hr | 0.25 km/hr |

**Table 8: Inspection time supervisors and districts versus the dike watch**

The total length to be inspected by dike watch teams differs between water boards but is often limited to a section of 5 kilometres.

### 4.3.4 The required time for placement [$T_{placement}$]

The placement is divided in three sub phases as shown in Figure 25:

#### Diagnostics

The diagnostics time is the time required to decide upon the placement of an emergency measure given a weak spot. From different interviews with supervisors of the Water Boards it is concluded that the diagnostics phase will take an average of 2 hours for **control measures**, which are prepared largely beforehand. A standard deviation of 0.25 hour is assumed as this could differ largely due to the large differences there are between types of measures.

For **emergency measures** it is assumed this process will take more time, as these are unprepared. A mean time of 3 hours seems reasonable after discussing with Groot Salland. Also here a standard deviation is 0.25 hour is assumed.

### Mobilization

To determine the time required for mobilization of all personnel, equipment and material interviews were conducted with the districts and contractors responsible for placement of the measures. The required time obviously depends on the conditions and type of measure to be applied. The following times were agreed upon for the different conditions:

| Who | Measure type | Condition | Mobilization time mean | Mobilization time deviation |
|---|---|---|---|---|
| Districts / contractors | Control and emergency measures | Favourable | 3 hour | 0.5 hour |
| Districts / contractors | Control and emergency measures | Unfavourable | 4 hour | 0.5 hour |

Table 9: Mobilization time

The time required for both the districts and contractors are assumed equal. In practice if there are no contracts with the contractors their mobilization will take more time.

### Placement

The time required for the actual placement of the control and/or emergency measures cannot be given explicitly as it not only depends on the conditions present, the personnel, the equipment and the extent of the damage but also on the measure itself. Water Board Groot Salland prepared a report in which the time required for placement of 'control' measures is given during both favourable and unfavourable conditions (WGS, 2012). In the different case studies these can be used as indicators of the time required. An overview is given in appendix VI.

### 4.3.5 Discussion

The assumed times in the previous sections are the result of expert judgement, interviews and workshops conducted with employees of Groot Salland and Rivierenland (partly). They serve as an indication of the actual times and are subject to changes when looking at different Water Boards. It is advised to do more onsite examinations in the case studies to validate the required times.

## 4.4 Technical reliability and effectiveness

The last part of the reliability analysis of control and/or emergency measures consists of the technical reliability of the measure itself in the operational phase (Construction), which is treated in this paragraph. The effectiveness of the measures is also treated. The effectiveness of the control and/or emergency measure is the effect the measure has on the safety (or probability of failure) of the dike ring.

### 4.4.1 Technical failure of emergency measures

The technical failure mechanisms of emergency measures are shown in Figure 30. For several emergency measures widely used by water boards probabilistic calculations are made to determine the reliability of these measures. With the results of the tests in Flood Proof Holland these calculations are validated. The measures treated are:

***A dike of sand bags***

A dike of sand bags can be built in single stacks or in a pyramid. From the guidelines of water boards these dikes are advised to be built twice as wide as the retaining height, which requires a large amount of bags and results in long placement times. In a bachelor thesis B. Stoop investigated the failure mechanisms of a dike of sand bags for different cross sections. She concluded that sliding at the interface of sand bags was dominant on peat subsoil. Probabilistic calculations are made in the following section to determine the failure probability at every interface of different cross sections.

***Big bags***

Big Bags are bags of 1 cubical meter, and as such retain 1 meter of water when filled completely, the stability against sliding is also checked.

***Containments of sand boils***

Containments of sand boils consist of circular dike of sand bags, the failure probability of these structures is equal to that of a dike of sand bags with the same retaining height.

### 4.4.2 Probabilistic calculation method

The sliding criterion is explained with the following equation (see chapter 3):

$$FS_{shear}\left[-\right]=\frac{T}{F_{w;h}}=\frac{f*\sum V}{\sum H} \tag{4-1}$$

- The own weight of the system (W [kN/m]);
- The horizontal water pressure ($F_{w;h}$ [kN/m]);
- The vertical water pressure (if present) ($F_{w;v}$ [kN/m]);

When the safety factor drops below $FS_{shear}=1$, the structure becomes unstable. The friction force depends on the resultant of the system weight (W) and upward water force ($F_{w;v}$) and the shear coefficient. This shear coefficient [f] depends on the material of the structure and the foundation.

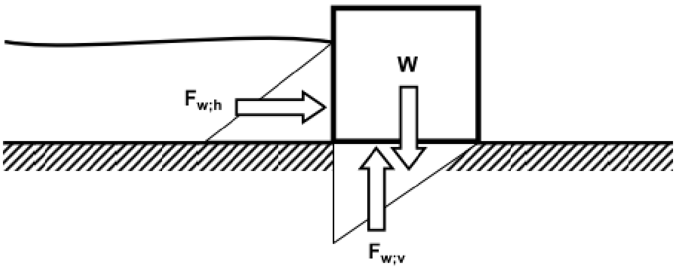



**Figure 39: Pressure and acting forces on an overtopping measure**(Boon, 2007)

### Upward water pressure

The upward water pressure under the structure lowers the actual weight of the structure and as such has a negative effect on the friction force necessary for stability of the structure. Whether or not the upward pressure is present depends on the type of subsoil (permeability), the loading time and the connection between the structure and the subsoil. In low permeable subsoil, which is present on flood defences, it is expected no upward pressure will be present from the subsoil because the loading time required to develop the complete water pressure is longer than the loading time of the structure.

However, due to the permeability of sand bags they will partly be filled with water that also results in an upward water pressure inside the bags. This will lower the resultant vertical pressure on the subsoil. The upward water pressure is taken in to account in the calculations through  a percentage of the total.

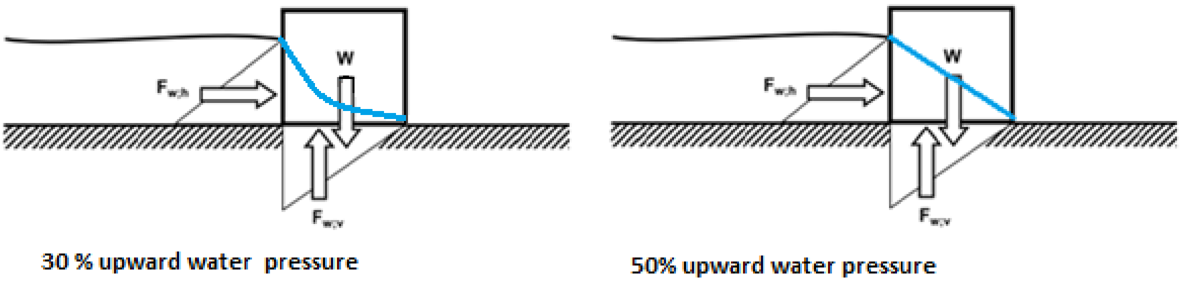



**Figure 40: Freatic line inside dike of sand bags**

### Friction force

The calculations are made for sand bags placed on top of a clay or peat layer, no calculations are made for structures on sand subsoil as it was concluded that on sand the structure will be unstable due to piping. An exception could be made for sand boils, where the top layer of the subsoil could consist of sand which eroded out of the boil. However, it is assumed the containments are placed around the boil on top of the clay layer and not on top of the eroded sand.

### Variables and corresponding distributions

In order to make a probabilistic calculation normal distributions are assumed for the variables which together determine the stability against sliding. The variables and the corresponding distributions are explained in appendix VII.

### 4.4.3 Results: technical reliability

Through Monte Carlo simulation the reliability of the different structures is determined. For a dike of sand bags the instability of each interface is calculated. The calculated probabilities represent the probabilities of failure for sliding of the structures and have the dimension probability per emergency measure with a certain retaining height. It is assumed the sliding probability of failure is represents the total failure probability of the emergency measure: once one interface fails the structure will fail according to the description given by (Stoop, 2013).

***Single stack***

Sand bags have dimensions of 0.3. * 0.4m. The bags could be placed in line with the flood defence which results in a width of 0.3 meter, or perpendicular to the line of the flood defence for a resultant width of 0.4 meter. The required height over width ratio and maximum retaining heights per option are shown in Table 10.

| **Single stack of sand bags** | | **Maximum retaining height for 25% of total upward pressure** | | | |
|---|---|---|---|---|---|
| **Direction of stacks** | **Failure at interface** | **Clay [m]** | **H/B ratio [-]** | **Peat [m]** | **H/B ratio [-]** |
| In line with flood defence b = 0.3 m | interface between sand bags and subsoil | 0.45 | 1.5 | 0.52 | 1.7 |
| Perpendicular to flood defence b = 0.4 m | interface between sand bags and subsoil | 0.60 | 1.5 | 0.67 | 1.7 |

**Table 10: Maximum retaining heights of single stacks**

Different upward water pressure percentages were taken in to account and compared with the results of the tests at Flood Proof Holland; an upward pressure of 25% approximates the results found at FPH best and is thus considered to be a reasonable estimate. For clay layers sliding will occur at the interface between sand bags and the subsoil, whereas on peat subsoil the interface between sand bags is dominant.

***Pyramid***

Similar probabilistic calculations are made for a cross section in the shape of a pyramid, where every next layer has one more sand bag then the layer on top of it. The results show, even for a maximum upward water pressure, that this structure is considered stable for all retaining heights treated.

***Big bags***

The probabilities of failure for big bags on clay and peat are given in the following table for both clay and peat subsoil. With an upward water pressure of 25% of the total the failure probability is about 0.05 on clay and negligible on peat.

| **Probability of failure of big bags** | **No upward pressure** | **Partly pressure** | **Partly pressure** | **Complete pressure** |
|---|---|---|---|---|

| [per bag] | [0%] | [25%] | [50%] | [100%] |
|---|---|---|---|---|
| Big bags on clay | 5 e-3 | 5 e-2 | 2 e-1 | 8 e-1 |
| Big bags on Peat | - | - | 3 e-6 | 1 e-2 |

**Table 11: Probability of failure of big bags on clay**

The calculations show that big bags are very stable for sliding on peat subsoil. Tests with a Box Barrier showed the same results for sliding. For the Box Barrier rotational instability proved to be dominant on peat subsoil, which could also be the case for big bags. But, considering that the top layer of dikes mainly consists of clay no further calculations for peat subsoil are made.

**Conclusions**

Through comparison with the results at the tests at Flood Proof Holland it is concluded that 25% of the total upward water pressure is a reliable estimate. A dike of sand bags on peat will fail due to sliding on the interface between sand bags, on clay subsoil the interface with the subsoil proved dominant. The cross sections advised by water boards (pyramid structures) have failure probabilities negligible compared to the orders of organizational and logistics failure.

Big bags are more stable on peat subsoil than on clay, however it is expected that on peat subsoil other failure mechanisms may be dominant. As the top layer of flood defences mainly consists of clay these are not further investigated. The failure probability is in the order of $5 * 10^{-2}$.

It should be mentioned these calculations are made assuming a uniform load on the structures (no flowing water). In a flow of water these structures are expected to be less stable, more research on this subject is required.

### 4.4.4 Effectiveness of emergency measures

The final stage in the analysis is that of determining the effectiveness of the emergency measures once correctly placed and functioning. M.J.J. Boon made different analyses on the effectiveness of temporary flood defences in his master thesis, which show the potential effect of such measures on the fragility curves of dikes. The fragility curve of a dike section (prior) is shown in Figure 41, illustrating the failure probability of overtopping (Po|h) and piping (Pp|h) failure dependent on the water level with respect to the crest of the dike.

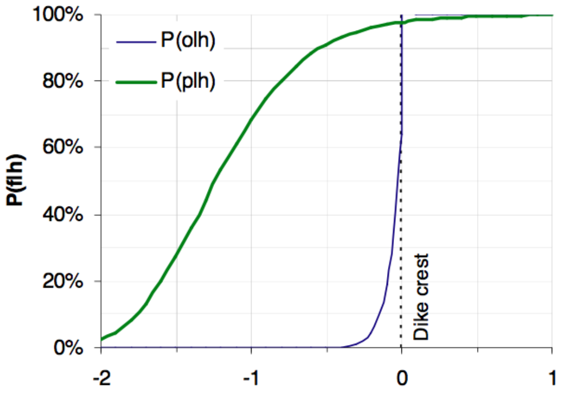



**Figure 41: Probability of failure of overtopping (Po|h) and piping P(p|h) related to the water level with respect to the crest of the dike** (Boon, 2007)

The figure shows that piping (P(p|h)) could occur for water levels below the crest whereas overtopping (P(o|h)) only becomes dominant with water levels close the crest of the dike. For overtopping, depending on the height of the emergency measure, the curve will move the to the right as shown in Figure 42.

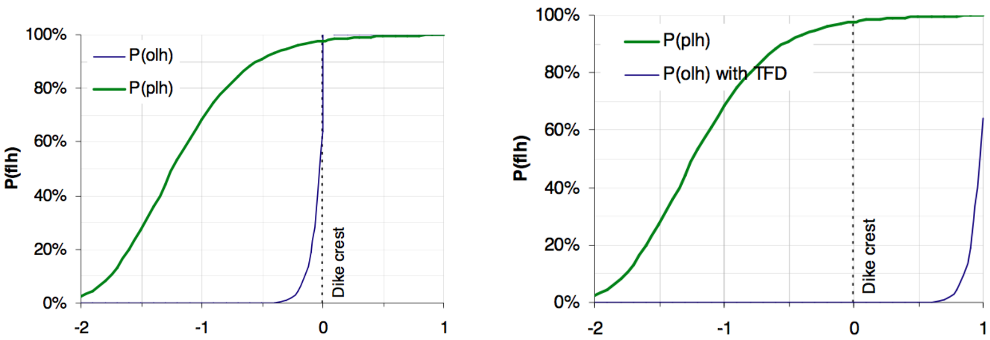



**Figure 42: Prior fragility curve (left) and posterior fragility curve (right) illustrating the effectiveness of an emergency measure (or Temporary Flood Defense TFD) for overtopping with a retaining height of 1.0 meter** (Boon, 2007)

For piping dominated sections a similar analyses is made, but the effect on the reliability is more complex than for overtopping dominated sections. Where overtopping measures are expected to move the entire fragility curve to the right, piping measures will have the largest effect on the lower river water levels. As was explained piping could already occur for water levels below the crest. It is therefore expected that once a certain (critical) water level with respect to the crest is reached the original (prior) reliability will hold, which is the water level where piping is expected to occur.

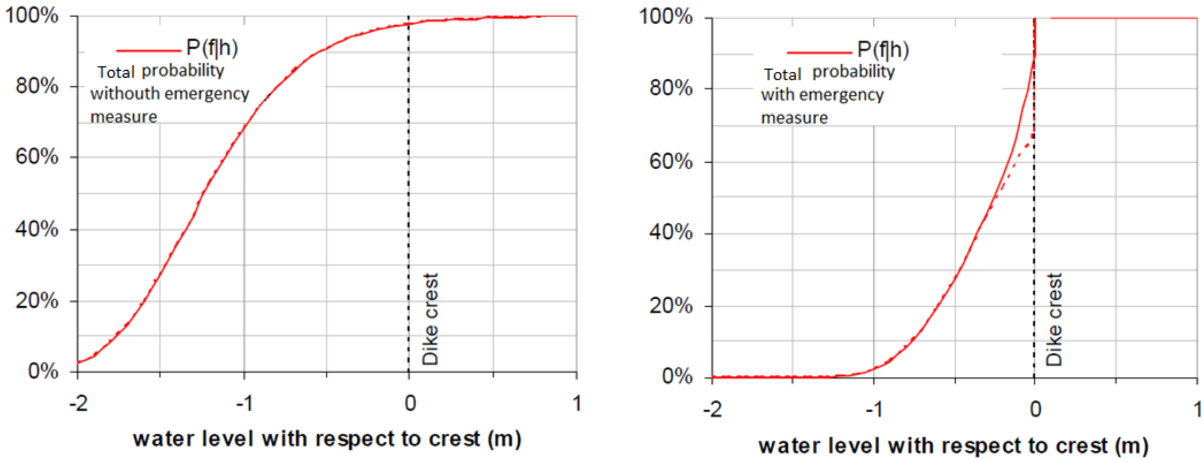



**Figure 43: Prior fragility curve (left) and posterior fragility curve (right) illustrating the effectiveness of piping emergency measure** (Boon, 2007)

When both the piping and overtopping failure probabilities are combined in the total failure probability of the dike section it becomes clear that overtopping measures only have effect for water levels close to the dike crest and piping measure have the largest effect on low water levels with respect to the crest.

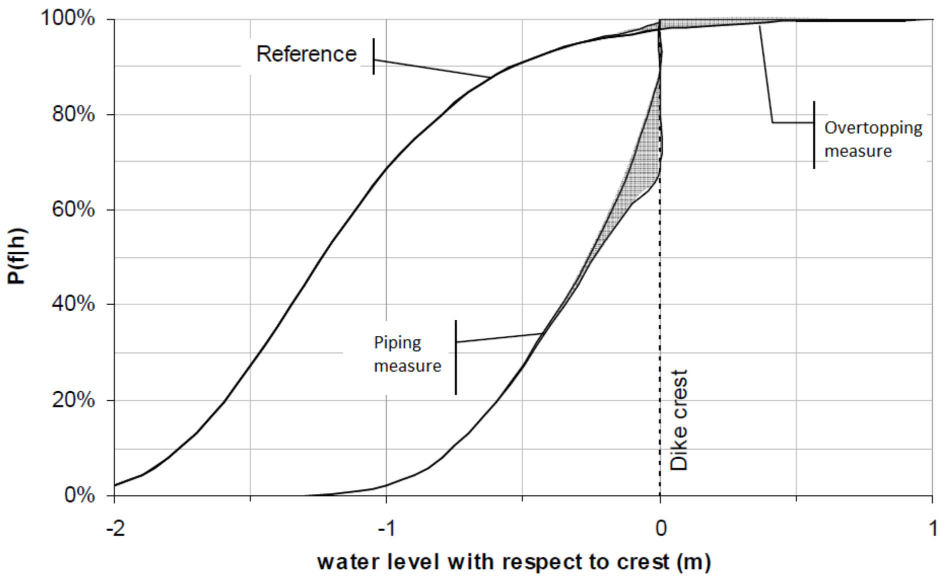



**Figure 44: Effect of overtopping (TFD) and piping (Water berm) measures on fragility curve of a dike section** (Boon, 2007)

## Effectiveness by project VNK2

To quantify the potential of emergency measures on reducing the failure probability of dike sections project VNK2 made several sensitivity analyses. For both overtopping and piping the effect of several emergency measures for dike ring 53 was calculated, this is treated in the next chapter.

## 4.5 Event tree including sub phases of reliability of emergency measures

The relations between organizational, feasibility in time, technical reliability and effectiveness will be integrated in this paragraph. In the general framework made in chapter 3 an event tree was used to model the reliability of control and/or emergency measures. During the analyses of all tasks and parties involved in the system it was observed that the event tree could rapidly grow in a very large size. Following the analyses made in this chapter the Detection and Placement phase are divided in two sub phases: organizational reliability and reliability in time.

### Detection

For the Detection phase this results in the phase 'complete or incomplete inspection (reliability in time)' and 'detection or no detection (organizational reliability)'.

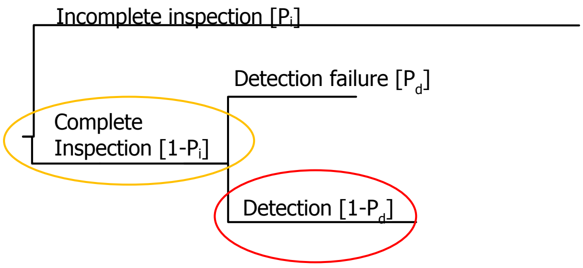



**Figure 45: Event tree detection**

*Note: in the figures red designates failure influenced by human error, orange shows failures due to insufficient time and green technical failures. The detection phase can fail due to a miss (not finding a weak spot) or a mistake (wrong judgement of a weak spot).*

The reliability in time is determined through the reliability function. The human performance probabilities are determined based on skill-, rule- or knowledge behaviour of the inspector. The length effect is taken in to account by assuming that the failure probabilities per task is representable for the probability of a mistake or miss **per dike section**.

- For **overtopping the inspection of each dike section is assumed dependent**, as it can be assumed that if a dike section is overtopped it is most probable that the next section will also be overtopped.
- For **piping the inspection of each dike section is assumed independent**, because of the variability in the subsoil. This will result in a high length effect.

### Placement

For the Placement phase distinction is made between the sub phase 'complete or incomplete placement (reliability in time)' and 'correct or incorrect placement (organizational reliability)'.

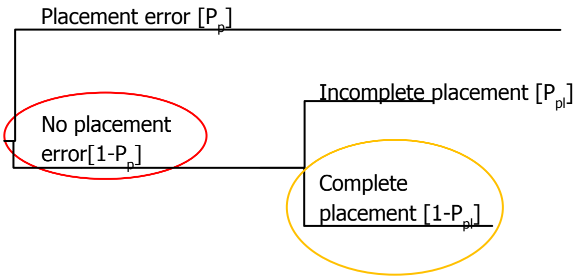



**Figure 46: Event tree placement**

The reliability in time is determined through the reliability function. The human performance probabilities are determined based on skill-, rule- or knowledge behaviour of the inspector. For all measures within one dike section it is assumed the probability of a placement error represents the probability an error within one dike section. Regarding length effect the same assumptions are used as in the detection phase.

## Total event tree

The reliability framework is summarized in one event tree in Figure 47. For every path the resulting failure probability is shown in the equations on the right hand side. The failure probability of an emergency measure is determined with the equation of $P_{emergency\ measure}$, shown in the figure.

To determine the effect of a system of emergency measures on the reliability of the dike section the probability of failure of each sub phase should be summed up to obtain the total failure probability of the dike section including emergency measures. This posterior probability of the flood defence is the summation of the following variables shown in the event tree: P1+P3+P5+P7+P9+P11.

The following assumptions were made:

- The length effect is taken in to account in each sub phase;
- When either the detection, placement or construction phase fails the prior reliability of the flood defence holds (before emergency measure).
- When every phase functions correctly the posterior reliability (effectiveness) of the flood defence holds, which is the effectiveness computed through the sensitivity analyses of VNK2.
- The different phases can fail independently.

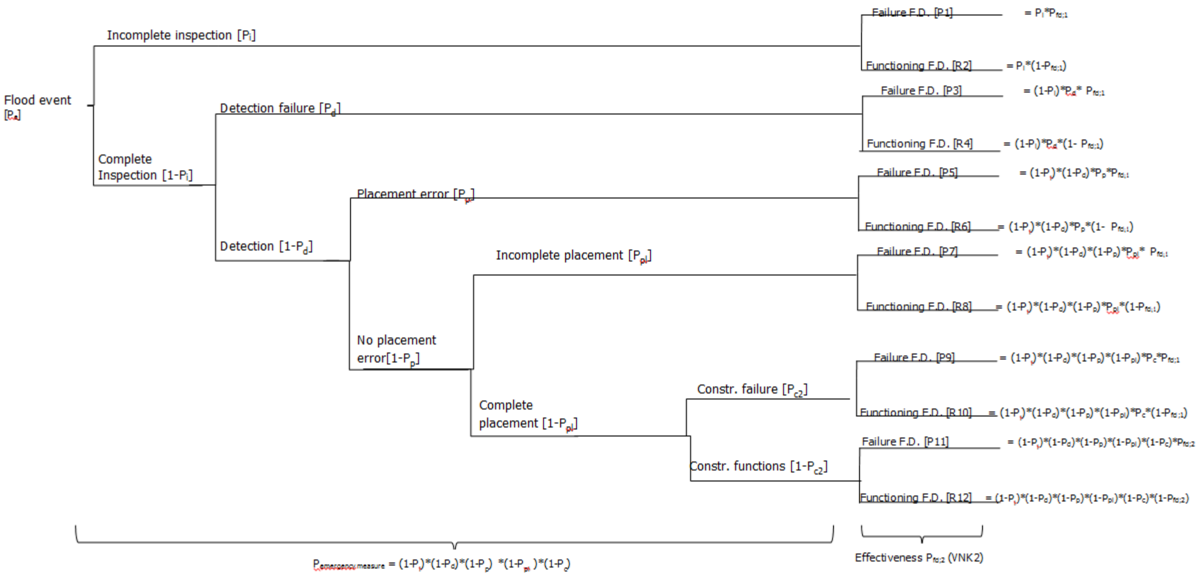


Figure 47: Total model event tree, note that the probabilities are conditional

### 4.5.2 Analysis using Bayesian networking

The tools used in the reliability framework for emergency measures until now have consisted of event and fault trees, which grow rapidly with increasing number of variables / factors. Bayesian nets are tools often used to model such large systems. As explained in a previous paragraph the Performance Shaping Factors (PSF) could also be used to model an engineered system in different components. The different PSF's are categorized in three groups:

1. **Environments**: environments
2. **Operations**: operators, organization & procedures
3. **Physical system**: structures & hardware

Between these categories there are different interfaces, for example how a physical system is operated and managed and how information of water levels is used for flood fighting. An influence diagram is used to display the interfaces between all factors. The interfaces are analysed using the following table:

| Category | Consists of | Reliability factors | Failure mechanism |
|---|---|---|---|
| **Environment** | Time of day | - | - |
| | Fog | - | - |
| | Wind | - | - |
| | Surge | - | - |
| | Rain | - | - |
| | Waves | - | - |
| | Visibility | - | - |
| | Water level | River / Sea levels | - |
| **Physical systems** | Levee | River / Sea levels | Overtopped<br>Seepage<br>Instability |

| | | | |
|---|---|---|---|
| | | | Outer slope erosion |
| | Emergency measure | Technical reliability depending on the measure | Overtopped<br>Seepage<br>Instability |
| **Operations** | Detection | Education<br>Training<br>Procedures/contracts<br>Material and equipment<br>Visibility | Inspection miss<br>Inspection error<br>Late inspection<br>Report error |
| | Placement | Education<br>Training<br>Procedures/ contracts<br>Material and equipment<br>Equipment/ material | Diagnose error<br>Placement error<br>Late placement |

**Table 12: Reliability aspects of emergency measures**

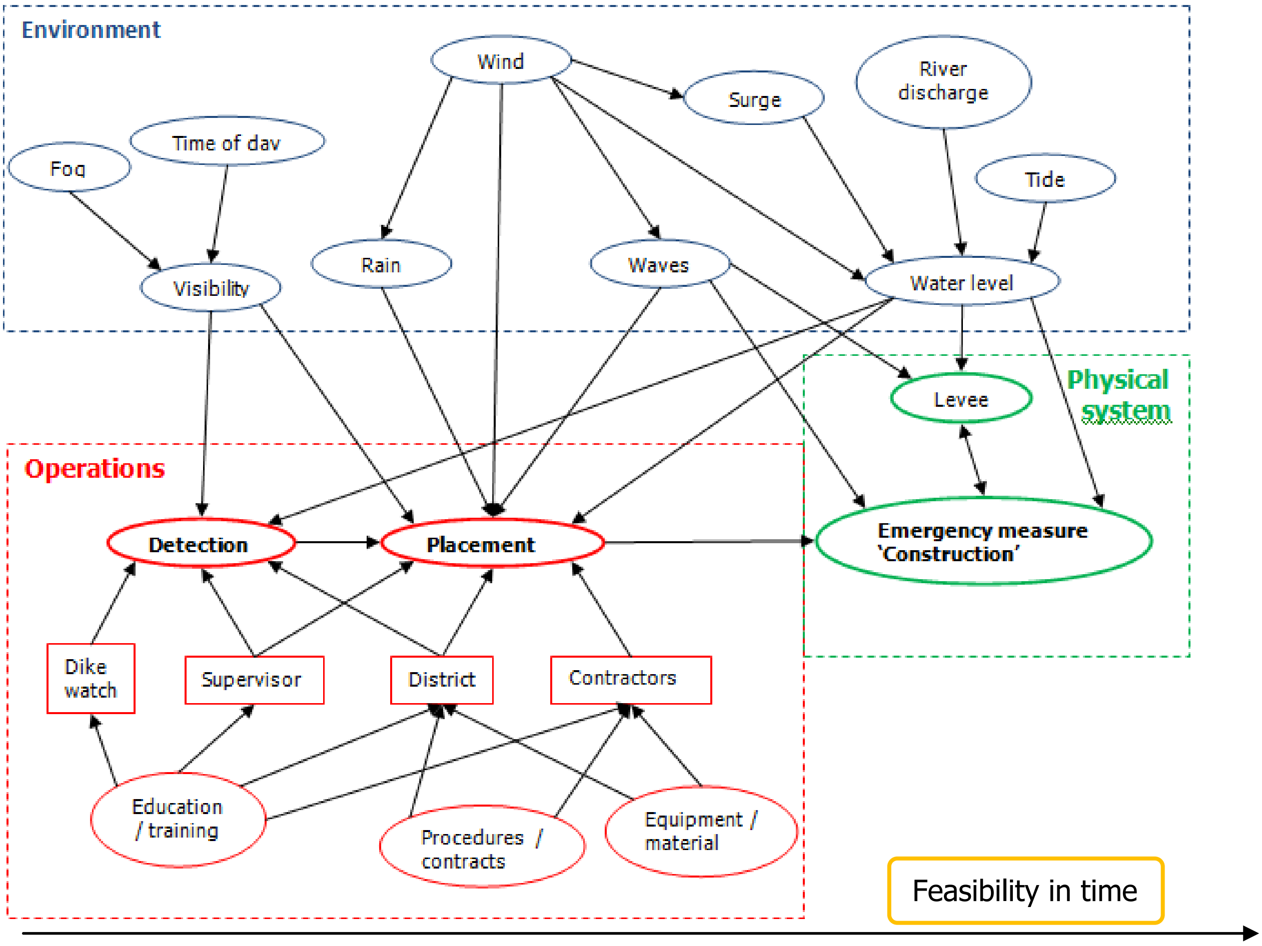



**Figure 48: Influence diagram emergency measure reliability (Red = human performance, Orange = feasibility in time & Green = technical reliability/effectiveness)**

The result is the influence diagram shown in Figure 44. This diagram can be used in more thorough analyses of reliability and effectiveness of emergency measures through Bayesian networking. Due to lack of data and time constraints this is not further elaborated in this report, but will be part of the activities for the STOWA & TUD project in 2014.

## 4.6 Conclusions and recommendations

In this chapter the reliability of the different phases of the event tree analysis in chapter 3 is investigated, methods are presented used to determine the reliability (or failure probability) of the different sub phases. The relations between organizational, logistics and technical reliability are integrated in an event tree and corresponding fault trees.

With the framework developed the probabilities of the system for every random set of variables can be determined to analyse the effect of changes in the system. An overview of the steps to be followed is given in Figure 49.

**Discussion**
The reliability framework is simulated with an event tree which only allows for an analysis in binary sense (probability of 'yes or no', 'correct or incorrect'). An analysis using Bayesian networks with distributions may give a more accurate reliability. Due to a lack of data and time constraints this is not further elaborated in this report, but will be part of the activities for the STOWA & TUD project in 2014.

The failure probability of the flood defence during a situation where emergency measures start playing a role is already higher than during normal situations see (Schweckendiek et al., 2014), this is not taken in to account in the reliability framework. Further, the failure probabilities of the system are probabilities per event, not probability per year. To translate these probabilities to failure probabilities per year they need to be multiplied by the number of times this framework comes in to action in one year, this is analysed in chapter 6.

**1) Determine the probability of flooding of the dike ring without emergency measures:**

a. Divide the ring in dike sections
b. Determine the dominant failure mechanisms and failure probabilities (priof $P_f$) of all dike sections
c. Calculate the probability of flooding of the dike ring

**2) Determine the reliability of a system of emergency measures:**

a. Determine all dike sections suitable for emergency measures
b. Determine organizational reliability of detection and placement
c. Determine the feasibility in time of the emergency measures
d. Technical reliability of all measures

**3) Determine effectiveness of the emergency measures:**

a. Determine the effect of emergency measures on the failure probability of the suitable dike sections
b. Calculate the resulting failure probabilities of all dike sections with emergency measures (posterior $P_f$)

**4) Calculate the probability of flooding of the dike ring with emergency measures (posterior $P_f$) and compare to the original flooding probability (prior $P_f$)**

**Figure 49: Flow chart framework for reliability and effectiveness of emergency measures**

### 4.6.1 Organizational reliability

To determine the human and organizational reliability for emergency measures a Human Reliability Analysis is made. For the quantification of the error rates the methods proposed by Rasmussen are used which divide human performance in three categories of behaviour: Knowledge based, Rule based or Skill based performance.

The probabilities determined with these methods are mostly based on 'expert judgment'; it is advised to do more onsite examinations in the case studies to validate these error probabilities. Methods to increase human performance consist of documenting procedures and rules and training of the personnel during normal and abnormal conditions, so they are prepared and known what to expect.

### 4.6.2 Feasibility of complete placement in time

For a correct functioning measure the available time must exceed the required time. To determine the reliability in time a reliability function is made which models the different sub phases with normal distributions.

**Available time**

Based on the past river floods and interviews with the water boards estimates are made for the available time for overtopping and piping measures. Overtopping only occurs when the water levels exceed the dike height, which will happen during the peak of the river flood. An available time for placement of overtopping measures is of 48 hours with a standard deviation of 12 hours is estimated.

Piping could occur at water levels below the peak of the river flood, a certain amount of time is required for a pipe to form under the flood defence. Water boards will start inspections for possible weak spots (sand boils) immediately following the expectation of a river flood (about 4 days in advance), which implies there is more time until the moment the river flood arrives. It is assumed the available time to detect and place piping measures is 96 hours with a standard deviation of 24 hours.

Sand boils are a sign that the piping process has already started (Schweckendiek et al., 2014). This is why it is advised that water boards treat all sand boils as critical, especially when the water levels are expected to keep rising. Further, it is advised to lay the water levels linked to the start of inspection down in the calamity programs of the Water Boards, which will increase the reliability of the system.

**Detection**

For the detection phase the required time depends on the people performing the inspections. An average detection speed of 2.5 kilometres per hour is determined for inexperienced personnel and a speed of 3.5 kilometres per hour for experienced personnel.

**Placement**

The time required for the placement of the emergency measures cannot be given explicitly as it depends on a lot of factors such as the weather conditions, visibility, organization capacity, equipment and the extent of the damage. Water Board Groot Salland prepared a report in which the time required for placement of control measures is given during both favourable and unfavourable conditions (WGS, 2012).

### 4.6.3 Technical reliability and effectiveness

Through probabilistic analyses of several emergency measure it is concluded that the technical failure probabilities are negligible compared to the organizational reliability and feasibility in time. Overtopping measures only effectively reduce the failure probability of the dike section for water levels close to the crest while piping measures could potentially reduce the failure probability at lower levels compared to the crest height. The actual effectiveness of several emergency measures is investigated for dike ring 53 by project VNK2.

# 5. Case study Groot Salland

## 5.1 Introduction

In this chapter first background information on the water board is given including why this water board was chosen as a case study. A short overview of the dike ring to be investigated is given followed by an investigation on piping and overtopping failure. In the next chapter the cost effectiveness of the emergency measures in the dike ring is determined.

### Groot Salland area

The current management area of the Water board Groot Salland lies in the western part of the Overijssel province in the Netherlands. The boundaries of the area are based on the watersheds of the water systems in the area, which are formed by the river Vecht, the river Ijssel and the 'Zwarte Water', all sub systems of the river Rhine.

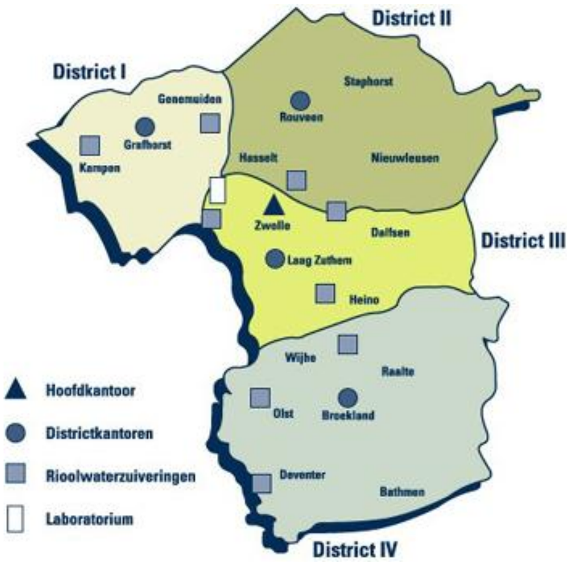



**Figure 50: Overview of Water board Groot Salland**

### Flood defences

The water board manages 200 kilometres of primary flood defences and 100 kilometres of regional flood defences. Of the 200 kilometre primary defences about 110 kilometres do not comply with the required safety standards (Maurits Van Dijk & Plicht, 2013). Piping and uplifting proved to be the dominant failure mechanism in the area.

### Control measures (Beheer maatregelen WGS)

As a result of the last assessment of the flood defences the water board investigated the feasibility of a system of control measures for the flood defences which did not pass the assessment. A data sheet was developed which, depending on the expected water levels, predicts the required control measures at locations where weak spots in the dike will develop due to the predicted water levels. For these 'problem locations' the required control measure was determined as well as the length over which it needs to be placed, the material and equipment required and the total costs of the operation.

The water board determined that for a Mean High Water event on the river Rhine (Pf = 1/1,250) 3.5 million euro is required to place all control measures and thus protect the flood defences (excluding removal cost and training of personnel). To compare this option with dike reinforcements insight is required in the obtained reduction of the failure probability of the dike ring for flooding, which is investigated in this chapter.

## 5.2 Dike ring 53: 'Salland'

Dike ring 53 was chosen as a case study, because it was possible to work together with project VNK2 who made several analyses which determine the potential reduction of failure probabilities per dike section in the dike ring. The dike ring has a total area of 41.000 hectares with a total of about 250,000 inhabitants. The following chart shows the flood defence system in the dike ring.

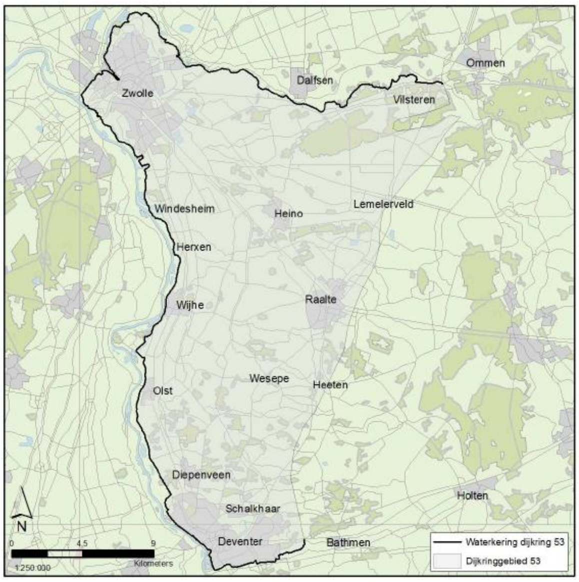



**Figure 51: Locations of flood defence line dike ring 10 (Maurits Van Dijk & Plicht, 2013)**

### 5.2.1 Water system

The south and west boundaries of the dike ring are formed by the river Ijssel, which flows from Deventer to Zwolle. To the north the dike ring is bounded by the 'Zwarte Water' and to the east the dike ring is bounded by higher grounds. According to the 'flood protection act' the safety standard for the primary flood defences in dike ring 53 is 1/1,250 per year, which is the probability of exceedance of the water level in the river. The adjacent dike rings (51, 52 and 9) also have the same safety standard of 1/1,250 per year, except for dike ring 10 which has a maximum probability of exceedance of 1/2,000 per year.

### 5.2.2 Flood defence schematisation

The primary flood defence system of the dike ring consists of a system of dikes and structures. A dike section is defined as a part of the flood defense with more or less homogeneous geometrical and strength parameters and loads (Rijkswaterstaat, 2005). Dike ring 53 is divided in a total of 72 dike sections, the borders of which are chosen such that they coincide with the sections chosen by the water board during the 2nd and 3rd assessment of the flood defences.

### 5.2.3 Results of reliability analyses by VNK

The calculated probability of flooding of the dike ring (for the primary flood defences) is larger than 1/100 per year, which is mainly the result of a high probability of failure for piping (1/63 per year). Emergency measures are not taken in to account in these calculations.

| Type waterkering | Faalmechanisme | Faalkans (per jaar) |
|---|---|---|
| Dijk | Overloop en golfoverslag | 1/370 |
| | Opbarsten en piping | >1/100 |
| | Macrostabiliteit binnenwaarts | 1/10.000 |
| | Beschadiging bekleding en erosie dijklichaam | 1/5.500 |
| Kunstwerk | Overslag/overloop | 1/940 |
| | Betrouwbaarheid sluiting | 1/740 |
| | Onder- en achterloopsheid | 1/230 |
| | Sterkte en stabiliteit | 1/4.600 |
| Overstromingskans | | >1/100 |

**Table 13: Failure probabilities dike ring 53 (Maurits Van Dijk & Plicht, 2013)**

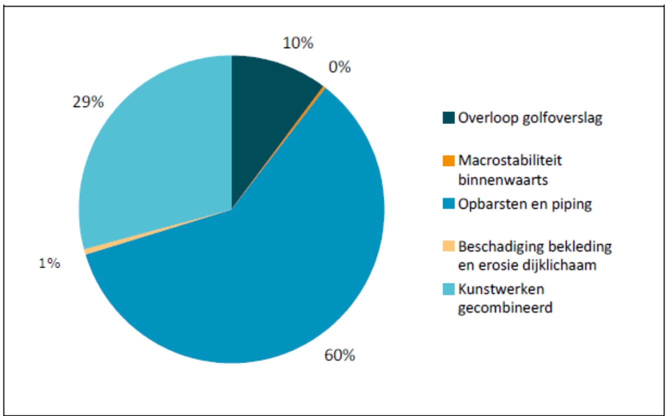



**Figure 52: Charts of distribution of failure probabilities per mechanism (Maurits Van Dijk & Plicht, 2013)**

The results from dike ring 53 show that piping account for 60% of the total probability of flooding, hydraulic structures account for 29% and third in line is overtopping with a contribution of 10%. These results are more or less the same for all river systems along the

Rhine showing that for dikes piping (85%) is the dominant failure mechanism followed by overtopping (15%). For this case study the other failure mechanisms will not be treated.

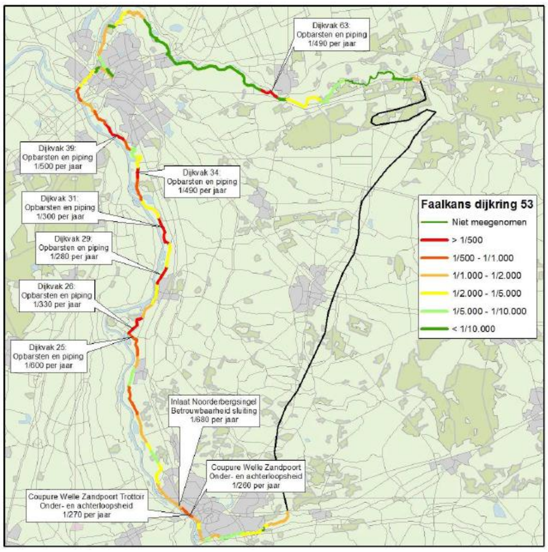


**Figure 53: Failure probabilities per dike section (Maurits Van Dijk & Plicht, 2013**

## Economical risk

The expected value of the losses during a flood is between a minimum of 15 million and a maximum of 9 billion euro, with an average loss of 3 to 4 billion euro per flood event. These consequences are largely dependent on the location and number of breaches. The annual expected loss (risk) is 71 million euro.

## Loss of life

The average loss of life in the dike ring during a flood event is between 80 and 900. The annual expected number of casualties in dike ring 53 due to flooding is 1.4. Also here the amount of casualties depends to a large extent on the location and number of breaches.

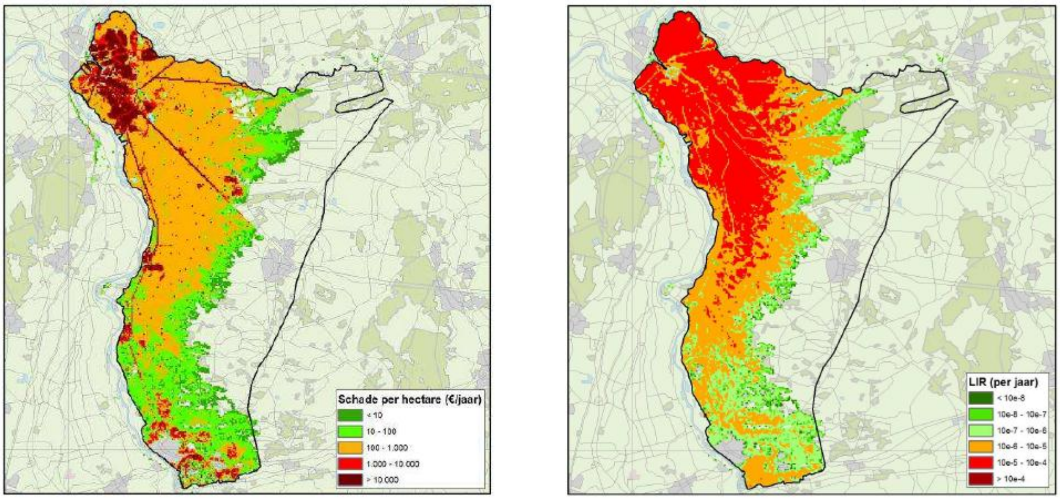


**Figure 54: Damage and Casualties dependant on location inside the dike ring (Maurits Van Dijk & Plicht, 2013)**

## 5.3 Emergency response Groot Salland

Each Water board has a calamity plan which contains organizational and operational information used during calamities. Water board Groot Salland works together with the water boards 'Rijn en Ijssel', 'Rivierenland', 'Vallei en Eem' and 'Stichtse Rijnlanden'. Together they form one team of water boards in central-Netherlands who keep the calamity plans up to date, organize trainings and yearly exercises. The calamity plan was last updated in 2008 and completely revised in 2009. It consists of 5 sub plans which deal with:

- Threats to the primary flood defences (river floods);
- Threats to regional flood defences (local flooding);
- Threat of water shortage due to droughts;
- Disruption of water treatment plants;
- Disruption of water quality (pollution).

The following paragraphs will determine the reliability of each sub event as defined in the reliability framework of chapter 4.

### 5.3.1 Organizational reliability

The organizational reliability plays a role during the detection of weak spots in the flood defence and during the placement of measures at these weak spots.

#### Detection reliability

Currently there are no actual procedures which determine when supervisors, districts or the dike watch inspect the dikes. This does not favour the reliability of the detection phase. It is known that in the beginning stages (low water levels) of a river flood supervisors will inspect the known problematic locations to see if control measures are required, see appendix VII.

When 'critical water levels' are expected the supervisors will no longer be performing the actual inspections, due to lack of capacity. The dike watch will be instructed to inspect the dikes. Each dike watch has to inspect a length of 5 kilometres along the flood defence. With an average length per dike section of 750 meters this results in a total of 7 sections. The following table shows the reliability per dike section, the failure probabilities are based on the Rasmussen method.

| Group | Knowledge | Experience | Performance level | Detection error probability per dike section (overtopping) |
|---|---|---|---|---|
| **Dike watch low training** | Low | Low | Knowledge based | ~ 1/10 – 1/20 |
| **Dike watch high training** | Relatively low | Relatively low | Rule based | ~ 1/20 – 1/100 |
| **District** | Relatively high | High | Rule based | ~ 1/200 – 1/2,000 |
| **Supervisors** | High | High | Skill based | ~ 1/2,000 – 1/20,000 |

Table 14 Human / organizational error probabilities for detection of overtopping weak spots

The length effect of emergency measures is taken in to account dependent on the failure mechanism. For **overtopping the inspection of each dike section is assumed dependent,** resulting in no length effect. For **piping the inspection of each dike section is assumed independent**, due to the large variability in the subsoil. This results in a large length effect. The following table shows the resulting failure probabilities per detection group for a detection length of 5 kilometres.

| Group | Knowledge | Experience | Performance level | Error probability per detection phase for each dike section (piping) |
|---|---|---|---|---|
| **Dike watch low training** | Low | Low | Knowledge | ~ 1/2 – 1/3 |
| **Dike watch high training** | Relatively low | Relatively low | Rule based | ~ 1/3 – 1/15 |
| **District** | Relatively high | High | Rule based | ~ 1/30 – 1/300 |
| **Supervisors** | High | High | Skill based | ~ 1/300 – 1/3,000 |

Table 15 Human / organizational error probabilities for detection of piping weak spots

It is clear that, due to the length effect, the reliability of the detection phase for piping decreases largely with increasing length. This can also be seen in the following figure.

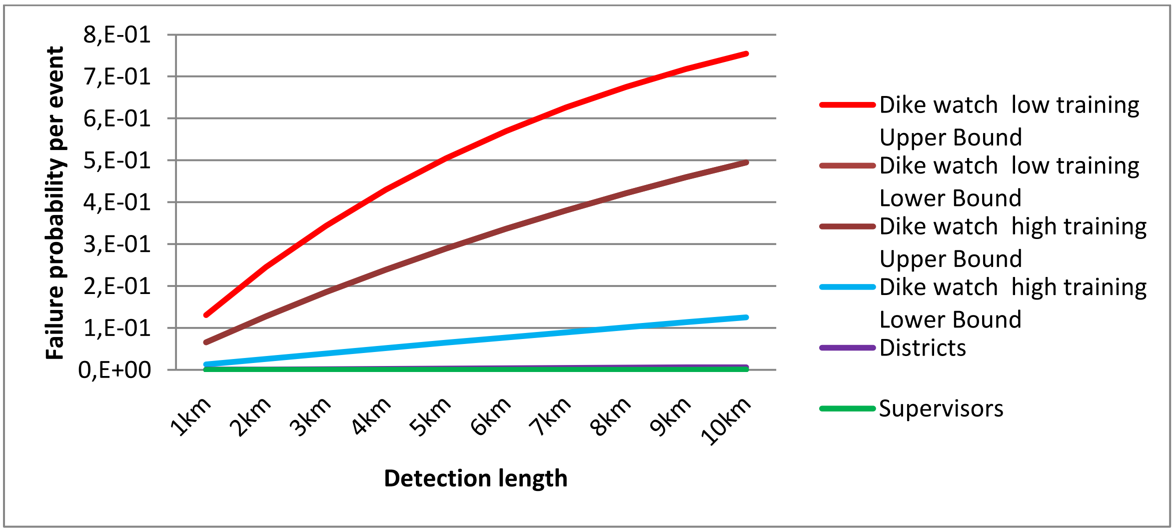



Figure 55: Relation of piping detection length and reliability

### Placement reliability for each dike section

Groot Salland is divided in four districts, see Figure 50. During calamities teams are formed with experienced and inexperienced personnel to place emergency measures (ex: district personnel and contractors). From interviews with district employees it became clear that the experience of contractors is low. The importance of proper training of the personnel is very important for the correct placement of measures.

| Group | Knowledge | Experience | Performance level | Placement error probability per dike section (overtopping) |
|---|---|---|---|---|
| **Volunteer** | Low | Low | Knowledge based | ~ 1/10 – 1/20 |
| **Contractor** | Low | High | Rule based: contractors follow given procedures | ~ 1/20 – 1/200 |
| **District** | Relatively high | High | Rule based: districts follow given procedures | ~ 1/200 – 1/2,000 |

**Table 16 Human / organizational error probabilities for placement**

Regarding the length effect in the placement phase it is assumed that each placement team is independent of the next. Each team has the task of placing emergency measures in one dike section, resulting in an increased length effect dependent on the amount of dike sections (emergency measures) to be placed.

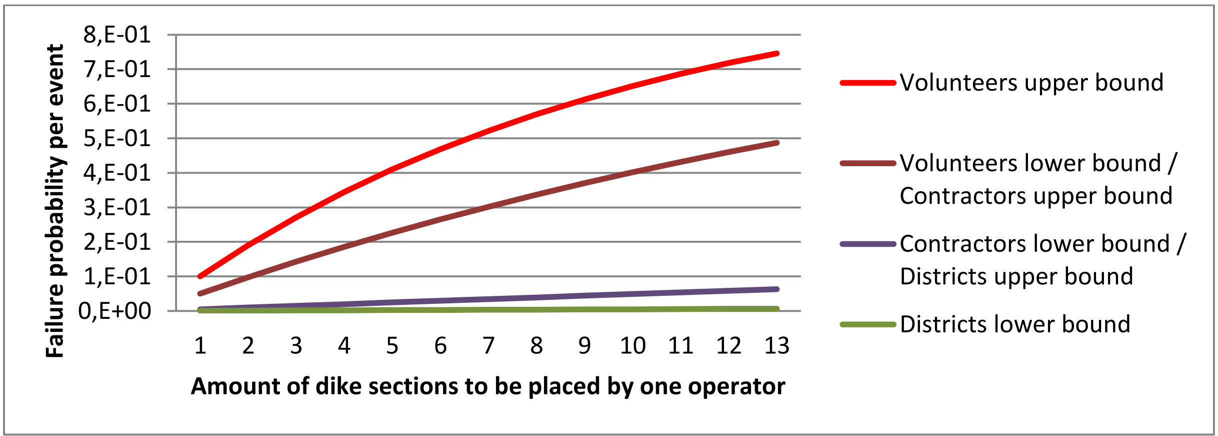



**Figure 56: Relation of placement length and reliability**

### 5.3.2 Feasibility in time

The expected required time for different emergency measures determined by Waterschap Groot Salland are used (WGS, 2012); note that these are assumed per placement team per dike section. Obviously when more teams are used less time is required or more measures can be placed. The following figure shows the probability of failure dependent on the total length to be placed of a a dike of sand bags with a retaining height of 0.45.

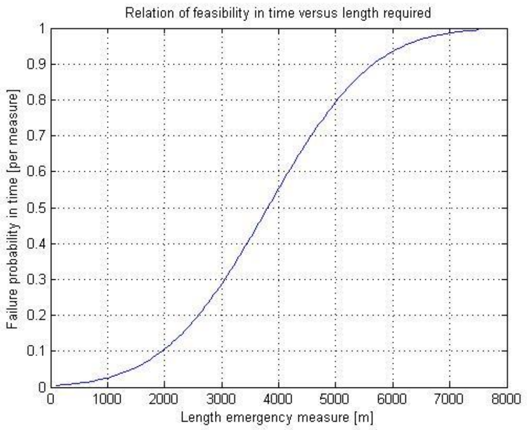



**Figure 57: Probability of failure in time versus length of sand bags with retaining height H = 0.45m during extreme conditions.**

The resulting distributions of the available time and required time are shown in Figure 58 for a length of 100 meters.

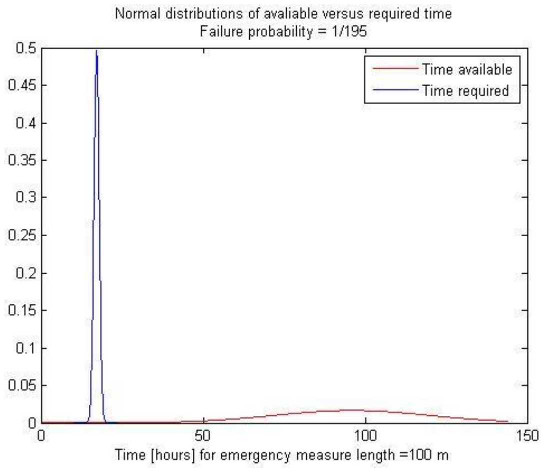



**Figure 58: Probability density functions of available versus required for placement of 100 meters of sand bags with retaining height H = 0.45m during extreme conditions.**

### 5.3.3 Technical reliability and effectiveness

Regarding the technical reliability (or failure probabilities) the calculations made in chapter 4 are used. It was concluded that the emergency measures widely used have failure probabilities of negligible order of magnitude compared to the organizational and/or logistics failure probabilities. The following section explains the effectiveness of the emergency measures treated.

**Effectiveness control / emergency measures in dike ring 53.**

Together with VNK2 sensitivity analyses were made for piping and overtopping to determine the effect emergency measures could have on the dikes in dike ring 53 (M. van Dijk, 2013).

**Piping dike ring 53**

Emergency measures against piping mainly consist of measures that reduce the hydraulic head over the flood defence and as such provide counter pressure for heave. To determine the effectiveness of raising the water levels inside a dike section on the failure probability of the dike section sensitivity analyses were made for reductions of the water levels with 0.5 meter, 1.0 meter and 1.5 meter.

The reliability of detecting the weak dike sections and placing the emergency measures is not taken in to account in these sensitivity analyses. The effect at ring level was determined through PC Ring, by taking the length effect of the flood defence in to account, see Table 17. In this analysis it is assumed that over the full length of these dike sections the head difference is reduced, which is a challenge for logistics (depending on the measure applied). It is assumed that for low densities of sand boils containments will be used to reduce the hydraulic head up to a maximum of 0.5 meter. A maximum of 3 boils per 100 meter is determined together with the water board. When more boils are found more 'drastic' measures will be used such as piping berms.

| Head difference reduction | Length required | Failure probability [per year] | Difference factor |
|---|---|---|---|
| 0 meter | - | 1/62 | 1 |
| 0.5 meter | 36.2 km | 1/150 | 2.4 |
| 1.0 meter | 36.2 km | 1/670 | 10 |
| 1.5 meter | 36.2 km | 1/3400 | 50 |

**Table 17: Effectiveness piping measures (based on (M. van Dijk, 2013))**

### Overtopping dike ring 53

To determine the effectiveness of overtopping measures sections with insufficient height where chosen where it is considered feasible to place emergency measures. Sections with a minimum height difference of 0.2 meter compared to the surrounding flood defence and a maximum length of 250 meters are considered feasible for emergency measures. If longer sections were chosen lengths of over 10 kilometres would have to be taken in to account which is considered unrealistic.

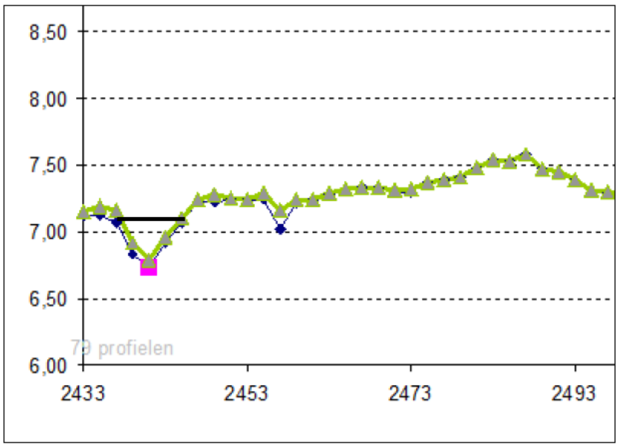



**Figure 59: Indication of 'dent' along dike section** (M. van Dijk, 2013)

The effect at ring level was determined through PC Ring. The dike section with the highest failure probability determines the probability of failure at ring level, because the sections behave dependently for overtopping failure. The failure probability without emergency measures is 1/330 per year; when all suitable sections are increased in height (with a total length of 1,310 meter) a failure probability of 1/470 per year is found which is a decrease of (only) a factor 1.4. This is mainly because other dike sections (not suitable for emergency measures) become dominant after these 'dents' are filled (M. van Dijk, 2013).

## 5.4 Scenarios

The reliability of emergency measures for different 'scenarios' in dike ring 53 is determined in the following sections. The scenarios consist of fictive dike rings containing a selection of dike sections based on data obtained by VNK (Maurits Van Dijk & Plicht, 2013) for dike ring 53. Three scenarios will be treated:

1. A fictive dike ring containing the 10 dike sections with the highest failure probabilities, the total length is 14.3 kilometre;
2. A fictive dike ring containing the 11 dike sections with a failure probability of piping higher than 1/1,250 per year, the total length is ;
3. A fictive dike ring containing the 16 dike sections with suitable sections for overtopping.

For each dike section the prior failure probabilities of overtopping and piping (prior failure probabilities) are given in appendix X. Further, the posterior failure probabilities (with a correct functioning emergency measure) are shown, <u>which does not include the failure probabilities of the emergency measure itself.</u> The actual reliability of the dike section with emergency measures is calculated in the following paragraph.

## 5.5 Scenario 1: top ten failure probabilities

For each dike section the reliability of all sub events in the event tree of Figure 47 is determined after which each branch of the event tree can be calculated and the resulting failure probability of the dike sections with emergency measures. By combining the failure probabilities of the different dike sections the failure probability at dike ring level is determined. In this fictive dike ring both overtopping dominated sections and piping dominated sections are present:

- Four dike sections for overtopping: 11, 21, 26 and 34.
- Six dike section for piping: 25, 29, 31, 38, 39 and 63
- Two dike sections with both overtopping and piping: 21 and 26

### 5.5.1 Reliability of emergency measures

The following table shows the failure of the emergency measures for each dike section. A detailed description of the failure probabilities used is given in appendix XI.

| Dike section | Detection [per event] | Placement [per event] | Feasibility in time [per event] | Technical [per event] | Failure probability [per event] |
|---|---|---|---|---|---|
| 11 | 1/20 | 1/20 | 1/83 | 0 | 1/9 |
| 34 | 1/20 | 1/20 | 1/192 | 0 | 1/9 |
| 21 | 1/20 | 1/20 | 1/71 | 1/29 | 1/7 |
| 26 | 1/20 | 1/20 | 1/909 | 1/13,000 | 1/10 |
| 21 | 1/3.5 | 1/25 | 1/370 | 0 | 1/3.2 |
| 25 | 1/3.5 | 1/25 | 1/60 | 0 | 1/3.1 |
| 26 | 1/3.5 | 1/25 | 1/714 | 0 | 1/3.2 |
| 29 | 1/3.5 | 1/25 | 1/212 | 0 | 1/3.1 |
| 31 | 1/3.5 | 1/25 | 1/61 | 0 | 1/3.1 |
| 38 | 1/3.5 | 1/25 | 1/416 | 0 | 1/3.2 |
| 39 | 1/3.5 | 1/25 | 1/120 | 0 | 1/3.1 |
| 63 | 1/3.5 | 1/25 | 1/68 | 0 | 1/3.1 |

**Table 18: Failure probabilities for all sub events of scenario 1**

The reliability of overtopping measures is in the order of 1/9 and the order of piping measures is in the order of 1/3. The distribution of the failure probabilities over the different aspects is shown for dike section 29 in the following pie chart:

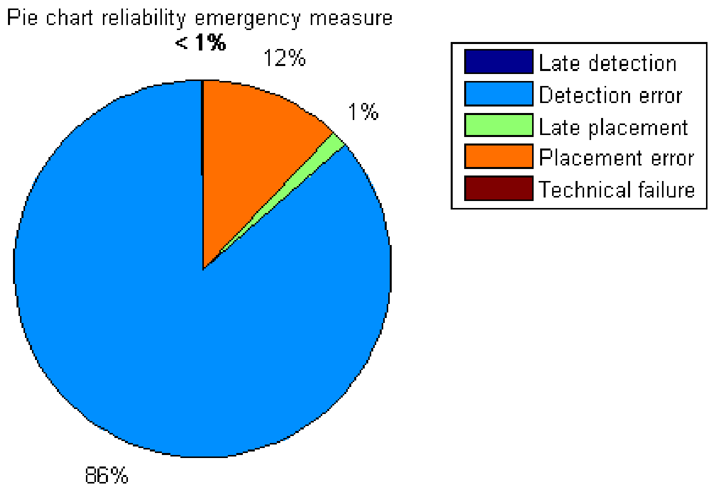



**Figure 60: Distribution of reliability aspects of probability of failure of emergency measures at dike section 29**

The chart shows that detection and placement error (organizational reliability) account for the largest contribution of the failure probability of emergency measures, followed by late placement (feasibility in time). An increase of the reliability of the organization will thus have a large effect on the failure probability of the emergency measure.

The resulting prior and posterior failure probabilities per dike section are shown in the following tables for overtopping dominated sections and piping dominated sections.

| Dike section | Dike section failure probability (prior) [per year] | Dike section failure probability (posterior) [per year] | Factor |
|---|---|---|---|
| 11 | 1/670 | 1/2,200 | 3.2 |
| 34 | 1/610 | 1/2,200 | 3.6 |
| 21 | 1/3200 | 1/6,100 | 1.9 |

| | | | |
|---|---|---|---|
| 26 | 1/740 | 1/1,900 | 2.6 |
| **Total** | **1/610** | **1/1,900*** | **3.1*** |

**Table 19: Failure probabilities before and after emergency measures for scenario 1 (overtopping)**

| Dike section | Dike section failure probability (prior) [per year] | Dike section failure probability (posterior) [per year] | Factor |
|---|---|---|---|
| 21 | 1/850 | 1/850 | 1 |
| 25 | 1/1,000 | 1/2,200 | 2.2 |
| 26 | 1/440 | 1/530 | 1.2 |
| 29 | 1/290 | 1/500 | 1.7 |
| 31 | 1/310 | 1/493 | 1.6 |
| 38 | 1/930 | 1/1,100 | 1.2 |
| 39 | 1/780 | 1/1,600 | 2.0 |
| 63 | 1/490 | 1/1,300 | 2.7 |
| **Total** | **1/65** | **1/100** | **1.6** |

**Table 20: Failure probabilities before and after emergency measures for scenario 1 (piping)**

The distribution of all reliability aspects, including the effectiveness, is shown in the following pie chart.

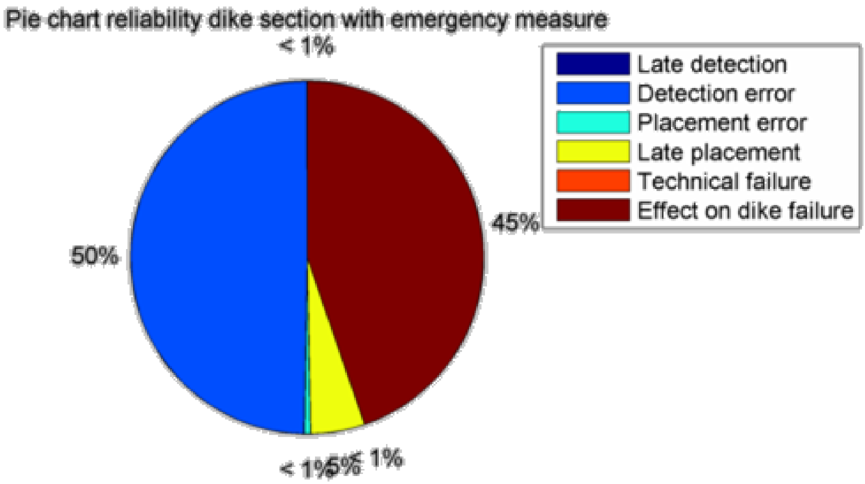



**Figure 61: Distribution of reliability aspects which determine the posterior failure probability of dike section 29 with emergency measures**

From the chart it becomes clear that the effectiveness of the measures contributes for about 45% of the (posterior) failure probability of the dike section. Increasing the effectiveness will thus have a large effect on reducing the failure probability of the dike section. Reducing the hydraulic head over the flood defense with 1.0 meter instead of 0.5 meter could do this.

## 5.6 Scenario 2: Piping

This scenario consists of a fictive dike ring containing all dike sections with failure probabilities below 1/1,250 per year (Table 40). The same data was used as in Scenario 1 for all sub phases (detection, placement and construction). The following table shows the failure probabilities of the emergency measures at each dike section.

| Dike | Detection | Placement | Feasibility in | Technical | Failure probability |
|---|---|---|---|---|---|

| section | [per event] | [per event] | time [per event] | [per event] | [per event] |
|---|---|---|---|---|---|
| 21 | 1/3.5 | 1/15 | 1/70 | 0 | 1/2.9 |
| 25 | 1/3.5 | 1/15 | 1/749 | 0 | 1/3.0 |
| 26 | 1/3.5 | 1/15 | 1/284 | 0 | 1/3.0 |
| 29 | 1/3.5 | 1/15 | 1/243 | 0 | 1/3.0 |
| 31 | 1/3.5 | 1/15 | 1/66 | 0 | 1/2.9 |
| 33 | 1/3.5 | 1/15 | 1/209 | 0 | 1/3.0 |
| 38 | 1/3.5 | 1/15 | 1/462 | 0 | 1/3.0 |
| 39 | 1/3.5 | 1/15 | 1/750 | 0 | 1/3.0 |
| 42 | 1/3.5 | 1/15 | 1/405 | 0 | 1/3.0 |
| 53 | 1/3.5 | 1/15 | 1/216 | 0 | 1/3.0 |
| 63 | 1/3.5 | 1/15 | 1/298 | 0 | 1/3.0 |

**Table 21: Failure probabilities of for all sub events for scenario 2**

The resulting failure probabilities for the dike sections with emergency measures (posterior) and without (prior) emergency measures are shown in Table 22.

| Dike section | Dike section failure probability (prior) [per year] | Dike section failure probability (posterior) [per year] | Factor |
|---|---|---|---|
| 21 | 1/850 | 1/850 | 1 |
| 25 | 1/1,000 | 1/2,100 | 2.1 |
| 26 | 1/440 | 1/500 | 2.7 |
| 29 | 1/290 | 1/500 | 1.7 |
| 31 | 1/310 | 1/500 | 1.6 |
| 33 | 1/1,200 | 1/2,400 | 2.0 |
| 38 | 1/930 | 1/1,100 | 1.2 |
| 39 | 1/780 | 1/1,500 | 1.9 |
| 42 | 1/1,100 | 1/2,200 | 2.0 |
| 53 | 1/1,200 | 1/3,200 | 2.7 |
| 63 | 1/490 | 1/1,300 | 2.6 |
| **Total** | **1/56** | **1/90** | **1.6** |

**Table 22: Failure probabilities before and after emergency measures for scenario 2**

## 5.7 Scenario 3: Overtopping

For the dike sections with 'dents', which are shown in Table 41, the reliability of all sub phases is calculated and explained in the following tables based on the same assumptions made for scenario 1. The following table shows the failure probabilities of all events for each dike section.

| Dike section | Detection [per event] | Placement [per event] | Feasibility in time [per event] | Technical [per event] | Failure probability [per event] |
|---|---|---|---|---|---|
| 6 | 1/20 | 1/20 | 1/211 | 1/13,000 | 1/9.8 |
| 8 | 1/20 | 1/20 | 1/227 | 1/29 | 1/7.5 |
| 11 | 1/20 | 1/20 | 1/87 | 0 | 1/9.3 |
| 20 | 1/20 | 1/20 | 1/174 | 1/13,000 | 1/9.7 |
| 21 | 1/20 | 1/20 | 1/227 | 1/13,000 | 1/9.8 |
| 26 | 1/20 | 1/20 | 1/76 | 1/29 | 1/7.1 |
| 27 | 1/20 | 1/20 | 1/170 | 1/105 | 1/9.0 |

| | | | | | |
|---|---|---|---|---|---|
| 28 | 1/20 | 1/20 | 1/195 | 1/13,000 | 1/9.8 |
| 30 | 1/20 | 1/20 | 1/237 | 1/13,000 | 1/9.9 |
| 32 | 1/20 | 1/20 | 1/234 | 1/13,000 | 1/9.9 |
| 34 | 1/20 | 1/20 | 1/217 | 0 | 1/9.8 |
| 50 | 1/20 | 1/20 | 1/76 | 1/29 | 1/7.1 |
| 51 | 1/20 | 1/20 | 1/227 | 1/13,000 | 1/9.8 |
| 56 | 1/20 | 1/20 | 1/64 | 0 | 1/9.0 |
| 69 | 1/20 | 1/20 | 1/91 | 0 | 1/9.3 |
| 72 | 1/20 | 1/20 | 1/193 | 1/105 | 1/9.0 |

**Table 23: Failure probabilities for all sub events of scenario 3**

The resulting failure probabilities for the dike sections with emergency measures (posterior) and without (prior) emergency measures are shown in Table 22.

| Dike section | Dike section failure probability (prior) [per year] | Dike section failure probability (posterior) [per year] | Factor |
|---|---|---|---|
| 6 | 1/1,700 | 1/3,300 | 1.9 |
| 8 | 1/1,900 | 1/3,600 | 1.9 |
| 11 | 1/670 | 1/2,200 | 3.2 |
| 20 | 1/3,100 | 1/6,000 | 1.9 |
| 21 | 1/3,200 | 1/6,400 | 2.0 |
| 26 | 1/740 | 1/1,800 | 2.4 |
| 27 | 1/1,800 | 1/4,100 | 2.3 |
| 28 | 1/3,300 | 1/5,300 | 1.6 |
| 30 | 1/2,400 | 1/4,400 | 1.8 |
| 32 | 1/3,800 | 1/6,500 | 1.7 |
| 34 | 1/610 | 1/1,100 | 3.7 |
| 50 | >1/1,000,000 | >1/1,000,000 | >1 |
| 51 | 1/5,900 | 1/11,600 | 2.0 |
| 56 | 1/44,000 | 1/34,500 | 8.5 |
| 69 | 1/150,000 | 1/321,300 | 4.1 |
| 72 | 1/73,000 | 1/415,600 | 5.7 |
| **Total** | **1/610** | **1/1,800** | **2.9*** |

**Table 24: Failure probabilities before and after emergency measures for scenario 3**

## 5.8 Conecto exercise

In October and November of 2013 the Dutch Water Board Groot Salland simulated a high water event on the river Rhine and its branches. During three weeks the water board was faced with a high water on the river Ijssel which reached levels never before seen; about 20-30 centimetres below the crest level of dikes along the river. To assure safety of the dikes these were inspected thoroughly and where necessary emergency measures were placed.

During the exercise data was obtained of the detection and placement of various measures which was used in a fourth scenario which is treated in a separate report, see appendix XIV. The exercise provided valuable information used to validate the assumptions made in the following scenarios, as will be explained.

### 5.8.1 Organizational reliability

During the detection phase inspections were done by both the districts and the dike watch. It was observed that the dike watch miss an average of 50% of weak spots over a length of 5 kilometres (failure probability of 1/2 per event). When comparing this with the theoretical failure probabilities it is concluded these dike watchers operate on a 'knowledge based' level with low training. The order of magnitude of the failure probability corresponds to those determined through the reliability framework and used in scenarios 1, 2 and 3.

### 5.8.2 Feasibility in time

When comparing the theoretical time required for emergency measures by the water board with those observed in the Conecto exercise it is concluded that these are optimistic. The time observed for the detection phase was more or less the same as those expected by the water board, however the time required for placement of a dike of sand bags, boxes and/or a piping berm was more than expected.

### 5.8.3 Concluding remarks

During the inspections by the district personnel part of the inspection were done from the car. This resulted in several detection errors: certain weak spots were not visible from the dike crest so these were not found. Further, driving on the crest of the dike is not allowed during a river flood.

Regarding the placement phase time could be saved if better suitable equipment is used. An excavator for the transportation of sand bags along the toe of the dike is slow and resulted in large vibrations that could undermine the stability of the dike. Based on these observations it is recommended to revise the 'Hoogwaterklapper WGS' of the water board.

## 5.9 Conclusions and recommendations

The calculated probability of flooding for dike ring 53 (for the primary flood defences) is larger than 1/100 per year, which is mainly the result of a high probability of failure for piping (1/63 per year), which accounts for 60% of the total probability of flooding. The average expected value of the losses during a flood is between 3 to 4 billion euro per event. The annual expected loss (risk) is 71 million euro. The average loss of life in the dike ring during a flood is between 80 and 900. The annual expected number of casualties due to flooding is 1.4.

The water board determined that for a Mean High Water event on the river Rhine a total of 3.5 million euro is required to place all 'control measures and protect the flood defences (excluding removal cost and training of personnel). A comparison of this system of 'control' measures with structural reinforcement is made in the next chapter, taking the acquired reliabilities in to account.

### 5.9.1 Conclusions reliability framework

The assumptions made for the reliability of the different phases in the three scenarios are based on the interviews with different people involved in the detection and placement of emergency measures at the water boards. With the framework developed in chapter 4 the contribution of emergency measures to the safety of the dike sections and dike ring is determined for overtopping and piping.

**Overtopping**

Overtopping measures were treated in scenario 1 and 3; the failure probability of the dike ring without emergency measures is 1/610 per year. In both scenarios the failure probability of each individual emergency measures (within one dike section) is in the order of 1/9 per event, which resulted in a failure probability of the dike ring with emergency measures of 1/3000 per year, a reduction with a factor 3.6*. The probability of failure of the emergency measures depends to a large extent on the detection and placement reliability. The distribution of the failure probability over the different aspects is shown in the pie chart:

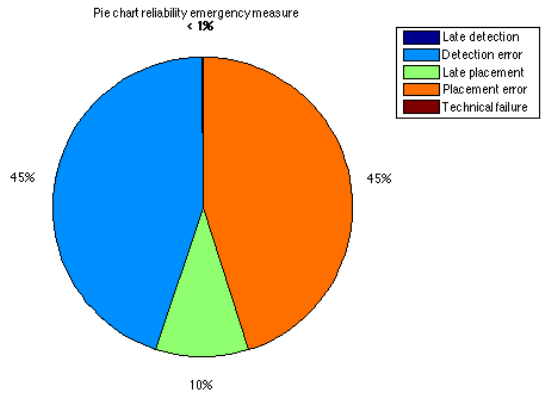



**Figure 62: Distribution of reliability of overtopping emergency measures at dike section 11 in scenario 3, resulting failure probability ~1/9 per event**

* The reduction of the failure probability of the dike section is determined by the combination of the reliability of the emergency measure and the effectiveness of the emergency measures. The effectiveness is limited which is why not a factor 9 but 3.6 reduction is obtained.

**Piping**

Piping measures were treated in scenario 1 and 2; the failure probability of the dike ring without emergency measures is 1/63 per year. In both scenarios the failure probability of each individual emergency measures (within one dike section) is in the order of 1/3 per event which resulted in a decrease of the failure probability per dike section with a factor 1.2 to 2.7. When determined at dike ring level the failure probability is reduced to 1/100 per year, a factor 1.9. This validates the statement made that with increasing length (number of weak spots) the contribution of a system of emergency measures to the reliability of the flood defence decreases.

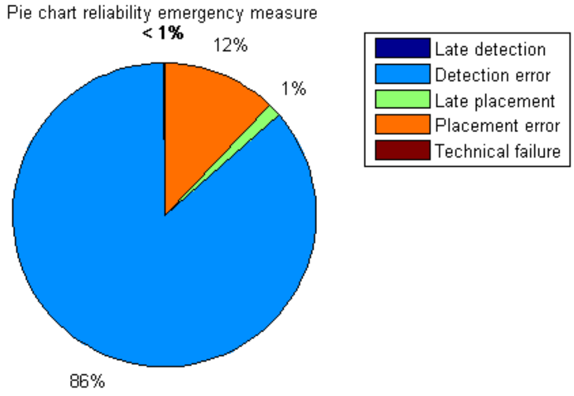



**Figure 63: Distribution of reliability piping emergency measures at dike section 29 for scenario 2, resulting failure probability ~1/3 per event.**

### Comparison with dike reinforcement

The contribution of the emergency measures to the safety of the dike sections is limited to the maximum effectiveness determined through the analyses by VNK ('Dents' for overtopping and raising the inside water level for piping).

Through dike reinforcement the failure probability of the dike ring is reduced with about a factor 10, compared to the factor 1.5 ~ 2 of emergency measures. For most river systems in the Netherlands, with failure probabilities of 1/100, the safety standards require a decrease with a factor 10 to 1/1,250.

## 5.9.2 Recommendations

Control and/or emergency measures are advised to be included in the calamity plans of the water boards, including water levels where these start to play a role. Further, it is advised to make (waakvlam) 'contracts' with third parties (contractors) to assure their availability during calamities.

The calculated organizational failure probabilities of the three different scenarios in the case study correspond in order of magnitude with those found during the Conecto exercise. The values used in this chapter are slightly optimistic. It is therefore advised to increase the training of the dike watch to increase the reliability of the emergency measures.

The observed time required for the placement of sand bags and a sand berm was longer than expected according to the data sheet of the water board. It is recommended to revise the 'Hoogwaterklapper WGS' of the water board based on the observations of Conecto.

When analysing the resulting probabilities for overtopping and piping it is concluded that the largest part of the failure probability is determined by the failure probability of the detection phase. It is thought that if the failure probability of this phase is decreased largely the failure probability of the measures will also decrease largely, resulting in more reliable emergency measures

# 6. Comparison of strategies

## 6.1 Introduction

In this chapter a cost comparison is made of different strategies used to increase the safety against piping. In the Netherlands about one thirds (1225km of total 3780km) of the flood defences currently do not meet the safety standards required for flooding. As a result large investments are required to reinforce the flood defences which do not comply with these standards. Besides reinforcements other options could be considered to improve the safety of the flood defence, each with their own effect on safety and costs:

- **Doing nothing**, which results in a high probability of failure and no additional cost;
- Perform **more (soil) investigations** against low additional cost. This could result in lower failure probabilities. (In probabilistics lack of data results in larger statistical uncertainties and thus higher failure probabilities (J. Vrijling, 2001)). This option has several disadvantages which are treated in (J. K. Vrijling et al., 2010).
- Deploy **emergency measures** against low (expected) cost which could lower the probability of failure with a factor 1.5~2;
- **Reinforce the dikes** (permanent measure) against large additional cost but assuring a reduction of the failure probability with a factor 10.

| | **Activity** | **$P_{failure}$/Risk** | **Cost** |
|---|---|---|---|
| **Not approved dike** | Nothing | High | None |
| | Soil investigations | Unknown | Low |
| | Emergency measure | Relatively low | Low |
| | Dike reinforcements | Low | High |

Figure 64: Scheme of actions for a dike which does not meet the safety requirements

Obviously doing nothing does not have any effect on the probability of flooding. According to the ENW doing nothing entails accepting a high risk of flooding which is not advised (J. K. Vrijling et al., 2010).

Soil investigations could potentially reduce the probability of failure of the dike ring because all uncertainties in the calculations of the failure probabilities are included resulting in higher probabilities of failure for mechanisms of which there is a lack of knowledge (piping). As a result the probability of failure can be reduced by increasing the knowledge of the dike with soil investigations (J. Vrijling, 2001).

Besides the options already mentioned a system of emergency measures could also be chosen to improve the safety of the flood defences. As explained earlier Groot Salland has a system of 'control' measures which are used for the 'problem locations' along the flood defence during a river flood. Whether or not this option is cost effective will be determined in the next sections and compared to the 'classical' approach of dike reinforcements.

## 6.2 Cost comparison framework

The total cost of the options is divided in three components, which are the investments (I) at moment t=0, the present value of the operational cost during a given period of N years (OPEX) and the present value of the risk during that same period (Risk), see equation 5-1.

$$TC = I_{t=0} + OPEX_{t=N} + Risk_{t=N} \quad [€] \qquad (5\text{-}1)$$

The present value of the annual operational cost (OC), denoted by $OPEX_{t=N}$, during a period of N years is found with equation 5-2, where r represents the interest rate.

$$OPEX_{t=N} = \sum_{n=1}^{N} \frac{OC}{(1+r)^n} \quad [€] \qquad (5\text{-}2)$$

The effectiveness of the option considered is taken in to account with a factor $\alpha$ (equation 5-3). The resulting annual risk is then calculated with equation 5-4.

$$Pf_{posterior} = \alpha * Pf_{prior} \quad [-] \qquad (5\text{-}3)$$

$$R_{annual} = Pf_{posterior} * D \; [€/yr] \qquad (5\text{-}4)$$

The present value of the risk, denoted by $Risk_{t=N}$, during a period of N years is found with equation 5-4. A rent percentage of 5.5% as used in the Cost benefit Analaysis of the water defences in the 21st century (Deltares, 2011).

$$Risk_{t=N} = \sum_{n=1}^{N} \frac{R_{annual}}{(1+r)^n} \quad [€] \qquad (5\text{-}5)$$

This framework can be used to compare the options of doing nothing versus emergency measures and/or dike reinforcements. Cost effectiveness is obtained when the cost of the option ($I_{t=0}$ + $OPEX_{t=0}$) are lower than the risk reduction ($\Delta Risk_{t=N}$) of that option.

### 6.2.1 Cost of 'doing nothing'

The initial cost of 'doing nothing' are zero as are the operational cost. The total cost during period N depends solely on the risk. The effectiveness of 'doing nothing' is zero which results in a factor $\alpha$ of 1, see equation 5-6.

$$Pf_{posterior} = 1 * Pf_{prior} \quad [-] \qquad (5\text{-}6)$$

This results in the following equation of the total cost of the option 'doing nothing' during period N.

$$TC_{nothing} = \sum_{n=1}^{N} \frac{Pf_{prior} * D}{(1+r)^n} \quad [€] \qquad (5\text{-}7)$$

### 6.2.2 Cost of dike reinforcement

The initial investment cost of (permanent) dike reinforcements are estimated at 5 e06 €/km in rural areas, which is an overestimate when compared to the values used in (J. K. Vrijling et al., 2010). The investment of dike reinforcement are determined with equation 5-8, depending on the length (L) of the reinforcement.

$$I_{t=0} = L_{reinforcement} * I' \quad [€] \qquad (5\text{-}8)$$

The operational cost of dikes which have been reinforced is assumed to be zero. The effectiveness of dike reinforcement is estimated with a factor 10 ($\alpha$ = 0.1) .

$$Pf_{posterior} = 0.1 * Pf_{prior} \quad [-] \qquad (5\text{-}9)$$

This results in the following equation of the total cost of the option 'dike reinforcement' during period N.

$$TC_{reinforcement} = L_{reinforcement} * I' + \sum_{n=1}^{N} \frac{0.1 * Pf_{prior} * D}{(1+r)^n} \quad [€] \qquad (5\text{-}10)$$

### 6.2.3 Cost of emergency measures

The initial cost of emergency measures is zero, this option mainly depends on the operational cost. The operational cost of emergency measures contains the cost for annual training of the personnel and organization ($C_{p\&ol}$) and the cost of all emergency measures during a river flood event ($C_{event}$). The annual cost of training of personnel and organization are estimated at 50,000 € (Conecto was 200,000 €). The cost of all emergency measures during a river flood event depends on the probability of the event ($P_{f;event}$) and costs of the measures applied during that event ($C_{event}$). The resulting operational cost of emergency measures is denoted in equation 5-11.

$$OC = C_{p\&o} + P_{f;event} * C_{event} \quad [€/yr] \qquad (5\text{-}11)$$

The effectiveness of emergency measures depends on the measures applied and the dike sections. For piping measures the effectiveness is about a factor 1.9 ($\alpha$ = 0.52) while for overtopping measures the effectiveness is about a factor 1.4 ($\alpha$ = 0.72).

$$Pf_{posterior} = 0.52{\sim}0.71 * Pf_{prior}\ [-] \qquad (5\text{-}12)$$

This results in the following equation of the total cost of the option 'emergency measures' during period N.

$$TC_{measures} = \sum_{n=1}^{N} \frac{C_{p\&o} + P_{f;event} * C_{event}}{(1+r)^n} + \sum_{n=1}^{N} \frac{0.52 \sim 0.71 * Pf_{prior} * D}{(1+r)^n}\ [€] \qquad (5\text{-}13)$$

### 6.2.4 Example calculation

For a fictive dike ring with a length of 10 kilometres these three options are compared. The following assumptions are made:

- Failure probability of dike ring is 1/100 per year;
- Damage potential in the dike ring during flooding is 10 billion euro;
- An interest rate of 5.5% is assumed.

The cost of dike reinforcement are 5 million euro per kilometre, there are no annual cost for this option. The effectiveness of dike reinforcement is estimated with a factor 10.

The initial cost for emergency measures is zero, the annual cost contains the cost for training and the cost per event. The cost for training of personnel and organization for emergency measures is 50,000 euro per year. The cost for all emergency measures during a river flood event are 3 million euro for an event probability of 1/1,250 per year. The effectiveness of emergency measures is estimated with a factor 2.

| Option | Failure probability [per year] | Investment [€] | Annual operational cost [€/yr] | Annual risk [€/yr] | PV of costs [€] | PV of risk [€] | Total cost [€] |
|---|---|---|---|---|---|---|---|
| **Doing nothing** | 1/100 | 0 | 0 | 1.0E+08 | 0.0E+00 | 1.7E+09 | 1.7E+09 |
| **Emergency measure** | 1/200 | 0 | 5.2E+04 | 5.0E+07 | 8.9E+05 | 8.5E+08 | 8.5E+08 |
| **Dike reinforcement** | 1/1,000 | 5.0E+07 | 0 | 1.0E+07 | 5.0E+07 | 1.7E+08 | 2.2E+08 |

**Table 25: Example cost effectiveness emergency measures versus dike reinforcement**

The options are compared for a period N of 50 years. It becomes clear that dike reinforcement has the lowest cost, but both emergency measures and dike reinforcement have are cost effective options when compared to 'doing nothing'.

## 6.3 Scenarios dike ring 53

For the three scenarios treated in chapter 5 the cost of both the emergency measures and dike reinforcement is calculated. A comparison is made based on a period of 50 years. The following assumptions are used:

- A rent percentage of 5.5%;
- The average damage during a flood in dike ring 53 is 3.5 e9 euro;
- The annual probability of an event where emergency measures are required is 1/200;
- The cost of annual training of the personnel is 50,000 euro;
- The reduction of the failure probability with dike reinforcement is a factor 10;

### 6.3.1 Scenario 1: Top ten failure probabilities

**Overtopping**

Among the ten dike section with highest failure probabilities four dike sections require emergency measures for overtopping, with a total length of 360 meters. The effectiveness of these measures is a factor 1.4, the total cost per event is estimated at 230,000 euro. The following table compares the total cost of doing nothing at these dike sections, applying emergency measures or dike reinforcements.

| Option | Failure probability [per year] | Investment [€] | Annual operational cost [€/yr] | Annual risk [€/yr] | PV of costs [€] | PV of risk [€] | Total cost [€] |
|---|---|---|---|---|---|---|---|
| **Doing nothing** | 1/610 | 0 | 0 | 5.7E+06 | 0 | 9.7E+07 | 9.7E+07 |
| **Emergency measure** | 1/854 | 0 | 5.1E+04 | 4.1E+06 | 8.7E+05 | 6.9E+07 | 7.0E+07 |
| **Dike reinforcement** | 1/6,100 | 2.5E+06 | 0 | 5.7E+05 | 2.5E+06 | 9.7E+06 | 1.2E+07 |

**Table 26: Scenario 1 cost effectiveness emergency measures versus dike reinforcement for overtopping**

Both emergency measures and reinforcements are cost effective. The difference in total cost between the emergency measures and dike reinforcement is a factor 5.8.

**Piping**

Among the ten dike section with highest failure probabilities eight dike sections require emergency measures for piping, with a total length of 12 kilometres. Due to the large uncertainties for piping it is not exactly clear which parts of these eight dike sections require dike reinforcements so it is assumed the reinforcement is done over the complete length of the dike. The effectiveness of these measures is a factor 1.6, the total cost per event is estimated at 113,000 euro. The following table compares the total cost of doing nothing at these dike sections, applying emergency measures or dike reinforcements.

| Option | Failure probability [per year] | Investment [€] | Annual operational cost [€/yr] | Annual risk [€/yr] | PV of costs [€] | PV of risk [€] | Total cost [€] |
|---|---|---|---|---|---|---|---|
| **Doing nothing** | 1/65 | 0 | 0 | 5.4E+07 | 0 | 9.1E+08 | 9.1E+08 |
| **Emergency measure** | 1/104 | 0 | 5.1E+04 | 3.4E+07 | 8.6E+05 | 5.7E+08 | 5.7E+08 |
| **Dike reinforcement** | 1/650 | 6.0E+07 | 0 | 5.4E+06 | 6.0E+07 | 9.1E+07 | 1.5E+08 |

**Table 27: Scenario 1 cost effectiveness emergency measures versus dike reinforcement for piping**

Both emergency measures and reinforcements are cost effective. The difference in total cost between the emergency measures and dike reinforcement is a factor 3.8.

### 6.3.2 Scenario 2: Piping

The length of all dike sections belonging to this scenario is 18 kilometres. Due to the large uncertainties for piping it is not exactly clear which parts of these eight dike sections require dike reinforcements so it is assumed the reinforcement is done over the complete length of the dike. The effectiveness of these measures is a factor 1.6, the total cost per event is estimated at 170,000 euro. The following table compares the total cost of doing nothing at these dike sections, applying emergency measures or dike reinforcements.

| Option | Failure probability [per year] | Investment [€] | Annual operational cost [€/yr] | Annual risk [€/yr] | PV of costs [€] | PV of risk [€] | Total cost [€] |
|---|---|---|---|---|---|---|---|
| **Doing nothing** | 1/52 | 0 | 0 | 6.7E+07 | 0 | 1.1E+09 | 1.1E+09 |
| **Emergency measure** | 1/83 | 0 | 5.1E+04 | 4.2E+07 | 8.6E+05 | 7.1E+08 | 7.1E+08 |
| **Dike reinforcement** | 1/520 | 9.0E+07 | 0 | 6.7E+06 | 9.0E+07 | 1.1E+08 | 2.0E+08 |

**Table 28: Scenario 2 cost effectiveness emergency measures versus dike reinforcement**

Both emergency measures and reinforcements are cost effective. The difference in total cost between the emergency measures and dike reinforcement is a factor 5.

### 6.3.3 Scenario 3: Overtopping

The total length of all local 'dents' requiring emergency measures is 1,310 meter. The effectiveness of these measures is a factor 1.4, the total cost per event is estimated at 5.8 million euro. The following table compares the total cost of doing nothing at these dike sections, applying emergency measures or dike reinforcements.

| Option | Failure probability [per year] | Investment [€] | Annual operational cost [€/yr] | Annual risk [€/yr] | PV of costs [€] | PV of risk [€] | Total cost [€] |
|---|---|---|---|---|---|---|---|
| **Doing nothing** | 1/610 | 0 | 0 | 5.7E+06 | 0 | 9.7E+07 | 9.7E+07 |
| **Emergency measure** | 1/854 | 0 | 7.9E+04 | 4.1E+06 | 1.3E+06 | 6.9E+07 | 7.1E+07 |
| **Dike reinforcement** | 1/6,100 | 6.6E+06 | 0 | 5.7E+05 | 6.6E+06 | 9.7E+06 | 1.6E+07 |

**Table 29: Scenario 3 cost effectiveness emergency measures versus dike reinforcement**

Both emergency measures and reinforcements are cost effective. The difference in total cost between the emergency measures and dike reinforcement is a factor 4.4.

## 6.4 Conclusions and recommendations

A framework is developed used to compare the total cost over a certain period for different strategies to increase the reliability of dike sections for flooding. The framework was used to compare dike reinforcements and a system of emergency measures with the total cost of the current situation ('doing nothing'). The following conclusions were made:

From the different scenarios can be concluded that both the emergency measures and dike reinforcements reduce the total cost over a period of 50 years, with dike reinforcement being the best option. Not only because dike reinforcement have lower total costs but also because through dike reinforcements the required safety standards are met which is not the case with emergency measures.

However, dike reinforcements require a large initial investment which could be delayed due to a lack of budget or other reasons. During the period reinforcements are delayed it could be a good option to choose emergency or 'control' measures as an interim measure to temporarily increase the safety of the dike ring.

*Example: If reinforcement of the ten most critical dike sections is delayed for 10 years the annual cost, for both the overtopping and piping measures, of 102,000 euro is lower than the annual risk reduction of 39 million euro due to the emergency measures.*

### Discussion and sensitivity analyses

For the values of the different parameters used in the cost comparison framework assumptions are made which require further investigation:

The cost for dike reinforcement are relatively constant, varying from 1 to 5 million euro per kilometre (J. K. Vrijling et al., 2010). However, in urban areas these costs could raise up to 20 million euro per kilometre. The influence on the cost comparison is investigated in the next chapter.

It is assumed the emergency measures are only used during events with an annual probability of 1/200. During a period of 50 years the probability of minimal one such event is 1/4.5 In practice the emergency measures might also be applied for river floods with annual probabilities lower than 1/200 per year resulting in higher operational cost.

Other factors, which are thought to have a large influence on the cost comparison, are the initial failure probability of the dike ring and the damage potential of the dike ring (the annual risk of flooding). When the initial failure probability is high (order 10 e-2) it is expected that dike reinforcement will be favourable. However for low initial failure probabilities (order 10 e-3) a system of emergency measures could become more favourable, because the initial failure probability of the dike sections is in the order of the optimal level for reinforcements, which can be determined with (Eijgenraam, 2006).

The next chapter will investigate for which combination of initial failure probability and damage potential a system of emergency measures will become more favourable than dike reinforcements.

# 7. Discussion / broader applications

## 7.1 Introduction

This chapter discusses the assumptions made in the framework developed to determine the reliability and effectiveness of emergency measures. In the last paragraph of all previous chapters results are discussed and recommendations given for further research. The first paragraph discusses the reliability framework used and the second paragraph discusses the strategy comparison made in chapter 6.

## 7.2 Reliability framework

For series systems the event with the highest probability of failure has the largest influence on the probability of failure of the system, as was seen in the pie charts. When analysing the results of the different scenarios it is concluded that the failure probability of the organizational phases are in most cases one order higher than the failure probability of the feasibility in time, while the technical failure probabilities are negligible.

### 7.2.1 Organizational reliability

For each individual emergency measure the failure probability could be decreased when the reliability of the detection and placement is increased, resulting in more reliable emergency measures. In practice this means training of detection and/or placement personnel so they operate on a higher level of behaviour according to (Rasmussen, 1982). This is illustrated with examples of the emergency measures required at dike section 11 (overtopping) and 29 (piping) of scenario 1, in the following table:

| Dike section | Detection [per event] | Placement [per event] | Feasibility in time [per event] | Technical [per event] | Failure probability [per event] | Factor |
|---|---|---|---|---|---|---|
| 11 | 1/20 | 1/20 | 1/83 | 0 | 1/9 | - |
| 11 | 1/200 | 1/200 | 1/83 | 0 | 1/45 | 3 |
| 29 | 1/3.5 | 1/15 | 1/243 | 0 | 1/3.0 | - |
| 29 | 1/35 | 1/15 | 1/370 | 0 | 1/10 | 3.3 |
| 29 | 1/350 | 1/150 | 1/370 | 0 | 1/74 | 5.3 |

Table 30: Influence of detection and placement reliability on reliability of emergency measure

For both measures it is clear that a decrease of the failure probability of the detection and/or placement phase with one order of magnitude results in about a factor 3 reduction of the failure probability of the emergency measure. To achieve such a reduction of the failure probability for example a dike watch with high training should be trained (Pf = 1/20 per event) such that his performance level is equal to that of a district employee (Pf = 1/200 per event). This requires extensive training and experience, as district employees work in the field daily.

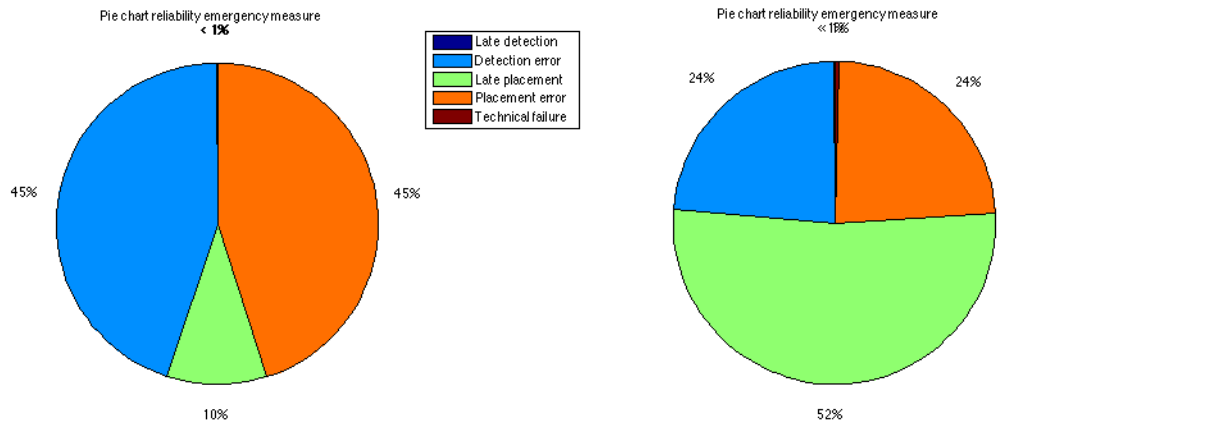



**Figure 65: Distribution of reliability with detection / placement failure probability of 1/20 (left) and 1/200 (right) for dike section 11 (overtopping)**

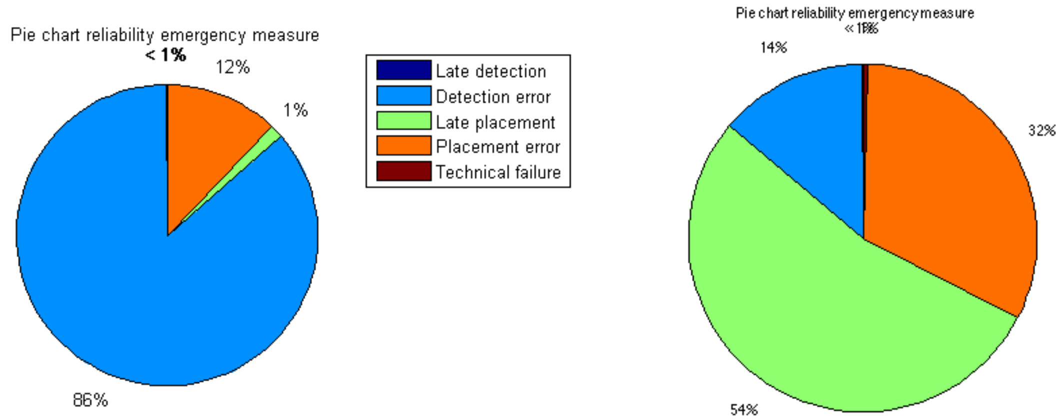



**Figure 66: Distribution of reliability with detection / placement failure probability of 1/3.5 (left) and 1/350 (right) for dike section 29 (piping)**

The pie charts show that when the detection and placement error probabilities are decreased with one order of magnitude the feasibility in time becomes more dominant. For piping specifically investments in the personnel responsible for finding sand boils, are very effective as the failure probability of the emergency measures for piping depends largely on the failure probability of the detection of sand boils. This was also concluded in (Corn & Inkabi, 2013), which states that 'the most effective way to improve flood-fighting performance is to take steps that would improve a flood-fighting patrol's ability to detect a sand boil'.

Increasing the reliability of the organization is only effective up to a certain level, when other factors such as the reliability in time and effectiveness become dominant. The effect of reducing the failure probability of the organization (detection / placement error) on the failure probability of the emergency measures is shown in Figure 67.

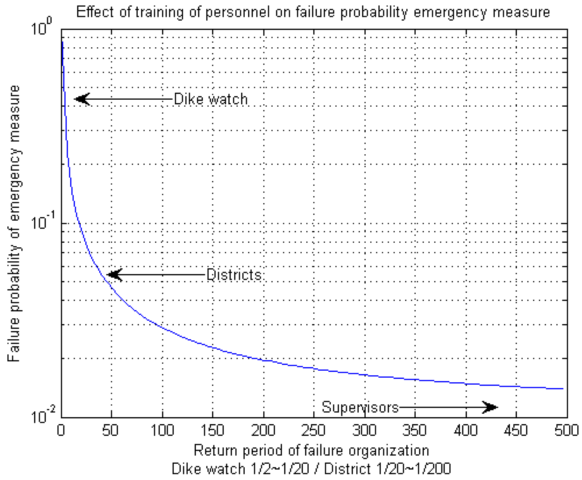



**Figure 67: Influence of failure probability of organization on total failure probability of the emergency measures**

It is concluded that reductions up to a failure probability of about 1/100, which corresponds with the level at which districts operate, are effective. Afterwards it will become more effective to invest in faster placement because the feasibility in time becomes more dominant.

### 7.2.2 Feasibility in time for different systems

Several assumptions were made to determine the feasibility in time of emergency measures. Specifically assumptions were made to determine the available and required time to detect and place emergency measures.

#### Rhine system

The scenarios treated are all part of the Rhine system, which has a prediction time of 4 days. This resulted in the assumption of an available time of 96 hours for piping measures and 48 hours for overtopping measures. It is questionable whether or not 96 hours are available for placement of piping measures, especially when sand boils are found in the detection phase. In that case the piping process has already started, which could result in less time for placement of the emergency measure. The influence of the available time for piping measures is investigated with Table 31.

| Dike section | Detection [per event] | Placement [per event] | Feasibility in time [per event] | Technical [per event] | Failure probability [per event] | Factor |
|---|---|---|---|---|---|---|
| 29 (t=96 hrs) | 1/3.5 | 1/15 | 1/243 | 0 | 1/3.2 | - |
| 29 (t=48 hrs) | 1/3.5 | 1/15 | 1/10 | 0 | 1/2.5 | 1.3 |
| 29 (t=24 hrs) | 1/3.5 | 1/15 | 1/1.1 | 0 | 1/1.1 | 3 |

**Table 31: Effect of different available time on emergency measures at dike section 29**

A calculation with an available time of 48 hours (dike section 21 in scenario 1) does not result in a significant increase of the failure probability of the emergency measure. This is explained by the fact that the failure probabilities of the feasibility in time are of an order lower (~$10^{-2}$) than the organizational failure probability (~$10^{-1}$). However, when the available time is decreased further the failure probability of the emergency measures becomes 1/1.1 per event(!). In conclusion the feasibility in time becomes dominant in systems with a warning time of under 48 hours.

### Other systems: river, coastal and regional system

The framework could also be used to determine the reliability of emergency measures for other systems such as a river system with shorter prediction time (Meuse) and a coastal or regional system.

The Rhine system has a warning time of 4 days contrary to the Meuse which has a prediction time of 2 days, because the catchment area is much closer to the Netherlands (Belgium, Luxemburg versus Southwest Germany).

A storm surge at sea has a short warning time of about 12 hours, which makes it very difficult to place emergency measures in time. Further, weather conditions will make placement even more difficult as these are correlated to the storm surge level (wind and rain). This could have a large influence on both the organizational and logistics reliability. However, the total duration of the storm surge is much shorter.

For a regional system (which are the secondary flood defences) the prediction time is equal to that of a storm surge because higher water levels on the 'boezems' are the result of heavy rainfall. Especially after long droughts this could be a danger for the 'boezemkades' because they could dehydrate causing instability. These phenomena could occur very locally and only be predicted in time spans of 12 hours in advance. As a result there is only limited time to place emergency measures if necessary.

### *Analyses*

The following graphs show the relation of the length versus the probability of failure for two types of emergency measures. Contrary to the scenarios treated in chapter 5 the required time for placement is estimated with the results of the 'Conecto' exercise, see Table 32. The failure probability of the dike sections without emergency measures is assumed 1/100 per year and with emergency measures 1/300 per year, see for more details appendix XIII.

| Measure type | Condition | Placement time mean [min / 100 meter] | Placement time deviation [min / 100 meter] | 95% Interval [min / 100 meter] |
|---|---|---|---|---|
| Sand bags +45cm | All | 120 | 15 | 90-150 |
| Containments (3 boxes per 100 meter) | All | 180 | 20 | 140-220 |
| Piping soil berm | Unfavourable | 360 | 60 | 240 - 480 |

**Table 32: Actual placement times based on observations during 'Conecto'**

The relation between failure probability and maximum length of sand bags (Hr = 0.45 m), sand boil containments and piping berms is shown for a river system such as the Rhine:

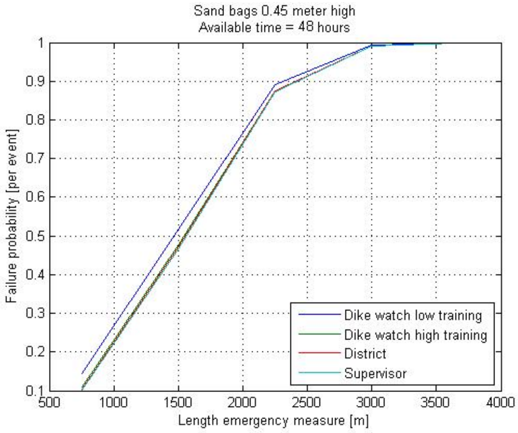
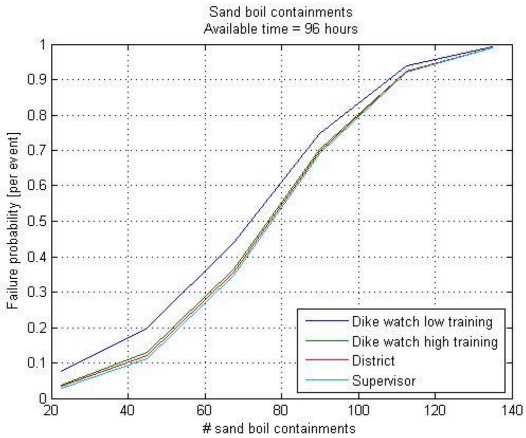



**Figure 68: Relation total failure probability with length of emergency measure**



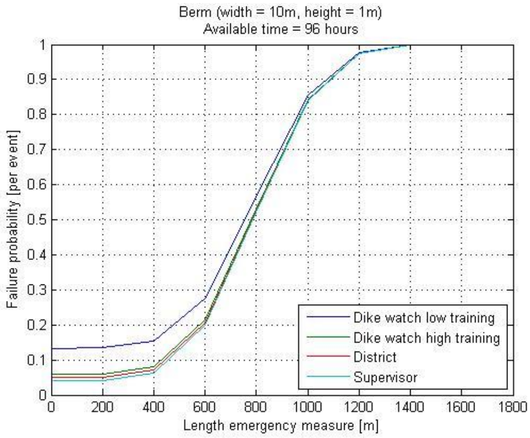




**Figure 69: Relation total failure probability with # of sand boil containments / length of piping berm**

The graphs show that the maximum length of overtopping emergency measures in a river system such as the Rhine (height = 0.45m) is limited to 3 kilometres and the maximum amount of sand boil containments (height = 0.5m) is limited to 120. Placement of a piping berm is limited to a length of 1,200 meter.

The same analyses are made for a coastal system. No detection time is taken in to account, because the assumed time required for detection (16 hours) is already longer than the available time (12 hours). When the detection time is omitted the following graphs are found for the relation of emergency measure length versus failure probability.

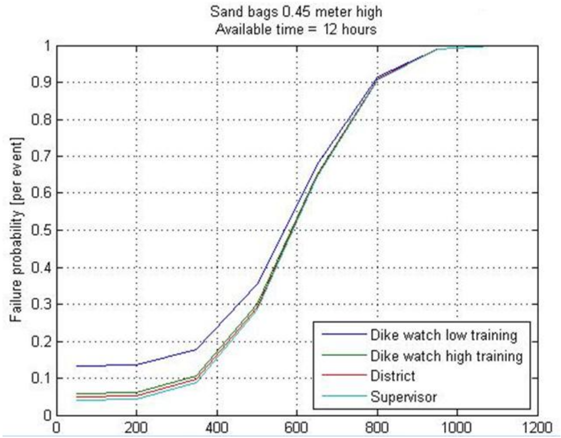



**Figure 70: Relation total failure probability with length of emergency measure**

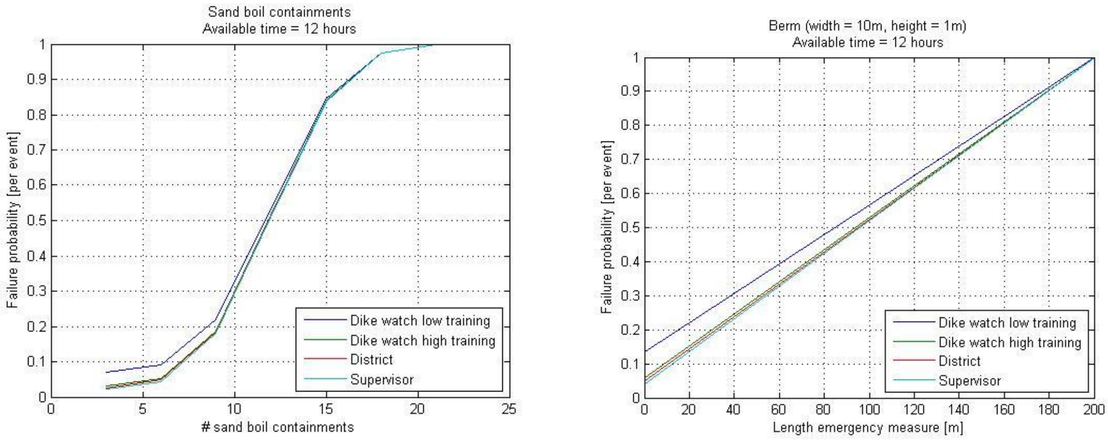



**Figure 71: Relation total failure probability with # of containments / length of piping berm**

Even when the detection is omitted the length of emergency measures in such a system is very limited, given the capacities used. For this system to be effective much more capacity is required as in river systems. The feasibility in time becomes dominant in systems with a prediction lead time below 24 hours.

### 7.2.3 Effectiveness of emergency measures

The reliability of individual emergency measures can be increased through training and experience of the personnel, but the contribution to the safety of the dike sections is limited to the maximum effectiveness of the emergency measures, see Figure 72.

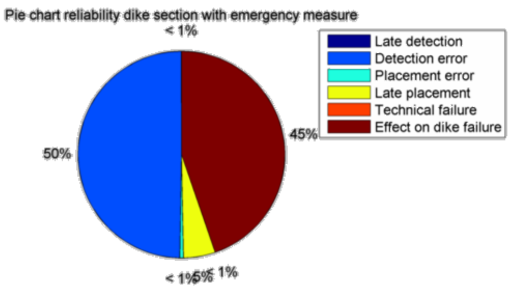



**Figure 72: Distribution of reliability aspects of dike section 29 with emergency measures**

For overtopping measures the maximum effectiveness was limited to sections with a length of 250 meter and a level difference of minimal 0.2 meter, otherwise sections would be found with lengths of over 1 kilometre. With the conclusions of the last section this is considered unfeasible.

For piping measures the effectiveness was limited to head reductions of 0.5 meters, the following section will investigate the influence of head reductions of 1.0 meter. This will influence both the final contribution to the reliability of the dike section as well as the feasibility in time of the individual measures. Calculations are made for dike section 29 of scenario 2 in the following tables.

| Dike section 29 head reduction | Feasibility in time [per event] | Failure probability emergency measure [per event] | Dike section failure probability (prior) [per year] | Dike section failure probability (posterior) [per year] | Factor |
|---|---|---|---|---|---|
| Containments 0.5m | 1/212 | 1/3 | 1/290 | 1/500 | 1.7 |
| Containments 1.0m | 1/54 | 1/3.1 | 1/290 | 1/750 | 2.6 |

**Table 33: Influence of available time on a fictive dike section suitable for emergency measures**

It is concluded that a head reduction of 1.0 meter will result in a reduction of the failure probability of the dike section with a factor 2.6, which is higher than the initial reduction of 1.6. This is a slight increase, but not very significant. In conclusion, the maximum effect of a system of emergency measures on the failure probability of dike sections / dike ring is limited to a reduction with a factor 1.6 ~ 2.4 (40~60%).

## 7.3 Comparison of strategies

The analysis made in chapter 6, which compares the total cost of 'doing nothing' with the cost of a system of emergency measures and dike reinforcements, is discussed further in the following sections. It was concluded that for dike ring 53, with an initial failure probability of 1/100, dike reinforcement are the better strategy. A system of emergency measures could however be a good interim solution, because dike reinforcement requires large investments. The cost of a system of emergency measure are lower than the risk reduction obtained, even for annual use of the system.

The influence of the cost of dike reinforcements is discussed as well as the frequency the use of a system of emergency measures. The relationship with the initial failure probability of the dike sections is also investigated, together with the influence of the damage potential, which together form the initial risk of flooding.

### 7.3.1 Influence of dike reinforcement cost

The cost indicators for dike reinforcement are based on very crude assumptions; the cost for reinforcement in rural areas is estimated at 5 million euro per kilometre and in urban areas

20 million euro per kilometre. In (J. K. Vrijling et al., 2010) an estimate of reinforcement cost is made which results in an average cost per kilometre of 1.2 million euro (lower than the estimates used in chapter 6). Lower reinforcement cost will favour the option of dike reinforcements as the total costs of this option will decrease (and vice versa for higher dike reinforcement cost). Examples are shown in Table 34 for scenario 2.

| Option | Failure probability [per year] | Investment [€] | Annual operational cost [€/yr] | Annual risk [€/yr] | PV of costs [€] | PV of risk [€] | Total cost [€] |
|---|---|---|---|---|---|---|---|
| **Doing nothing** | 1/52 | 0 | 0 | 6.7E+07 | 0 | 1.1E+09 | 1.1E+09 |
| **Emergency measure** | 1/98 | 0 | 5.1E+04 | 4.2E+07 | 8.6E+05 | 7.1E+08 | 7.1E+08 |
| **Dike reinforcement I'= 1mln €/km** | 1/520 | 1.8E+07 | 0 | 6.7E+06 | 1.8E+07 | 1.1E+08 | 1.3E+08 |
| **Dike reinforcement I'= 5mln €/km** | 1/520 | 9.0E+07 | 0 | 6.7E+06 | 9.0E+07 | 1.1E+08 | 2.0E+08 |
| **Dike reinforcement I'= 20mln €/km** | 1/520 | 3.6E+08 | 0 | 6.7E+06 | 3.6E+07 | 1.1E+08 | 4.7E+08 |

**Table 34: Example cost effectiveness emergency measures versus variable dike reinforcement cost in scenario 2**

Table 34 shows that for the conditions at dike ring 53 the total cost of dike reinforcement is lower than the system of emergency measures, irrespective of the dike reinforcement cost which are fairly constant.

### 7.3.2 'High reliable emergency measures' (?)

A calculation is made to determine the required reliability of a system of emergency measures to obtain the same order of total cost as dike reinforcement. If the emergency measures are able to reduce the failure probability on dike ring level with a factor 6 (dike reinforcements provide a reduction with a factor 10) the total cost will be similar to those of dike reinforcements.

In practice this is considered not feasible, because this requires all operators (including the dike watch) in the system to perform on a 'rule based' performance level with task error probabilities of 1/200. But this will still only increase the safety with a factor 2.3.

Another option to increase the contribution of the system of emergency measures to the failure probability of the dike ring is by reducing the head difference over the dike with another 0.5 meter for piping (compared to the initial reduction of 0.5 meter). In theory this would reduce the failure probability with an order 10, but these orders are not reached as seen in Table 33.

It can thus be concluded that with the current variables and data the system of emergency measures is not able to obtain the same level of safety as is obtained with dike reinforcements. The dike reinforcements remain therefore the best option with the lowest total cost.

### 7.3.4 Influence of initial failure probability

All the analyses made were representative for dike ring systems with an initial failure probability of about 1/100. Through dike reinforcements a safety level of 1/1,000 is obtained compared to (only) 1/200 with emergency measures. As shown the cost of dike reinforcements and emergency measures are fairly constant and as such do not have a large influence on the conclusions regarding cost effectiveness.

The question remains: when will a system of emergency measures become a more interesting (cost effective) option than dike reinforcements. The answer is sought for in the combination of the initial failure probability of the dike ring and damage potential during flooding. In other words, for what annual risk of flooding will emergency measures be more interesting?

This is investigated for a fictive dike ring, based on data of the water board Groot Salland. Dike ring 53 has total length of 85 kilometers, of which 33% requires dike reinforcements or emergency measures. Dike reinforcements have an effectiveness of a factor 10 and a total cost of 1 mln euro / kilometre. Emergency measures have an effectiveness of a factor 2 and a cost of 1.5 million euro per MHW event (Pf = 1/1,250). A flood damage potential of 4 billion euro is assumed for the whole area.

The total cost of the three strategies is shown dependent on the initial failure probability and corresponding annual risk in the following figures:

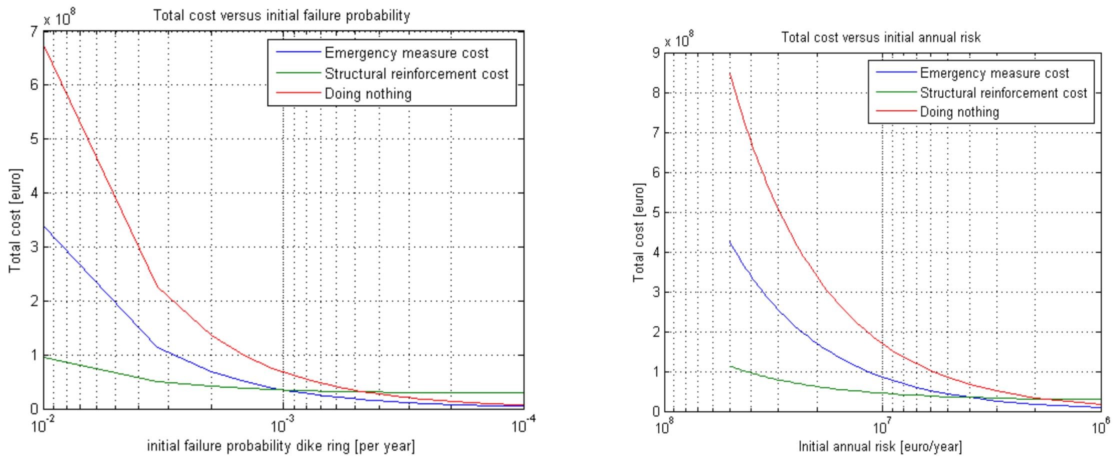



**Figure 73: Total cost versus initial failure probability (left) and annual risk (right) for strategy comparison of dike reinforcement versus emergency measures**

For this example it is concluded that dike reinforcements are the better option for initial failure probabilities of 1/100 ~ 1/1000 (annual risk of flooding of 4 million euro). For failure probabilities below 1/1,000 dike reinforcement is more expensive and emergency measures would be the better strategy. It is expected this is more or less the optimal safety level for flood defences in this type of dike ring, which can be investigated with (Eijgenraam, 2006).

## 7.4 Conclusions and recommendations

### 7.4.1 Reliability of emergency measures

The reliability of a system of emergency measures depends to a large extent on human performance during the detection and placement phase. For both piping and overtopping measures a decrease of the failure probability of the detection and/or placement phase with one order of magnitude results in about a factor 2-3 reduction of the failure probability of the emergency measure. It is shown that reductions of the failure probability of detection and placement of one order of magnitude are very effective, but further reductions will be less effective because the feasibility in time and effectiveness will become more dominant.

The feasibility in time has failure probabilities of one order lower than the organizational failure probabilities. The failure probability in time becomes dominant when the available time is below 24 hours. River systems have prediction times of 2 to 4 days. As a result river systems have long lengths are possible for emergency measures: 3 kilometres for overtopping measures (height = 0.45m) s (!) and a maximum amount of sand boil containments (height = 0.5m) of 120. For a coastal system (without taking the detection in to account) the maximum length of overtopping measures is limited to about 800 meters, while the total number of sand boil containments placed is limited to 15.

### 7.4.2 Cost effectiveness

For typical dike rings along the Dutch rivers, with initial failure probabilities of 1/100, it is concluded that the increase in safety of a system of emergency measures (factor 2) is insufficient to be an alternative for dike reinforcements (factor 10).

When comparing the total cost of dike reinforcement versus a system of emergency measures it is concluded that, for these dike rings, dike reinforcements are more cost effective than a system of emergency measures (even for reinforcement cost of 20 million euro / kilometer). But, a system of emergency measures could be an interesting interim solution when investments in dike reinforcements are delayed.

The three strategies (‘doing nothing’, emergency measures and dike reinforcements) were compared for varying initial failure probabilities (or annual risk) of the dike ring. In the example treated, where 33% of the dike ring required dike reinforcements and/or emergency measures, it is concluded that dike reinforcements are the better option for initial failure probabilities of 1/100 ~ 1/1,000, corresponding with an annual risk of flooding of 4 million euro.

However, for initial failure probabilities below 1/1,000, dike reinforcement proved to be more expensive resulting in emergency measures being the better strategy. It is expected this is more or less the optimal safety level for flood defences in this type of dike ring, which can be investigated with (Eijgenraam, 2006).

# 8. Conclusions / recommendations

## 8.1 Introduction

This chapter discusses the main results found in this report, more details are found in the last paragraph of each individual chapter. The goal is to provide feedback on the different research questions as defined in the introduction, which together form the main conclusion of this report. The research objective is repeated below:

*The objective of this research is to develop methods to analyse the reliability and effectiveness of emergency measures for flood defences. Attention will be paid to the quantification of the reliability of emergency measures through an extensive risk (failure probability) analysis.*

This project focused mainly on river dike systems. From the assessment of the flood defenses and the risk analyses made by VNK it is clear that piping accounts for the largest contribution to the failure probability of dikes in the river systems, followed by overtopping failure. Emergency measures do not form part of the primary flood defence system and are not part of the assessment of flood defences. These measures can be divided in 'control' measures, which are prepared beforehand for a specific situation, and emergency measures which are unprepared and site specific.

## 8.2 Reliability framework emergency measures

When including emergency measures (human intervention) in the reliability analysis of flood defences failure will occur when both the flood defence and the emergency measure fails.

For piping, measures are used to reduce the hydraulic head over the flood defense: either locally with containments around sand boils or over a larger area by increasing the groundwater level. Piping berms (soil berms) are also used to increase the stability of the flood defenses against piping. For overtopping, measures are used to temporarily increase the retaining height of the flood defense. Sand bags are still widely used for this purpose; although new products are being developed this report focuses on the use of sand bags.

To determine the failure probability of flood defences with emergency measures two assessments are made: Firstly the probability of failure of the emergency measure is determined and secondly the effect on the failure probability of the dike section and dike ring. The reliability of emergency measures is determined with event and fault tree analyses. The probability of a correct functioning control and/or emergency measure depends on the completion of three phases: Detection – Placement – Construction. The system is modelled in an event tree: it only functions when each event is completed on time and correctly.

1) Detection: in this phase the water boards monitor the upcoming high water and perform inspections of the flood defences to find weak spots.
2) Placement: after weak spots are found a diagnosis is required whether or not measures are required after which those necessary are placed.
3) Construction: this is the actual operational phase of the 'control' and/or emergency measure where it needs to function correctly.

For each phase fault tree analyses was used to determine the failure mechanisms and corresponding failure probability. The reliability of the detection and placement phase is dependent on the people performing each individual task and the feasibility of completion of the task within the time available. The construction phase depends on the technical reliability of the emergency measure.

The framework developed is based on the Dutch situation, which has specific government organizations, water boards, who manage the flood defences. The framework is however expected to be applicable in other areas and systems subject to flooding.

**Length effect**

An important aspect in the reliability assessment is the length effect; the longer the flood defence the higher the probability of it having a weak spot. In this report two types of length effect are treated: (1) The length effect of the flood defence (failure mechanism) and (2) the length effect of the emergency measure.

**Ad 1) The length effect of a flood defence** is modelled as a series system, which divides the dike in different dike sections each with its own strength characteristics. Distinction is made between the failure mechanisms of the flood defence.

**Ad 2) The length effect of the emergency measures** is also modelled as a series system, but does not depend on the dike sections. It depends on the amount of weak spots found along the flood defence (in the dike ring). Due to large uncertainties and irregularities in the subsoil piping has a large length effect.

With increasing amounts of weak spots along a flood defence the contribution of a system of 'control' and/or emergency measures to the reliability will then decrease. The length effect determines to a large extent the feasibility and type of emergency measure.

### 8.2.1 Organizational reliability

To determine the organizational reliability for emergency measures a Human Reliability Analysis is made. For the quantification of the error rates the methods of Rasmussen are used which divide human performance in three categories of behaviour: Knowledge based, Rule based or Skill based performance. For both the detection and placement phases the failure probabilities for each dike section (per event) are determined depending on the operators performing each individual task. The length effect has a large effect on dike sections where piping is dominant.

### 8.2.2 Feasibility in time

For a correct functioning measure the available time must exceed the required time. To determine the feasibility in time a reliability function is made which models the different sub phases with normal distributions. Based on the past river floods and interviews with the water boards estimates are made of the available time for overtopping and piping measures. For the detection phase the required time depends on the people performing the inspections (dike watch, districts, supervisors), the required time for placement depends on the weather conditions, personnel and equipment and the extent of the damage. For each dike section the probability of no (incomplete) placement is determined.

### 8.2.3 Technical reliability and effectiveness

The failure probability of a dike of sand bags (used for overtopping or sand boil containments) is determined with probabilistic analyses. The dominant failure mechanism (rotation, sliding or piping) depends on the sub soil: on clay or peat sliding is dominant, while on sand piping is dominant.

With Monte Carlo analyses it is concluded that single stacks of sand bags could retain water heights of about 0.45-0.60 meter, depending on the subsoil (clay or peat). A pyramid structure of sand bags (b/h = 2) is stable for sliding, because the weight of the structure grows exponentially with increasing retaining heights, which favours the stability of the structure. As water boards place the sand bags in pyramid structures the technical failure probabilities are negligible compared to those of the organization or feasibility in time.

The contribution of the emergency measures to the safety of the dike sections and dike rings is determined with sensitivity analyses of VNK2. Overtopping measures only have effect for water levels near the crest height of the dike while piping measures have the largest effect for water levels below the crest of the dike. A method is developed to determine the effectiveness of overtopping and piping measures.

## 8.3 Results case study dike ring 53

A case study is made for dike ring 53, which is part of the area managed by water board Groot Salland near the city of Zwolle in the Netherlands. The probability of flooding for dike ring 53 (for the primary flood defences) is larger than 1/100 per year, which is mainly the result of a high probability of failure for piping (1/63 per year).

**Piping**
The failure probability for piping measures in dike ring 53 is estimated at 1/3 per event. Taking the effectiveness of the measures in to account this resulted in a decrease of the failure probability of the section with a factor 1.2 to 2.7. At dike ring level the failure probability is reduced to 1/120 per year, a factor 1.9.

This validates the statement made that with increasing length (number of weak spots) the contribution of a system of emergency measures to the reliability of the flood defence decreases. Due to the length effect the reliability is lower than that of the dike section with the lowest reliability. The failure probability of the system depends largely on the probability of detecting weak spots in the dike, see Figure 74. Experience with passed high waters revealed sections where boils are likely to occur, however it is not known how the system will react to an actual Normative High Water event. The reliability of the detection phase is influenced by the knowledge and experience of the detection personnel, but also by the weather conditions and visibility.

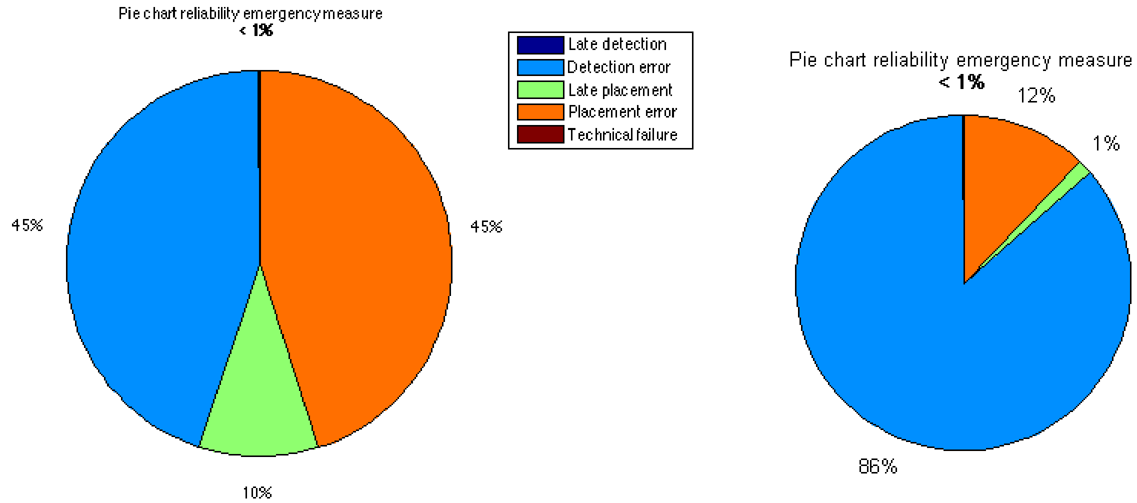



**Figure 74: Distribution of reliability of overtopping emergency measures for dike section 11 (left) and piping emergency measures for dike section 29 (right)**

### *Overtopping*

The overtopping failure probability of the dike ring is estimated by VNK at 1/610 per year (Dijk & Plicht, 2013). The contribution of increasing local 'dents' in the dike is also determined. For these sections a failure probability is found of 1/9 per event. Together with the effectiveness this resulted in a reduction of the failure probabilities of the dike sections with a factor 2 to 6. This resulted in a failure probability of the dike ring with emergency measures of 1/3000 per year, a reduction with a factor 3.6.

The failure probability of measures against overtopping is determined largely by the probability of detection of weak spots and the probability of correct placement of the emergency measure (sand bags). Both analyses show that overtopping measures are more reliable than piping measures, which is explained by the fact that it is easier to detect overtopping than piping.

## 8.4 Discussion reliability of emergency measures

### Organizational reliability

With the framework developed it is determined that overtopping measures have failure probabilities of 1/9 per event. Piping measures have higher failure probabilities due to the length effect: 1/3 per event.

The reliability of a system of emergency measures depends to a large extent on human performance during the detection and placement phase. For piping specifically investments in the personnel responsible for finding sand boils, are very effective as the failure probability of the emergency measures for piping depends largely on the probability of finding sand boils. Increasing the reliability of the organization is only effective up to a certain level, when other factors such as the reliability in time and effectiveness become dominant. Reductions up to a failure probability of 1/100 are effective, which corresponds with the level at which districts operate. Further reduction can be achieved by investing in logistics (placement speed).

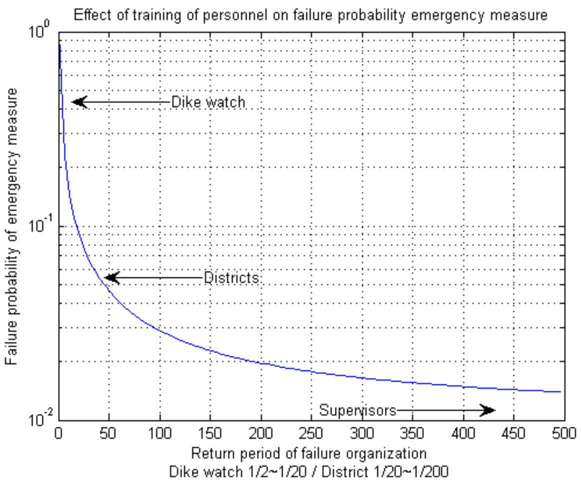



**Figure 75: Influence of failure probability of organization on total failure probability of the emergency measures**

### Feasibility in time

The feasibility in time has failure probabilities of one order lower than the organizational failure probabilities. It becomes dominant when the available time is around 24 hours. River systems have prediction times of 2 to 4 days, but coastal systems have much shorter available time (order 12 hours). It is expected that a system of emergency measures will have little effect on the reliability of a dike ring in a coastal system.

### Effect on dike sections

The contribution of a system of emergency measures to the safety of dike sections / dike rings are limited to the maximum effectiveness of the measure: a dike with a correct functioning emergency measures could still fail. For overtopping measures maximum lengths of 250 meters are assumed, because longer lengths are assumed not feasible. The effect on dike ring level is limited to a reduction with a factor 1.4.

For piping the effect of reducing the hydraulic head over the flood defence with 0.5 meter was assumed. The effect of reducing the head difference over the flood defence with another 0.5 meter was investigated and resulted in a reduction of the failure probability with a factor 2.6, which is higher than the initial reduction of 1.6, but not very significant.

## 8.5 Emergency measures versus dike reinforcement

On dike ring level dike reinforcements reduce the failure probability with a factor 10, compared to the factor 1.5 ~ 2 of emergency measures. Which strategy is preferred depends on the specifications of the dike ring.

For typical dike rings along the Dutch rivers, with initial failure probabilities of 1/100, the increase in safety of a system of emergency measures (factor 2) is insufficient to be an alternative for dike reinforcements (factor 10), because the failure probability is limited to 1/1,250 by law. These norms could even become more stringent in the future. Dike reinforcements are more cost effective than a system of emergency measures. But, a system of emergency measures could be an interesting interim solution if investments in dike reinforcements take years (or decades).

The total cost of all strategies depends largely on the initial failure probability (or annual risk) of the dike ring. For dike ring 53, where 33% of the dike required reinforcement / emergency measures, dike reinforcement is the best option for initial failure probabilities of 1/100 ~ 1/1,000. This corresponds with an annual risk of flooding of 4 million euro (with an average damage cost during a flood of 2~10 billion euro). For initial failure probabilities below 1/1,000 a system of emergency measures becomes more cost effective. It is expected this is more or less the optimal safety level for flood defences in this type of dike ring, which can be investigated with (Brekelmans, Hertog, Roos, & Eijgenraam, 2012).

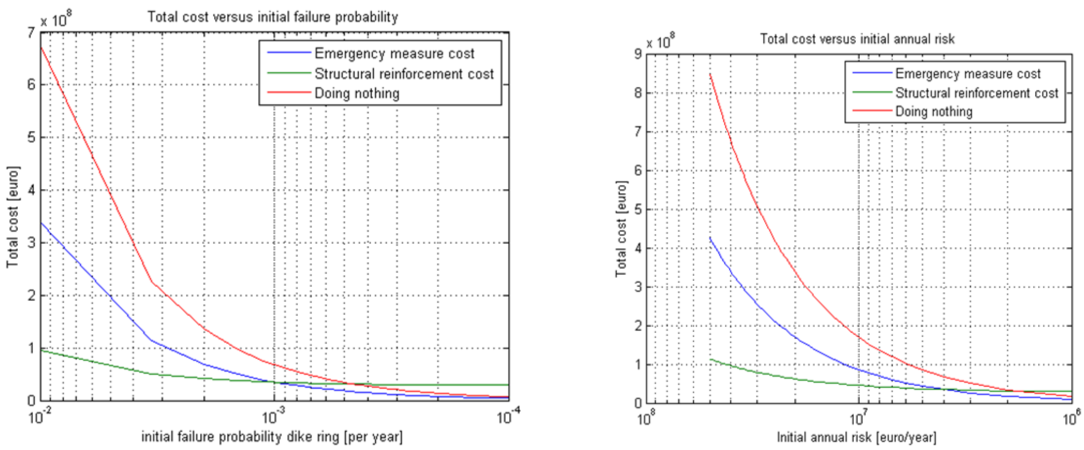



**Figure 76: Total cost versus initial failure probability (left) and annual risk (right) for strategy comparison of dike reinforcement versus emergency measures**

A comparison of emergency measures and dike reinforcements showed that both strategies contribute to a reduction of the probability of flooding. Emergency measures could reduce the failure probability of a dike with a factor 2 ~ 5, depending on the failure mechanism, organizational reliability and the length effect of the emergency measure. Dike reinforcements could achieve higher reductions of the failure probability. Looking at the stringent safety standards for flood defenses it is concluded that dike reinforcements are the only option to achieve the required safety levels (higher than 1/1,000 per year).

If emergency measures are included in the assessment of flood defenses safety standards are required for their reliability. In other areas where temporary/moveable defenses are applied, for example in hydraulic structures, the probability of non-closure may not exceed 10% of the safety standard. For Dutch rivers, with a safety standard of 1/1,250 per year, this corresponds with a probability of 1/12,500 per year. Human failure is included in these methods. Taking the results of this research in to account it seems similar criteria for emergency measures are not feasible.

## 8.6 Recommendations

### 8.6.1 Recommendations for further research

The reliability of the emergency measures depends largely on the reliability of human actions, which is determined with a Human Reliability Analysis (HRA). The assignment of error rates to the different employees of the water boards is based on expert judgement of the author, which was quite accurate when compared to observations in the field. However, further investigation (possibly with Bayesian networking, (Jager, 2013)) could provide more insights in human performance during floods.

The framework is simulated with an event tree, which only allows for an analysis in binary sense (probability of 'yes or no', 'correct or incorrect'). An analysis using Bayesian networks with distributions may give more accurate reliabilities and insight in the interdepecies and common factors such as weather and visibility. Due to a lack of data for distributions of organizational reliability and effectiveness of the emergency measures this method requires further investigation.

Research in the use of alternative (innovative) emergency measures is recommended, as a lot of products are currently being developed for flood fighting. The main disadvantage of sand bags is the required time for placement, which is rather high. Several new products are being tested which could be an alternative for the classical sand bag, yet these products have technical reliabilities which are lower than sand bags.

The results found in this report are mainly based on the case study of dike ring 53 at water board Groot Salland. It is recommended to apply the framework to other dike rings / water boards in the Netherlands to gain insight in the reliability of the emergency measures in these areas, as each water board has a different organization and local flood defences.

Further, dike ring 53 is loaded by the river Rhine which has quite a large prediction time (4 days). Research in systems with shorter prediction time will result in lower reliabilities of the emergency measures, for example along the Meuse or a coastal system (see chapter 7). It could be interesting to investigate how the reliability of a system of emergency measures could be improved in these systems.

### 8.6.2 Recommendations for Water Boards

For dike rings with failure probabilities of ~1/100 water boards are advised to choose a system of emergency measures to temporarily increase the safety of the flood defenses, in anticipation of dike reinforcements. A prioritization of dike sections suitable for emergency measures is advised to determine where emergency measures have the largest effect. To determine these dike sections similar sensitivity analyses are required such as those made for dike ring 53 by VNK2, for both piping (head reductions) and overtopping (dents) sections.

Control and/or emergency measures are advised to be included in the calamity plans of the water boards, including water levels where each phase (detection, placement and construction) need to start. Water boards are recommended to invest in the training and knowledge of the employees with high failure probabilities such as the dike watch for detection and contractors/military for placement. Especially in the river systems where piping is dominant investments in the detection personnel (dike watch) responsible for finding sand boils could be very effective.

Each dike watch is assigned a specific dike section and receives procedures and tools to perform the inspection. These tools, such as the 'Handboek dijkbewaking', could be further improved using site-specific information. When given specific information on dominant failure mechanism and corresponding observations the detection phase will be more reliable.

During every exercise water boards are advised to collect (historical) data regarding human performance and time required for placement of all emergency measures. For example during 'Conecto' it was concluded that the time estimated by the water board for placement of the emergency measures was optimistic, resulting in the recommendation to revise the data sheet used to determine the required time for each emergency measure.

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# Appendices

## I Deltares onderzoek noodmaatregelen (Dutch)

Bij een (dreigend) hoogwater spelen noodmaatregelen een onmiskenbare rol. Veel is reeds onderzocht en veel waterkeringbeheerders beschikken reeds over de nodige kennis en ervaring, alsmede hulpmiddelen om tot effectieve inzet van noodmaatregelen over te gaan. Toch hebben waterkeringbeheerders nog diverse behoeftes op dit gebied, reden voor Rijkwaterstaat en STOWA om dit te onderzoeken.

Aan de TU Delft wordt momenteel onderzoek gedaan naar de **effectiviteit en betrouwbaarheid van noodmaatregelen bij hoogwater**. Aanleiding hiervoor is dat er nog beperkt inzicht is in de daadwerkelijke betrouwbaarheid van noodmaatregelen bij hoogwater (en de bijdrage aan faalkans van de keringen).

Bij de beoordeling van de betrouwbaarheid van noodmaatregelen is het nodig meer inzicht te krijgen in logistieke, organisatorische en technische aspecten. Voor een succesvolle toepassing moet een keten aan stappen succesvol worden doorlopen (waarneming, plaatsing) en de "noodconstructie" (bv. bestaande uit zandzakken, geotextielen of andere materialen) moet veilig functioneren. De omstandigheden tijdens een dreigende overstroming (weer en wind en de kans op meerdere doorbraken) kunnen het nemen van effectieve noodmaatregelen bemoeilijken. In andere domeinen, bijvoorbeeld bij mobiele waterkeringen en stormvloedkeringen zijn reeds benaderingen ontwikkeld om rekening te houden met deze factoren, de TU Delft onderzoekt momenteel hoe de betrouwbaarheid van noodmaatregelen gekwantificeerd kan worden.
Rijkswaterstaat heeft het initiatief genomen om toe te werken naar een generiek toepasbaar **beslissing ondersteunend systeem voor de inzet van noodmaatregelen**, waar waterkeringbeheerders gebruik van kunnen maken. Eerste stap hierbij is het in beeld brengen van de structuur (hoe kom je van een waargenomen schadebeeld tot daadwerkelijke inzet van een noodmaatregel) en de "witte vlekken" in de inhoud en proces hieromtrent. Bij de uitvoering van deze stap wordt verkend welke ontwikkelingen er spelen en gespeeld hebben in met name Nederland en wordt in het bijzonder ingezoomd op de praktijk van Waterschap Rivierenland en Hoogheemraadschap Delfland. Vervolgens zullen met betrokken partijen op basis van de geïdentificeerde witte vlekken en wensen, prioriteiten worden gesteld ten aanzien van vervolgstappen om te komen tot genoemd beslissing ondersteunend systeem. Een mogelijke vervolg is het opzetten van een WIKI (koude fase) met overzicht van kennis, hulpmiddelen en ervaring en het opzetten van generiek toepasbaar beslissing ondersteunend systeem (warme fase). Dit onderzoek wordt uitgevoerd door Deltares.

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# II Risk assessment of flood defences

This appendix is intended to further explain the approaches used in the Netherlands to determine the risk of flooding and required safety levels against flooding.

## II.I Risk of flooding

This section will gives a short summary of how the risk of flooding is determined as these methods also form the basis of the risk analyses of 'control' and emergency measures. The annual risk of flooding [R] is determined by a probability of failure [Pf] multiplied by the corresponding damage [S]. When this is divided by the discount rate [r '] one obtains the Net Present Value of the risk, see equation 2-1.

$$R = \frac{P_f * S}{r'} \tag{2-1}$$

### Failure probabilities

The failure probability can be determined using different techniques; most common are the fault tree analysis and event trees. To perform a reliability analysis three steps are performed:

1. A qualitative assessment of functions and components of the system, this can be visualized using an event tree or fault tree, see chapter 3.
2. A quantitative comparison of the system, failure probabilities are assigned to the different components of the system which together determine the probability of failure of the system, see chapter 4.
3. In the final phase, the system with probabilities of failure is analyzed and evaluated in order to draw conclusions concerning the risk of the entire system.

### *Series or parallel*

The various components in a system can be modelled as a series or parallel system. Depending on the properties of the system, the different components of the system could be considered independent or dependent of each other. This has implications for the probability of failure of the entire system. In Table 35, the calculation methods of the various options presented. By multiplying the failure probability of the system with the corresponding consequences one obtains the annual risk, see equation 2-1.

$P_{f,system}$ (with $n$ components):

| system | gate | operator | components | | |
|---|---|---|---|---|---|
| | | | mutually exclusive | independent | fully dependent |
| series | OR | $\cup$ | $\sum_{i=1}^{n} P_i$ (upper bound) | $1-\prod_{i=1}^{n}(1-P_i)$ | $\max\{P_i\}$ (lower bound) |
| parallel | AND | $\cap$ | $0$ (lower bound) | $\prod_{i=1}^{n} P_i$ | $\min\{P_i\}$ (upper bound) |

**Table 35: Failure probabilities of a series and parallel system** (Dupuits, 2011)

### Consequences

The damage caused by flooding can be divided into three categories: direct (material) damage, indirect (economic) damage and loss of life (Jonkman, Lentz, & Vrijling, 2010). For each category the relationship between inundation depth and corresponding damage is investigated. Further elaboration of the consequences of a flood is beyond the scope of this report as it focuses on the reliability (probability of failure).

### Cost benefit analysis

After determining the risk of a certain system one could compare the cost of several risk reduction methods in a cost benefit analysis to determine which method is most cost effective. Such cost benefit analyses have long been used in the Netherlands to inform policy debates about the safety of flood defences (Jongejan et al., 2012)(Eijgenraam, 2006). The following paragraphs give a short overview. Such methods will be used to make cost benefit analyses of structural dike reinforcements versus 'control' and emergency measures.

## II.II Economic optimization of flood defences

In the approach used by the Delta Committee in 1960 the required flood defence level was determined through a cost benefit analysis (van Dantzig, 1956). The exceedance frequency of a certain water level was theoretically determined through an economic optimization: the optimum between on one hand the investments (I) required to raise the flood defence (h) and on the other the corresponding reduction of the risk (R) due to the lower probability of exceedance ($P_f$). The probability of exceedance was determined by extrapolating observed water levels to levels never seen before.

The optimum is found by minimizing total cost function of equation 2-2, which is illustrated in the graph of Figure 16 (Jonkman & Kok, 2008). Recent work have made some alterations to the approach used (Eijgenraam, 2006).

$$C_{tot} = I(h) + R(h) \quad (2\text{-}2)$$

$$I(h) = I_0 + I_d * h \quad (2\text{-}3)$$

$$R(h) = \frac{P_f * S}{r'} \quad (2\text{-}4)$$

$$P_f = e^{-\frac{h-a}{b}} \quad (2\text{-}5)$$

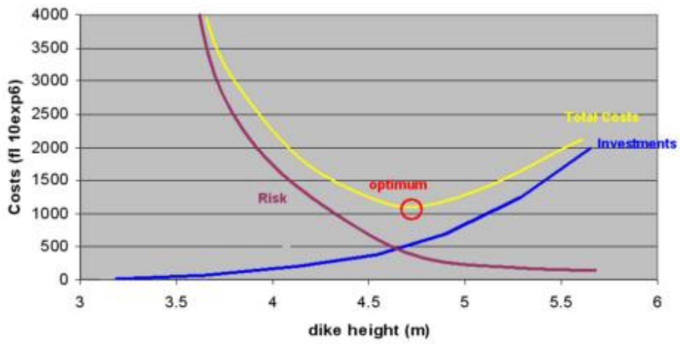


**Figure 77: Economic optimisation for determining the required flood defence level by Van Dantzig** (Jonkman & Kok, 2008)

A disadvantage of the approach used is the fact that the probability of flooding is assumed to be equal to the probability of exceedance of a certain water level, implying that overtopping is the only failure mechanism which could cause flooding. Recent work has proved that other failure mechanisms could also result in dike breaching long before it is overtopped.

## III Closing procedure of temporary flood defences

In the Netherlands there are several temporary flood defence structures which need to be closed when a certain water level on the rivers is exceeded, which is called the 'Closure level' (sluitingspeil). An example is the barrier at Kampen Midden in which several houses form part of the dike infrastructure. This flood defence is closed with the help of the 'high water brigade' which is a group of volunteers (Leeuw et al., 2012). Following from 'Leidraad Kunstwerken' the maximum allowable probability of failure for a temporary flood defence is 10% of the required safety standard.

The phases which are followed for the correct functioning of a temporary flood defence are the warning phase, mobilization phase, construction phase and the operational phase. The warning phase initiates after the water level reaches a certain 'warning level' (waarschuwingspeil), see Figure 78.

From this moment the weather and water level forecasts are monitored extensively and all parties involved are warned to be prepared for possible closure of the temporary defences. When the water level reaches another level, the mobilization level, the decision is made to mobilize everyone involved.

If the water level keeps rising and the closure level is reached all temporary / moveable defences need to be closed before the water level reaches the OKP (Open Keer Peil). At this moment all defences need to be closed, because closure for higher water levels is hindered by the inflow of water. The flood defence can be reopened after the water level reached a level lower than the closure level.

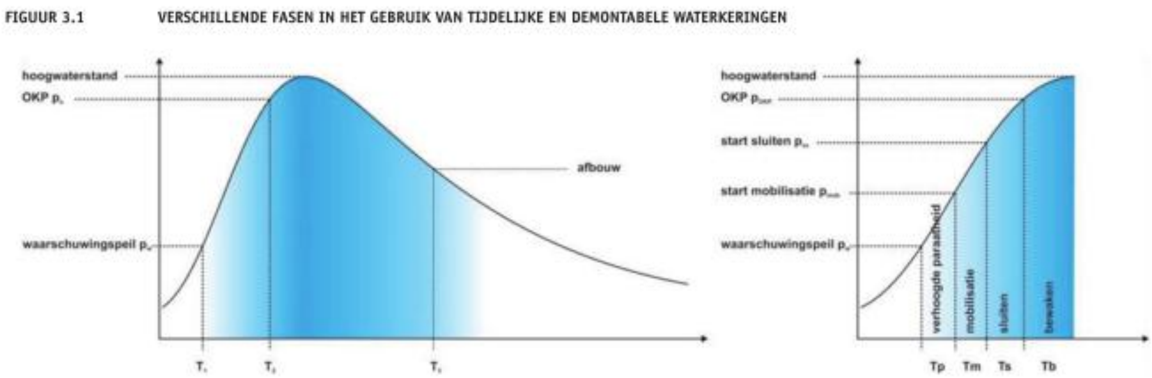


**Figure 78: Phases of temporary / moveable flood defence (STOWA, 2008)**

# IV Reliability of overtopping measures

Measures to prevent overtopping consist of small water retaining structures which can be modeled as gravity structures. The forces acting on the structure are shown in the following figure:

- The own weight of the system (W [kN/m]);
- The horizontal water pressure ($F_{w;h}$ [kN/m]);
- The vertical water pressure (if present) ($F_{w;v}$ [kN/m]);

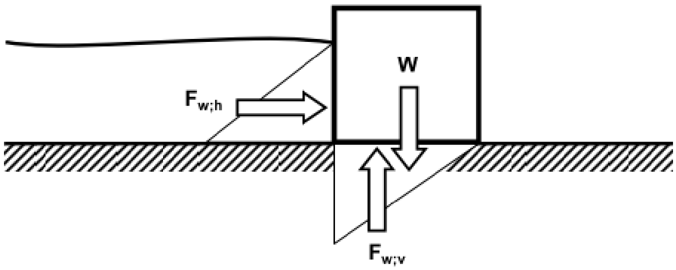


**Figure 79: Pressure and acting forces on an overtopping measure**(Boon, 2007)

Whether or not the vertical water pressure develops like it is illustrated in the figure depends on the subsoil and the time the structure is retaining water (the water pressure requires a certain amount of time to infiltrate the subsoil). However, in the calculations the maximum upward water pressure is taken in to account which has a negative effect on system stability. In reality this is an overestimation of the instability as shown by Boon (Boon, 2007). These structures are subject to the following failure mechanisms, illustrated in **Figure 29**.

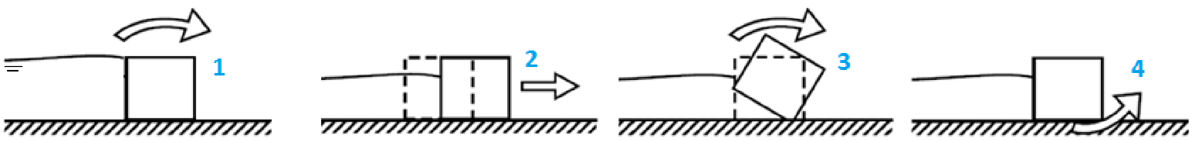


**Figure 80: Overtopping (1), Sliding (2), Rotation (3) and piping (4)** (Boon, 2007)

1. Overtopping, insufficient retaining height
2. Sliding, horizontal sliding of the structure due to the horizontal water forces
3. Rotation, tipping over of the structure due to the horizontal water forces
4. Piping, under seepage or piping under the structure due to the head difference over the structure causing instability

Depending on the measure applied different reliabilities can be found. In a master thesis made by M.J.J. Boon calculations were made of the safety of several retaining measures against sliding, rotation and piping. (Overtopping was not taken in to account because this would simply require a higher structure). The results are presented in the following sections.

## IV.I Sliding

The factor of safety against shear is the ratio between the (resisting) friction force along the bottom of the system as a result of the vertical forces (V in kN/m) and the (driving) horizontal hydrostatic force (H in kN/m), see equation 3-1:

$$FS_{shear}\left[-\right] = \frac{T}{F_{w;h}} = \frac{f * \sum V}{\sum H}$$

(3-1)

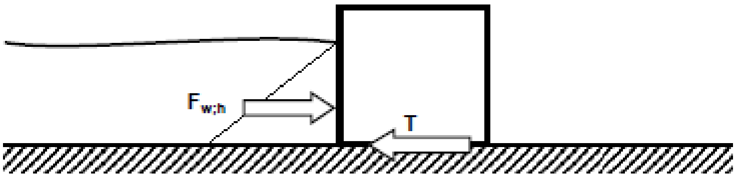


**Figure 81: Shear safety** (Boon, 2007)

When the safety factor drops below FS=1, the structure becomes unstable. The friction force depends on the resultant of the system weight (W) and upward water force ($F_{w;v}$) and the shear coefficient. This shear coefficient [f] depends on the material of the system and the foundation. For the calculations a shear coefficient of 0.25 was assumed for all systems. The figure shows that the Aqua levee is the least stable while the Aqua barrier proved to be the most stable.

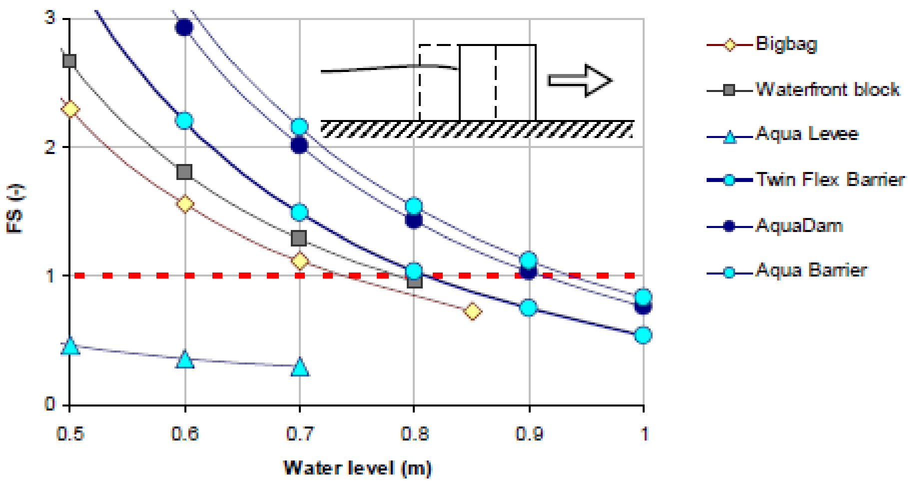


**Figure 82: Shear resistance for different emergency measures (Boon, 2007)**

## IV.II Rotation

To calculate the safety of rotation one should divide the driving moments consisting of the horizontal and vertical water pressures by the resisting moments consisting of the weight of the structure, see equation 3-2. Choosing the location of the rotation point proved to be important: rigid structures tend to rotate around a point at a distance of 2/3 their width while more flexible structures rotate around a point somewhere between 2/3 and 1 time its width. For a first impression of the rotational stability of 2/3 (which is the most unfavourable situation) will be assumed (Boon, 2007).

$$FS_{rotation} = \frac{\text{driving moments}}{\text{resisting moments}} \tag{3-2}$$

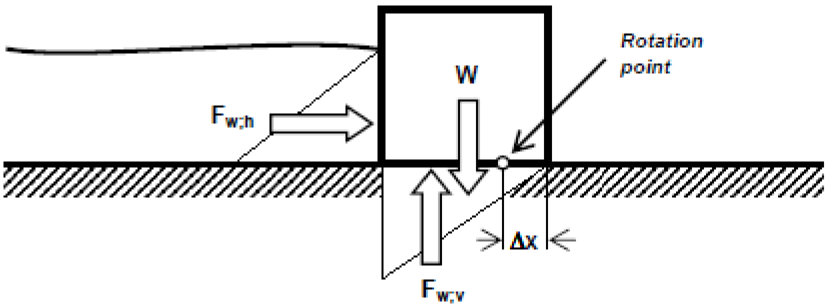


**Figure 83: Rotation safety (Boon, 2007)**

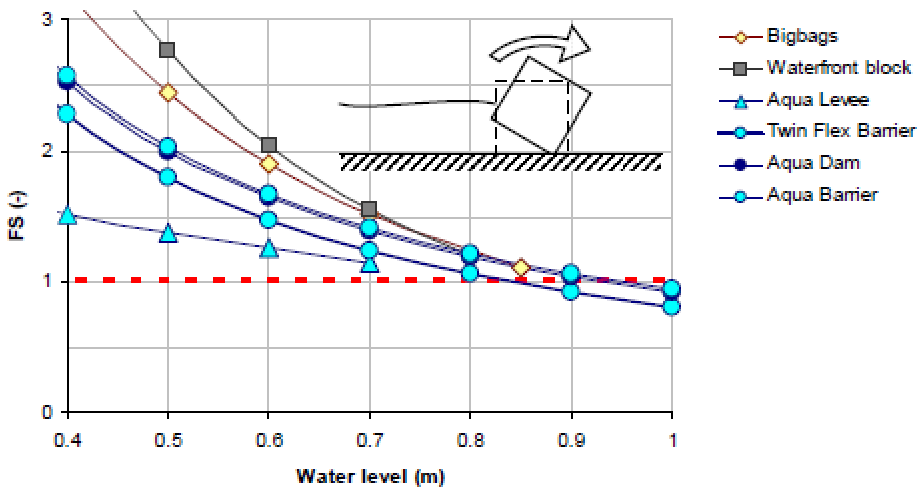


**Figure 84: Rotation resistance for different emergency measures (Boon, 2007)**

The stability of all systems with respect to rotation is somewhat better than their shear stability, which means that the structures will theoretically fail through shear and not rotation. The rotational stability of a sandbag dam is not assessed since it consists of different components (bags), its failure is treated in the last section.

**Box barrier at Flood Proof Holland**

*The Box barrier is not treated in the figure; its stability was investigated at Flood Proof Holland. The stability depends to a large extent on the subsoil; on hard subsoil the shear stability proved dominant while on softer soils such as those present at FPH the Box barrier tends to tilt over proving rotation to be dominant. These problems are however easily avoided by placing boxes behind the dike for extra support.*

## IV.III Piping

The last failure mechanism treated is piping, which occurs when seepage water flows underneath the structure from the upstream side to the downstream side. This could cause problems for measures which have a small width and therefore a short piping length. The subsoil on which the measures are placed is of great importance: piping will hardly occur on peat and clay subsoil, in contrast to sandy subsoil which does form a problem.

For sandy subsoil the required piping length (construction length) can be calculated with the Sellmeijer and Bligh methods for a given head difference. The four diagonal lines in Figure 85 display the minimally necessary system width ($L_c$) with respect to the controlled water height ($\Delta h$), or the other way around: the maximally controlled water height for a system of a certain width. This has been displayed for both Bligh and Selmeijer and for very coarse as well as very fine sand (Boon, 2007).

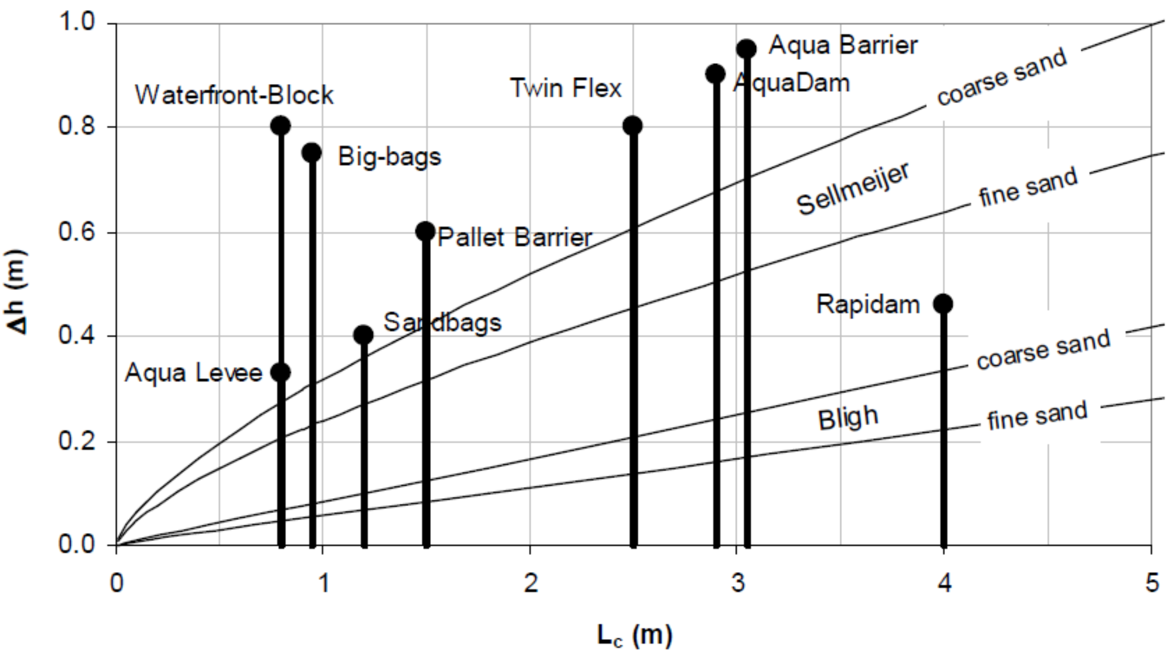


**Figure 85: Piping safety for different emergency measures (Boon, 2007)**

From the figure can be concluded that all measures are unsafe on sandy subsoil, whether it is coarse or fine sand. These measures are therefore not advised on sandy subsoil or only to be loaded to the maximum allowed head difference [Δh].

## IV.IV Conclusion

The previous calculations show that when the design rules are followed the emergency measures perform quite well on peat and clayey subsoil which are mostly found on dikes. On sandy subsoil the measures prove to be unstable for piping failure. Sliding proved to be the dominant failure mechanism. Probabilistic calculations of the stability of a dike of sand bags are made in chapter 4 to obtain an order of the reliability of these structures.

# V Human and organisational reliability

HRA has been developed during the last thirty years, it has seen its primary applications in nuclear power plants and chemical processing plants. The objective of HRA is to determine what human errors can occur during the operation, how likely they are and how they can be prevented or recovered (Kirwan, 1996). HRA provides input for probabilistic risk analysis.

A HRA proceeds through 8 basic steps, see the figure: (source)

1. **Problem definition:** definition of the system to be studied and what human involvements are to be assessed
2. **Task analysis**: definition of human actions associate with the events
3. **Error identification:** definition of types of human and organizational errors
4. **Representation:** analytical characterization of how errors can interact with the other components of the system through event or fault trees, also analysing their inter dependencies
5. **Quantification:** numerical characterization of how the likelihood of errors and their effects on the reliability of the system
6. **Impact assessment:** evaluation of how to reduce the likelihood of errors and/or its impact until the reliability is considered sufficient
7. **Documentation and quality assurance**: recording the analyses, results and assumptions to review the processes which have been correctly implemented

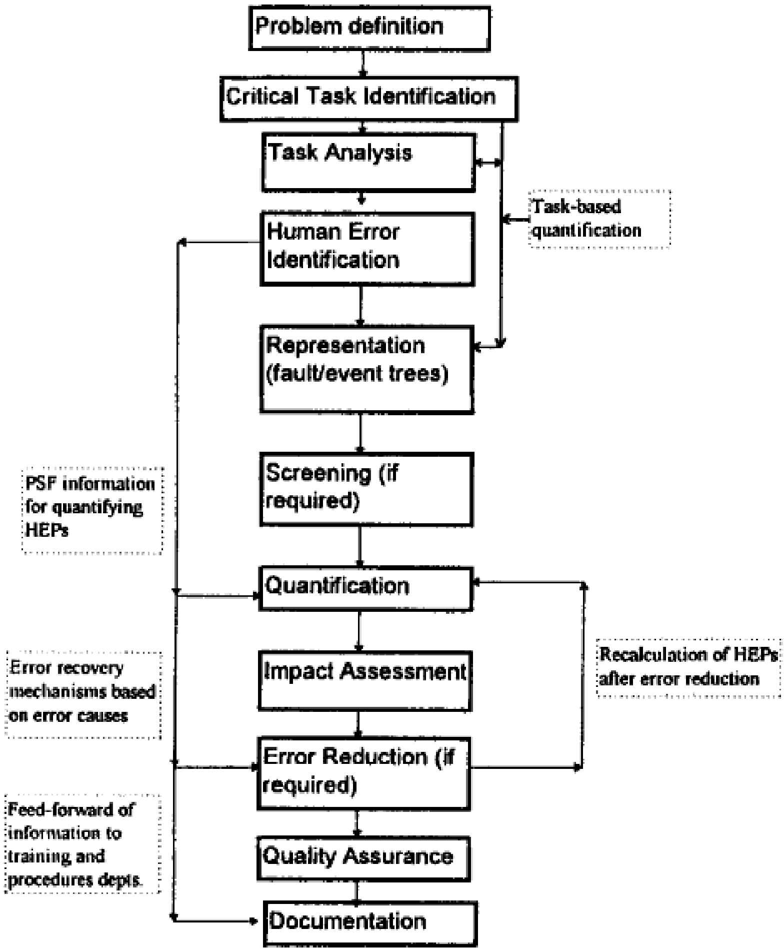


**Figure 86: Flow chart of a HRA (Kirwan, Scannali, & Robinson, 1996)**

In engineering practices the HEART technique and THERP technique are often used to quantify the probabilities of errors in an HRA:

### HEART

This method uses a set of generic error probabilities for different types of tasks, for each task a base error rate is determined and multiplied by error producing condition factors (comparable with PSF's) to obtain the human error probability.

### THERP

This method, compatible with fault tree methods, includes models for human error using event trees and models of dependence, performance shaping factors which affect the tasks and a database of human error probabilities. Using event trees allows for the method to be evaluated mathematically, identifying tasks which dominate the reliability of the system. This however requires a detailed analysis of all tasks required within the system.

### Comparison HEART and THERP

These techniques were validated in an article by Kirwan which consists of three parts, the conclusions are summarized below (Kirwan, Kennedy, Taylor-Adams, & Lambert, 1997):

The results of a validation of the techniques applied to a case study show a significant correlation of all estimates with the known true values. A precision range of 60 – 87% was reached with an average of 72%. These results lend support to the empirical validity of these techniques in particular, and to HRA in general.

## V.I HRA for emergency measures

For the analysis of the human reliability in the application of emergency measures the THERP method will be used, a similar approach is used in 'Leidraad Kunstwerken' to determine the 'Reliability of non-closure'. An event tree is made to model the usage of emergency measures as a measure against flooding. This is the first step of the THERP method. The THERP method includes the following key elements (Kirwan, 1996).

- Modeling of the HRA tasks in an event tree
- Decomposition of the tasks into elements
- Assignment of nominal human error probabilities to each element
- Determination of the PSF's on the error probabilities of each element
- Calculation of effects of dependence on probabilities between elements and tasks
- Quantification of total HRA event tree

Note that this approach was more or less followed in chapter 3 when analysing the steps required for the correct application of emergency measures. In fact, we can now focus on the quantification of human reliabilities for each task. The results of a HRA should always be evaluated thoroughly to decide whether they are valid for the system which is investigated.

## V.II Human error quantification

A Human and Organizational Error is a deviation from acceptable or desirable practice on the part of an individual (human error) or group of individuals (organizational error) that can result in unanticipated and/or undesirable results (Stamler, 1993). Human Error Probabilities (HEPs) are defined as follows:

HEP = number of errors occurred / number of opportunities for error

Human reliability practitioners have had to rely on expert judgment in combination with limited numerical data due to a lack of a successful database of human error probabilities. This database is then manipulated by the assessor to find probabilities of errors for the specific tasks to be performed within the system. The analysis of reliability in the engineering/technology vocations typically seek only orders of magnitude of estimations of errors rather than exact descriptions (R Bea, 2010).

### Mean error rates

Swain and Guttman performed research on the order of magnitude of human error rates and the relation with the routines of the task and the time available to perform the task. Results from the experiments performed by Swain and Guttman (1983) are summarized in the following tables.

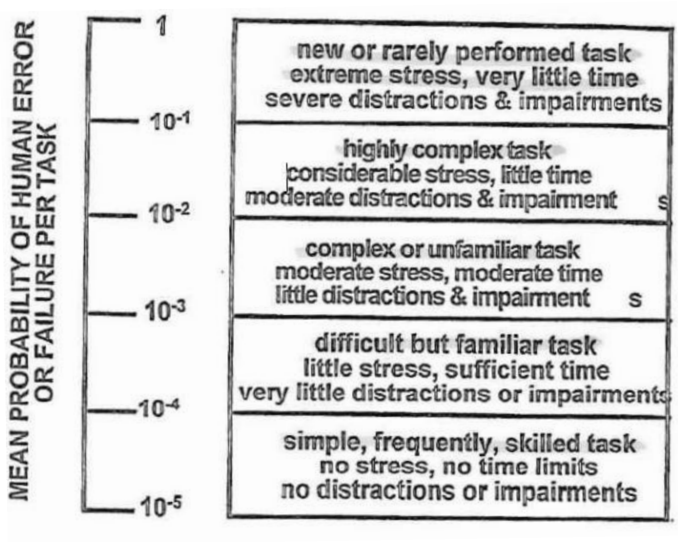


**Figure 87: Results from research of Swain and Guttman (1983)**

Generic human error rates are assigned to general tasks performs under general types of influences and impediments. The range of error probabilities are intended to be associated with the potential ranges in the influences and impediments: if the influences and impediments are intense then the error probability is toward the higher side.

The standard deviations associated with the generic error rates of human errors are published by Williams (1988). It is important to note that the severity of the error is not captured in any of the available quantitative information. Errors are either major and significant or minor and insignificant. Minor and insignificant errors are generally caught by the individual and corrected, hence their lack of importance according to Swain and Guttman (1988). These probabilities were also used in 'Leidraad Kunstwerken' to determine the human error probabilities.

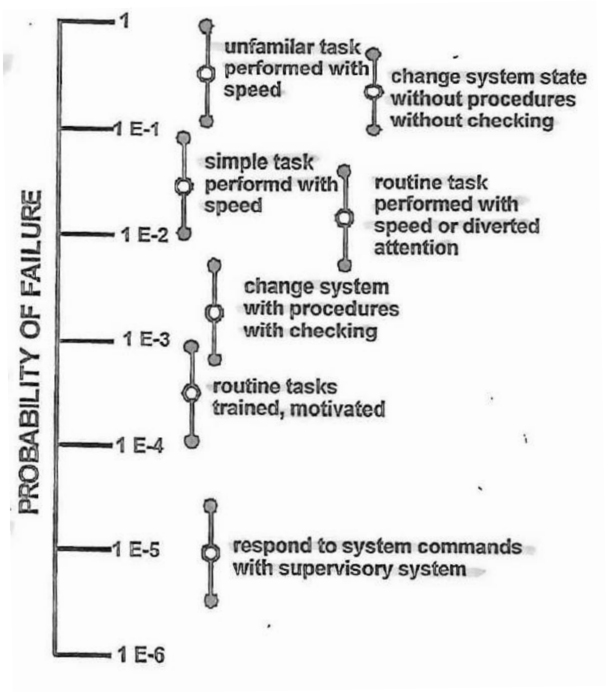


**Figure 88: Normal human task performance reliability by Williams (1988)**

Rasmussen (1982, 1983) described that humans tasks are divided in three performance levels; skill based, rule based and knowledge based.

- **Knowledge based** performance is the most cognitively demanding level, at this stage there are no pre planned actions which can be called upon because of the novelty of the situation.
- **Rule based** performance is the next cognitive level; this class involves responding to a familiar problem according to standardized rules.
- **Skill based** performance is the least cognitively demanding level; at this level the calling conditions occur so often that knowledge retrieval and action are virtually automatic.

The relation between the error probabilities and the three performance levels is show in the figure below. Watson (1986) and Collins (1995) have addressed these human performance reliabilities associated with skill-, rule- and knowledge based tasks. Onsite examination of tasks, interviews and expert judgment are used to identify the range of error probabilities for each task within a system.

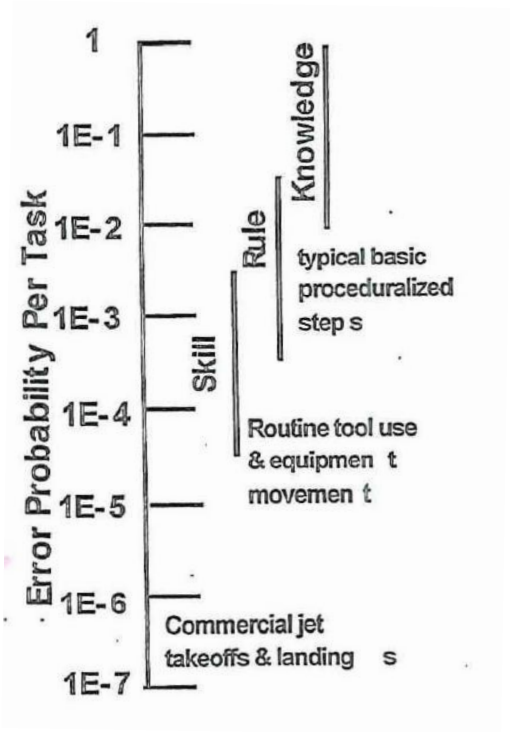


**Figure 89: Relation human error probabilities and performance levels by Watson and Collins (R. Bea, 2010)**

## Performance shaping factors

Information has been developed on human error performance shaping factors (PSF) (Williams, 1988; Swain & Guttman, 1983). These factors are influences that can result in an increase in the mean rates of human errors. These factors are useful in helping develop quantification of the potential effects of changes in seven categories:

1. operator training
2. organization structure
3. procedures available
4. equipment to be used
5. structure
6. environments
7. interfaces

The factors which are most relevant to this research are those including examples. The use of performance shaping factors (PSF) was used primarily to evaluate the influences on the base rates ('normal conditions') of errors committed by personnel. The final probability is found by multiplying the mean error rates with the PSF, as shown in the relation of the following equation:

$$P(E_{jkm}) = P(E_{jkm}) \bullet \prod \mathrm{PSF}_{Ejkm}$$

$$P(E_{jkm}) \leq 1.0$$

A scale for the performance shaping factors is given in the figure below. The scales shown are based on the SYRAS method or the SMAS method. Both methods allow the base rates of human errors to be increased or decreased by three orders of magnitude.

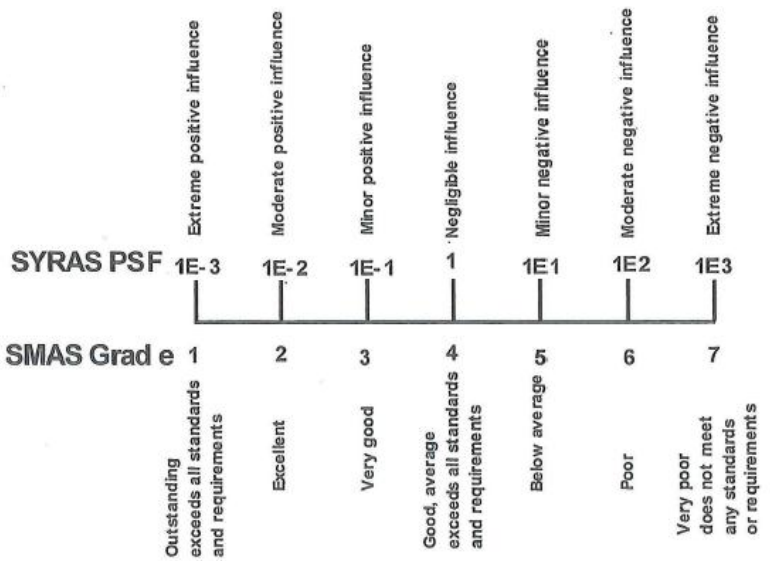


**Figure 90: Scale of PSF (R. Bea, 2010)**

In practice assessors use PSF rarely, because these are considered highly subjective. The choices are mainly based on the assessor's qualitative analysis and experience in HRA. Instead assessors more often only use the factor stress to determine the spread around the mean base rates of human errors. This is not how it is meant to be used by THERP but is considered applicable (Kirwan, 1996).

## V.III Error mitigation

Organizations can take the following steps to reduce the probability of human errors within the organizationas determined by Roberts and Rousseau (R Bea, 2010).

- **Command by exception or negation,** management activity in which authority is pushed to the lower levels of the organization
- **Procedures and rules,** procedures that are correct, accurate, complete, well organized, well documented and not excessively complex are an important part of Higher Reliability Organisations
- **Training** in the conduct of normal and abnormal conditions is mandatory to avoid errors
- **Appropriate rewards and punishments** are critical
- **Ability of management to see the big picture,** decision makers are required to understand the big picture in order to perceive the important developing situations, properly integrate these and develop high reliable responses.

## V.IV Conclusion

To determine the human and organizational reliability for emergency measures the steps followed in a Human Reliability Analysis are followed. For the quantification of the mean error rates the methods proposed by Rasmussen are used which divide the performance of humans in three categories. Knowledge based, Rule based or Skill based performance, each with corresponding mean error rates.

## V.V Bayesian network for organizational reliability

For a more thorough investigation based on expert judgement the following steps could be followed, originating from a master thesis investigation by W. Jager in 2013 (Jager, 2013a). This assessment is based on the Classical model which has been developed for the European Space Agency for risk assessment applications, it's objective is to properly ellicitate expert judgment for probabilistic hazards.

1. Propose a certain net structure for the variables to be investigated.
2. Use questionnaires to obtain data on probability distributions of different variables based on expert judgment of the 5%, 50% and 95% quintiles (intervals.).
3. Elicitate the reliability of the experts by using questionnaires on the different subjects to make a ranking of their objectivity.
4. Analyse the results and determine the probability distributions of the variables based on the results.
5. Determine the dependencies between each variable by expert judgment and questionnaires (fitting the distributions etc.) → determine the arcs

In order for such an exercise to work the experts need to be trained to understand the basic concepts of probability and dependence. Examples of questionnaires are given in the appendices of the master thesis of W. Jager, for both the elicitation of probability distributions and correlations as well as the validation/calibration questions. In the past, the total man power time for such studies varied between one man-month to one man-year (Jager, 2013b).

For this project it seems unreasonable to perform these actions due the lack of data and time constraints. The probabilities determined with the HRA model of Rasmussen will be used.

# VI Required time for placement of 'control' measures at Groot Salland

The following table assumes normal distributions based on the indications Waterschap Groot Salland made of the required time for placement of the emergency measures.

| Measure type | Condition | Placement time mean<br><br>[min / 100 meter] | Placement time deviation<br><br>[min / 100 meter] | 95% Interval<br><br>[min / 100 meter] |
|---|---|---|---|---|
| Sand bags +15cm | All | 10 | 2 | 6-14 |
| Sand bags +30cm | All | 30 | 5 | 20-40 |
| Sand bags +45cm | All | 50 | 5 | 40-60 |
| Sand bags +60cm | All | 110 | 10 | 90-130 |
| Sand bags +75 cm | All | 160 | 15 | 130-190 |
| Big bags +100cm | All | 100 | 10 | 80-120 |
| Raise inside water level (pumping station) | All | 120 | 10 | 100-140 |
| Raise inside water level (sand bags) | All | 28 min per dam | 5 | 18-38 |
| Opkisten (3 boxes per 100 meter) | All | 75 min | 5 | 65-85 |
| Piping berm (10m wide) | Favourable conditions | 120 | 15 | 90-150 |
| Piping berm (10m wide) | Unfavourable conditions | 240 | 30 | 180-300 |

**Table 36: Placement time**

*During the river floods in 1995 an emergency dike was constructed over a length of approximately 300 metres. This operation took 2 days to complete. The employees of the districts which were involved stated that such operations are possible within a time frame of 2 days but longer lengths are almost impossible (see appendix VII).*

# VII Variables and corresponding distributions for sliding calculations

In order to make a probabilistic calculation normal distributions are assumed for the variables which together determine the stability against sliding. The variables and the corresponding distributions are explained in the following table:

| Variable | Distribution | Argumentation | Mean | Standard deviation | Source |
|---|---|---|---|---|---|
| Sand bag length [l] | - | As used by WGS | 0.4 m | - | (WGS, 2012) |
| Sand bag width [w] | - | As used by WGS | 0.3 m | - | (WGS, 2012) |
| Sand bag height [h] | - | As used by WGS | 0.15 m | - | (WGS, 2012) |
| Total length of dike [ldike] | - | Calculation per running meter | 1 m | - | - |
| Degree of filling [m] for sand bags | Normal | 95% of the sand bags are filled within 40% and 60% | 0.5 | 0.05 | (Stoop, 2013) |
| Degree of filling [m] for big bags | 1-LogNormal | Big bags are filled nearly but not more than 100% | 0.05 | 0.005 | |
| Sand weight (dry) [Yd] | Normal | 95% of the dry sand weighs between 13 and 17 kN/m$^3$ | 15 kN/m$^3$ | 1 kN/m$^3$ | |
| Sand weight (wet) [Yn] | Normal | 95% of the wet sand weighs between 17 and 21 kN/m$^3$ | 19 kN/m$^3$ | 1 kN/m$^3$ | |
| Clay angle of internal friction [δc] | Normal | 95% of the clay has an internal angle of friction between 20 and 25 degrees | 22.5 degrees | 1.25 degrees | |
| Peat angle of internal friction[δp] | Normal | 95% of the peat has an internal angle of friction between 30 and 35 degrees | 32.5 degrees | 1.25 degrees | |
| Friction between sand bags [δsb] | Normal | Results of research by (Krahn, Blatz, Alfaro, & Bathurst, 2007) | 24 degrees | 1 degree | (Krahn et al., 2007) |

**Table 37: Placement time**

For a dike of sand bags the degree of filling determines the amount of bags required to obtain a certain retaining height. It is advised by the US Army Core to fill the bags for about 50%. Big bags are filled for about 90% resulting in a maximum retaining height of 0.9 meter.

## VIII Workshop with different parties (notes)

Date: 12 juni 2013

**Deelnemers**

- Rob den Dulk, Delfland;
- Kees Dorst, RWS;
- Arno Rozing, Deltares;
- Hans Knotter, Rivierenland;
- Kasper Schreuder, Hollandse Delta;
- Matthijs Kok, TU Delft;
- Kasper Lendering, TU Delft;
- Derk Jan Sluiter, Groot Salland (net terug uit Duitsland);
- Ulrich Föster, Deltares;
- Eric Huijskes, Deltares;
- Wout de Vries, STOWA.

**Introductie Wout de Vries**

(zie ppt);

**Introductie Eric Huijskes**

(zie ppt).

Focus op inhoud, Uitwerken voor verschillende soorten waterkeringen, Uitwerken noodmaatregelen, Kennisleemten inventariseren.

➔ Relatie Schadebeelden/Faalmechanisme/Noodmaatregelen

Doorontwikkelen, uitbreiden, naar een Dashboard en andere tools, delen van ervaring.

**Elementen uit de discussie**

- *Is de opzet herkenbaar?*
  - Trits is herkenbaar;
  - Diepgang groter dan verwacht;
  - Weinig kennis beschikbaar over scheuren en verzakkingen bij overgangsconstructies;
  - Opzet handig voor bepalen in zet van noodmaatregelen;

- Werkinstructies geven inzicht in benodigde tijd. Het element tijd zou ook in de beslissingsboom meegenomen worden;
    - Prioritering en tijdlijn toevoegen. Als je te weinig tijd hebt om bijv. zandzakken te plaatsen, beginnen we er niet aan. Daarnaast: betrouwbaarheid ook afhankelijk van bijvoorbeeld gevoeligheid voor vandalisme;
    - Opblaasbare dijken: bewijs dat die het niet altijd doen is weer in Duitsland weer geleverd;
    - Uit interne workshop kwam ondermeer het risico van niet goed opkisten naar voren, met aandacht nodig voor wijze van aanbrengen, controle;
    - Onderscheid naar soort waterkering (wordt in 3$^{e}$ of 4$^{e}$ kolom aangebracht);
    - Uitgangspunt: Schadebeelden zijn visueel te bepalen;
    - Vraag: Hoe geconstateerd schadebeeld combineren met de kennis die je al hebt van de dijk (toetsing) i.c.m. bijv. verwachtingen over windrichting;
    - Verschil tussen preventief en correctieve analyse. Deze manier van benaderen is meer correctief ingestoken. Aanbeveling: besteed ook aandacht aan de preventieve kant;
    - Monitoren van schadebeeld + genomen noodmaatregel ook meenemen?
    - Is lijst met groene vakken niet te optimistisch?
- *Waar liggen de behoeftes?*
    - Urgentiebepaling (welke wel moet je als eerste pakken);
    - Tijdlijn (heb je nog genoeg tijd voor nemen noodmaatregelen);
    - Stabiliteit en dimensionering van de noodmaatregel;
    - Invloed van noodmaatregel op faalmechanisme;
    - Spanningsveld Database ←→ beslissingsondersteunend systeem. Er is een grote behoefte aan een DSS;
    - Cyclus inbrengen: terugkoppeling van effect van genomen maatregel op geconstateerd schadebeeld;
- *Welk proces om tot eindproduct te komen?*
    - Uitwerken van tips van vandaag komen voor de zomervakantie terug ter commentaar.

**Introductie Kasper Lendering**

(zie ook ppt)

- Analyse richt zich op 4 faalmechanismen: overtopping, piping, instabiliteit, talud erosie;
- Doelen:
    - Werking en effectiviteit noodmaatregelen;
    - Betrouwbaarheid maatregelen kwantificeren;
- Onderscheid keringen naar: Permanente kering, tijdelijke (beweegbare) als onderdeel van de kering (ook onderdeel toetsing), beheermaatregelen (inzet bij afgekeurde keringen), noodmaatregelen;

- Keten noodmaatregelen: waarneming (toetsing/veld), plaatsen, constructie moet functioneren;
- Sterke afhankelijkheid van menselijk handelen
    - Skill based;
    - Rule based;
    - Knowledge based.

**Stellingen**

1. *Kennis neemt van opzichter naar dijkwachter (sterk) af;*
    - Dijkwacht → Postcommandant → Ringcommadant → WAT → ….

   Per waterschap is dat verschillend ingevuld. Er is dus veel nuance;
   Zeedijken hebben specifiek eigen (veel kleinere) handelingsperspectieven;
2. *Kennis van de dijk is noodzakelijk voor een correcte uitvoering, kennis neemt via opzichters, districten naar aannemers sterk af*
   Is maar de vraag. Aannemers worden als deskundig ingeschat. Wisselt ook sterk per waterschap;
3. *Wie heeft het grootse verantwoordelijkheidsgevoel?*
   Is niet eenduidig. Hangt af in welke fase je zit en waar je in het land bent. Bijvoorbeeld rol van aannemers. Manier van uitvoeren van waakvlamovereenkomsten hoeft nauwelijks effect te hebben op de betrouwbaarheid van de maatregel. Hoeveelheid van het werk is belangrijker. Het aansturen van aannemers is aandachtspunt.
4. *Bij meerdere kritieke plekken neemt de bijdrage van een systeem van beheer- en/of noodmaatregel af. Het lengte-effect en het daarmee gepaard gaande aantal zwakke plekken bepaalt in grote mate de haalbaarheid en het type in te zetten maatregelen:*
    - Betrouwbaarheid organisatie: zeer variabel (grootste ← → kleinste opgave);
    - Haalbaarheid in de tijd: snelheid wordt vaak te hoog ingeschat. Oefenen geeft hier inzicht in + goede input voor verbeteren werkinstructie;
    - Betrouwbaarheid van de constructie: ook variabel (is wel ← → niet bekend).

Voor afgekeurde vakken wordt aanbevolen om van te voren maatregelen op de plank klaar te hebben liggen.

**Discussie**

- Verschil in beheerobjectgebied maken vanwege invloed op aspecten als dominant faalmechanisme, handelingsperspectief:
    - Bovenrivierengebied (bijv. piping);
    - Benedenrivierengebied;
    - Zeedijken;
    - Boezem (bijv. droogte);
- Schaalgrootte van de noodmaatregel is van belang;

- Aandacht voor generieke processen en handelingsperspectieven, ivm het bijspringen bij hoogwaters van collega-beheerders (kennispool instellen);
- Verschillen in praktijken en aanpakken inzichtelijk maken door bijvoorbeeld via een groeimodel te werken en meer beheerders uit te dagen. Hiervoor is wel een werkend product nodig;
- Samenwerking tussen waterschappen is gaande (Delfland, Rijnland, Schieland; Rivierenland en Hollandse Delta). Gebeurt nu op terreinen als handhaving. Verwachting is dat dat verder zal uitbreiden (uitwisselen van werkinstructies, oefenmateriaal). Moet in waterschapsorganisaties ook van bovenaf gedragen en gestuurd worden;
- Er is een tool van ESRI voor inspecties met smartphones beschikbaar.

**Planning**

In december wordt een seminar gehouden voor alle waterkeringbeheerders, waarin de resultaten van deze onderzoeken zullen worden gepresenteerd.

# IX Case Waterschap Groot Salland (interviews)

Hier worden een aantal verslagen van specifieke interviews met werknemers van Waterschap Groot Salland gegeven. Naast deze interviews hebben er meerdere vergaderingen plaatsgevonden, zie hiervoor het logboek.

## IX.I Interview Waterschap Groot Salland

Locatie: Waterschap Groot Salland, Zwolle
Datum: 9 april 2013
Interviewer: K.T.Lendering
Personen: Derk Jan Sluiter (beheerder) en Wijnand Evers ( opzichter waterkeringen)

### Toelichting datasheet beheer maatregelen

Waterschap Groot Salland beheert een datasheet waar beheer maatregelen in opgenomen zijn die ingezet kunnen worden afhankelijk van de optredende waterstand op de rivieren Ijssel en Vecht. Deze datasheet gaat uit van de resultaten van de laatste toetsing van de waterkeringen. De input bestaat uit het resultaat van de laatste toetsingsronde. Voor de afgekeurde dijkvakken zijn beheer maatregelen bepaald, gedimensioneerd en voorbereid.

1. Het waterschap heeft een hypothese gesteld dat beheer maatregelen in hun definitie een vervanging zouden kunnen zijn (alternatief) voor dijkversterkingen. Zeker gezien de lagere kosten van beheer maatregelen

(orde 5 miljoen euro t.o.v. orde 200 miljoen euro). Echter hierbij is geen rekening gehouden met de faalkans van de beheermaatregelen.

**a. Hoe ziet het waterschap dit?**

*In theorie heb je gelijk: de norm zul je per definitie niet halen vanwege het feit dat de faalkans inherent groter is dan 0. Maar dit beginsel geldt voor te sluiten kunstwerken ook en daarvoor zijn praktische criteria ontwikkeld (een acceptabele faalkans). Aan deze criteria moeten we de beheermaatregelen toetsen (theoretisch en dmv praktische verificatie (of falsificatie eigenlijk). Zie de aanname onder de beheermaatregelen dus als een hypothese.*

*Uiteindelijk zullen er locaties uit komen waar beheermaatregelen i.p.v. dijkversterking niet verstandig zijn, bv op slecht bereikbare locaties (hoge faalkans), daar waar de dijk zo zwak is dat een te groot 'veiligheidsgat' gedicht moet worden, of daar waar de gevolgen te groot zijn.*

2. Waar ligt het grote verschil in kosten van de beheermaatregelen en de structurele dijkverbetering aan?

   *Als eerste zijn de kosten van de beheermaatregelen bepaald exclusief de opruim en sloopkosten na het hoogwater. Daarnaast zijn de de maatgevende kosten bij het realiseren van een klassieke dijkversterking meestal aankoop van grond en uitkopen, slopen, verplaatsen van vastgoed, infrastructuur, kabels en leidingen. Met die kosten heb je allemaal niet te maken bij beheermaatregelen.*

3. Wat gebeurt er als er een waterstand optreedt boven MHW?

   *Dat zit niet in het plan. We weten ook niet hoe onze dijken zich dan zullen gedragen, omdat deze waterstanden buiten de toetsingsscope vallen, want: kans < norm kans. Wellicht kan er o.b.v. VNK, waar met een groter spectrum aan overschrijdingskansen gerekend wordt, waaronder ook kleinere overschrijdingskansen dan de norm, iets zinnigs over gezegd kan worden. Voor zover ik weet is daar ook geen scenario voor in de hoogwaterprotocollen. WGS zal vanuit zijn zorgplicht altijd het hoogwater blijven bestrijden.*

   *Bij een hoogwater > MHW zullen noodmaatregelen op basis van inspectie een grotere rol gaan spelen. De inspectie is in wezen verdeeld over drie groepen, afhankelijk van de benodigde inzet:*

   *Als eerste komen de <u>opzichters</u> in actie (4 man) deze controleren de 'bekende plaatsen'. Wanneer zij het niet redden om alle keringen te redden (door tijdnood of een onverwacht hoogwater) worden de <u>Districten</u> ingezet en als laatste de <u>Dijkwacht</u>.*

4. De inzet van beheermaatregelen is ook te bepalen afhankelijk van de beschikbare tijd en benodigde tijd. Bij een benodigde tijd van boven de 5 dagen wordt het minder haalbaar een bepaalde maatregel in te zetten.

   *Er zijn aannames gedaan betreft aanrijtijden vanuit verschillende locaties, wanneer dit niet meer haalbaar is kan in de meeste gevallen ook nog materiaal uit het veld gebruikt worden. Zeker in een 'noodsituatie' kan klei/zand uit de weilanden eenvoudig gebruikt worden om nooddijken op te werpen.*

5. Lengte effect: waar baseer je de keuze voor slootpeil opzetten / opkisten / piping berm op?

   *Bij de eerste wellen die geconstateerd worden zal je het peil opzetten en/of opkisten. Als de wellen snel in aantal toenemen en er wordt nog een forse stijging van de waterstand verwacht zal je besluiten tot het aanleggen van een kwelkade of piping berm.*

   *Met andere woorden, er zal altijd eerst getracht worden het peil op te zetten en individuele wellen op te kisten. Bij een hoge dichtheid van de wellen kan besloten worden tot het aanleggen van een kwelkade of piping berm, een en ander ook afhankelijk van het verloop van het hoogwater.*

   a. Per maatregel, wat is het maximum aan lengte haalbaar?

   *Dit zal per locatie verschillen en van de toe te passen maatregel. Kunnen we snel een kwelkade opzetten door middel van een ploeg? De maximale lengte is afhankelijk van op hoeveel locaties we kunnen starten met de aanleg. Als er om de paar honderd meter een toegangsweg naar de dijk is. Kun je op meerdere locatie beginnen en naar elkaar toewerken.*

6. Waarom is een piping berm of grondberm aanleggen geen permanente maatregel voor dijkverbetering?

   *Als eerste, betreft de kosten, is het aanleggen van een berm met zand en een doek een andere investering dan de aanleg van een berm met klei. Afhankelijk van het materiaal en de lokale condities wordt een berm ook weggehaald, zeker wanneer deze allen tijdens nood is aangelegd op het terrein van een particulier.*

   *Er zal echter niet altijd voor een grond berm gekozen worden, een waterberm is ook een mogelijkheid. Daarnaast is een berm aanleggen over een paar honderd meter vaak wel haalbaar maar wanneer over kilometers gepraat wordt dit uiteraard moeilijker wordt.*

## Toelichting organisatie calamiteitenzorg

1. Hoe is de calamiteitenzorg georganiseeerd?

   **Dijkwachters (650 vrijwilligers):** patrouilleren en inspecteren de waterkeringen tijdens een (dreigende) calamiteit, om zo de conditie van de waterkering vast te stellen; zij doen zo nodig ook de schademeldingen; (soms alleen bestaande uit vrijwilligers of combinatie van waterschappers en vrijwilligers). Vanwege de subjectiviteit rondom de waarnemingen van de dijkwachters zullen de opzichters hen altijd controleren.

   **Dijkpost:** sturen dijkwachters aan en coördineren hun inzet; de dijkpost houdt alle gebeurtenissen / schademeldingen bij; Een dijkpostpostcommandant verzameld de gegevens en stuurt deze door naar de ringcommandant van het WAT.

   **Waterschap Actieteam / Crisiscentrum:** neemt besluiten over beheers- en noodmaatregelen en raadpleegt hierbij diverse deskundigen;

   **Waterschap Operationeel Team**: houdt zich op tactisch niveau bezig met de besluitvorming tijdens een (dreigende) calamiteit;

   **Waterschap Beleidsteam:** houdt zich op strategisch niveau bezig met de besluitvorming tijdens een (dreigende) calamiteit.

   **Districten / aannemers:** zijn verantwoordelijk voor het uitvoeren van de beheermaatregelen.

2. Wie heeft de verantwoordelijkheid van de te nemen beslissing omtrent noodmaatregels?

   *Beleid: Hoofd uitvoering in de persoon van Jan Put en de opzichters (4 man). Aangenomen kan worden dat dit onder maatgevende omstandigheden ('s nachts etc. 1 of maximaal 2 opzichters zijn, werk in ploegen).*

   *Normaal is er overleg tussen Jan Put (of hoofd WAT team) en de opzichters, bij extreme verwachtingen/situaties is er ook overleg met de beleidsmedewerkers.*

7. Wanneer wordt het plan gemobiliseerd, wat is de trigger?

   *Het plan is (nog) niet opgenomen in de hoogwaterprotocollen. Het krijgt met name een functie bij hoogwaters hoger dan wat in het 'collectieve geheugen' van de medewerkers van WGS die bij hoogwaterbestrijding betrokken zijn opgeslagen is (hoogwater jan 2011 IJssel, hoogwater Vechtsysteem 1998etc. Van het hoogwater van 1995 is al veel minder operationele ervaring beschikbaar). Tot die tijd opereren we vooral op basis van eerdere ervaringen* *(zo weten we bijvoorbeeld vrij goed waar zandmeevoerende wellen zullen ontstaan).*

*<u>Ik realiseer me dat hierbij het gevaar van focus op de bekende probleemlocaties ontstaat</u>. Bij hoogwaters hoger dan tot waar onze ervaring strekt, wordt de onzekerheid over events groter, waarmee het plan (voor een substantieel deel gebaseerd op theoretische gegevens) een grotere rol krijgt.*

*Momenteel is er geen harde grens voor de inzet van de dijkwacht of de opzichters, aangenomen kan worden dat er bij een hoogwater 1 a 2 opzichters op de dijk lopen. WGS krijgt een signaal van Rijkswaterstaat binnen 4 a 5 dagen voor het optreden van de bepaalde waterstand. Het is aan het waterschap te bepalen of zij bij deze waterstand (+10.2m NAP) moeten opschalen.*

*Als er een MHW verwacht wordt is de verwachting dat 5 dagen voor de piek de waterstand al boven dat van 1995 optreedt waardoor er dan al mensen op de dijk lopen. In principe is de verwachting dat men 7 a 10 dagen van te voren al op de dijk loopt.*

8. Hoe is de beschikbaarheid van personeel / materieel / materiaal geregeld?

*De uitvoering van de maatregels wordt uitgevoerd door de districten en/of aannemers. In principe is het de taak van de districten om de beschikbaarheid te controleren. Dit is niet altijd van te voren tot in detail vastgelegd, zeker met de aannemers niet.*

*Duidelijk is dat dit nog een opgave is voor dit plan. Net alleen voor beschikbaarheid personeel, materieel en materiaal, maar ook voor wat betreft de gemeenten die bv wegen moeten afsluiten.*

*Dit kan georganiseerd worden door een meeting met een aannemer, met een contract in de vorm van dat het Waakplan Kampen Midden. Daarmee zouden relevante vragen gesteld kunnen worden over de inzet van personeel, materiaal en materieel.*

3. Zijn alle procedures vastgelegd (schriftelijk)?

*Nee, niet alles. Voor bv opkisten bestaan werkinstructies. Voor het aanbrengen van zandzakken, bekramming etc zijn uitgebreide werkinstructies. Ook in het handboek dijkbewaking staan de noodmaatregelen omschreven. <u>Deze moeten worden gebruikt bij de aanleg van de maatregelen.</u>*

4. Wat is de mate van oefening van het personeel, hoeveel ervaring hebben ze?

*Elke 2 jaar wordt geoefend met de dijkwachters, maar dit wordt als onvoldoende beschouwd. De dijkwachters beleven de faalmechanismen etc.*

*heel anders dan de opzichters. Daarom moeten zij voeren de opzichters zelf altijd een controle uit van de waargenomen schadebeelden van de dijkwacht. Met het personeel van de districten wordt jaarlijks geoefend*

5. Hoe snel moet de taak uitgevoerd worden?

   *Een indicatie van de tijd benodigd voor de maatregelen is gemaakt in de datasheet beheer maatregelen WGS.*

6. Is er mogelijkheid tot herstel, worden uitgevoerde maatregelen gemonitord?

*Alle uitgevoerde maatregelen worden gemonitord en zo nodig hersteld bij schade.*

## Interview invulling risk framework

Onderstaande vragen geven inzicht in de betrouwbaarheid van de verschillende fasen. Na een discussie zijn de antwoorden van deze vragen verwoord in onderstaand verslag.

1. Hoeveel man zijn verantwoordelijk voor elke fase binnen het raamwerk?
2. Wat is de mate van oefening van het personeel, hoeveel ervaring is er?
3. Wat is de beschikbare tijd voor elke taak vooral in relatie tot de benodigde tijd?
   a. Waar moeten de mensen, het materiaal en het materieel vandaan komen?
4. Zijn alle taken schriftelijk vastgelegd in procedures?
5. Is er mogelijkheid tot herstel, worden uitgevoerde maatregelen gemonitord?

## Waarneming

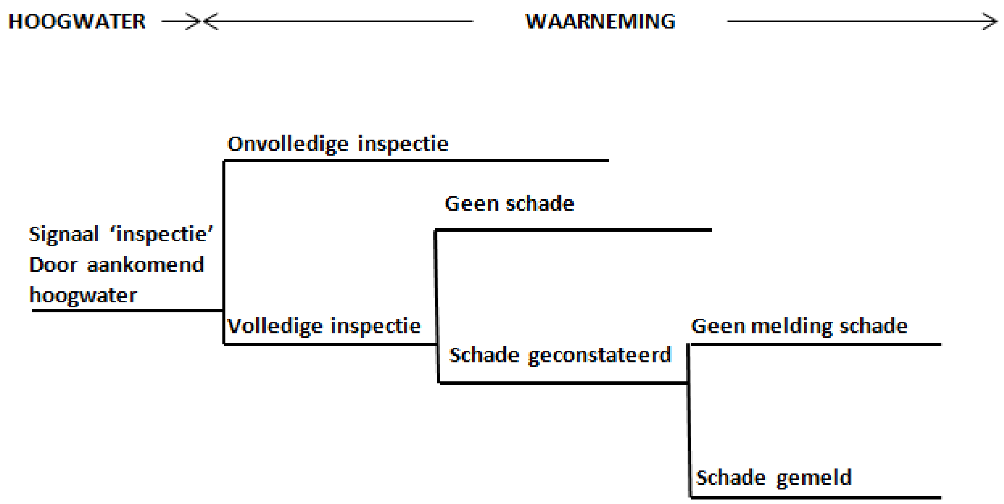


**Figure 91: Event treet detection**

### Volledigheid inspectie

Zoals eerder beschreven wordt de inspectie in eerste instantie uitgevoerd door de opzichters (4 man: veel ervaring). Als blijkt dat er onvoldoende tijd is om alle waterkeringen te inspecteren worden de disricten en de dijkwacht (650 man: weinig tot geen ervaring) ingeschakeld.

Wat betreft de inzet van de verschillende partijen bij een dreigende overstroming is waterschap Groot Salland positief. Bij een laatste oefening was iedereen binnen enkele uren paraat. Een nieuwe samenwerking met defensie staat op het programma, de inzet van defensie bij een dreigende overstroming is echter wel afhankelijk van de grootte van de dreiging en de spreiding over het land.

### Constatering van de schade en melding

Inspectie is nog subjectief en hangt ook voor een deel af van de ervaring van de dijkwachters. De opleiding van de dijkwachters is per waterschap ook verschillend. Daarom worden, ook bij waterschap Groot Salland de waarnemingen gecontroleerd door de opzichters van de waterkeringen. Standaardisatie lijkt noodzakelijk om een uniform systeem te hebben, dit geldt ook voor de aansluiting met de faalmechanismen.

### Betrouwbaarheidsaspecten

#### *Tijdslijn*

Voor de bepaalde dijkring kan het aantal kilometer te inspecteren waterkering bepaald worden en hiermee de benodigde tijd om een volledige inspectie uit te voeren. Vervolgens kan per fase de benodigde tijd en beschikbare tijd bepaald worden om te beoordelen of het haalbaar is om elke fase uit te voeren.

### *Afhankelijkheid*

Duidelijk is dat de opzichters van het waterschap een belangrijke rol spelen in deze fase. Zowel de inspectie als de melding wordt uiteindelijk door hen uitgevoerd waardoor het systeem een afhankelijk karakter krijgt.

### Voorbeeld: Waarnemen zandmeevoerend wel

Wanneer het gaat om de waarneming van een zandmeevoerend wel is de kans klein dat men deze niet vindt, volgens Wijnand Evers. Men kent de situatie goed en weet derhalve waar er risico is voor het optreden van zandmeevoerende wellen.

Wel realiseerd hij zich dat er altijd onvoorziene situaties kunnen ontstaan, zoals onlangs toen een aannemer het slootpeil lokaal verlaagd had tijdens een hoogwater waardoor er wellen ontstonden op locaties waar die normaal gesproken niet verwacht worden.

## Plaatsing

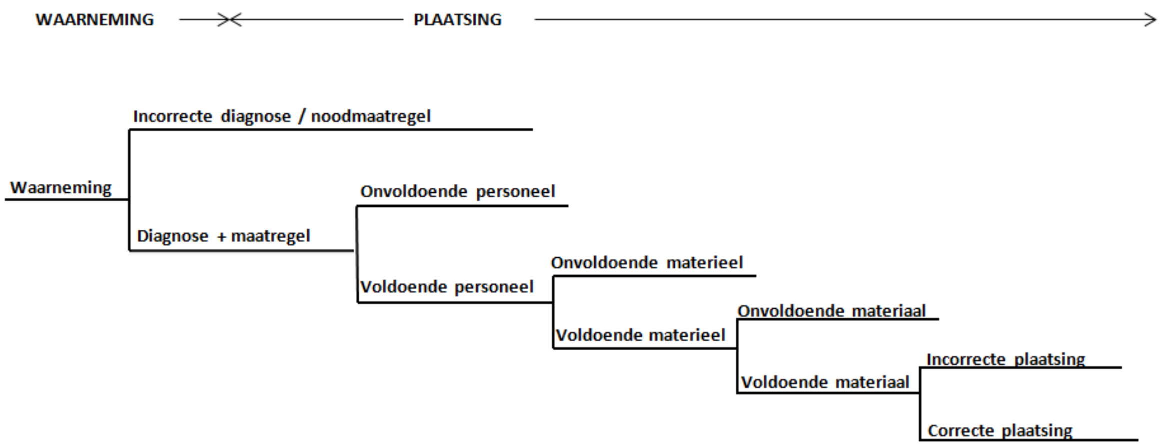


**Figure 92: Event tree placement**

## Diagnostiek

De diagnostiek wordt uitgevoerd door de opzichters in samenwerking met het hoofd van de uitvoering J. Put en het beleidsteam. De dimensionering is hierbij in grote mate vooraf bepaald.

## Bereikbaarheid

In vergelijking tot de organisatorische kant zijn er meer onzekerheden omtrent de logistieke kant van de inzet van noodmaatregelen. Vooral moeilijk bereikbare plekken ten tijde van een hoogwater vormen een probleem. Als voorbeeld wordt genoemd het bereiken van plekken langs de dijk waar veel kwelwater is, dit zal voor materieel op banden middels rijplaten moeten gebeuren wat aanzienlijk veel tijd kan kosten. Het alternatief is dan materieel op rupsbanden, wel of niet van defensie, hierbij is het waterschap dus <u>voor een groot deel afhankelijk van derden.</u>

### Uitvoering

In de uitvoeringsfase wordt de beheers- en/of noodmaatregel ook daadwerkelijk geplaatst. Hiervoor hebben waterschappen werkinstructies en procedures vastgelegd waar de aannemer (in de meeste gevallen) zich aan dient te houden. De opzichters voeren controle uit op de uitgevoerde werkzaamheden en corrigeren deze waar nodig.

### Betrouwbaarheidsaspecten

#### *Tijdslijn*

Voor de bepaalde dijkring kan het aantal kilometer te plaatsen maatregels bepaald worden (ahv datasheet) en hiermee de benodigde tijd. Vervolgens kan per fase de benodigde tijd en beschikbare tijd bepaald worden om te beoordelen of het haalbaar is om elke fase uit te voeren.

#### *Afhankelijkheid*

Duidelijk is dat de opzichters van het waterschap een belangrijke rol spelen in deze fase. Ook hier zijn zij het die de diagnostiek uitvoeren en aan het eind de controle. Echter, door de uitvoering uit te besteden aan aannemers ontstaat een meer onafhankelijke relatie tussen de fasen diagnostiek en uitvoering.

*Note: De aannemer is niet geheel onafhankelijk, als aangenomen wordt dat deze uit dezelfde regio komt als de regio die bedreigd wordt tijdens de overstroming. Bovendien zijn het de opzichters die de controle op de aannemer uitoefenen.*

## constructie

Voor het opzetten van het slootpeil is door VNK de invloed op de faalkans van piping bepaald. Voor wat betreft opkisten volgt hier een korte uitleg:

#### *VB: Haalbaarheid opkisten specifiek*

Betreft de technische kant van het opkisten blijkt dat er veel ervaring is met opkisten. Van een aantal dijkvakken langs de IJssel en de Vecht is bekend dat hier bij elk hoogwater wellen optreden. De inspectiezone is recentelijk vergroot tot 50 meter buiten de dijk. Toch worden er nog wellen gevonden tot 250 meter van de dijk. Dit zijn aanzienlijk grotere afstanden dan 18*H (Bligh), echter verwacht wordt dat deze geen bedreiging vormen voor de waterkering.

Wat opkisten betreft blijkt dat dit heel gevoelig is. De gevoeligheid voor een extra verhoging van 10 centimeter is groot, die ene 10 centimeter kan ertoe leiden dat de wel verplaatst. Derk Jan merkt op dat het idee heerst dat bij wellen het water zich als een soort delta onder de grond beweegt.

Wanneer er meerdere wellen binnen een dijkvak geconstateerd worden kan gekozen worden om in plaats van individuele wellen op te kisten een piping berm aan te leggen of de waterstand binnendijks te verhogen. Reden hiervoor is dan vooral de logistieke haalbaarheid van opkisten wat niet gegarandeerd kan worden.

## IX.II Interview aannemer Waterschap Groot Salland

Door: K.Lendering, DJ. Sluiter
Wie: Aannemer Mulder
Datum: 4 juni 2013
Locatie: Waterschap Groot Salland, Zwolle

Aannemer Mulder voert na de schouw van de waterkeringen diverse reparaties aan de dijken uit, na constatering van schades. Momenteel zijn er geen afspraken over de inzet bij calamiteiten. Dit gesprek dient ervoor te inventariseren hoe de huidige kennis is van de aannemer en hoe in de toekomst de inzet van een aannemer georganiseerd dient te worden tijdens een calamiteit.

### Kennisniveau

1. **Kent de aannemer het gebied en de bijbehorende keringen?**

*De aannemer komt uit hetzelfde gebied en voert na schouw diverse reparaties uit, hierdoor is de kennis van het gebied groot, tevens kent de aannemer de waterkeringen redelijk goed.*

2. **Kan de aannemer de schade herkennen en koppelen aan faalmechanisme?**

*Na het gesprek was duidelijk dat de kennis over faalmechanismen en bijbehorende schades bij de aannemer zeer laag is. Hier ligt een groot verbeterpunt, mochten zij ingezet worden voor calamiteiten zal deze (basis) kennis middels trainingen overgedragen moeten worden.*

*Een aannemer zal altijd wachten tot er een signaal vanuit het waterschap komt alvorens een maatregel uit te voeren, zeker gezien het feit dat het kennisniveau momenteel zeer laag is zullen zij deze verantwoordelijkheid niet zelf nemen.*

*Daarnaast geeft de aannemer (terecht) aan dat er bepaalde infrastructuur onder grond ligt die bij uitvoering van maatregelen beschadigd kunnen worden. De aansprakelijkheid in deze gevallen zal eerst juridisch vastgelegd moeten worden alvorens de aannemer aan het werk gaat.*

*Dit blijkt duidelijk een groot aandachtspunt bij de aannemer, een mogelijkheid is om de aannemers de dijkwachterstraining te laten volgen en daarnaast meerdere oefeningen per jaar te doen, op vooraf onbekende momenten. Op deze manier kunnen de ontstane fouten bekeken worden en verbeterpunten gevonden.*

## Tijdsinvloeden

3. **Welk signaal ontvangt de aannemer als aanleiding voor de voorbereiding op een hoogwater?**

*De aannemer zal bij een aankomend hoogwater in een hogere staat van paraatheid gebracht kunnen worden, dagen voordat het hoogwater eraan komt. Op deze wijze kan de aannemer voorbereid zijn op de inzet van zijn materieel en personeel tijdens de calamiteit.*

*Dit geldt voor een rivieren gebied, uiteraard is dit in een kustsysteem niet het geval. Hierbij wordt de aannemer zeer onverwacht (orde uren tevoren) benaderd voor een calamiteit.*

De uitvoering van de maatregels wordt uitgevoerd door de districten en/of aannemers. In principe is het de taak van de districten om de beschikbaarheid te controleren. Dit kan georganiseerd met een contract in de vorm van dat het Waakplan Kampen Midden.

4. **Hoeveel tijd heeft de aannemer nodig voor mobilisatie?**

*Uiteraard is dit sterk afhankelijk van de in te zetten maatregel en het benodigde materieel. Als richtlijn kan aangenomen worden dat de mobilisatie minimaal 2 uur in beslag neemt.*

*Duidelijk is dat tijdens een calamiteit rupskranen nodig zijn om in het drassige landschap te kunnen bewegen, tevens zijn er dumpers nodig om zand en klei te transporteren. Als voorbeeld wordt een kwelkade gesimuleerd over een afstand van 200 meter:*

- *Voor de mobilisatie heeft de aannemer 2 uur nodig, het in te zetten materieel bestaat uit een rupskraan en drie dumpers.*
- *Met dit materieel kan de aannemer in orde 3 uur de benodigde kwelkade opzetten.*
- *Middels een vijzelpomp kan de kwelkade gevuld worden, dit gaat met grote capaciteiten.*

Daarnaast is een voorbeeld genoemd over het lengte effect. Stel dat er tijdens een MHW langs de dijk tussen Zwolle en Deventer op 10 a 12 locaties over 1 kilometer een dergelijke kwelkade geplaatst moet worden binnen een tijdsbestek van 6 uur. Wat komt daarbij kijken.

*De aannemer geeft aan dat we dan wel praten over 60 rupskranen en 100 dumpers. Dit heeft hij zelf niet op voorraad, hiervoor zouden onderaannemers aangenomen moeten worden. Mits het materieel beschikbaar is een dergelijke operatie mogelijk, maar het is duidelijk dat dit moeilijk haalbaar is.*

## IX.III Interview opzichter over tijdslijn

Door: K.Lendering, DJ. Sluiter
Wie: W. Evers
Datum: 4 juni 2013
Locatie: Waterschap Groot Salland, Zwolle

Als er een MHW verwacht wordt is de verwachting dat 5 dagen voor de piek de waterstand al boven dat van 1995 optreedt waardoor er dan al mensen op de dijk lopen. In principe is de verwachting dat men 7 a 10 dagen van te voren al op de dijk loopt.

De opzichter geeft aan dat tijdens een MHW de opzichters zelf niet meer over de dijk zullen lopen, zij zijn dan voornamelijk met diagnostiek en schades bezig. De dijkwacht voert in deze situatie de waarnemingen uit. Bij een melding van de schade zal de opzichter afhankelijk van de locatie en aard (is het een bekende of onbekende locatie voor die schade) direct de maatregel inzetten of eerst een controle uitvoeren. Iedere dijkwacht heeft een bepaald tracé aangewezen gekregen tijdens de trainingen die hij of zij moet beslaan.

### Waarneming

1. **Zijn er gegevens bekend over de tijd benodigd om de gehele dijkring te inspecteren met achtereenvolgens de dijkwacht, districten en de opzichters (bv dijkring 10)?**

*Iedere dijkwacht heeft een trace van 5 kilometer, aangenomen dat zij met een snelheid van 3 km/uur lopen zullen zij elke 1.5 uur een geheel dijkvak bekeken hebben.*

2. **Worden er schades over het hoofd gezien waar normaal gesproken wel een maatregel ingezet wordt (data) ?**

*Door de hoge dichtheid aan controles, is het aannemelijk te stellen dat de dijkwacht schades altijd ontdekken. Echter zowel de opzichters als districten geven aan dat de dijkwacht altijd schades kan missen.*

### Plaatsing

3. **Is er bekend hoelang de diagnose duurt, of kan duren afhankelijk van vertraging in de keuze voor een maatregel door monitoren?**
    a. Wordt de beschikbare tijd tot de piek van het hoogwater meegenomen in de afweging of wordt bij elke schade tijdens een hoogwater overgegaan tot actie?
    b. Heeft de opzichter de mogelijkheid de 'bureaucratische stappen' over te slaan zodat vanuit een schade direct actie ondernomen wordt?

*De mobilisatie vanaf waarneming naar de inzet van een maatregel via het WAT team zal gemiddeld 3 uur in beslag nemen. Men doet lever een maatregel te veel dan bij* *een schade besluiten tot monitoren en daarmee een fout begaan. Er worden dus geen vertraagde beslissingen genomen. Deze fase wordt in de regel niet overgeslagen.*

*Dijkwacht → Postcomandant → Ringcommandant → WAT → Opzichter*

4. Hoe beoordeeld de opzichter de ervaring, kennis en berichtgeving van de dijkwacht, districten en aannemers?

*Op de kritieke plaatsen zal de opzichter altijd zelf aanwezig zijn, maar men kan niet ontkennen dat de dijkwacht een hele belangrijke taak hebben. Daarnaast kan men ook niet ontkennen dat het kennisniveau van de dijkwachters beter moet zijn. Hier moet aandacht aan besteed worden.*

## IX.IV Interview district 1

Door: K.Lendering, DJ. Sluiter
Wie: F. Schutten / J. Goos
Datum: 4 juni 2013 / 21 juni 2013
Locatie: Waterschap Groot Salland, Zwolle

Freddy Schutten is hoofd van District I in Zwolle, hij geeft uitleg over de werkzaamheden van de districten. De hoofdtaak van de districten is de uitvoering van de noodmaatregelen. Zij opereren op aangeven van het waterschap, niet op eigen initiatief.

### Kennisniveau

In Waterschap Groot Salland zijn er 4 districten, waar elk 10 mensen werkzaam zijn. Tijdens calamiteiten worden ploegen gevormd met ervaren / onervaren werknemers om te zorgen voor voldoende kennis bij de taken. (vb: districtsmedewerker met aannemer).

Een probleem wat J. Schutten aangeeft is het gat tussen de uitvoering en kennis. Mede hierdoor worden ervaren en onervaren werknemers gekoppeld, hier valt veel winst te halen (trainingsrondes etc.).

Het kennisniveau van de aannemers is zeer laag, maar ook bij de districten is dit niet voldoende. Voor een correcte uitvoering van de maatregelen moet er voldoende kennis van het welzijn van de dijk zijn, wat betwijfeld wordt. Het kennisniveau van de dijkwachters is onvoldoende voor de cruciale rol die zij hebben, vandaar dat een dijkopzichter altijd een controle zal uitvoeren van deze waarnemingen.

Als het kennisniveau uitgedrukt wordt op een schaal van 1 – 10 voor verschillende partijen is het resultaat:

- Opzichters: 10
- Districtsmedewerkers: 8
- Dijkwachters: 4

### Tijdslijn

De uitvoering van de maatregels wordt uitgevoerd door de districten en/of aannemers. In principe is het de taak van de districten om de beschikbaarheid te controleren. Dit kan georganiseerd met een contract in de vorm van dat het Waakplan Kampen Midden.

Na het plaatsen is het de taak van de opzichter om de maatregel te monitoren, de districten zullen vervolgens eerder gaan met andere maatregelen. Tijdens een calamiteit is het belangrijk dat er korte lijnen zijn tussen het WAT en de uitvoerende partijen.

*Waarneming J. Goos: Momenteel is er een proces gestuurde organisatie waardoor in de bureaucratie veel tijd verloren gaat wat de veiligheid in gevaar kan brengen.*

### Voorbeelden

Een voorbeeld over de mobilisatie, voor het opkisten van 8 wellen langs een dijk:

- Inladen materiaal en materieel → 30 minuten
- Transport naar locatie →60 – 90 minuten
- Plaatsen kisten → 30 a 60 minuten

In 1995 is er bij Kampen een nooddijk aangelegd over een afstand van +/- 300 meter bestaande uit zand, deze operatie heeft toen 2 dagen geduurd. Het water is er nooit gekomen.

**Belangrijke constatering hier is dat, betreft het lengte effect, orde grootte 100 meter maatregelen wel haalbaar zijn. Maar als men praat over kilometers die niet meer haalbaar zal zijn.**

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# X Scenario's case study dike ring 53

## X.I Scenario 1: top ten failure probabilities

From the results of the report of VNK for dike ring 53 the top 10 dike sections with highest failure probabilities are displayed in the following tables.

| Dike section* | Length [m] | Dominant failure mechanism | Pf Overtopping [per year] | Pf Piping [per year] | Combined Pf [per year] |
|---|---|---|---|---|---|
| 11 | 1300 | Overtopping | 1/670 | | 1/670 |
| 34 | 900 | Overtopping | 1/610 | 1/780 | 1/490 |
| 21 | 2100 | Piping | 1/3,200 | 1/850 | 1/710 |
| 25 | 600 | Piping | | 1/1,000 | 1/600 |
| 26 | 1200 | Piping | 1/740 | 1/440 | 1/330 |
| 29 | 1300 | Piping | | 1/290 | 1/280 |
| 31 | 2200 | Piping | | 1/310 | 1/300 |

| | | | | | |
|---|---|---|---|---|---|
| 38 | 900 | Piping | | 1/930 | 1/630 |
| 39 | 1700 | Piping | | 1/780 | 1/500 |
| 63 | 2100 | Piping | | 1/490 | 1/490 |

**Table 38: Failure probabilities of 10 dike sections with highest failure probabilities**

*Dike sections in red did not pass the assessment of the flood defences.

The failure probabilities (posterior failure probabilities) with correct functioning emergency measures are shown in the following table.

| Dike section* | Prior Pf, without E.M. [per year] | Emergency measure | Length of dent [m] | Depth of dent [m] | # of sand boils [-] | Posterior Pf, with E.M. [per year] | Factor [-] |
|---|---|---|---|---|---|---|---|
| 11 | 1/670 | Sand bags H = 0.6m | 230 | 0,5 | | 1/3,000 | 4.5 |
| 34 | 1/490 | Sand bags H = 0.75m | 20 | 0,71 | | 1/3,200 | 6.5 |
| 21 | 1/710 | Reduction of hydraulic head with 0.5 meter due to sand boil containments (boxes). | 50 | 0,27 | 63 | 1/850 | 1.2 |
| 25 | 1/600 | | | | 18 | 1/4,900 | 8.2 |
| 26 | 1/330 | | 60 | 0,37 | | 1/580 | 1.8 |
| 29 | 1/280 | | | | 39 | 1/770 | 2.8 |
| 31 | 1/300 | | | | 66 | 1/690 | 2.3 |
| 38 | 1/630 | | | | 27 | 1/1,200 | 1.9 |
| 39 | 1/500 | | | | 51 | 1/2,900 | 5.8 |
| 63 | 1/490 | | | | 63 | 1/7,600 | 15.5 |

**Table 39: Prior and posterior failure probabilities of 10 dike sections with highest failure probabilities**

## X.II Scenario 2: Piping

From the results of the report of VNK for dike ring 53 all dike sections with piping failure probabilities below 1/1,250 per year are displayed in the following table. The table shows each dike section with the maximum number of sand boils, the corresponding (prior) failure probabilities for piping and the failure probability (posterior) of the dike section with a reduction of the head difference of 0.5 meter. It is noted the amount of boxes required for the piping scenarios are much more than occurred during the river floods of 1993 and 1995.

| Dike section* | Length [m] | # of sand boils [-] | Prior Pf, without E.M. [per year] | Posterior Pf, with E.M. H = 0.5m [per year] | Factor [-] |
|---|---|---|---|---|---|
| 21 | 2100 | 63 | 1/850 | 1/850 | 1 |
| 25 | 600 | 18 | 1/1.000 | 1/4,900 | 4.9 |
| 26 | 1200 | 36 | 1/440 | 1/580 | 1.3 |
| 29 | 1300 | 39 | 1/290 | 1/770 | 2.7 |
| 31 | 2200 | 66 | 1/310 | 1/690 | 2.2 |
| 33 | 1400 | 42 | 1/1.200 | 1/5,100 | 4.3 |
| 38 | 900 | 27 | 1/930 | 1/1,200 | 1.3 |
| 39 | 1700 | 51 | 1/780 | 1/2,900 | 3.7 |
| 42 | 1000 | 30 | 1/1.100 | 1/4,200 | 3.8 |
| 53 | 1400 | 42 | 1/1.200 | 1/23,000 | 19 |
| 63 | 1200 | 36 | 1/490 | 1/7,600 | 15.5 |

**Table 40: Failure probabilities all piping sections with Pf below 1/1,250 per year**

## X.III Scenario 3: Overtopping 'dents'

The table shows each dike section with the dimensions of the 'dents', the corresponding (prior) failure probabilities for overtopping and the combined (posterior) failure probability of the dike section.

| Dike section* | Length [m] | Reference height [m] | Heigth at dent [m] | Depth of dent [m] | Prior Pf, without E.M. [per year] | Posterior Pf, with E.M. [per year] | Factor [-] |
|---|---|---|---|---|---|---|---|
| 6 | 80 | 9.02 | 8.76 | 0,26 | 1/1,700 | 1/3,700 | 2.2 |
| 8 | 50 | 9.04 | 8.74 | 0,3 | 1/1,900 | 1/4,200 | 2.2 |
| 11 | 230 | 8.5 | 8 | 0,5 | 1/670 | 1/3,000 | 4.5 |
| 20 | 250 | 8 | 7.75 | 0,25 | 1/3,100 | 1/6,600 | 2.1 |
| 21 | 50 | 8 | 7.73 | 0,27 | 1/3,200 | 1/7,200 | 2.3 |
| 26 | 60 | 7.16 | 6.79 | 0,37 | 1/740 | 1/2,300 | 3.1 |
| 27 | 80 | 8.05 | 6.69 | 1,36 | 1/1,800 | 1/4,900 | 2.7 |
| 28 | 160 | 7.02 | 6.82 | 0,2 | 1/3,300 | 1/5,700 | 1.7 |
| 30 | 30 | 6.5 | 6.26 | 0,24 | 1/2,400 | 1/4,900 | 2.0 |
| 32 | 20 | 6.05 | 5.84 | 0,21 | 1/3,800 | 1/7,100 | 1.9 |
| 34 | 20 | 6 | 5.29 | 0,71 | 1/610 | 1/3,200 | 5.2 |
| 50 | 60 | 3.7 | 3.37 | 0,33 | 1/1,000,000 | 1/1,000,000 | 1.0 |
| 51 | 50 | 2.88 | 2.64 | 0,24 | 1/5,900 | 1/13,000 | 2.2 |
| 56 | 70 | 3.2 | 2.81 | 0,39 | 1/44,000 | 1/680,000 | 14.8 |
| 69 | 50 | 5.8 | 5.39 | 0,41 | 1/150,000 | 1/1,000,000 | 6.7 |
| 72 | 50 | 7 | 5.7 | 1,3 | 1/73,000 | 1/1,000,000 | 13.7 |

**Table 41: Failure probabilities of all dike sections with 'dents'**

It is concluded that the potential for emergency measures in these sections is rather high with reduction factors between 2 and 15, however on dike ring level a failure probability for overtopping remains of 1/470 per year (a factor 1.5). Due to the dependencies between overtopping dike sections sections not suitable for emergency measures (length of dents over 250 meters) will become dominant which still have rather high failure probabilities.

# XI Reliability of emergency measures for scenario 1: top10 failure probabilities

For each dike section the reliability of all sub events in the event tree of **Figure 47** is determined after which each branch of the event tree can be calculated and the resulting failure probability of the dike sections with emergency measures. By combining the failure probabilities of the different dike sections the failure probability at dike ring level is determined. In this fictive dike ring both overtopping dominated sections and piping dominated sections are present:

- Four dike sections for overtopping: 11, 21, 26 and 34.
- Six dike section for piping: 25, 29, 31, 38, 39 and 63
- Two dike sections with both overtopping and piping: 21 and 26

## XI.I Reliability of all sub events

### Organizational reliability

It is assumed the detection is performed by well trained dike watchers, resulting in a probability of 1/20 per dike section. The placement of overtopping measures is done by well trained contractors / military, resulting in a probability of 1/20 per dike section. The piping measures are placed by districts which have a lower bound for the failure probability of 1/200 per dike section. As overtopping sections are dependent and piping sections independent the resulting failure probabilities for all dike sections are different due to the length effect of emergency measures.

| Failure mechanism | Detection operator | Detection failure probability [per event] | Placement operator | Placement failure probability [per event] |
|---|---|---|---|---|
| Overtopping | Dike watch well trained | 1/20 | Contractor / military | 1/20 |
| Piping | Dike watch well trained | 1/3.5 | Districs | 1/25 |

Table 42: Organizational reliability scenario 1

### Complete versus incomplete placement: feasibility in time

The failure probabilities of the placement in time are shown in the following table.

| Dike section* | Overtopping failure probability in time [per event] | Piping failure probability in time [per event] |
|---|---|---|
| 11 | 1/83 | |
| 34 | 1/192 | |
| 21 | 1/71 | 1/370 |
| 25 | | 1/60 |
| 26 | 1/909 | 1/714 |
| 29 | | 1/212 |
| 31 | | 1/61 |
| 38 | | 1/416 |
| 39 | | 1/120 |

| | | |
|---|---|---|
| 63 | | 1/68 |

**Table 43: Failure probabilities of feasibility in time for scenario 1**

## Technical reliability for each dike section

In chapter 4 it was concluded that the technical failure probabilities of the emergency measures are negligible. For sake of completeness these are still calculated for the measures in scenario 1, assuming a dike of sand bags for overtopped sections and containments of 0.5 meter in height for sand boils.

| Dike section | Failure mechanism | Emergency measure | Retaining height [m] | Required height [m] | Failure probability [per event] |
|---|---|---|---|---|---|
| 11 | Overtopping | Dike of sand bags | 0.6 | 0.5 | 0 |
| 34 | Overtopping | Dike of sand bags | 0.75 | 0.71 | 0 |
| 21 | Overtopping | Dike of sand bags | 0.30 | 0.27 | 1/29 |
| 26 | Overtopping | Dike of sand bags | 0.45 | 0.37 | 1/13,000 |
| 21, 25, 26, 29, 31, 38, 39, 63 | Piping | Sand boil boxes | 0.6 | 0.5 | 0 |

**Table 44: Technical failure probabilities scenario 1**

Regarding the orders of the failure probabilities it can be concluded that these are indeed negligible compared to the failure probabilities of organizational and feasibility in time.

## *Example calculation of dike section 29*

To explain the results an example is given of the reliability of one emergency measure and its effect on the reliability of the dike section.

The probability of failure of the emergency measure is shown in the equation of $P_{emergency\ measure}$ (1/3.1 per event). The posterior probability, with emergency measures, of the flood defence is the summation of the different failure probabilities in the event tree: P1+P3+P5+P7+P9+P11, which for dike section 29 is 1/500 per year. For a thorough explanation of the methods used reference is made to chapter 4.

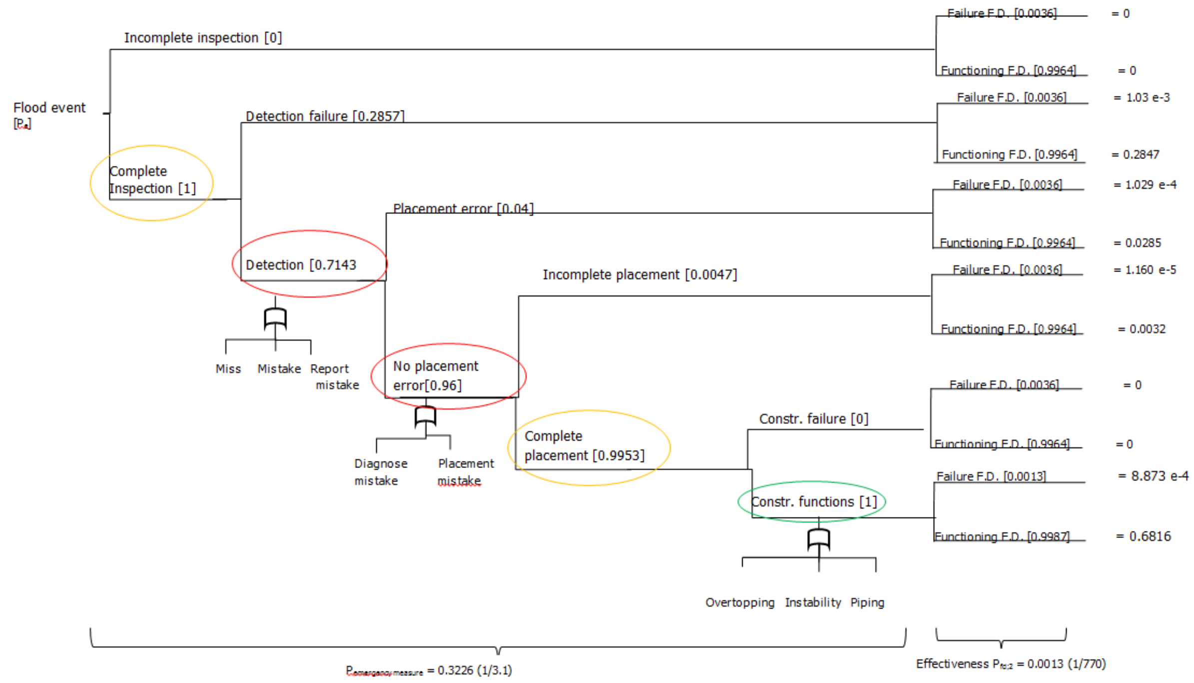



**Figure 93: Reliability event tree for dike section 29**

# XII Logboek vergaderingen

Een kort overzicht van vergaderingen met betrekking tot noodmaatregelen in 2013, dit overzicht is niet volledig maar geeft een beeld van de betrokken partijen bij het onderzoek.

| Datum | Actie | Personen aanwezig | Locatie |
|---|---|---|---|
| 12 februari 2013 | Bespreking samenwerking RWS / DELTARES / STOWA / TUD, start onderzoek noodmaatregelen. | Matthijs Kok (TUD)<br>Kasper Lendering (TUD)<br>Eric Huijskes (DELTARES)<br>Erik Vastenburg (DELTARES)<br>Wout de Vries (STOWA)<br>Harry Stefess (RWS) | RWS Westraven, Utrecht |
| 7 maart 2013 | Overleg bij waterschap Groot Salland over de inzet van noodmaatregelen en het verschaffen van informatie over calamiteitenorganisatie en zandmeevoerende wellen | Kasper Lendering (TUD)<br>Matthijs Kok (TUD)<br>Jan Put (Groot Salland)<br>Dirk Jan Sluiter (Groot Salland)<br>Wijnand Evers (Groot | Waterschap Groot Salland, Zwolle |

| | | | |
|---|---|---|---|
| | | Salland | |
| 14 maart 2013 | Overleg over onderzoek in proefpolder | Kasper Lendering (TUD)<br>Bas Jonkman (TUD)<br>Inge van den Bosch (BAM INFRA)<br>Bas Reedijk (BAM INFRA) | Faculteit CiTG, TUD |
| 14 maart 2013 | Overleg voortgang onderzoek noodmaatregelen STOWA | Kasper Lendering (TUD)<br>Bas Jonkman (TUD)<br>Ludolph Wentholt (STOWA)<br>PCWK | Waterschap Delfland |
| 2 april 2013 | Bespreking samenwerking RWS / DELTARES / STOWA / TUD | Matthijs Kok (TUD)<br>Kasper Lendering (TUD)<br>Eric Huijskes (DELTARES)<br>Erik Vastenburg (DELTARES)<br>Wout de Vries (STOWA)<br>Ludolph Wentholt (STOWA)<br>Harry Stefess (RWS) | Deltares Delft |
| 9 april 2013 | Overleg bij waterschap Groot Salland over pakket beheersmaatregelen en schouw meelopen | Kasper Lendering (TUD)<br>Jan Put (Groot Salland)<br>Dirk Jan Sluiter (Groot Salland)<br>Wijnand Evers (Groot Salland | Waterschap Groot Salland, Zwolle |
| 23 april 2013 | Overleg bij waterschap Hollands Noorderkwartier over samenwerking bachelor eindwerk studenten en Water Gate als noodmaatregel | Kasper Lendering (TUD)<br>Oliver Fermon (BFDS)<br>Floris Geeris (BFDS)<br>Roald Watergeer (HNK)<br>Mariska Schoo (HNK)<br>Dirk Pruimboom (HNK | Waterschap HNK, Noorderkwartier |
| 27 mei 2013 | Bespreking samenwerking RWS / DELTARES / STOWA / TUD | Matthijs Kok (TUD)<br>Kasper Lendering (TUD)<br>Eric Huijskes (DELTARES)<br>Wout de Vries (STOWA)<br>Harry Stefess (RWS)<br>Kees Dorst | Deltares Delft |
| 29 mei | Overleg samenwerking | Kasper Lendering | TU Delft |

| | | | |
|---|---|---|---|
| 2013 | met veiligheidskunde afdeling TBM | (TUD)<br>Ellen Jagtman (TUD)<br>Simone Sillum (TUD) | |
| 4 juni 2013 | Interview met Aannemer Mulder | Kasper Lendering (TUD)<br>DJ Sluiter (WGS)<br>Mulder | Waterschap Groot Salland, Zwolle |
| 4 juni 2013 | Interview met Jerry Schutten, Districtshoofd | Kasper Lendering (TUD)<br>DJ Sluiter (WGS)<br>J. Schutten (WGS) | Waterschap Groot Salland, Zwolle |
| 4 juni 2013 | Interview met opzichter Wijnand Evers | Kasper Lendering (TUD)<br>DJ Sluiter (WGS)<br>W. Evers (TUD) | Waterschap Groot Salland, Zwolle |
| 19 juni 2013 | Interview met district 1: Johan Goos | Kasper Lendering (TUD)<br>DJ Sluiter (WGS)<br>J. Goos (WGS) | Waterschap Groot Salland, Zwolle |
| 19 juni 2013 | Presentatie bevindingen Duitsland overstromingen | Kasper Lendering (TUD)<br>DJ Sluiter (WGS)<br>Team Waterschap Groot Salland | Waterschap Groot Salland, Zwolle |
| 3 juli 2013 | Presentatie Maurits van Dijk VNK rapport dijkring 53 inclusief gevoeligheid analyse noodmaatregelen | Kasper Lendering (TUD)<br>DJ Sluiter (WGS)<br>M. van Dijk (VNK2) | Waterschap Groot Salland, Zwolle |
| 9 september 2013 | Overleg M. Kok & S.N. Jonkman over voortgang onderzoek | Matthijs Kok (TUD)<br>Kasper Lendering (TUD)<br>Bas Jonkman (TUD) | TU Delft |
| 16 oktober 2013 | Bespreking samenwerking RWS / DELTARES / STOWA / TUD | Matthijs Kok (TUD)<br>Kasper Lendering (TUD)<br>Eric Huijskes (DELTARES)<br>Wout de Vries (STOWA)<br>Harry Stefess (RWS)<br>Kees Dorst | Deltares Utrecht |
| 24, 25 oktober 2013 | Waarnemingen tijdens 'Conecto' oefening Waterschap Groot Salland | Kasper Lendering, Rolf Ziel, Lieuwe van der Meer, Youri Jongerius & Mark Postma | Waterschap Groot Salland, Zwolle |
| 31 okt & 1 nov 2013 | Waarnemingen tijdens 'Conecto' oefening Waterschap Groot Salland | Kasper Lendering, Rolf Ziel & Mark Postma | Waterschap Groot Salland, Zwolle |

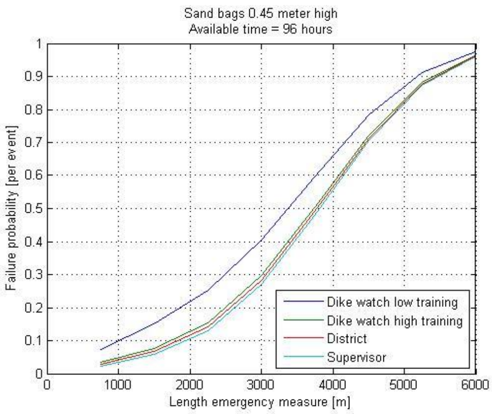
# XIII Maximum length of emergency measures

From interviews with water board employees it was determined that emergency measure lengths in order of 100 meter are feasible, but when increased to orders of kilometers it will become almost impossible to place all emergency measures required. The following graphs show the relation of the length versus the probability of failure for three types of emergency measures. Contrary to the scenarios treated in chapter 5 the required time for placement is estimated with the results of the 'Conecto', see **Table 32**. The failure probability of the dike sections without emergency measures is assumed 1/100 per event and with emergency measures 1/300 per event.

| Measure type | Condition | Placement time mean<br><br>[min / 100 meter] | Placement time deviation<br><br>[min / 100 meter] | 95% Interval<br><br>[min / 100 meter] |
|---|---|---|---|---|
| Sand bags +45cm | All | 120 | 15 | 90-150 |
| Containments (3 boxes per 100 meter) | All | 180 | 20 | 140-220 |
| Piping soil berm | Unfavourable | 360 | 60 | 240 - 480 |

**Table 45: Actual placement times based on observations during 'Conecto'**

## Sand bags 0.45 meter in height



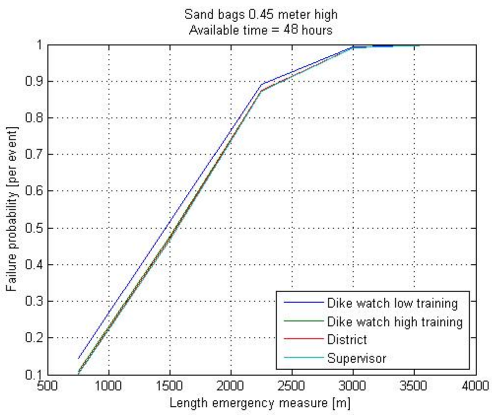




**Figure 94: Relation failure probability with length of overtopping measure**

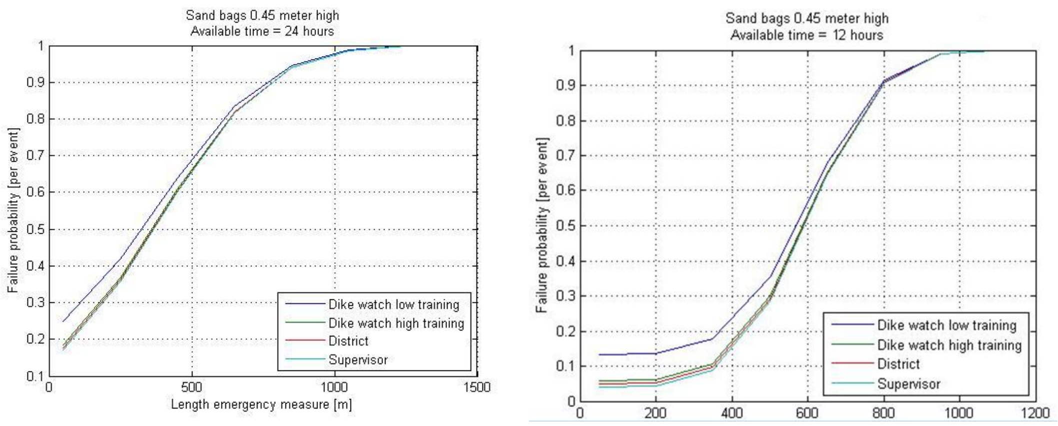



**Figure 95: Relation failure probability with length of overtopping measure**

## Piping measures: sand boil containments

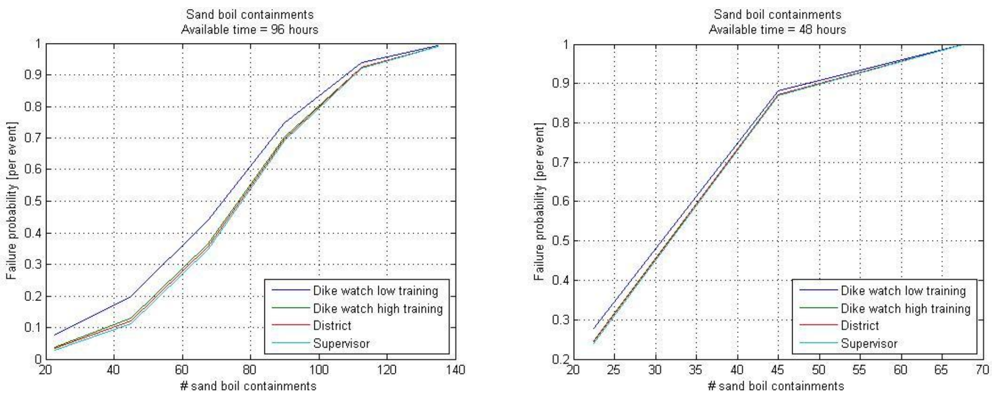



**Figure 96: Relation failure probability emergency measure with # of sand boil containments**

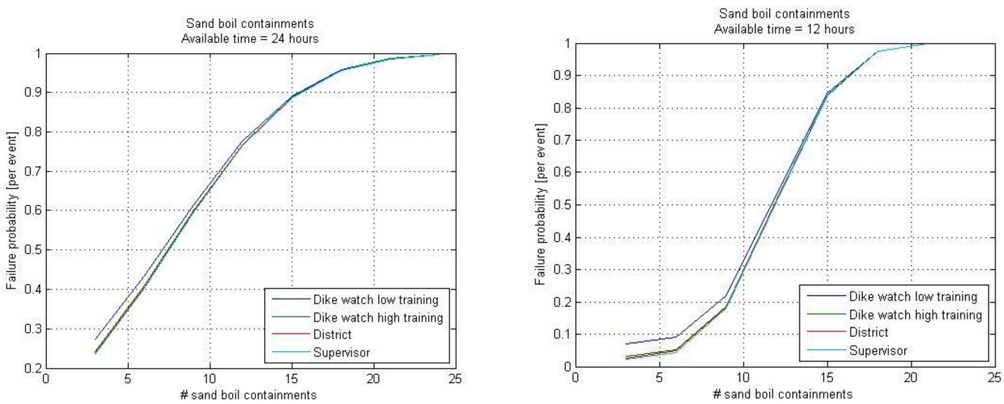



**Figure 97: Relation failure probability emergency measure with # of sand boil containments**

## Piping measures: piping (soil) berm

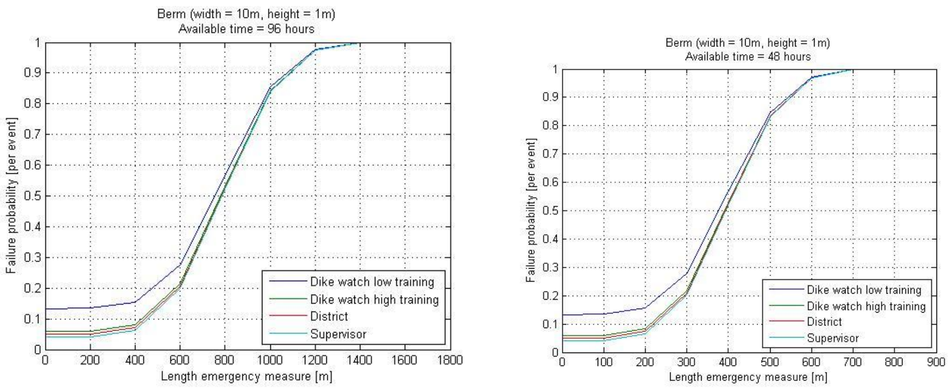



**Figure 98: Relation failure probability emergency measure with length of berm**

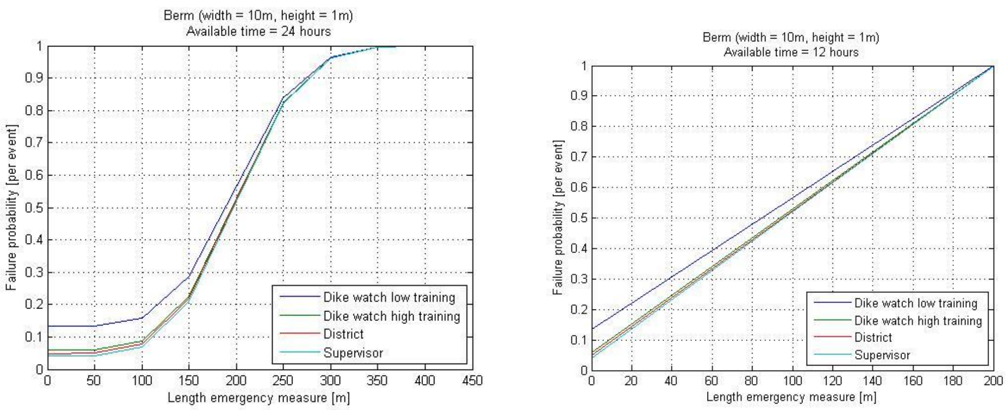



**Figure 99: Relation failure probability emergency measure with length of berm**

# XIV Rapporten Flood Proof Holland & Conecto

Toegevoegd aan dit rapport zijn de rapporten van de werkzaamheden bij Flood Proof Holland in 2013 en een verslag van de waarnemingen tijdens de Conecto oefening van waterschap Groot Salland.