Ministerie van Verkeer en Waterstaat

Flood Risks and Safety in the Netherlands (Floris)

Floris study - Full report

November 2005

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Foreword

This is the full report of Flood Risks and Safety in the Netherlands (Floris) project. This report gives the results of the study into the risk of flooding in 16 dike ring areas in the Netherlands. This report presents both the method and the results.

The "Flood Risks and Safety in the Netherlands: Interim Report of the Floris study" has also recently been published. This interim report describes the main findings of the Floris study.
This Full Report describes the results in more detail than in the Interim Report. The Full Report also describes the method for calculating the consequences of flooding, the probability of flooding and the flooding risks. The conclusions and recommendations are identical in both reports.

Besides the Interim Report and the Full Report, other detailed technical reports were also drawn up during the Floris study, including three reports describing the 'risk cases' and 16 dike ring reports. The risk case reports provide a description of the detailed method for determining the consequences and risks of flooding. The 16 dike ring reports provide a description of the results for the global consequences, probabilities of flooding and the risks for all 16 dike rings investigated.

Many companies and organisations have contributed to the Floris research project. I would like to thank everyone for their constructive contributions and congenial cooperation.

C.J. van Westen
Floris Study Project Manager

Summary

The purpose of the Floris Project
The government considers it important that the public has a better understanding of the probability of their area being hit by a flood. The government also wants to have a clear view of the relatively weaker areas in flood protection. Other experts have, moreover, indicated that the protection against flooding may no longer be properly in proportion to the consequences of flooding.

The Flood Risks and Safety in the Netherlands (Floris) Project was therefore initiated in 2001 at the request of the State Secretary of Transport, Public Works and Water Management. The purpose of the Floris project is to gain an understanding of the consequences and the probability of flooding in the Netherlands. The project was conducted by the Road and Hydraulic Engineering Institute of the Netherlands Public Works Department (Rijkswaterstaat), in close cooperation with the Water Boards and Provinces. The results were released in the summer of 2005.

Essence of the method
The Flood Risks and Safety in the Netherlands Project has resulted in the further development and application of a new method which can be used to calculate the consequences of flooding. Detailed calculations have been made of the number of victims and the economic losses resulting from various flooding scenarios for three dike rings. The consequences have been determined more globally for the remaining dike rings.

A new method has also been applied for determining the probability of flooding. The essence of the method is that various 'failure mechanisms', as they are known, can initiate a flood: not only extremely high water levels, but also instability in a dike or failure to close a hydraulic structure on time. Any failure mechanism carries a risk of flooding. The probability of all failure mechanisms together determines the risk of flooding in a dike ring. This method has been used to determine the flood risks of 16 of the 53 dike rings. The 16 dike rings were selected to give a representative view of safety in the Netherlands related to flooding. The calculations also show where the relatively weak locations in the water defences lie.

A great deal of data was needed to be able to apply the new methods, including information about the subsoil under the dikes and hydraulic structures. In some cases, this data is surrounded by many uncertainties. An essential element in the probability calculations is that the order of uncertainty is expressly included in the calculation. The greater the uncertainty, the greater the probability. Further research can, in some cases, reduce the uncertainty. In which event the probability of flooding will also turn out to be smaller. This research will take place in the next phase of the Floris Project. Only then can the probability of flooding be established on a sound basis.

Consequences of flooding

From the study it appeared that in the event of flooding there could be anything between a few dozen to several thousand victims. Most are likely to occur if the flooding is unexpected and evacuation is therefore no longer possible. It appears from the most likely flooding scenarios that floods will occur unexpectedly.

The maximum economic damage in the event of flooding of a dike ring ranges from € 160 million in Terschelling to almost € 300 billion in the province of South Holland. These amounts have been roughly calculated and show the damage which would occur if the entire dike ring was to fill up with water. For three dike rings the average damage has also been calculated in detail. During this process it was analysed in various flood scenarios which part of the dike ring would be inundated and how much damage would be caused as a result. From these calculations it appears that in the most likely flood scenarios 'only' part of the dike ring would be flooded. Only in the rivers region would the dike ring almost always be completely flooded. The average damage in the province of South Holland amounted to approx. € 6 billion. The global method can therefore lead to huge overestimation of the damage, particularly for the larger dike rings which are divided into compartments by obstacles.

Probability of flooding

The study shows that the probability of flooding in the 16 dike rings varies from 1/2500 per year in South Holland to more than 1/100 per year in a number of dike rings in the rivers region. These figures give only an indication of the actual probability of flooding and cannot yet be seen as absolute values. The method is not yet robust enough for that. The calculations do, however, provide the opportunity to analyse which failure mechanisms contribute most to the flooding probability and where the weakest locations are in a dike ring.

In the 1950s the Delta Committee established that extremely high water levels constitute the greatest threat of flooding. This insight provided the basis for the present safety standards for water defences. From the results of the Floris project it appears that this assumption is now no longer universally applicable. The probability of flooding due to high water levels is sometimes small compared with the risk due to other failure mechanisms.

In most dike rings the failure mechanism of 'piping' constitutes the greatest threat. Here the water forms channels under the dike, causing the dike to collapse. The large probability is probably partly due to the uncertainties surrounding the subsoil under the foundations of the water defences. Further investigation at the sites in question can show whether there actually is a relatively weak spot. But it is clear that piping is a real threat in the sandy and clay subsoil of the Netherlands. With each high water the Water Boards carefully check the water defences for signs of this phenomenon. They are also prepared, if signs of piping are found, to take emergency measures, such as covering the dike with textile and sandbags. The effects of this human intervention are otherwise not included in the calculation of the probability of flooding.

The failure mechanism of 'not closing hydraulic structures' also led to a high probability of flooding in a number of dike rings. In almost all cases this was because the closing procedures were not properly defined. This risk can be quickly and easily reduced by having the procedures documented and through regular exercises. Further to the Floris project, several Water Boards have now taken these measures.

Flood risks

The risk of flooding in a dike ring is the flood damage multiplied by the probability of flooding. Based on a rough calculation of the maximum flood damage, the risk in the 16 dike rings ranges from € 0.1 to 180 million per year. In the three dike rings where the potential damage has been calculated in detail, the risk of flooding ranges from € 2 to 37 million per year. The flooding risk can be seen as the amount that should be set aside per year to be able, in the long term, to compensate for the damage caused by a flood. In dike rings along the rivers the risks of flooding are relatively great. This is partly because the flooding probabilities along the rivers are greater. In addition to this, the consequences are large because if there are floods, almost the entire dike ring will be inundated with water. Other dike rings in most cases will 'only' partially flood.

Value of the figures and how they can be used

The Floris project is just one step in a longer development pathway. For all 16 dike rings the flooding risks have now been identified at the first development level. The calculated value of the flooding probability gives an indication of the actual flooding probability, but cannot yet be considered as an absolute value. It is possible to identify the relatively weaker locations in each dike ring and their causes. For a number of these locations it will first be necessary to investigate whether the probability of failure is actually great, or if it is due to uncertainty in the data.

The Floris project has reached the second development level for three dike rings. These are the dike rings where the consequences have been calculated at a detailed level. The results at this level of development are robust enough to be able to compare the flooding probabilities and the flood risks with other similar types of dike rings. As soon as the flood risks of all the dike rings in the rivers region are available at this level, this will create an overview of the consequences of a flood and the weakest links throughout the rivers region. Priorities can also be set for similar types of dike rings, along the coast or in tidal river areas. Development level three will be reached in the future when the flood risks for all dike rings have been soundly determined, with an acceptably small margin of error. The flood risks of dike rings throughout the Netherlands can then be compared with one another. It is necessary to reach this level to be able to make a cost/benefit analysis of investments to be made in providing flood protection and to be able to evaluate whether the present standards offer sufficient protection. The total risk of flooding in the Netherlands can then also be compared in absolute terms with other collective national risks.

Conclusions and Recommendations
All those involved share the view that the method used offers added value. The calculations provide the most realistic picture of the probability of flooding based on current understanding. The calculated probability of flooding, however, is not yet robust enough for these figures to be considered as absolute values. Further research and development of the method could help to make the method more robust in the future.

For most applications the national picture of the flood risks needs to be completed. Therefore it is recommended that the method also be applied to the remaining 37 dike rings. To obtain a proper estimate of the consequences, the detailed method needs to be used for all dike rings. More attention also needs to be focused on providing cost/benefit analyses for dealing with relatively weak locations. The study should continue, preferably coordinated from one central point, to be able to compare all the results.

The mechanism of piping plays a major role in the present flooding probabilities and deserves further investigation. The study should focus on a method of calculating the probability of piping, reducing the uncertainty in the data and ways of reducing the probability of piping. In so doing it is also important, of course, not to lose sight of other failure mechanisms.

1. Introduction

The Flood Risks and Safety in the Netherlands (Floris) research project investigated the risks of large scale flooding. To be able to do this it is necessary to know the probability of flooding and the ensuing consequences. Risk, in this case is defined as the probability of flooding multiplied by the attendant consequences of that flood. After the terrible flood disaster in 1953 the Delta Committee adopted the risk approach, but in the implementation of the plan the risk approach was relegated to the background. In the policy document "Living with water, water management policy for the 21st century" (Ministry of Transport, Public Works and Water Management, 2000) the government advocated a better understanding of the risks.

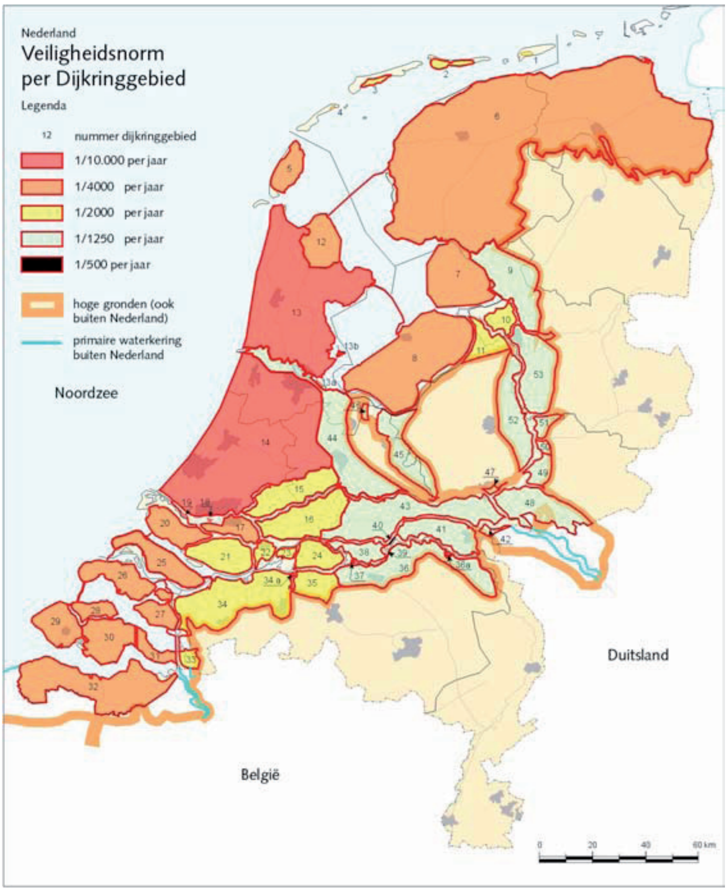
1.1 Risks demand attention

Modern western societies can be described as societies in which risks are minimized on the one hand, but in which new risks are always appearing on the horizon, on the other. Terrorist threats, the impact of gene technology, the influence of dust particles on our health and the excessive movements from A to B, are examples of these risks. Many of these activities implicitly involve a risk assessment: does the benefit of the activity outweigh the drawbacks? Flying to Barcelona is quick and cheap, but also involves a risk.

One of the risks of living and working in the Netherlands is that most of the country is vulnerable to flooding and its effects. In previous centuries various solutions were devised for this, with the many dikes, embankments and pumping stations as a constant factor. Without these structures, large parts of the Netherlands would be uninhabitable. But just as aeroplanes need technical maintenance to be able to fly safely from A to B, the water defences and their related risks too, need constant attention. Due to the major technological advances that have been made it appears as if the nature of the flood risk has changed: from a 'natural disaster' (or an act of God) to a 'man-made' disaster (National Institute of Public Health and the Environment, 2004). Since it is the man-made and managed water defences which must provide sufficient protection. It is therefore very important to evaluate on a regular basis whether we are sufficiently aware of these risks and whether the protection is appropriate.

In the Netherlands protection against large scale flooding is provided for by law. The Flood Defences Act gives protection levels which the water defences must meet. These protection levels are based on a risk analysis made by the Delta Committee in the 1950's. The protection level is expressed as the probability of exceeding a certain water level. The present approach to safety is laid down in the Flood Defences Act (1996). In this legislation the safety standard is defined as follows: "*In an annexe to this Act a safety standard is given for each dike ring area, expressed as the average exceedance probability - per year - of the highest water level which the primary water defence must be capable of withstanding from the outside, while taking into account other factors which determine the water defensive capability.*

The dike rings are shown in Figure 1-1. The safety standard is given for each dike ring. The standards vary for thinly populated dike ring areas and areas with a lesser economic value to be protected. For the dike rings along the non-tidal part of the Maas normative water levels with an exceedance frequency of 1/250 per year apply, in the upper rivers region 1/1250 per year, in the transition area 1/2000 per year, for the dike rings along the coast (apart from North and South Holland) 1/4000 and for North and South Holland, the densely populated western conurbation known as the 'Randstad' and the economic heart of the Netherlands, 1/10,000 per year.



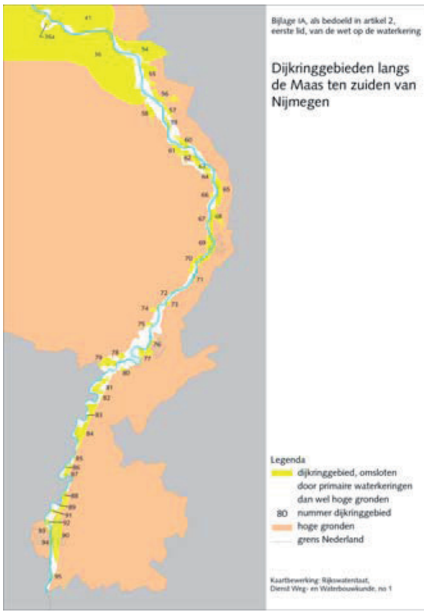


Figure 1-1 the 99 dike ring areas in the Water Defences Act (2005). The dike ring areas along the Maas south of Nijmegen were added in 2005 to the draft legislation, and fall outside the scope of the Floris study.

The Minister of Transport, Public Works and Water Management has issued guidelines which lay down the standards which the structural design must meet. According to the guidelines the crest of the dike must be at least half a metre higher than the normative water level. The guidelines lay down the regulations not only for the height but also the strength of the water defences. Each failure mechanism is looked at separately. The guidelines provide specifications for the design and strengthening of dikes.

The Water Defences Act stipulates that every five years the Ministry of Transport, Public Works and Water Management must test whether the normative water levels have changed, e.g. due to climate change. On this basis the Directorate-General for Public Works and Water Management sets the hydraulic boundary conditions that the water defences must meet in the next five years. The dike managers then assess whether each section of dike meets these boundary conditions and reports on the results to the Minister of Transport, Public Works and Water Management. In the recent amendment to the Water Defences Act it was laid down that the Minister of Transport, Public Works and Water Management must report every ten years on the effectiveness of the safety standards.

In the current statutory standards only exceeding the normative water levels is expressed as a probability (failure mechanism of overflow and wave overtopping). The occurrence of other failure mechanisms is not expressed in probabilities. The statutory standard is not the total exceedance probability for the entire dike ring, but for a section of dike several hundreds or thousands of metres long. For these reasons, the present exceedance standard does not match the probability of flooding of a dike ring. The other failure mechanisms, however, are taken into account in the design and safety assessment of the water defence.

In practice, the term 'probability' seems to be a difficult concept for many people to grasp. Certainly when it comes to small probabilities in the order of 1/1000 or 1/10,000 per year. When expressed as a chance of 1 or 5% in a person's life the term probability can be more easily understood. When probabilities get larger (e.g. 1/5 or 1/10 per year) people can grasp the concept fairly well. If in the last century about 10 Elfstedentocht skating marathons were held then it is easy to explain that the average chance of an Elfstedentocht is roughly 1/10 per year. And that an average probability of 1/10 per year is not the same as once every 10 years is, with some historical perspective, also easy to understand. It did occur, after all, that there was an Elfstedentocht race in two successive years, while after the severe conditions of 1963, it was almost 25 years before the next Elfstedentocht skating marathon took place. These unpredictable factors in the calculation of probability also apply even if the chances are smaller by a factor of 100 or 1000. These small probabilities cannot, in this case, be directly determined by observation - unlike the chance of an Elfstedentocht skating race taking place. The probability of rare events occurring can only be deduced by extrapolation. The term 'probability' therefore remains a difficult one; but is nevertheless an essential part of the term 'risk'.

1.2 Background to the study

Higher water levels and more powerful waves impacting on the dikes and dunes and the ever increasing consequences of a dike breech demand a pro-active policy to ensure that protection against flooding is maintained. The government's policy document "Living with water" on water management for the 21st century, is based on an anticipated increase in the probabilities (climate change) and consequences (more inhabitants) of a flood. Therefore it is important to have as clear a picture as possible of the probability and the consequences of flooding. The risk is the product of the probability of flooding and the consequences of the flood in question. The government's policy document "Living with water" also states that the population should be informed about the risks of living in a delta. Finally, the government wishes to make the costs and benefits of investing in protection against flooding more transparent.

In a nutshell, having an understanding of the present and future flooding probabilities and the consequences is very important to ensure that the safety approach is kept up-to-date. This knowledge is necessary to be able to ensure the best possible approach to dealing with the present flood risks. This is necessary to be able to make clear and soundly-based decisions about the desired levels of safety and protection against flooding in the social and political context (i.e. to balance the costs and benefits of further investments in safety).

In the technical area, in 1992 the Technical Advisory Committee on Water Defences (TAW) made a start on setting out a new safety approach in the research programme: "Flooding risks: a study of the probabilities and consequences". The aim of the research programme was to arrive at a safety approach in which the probabilities and consequences of flooding were seen in relation to one another.

In June 2000 the TAW completed its report "From exceedance frequency to flooding probability" (Technical Advisory Committee on Water Defences, 2000). In this report a new method was successfully tested for calculating the probability of flooding and gaining insight into the relatively weak spots in a dike ring. A major conclusion was that hydraulic structures constitute a relatively weak location in a dike ring, but this could not be established with any certainty, however. The former State Secretary of Transport, Public Works and Water Management then decided to have calculations carried out on the probability of flooding for all the dike ring areas.

Advantages of the risk approach
The calculation of flooding risks has the following advantages:

1. As preparation to answer the question of whether the Netherlands is safe enough. In principle, the politicians (the Cabinet and the Lower House of Parliament) should answer this question. To be able to conduct a proper discussion of policy it may well be important to have an understanding of the present

risks and the costs, and other effects of measures taken to reduce the probabilities and limit the consequences.
2. Prioritization of measures to improve safety. Understanding the costs and benefits of measures makes it possible to set priorities on this basis in relation to the measures to be taken.
3. Insight into the relatively weak spots in dike rings. A risk assessment of dike rings provides insight into the contribution made by individual factors which determine the risk;
4. Contribution to disaster preparedness. Large scale floods are disasters. To prepare for such disasters it is necessary to have an understanding of the development of a flood and the risks.

1.3 Goal of the Floris project

The Floris project formulated its goal in 2001 as follows: "to obtain insight into the probability of flooding in the Netherlands, the consequences of flooding and the uncertainties involved when identifying the probabilities and consequences. Based on this understanding it will be possible to gain an overview of the weak spots in the dike rings and the risks of flooding can be determined." (Floris Project Bureau, 2001):

The task of the Floris project turned out to be ambitious. Despite the fact that the Netherlands is at the forefront when it comes to expertise on flooding, it is still difficult to turn the failure mechanisms of flooding into manageable mathematical models. The use of new methods for determining the probabilities of flooding and the consequences along the considerable length of the water defences took more time and effort than had been envisaged, not least because the necessary data on the dikes was not always to hand. A great deal of energy was also put into the development and application of an assessment method for the problem of hydraulic structures.

The project began with six dike rings in the rivers region, designated as the frontrunners. The original aim of the Floris project was that the risks would then be determined for all the dike rings in the Netherlands. During the course of the project the goal was modified and it was decided to determine the risks for 16 dike rings. The remaining ten dike rings were chosen such that together with the six front runners, they provided a representative picture of the Dutch dike rings and reflected as many different characteristics as possible. The dike rings selected are found along the coasts of Holland and Zeeland, in the tidal river areas, the upper river sections, along the IJsselmeer and the Markermeer lakes and in the Wadden Sea. The dike rings chosen included ones in large and densely populated areas and smaller ones in areas with fewer inhabitants.

1.4 Approach taken by the Floris project

To achieve the stated goals four routes were set out within the Safety in the Netherlands (Floris) project, i.e.:

1. determining the probability of flooding for 16 dike ring areas;
2. gaining an understanding of the problems affecting hydraulic structures;
3. gaining an understanding of the possible consequences of flooding;
4. presenting a picture of the order of various types of uncertainties and how to deal with them.

To be able to reveal the flooding probabilities and risks, a suitable calculation method is required. Further work was done in the Floris study on the new method developed by the TAW in 2000 for calculating the probabilities, consequences and risks of flooding. A secondary goal of the project was to propagate previously acquired knowledge about the method for calculating the probability of flooding and the concept of risk, and disseminate it among the public authorities and market players concerned.

The results of the Floris study form part of a long-term process which began in 2001. In this way, step by step, a new way of thinking about safety and protection against flooding is being developed. The usefulness of the results of this phase of the project should be seen in the context of the three development levels defined in the project itself and communicated to the Lower House of Parliament. These three separate development levels are:

Development level 1:
At this stage, the calculated value of the probability of flooding gives an indication of the actual probability but cannot as yet be seen as an absolute. It is possible to indicate where the weakest locations are within a dike ring and what failure mechanisms are responsible for this. The dike manager can use this information to set soundly-based priorities for the maintenance of the dike ring.

Development level 2:
At this level, the probability of flooding and its consequences can be compared with other similar types of dike rings. Once the probabilities of flooding are available at this level for several dike rings in the rivers region, this provides insight into where the weakest spots are throughout the entire rivers region. In this way similar dike rings along the coast or in the tidal river areas can be compared and priorities set for the measures to be taken.

Development level 3:
The final level provides robust values for flooding probabilities and the consequences with an acceptably small margin of error. It is necessary to reach this level to be able to make a cost/benefit analysis of investments to be made in providing flood protection and to be able to evaluate whether the present standards offer sufficient protection.

The Floris project has created an overview of the flooding risks at the first level for 13 dike rings. The flood risks have been determined at the second level for three dike rings. The results of the Floris project, therefore, cannot yet be considered to be robust but they do give a first impression of the flooding risks in the Netherlands.

1.5 The parties involved

The client
The formal client for the Flood Risks and Safety in the Netherlands (Floris) study is the Ministry of Transport, Public Works and Water Management, Directorate-General for Water Affairs. The coordination of this very large project was handled by the Ministry of Transport, Public Works and Water Management, Directorate-General for Public Works and Water Management (RWS), Road and Hydraulic Engineering Institute (DWW), who set up a special project bureau for this purpose.

Water Boards and Provinces
In the context of the Floris project there was close cooperation with the Water Boards and the provincial authorities. As the bodies responsible for the management of the flood defences, the Water Boards are responsible for the safety of the dike rings in their area of control. They provided data on the properties of the dikes, dunes and other flood defence elements. The Provinces were involved as supervisors of the Water Boards and contributed by providing information on the possible consequences of flooding.

Knowledge development and dissemination
Various people contributed to the development of methods: staff of the Directorate-General for Public Works and Water Management (RWS), universities and other centres of expertise, as well as specialist consulting firms. The calculations were largely carried out by a number of consulting engineering firms, selected by means of a European tendering procedure.

Quality assurance
The TAW (since 1 July 2005, Water Defences Expertise Network (ENW)) provided the quality assurance for the technical aspects of the project. The TAW quality audit team set up for the Floris project supervised the process aspects. The aim of the TAW quality audit team was to assess the quality of the instruments and indicate what the potential implications of the combined reports on the probabilities and the consequences of flooding might be relation to society and policy matters. Instruments refers to all methods, procedures and manuals which were used for the Floris project.

The technical methods and the results obtained were reviewed by the TAW Safety working group from September 2004.

1.6 Testing of the Water Defences Every Five Years

Under Water Defences Act all the primary water defences must be tested every five years by the Water Boards to see if they still meet the current statutory standards. Undertaking the tests will provide information about whether a particular water defence meets the statutory standard in force. The safety tests conducted every five years can be seen as a policy evaluation instrument.

The calculation of the flooding probabilities in the Floris project is closely related to this safety assessment. Much of the information needed for the safety assessment is also needed to calculate the probabilities. However, more data is often needed to carry out the probability calculations in Floris than for the safety assessment, and in the probability calculations the less data there is, the greater the uncertainty becomes. As a result relatively large probabilities are then calculated. Dike sections for which insufficient data is available should be neither 'approved' nor rejected' in the safety assessment but given a 'no verdict' result. The results of this five-yearly safety assessment would therefore not have to fully agree with the Floris findings. Although it is reasonable to expect that water defences which as a result of the assessment are 'rejected', or have not yet been improved, will make a relatively large contribution to the probability of flooding. Based on the results of the safety assessment, measures will be taken for the 'rejected' water defences to ensure that the current statutory standard is again met. The results of the second safety assessment will be released in 2006.

1.7 Projects aimed at flooding risks

In the "Flood Risks and Safety in the Netherlands (Floris)" research project a new method was used to calculate flooding risks. Because the approach is new, the results of this study do not fully agree with the results of other studies. These other studies are often based on different principles and fit into another stage of the policy cycle.

1.8 Report structure

Chapter 2 describes the method used in the Floris project for determining the flooding probabilities, the consequences of flooding and the risks. Chapter 3 elucidates the results of applying the method. Chapter 4 provides a more detailed analysis of the results, and indicates the value of the method. Finally, the conclusions and recommendations are given in chapter 5.

2. Description of the method

To calculate the risk of flooding it is necessary to determine the consequences and the probability of flooding. It is not possible to take the safety standards for the probability of flooding from the Flood Defences Act because these standards only include a few of the factors which determine the probability of a flood. All other factors are implicitly included. In a risk assessment however all the relevant factors must be included. What is new here is the inclusion of these factors in the assessment, and also that the consequences of flooding are explicitly taken into account.

2.1 The essence of the method

The Flood Risks and Safety in the Netherlands (Floris) research project is concerned with flooding risks. The definition of risk used for this is:

*Risk of flooding = Consequences of flooding * Probability of flooding*

Viewed in the very long term, the risk of flooding is the average consequence (i.e. damage caused) of flooding per year. There are many dimensions to the consequences of flooding. In the Floris project it was decided to focus on two dimensions: 'economic damage' and 'number of victims'. The risk is generally expressed in terms of a financial sum and the number of victims per year.

The risks were separately calculated for each individual dike ring. This means that any dependency between dike rings is not taken into account in the calculation of the risk. This dependency occurs mainly in the rivers region, because here a breach in a water defence (collapse) may have an impact on the probability of flooding of other, neighbouring dike rings. A flood in the rivers region, for example, can result in a drop in water levels downstream. The probability of flooding in a dike ring downstream will therefore be reduced. But flooding can also lead to two rivers meeting, with one of the rivers then having to cope with much more water. As a result the probability of flooding will increase. The effect of this interdependency ('system effect') is difficult to predict. This system effect is also not taken into account in current design and safety assessment practice.

Flooding probabilities and consequences
To determine the **consequences** of flooding the Floris project focused on determining the number of victims, the economic damage and damage to the landscape, wildlife and cultural heritage (natural features). It is difficult to validate what is known about determining these effects, particularly as there is also so little practical data available. The methods for determining the effects of a flood are therefore largely based on the experience of the flood disaster in 1953 and experience from abroad. In the Floris project major advances have been made in defining the possibility of evacuation (new evacuation module: how quickly a population can be evacuated) and possible flooding scenarios (how and how quickly the water flows into the dike ring and what depth of inundation occurs as a result). On the basis of these scenarios the number of victims and the economic damage can be determined. On the

basis of the flooding scenarios it is also possible to provide a more solid foundation for disaster preparedness planning, because these scenarios provide insight into critical locations and critical escape routes.

To determine the ***probability of flooding*** the dike ring is viewed as a chain made up of links. For this purpose the dike rings are divided into three types of flood defences: dikes, dunes and hydraulic structures. The dikes and dunes are then subdivided into sections. A section is a part of a water defence with roughly the same strength and load properties. Besides the classification into types of flood defences, a breakdown was also made of the various ways in which a dike can fail. This is discussed further in section 2.3.4.

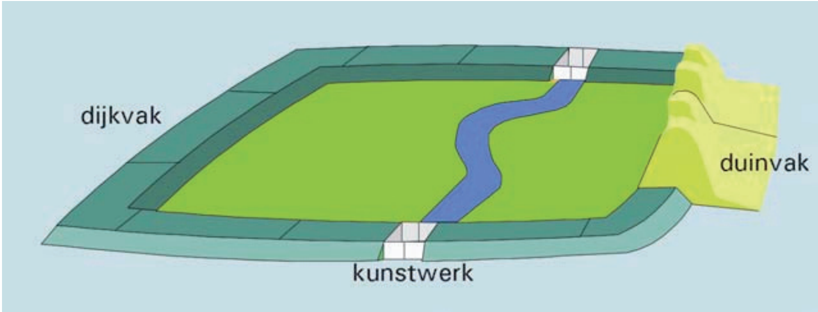


Figure 2-1 A dike ring as a chain with individual links

Conservative assumptions
Where there was insufficient knowledge or data available to carry out the calculations, the Floris project took the uncertainty explicitly into account in the calculation through uncertainty distributions, or, if this was not possible, by making conservative assumptions. The consequence of both of these methods is that the flooding risks may possibly be slightly overestimated and that the probability of flooding is greater relative to the situation than if the uncertainty had not been taken into account.

This chapter will further consider the data and the method for determining the consequences of flooding (victims, economic damage and damage to the landscape, wildlife and cultural heritage (natural features)) and the probability of flooding.

2.2 Determining the consequences of a flood

2.2.1. Outline

In the Floris project research was done on the consequences of a flood. A flood from the sea, or a lake or river will often take on the proportions of a major disaster. These consequences have many dimensions. It was decided to focus most attention on the economic damage and the number of victims. Some attention was also devoted to damage to the landscape, wildlife and cultural heritage (natural features) and environmental damage.

To calculate the consequence of a flood it is necessary to have an understanding of the hydrodynamic aspects of water inundation. These aspects were revealed with the aid of 'flooding scenarios'. A flood scenario refers to the pattern of flooding which occurs following a breach (or possibly several breaches) somewhere in the dike ring. There are many different flood scenarios possible for a dike ring. In the Floris project research was done to find a method which would reveal these scenarios as clearly as possible. Beside the size of the breach and the number of breaches, the volume of available water is an important variable in determining the consequence of a flood. This is because the more water, the greater the inundation depth and the greater the damage and the chance of loss of human life.

This section will first consider the flooding scenarios. We will then turn our attention to determining the economic damage and victims, the natural features aspects and the environmental damage.

2.2.2. Flooding scenarios

Two methods were used In the Floris project to define flooding scenarios. These methods can be designated as 'global' and 'detailed'. The global approach defined a 'worst case' flooding scenario to be able to determine the damage in simple terms. Due to the lack of essential hydrodynamic parameters (e.g. the speed at which the water rises) with this method it is not possible to determine the number of victims reliably. Under the global approach it is not necessary to indicate the location of the breach, but it is assumed that there is enough water to inundate the entire dike ring area. In the detailed method, however, the flooding pattern can be calculated using a hydrodynamic model. SOBEK 1D-2D (WL, 2003), developed by WL|Delft Hydraulics, was used for this.

Global flooding scenarios

The method of the global approach is described in the Floris project report *Globale schadeberekening* [Global damage calculation] (Floris project bureau, 2005). In the global method the water depth (which is important for determining the damage) is determined on the basis of a flooding scenario that was created on the basis of the following principles:

- the dike rings are considered as a whole (i.e. not separate compartments);
- for each dike ring a water level was set which is the same as the lowest crest of the dike ring (or in special cases, the highest test standard within the dike ring);
- there is enough water to inundate the entire dike ring area.

For sloping areas an additional assumption was made: in the sloping area a water depth of 1 metre was taken. In dike rings with sloping areas (e.g. the rivers region) it was effectively assumed that the dike ring would flood from the most upstream point of the dike ring (Figure 2-2).

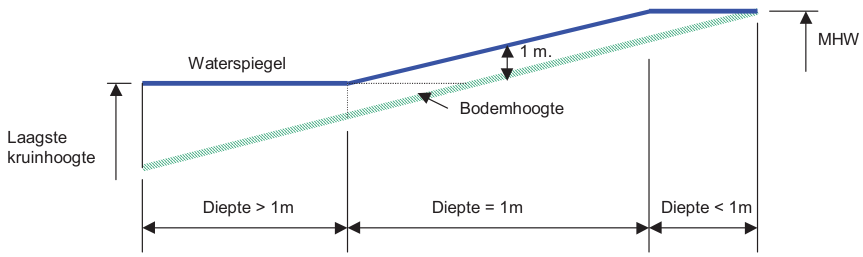


Figure 2-2 Diagram showing how the inundation depth was determined in the global consequences method

It should be noted that the global method gives a (high) upper limit for the depth of inundation. From the Floris study (Floris project bureau, 2005) it appears that for the dike rings along the coast and the lakes it is very unlikely that as much water will flood the area as was assumed in the global scenarios. What this approach does give is an impression of the vulnerable locations, and these are often the lower lying areas.

Detailed flooding scenarios
To determine water depths (and other characteristics which determine the damage), the hydrodynamic model SOBEK 1D-2D was used in the detailed approach. In this way the behaviour of a water system can be simulated, in which flooding over land occurs. The mathematical model consists of a two-dimensional flow model, and can be linked to a one-dimensional flow model to represent the course of the water in the flooded area. In this way the consequences of a breach in the flood defence can be properly calculated. There is, in general, however, no means of validating the results of the calculation with measurements, because this data is not available: flooding rarely occurs in the Netherlands. It was investigated whether data from floods in the distant past could be reproduced using the model. This turned out to be the case so it may be concluded that the model is suitable for simulating floods. The results were also submitted to officials of the provinces and regional water boards who made corrections on the basis of their knowledge of the area.

To carry out a flood calculation a great deal of data is necessary. This therefore requires a representation of the area (elevation, soil use, location of water courses and possible obstacles, such as drainage water dikes and compartment dikes), the location of the breach(es) and the hydraulic load (height and duration of the high water level).

To determine the locations of the breaches and the hydraulic loads the results of the failure probability calculations were used (see section 2.3). From these calculations with PC-Ring it was possible to determine the probability of failure for each dike section, dune section and hydraulic structure. On the basis of this information, several locations were chosen in the most vulnerable areas with the aid of a program specially developed for this purpose ('ScenarioKans', see Thonus, Vrouwenvelder and Steenbergen, 2004). Multiple collapses can also occur here. These multiple collapses result in more damage than a single collapse because then more water flows into the dike ring area. It was examined per water system whether it was possible for multiple collapses to occur. The chance of multiple collapses was also calculated. The hydraulic load during a calculation of a flooding scenario was also determined with PC-Ring on the basis of the most likely combination of load and strength parameters.

2.2.3. Determining the economic damage due to flooding

The results of the flood calculations were used to calculate the economic damage as a result of a flood. The inundation depth is the most important parameter which determines the damage. The *HIS Schade en Slachtoffermodule* [HIS Damage and Victim Module] (version 2.1), was used for this in the Floris project. HIS stands for High water Information System (Huizinga et al., 2004). The damage is determined for each location on the basis of the land use and a damage function. This function describes what damage occurs as a function of the inundation depth.

The method is shown in the form of a diagram in Figure 2-3. As can be seen from the figure, the method is based on geographic information. A Geographic Information System (GIS) is therefore used to determine the damage per dike ring area.

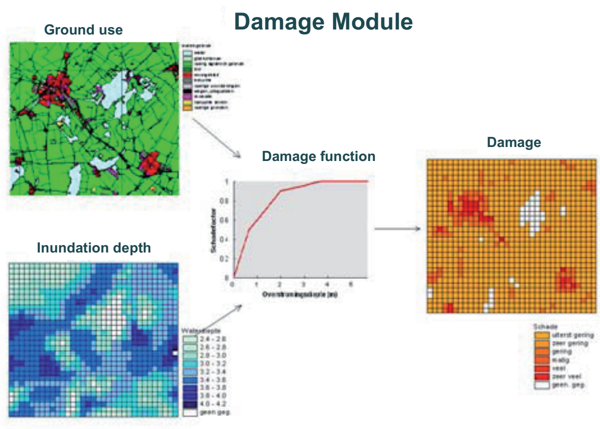


Figure 2-3 Flow diagram for damage calculation

The four steps in Figure 2-3 are:

1. Determining the flooding scenario: the inundation depth is needed as input, and this can be found from a flooding scenario taken from the global approach described above or from the detailed approach;
2. Determining the land use: the various forms of land use throughout the Netherlands are available in the form of a map;
3. Defining the damage functions for all types of land use. Each damage function consists of a maximum damage sum and a damage factor. The maximum damage amount is the maximum damage which can occur in a flooding scenario and is based on the replacement value. The damage factor is a figure between 0 and 1 and is a function of the inundation depth and the current velocity;

4. The damage is calculated by combining the inundation depth, current velocity and the damage function for each land use form in a mathematical unit.

When determining the damage a distinction is made between three different categories of damage:

1. Direct damage – material;
   Direct material damage refers to the damage which is caused to objects, capital goods and movable goods as a result of direct contact with water. This includes:
   - Cost of damage repair to immovable property (land and buildings) rented or in ownership: land and buildings;
   - Cost of damage repair to means of productions, such as machinery, equipment, process plant and means of transport;
   - Damage to property contents;
   - Damage due to the loss of moveable property, such as raw materials, auxiliary materials and products (including damage to harvest).
2. Direct damage - due to business interruption;
   The second category of direct damage is defined as damage due to business interruption, i.e. the commercial losses caused by lost production.
3. Indirect damage.
   The indirect damage comprises the damage to business suppliers and customers outside the flooded area and travel time losses due to inoperability of roads and railways in the flooded area.

The output of the HIS Damage and Victim module is formed by maps which show the damage for each flood scenario.

2.2.4. Determining the number of victims

The number of victims is also calculated on the basis of the hydrodynamic aspects of a flood as described in section 2.2.2. How of the number of victims is represented is shown in the diagram in 2-4. The two steps are roughly as follows:

1. Analysis of evacuation, escape routes and the presence of people in the area;
2. Estimate of the number of victims among those present in the area.

The HIS Damage and Victim module (version 2.1) was used to calculate the number of victims.

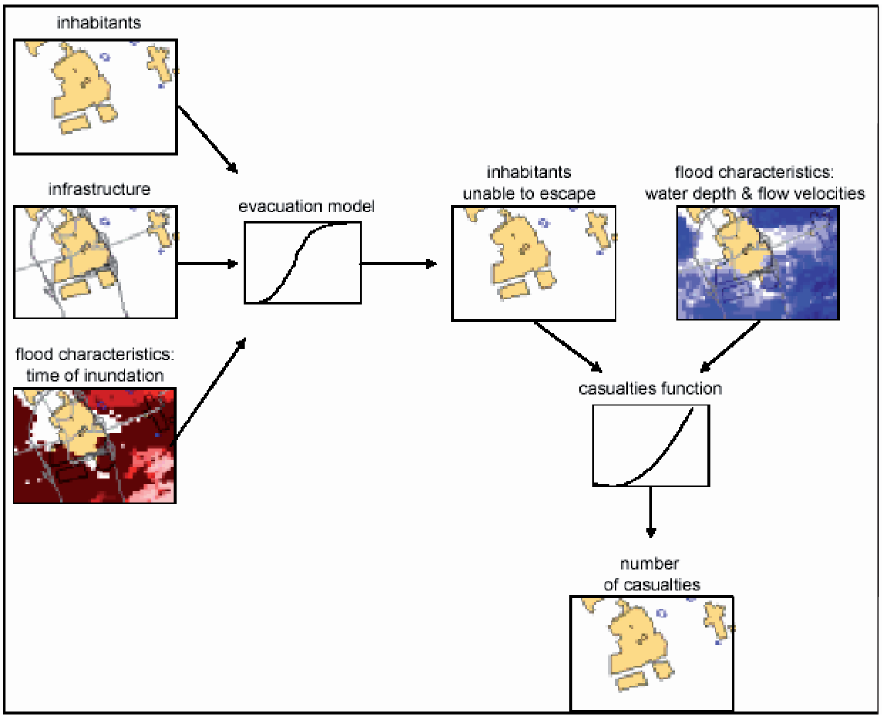


Figure 2-4 Flow diagram for calculating the number of victims

In the first step the number of persons still present in the area at the time of the flood is determined. Evacuation is one of the measures to limit the number of people affected and thus the number of victims in the event of a flood. The possibility of evacuation depends on the time available until the dike collapse and the time necessary for the evacuation.

The **available time** means the time period between the detection or prediction of a critical situation and the actual collapse. The available time will firstly depend on the ability to make predictions concerning the water system in question (sea, lake, tidal or non-tidal river reaches). Extremely high water levels on the rivers usually presage their arrival a few days in advance. A storm surge at sea is often only predictable at much shorter notice. The predictability of a certain failure mechanism occurring and the speed with which the dike then succumbs to that failure mechanism is also important.

The **necessary time** is the time needed to undertake a full evacuation. There are four distinct phases to this:

1. the decision-making phase;
2. the warning phase;
3. the response phase;
4. the actual evacuation (residents leave the area).

An estimate was made of the time necessary for phases 1 (decision-making) and 2 (warning) based on values given in the literature (Frieser, 2004). With the aid of the evacuation calculator developed in the Floris project (University of Twente, 2004), the time duration for phases 3 (response) and 4 (actual evacuation) was determined. Finally, an 'evacuation curve' could be derived which shows how many people have left the area as a function of time.

On the basis of this the number of people present per location can be deduced for a given collapse, including the prediction time. The available time greatly depends on whether or not a flood occurs unexpectedly. The necessary time greatly depends on the degree of organisation of an evacuation, given that the better this is organised the more effective it is. On basis of this, the following four situations could be identified, as shown in figure 2-5.

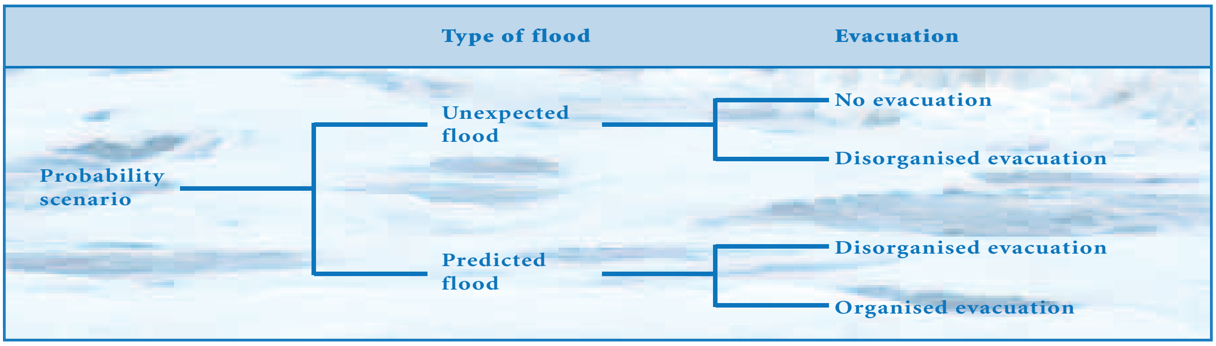


Figure 2-5 Situations considered to determine the number of people present in the dike ring and estimate the number of victims

The available and the necessary time was determined for each of these situations. An estimate was made in each case of the part of the population still present in the dike ring. It was further assumed that residents of high-rise buildings would be safe and thus they would not be directly exposed to the flooding. The number of victims was estimated on the basis of the number of people present and the type of flooding.

The number of victims was estimated on the basis of three zones within the dike ring (Jonkman, 2004):

1. victims in the zone characterised by high current velocities resulting in buildings and people close to the breach being swept away;
2. victims in the zone characterised by a rapid rise in water level as a result of which people have few opportunities to escape to higher floors or other places of refuge.
3. victims in the remaining zone in which the water rises more slowly, but where it does become deep. Due to the slower rate of rise in the water level people can more easily reach a safe place, but due to the relative depth victims may also occur in this zone.

The number of victims was estimated using 'victim functions', as they are called. These lay down a relationship between the characteristics of the flood (rate of rise, inundation depth) and the number of victims among those present. The victim functions are based on data from the Flood Disaster of 1953 and from the international literature on flooding (Jonkman, 2005). From this literature it appears that the number of victims is usually 0.1% to 1% of the people affected. However, where rapidly rising water and greater inundation depths are involved a larger percentage of the population often dies.

2.2.5. Damage to natural features

A large scale inundation also has a major impact on the quality of the landscape, wildlife and cultural heritage, usually referred to as the 'natural features'. Each of these terms covers several aspects. Within the scientific community there is no broad consensus on the aspects to be taken, although there is, in general terms, about which are important. In terms of the quality of the landscape the main concerns here are the geographical aspects, the ecological aspects of the landscape, its cultural heritage aspects, the scale and the land use. In relation to nature, the presence of flora and fauna can be used as an indicator of quality. The spatial conditions for wildlife can also be seen as a quality indicator for nature. Cultural heritage is often subdivided into three aspects (including in the Belvedère policy document (Ministries of Housing, Spatial Planning and the Environment (VROM), Education, Culture and Science (OCW), Transport, Water Management and Public Works (V&W) and Agriculture, Nature and Food Quality (LNV), 1999)): archaeological aspects, aspects of historical architecture and buildings, and historical geographical aspects.

To determine the consequences of flooding in relation to the natural features a selection was made of the aspects which would be taken into consideration (Nieuwenhuizen et al., 2003). This selection was made on the basis of an initial estimate of the effects and the ability to show the effects at dike ring level. The availability of data played an important part in this. The following four aspects were selected:

1. taller vegetation;
2. vegetation;
3. freshwater ecosystems;
4. historic architecture.

On the basis of information taken from the literature supplemented with expert knowledge, the damage as a result of a large-scale flood was determined for these four aspects. The damage largely depends on the water depth, as well as the salt content of the water and the duration of the inundation.
The method for determining damage to natural feature aspects was implemented in a separate HIS module (HIS-LNC module). This module also included the data necessary to be able to calculate the damage.

2.2.6. Environmental damage

The aim of the investigation into environmental damage was to develop a method which, on the basis of an overview, provides insight into the most important risks due to the spread of environmentally hazardous substances and their release from industrial sites further to flooding of a dike ring area (Snuverink et al., 2004).

The underlying goal in the context of the Floris study was to find out whether and to what degree environmental damage should be taken into account in policy development on protection against flooding.

The following elements were considered in the development of the method:

- the selection of substance groups or substance clusters;
- the selection of types of business activities where these substances may be present;
- the chance of substances being released per plant, in the event of a flood;
- the distribution of substances over an area;
- the measures to be taken to limit the consequences.

With the method it is, in principle, possible for any dike ring area, given a set flooding scenario, to quickly obtain a global overview of the environmental damage to be expected within the dike ring area.
Data about the activities in an area, however, needs to be collected.

2.3 Determining the probability of flooding

The probability of flooding indicates the chance of a dike ring being inundated due to the collapse or other failure of the flood defence function of one or more flood defences around the area.

2.3.1. Process

The first step in determining the probability of flooding is to gather data on the flood defences and then to make a representation of the actual dikes. This was carried out by the regional water boards and provinces, under the supervision of the Floris project. A special manual was drawn up for this activity (Floris project bureau, 2002) which the water defence managers used to supply the data on their flood defences. If they preferred, the regional water boards and provinces, could obtain support with this from consulting engineering firms. The quality of the data collected was checked by the Floris project team.

Consulting engineering firms carried out the calculations of the probability of flooding using the PC-Ring calculation software (Vrouwenvelder et al., 2003). They were supported in this by the Floris project team.
PC-Ring was developed by TNO Building and Construction Research in association with experts from the Directorate-General for Public Works and Water Management (RWS), universities and other centres of expertise, as well as specialist consulting firms. It was also used in the report published in 2000 by the Technical Advisory Committee on Flood Defences (Technical Advisory Committee on Flood Defences, 2000). In the context of the Floris project the software was further developed by adding all the hydraulic loads on the various water systems (coast, lake, river) (Diermanse et al., 2001). Until the Floris project began, PC-Ring had only been used by the program developers. As the number of users would increase because of the Floris project, a user-interface was made.

While the probabilities of flooding were being calculated, additional information was, in the meantime, obtained from the flood defence managers to improve the results. The results were discussed in a workshop attended by the water board, its advisor, the province and the Floris team, together with specialists from TAW (Technical Advisory

Committee on Flood Defences). The aim of this workshop was to establish to what extent the manager now agreed with the results and to decide on whether or not to include the results for dike sections or hydraulic structures in the calculation of the probability of flooding of the dike ring. Sometimes, further to the workshop, final corrections were made to the calculations. The final probabilities of flooding are described for each dike ring examined, in the dike ring reports (Floris project bureau, 2005).

2.3.2. Data collection

The starting point for the data collection was the present status of the dike ring. The only exceptions being sections where dike strengthening was actually taking place, or where it was certain that this would happen in the near future and the design has been finalised.

For some failure mechanisms the detailed data collection and carrying out the probabilistic failure analyses is very labour-intensive. It is therefore desirable in the analysis of the probability of flooding to limit the number of dike sections for these mechanisms, by making a well-considered selection. This means that there are dike sections which were not taken into account in the calculation of the probability of flooding and dike sections where not all mechanisms were considered. The arguments for omitting these dike sections are given in the report on the data collection. The aim here, after all, is to consider the entire dike ring and decide for each section whether or not it should be included. The number of dike sections included in the representation depends on the failure mechanism. In general, more dike sections were included for the failure mechanism of overflow and overtopping than for the mechanism of sliding or heaving, for example. Making a good representation of a dike ring requires specialist knowledge because the overview must be consistent with the calculation method used in PC-Ring.

For the hydraulic structures a selection was made if there were a large number of them present in a dike ring. A representative selection was ensured (Floris project bureau, 2004) in which those hydraulic structures were specifically selected where it was expected in advance that they would make a large contribution to the probability of flooding. For identical hydraulic structures which occur more frequently in a dike ring and whose hydraulic load is similar, only one was considered. The result was also applied to the identical hydraulic structures.

2.3.3. Categories of flood defences

A 'primary' water defence is a water defence which protects against flooding either because it is part of the system that surrounds a dike ring area - possibly together with high ground - or which is situated in front of a dike ring area. Under the present management regime four categories of primary water defences are defined, see Table 2-1.

Category	Description
a.	Primary water defences which belong to systems which enclose dike ring areas - possibly together with high ground - and defend directly against external water.
b.	Primary water defences which are situated in front of dike ring areas and hold back water from outside (e.g. Afsluitdijk, Oosterscheldekering).
c.	Primary water defences not intended to provide direct defence against water from outside (e.g. dikes along the Amsterdam Rhine canal, Diefdijk).
d.	In one of the categories a to c but situated outside the national borders.

Table 2-1 Overview of the four categories of flood defences

Primary water defences in category a
In the 16 dike rings investigated all the flood defences in category a were included.

Primary water defences in category b
Flood defences in category b are connecting water defences. Examples include the Afsluitdijk, the Haringvlietdam and the IJmuiden locks. For most connecting flood defences there is ample storage available behind the defence. In many cases a collapse does not directly lead to a large contribution to the probability of flooding of the dike rings behind it. The probability of flooding of a primary water defence in category b with a stricter standard than the water defence behind it usually makes a negligible contribution to the probability of flooding of that dike ring. This applies, for example, to the Kadoelersluis with a exceedance frequency of 1/4000 and dike ring area 9 (Vollenhove) with an exceedance frequency of 1/1250. It was decided in the Floris project not to include the connecting flood defences in the calculation of the probability of flooding of the dike ring areas behind them. The only exceptions to this being the Maeslantkering for determining the probability of flooding of dike ring 14 (Zuid-Holland) and the Ramspolkering for determining the probability of flooding of dike rings 7 (Noordoostpolder) and 10 (Mastenbroek). These defences have a major influence on the hydraulic regime of the water behind them.

Primary water defences in category c
Category c defences are primary water defences which do not directly hold back external water, for example, because they form a divide between dike rings (Diefdijk) or because they are situated, for example, alongside a canal, (e.g., the Amsterdam Rhine Canal).

For flood defences in category c which form a divide between dike rings, as a rule, the category a water defence had to fail first before the category c defence would fulfil its role. In the Floris project the contribution made by the category c defences to the probability of failure was not included due to the lack of data on hydraulic loads. In the Flood Defences Act it states that the situation in 1996 must be maintained ('standstill'), and the Minister of Transport, Public Works and Water Management has so far issued no boundary conditions for these water defences.

Primary water defences in category d
The contribution made by the primary water defences in category d (flood defences abroad) were looked at on a case-by-case basis. These defences were not included due to a lack of data.

The different categories of flood defences in the Floris project
Therefore not all flood defences were included in the calculation of the probabilities of flooding presented in this report. Most of the b, c and d flood defences were not included in the calculation of the probability of flooding of the dike rings. The reasons for this were lack of data (such as the hydraulic loads) and it was estimated that the risk in the event of collapse of these defences is much smaller than the risk associated with the collapse of flood defences which are in direct contact with external water. This however, does not apply to the category d defences which do directly defend against external water. This could therefore mean that a picture of the probability of flooding may be created which is too favourable. In 'reality' this probability could thus be slightly bigger (and the safety thus lower).

2.3.4. Dikes

The Guide to the Fundamentals of Flood Defences report of the Technical Advisory Committee on Flood Defences (Leidraad Grondslagen Waterkeren, Technische Adviescommissie voor de Waterkeringen, 1998) includes an overview of the various ways in which a dike can fail: the failure mechanisms. For the water-retaining soil structures the Guide identifies 12 mechanisms. In the Floris project it was decided not to include all these failure mechanisms in the calculation of the probability of flooding. The reasons for this were: they were less relevant to the goal of the Floris project (e.g. 'settlement', this mechanism does not immediately result in flooding) and lack of insight into the process (e.g. 'softening'). This can mean that the probability of flooding in 'reality' is slightly greater.

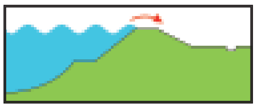
The following four failure mechanisms were taken into account in calculating the probability of failure of a dike (see also Figure 2.6):

1. *Overflow or wave overtopping*
   With this failure mechanism the dike collapses because large quantities of water run over the top of the dike or because the waves break over the dike. With an offshore wind or where the wave height is otherwise very small, the failure mechanism of overflow is used to describe the collapse. In other cases by the failure mechanism of wave overtopping. An erosion process of the inner slope then starts.
2. *Uplifting and piping*
   With this failure mechanism the dike collapses due to sand being washed away from under the dike. Due to the pressure of the water the uppermost (sealing) layer of clay, if present, above the layer of sand first uplifts (becomes raised). This allows the 'piping' to take place, in which the sand is washed away and the dike subsides (collapses).

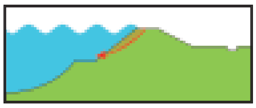
3. *Damage to the revetment and erosion of the dike body*
   With this failure mechanism the dike collapses because the revetment is first damaged by wave attack and then the profile of the dike core is reduced due to erosion.
4. *Sliding or heaving of the inner slope*
   With this failure mechanism the dike collapses because part of the dike becomes unstable due to high water levels over a long period of time, and it then slides or heaves.

There are four important failure mechanisms for dike rings:

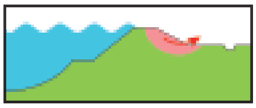
overflow and overtopping the water level or the waves are higher than the crest of the dike, the water flows over the dike causing erosion of the inner slope;



damage to revetment the dike facing (or revetment) becomes damaged by the waves, following which part of the dike is washed away;



sliding of inner slope the landside of the dike becomes unstable and subsides;



piping water seeps under the dike creating channels which undermine it.

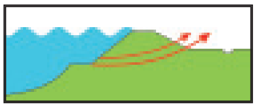


Figure 2-6 Dike failure mechanisms considered

Overflow or wave overtopping
With this failure mechanism the dike collapses due to the large quantities of water running over the dike or waves breaking over the dike. As a result of these large quantities of water the dike collapses because the volume of water is more than what the inner slope can bear. In the Floris project only the strength of the inner slope revetment (usually the turf) was taken into account for the deterioration of the inner slope, and not the softening (because the process is not well understood).

Overflow occurs if the water level is higher than the crest or crown of the dike. According to the standard the crest of the dike should be half a metre higher than the design level, so that the contribution made by this mechanism to the total ring probability is generally fairly small. The monitoring level (essentially the difference between the crest and the safety level if the dike is 'in order') is designed partly because of possible waves caused by wind. With wave impact the difference between the crest level and the safety level is often more than half a metre to limit the overtopping.

If too much water gets over the dike the inner slope can erode, which can lead to collapse of the flood defence. This phenomenon is known as wave overtopping. The load for this mechanism in PC-Ring is therefore given by the overtopping flow rate q_0. The strength of the dike consists of the critical flow q_c at which the revetment of the inner slope collapses. The dike fails when the overtopping flow rate is greater than the critical flow rate. Because both flow rates are defined as stochastic variables, the probability of failure can be calculated. The uncertainty about the known occurrence and the critical flow rate are also taken into account In PC-Ring.

Figure 2-7 Flooding due to a dike overflow

To determine the strength of grass slopes a strength model for grass was used. The use of this model resulted in values for critical flow rates of 30 to 50 l/s/m, with a standard deviation of approx. 10 l/s/m. These values deviate from the critical overtopping flow rates in the Safety Assessment Guidelines which are used in the 5-yearly safety assessment (Ministry of Transport, Public Works and Water Management, 2004). The reason for this is that the 'residual strength', as it is known, of the grass slopes was specifically included in the Flood Risks and Safety in the Netherlands (Floris) project. In other words: in the design as well as in the safety assessment, 'safe' values are usually used and in the Floris project as good an estimate as possible was made of the chance of a breach due, in this case, to wave overtopping.

Damage to the revetment and erosion of the dike body
The failure mechanism of damage to the revetment can be applied to the following types of revetment: grass, stone and asphalt. Dikes are often covered with various types of revetment. In the rivers region grass is often used. As soon as wave impact plays a role (e.g. coast, lake) grass is no longer adequate. In zones where wave impact may be expected stone or asphalt is used. Due to the various types of loads there are even dike sections with three types of revetment. Within these the quality and the type can further vary. The representation in PC-Ring was set up in such a way that it was assumed that the covering from the crest to the foot of the dike consisted of one type of revetment.

PC-Ring calculated the probability of failure of the revetment. Given that failure of the revetment does not necessarily mean that a breach also occurs, the probability of erosion of the dike body was also taken into account. For the strength, data was used such as the durability of the grass, the thickness, weight and type of stone and asphalt, and the structure and make-up of the dike body. This mechanism therefore has two parts to it, i.e. one for damage to the revetment and one for erosion of the dike body.

Grass cover
The dike fails under this mechanism if the time which a particular storm needs to damage the revetment and to wash away the rest of the dike core is shorter than the duration of the storm. The strength is equal to the length of time it takes until a breach occurs in the dike, including the strength of the turf. The dike profile is roughly divided into three parts: the grass cover, the covering layer of clay under the revetment and the rest of the dike core.

Stone revetment
For a stone revetment it was assumed that stone pitching on a granular filter was used. The probability of failure of the stone pitching was determined, among other things, on the strength, relative density and the thickness of the stone pitching, the gradient of the outside slope and the wave rigidity. The residual strength of the filter and the dike body is determined by erosion coefficients and the structure of the dike body.

Asphalt revetment
The residual strength of the dike body was also taken into account in the deterioration of the asphalt revetment. The failure of an asphalt revetment may be due to water overpressure or wave pounding.
The secondary mechanism of failure due to water overpressure occurs if the pressure difference across the revetment at the water line exceeds the weight of the asphalt layer. The factors which play a part here are the weight and thickness of the asphalt as well as the position of the revetment and the gradient of the inner slope. The formula used for this was taken from the report of Technical Advisory Committee on Flood Defences (Technische Adviescommissie voor de Waterkeringen, 2000).
In the secondary mechanism of failure due to wave pounding, the necessary thickness of the asphalt was compared with the thickness found. The necessary thickness was determined here on the basis of the angle of the gradient k, the significant wave height and the type of subsoil.

Application
Given that it was not possible to calculate the slope with the various coverings in PC-Ring, choices had to be made. The Floris project took a conservative line in this. In principle, cautious choices were initially made concerning the quality of the revetment. Subsequently, the probabilities were determined for all revetment types found. From this the revetment was selected which makes the biggest contribution to the probability. If it later appeared that the section in question made a large contribution to the ring probability, this was then analysed in more detail. From the calculations it was shown, for example, under what circumstances the

dike section fails and in which zone the revetment is attacked. By finding out which covering is on the attack zone, it is possible to select the right revetment.

Uplifting and piping

With uplifting and piping the dike collapses because the sand under the dike is washed away. In practice, this mechanism is linked to the occurrence of sand-bearing seepages. Due to the pressure of the water the sealing layer of clay behind the dike, if present, first uplifts. Then 'piping' occurs in which channels develop from the inside to the outside of the dike. As a result the sand is washed away and the dike subsides. The collapse mechanism consists of two parts: uplifting and piping. Failure only occurs if, for both mechanisms, the load is greater than the strength.
The submechanism uplifting occurs if the sealing layer lifts. This occurs if the difference in water pressure over the dike which causes the upward pressure under the sealing layer is greater than the downward pressure due to the effect of gravity. As soon as uplifting occurs, seepage behind the dike will start to take place. As soon as this flow starts, sand particles under the dike can be carried away thereby creating channels (piping). Due to the cohesive forces of the sealing clay layer these channels will not cave in and the piping gets the chance to grow right through to the foot of the outside slope of the dike. This is then described as a continuous pipe The water carries the sand with it from under the dike which results in its collapse. It is assumed that after this collapse there is no further residual strength: a breach in the dike has occurred and flooding will be a matter of fact. If there is no sealing layer of clay present piping may well occur but it cannot grow because the soil on top will cause the channel (pipe) to collapse. In this case it is not worthwhile to include this mechanism, as the chance of continuous piping will be negligibly small.

In the Floris project the phenomenon of uplifting and piping was calculated using the Sellmeijer formula (Technical Advisory Committee on the Flood Defences, 1999). In the Safety Assessment this formula was applied in advanced testing (Ministry of Transport, Public Works and Water Management, 2004). Initially in the assessment the available seepage length was compared with the necessary seepage length. This was done using the Bligh method which relates the necessary seepage length to the difference in water pressure over the dike using a 'creep factor'. For sand dikes this factor varies between 12 and 18. Only after it appears that the seepage length was too short, will the advanced test be carried out. However, this requires additional information about the soil properties. Determining the permeability of the soil layer is a particular problem here. Firstly, it is difficult to determine this and secondly it can vary greatly. The data collection manual (Floris project bureau, 2002) suggests how the permeability can be determined, in order of preference:

- On the basis of a pumping-test in the area: in which the kD values can be found, with an indication of the thickness D of the water-bearing sand layer, until a permeability k can be deduced;
- On the basis of a local permeability measurement: however this will not generally be available;

- On the basis of the results of sieve analyses of sand from the water-bearing sand layer: the sieve analyses will give an indication of the small grain fraction d10 and the uniformity u = d60/d10. The permeability can be estimated in this way;
- An estimate on the basis of the groundwater map of Geoscience TNO National Geological Survey (TNO-NITG).

Application
In practice it appears that there is very little measurement data on permeability. During the project it was also discovered that relating the grain data to permeability can actually only be applied if extensive sieve analyses are available. Because is often not the case, it was generally decided to derive the permeability from the groundwater maps. This is major difference with the report of (Ministry of Transport, Public Works and Water Management, 2004) in which the permeability was determined with the formula C_{Bear} based on grain properties. Because the data is generally known to be conservative, this will have an effect on the flooding probability for this mechanism, particularly where the soil properties very widely. The reasoning adopted is described in more detail in the review led by Professor Vrijling of Delft University of Technology which was conducted in 2004 (Vrijling et al., 2004). The recommendation made in this report (Vrijling et al., 2004), was, among other things, in the event of strong soil stratification, to obtain information about the uppermost soil layer and the deeper layer of soil. Using derived formulas based on MSeep calculations it is possible to determine a representative permeability, which can then be used to determine probability (Duinen, 2005). Unfortunately, it turned out that the necessary data was not available, which meant that it was not possible to use the proposed method for the Floris project. We will return to this in section 4.1.

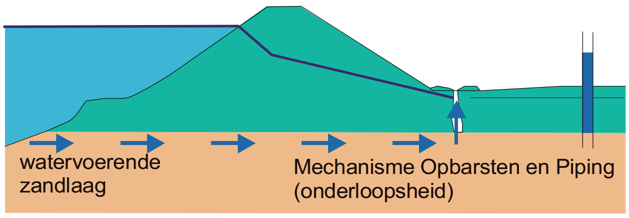


Figure 2-8 Mechanism of uplifting and piping in dikes

Sliding of inner slope
A distinction can be made with this failure mechanism between two situations: i.e. sliding of the inner slope along a shallow slip curve (Figure 2-9) and sliding as a result of heaving (uplifting and sliding) of the inner covering layer (Figure 2-10).

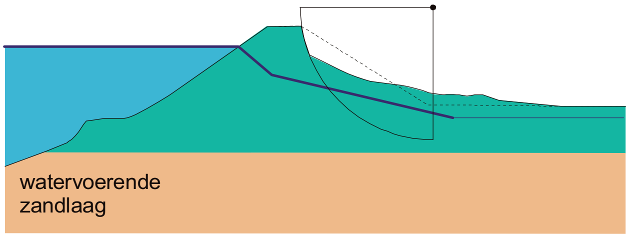


Figure 2-9 Sliding of the inner slope along the slip curve

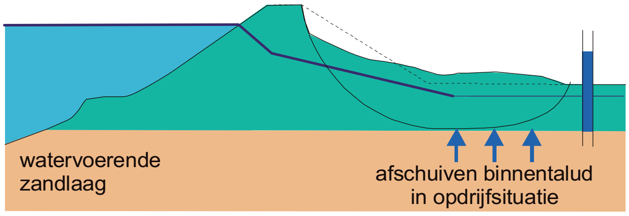


Figure 2-10 Sliding of the inner slope due to heaving (uplifting and sliding) of the inner covering layer

The first may be due to an increase in the phreatic water pressure in the dike, for example due to infiltration of outside water into the dike at a high water level, but also due to infiltration of (extreme) precipitation on the dike. Generally in a safety assessment both of these 'loads' are tested. The second form of sliding can occur when, as a result of a high external water level, the potential in the sand layer under the dike increases such that the inside covering layer of clay and/or peat starts to rise (heave). The effective grain tension (the contact tension between the soil particles) in the transition between the covering layer and the underlying sand layer is then lost, as a result of which the covering layer no longer provides any indirect support to the inner slope of the dike. This form of sliding was the cause of the dike collapse at Streefkerk in 1984 and led to the development of the heaving theory and the mathematical model for stability in the event of heaving.

Figure 2-11 Example of sliding of the inner slope.

For sliding of the inner slope along a slip curve, PC-Ring makes use of the results of the probabilistic stability analyses of MProstab (Geodelft, 2003). Where the sliding occurs as a result of heaving the results from MProlift were used. If, for a dike section both sliding of the inner slope along a slip curve and heaving are important, both mechanisms were included in the calculation. Only the normative mechanism for that dike section was included in the ring probability.

To carry out a stability calculation detailed information is required about the geometry of the dike, the separation planes of the soil layers and specifications of materials. Information is also needed on soil parameters such as cohesion, angle of internal friction and weight by volume. At least three phreatic lines should also be included: for normative situations, for a high water situation under normative high water levels and under average conditions. The model generates failure probabilities for these three situations. The results of the stability calculations in PC-Ring are then combined with the water level statistics (Vrouwenvelder et al., 2003) which results in a probability of flooding for the dike section.

Due to the nature of the sliding failure mechanism, undertaking a MProstab/MProlift calculation is more time-consuming than a PC-Ring calculation. This was one of the reasons why the Floris project limited the number of calculations to roughly five profiles per dike ring. This background should be taken into account in the analysis of the results.

2.3.5. Dunes

In the probability of flooding of a dike ring a probability is also included for 'dune erosion', see figure 2-12. In PC-Ring the difference between the critical position of the erosion point (the strength), and the calculated position of the erosion point (the load) is determined. If the calculated position is equal to the critical position then failure may be said to occur. This method is identical to the method described in the Guide to the Fundamentals of Flood Defences (Technical Advisory Committee on Flood Defences, 1984). Stochastic functions such as duration of the storm surge, wave height and water level are included as load. Data on the dune, such as the orientation of the dune profile and the grain diameter, are used. A full description of the method can be found in 'Aanpassing duinmodule PC-Ring' [Adaptation of the dune module in PC-Ring] (Floris project bureau, 2003). Where a comparison is also made between the model in the Guide and the dune model in PC-Ring. The differences in the results between both models can be explained by the use of different boundary conditions. In addition, it was ascertained that the dune module in PC-Ring does not yet work properly in the case of deep channels or trenches just before the coast. Taking into account these differences, it may be concluded, however, that both models generated similar results.

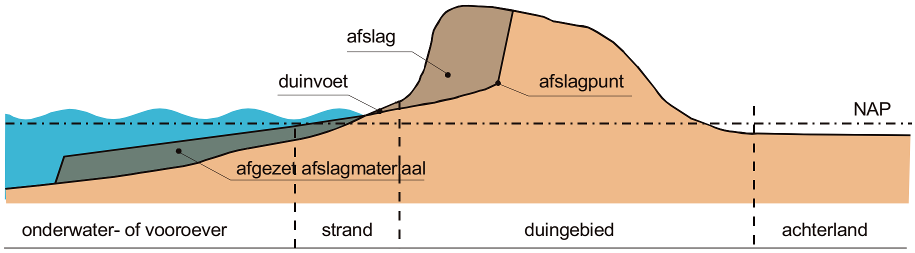


Figure 2-12 Failure mechanism for dunes

In the Floris project it was necessary to make a selection of the site and year for the dune sections (Jarkus profile). The location was selected on the basis of contribution to the probability of flooding. This does not deviate from the selection of dike sections. In principle, the Floris project aims to provide insight into the protection against flooding at the present time. In opting for the Jarkus profile this was deviated from: the picture could be too rose-coloured if a dune range were to be selected just after beach nourishment had occurred at that site. Therefore the following step-by-step plan was adopted:

- Based on the basic coastline report it was investigated in what year certain profiles were considered less safe. This report gives the present situation, the trend and forecasts for necessary nourishment;
- Then for the relevant year the Jarkus profile was found for the dune section and calculated. In this way an upper limit for the probability of failure of the dune was found;
- When a probability of failure is calculated which makes a large contribution to the total probability of flooding of the ring, this was looked at more closely by also taking a year in which recent beach nourishment has taken place. Further calculation of that profile then gives a lower limit for the probability of failure for the dune in question.
- On the basis of the results it was finally decided which probability to include in the probability of flooding of the dike ring.

2.3.6. Hydraulic structures

For hydraulic structures the probability of flooding is determined using an assessment method. In the method it is assumed that this probability is made up of three separately defined elements which must be combined to arrive at an estimate of the total contribution made by the hydraulic structure to the probability of flooding. These elements are wave overtopping, not closing and structural failure. Assessment methods have been drawn up for the following types of hydraulic structures: pumping stations, cuts, locks, tunnels, pipelines and longitudinal structures (Floris project bureau, 2002).

The failure of a hydraulic structure due to wave overtopping or not closing need not necessarily lead to the creation of a breach in the flood defence and thus flooding of a dike ring area. For hydraulic structures which are in contact with interior water, water flowing in from outside can often be taken up in the water system behind them without this leading to a flood. A hydraulic structure can also often handle a large discharge without loss of stability. The failure probabilities calculated in the initial approach, caused by wave overtopping or failure to close, can be tightened up in the assessment system to the level of the flooding probabilities. These are smaller probabilities *per se*. This tightening up requires additional work and was therefore only carried out when the initial approach led to relatively large probabilities relative to the present standard frequency for design water levels. For the mechanism 'structural instability' it was assumed that stability would be lost immediately, resulting in breaching. The associated probability of failure was therefore considered as the probability of a breach occurring, or the probability of flooding.

Mechanisms

To determine the probability of failure of hydraulic structures the exceedance frequency curve of water levels was correlated with the strength of the flood defence. With the hydraulic structures too, the uncertainties in the input data were explicitly taken into account.
In determining the probability of failure of a hydraulic structure, the following failure mechanisms were considered (Figure 2-13):

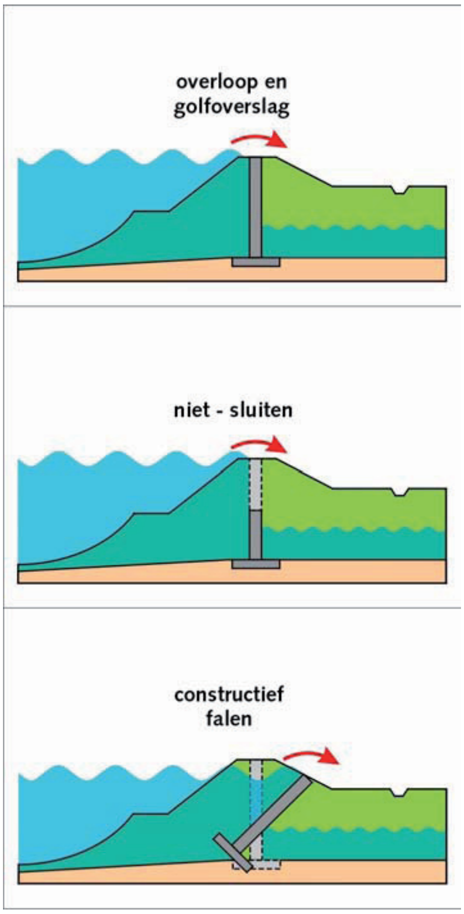


Figure 2-13 Hydraulic structure failure mechanisms considered

Overflow or wave overtopping

For the failure mechanism overflow and wave overtopping the hydraulic structure collapses because water flows over the hydraulic structure. The assessment of the hydraulic structure is based on a comparison of the water level to be retained in relation to the exceedance frequency curve of the exterior water level.

Not closing
With the failure mechanism 'not closing' the hydraulic structure collapses as a result of the closing mechanism not being closed on time. The assessment of the hydraulic structure is based on a comparison of the exceedance frequency curve of the exterior water level with the open defence level, taking into account the probability of the closing mechanism 'not closing'.

To determine the probability of 'non-closure' of closing mechanisms the Floris project adopted the method given in the Hydraulic Structures Guideline (Leidraad Kunstwerken, 2003). This guideline identifies four main causes of failure:

- Failure of the high water warning system: failure of the water level monitoring, failure of the alarm, etc.
- Failure of the mobilisation: operational personnel are not present at the flood defence on time.
- Failure as a result of operational errors: incorrect or negligent actions.
- Technical failure of the closing mechanism: failure of the operating mechanism.

Structural failure
With structural failure the hydraulic structure collapses as a result of failure of the structure itself or parts of it. The assessment of the hydraulic structure is based on an inspection of the structural strength and stability of the structure in relation to the load and the high water to be held back. In this assessment the following mechanisms apply:

- structural failure of the defensive mechanism due to the load caused by differences in the water pressure;
- structural collapse of the concrete structure;
- structural failure of the foundations;
- loss of stability due to instability of the bed protection;
- collapse due to piping;
- collapse due to collision.

Application
Given that it is not feasible to assess all the hydraulic structures a selection of them was made per dike ring. This selection was made on the basis of an estimate of the contribution made to the probability of flooding and the available information. Furthermore, the Floris project did not take into account tunnels, pipelines and longitudinal structures mainly for practical reasons, such as the limited availability of data.

As soon as the failure probabilities of the hydraulic structures were known, the contribution made by the hydraulic structures to the probability of flooding of the dike ring was considered. The hydraulic structures with a large share were further examined in terms of:

- whether the mechanism can actually occur;
- what the consequences would be of the mechanism occurring.

Both these cases can be illustrated. The probability of failure due to insufficient height was missing in the probability of flooding of the Noordoostpolder for the Lemmer and Ramspol intake culverts. Both these intake culverts (or sluices) are situated in the dike body, as a result of which it would be the dike which would fail at the flood defence height.
In addition, it appeared that in the event of failure to close, the inward flow was so small that this would not lead to a flood. The polder pumping station can cope with this discharge flow. The current velocities which would occur are also not such that the structure would fail. The probability of failure for the mechanism of 'not closing' of the intake culverts was therefore not included in the calculation of the probability of flooding of the dike ring.

2.3.7. Weak locations analysis

Once the ring probability has been determined, a weak locations analysis can be carried out. Here it is investigated what measures can be taken to reduce the calculated probability of flooding of the dike rings. The costs of the measures concerned are also globally estimated. In this way a first impression is given of the cost involved to achieve better protection against flooding. On the basis of the calculated flooding probabilities the 'weak spots' or locations are identified, with a general estimate of the cost of possible measures to improve these relatively weak locations. In the identification of relatively weak locations and determining the cost of possible measures a distinction was made between dike sections and hydraulic structures.

The identification of relatively weak locations takes place by setting a boundary for the probability of flooding (without making any assumptions about a possible standard). This boundary represents the probability on the basis of which relatively weak spots are selected. Dike sections with a greater probability than this are therefore designated as 'weak'. In addition a second boundary was established which distinguished between main weak locations and other weak locations. The idea here is that it may be possible to bring about a major improvement in the ring probability with a limited number of measures. The choice of these boundaries was fairly arbitrary.

To calculate the cost of the improvement measures a separate cost module was developed in the Floris project for the dike sections. In this way the costs involved in improving the main weak locations and the other weak locations can be revealed. For the hydraulic structures a procedure was followed which is based on an assessment per structure. Where this involved possible physical measures a very general cost estimate was also made. It should be emphasised here that the cost of the measures were not calculated to the point at which an optimum is achieved in terms of the costs, on the one hand, and the benefits, on the other. A weak points analysis is therefore certainly not a cost/benefit analysis.

Application

A weak locations analysis was conducted for a number of dike rings with a calculation of the costs of the necessary improvements to reduce the probability of flooding (Baarse, 2005). Due to budgetary limitations and insufficient time, a weak locations analysis could not be carried out for all the dike rings.

2.3.8. Influence of human intervention

Human intervention was not taken into account in the calculation of the probability of failure for the dikes and dunes. Human intervention was taken into account with the failure mechanism not closing of hydraulic structures because human action is specifically an element in the intended functionality of the object.

Figure 2-14 Human intervention

Under the present management regime, however, there is intervention in the dikes and dunes as well, particularly in relation to piping in the rivers region. By not including human intervention, the probability of failure may possibly be overestimated, and in practice the probability of flooding may be smaller than calculated in the Floris project.
During high water conditions every manager will always inspect the flood defences, including, among other things, looking for any sand-carrying seepages. The way in which an inspection should be carried out during high water conditions is generally laid down in the High Water disaster preparedness plan. This plan includes the following text under coordination phase 2: "Permanent dike monitoring. The dike sections for which the dike posts were set up should generally be inspected by car, bicycle and/or on foot. The dike inspection should take place on a continuous basis." For example, during periods of high water the Rivierenland water board implements these rules in practice by continually patrolling in a three-shift team. Every day the entire length of the dike track is inspected three times (every 6 to 8 hours). The possible occurrence of the failure mechanism uplifting and piping can often be seen in advance. In places where it is expected that seepage will definitely occur (experience) and where something is already happening, for example where boiling is starting (no sand) and where rising water has been contained, extra checks are carried out once or twice a day.

If sand-bearing rising water (welling) is discovered within the 'protection area' then it is contained. On average the water will be capped at 50-75 cm to inhibit sand erosion. It very much depends on the local circumstances how high the welling can be contained.

Containment is carried out with sand bags. A low wall of sand bags is built around the sand-bearing stream. It looks like a 'water well' surrounded by a low wall of sand bags. Sometimes filter cloth is placed over the welling water. It is one option, but not essential. This 'containment' is simple and effective and can be done by anyone. This containment technique was simple to apply with the high water levels seen so far, but its effect at relatively higher water levels is not clear.

Figure 2-15 Containment in practice

In (Vrijling et al., 2004) a calculation was made of what impact containment has on the probability. In Figure 2-16 the effect is shown for several dike sections in dike ring 43 (Betuwe, Tieler- and Culemborgerwaarden).

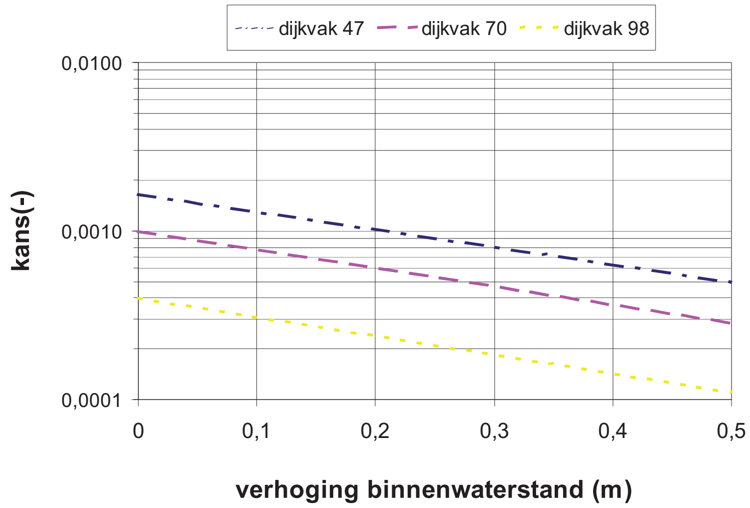


Figure 2-16 Relationship between probability of failure and containment

What is striking is that the probability of failure is almost loglinear in proportion to the increase in the inner water level. With a minimal increase in the internal water level by half a metre, according to the figure the probability of failure will drop from 1/1000, for example, to 1/3500. In practice, what often occurs is that a new stream of rising water (welling) occurs after containment of the first. This was not taken into account in the sensitivity analysis. It was assumed in the calculation that the welling does not move.

2.4 Perception of risk

Besides the 'objective' risk of flooding (risk = consequence x probability) the risk perception is also important. This perception is, by definition, subjective, which means that it depends on the individual person (or group of people).

In the Flood Risks and Safety in the Netherlands (Floris) research project two surveys were conducted (van Ast et al., 2003) on the perception of risks. These surveys investigated the following:

- what is known about the present perception of flood risks;
- what is important in the communication on flood risks;
- how can the subjective perception of flood risks be quantified and rated in a decision-making context;
- what is known about the relationship between the standards and parameters of flood risks and the regulation of risks.

It may be concluded that not much is yet clear when it comes to the perception of flood risks. Like other risks (e.g. smoking, driving a car, flying, bungee jumping, etc.) the risk of flooding is present every day, but it not visible every day. What is particular about flood risks is that there is often no awareness of this, and also not that the taxpayer pays for his or her own protection (van Hall, 2005).

2.5 Cost/benefit analysis

In the discussion of measures to increase the protection against flooding, the costs and benefits of these measures play an important role. Costs, after all, have to be weighed against the benefits of greater safety. This involves not only the financial and economic costs and benefits, and victims, but also the costs and benefits in relation to nature, the environment and spatial quality, etc. The benefits are often defined as the reduction in the annual flood damage (probability x consequence). Optimum protection in economic terms can be achieved through the implementation of measures in which the sum of the costs of the measures and the expected flood damage are minimised.

The benefits of a measure in the Floris project is a reduction in both the number of victims and the damage. The damage is expressed in euros but the number of victims is not. The question is whether victims should also be valued in economic terms. To do this it is necessary to have an understanding of the number of victims and an economic appreciation of victims. This is a difficult topic, and in chapter 3 it has been decided to adopt the approach of the CPB (Netherlands Bureau for Economic Policy Analysis) (Centraal Planbureau, 2005), in which a supplement is used for the so-called 'immaterial' damage.
"In the first instance a sum of €5000 per inhabitant will be used for the immaterial damage. The thought behind this is that is that it represents an amount for the nuisance and evacuation costs rather than a value for the loss due to injuries and fatalities."
The cost of measures was estimated on the basis of global appraisals. This means that no detailed designs were made of the improvement measures. In the further detailing of the measures the costs may well change because the uncertainty declines as more detail is added. The additional maintenance and management costs are included in the estimate of the costs.
There are various methods available for conducting a cost/benefit analysis (Noortwijk et al., 2005). These methods, however, are largely based on identical principles, such as determining the present value of the annual risk. What is important to the optimisation is not only how much should be invested, but also when. The First Year Rate of Return principle, as it is known, was applied for this last criterion in (Centraal Planbureau, 2005). In the context of the Floris project a start was made on a cost/benefit analysis for dike ring 14, Zuid-Holland.

2.6 Uncertainties

A flood defence fails if the condition of the dike and the loads impacting on it are such that water flows over, through or under the dike to result in inundation of the hinterland. When and how this failure will occur can never be predicted with any certainty because both the loads and the properties of the flood defence are not precisely known. Because of these uncertainties statements can only be made in terms of probabilities.

The question is how accurately can we calculate the probabilities? This requires an analysis of the uncertainties. There are three types of uncertainties: natural, model and statistical uncertainties.

1. *Natural variability* This is due to the unpredictability of natural fluctuations. A distinction is made here between fluctuations in time (e.g. the water level at Hoek van Holland) and fluctuations in space (e.g. the thickness of an underground layer of clay).

2. *Model uncertainties due to representation in the physical models* Mathematical models are used in probability of failure calculations to indicate which combinations of load and dike properties will lead to failure. These models always give a very representational image of reality. Given the present level of understanding it is not possible to describe precisely a complex natural phenomenon such as the failure of a dike with a physical mathematical model. The uncertainties in the model are not exactly known. By comparing the predictions made by a model with observations (for example, taken from practical or laboratory tests) an idea can be obtained about the order of these uncertainties.

3. *Statistical uncertainty due to a small number of observations* In a failure probability analysis statistical distributions are given for the variables which the natural or model uncertainties describe (e.g. for the probability of exceeding a certain water level or wind speed). Because, in most cases, however, only a relatively small amount of measured data is available, a large degree of extrapolation is often required. For the design of a dike with a probability of failure of 1/1000 per year, for example, only around 100 years of measured data is available. In some cases, particularly for the model uncertainties, there are even fewer or no observations at all. Then the intuition of experts is relied upon (engineering judgement).

In the present safety approach only the natural variability in the water levels was specifically taken into account. After determining the normative high water level or the assessment level a safety margin was included for other uncertainties. The method used in the Floris project to calculate flooding probabilities however, makes it possible to include all these uncertainties right from the outset. This has the following advantages:

- All uncertainties form an integral part of the calculations and are seen as such;
- The method shows which uncertainties make the largest contribution to the results of the calculations;
- On the basis of this it can be decided whether it is useful to reduce the uncertainties with research or whether the preference is to strengthen the flood defence with physical measures.

The calculated probability of flooding is the most realistic portrayal of the probability of flooding given the available information. The greater the uncertainty, the greater the probability in the calculation. Sometimes the uncertainty can be reduced by conducting further research, e.g. on the structure of the subsoil. Depending on the results of this further research, this could lead to a smaller probability of flooding. It is also possible, however, that further research indicates that the situation has been correctly estimated, or is actually worse. The uncertainty may then have been reduced, but the mean has shifted to a less favourable value. Other uncertainties, such as uncertainty about the extent of the rise in sea level or the increase in river discharge, cannot be reduced within the foreseeable future.

The water level on a river, at a given discharge, is an example of 'knowledge uncertainty'. Uncertainty in these water levels is also not taken into account in current design and safety assessment practice. This uncertainty comes, for example, from uncertainty in the flow distribution at branching points or in the hydraulic roughness.
Figure 2-17 gives an example of this uncertainty for a location along the Waal.

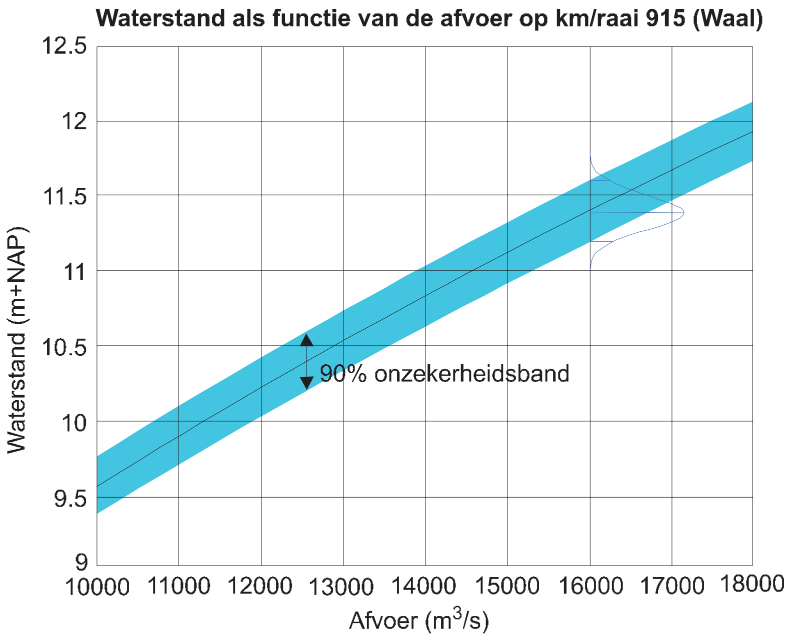


Figure 2-17 Illustration of uncertainty: possible water levels as a function of the discharge at km/section line 915 (Waal)

A description is given in section 2.7 of the consequences of the uncertainties in relation to the results of the Floris project and how the calculated probability of flooding should be interpreted, given the type of uncertainties.

2.7 Step-by-step analysis of the results

A great deal of data is needed to be able to determine flooding probabilities, which must also fit with the probabilistic methods used. Early in 2004 a review was carried out in the Floris project by a group under the chairmanship of Professor Vrijling, further to the relatively large flooding probabilities of the 'front runners', six dike rings in the rivers region (Vrijling et al., 2004). 'Large' here refers to probabilities which were much greater than would be expected on the basis of insight and experience. The flood defences have been greatly improved in the last 50 years, and it is reasonable to expect that flooding probabilities greater than 1/100 are most likely based on lack of knowledge and data to be able to calculate the probability in a sound manner. The review provided a step-by-step plan for carrying out an analysis of the results in the event of large flooding probabilities. This method is reproduced below and is taken from the review report (Vrijling et al., 2004).

If relatively high flooding probabilities are calculated it is open to question whether the results of the calculation actually reflect the situation with regard to the flood protection or whether there are other factors which play a role. In the first case, this leads to the problem of how to communicate this, but the essence of the message is inescapable. In the second case, it must be possible to show that either clear errors have been made in the calculation, or that the calculated probability of flooding may well be correct, but placed in the correct context need not give cause for alarm.

It should also be noted that underestimation of flooding probabilities is undesirable as this could lead to a 'false sense of security', which could ultimately result in an insufficient level of protection. The rest of the description, however, will consider a situation where large (not credible) calculated probabilities of flooding have been arrived at. In principle, there are three separate causes which can lead to a large calculated probability of flooding:

1. The representation, basic principles or assumptions are incorrect. This can relate to the selection and representation of dike sections and the modelling of the calculation of the contribution made by various failure mechanisms to the flooding probability.
2. There is insufficient understanding of the properties of the subsoil, for example. This can lead to a conservative estimate of the mean and/or the standard deviation of critical properties. Due to the lack of insight, the uncertainty, a large probability of flooding is calculated. In addition, the limited accuracy of the model can have an impact on the calculated probability of flooding. The reasons for the model to give a less accurate approximation of reality could be either insufficient knowledge or inefficiency. Sometimes a simple model is used because the reality is not well understood, or to save work.
3. There is a real defect in the flood defence.

On the basis of these situations three steps can be taken to tighten-up the calculated probability of flooding:

Step 1: test basic principles and assumptions
As a basic step in the interpretation of a calculated probability of flooding, the good engineering custom of checking the calculations for incorrect representations is combined with an analysis of the influence of assumptions and underlying principles. Here providing feedback to the water defence manager and model specialists is desirable or even vital. The calculated probability of flooding is discussed with the water defence manager to compare the result with the manager's judgement. Particular

attention should be given to the elements which the manager does not agree with.

Step 2: reducing uncertainties
Where there is a lack of knowledge reducing the calculated probability of flooding can be done by reducing the uncertainties. This could involve collecting more information about the most important variables which determine the strength or load, or by improving the model. Sometimes collecting that information is relatively easy. If the high calculation of the probability of flooding is caused by the fact it is not certain whether a particular construction element (e.g. a piping screen) is present or not, this can easily be investigated. In the first round of data collection the information to hand will also often be accepted as satisfactory, because collecting better information is time-consuming. When it appears that this lead to contributions to the probability of flooding which appear to dominate the total flooding probability, further data collection at agreed cost could be considered. If, for example, too little is known about the subsoil, only expensive soil analysis can reduce the data lacuna.

The use of a more advanced mathematical model is sometimes, but not always, easily done.
A particular example of knowledge gained is 'proven strength'. If the dike has functioned properly for a number of years, then it is reasonable to expect that the probability of failure will be the reciprocal of that number of years. This applies if the period is large enough and the calculation exceeds this period. Calculated probabilities of flooding which are large in proportion to the period of experience therefore need to be treated with some suspicion.

In the foregoing a distinction was made between the 'calculated probability of flooding', which gives an estimate of the probability of flooding including all uncertainties, and the 'actual probability of flooding' which indicates how often the dike will collapse in a given period. This difference depends on the type of uncertainties. If the uncertainty mainly arises out of the hydraulic boundary conditions (due to the high water exceedance curve) then the calculated probability of flooding may be considered to be roughly the same as the reality. If the uncertainty mainly relates to the strength of the dike then the calculated probability of flooding, in most cases, will be greater than the reality. The strength of the dike is, after all, within certain limits, unknown to humankind, but it is there. Without further measures it is only revealed however, whether or not the strength of the dike is disappointing, if it has withstood a vigorous high water event (the minimum strength has then been proved). Measurements and assessment of the quality of the dike can, of course, at least in most cases, help to reduce the uncertainty and thus the calculated probability of flooding. It is indicated in the calculation of the probability of flooding whether the uncertainty is mainly due to of the strength or the hydraulic load.

Step 3: Improving the flood defence
In the event of an actual defect, improvement and strengthening of the flood defence will lead to a reduction in both the calculated and the actual flooding probability. The organisation and, if necessary,

implementation of strengthening activities during a high water situation will also lower the probability of flooding. So far, in the Netherlands, only high water interventions at hydraulic structures were included in the calculated dike safety because this is what the hydraulic structures were designed for. Closing procedures form an integral part of the design. Interventions during high water are not included in the calculated safety for dikes. Therefore emergency measures such as raising the dike with sand bags and containing rising water (welling) have been treated separately (see section 2.3.8).

The results of the Floris project must be interpreted in the context of the above improvement strategies, the investments needed for this and the effect that his will have on the probability of flooding. In general, the first two strategies were implemented in the Floris project. These were aimed at evaluating the underlying principles and methods (step 1) and reducing the uncertainty through research and measurement (step 2). If the uncertainty mainly relates to the strength of the flood defence, the calculated probability of flooding will probably be reduced under the second strategy. Besides the calculation of the contribution made to the probability of flooding based on conservative basic principles and assumptions (taken from factual knowledge and information, if necessary), it is therefore also worthwhile to make a calculation on the basis of (speculative) realistic assumptions.

Sometimes the study can reveal a real defect in the flood defence. It then becomes clear in advance whether there really is a problem with the flood defence or if a lack of information and insight is the problem. When the input of realistic values leads to the conclusion that further investigation would be useful this was termed a recommendation. And if, in such cases, the flood defence manager does not agree with the high probability of failure calculated, then the calculated probability of failure in question of a failure mechanism of a specific dike section, or a failure mechanism of a dike ring, can be left out of the calculation of the probability of flooding.

We cannot rule out that there may actually be a physically weak spot when the calculated probability of failure is dominated by knowledge uncertainty further to entering realistic optimistic values. Then it would seem sensible to design measures which achieve a smaller probability of flooding and which prevent spiralling costs. Although such a decision would never have to be made on the basis of the results of the Floris project . Measures are only taken further to the safety assessment of the water defences. In 2006 the results of the second safety assessment will be released. When the second safety assessment is published it is recommended that the results be compared with the weak locations identified in the Floris project, and that extra attention be given to the need for and value of further research and improvement measures in the context of the safety assessment.

3. Results for 16 dike rings

This chapter presents the results of applying the risk of flooding method to 16 dike rings. The results have provided new insights into protection against flooding. Some examples of additional information from the risk calculations are also given, such as the results per dike section and the results of flooding calculations.

3.1 The dike rings considered

As indicated in chapter 1, the Floris project considered 16 dike rings. The project began with six dike rings, which served as the 'front runners'. These dike rings are all situated in the upper rivers region. These dike rings were selected because they play a part in the present water management policy 'Space for Rivers'. These dike rings also function as 'pilots' to complete and test calculation and assessment methods.

A representative selection of dike rings was also made with as many different characteristics as possible. In this way the various types of threats, from the sea, from the rivers, from the IJsselmeer and Markermeer, and the transition area between sea and rivers, are represented. For the large dike rings where flooding could result in a lot of damage and many victims, both of these were included. This affects the provinces of South and North Holland. But smaller dike rings were also considered. The selection was made to allow all aspects and elements of the method to be tested. An overview of the dike rings investigated is given in Figure 3-1. Because we started with six dike rings in the rivers region, relatively many dike rings in this region were investigated.

Figure 3-1 Overview of dike rings included in the Floris project

From the overview in Table 3-1 it can be seen that the size of the dike ring areas in the Netherlands differ greatly from one another: from a few thousand to hundreds of thousands of hectares and from a few thousand to several million inhabitants.

Nr.	Dike ring	Threat	Area [ha]	Inhabitants
3	Terschelling	Zee	1.900	1.900
7	Noordoostpolder	Meer	49.000	60.000
10	Mastenbroek	Rivier	9.400	29.000
13	Noord-Holland	Zee, meer	153.000	959.000
14	Zuid-Holland	Zee, rivier	223.000	3.255.000
15	Lopiker- en Krimpenerwaard	Rivier	32.000	196.000
16	Alblasserwaard en Vijfheerenlanden	Rivier	39.000	197.000
25	Goeree-Overflakkee	Zee	22.000	46.000
32	Zeeuwsch Vlaanderen	Zee	72.000	106.000
36	Land van Heusden / De Maaskant	Rivier	74.000	407.000
38	Bommelerwaard	Rivier	11.000	45.000
41	Land van Maas en Waal	Rivier	28.000	242.000
42	Ooij en Millingen	Rivier	3.400	14.000
43	Betuwe, Tieler- en Culemborgerwaarden	Rivier	63.000	299.000
48	Rijn en IJssel	Rivier	29.000	156.000
52	Oost-Veluwe	Rivier	31.000	105.000

Table 3-1 Some of the characteristics of the dike ring areas investigated

In this chapter the results for the 16 dike rings will be presented in two groups. The division has to do with the way in which the consequences were determined ('detailed' or 'global'). The flooding probabilities were determined for both groups in the same way.

1. **Detailed method**
   For three dike rings, 7, 14 and 36, a detailed calculation of the consequences was carried out. The consequences of flooding were determined using the most sound method theoretically, i.e. with the aid of 'detailed' flooding scenarios (see section 2.2.2).
2. **Global method**
   A global calculation of the consequences was carried out for all 16 dike rings. The consequences of flooding were determined in general terms with the global method (see section 2.2.2).

In this chapter no flooding probabilities for the dike rings will be presented which are greater than 1/100 per year, although these were calculated for a number of dike rings. The reason for this is that at the present hydraulic loads and given the present condition of the primary water defences such large probabilities are not to be expected. The relatively high probabilities are most probably due to a lack of knowledge and information. Further investigation will lead to a reduction in the relatively large flooding probabilities. In the tables flooding probabilities greater than 1/100 per year are indicated by >1/100 per year. The risks in these cases were determined with a probability of flooding of 1/100 per year.

An area description is included in Appendix B per dike ring area and the calculated risks, consequences and probabilities per dike ring are explained in more detail.

3.2 Risks on the basis of detailed calculation of consequences

This section discusses the results for the three dike rings for which a detailed calculation of the consequences was carried out. In chapter 2 it was indicated that the risk of flooding of a dike ring area is the product of the consequences of flooding multiplied by the probability of flooding. To determine the consequences in this study we looked at the economic risk and the victim risk. No global method for calculating the number of victims was developed in the Floris project. To calculate the victim risks more 'detailed' flooding scenarios are therefore necessary. These are only available for the three dike rings for which a detailed calculation of the consequences was carried out. The victim risk was therefore only determined for these three dike rings.

The flooding risks are given in Table 3-2: the economic risk, the victim risk, the economic damage, the number of victims and the probability of flooding. The information in this section is taken from the individual dike ring reports (the risk cases) on flooding scenarios, economic damage and the calculation of victims.

The economic risk is the amount that over a long period should be set aside per year to be able, in theory, to cover the damage caused by floods. The economic risk is calculated as the sum of the products of the damage and the probability of flooding of the various flooding scenarios.

The calculated damage and the number of victims vary per flooding scenario. The bandwidth in the damage is due to the different flooding scenarios considered. Apart from the different flooding scenarios taken into account, the number of victims of a flood also depends on the possibility and the rate of evacuation. Whether a flood can be predicted or not depends on the failure mechanism and the threat. Extremely high water levels on the rivers usually presage their arrival a few days in advance while a storm surge at sea is often only predictable at much shorter notice. And a flood caused by piping can occur totally unexpectedly. The upper limit for the numbers of victims in Table 3-2 is based on unexpected flooding where no evacuation takes place. The lower limit is based on a predictable inundation in which an organised evacuation takes place. With more extreme flooding scenarios than those which have now been considered, there could be more victims. An estimate of the upper limit which also takes into account how people react in alarming situations is difficult to make.

Dike ring	**Economic risk: flooding probability times economic damage [million €/year]**	Consequence: average economic damage* [million €]	Consequence: victims** [number]	Annual probability of flooding
Noordoostpolder	**2.1**	1,900	5 - 1400	1/900
Zuid-Holland	**2.3**	5,800	30 - 6100	1/2500
Land van Heusden / De Maaskant	**37**	3,700	5 - 800	>1/100

* The average damage in the different flood scenarios.
** The margin gives the number of victims for different flood scenarios and different evacuation scenarios.

Table 3-2 Overview of the risks, consequences and probabilities in three dike ring areas

The following can be concluded from Table 3-2:

- The economic risks in the present situation are approx. € 2 million per year for both Zuid-Holland and the Noordoostpolder. For dike ring 36 Land van Heusden/De Maaskant the economic risk is more than a factor 10 greater, i.e. approx. € 37 million per year.
- The upper limit of the damage range for the Noordoostpolder amounts to € 4200 million and € 7500 million for Land van Heusden/De Maaskant. This amount is much higher for Zuid-Holland: € 37,000 million. The number of victims for Zuid-Holland may also be higher than for the other two dike rings. Particularly with multiple breaches from the coast large areas with many inhabitants could be inundated.
- The probability of flooding for dike ring 14 Zuid-Holland is relatively small: approx. 1/2500 per year. The most significant mechanisms here are dune erosion, uplifting and piping of one dike section and the reliability of the closing procedures of some hydraulic structures. For dike ring 7 Noordoostpolder the probability of flooding amounts to 1/900 per year and here the most significant mechanism is structural failure of two hydraulic structures. For dike ring 36 Land van Heusden/De Maaskant, the mechanism of uplifting and piping, the non-closure of two hydraulic structures and insufficient defensive height of a tidal lock contribute the most to the probability of flooding.
- From research it appears that only to a limited extent is it possible to predict well in advance flooding from the sea or a lake such as at dike ring 7 Noordoostpolder and dike ring 14 Zuid-Holland. The failure mechanism uplifting and piping is also almost impossible to predict, such that in the present situation it

would be difficult to arrange preventive evacuation for dike ring 36 Land van Heusden/De Maaskant.

By adopting a few measures the risks can be greatly reduced. This was investigated in the weak locations analysis. The most cost-effective measures and the effect on the risks and the flooding probabilities are given in appendix B. The measures could consist of undertaking further research (e.g. by taking soil samples), revising the closing procedures for hydraulic structures or making physical changes to the flood defence. Often a considerable improvement in the safety can be achieved just by tackling a few dike sections. And in some cases the weak location had already been found in the 5-yearly safety assessment, and plans had already been made to improve the section or hydraulic structure.

Costs are involved in taking measures. In determining the costs it was assumed that physical measures had to be taken. However, it is also possible that further investigation shows that the weak location is not actually weak. That is then a blessing, because the cost of investigation is generally less than the cost of making improvements. The recommendation is therefore, to always carry out further investigation first. If it should turn out that all the measures are necessary, then the order of magnitude of the costs will be around several million euros for dike rings 7 and 14 and several tens of millions for dike ring 36.

3.3 Risks on the basis of global calculation of consequences

The flooding risks for all 16 dike rings considered are given in table 3-3: the economic risk, the economic damage and the flooding probability. The economic risk can be seen as the amount that should be set aside per year to be able, in theory, to cover all the damage caused by flooding.

The information in this section is taken from the dike ring reports. The economic damage was calculated using the 'global method' (see section 2.2.2). To calculate the number of victims more 'detailed' flooding scenarios are needed. These are only available for the three dike rings for which a detailed calculation of the consequences was carried out. In the global method no numbers of victims and victims risks are calculated. These figures were calculated in (National Institute for Public Health and the Environment, 2004).

Dike ring	Economic risk: flooding probability multiplied by the economic damage [million €/year]	Consequence: maximum economic damage* [miljoen €]	Annual probability of flooding
Noordoostpolder	10 **	9,000	1/900
Zuid-Holland	116**	290,000	1/2500
Land van Heusden / De Maaskant	180**	18,000	>1/100
Terschelling	0.1	160	1/1500
Mastenbroek	12	1,200	> 1/100
Noord-Holland	116	58,000	1/500
Lopiker- en Krimpenerwaard	100	10,000	>1/100
Alblasserwaard	48	19,000	1/400
Goeree-Overflakkee	3	3,700	1/1200
Zeeuws Vlaanderen	140	14,000	>1/100
Bommelerwaard	10	2,600	1/250
Land van Maas en Waal	64	6,400	>1/100
Ooij en Millingen	0.7	1,000	1/1.400
Betuwe, Tieler- en Culemborgerwaarden	180	18,000	>1/100
Rijn en IJssel	34	6,800	1/200
Oost-Veluwe	31	3,100	>1/100

* The damage is the maximum damage which would occur if the entire dike ring area were to be flooded. This is overestimated for major dike ring areas and dike ring areas with compartments. The number of victims cannot be determined with the global method.

** The damage calculated using the detailed method appears to be much less than the damage calculated with the global method.

Table 3-3 Overview of economic risk, damage and probabilities for all 16 dike rings considered

The following conclusions can be drawn from Table 3-3 :

- The economic risk per dike ring area exhibits wide variation: from approx. € 0.1 million for Terschelling to almost € 200 million for Land van Heusden/De Maaskant and Betuwe, Tieler- and Culemborgerwaarden.
- The economic risk for the dike rings along the rivers is relatively large compared with other dike rings. This is mainly due to large flooding probabilities.
- The damage in the event of flooding of the dike rings calculated with the global method varies from € 160 million for Terschelling to € 290 billion for Zuid-Holland. The low value for Terschelling is mainly due to its small size and the modest number of economic activities. The relatively large values for Zuid-Holland

are due mainly to the presence of lower-lying areas with a large number of economic activities which would be relatively quickly inundated.

- For dike rings 10, 15, 32, 36, 41, 43 and 52 the probability of flooding is less than 1/100. It turned out that the mechanism uplifting and piping contributed most to the probability of flooding for practically all the dike rings. In a number of dike rings it appeared that closing procedures for hydraulic structures also made a relatively large contribution to the probability. Only for Noord-Holland was another mechanism dominant, namely sliding.
- For several dike rings the probability for the mechanism of uplifting and piping was very high. This is partly due to the large knowledge uncertainties (little is known about the subsoil) but it is also possible that uplifting and piping is underestimated as a phenomenon. The current practice is for large-scale 'containment' and the effect of containment is not included in the calculation of the probability of flooding, partly because the human intervention aspect is a somewhat unpredictable factor.

Here too, as with the results of the detailed calculation of consequences, it is the case that a small number of sections or hydraulic structures can make a relatively large contribution to the probability of flooding. By undertaking further research or taking a small number of measures, the flooding probability can be limited and with it the risk, too. For a number of dike rings with a relatively large probability, the costs of measures and the effect, or the risk reduction, were investigated in the weak locations analysis. This was the case for dike rings 10, 14, 15, 25, 36 and 52. The most cost-effective measures and the effect on the risks and the flooding probabilities are given in appendix B. Due to budgetary limitations and insufficient time, a weak locations analysis was not carried out for all the dike rings.

3.4 Additional information obtained from the risk calculations

Besides giving information on the risks, the method for calculating flooding risks also provides plenty of other relevant information which is particularly useful to understanding safety and the opportunities for improving it.

For example, so far only flooding probabilities per dike ring have been presented, but the analysis also gives 'sub-results': the contributions to the probability of flooding per mechanism over all sections or hydraulic structures, the contribution to the probability of flooding per section or per hydraulic structure over all mechanisms, or the contribution to the probability of flooding per section or per hydraulic structure per mechanism.

The information presented in this section can be used for various purposes. It is not the intention here to give an exhaustive overview, but rather to give an impression of the relevant results. This section includes:

- insight into the contribution made by the separate failure mechanisms in the probability of flooding;
- insight into the contribution made by the separate sections or hydraulic structures per failure mechanism;
- insight into hydrodynamic flooding scenarios;
- insight into the economic losses per flooding scenario;
- insight into the numbers of victims per flooding scenario;
- insight into the costs and benefits of measures for determining optimum economic protection levels;
- insight into the damage to natural features (the landscape, wildlife and cultural heritage);
- insight into environmental damage.

The results are given per subject or for one or several dike ring areas. For other results please see the individual dike ring reports.

3.4.1. Contribution of the individual failure mechanism

The results per mechanism per dike ring are presented in Table 3-4 to Table 3-7. These results are available for all the dike ring areas considered, but here we present these only for the three dike rings for which a detailed calculation of the consequences was carried out.

Nr.	Dike ring	Overflow and wave overtopping	Uplifting and piping	Damage to the revetment and erosion of the dike body	Sliding of innerslope
7	Noordoostpolder	1/30.000	$<10^{-6}$	$<10^{-6}$	1/50.000
14	Zuid-Holland	1/150.000	1/7000	1/70.000	$<10^{-6}$
36	Land van Heusden / De Maaskant	1/1200	1/100	1/900	$<10^{-6}$

Table 3-4 Dike flooding probabilities per failure mechanism for three dike ring areas

The following can be concluded from Table 3-4:

- The probabilities for the failure mechanism overflow and wave overtopping are relatively small. The probability is directly related to the height of the flood defence, and this appears to be in good order. In comparison with dike rings 7 and 14, the probability for dike ring 36 Land van Heusden/De Maaskant is relatively large. This has partly to do with the increase in the normative discharge for the Rhine and the Maas made in 2001 (Ministry of Transport, Public Works and Water Management, 2001). A normative discharge rate was not taken into account in the Floris project, but this change does have an impact on the probability distribution used for extreme discharges. However, the river and the dikes have not yet been adjusted to this new situation. This will be the case, however, after the Space for Rivers programme is implemented.

- For Dike ring 14 (Zuid-Holland) the probability is relatively small, and this is partly because, in accordance with the Leidraad Benedenrivieren (Guideline for tidal rivers), a dike ring approach had already been applied when determining the height of the flood defences, etc. This means that the safety standard from the Flood Defences Act applies not to a section in this dike ring, but to the entire ring.
- For dike ring 36 Land van Heusden/De Maaskant the probability for the mechanism uplifting and piping is very high. This is partly due to the large knowledge uncertainties (little is known about the subsoil) but it is also possible that uplifting and piping is underestimated as a phenomenon.
- The contributions made by the other two mechanisms is small.

Nr.	Dike ring	Dune erosion
7	Noordoostpolder	n.v.t.
14	Zuid-Holland	1/5700
36	Land van Heusden / De Maaskant	n.v.t.

Table 3-5 Flooding probabilities for dunes in three dike ring areas

Table 3-5 shows the flooding probabilities for the dunes. Dunes are, of course, not relevant for dike rings 7 and 36. All dune sections for dike ring 14 give a probability of flooding of 1/5700, in which the dunes along the Scheveningen promenade make the largest contribution. In relative terms this is, therefore, a relatively weak location in the dike ring. For the dunes in South Holland it appears that the high priority weak links along the coast have a greater probability than other dune sections along the South Holland coast. In absolute terms the dunes in the Floris project calculations are not seen as weak locations, but this occurs because in the Floris project the current hydraulic loads (boundary conditions) were used, as laid down every five years (and most recently in 2001) by the Minister of Transport, Public Works and Water Management. These 2001 hydraulic boundary conditions do not yet take into account the possibly heavier wave conditions, as indicated in the report of the Ministry (Ministry of Transport, Public Works and Water Management, 2005).

Nr.	Dike ring	Overflow and overtopping	Not closing	Structural failure
7	Noordoostpolder	1/10.000	1/15.000	1/1000
14	Zuid-Holland	1/20.000	1/9000	<1/10000
36	Land van Heusden / De Maaskant	1/2000	1/300	1/1000

Table 3-6 Flooding probabilities of hydraulic structures per failure mechanism for three dike ring areas

Table 3-6 shows the flooding probabilities for the hydraulic structures. For hydraulic structures which remain open under normal conditions the mechanism of 'not-closing' generally makes the largest contribution. Often an effective measure, such as revision of the closing procedures, is sufficient to reduce the probability of a problem occurring.

Figure 3-2 shows, as a bar chart, the contribution made by all mechanisms for dike ring 14: Zuid-Holland. Here too, it appears that uplifting and piping and dune erosion are the most significant mechanisms.

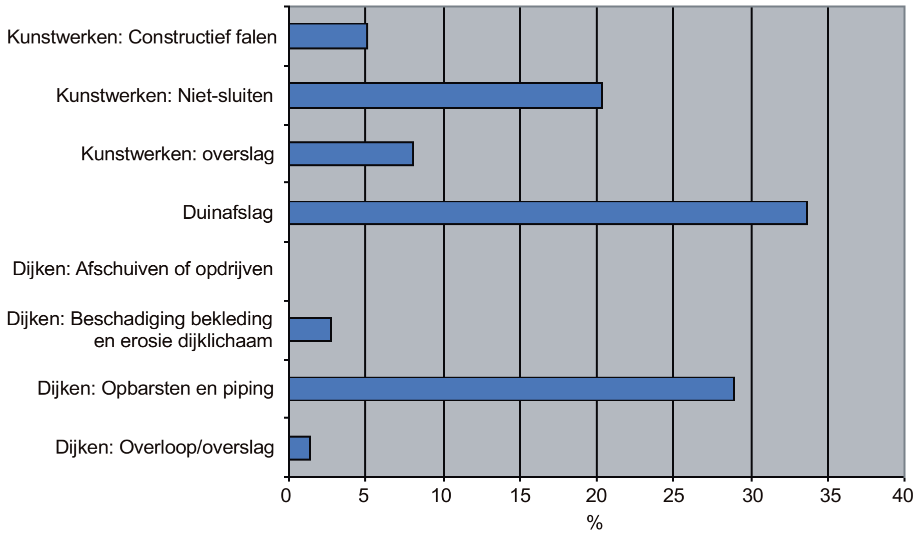


Figure 3-2 Relative contribution (in %) made by the failure mechanisms to the probability of flooding for dike ring 14: Zuid-Holland

Table 3-7 gives an overview of the mechanism overflow and wave overtopping for all dike rings. From this table it appears that the probabilities are often relatively small, but it should be remembered that the submechanism 'sliding of inner slope' (as a part of the mechanism overflow and wave overtopping) was not included in the Floris project. It is expected that the inclusion of this mechanism will result in a relatively small increase in the probability. What is clear is that the dike rings along the rivers have relatively the largest probabilities, and that the reasons for this are because the safety standard in the Flood Defences Act is relatively the highest for these areas, while the failure mechanism overflow and wave overtopping is mainly concerned with the dike height. Furthermore, the Space for Rivers programme still has to be implemented for these dike rings, and it is expected that this programme will halve the probabilities for the mechanism overflow and wave overtopping. The Space for Rivers programme is not expected to have much impact on the failure probabilities for all other failure mechanisms.

Number	Dike ring	Failure probability due to overflow or wave overtopping
3	Terschelling	1/30.000
7	Noordoostpolder	1/30.000
10	Mastenbroek	1/1200
13	Noord-Holland	1/5000
14	Zuid-Holland	1/150.000
15	Lopiker- en Krimpenerwaard	1/2000
16	Alblasserwaard en Vijfheerenlanden	1/15.000
25	Goeree-Overflakkee	1/7000
32	Zeeuwsch Vlaanderen	1/10.000
36	Land van Heusden / De Maaskant	1/1200
38	Bommelerwaard	1/1600
41	Land van Maas en Waal	1/1300
42	Ooij en Millingen	1/1900
43	Betuwe, Tieler- en Culemborgerwaarden	1/1600
48	Rijn en IJssel	1/2000
52	Oost-Veluwe	1/600

Table 3-7 Flooding probabilities for the mechanism overflow and wave overtopping for all dike rings considered.

It is also striking that the probability for Noord-Holland is relatively large, while the probability for Zuid-Holland is relatively small. The relatively large probabilities for Mastenbroek and Goeree-Overflakkee are also notable.

3.4.2. Contribution of the individual sections

The calculations of the flooding probabilities also provides insight into the contribution of each section or hydraulic structure to the total probability of flooding, possibly as the sum of all failure mechanisms. In this section we present the contribution made by the separate sections for the failure mechanism overflow and wave overtopping for two dike rings (14: Zuid-Holland and 43: Betuwe, Tieler- and Culemborgerwaarden). For dike ring 14: Zuid-Holland the contribution of the separate sections are also given for the mechanisms uplifting and piping. Figure 3-3 shows the contribution of the dike sections, for overflow or wave overtopping, along the Nieuwe Waterweg and along the Nieuwe Maas. The wide fluctuation between the sections and that the individual probability of failure of each section separately is less than 1/200,000, are striking. The contribution made by the mechanism for all sections is equal to 1/150,000 which is just slightly larger than the contribution of the section with the largest probability of flooding. This is because this is a failure mechanism which is closely related to the water level and therefore they are mutually linked.

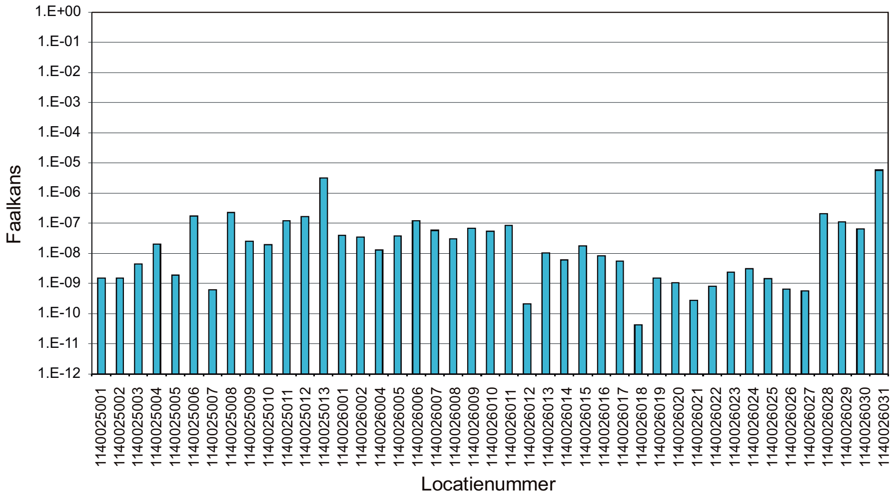


Figure 3-3 Probability of failure of the dike sections in dike ring 14: Zuid-Holland for the mechanism overflow or wave overtopping.

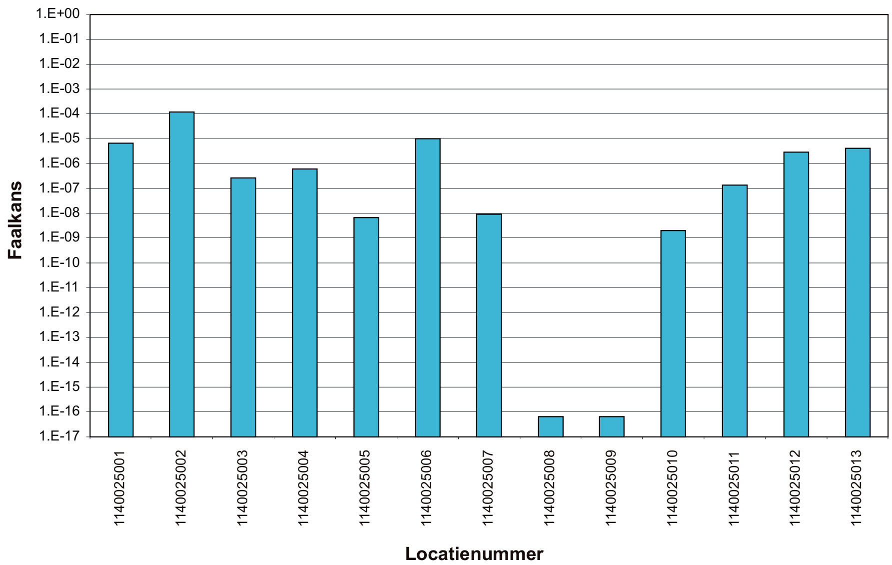


Figure 3-4 Probability of failure of the dike sections in dike ring 14: Zuid-Holland for the mechanism uplifting and piping.

From the above figures it can be concluded that dike ring 14 is in order when it comes to the height, but that the mechanism uplifting and piping contributes much more to the probability of flooding than overflow and wave overtopping. This is the type of insight which can be gained with the Floris method.

For dike ring 43 too, the probability of failure of all dike sections is given for the failure mechanism overflow and wave overtopping. Figure 3-5 shows the difference between the dike height and the 'assessment level' (the normative high water level associated with a normative discharge of 16,000 m^3/s). This difference we have called the 'retaining height', and according to the design guidelines of the Minister of Transport, Public Works and Water Management should be at least half a metre; it also depends on the height of the local wave regime. Because the dikes and/or the river have not yet been resized in relation to the new normative discharge, the height is insufficient for several dike sections. This problem will be resolved in the Space for Rivers programme by making modifications to the river or the dikes. Figure 3-5 shows a clear relationship between the repeat interval of a section and its height relative to the assessment level: if the dike is higher than the 'assessment level' then the repeat interval of that dike section is relatively large. This is as would be expected.
The smallest repeat interval for one section is roughly 2200 years, and the repeat interval for this mechanism for all sections is 1600 years.

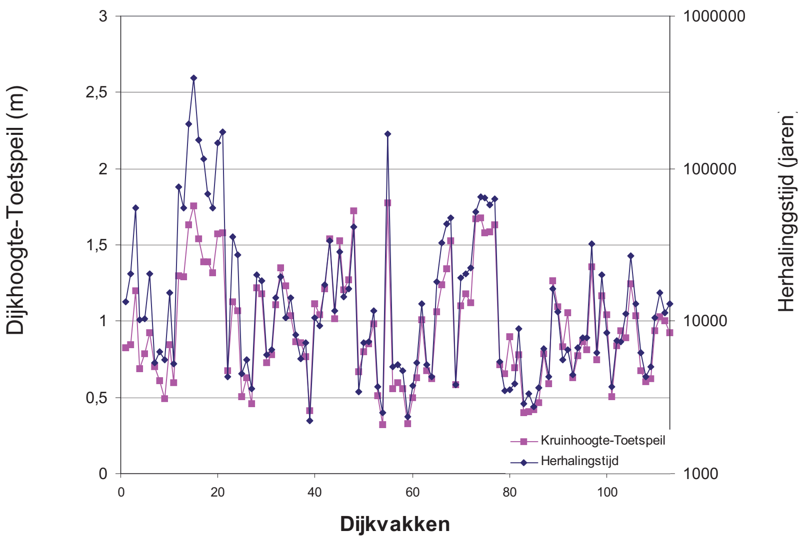


Figure 3-5 Relationship between dike height minus assessment level and repeat interval

3.4.3. Flooding scenarios

As indicated in chapter 2, the consequences of flooding can be determined in two ways: the 'global' method in which the flooding scenario is based on the principle that the water reaches the lowest level of the crest, and the 'detailed' method in which the effects of a flood can be progressively calculated using simulation models.
In the global method a map is developed with the maximum water depths. This map is shown in Figure 3-6. The map gives a picture of the

maximum water depths which can occur in the event of a flood and is therefore very important. For example, it can be seen on the map that the coastal region of North and South Holland is much higher than the polders behind this coastal area. What this means is that a city like The Hague is much less vulnerable than the Willem Alexanderpolder near Rotterdam.

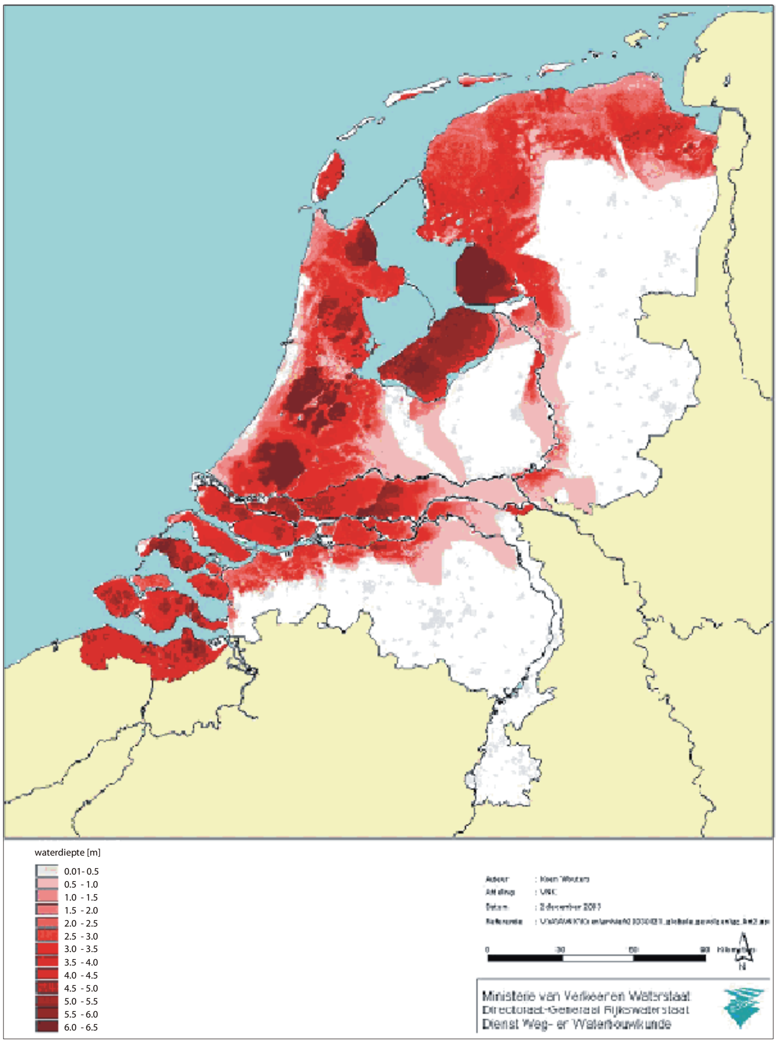


Figure 3-6 Maximum water depth in the event of a flood

To determine the 'detailed' consequences of a flood, calculations were carried out in the context of the Floris project using a hydrodynamic simulation model. These calculations are available in the form of 'short films' in which the course of a flood over time can be followed. These short films are now available for several dike rings: for dike ring 7: Noordoostpolder, dike ring 14: Zuid-Holland and dike ring 36: Land van Heusden/De Maaskant. More than 10 different scenarios were calculated for each dike ring. A particularly difficult problem in these simulation calculations is the behaviour of the non-primary flood defences in a dike ring area, such as a secondary dike or an old flood defence. These so-called 'linear elements' can retain water, as a result of which fewer areas are inundated or the flooding is delayed. However, it is also clear that these flood defences are not built for these loads and are not maintained for that purpose. Therefore two calculations were made in the Floris project: one in which these defences hold until they overflow, and one in which these quasi-flood defences collapse at an earlier stage.

Only the results for dike ring 7: Noordoostpolder are discussed in this section. Figure 3-8 shows the results of a flooding calculation, i.e. the water depths in dike ring 7: Noordoostpolder. The breach location for the breach scenario in question lies south of Urk (Figure 3-7).

Figure 3-7 Breach scenario with breach location south of Urk

In this scenario floodwater depths of more than 3 metres occur in the western part of the dike ring. From figure 3-8 it can also be seen that the edges of the dike ring area are clearly higher: that area will not be flooded.

Besides maps with water depth, various other relevant maps can also be made. In this way information about the speed at which the water rises can also be obtained. This information is important when estimating the number of victims.

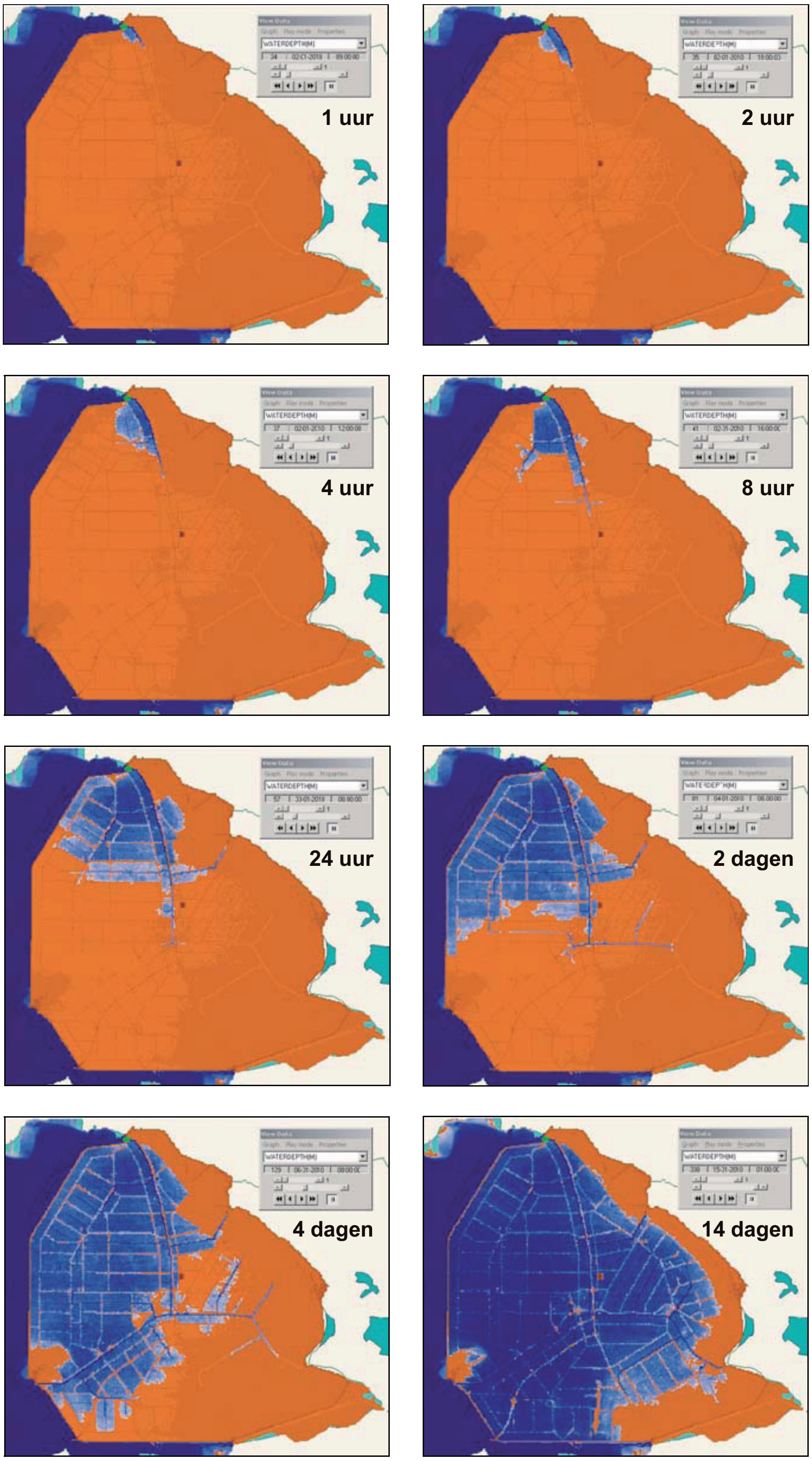


Figure 3-8 The course of a flood for a breach scenario in the Noordoostpolder

3.4.4. Economic damage per flooding scenario

Flooding scenarios were used to estimate the economic damage in the event of a flood. In the global method the map with maximum water depths (Figure 3-6) was used to determine the damage. The results are shown on the map in Figure 3-9.

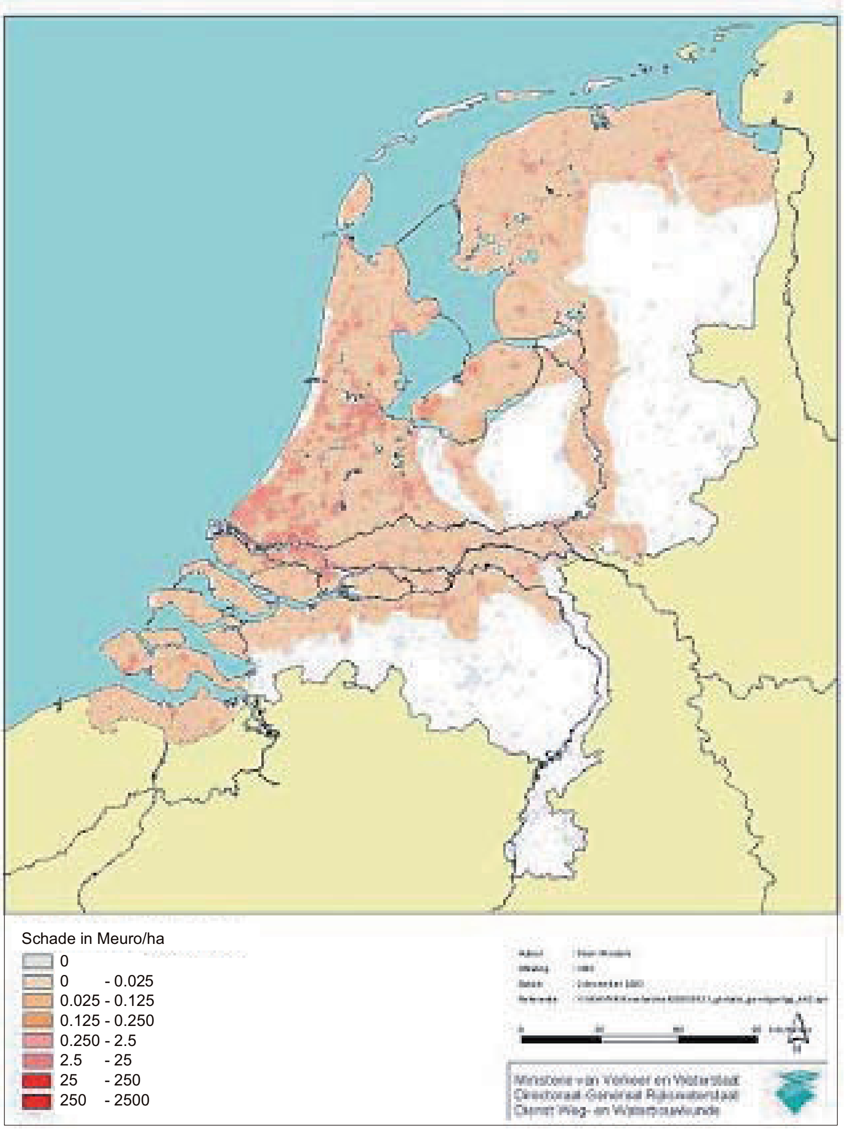


Figure 3-9 Map of damage in the Netherlands at the water depths given in Figure 3-6.

In the detailed method the economic damage is determined per flooding scenario, each of which is calculated with a hydrodynamic model. The breach sites were chosen at the weak locations. Table 3-8 gives an overview of the ten most likely flooding scenarios for dike ring 14 in the present situation. It is also shown whether the flooding occurs from the coast or from the river, and how many breaches occur. The maximum water level along the coast or the river before the flood is also given. The sum of all flooding scenarios is equal to the probability of flooding for the entire ring. The economic risk for the entire dike ring is equal to the sum of the risk (i.e. damage * probability) for all flooding scenarios.

Number scenario	Break location	Probability [-]	Damage [billion €]	Type	Number of breaches	Water level [m +NAP]
1	Kralingen	1/7300	6,8	Rivier	1	1,95
2	Scheveningen Boulevard	1/8400	1,9	Kust	1	4,65
3	Scheveningen sluis	1/13.000	3,6	Kust	1	5,1
4	Katwijk	1/41.000	11,3	Kust	1	4,43
5	Hoek van Holland	1/87.000	2,0	Kust	1	4,95
6	Katwijk en Scheveningen Boulevard	1/120.000	13,4	Kust	2	4,65
7	Scheveningen Boulevard en Ter Heijde	1/140.000	22,8	Kust	2	5,67
8	Rotterdam West	1/200.000	2,5	Rivier	1	3,79
9	Rotterdam Oost	1/270.000	5,7	Rivier	1	3,73
10	Katwijk, Scheveningen Boulevard en Ter Heijde	1/450.000	37,2	Kust	3	5,67

Table 3-8 Overview of the damage per flooding scenario for the present situation in dike ring 14 Zuid-Holland.

The damage figures in Table 3-8 are lower (sometimes much lower) than the damage figure from the global damage calculation, where an amount of approx. 280 billion euros is given. The reason for this is that, as the detailed flooding calculations show, it is not very likely that the entire dike ring 14 would be inundated right up to its lowest crest. This also does not mean, either, that an amount of 280 billion euros damage is physically impossible, because no upper limit for extreme seawater levels and waves is known. It was calculated in the Floris project, for example, that a 'more extreme' scenario than scenario 10 in Table 3-8 with a seawater level of 7 m over mean sea level (Amsterdam ordnance level (AOL)) would lead to damage of almost 80 billion euros. The probability of this is smaller than 10^{-6} so its contribution to the risk is small.

3.4.5. Number of victims per flooding scenario

The flooding scenarios were also used to determine the number of victims. For the three dike rings to which the detailed method for determining the consequences could be applied, the number of victims was calculated per flooding scenario. This was not possible for the dike rings where the global method for determining consequences was used, because a number of essential variables (such as the speed of the water rising) are not available.

To illustrate this the results are given for dike ring 36: Land van Heusden/De Maaskant. The area has 407,000 inhabitants, but only a proportion of them would be affected by a flood. The number of people affected is given in Table 3-9, together with the number of victims. Evacuation was not taken into account in the calculation of the number of victims since this is an unexpected flood.

Number	Breach location	Number of people affected	Number of casualties
1	Bokhoven	3300	20
2	Boxmeer	1200	20
3	Cuijk	43.000	300
4	Dieden	111.000	480
5	Doeveren	9000	40
6	Gewande	63.000	240
7	Heusden	28.000	80
8	Keent	87.000	320
9	Kraaijenbergse plassen	179.000	800
10	Lith	49.000	170
11	Maaspoort	42.000	120
12	Oijen	46.000	120
13	Ravestein	81.000	320

Table 3-9 Overview of the number of people affected and the number of victims per flooding scenario for the present situation in dike ring 36: Land van Heusden/De Maaskant

The water depth in the flooding scenario with the largest number of victims is shown in Figure 3-10. The location of the breach is shown with a red arrow. In general, the flooding depths may be said to be limited at 1-2 metres. Only in the rural area to the west of Oss are greater flooding depths noted. This area is sparsely populated. In some places in the area the speed at which the water rises is very rapid which often results in more victims.

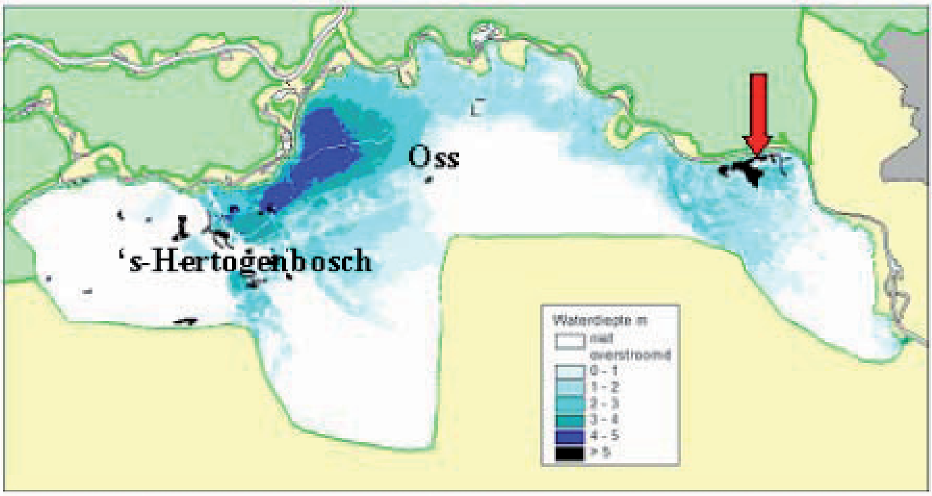


Figure 3-10 Water depths for the breach scenario at the Kraaijenbergse Plassen lakes

Evacuation was not taken into account in Table 3-9. For the rivers region in particular, it is often suggested that evacuation can easily take place, because high water on the river can be predicted. Therefore the influence of evacuation (Doef and Cappendijk, 2005) was investigated in the Floris project. It goes without saying, however, that the inclusion of evacuation in any determination of numbers of victims can only be justified if measures are also taken to implement this measure, e.g. in disaster preparedness plans.

The number of victims in the event of a flood was determined for four situations, depending on a predicted or unpredicted inundation and the use of evacuation (Doef and Cappendijk, 2005). Figure 2-5 shows the event tree which was used to investigate the influence of evacuation. The ability to predict a flood is critical to preventive evacuation. The level of predictability depends on the type of threat and the type of failure mechanism. Extremely high water levels on the rivers usually presage their arrival a few days in advance. A storm surge at sea is often only predictable at much shorter notice. Uplifting and piping is more difficult to predict than overflow and wave overtopping.

Table 3-9 gives the victims for the event 'unexpected flooding, no evacuation'. The other events lead to fewer victims, where 'predicted flooding' in particular results in far fewer victims. The maximum number of 800 victims is then reduced to around 40. By allocating a probability to all events, an FN curve, as it is called, can be made: a means of presentation frequently used in other safety areas. See Figure 3-12 for this. The FN curve shows the probability of exceeding a certain number of victims. The figure also shows the FN curve which was used in the RIVM study (National Institute for Public Health and the Environment (RIVM), 2004).

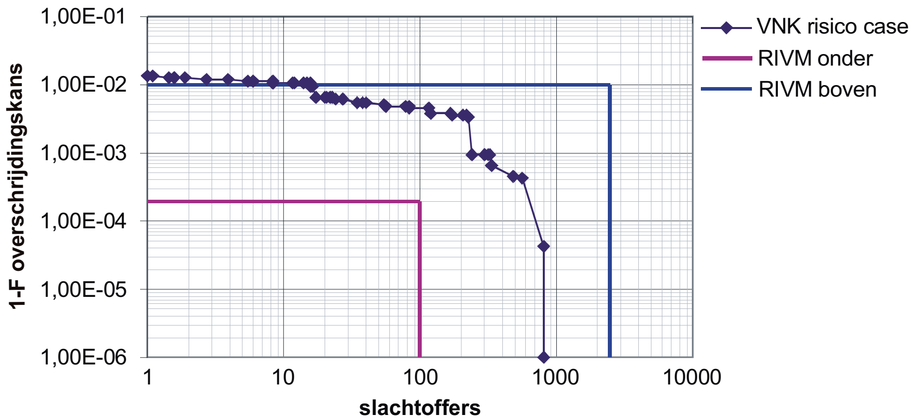


Figure 3-11 Group risk curve for dike ring 36 and comparison with RIVM estimates

The probability calculated in the Floris project is greater than the RIVM upper limit. In many cases the consequences will be smaller than the lower limit estimate of the RIVM. The scenarios with the largest numbers of victims lie roughly between the lower and upper limits given by the RIVM.

The breach scenarios 8 and 9 at Keent and the Kraaijenbergse Plassen make major contributions to the group risk. This scenario partly caused the downward jump in the middle of the FN curve.

Based on the flooding scenario with the largest number of people affected (approx. 180,000 people) the average individual risk is 7.10^{-6} per year (i.e. 1.31/180,000 in which 1.31 is the annual victim risk, see Table 3-2).

3.4.6. Overview of cost/benefit analysis for dike ring 14

In the Floris project a first step was made towards a cost/benefit analysis for dike ring 14 (Thonus et al., 2005). The results of this survey may not be used for any discussion of optimum safety standards because a number of factors have not yet been included in the analysis. For example, the anticipated climate change has not been taken into account, and these changes could have an impact on the optimum. The cost calculation was also carried out in very rough terms, as a result of which the costs could be overestimated or underestimated.

Measures for the flood defences were defined in the study. The effect of each measure on the probability of flooding was investigated with the aid of PC-Ring. For a number of measures this is relatively easy because there is a clear connection with a variable in PC-Ring. In this way measures can be defined for the mechanism uplifting and piping by increasing the seepage length. But there are also measures where no clear connection can be made with a variable, such as for the Scheveningen promenade and the hydraulic structures. In these cases a global estimate was made of the effects of measures.

It was then estimated what costs would be involved in taking measures. These costs are often locally dependent (the presence of built structures often has a major impact on the costs). The benefit of the measures is the reduction in the risk of flooding. To be able to compare benefits with the investment costs the present value (or cash value) of the risk was determined. In the analysis a discount rate of 4% and an economic growth of 2% were assumed. It was also checked in the investigation whether the First Year Rate of Return criterion was met (Netherlands Bureau for Economic Policy Analysis, 2005).

Four aspects were considered in the investigation:
1. analysis for material damage only for the entire dike ring;
2. analysis for both material and immaterial damage for the entire dike ring;
3. analysis for material damage only, and only for the dikes in the dike ring;
4. analysis for both material and immaterial damage, only for the dikes in the dike ring;

Only the results for the second aspect are presented in this section. The results of the analysis are given in Figure 3-12: the investment costs of measures, flooding risks and the total costs are shown as a function of the probability of flooding. From this figure it can be seen that the economic optimum lies at a probability of flooding of 1/30,000. The investment costs then amount to roughly 140 million euros. The results are heavily dominated by changes to the Scheveningen promenade: for which the estimated cost is almost 50 million euros. If this modification can be carried out more cheaply, then the probability of flooding associated with the economic optimum would be less than 1/100,000.

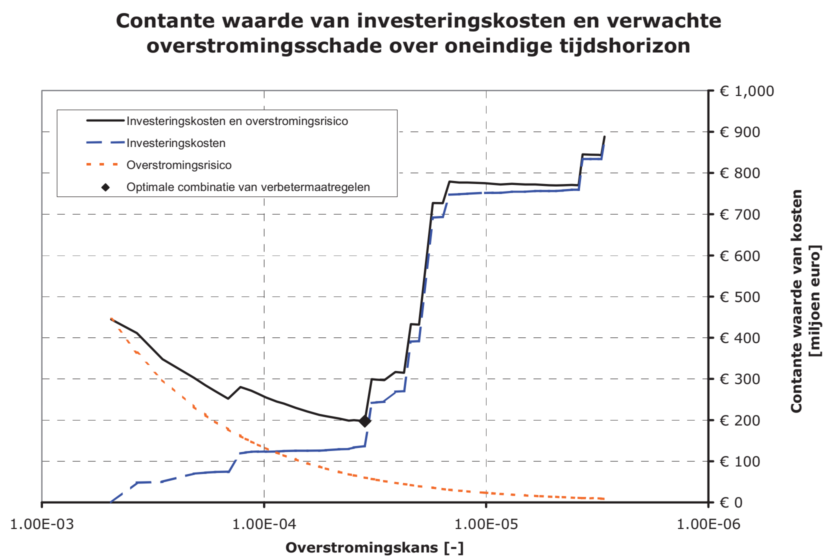


Figure 3-12 Costs and benefits for dike ring 14: Zuid-Holland

3.4.7. Damage to natural features and the environment

Natural features
For two dike ring areas (dike ring 14: Zuid-Holland and 36: Land van Heusden/De Maaskant) an indicative calculation was made of the damage to aspects of the natural features. From this calculation it appears that the damage due to salt water flooding would be much greater than as a result of flooding with freshwater. It also appears that the damage to the aspects considered is significant (often more than 75% of the extant features would be lost, resulting in a disaster within a disaster). The method for calculating damage to natural features was developed in the Floris project, but not further applied.

Environmental damage
The method for obtaining a global overview of the environmental damage which may be expected was tested in a pilot study for one dike ring area (36: Land van Heusden/De Maaskant). Although no dispersion calculations have yet been done in the pilot, on the basis of this pilot no large scale environmental pollution is expected due to the release of substances from the industrial sites surveyed. However, it is recommended that businesses at risk have emergency plans in place to deal with possible flooding, so that they can take the necessary measures at the time to prevent as far as possible the release of substances. This also applies to oil tanks. According to (Delft Cluster, 2003) the amount of hazardous substances contributed by offices and households is negligibly small. Moving activities to higher and safer areas would, for the time being, appear to be going too far and is very costly in comparison with the scale of the risks.

4. Analysis and utility of the method

In this chapter the results from chapter 3 will be analysed in more detail. First of all, it will be considered whether the calculated probabilities are not far too big in comparison with the standards set for the primary flood defences in the Flood Defences Act. This will be followed by a discussion of a possible use for the results, i.e. to conduct a public debate on the basis of our understanding of flooding risks and the cost of further reducing these risks. The results of the Floris project however are not suitable for this, but a major step forward has been taken towards that discussion. Although some comments can already be made about what contribution the Floris project results can make.

4.1 Are the calculated probabilities not too large?

The most striking results in this report are the relatively large flooding probabilities which were calculated. The question is: how can we explain this?

Available knowledge and information
First of all, it is important to note that the calculated probability of flooding is the most realistic portrayal of the probability of flooding *given the available knowledge and information*. The calculated probability is not changed only by physically strengthening the flood defence. With further research the available information can be increased and the knowledge uncertainty reduced. Whether this will actually lead to a smaller probability depends on the results of the research. If the research turns out favourably then further research results in a lower probability of flooding. A less favourable result will lead to a higher probability of flooding.

Relationship with exceedance frequency
Often the calculated probability of flooding is compared with the safety standard from the Flood Defences Act. This safety standard however, is not a probability of flooding, but an exceedance frequency of water levels (Technical Advisory Committee on the Flood Defences, 2000). The water defence is designed on the basis of this water level (the design level), not only in terms of height but also in relation to other failure mechanisms. Although, for these mechanisms no specific standards are formulated in the Flood Defences Act. The Delta Committee assumed that the probability of flooding would be smaller than the exceedance frequency: "..... some exceedance of the design level does not immediately have to result in a disaster. In the calculation of the level referred to in the contribution, this was however based on the idea that exceeding this level would lead to a disaster with maximum damage. This level was therefore referred to as a disaster level; the design level could be lower" (Geodelft, 2004, p. 33). The Delta Committee calculated at the time an economically optimum probability of flooding of 1/125,000 for dike ring 14. This probability is much smaller than the exceedance frequency in the Flood Defences Act (1/10,000), because it is reasonable to expect that the flood defence would not directly fail if the normative water level were to be exceeded (residual strength).

The Floris project method for determining flooding probabilities differs from the present approach based on exceedance frequencies in three respects:

- A dike ring approach is taken instead of a dike section approach: a dike ring is a combination of dike sections, dunes and hydraulic structures;
- the specific inclusion of various ways in which a dike can collapse (failure mechanisms such as loss of stability and overflowing of a dike);
- the inclusion of uncertainty in the calculation of the probabilities.

The probability of flooding is thus based on different principles than the exceedance frequency and thus gives different results. There is a strong relationship, however, between the exceedance frequency of water levels and the probability of flooding for the failure mechanism overflow and wave overtopping. In general, it is the case that if the safety standard in the Flood Defences Act is relatively small, that the probability of failure for a dike section is therefore relatively small for the mechanism overflow and wave overtopping. In determining the probability of failure for this mechanism the 'residual strength' as it is known, is also included, which means that a flood defence will not immediately collapse if it not longer meets the safety standard laid down in the Flood Defences Act. For example: a flood does not immediately have to occur at a higher water level than the 'normative' assessment level because the flood defence is built higher than the 'normative' assessment level.

The flooding probabilities calculated in the Floris project are usually bigger and sometimes smaller than the safety standard. This is logical because the probability of flooding was determined in a different way than the standard.

The probability of flooding may be larger than the present standard for the following reasons:

- In the rivers region the design water level, which is derived from the standard, was raised a few years ago. Not all the flood defences yet meet the new design standards; in the Floris project the condition of the flood defences before the implementation of the Space for Rivers programme was what was used.
- The probability of flooding is the probability of failure of all dike sections in a dike ring combined; the present standard applies only to a dike section. The probability of flooding is always greater than the probability of failure of one of the individual dike sections.
- The probability of flooding combines the probabilities of all failure mechanisms for a dike ring. The probability of flooding is always greater than the probability of one of the individual failure mechanisms.
- The probability of flooding includes uncertainties (in knowledge and other aspects), which leads to a greater probability.

But the probability of flooding may also be smaller than the present standard, for the following reasons:

- The dikes do not flood immediately if the water level is higher than the design water level, because the dikes are built at least a half a metre higher.
- If a failure mechanism occurs, the flood defence does not necessarily immediately collapse; this 'residual strength' was taken into account in the Floris project.
- In some places the flood defences are considerably stronger than the norm, e.g. because in the past a stricter standard applied.

From the results it appears that the probabilities are much bigger than expected mainly for the mechanism uplifting and piping for dikes and not-closing for hydraulic structures. But in some dike rings other mechanisms set the standard. Further investigation should show whether the flood defence has an actual physical defect or whether this is due to lack of knowledge and information.

4.2 Analysis of the consequences of flooding

The risk approach also focuses on the consequences of flooding, the number of victims and the economic damage. To calculate damage and numbers of victims flooding scenarios are required.
The calculations show that in the event of large-scale flooding in the Netherlands, victims may be expected. The number of victims can vary from a few people to several thousands in extreme cases. The number of victims largely depends on the breach scenario and it is therefore difficult to make any statement about the nature of the numbers of victims for a particular dike ring. The number of victims seems to be much lower than the upper limits given in (Klijn et al., 2004) and (National Institute for Public Health and the Environment (RIVM), 2004). A major reason for this is that because of the conservative assumptions the flooding scenarios used in (Klijn et al., 2004) and (National Institute for Public Health and the Environment (RIVM), 2004) are very extreme.

The economic damage in the event of flooding of a dike ring area could amount to several billion euros or even several tens of billions of euros. Amounts in excess of 100 billion euros for one dike ring area however seem unlikely. The annual economic risk per inhabitant of a dike ring area varies widely: for dike ring 14 Zuid-Holland this amounts to approx. 1 euro, for example, but in the rivers region in particular, the risk per inhabitant is a factor 10 to 100 higher.

4.3 Risk assessment essential

In this presentation of the initial results from the Floris project, it is first and foremost the 'causes' and the background to the failure probabilities which are most important. This step includes an assessment of the influence of the underlying principles and the methods used on the calculation results. For example, it was specifically stated in the Floris project that conservative basic assumptions were taken because of insufficient or incomplete information. At the same time a possible perspective was outlined of what the results of the calculations could look like if realistic optimistic assumptions were applied. Then the most significant uncertainties and their impact on the flooding probabilities was analysed. An overview of the means and costs of reducing uncertainties and at the same time the calculated probability of flooding forms an essential part of this. This was done in the Floris project for a number of dike rings.

In this way the 'calculated probability of flooding' will gradually become closer and closer to the 'actual probability of flooding', The last step is to actually design strengthening measures which reduce the probability of failure of a flood defence. Increasingly advanced measures provide ever greater safety at ever greater cost. The framework for this introduction is, in fact, equivalent to the economic considerations which were once made by the Delta Committee.

4.4 Comparison with other studies

In other studies too, the flooding probabilities and the consequences of flooding were investigated. The question is, how do the results from the Floris project relate to some of the other studies? It should be noted, however, that other studies were based on quite different principles. But a comparison is useful, because we can evaluate how the results of the Floris project compare in relation to these other studies.
The flooding probabilities for the mechanism overflow and wave overtopping were compared with the flooding probabilities in *Rampen Beheersing Strategie Overstromingen Rijn en Maas* project [Disaster Preparedness Strategy Flooding Rhine and Maas] (Ministry of Transport, Public Works and Water Management, 2005), and the numbers of victims was compared with the results of (National Institute for Public Health and the Environment (RIVM), 2004).

Flooding probabilities in RBSO study and Floris project for one failure mechanism
The table below shows the results of the Floris project and the RBSO study for the failure mechanism overflow and wave overtopping, for seven dike ring areas in the rivers region. The RBSO study only investigated dike rings in the non-tidal river reaches.

Nr.	Dike ring	RBSO	Floris
36	Land van Heusden / De Maaskant	1/2050	1/1200
38	Bommelerwaard	1/2450	1/1850
41	Land van Maas en Waal	1/2000	1/1400
42	Ooij en Millingen	1/3600	1/2350
43	Betuwe, Tieler- en Culemborgerwaarden	1/1350	1/1600
48	Rijn en IJssel	1/4100	1/2350
52	Oost-Veluwe	1/1100	1/650

Table 4-1 Comparison of RBSO study and Floris project for the failure mechanism overflow and wave overtopping

It is noticeable in Table 4-1 that the probabilities in the RBSO study are almost always smaller than in the Floris project. That is to be expected, because in the RBSO study the calculations were based on the expected situation in 2015, i.e. after the Space for Rivers programme has been implemented. The calculations in the Floris project are based on the present situation. An overview of the differences in the calculation methods used by the RBSO study and the Floris project is included in (Ministry of Transport, Public Works and Water Management, 2005).

Number of victims in the Floris project and RIVM study
In the Floris project the number of victims was calculated for three dike rings. To determine the group risk an estimate was also made in the RIVM study (Klijn et al., 2004 and RIVM, 2004) of the number of victims in the form of a range.

Nr.	Dike ring	Victims Floris	Victims RIVM
7	Noordoostpolder	5 – 1400	700 - 3500
14	Zuid-Holland	30 - 6100	2.500 – 139.500
36	Land van Heusden / De Maaskant	5 - 800	100 – 2.500

Table 4-2 Expected numbers of victims in the event of a flood in the Floris project and in the RIVM study

What is striking in Table 4-2 is that the number of victims estimated in the Floris project is much lower for dike ring 14 than it is in the RIVM study. The reason for this is the understanding of flooding scenarios which was generated by the Floris project (see 3.2).

4.5 Assessment of risks

The desired level of protection against flooding is a political consideration which therefore belongs with government and parliament.

Studies such as the Floris project can provide information which are important in the public debate. But on the basis of what criteria and by what yardstick can we assess what risks are acceptable? And how can these risks be compared with other risks? A great deal has been published about this in the literature and in this section we will briefly explain just one approach (Vrijling et al., 1998).

The long-term accident statistics provide the basis for the approach in (Vrijling et al, 1998), because these implicitly reveal (through behaviour) the preferences of individuals and society in general. These statistics implicitly reflect what level of protection is accepted by society because no measures are taken to further reduce the risk. Another principle also adopted in the approach is that the risk of an activity cannot be assessed in isolation, but that all other relevant aspects also have to be looked at, such as the benefits of an activity. When thinking about setting standards and then the level of the standards, various factors play a role, such as the degree of voluntariness, the extent to which the people involved have a direct benefit from the activity and the costs which must be incurred to further reduce the risk. Three approaches were taken in (Vrijling et al., 1998):

1. *Individual risk*
   The individual risk gives the probability of death based on the assumption that the individual is exposed to the danger (in this case: flooding). Under this approach the criterion for acceptable risk is made dependent on the degree to which a person is subject to the risk voluntarily.
2. *Group risk*
   The approach to the group risk taken in (Vrijling et al., 1998) is contrary to the approach usually taken, based on the national level (and therefore not the activity at local level). The risk at national level is the sum of the risks at local level from industrial plants or activities. Most group risk standards (e.g. the VROM risk standard) are implicitly based on the local level. This can lead to undesirable effects, because it is likely that the standards will be tightened up if the number of activities in a particular category increases by a large factor (e.g. a factor 100). To determine the group standard accident statistics are used to reveal public preferences. It is likely that the public aversion to risk acceptance plays a part. Small accidents occurring relatively often are more easily accepted than rare large accidents with many victims.
3. *Balancing of costs and benefits*
   The problem of acceptable risk can also be formulated as an economic decision-making problem. The costs of making a system safer can be offset against the benefits, i.e. a reduction in the present (or cash) value of the risk. The optimum level of safety is thus the probability at which the total costs are minimal. An additional item can be added on the damage side which expresses the economic value of a human life, e.g. the average value added to the gross national product. A risk aversion can then also be considered under this approach. The three measures of risk can each give a different result. In (Vrijling et al., 1998) it is proposed that the strictest criterion be used.

5. Conclusions and Recommendations

5.1 Conclusions

1. Representative picture
   The Floris project studied 16 dike ring areas which together provide a reasonably representative picture of the risk of flooding. The dike rings protect against different types of water bodies: the North Sea, the Wadden Sea, the IJsselmeer and Markermeer lakes, Westerschelde (Western Scheldt river) and the major rivers. This enables various types of flood defences to be taken into consideration. The dike ring areas are found in both urban and rural areas as well as deep-lying polders and old land. The calculations were carried out by various people, but coordinated from one central point. Because of the consistent methodology the results for the dike ring areas could be compared with one another.

2. Value of the results
   The Floris project is just one step in a longer development pathway. The flood risks have been identified for 13 dike rings at development level 1. For these dike rings it is possible to trace the relatively weak locations in the dike ring and the reasons for them. The Floris project has reached the second development level for three dike rings. The figures calculated for these three dike rings can be compared with the results of similar types of dike rings. The calculated figures at these two levels cannot yet be seen as absolutes. This requires further enhancement of the method to reach level 3.

3. Consequences of flooding
   The maximum economic damage in the dike rings ranges from several hundred million euros to almost three hundred billion euros in South Holland. This damage would occur if the entire dike ring were to fill up with water. From the detailed calculations of the damage in South Holland it appears that in the most likely flood scenarios 'only' part of this dike ring would be flooded. Due to various obstacles, the flooding would often be limited to a small section of the dike ring. The average economic damage is therefore much less than the maximum damage. Only in the rivers region would the dike ring almost always be completely flooded. Depending on the flood scenario there could be anything between a few dozen and several thousand victims in the event of a flood. Most are likely to occur if the flooding is unexpected and evacuation is not possible.

4. Probability of flooding
   The Floris study showed that the flood defences are generally so high that the probability of flooding due to extremely high water levels is very small.
   According to the calculations the flooding probability is at the moment mainly dictated by the high probability of the phenomenon of 'uplifting and piping" (where water seeps under the dike) and the non-closure of hydraulic structures. These failure mechanisms are not included in the present safety standard.
   In some cases the large probability of uplifting and piping is due to uncertainty about the structure of the underlying soil. In such cases further investigation can result in the probability of flooding being reduced. The use of a more detailed model can sometimes also tighten up the calculated result. But it is clear that uplifting and piping constitute a real threat in the Netherlands. This is discussed in more detail in conclusions 6 and 7.
   Where there is a high probability of failure due to non-closure of hydraulic structures, this is often due to the fact that procedures are not properly documented or insufficiently practised. The probability of flooding can be easily, effectively and cheaply reduced in such cases. Further to the Floris project many regional water boards have since done this.

5. Support for the study
   During the course of the Floris project the bodies and the people involved became convinced of the added value offered by the flooding probability approach and the ability in the short term to provide a clearer understanding of the safety of the Netherlands in relation to flooding.

6. Method
   The product of the Floris project is a method which can be used to calculate flood risks in a consistent manner. To achieve this, existing methods were adapted and new methods developed. New methods were necessary, for example, to assess hydraulic structures and the impacts on wildlife, the landscape, cultural heritage and the environment. A method was also developed to be able to turn all flood defences into comparable data for input into models. The loads from water levels, currents and waves were calculated in the same way for all dike rings. For some components the methods will need to be developed further. For example, it would be desirable to include the effect of human intervention during high water levels in the flood risk, to reduce the uncertainties in the probability of uplifting and piping and calculate the failure probability of several other flood defences (category c flood defences).

7. The art of building dikes is being able to draw correct conclusions from uncertain data.
   The calculated probability of flooding is the most realistic portrayal of the probability of flooding given the available information and state of knowledge. In calculating the probability of flooding various uncertainties play a part, not least about the structure of the subsoil under the foundations of the flood defences. An essential element in the probability calculations is that the order of uncertainty is expressly included in the calculation. The greater the uncertainty, the greater the probability in the calculation. This is the usual method applied in risk assessment. Sometimes the uncertainty can be reduced through further investigation, e.g. of the structure of the subsoil. Depending on the results of this further investigation, this could lead to a smaller probability of flooding. Other uncertainties, such as uncertainty about the extent of the rise in sea level or the increase in river discharge, cannot be reduced within the foreseeable future. These concepts were included in the Floris project in the analysis of relatively weak locations. For example, at a particular relatively weak location it was checked whether this was mainly due to uncertainty and thus further investigation would be preferred or whether this is a relatively weak location physically where measures needed to be taken. In general, it is usually the case that investigation pays off.

8. Hydraulic structures assessed
   At the start of the Floris project the flooding probability of hydraulic structures was unknown. During the course of the project methods were developed and applied for assessing six types of hydraulic structures. Surveys were carried out for hydraulic structures such as pipelines and longitudinal structures.

9. Cooperation and knowledge transfer
   A secondary goal of the project was to transfer knowledge about the calculation of flooding risks. To achieve this goal there was systematic knowledge transfer to the regional water boards and provinces throughout the course of the project. It was also decided to have the calculations carried out by external consulting engineering firms. The Floris Project Bureau spent a great deal of time on guiding and supporting these firms.

5.2 Recommendations

1. The results of the Floris project give a good first impression of the flood risks in the Netherlands. The figures are, however, not yet robust enough to be considered as absolute values. It is recommended that the methods be further developed and detailed data collected, so that ultimately the flood risk can be determined at level 3.

2. It is recommended that as complete a picture as possible should be created of the probabilities of flooding and the flood risks in all 53 dike rings. This will provide a basis for political and public

debate on how to cope with flood risks and possibly about a different safety standard. Continuation of the Floris project for the remaining 37 dike rings should be coordinated from one central point, to ensure the consistency of the results. It is recommended that a number of dike ring areas along the undiked stretch of the Maas should also be included.

3. In the Floris project the consequences of flooding were determined for three dike rings using detailed flooding scenarios. For the remaining dike rings a global method was used, which often resulted in a large overestimate of the consequences. To gain a good impression of the consequences of flooding, it is important that these consequences are calculated in consultation with the regional water boards, using detailed flooding scenarios for all dike rings.

4. The Floris project revealed that the mechanism 'uplifting and piping' to a large extent determines the probability of flooding. It is crucial that more attention be devoted to this failure mechanism. It is recommended that further research should be carried out on a method to calculate the probability of uplifting and piping. At the same time it can be examined what impact the use of structures such as sheet piling and filters would have. It is also recommended that the necessary data be collected and where necessary physical measures are taken to reduce the probabilities of uplifting and piping.

5. The Floris project explored a method for comparing the costs and benefits of investments made in high water protection. It is recommended that this method be further developed to include the influence of economic growth and the rise in sea level.

6. From the results of the Floris project it appeared that in some cases further investigation can lead to a different estimate of the probability of flooding, which is often more favourable. Good data is essential for a follow-up study to the Floris project. It is recommended that the regional water boards concerned actively collect data on the subsoil, particularly through soil surveys. This is critical to a successful follow up study.

References

The list of references is divided into two parts: reports which were prepared in the context of the Floris project and other literature.

Floris project literature

A dike ring report was drawn up for each of the 16 dike rings. Risk case reports were also drawn up for three of these 16 dike rings. The Floris project also published a number of other reports and memoranda. The reports and memoranda referred to in the text of this Full Report are listed below.

Ast, van, J. et al., 2003. *Waardering van overstromingsrisico's.* Eindrapport. Erasmus Centre for Sustainable Development and Management.

Baarse, G., 2005. *Ondersteuning zwakke plekken analyse en kostenraming. Overzicht en beschrijving activiteiten en producten.* BB&C Baarse Beleidsondersteuning & Consult.

Barendregt, A. et al., 2004. *Standaardmethode Schade en Slachtoffers als gevolg van overstromingen*, [Standard Method, Damage and Victims resulting from Flooding] DWW-2005-05. RWS Dienst Weg- en Waterbouwkunde, 2004.

Barendregt, A. et al., 2004. *Bepalen beschikbare en benodigde tijd voor evacuatie bij dreigende overstromingen.* HKV LIJN IN WATER, rapport PR742.

Diermanse, F., B. Thonus, F. den Heijer and I. Lammers. 2001. *Inventariseren en inbouwen van hydraulische randvoorwaarden in PC ring.* WL|Delft Hydraulics en HKV LIJN IN WATER.

Doef, M.R., A.M. Cappendijk-de Bok, 2005. *Modellering van evacuatie voor risicocases VNK*. RWS Dienst Weg- en Waterbouwkunde, 2005.

Duinen, T.A. van, 2005. *Mseep berekeningen met piping voor VNK.* Geodelft.

Flinterman, M. et al., 2003. *De Perceptie van overstromingsrisico's.* Rijkswaterstaat, Bouwdienst, 2003.

Havinga, F.J, 2003. *Pilot bekledingen*. HKV LIJN IN WATER, rapport PR744.

Huizinga, H.J. et al., 2004. *HIS-Schade en Slachtoffermodule Versie 2.1 Gebruikershandleiding*. DWW-2005-004. RWS Dienst Weg- en Waterbouwkunde, 2004.

Jonkman, S.N., 2004. *Methode voor de bepaling van het aantal slachtoffers ten gevolge van een grootschalige overstroming*. DWW-2004-042. RWS Dienst Weg- en Waterbouwkunde, 2004.

Jonkman, S.N., A.M. Cappendijk-de Bok, 2005. *Risico-cases VNK - Inschatting van het aantal slachtoffers ten gevolge van overstroming*. RWS Dienst Weg- en Waterbouwkunde, 2005.

Nieuwenhuizen, W. et al, 2003. *Standaardmethode Schade aan LNC-waarden als gevolg van overstromingen. Methode voor het bepalen van de gevolgen van overstromingen voor de aspecten opgaande begroeiing, vegetatie, aquatische ecosystemen en historische bouwkunde*. Alterra, HKV LIJN IN WATER en Geodan IT. Alterra rapport 709, 2003.

Noortwijk, J.M., M. Kok and B. Thonus. 2005. *Overzicht van methoden voor kosten-batenanalyse voor maatregelen ter beperking van overstromingsrisico's*. HKV LIJN IN WATER. Technisch rapport PR906.

Projectbureau Veiligheid Nederland in Kaart (Floris Project Bureau), 2001. *Projectplan Veiligheid Nederland in Kaart.* [Project Plan for Flood Risks and Safety in the Netherlands (Floris) research project]

Projectbureau Veiligheid Nederland in Kaart, 2002. *Schematisering en gegevensverzameling van dijken en duinen; handleiding ten behoeve van de bepaling van overstromingskansen van dijkringen*.

Projectbureau Veiligheid Nederland in Kaart, 2003. *Rapportage VNK Langsconstructies.*

Projectbureau Veiligheid Nederland in Kaart, 2004. *Memo selectie kunstwerken.*

Projectbureau Veiligheid Nederland in Kaart, 2005. *Globale schadeberekening. Achtergronddocument. De benadering van de schade na een grootschalige overstroming met behulp van een globale methode*.

Projectbureau Veiligheid Nederland in Kaart, 2005. *Modellering van de evacuatie, evacuatiecurven dijkringen 7, 14 en 36*.

Projectbureau Veiligheid Nederland in Kaart, 2005. *Overstromingsrisico's van dijkringen. Omgaan met onzekerheden bij de analyse van kansen op en gevolgen van overstromingen. Visienotitie (eindconcept), June 2005.*

Steetzel, H., 2003. *Aanpassing duinmodule binnen PC-Ring.* Rapport A917. Alkyon.

Snuverink, B. et al., 2004. *Verkenning van milieurisico's door het vrijkomen van stoffen bij stationaire activiteiten van bedrijven binnen het project VNK/gevolgenspoor, hoofdrapport en pilot studie.*Tebodin.

Thonus, B., A.C.W.M. Vrouwenvelder, H.M.G.M. Steenbergen, 2004. *ScenarioKans versie 1.02.* HKV LIJN IN WATER and TNO Bouw project PR 751.

Thonus, B., A.C.W.M. Vrouwenvelder, H.M.G.M. Steenbergen, 2004. *Gebruikershandleiding ScenarioKans*. HKV LIJN IN WATER en TNO Bouw rapport PR 751.

Thonus, B., M. Kok and J.M. van Noortwijk, 2005. *Verkenning kosten-baten analyse Dijkring 14: Zuid-Holland.* HKVLIJN IN WATER rapport PR906.

Universiteit Twente, 2004. *Evacuatie van een dijkringgebied bij dreigende overstromingen. De evacuatie Calculator (EC), versie 1.0*.

Van der Meer, J. et al., 2002. *Methode voor beoordeling van gemalen, coupures, keersluizen, schutsluizen, uitwatering- en inlaatsluizen, tunnels en van pijpleidingen*. Fugro.

Vrouwenvelder, A.C.W.M. et al, 2003*. Theoriehandleiding PC-Ring, versie 3.0.* TNO Bouw.

General references

Reference is also made in the main report to the following publications:

CPB, 2005. *Veiligheid tegen overstromen - Deel 1: kosten-batenanalyse voor Ruimte voor de Rivier.* Centraal Planbureau. CPB document nr. 82.

Delft Cluster, 2003. *Environmental impact of flooding*. DCI-233-8.

Deltacommissie, 1960. *Eindverslag en interim-adviezen, deel 1.*

Frieser B., 2004. Probabilistic Evacuation Decision model for River floods in the Netherlands, Afstudeerrapport TU Delft.

Geodelft, 2003. *Handleiding Mprostab.*

Geodelft, 2004. *Handleiding Mprolift*.

Geodelft, 2005. *Handleiding Mstab.*

Hall, A. van, 2004. *Percepties van veiligheid.* Paper presented at Lelysymposium in Lelystad on 23 September 2004.

Jonkman, S.N., 2005 *Global perspectives on Loss of human life caused by floods. Natural Hazards*, 34, 151-175.

Klijn, F., H. van der Klis, K. de Bruin, J. Stijnen and M. Kok, 2004. *Overstromingsrisico dijkringen in Nederland – betooglijn en deskundigen oordeel.* WL|Delft Hydraulics en HKV LIJN IN WATER, Delft/Lelystad.

Ministries VROM, OCW, V&W and LNV, 1999. *Nota Belvedère*.

Ministerie van Verkeer en Waterstaat [Ministry of Transport, Public Works and Water Management], 2000. *Anders omgaan met water, waterbeleid voor de 21^{e} eeuw*.

Ministerie van Verkeer en Waterstaat, 2001. *Hydraulische Randvoorwaarden 2001 voor het toetsen van primaire waterkeringen.*

Ministerie van Verkeer en Waterstaat, 2003. *Nieuwe inzichten in golfbelastingen langs de kust. Samenvatting Rondom veiligheid tegen overstromen spelen verschillende ontwikkelingen en projecten. Het gaat om de vijfjaarlijkse toetsing op veiligheid en versterkingen van waterkeringen.*

Ministerie van Verkeer en Waterstaat, 2004. *De Veiligheid van de primaire waterkeringen in Nederland, voorschrift Toetsen op Veiligheid 2001-2006*.

Ministerie van Verkeer en Waterstaat, 2005. *Tussenbesluit Rampenbeheersingsstrategie Rijn en Maas*.

Projectbureau Ruimte voor de Rivier [Space for Rivers Project Bureau], 2005. *Planologische Kernbeslissing deel 1: Ruimte voor de Rivier*

Rijkswaterstaat Rijksinstituut voor Kust en Zee, 2004. *Rapport Basiskustlijn*.

Rijksinstituut voor Volksgezondheid en Milieu, 2004. *Risico's in bedijkte termen. Een evaluatie van het beleid inzake de veiligheid tegen overstromen. Milieu en Natuurplanbureau.*

Rijkswaterstaat Bouwdienst, 2004. Beoordeling van leidingen in en nabij waterkeringen, voorbeelden ter illustratie van de methode.

Schokker, J., 2004. *De ondergrond van primaire waterkeringen en veenkaden.* TNO-NITG 05-003-B.

Technische Adviescommissie voor de Waterkeringen [Technical Advisory Committee on the Flood Defences], 1984. *Leidraad voor de beoordeling van de veiligheid van duinen als waterkering.*

Technische Adviescommissie voor de Waterkeringen, 1988. *Grondslagen voor Waterkeren*.

Technische Adviescommissie voor de Waterkeringen, 1996. *Veiligheid van waterkeren, de nieuwe visie volgens het onderzoeksprogramma TAW Marsroute*.

Technische Adviescommissie voor de Waterkeringen, 1999. *Technisch Rapport Zandmeevoerende wellen*. Technische Adviescommissie voor de Waterkeringen [Technical Advisory Committee on the Flood Defences].

Technische Adviescommissie voor de Waterkeringen, 2000. *Van overschrijdingskans naar overstromingskans* [Flooding Risks - a study of the probabilities and consequences], brochure and background report.

Technische Adviescommissie voor de Waterkeringen, 2000. *Technisch rapport Asfalt voor Waterkeren. Concept revisie 6.6 dd. 31-08-2000.*

Technische Adviescommissie voor de Waterkeringen, 2003. *Leidraad kunstwerken*.

Vrijling et al., 1998. *Acceptable Risk as a basis for Design. Reliability Engineering and System Safety 59 (1998).* 141-150, 1998.

Vrijling, J.K., E. Calle, A. Vrouwenvelder, M. Kok and B. Jonkman, 2004. *Review koploper resultaten VNK.* April 2004, TU Delft

WL, 2003. *HIS overstromingsmodule*. WL|Delft Hydraulics. *(website www.sobek.nl)*

Appendix A. Glossary of terms

Area managed — The area specified in the file which is designated as flood defence and which is managed by the flood defence manager.

AOL-fall — The drop in the AOL level due to movements of the earth's crust. Due to the lack of a measurable reference point, this fall cannot be quantified and can only be quantified in combination with the rise in sea level.

Assessment level yyyy — The water level with an exceedance frequency in accordance with Annexe II of the Flood Defences Act which is used to assess the condition of the flood defences, which will be reported on to the Minster of Transport, Public Works and Water Management in year yyyy. The Assessment level includes the expected rise in high water level (including AOL-fall) up to and including year yyyy.
The Assessment levels for rivers are given along the axis of the river; for lakes at some distance from the foot of the flood defence (usually 200m), for dunes at the AOL -20 m depth line and for the other flood defences along the coast and estuaries, usually near the foot of the flood defence.

Behind the dike — On the landward or inland water side of the dike.

Boundary condition — The condition in which the strength of a structure or a part of it is exactly in balance with the forces at work on it.

Breach — A hole in the flood defence.

Cohesion — Mutual attraction between fine soil particles of some soil types, which keeps them bound together as a solid mass without external forces.

Collapse — The loss of internal equilibrium (e.g. shear) and/or the loss of material cohesion (e.g. softening) and/or the appearance of unacceptably large distortions in a dike, dune or hydraulic structure.

Collapse mechanism — The way in which a structure collapses (e.g. sliding, piping).

Conditional load probability — This is the probability of a particular load occurring given that another defence has recently failed.

Crest — The strip between the external and the internal crest lines.

Crest level — The height of the external crest line.

Cut — An interruption in the flood defence to allow the passage of a road, waterway or railway line which can be closed in the event of high water levels.

Damage factor — The partial factor used to take into account the consequences of collapse.

Decimation height — The variation in level associated with an increase or decrease in the exceedance frequency by a factor 10.

Design erosion zone	That part of the dune range which will be eroded during design conditions (design storm surge).
Design water level	Extreme high water level with a prescribed exceedance frequency.
Difference in water pressure	The difference in hydraulic head between two points, e.g. the two sides of a flood defence.
Dike	A body of earth which acts as a flood defence.
Dike ring	Set of flood defences, or areas of high ground, which enclose and protect a dike ring area against flooding.
Dike ring area	An area which has to be protected against flooding by a system of flood defences or areas of high ground, particularly in the event of a storm surge, during high upstream water levels in one of the major rivers, high water on the IJsselmeer or Markermeer or a combination of any of these.
Dike section	A section of a flood defence with roughly the same strength and load properties.
Dune	A body of sand (reinforced or not) intended to hold back water based on its mass.
Dune erosion	See 'Design erosion zone'.
Dune foot	The transition from beach to dune. The position of the dune foot in cross-section is defined by many managers using an elevation contour which does not change over time (e.g. AOL + 3m).
Exceedance frequency	The average number of times that a phenomenon reaches or exceeds a certain value within a set period of time.
Exceedance probability	The probability that the design water level will be reached or exceeded.
Economic risk	That part of the flooding risk which relates to the damage as a result of a flood.
Entry point	The theoretical point where outside water enters the aquifier as a result of the difference in water pressure across the flood defence.
Exit point	The location on the landward side where seepage water first appears on the surface.
Exit gradient	The hydraulic gradient in the groundwater at the site of the exit point.
Expected value	The weighted average of a stochast, also called the first moment.
External water	The surface water whose water level is subject to direct influence in the event of a storm surge, during high upstream water levels in one of the major rivers, high water on the IJsselmeer or Markermeer or a combination of any of these.

Failure mechanism — The series of events which lead to failure.

Failure — No longer being able to fulfil the primary function (hold back water) and/or no longer meeting the set criteria.

Fetch (length) — The horizontal length of the water surface behind the flood defence over which the wind blows.

File — A description of the minimum requirements which the primary or other flood defence must meet in terms of direction, design, dimensions and structure and in which the inspection limits are laid down.

Filter — An intermediate layer in the slope revetment which prevents fine-grain material from being washed out of the subsoil by the upper layer of the revetment.

Five-yearly Safety Assessment — Periodic evaluation of the safety and strength of a dike ring. This means checking whether the condition of the structure at that moment still meets the functional and statutory requirements in force. The Safety Assessment Guidelines describe how the assessment should be carried out and is intended as a uniform gauge for assessing the quality of the flood defences.

Foreshore — The area on the seaward side of the dike.

Flood defence — Artificial and natural elevations (or parts of these) or high ground, including structures built in or on them, which have a fully or partly flood defensive capability, and which are registered as such.

Flood plain — See 'Main bed'.

Heaving — The raising of the covering soil layer due to reaching the boundary potential.

High ground — The naturally high areas of the Netherlands. These are designated in Annexe 2 to the Flood Defences Act as the Mean Sea Level or Amsterdam Ordnance Level (AOL) + 1 m line in the event of a threat from the IJsselmeer and the Markermeer, the AOL + 2 m line in the event of a threat from the sea, or if higher along the rivers, as the furthest expected floodline running from the normative high water level (MHW) on the upstream side of the dike ring area to the lowest crest height of the primary flood defences on the downstream side of the dike ring area, plus 1 m.

Hydraulic gradient — The ratio between the difference in the hydraulic head between two points and the distance between those points; also referred to as gradient.

Hydraulic head — The level to which the water would rise in a monitoring well with filter at the relevant point; expressed in metres head of water relative to a reference area.

Hydraulic structure	A civil engineering work or installation associated with the wet and/or dry infrastructure to serve one or more functions.
Inner foot	The lower edge of the dike body on the landward side of the dike (the transition from dike to ground surface).
Inner slope	The sloping section of the dike body on the landward side of the dike.
Inundation	Water ingress resulting in flooding.
Inundation line	The maximum water depth in the event of flooding in a dike ring area.
JARKUS	The national database with annual depth and height measurements for the sandy Dutch coast.
Lake dike	A primary flood defence generally situated alongside large bodies of water other than rivers, with no tidal effect.
Limit profile	The minimum profile that must be present as flood defence after dune erosion during design conditions.
Load	The internal and external forces impinging on a structure (a flood defence), or the degree to which a structure is subject to internal and external forces, expressed as a physical quantity.
Local wind set-up	Wind set-up between the location for which the hydraulic boundary conditions were specified and the flood defence.
Length effect	The degree to which the probability of a mechanism occurring depends on the length of the flood defence.
Macrostability	The resistance to a slip occurring in the slope and the subsoil.
Main bed	The main part of the river bed (between the summer level and the outermost winter level).
Major dike	The river dike enclosing the main bed.
Manage	The entirety of activities necessary to ensure that the functions of the flood defence continue to meet the specified standards and requirements for that purpose.
Manager	The public authority responsible for the management of the primary or other flood defence.
Marsroute	Predecessor to the 'A study of the probabilities and consequences of flooding' research programme.
Mean sea level, Amsterdam ordnance level/datum (AOL)	Amsterdam ordnance level/datum (AOL). Dutch abbreviation: NAP.
Mean value	The expected value (μ) of a stochastic function.
Microstability	The slope's resistance to erosion due to exiting water.

Model factor	The partial factor used to take into account uncertainties in the calculation methods.
Monitoring level	The monitoring level at any given moment is the difference between the measured or expected crest level at that moment and a still water level at the same moment.
Non-primary flood defences	See 'Regional flood defence'.
Non-tidal (upper) river region	The river region fed by the Rhine and the Maas to the east of the line Schoonhoven - Werkendam - Dongemond. The water levels here are not affected by the tidal movements of the North Sea.
Normative high water level	The design water level.
Normative high water level xxxx	The design level laid down in year xxxx. The design level is equal to the Safety Assessment level multiplied by the expected increase in high water level (including AOL -fall) up to the end of the planning period.
Operating line	The relationship between the river discharge and the statistically determined exceedance frequency of the river discharge, as applied by the Minister of Transport, Public Works and Water Management in determining the design discharge for dike strengthening.
Outer berm	An extra widening of the external side of the dike to provide extra support to the dike body, to prevent sand-bearing seepages (welling) and/or to reduce the effects of wave impact.
Outside the dike	On the water retaining side of the flood defence.
Outer slope	Sloping section of the dike body on the defensive side.
Outer foot	The lower edge of the dike body on the defensive side of the dike (the transition from dike to ground surface and/or foreshore).
Overload	Exceeding the set wave overtopping criterion.
Overflow	The phenomenon in which water runs over the crest of the dike into the hinterland because the water level in the river is higher than the crest.
Overtopping	See 'Wave overtopping'.
Phreatic surface	The free groundwater table.
Piping	The phenomenon in which a hollow pipe-shaped channel is created under a flood defence due to the erosion process of a sand-bearing current (seepage).
Polder	An area discharging or draining into a body of water.
Polder level	The level of the surface water within a managed territory.
Potential	The hydraulic head in an aquifier.

Primary flood defence

A flood defence which protects against flooding either because it is part of the system that surrounds a dike ring area - possibly together with high ground - or which is situated in front of a dike ring area.
Primary flood defences can be subdivided into the following categories:

category	Description
a.	Flood defences which belong to systems which enclose dike ring areas and defend directly against external water.
b.	Flood defences situated in front of dike ring areas and which hold back water from outside.
c.	Flood defences not intended to provide direct defence against water from outside.
d.	In one of the categories a to c but situated outside the national borders.

Probability of flooding

The probability of an area being flooded because the flood defences around that area (the dike ring) fail in one or more places.

Risk of flooding

Probability of flooding x consequences.

Regional flood defences

Non-primary flood defences.

Register

Description of the actual condition of the flood defence, with the necessary construction data related to maintaining the flood defensive capabilities.

Revetment

See 'Slope revetment'.

Rise in sea level

The increase in the average sea level relative to the Amsterdam Ordinance Level (AOL).

Risk assessment

An investigation of the probability of undesirable events and the consequences of such events.

River dike

A river dike enclosing the main bed.

Safety Standard

The standard which a primary flood defence must meet, expressed as the average exceedance probability - per year - of the highest water level which the primary flood defence must be capable of withstanding from the outside, while taking into account other factors which determine the defensive capability.

Sand-bearing seepage (welling)

Water welling up from the subsoil carrying sand with it.

Sea dike

A primary flood defence in category a. which retains salt water.

Seepage

The extrusion of groundwater under the influence of greater hydraulic head outside the area under consideration.

Settlement

The vertical distortion of soil layers, mainly due to loads from above.

'Schaar' dike

A river dike situated next to the river bed in summer.

Secondary flood defence See 'Regional flood defence'.

Seepage cut-off An impermeable, generally vertical, structure for extending the seepage length.

Seepage channel A channel or ditch on the inside of the dike which is intended to collect and drain seepage water.

Seepage path A possible track in the ground which leads the seepage water away from the point of entry to the point of exit.

Seepage length The distance which the seepage water covers in the ground.

Stability factor The factor used to express the difference between strength and load.

Standard deviation A measure of the dispersion around the mean.

Still water level The water level without the effect of wave run-up, but with allowances. Allowances include: local wind set-up, wind oscillations and wind gusts.

Stochastic See stochastic variable.

Stochastic variable In many experiments we pay particular attention to values which certain variables assume in those experiments. We are, for example, interested in the highest water level at a certain location or the total number of people in a dike ring area. Such a value is referred to as a stochastic variable and is defined by its probability distribution.

Storm surge A high water period in which at the Hook of Holland the accepted level (with a mean exceedance frequency of 0.5 per year) is reached or exceeded (see the tide tables for the accepted high water level).

Sliding The displacement of part of an earth body due to exceeding its equilibrium bearing-capacity.

Slope The gradient of the side of earthworks, dikes, railway tracks and defences.

Slope revetment The covering over the core of a dike to protect it against wave attack and water flowing along it. The dike revetment consists of an erosion-resistant upper layer, including the underlying brick layer, filter layer, clay layer and/or geotextile.

Softening The loss of cohesion in the grain structure as a result of an increase in the water tension (in the pores).

Summer level The cross-section of the river where the river discharge takes place at normal and lower water levels.

Summer dike Demarcation between the main (winter) bed and the summer level of the river.

Superelevation An extra amount of soil which is applied to achieve the desired profile after settlement of the subsoil and the dike body.

Tidal (lower) river region The area fed by the Rhine and the Maas to the west of the line Schoonhoven - Werkendam - Dongemond, including Hollands Diep and Haringvliet, apart from the Hollandsche IJssel.

Uplifting The collapse of the soil due to a lack of vertical equilibrium in the soil, under the influence of water pressure.

Variation coefficient (V) The relative value of the standard deviation (σ) in relation to the expected value (μ), i.e. $V= \sigma/\mu$.

Victim risk That part of the flooding risk which relates to the victims as a result of a flood.

Water over/under pressure The difference between the water pressure present and the hydrostatic water pressure.

Water pressure The pressure in the groundwater.

Wave run-up The height above the still water level which a wave reaches against the slope (the 2% wave run-up is exceeded by 2% of the waves).

Wave overtopping The amount of water which breaks over the flood defence per metre per time unit on average.

Wind set-up The increase in the local water level due to the forces exerted on a body of water by the wind.

Appendix B. Area description and results for the 16 dike rings

This appendix includes an area description of the dike rings considered followed by the results of the calculations with an explanation.

Dike ring 3: Terschelling

Area description
Dike ring 3 Terschelling lies in the province of Friesland and is one of the five dike rings in the Netherlands which is also an island. On the south side the area is protected by dikes against the Wadden Sea. On the north, west and east sides dunes protect the area from the North Sea. The area of the dike ring is approx. 1900 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/2000 per year.

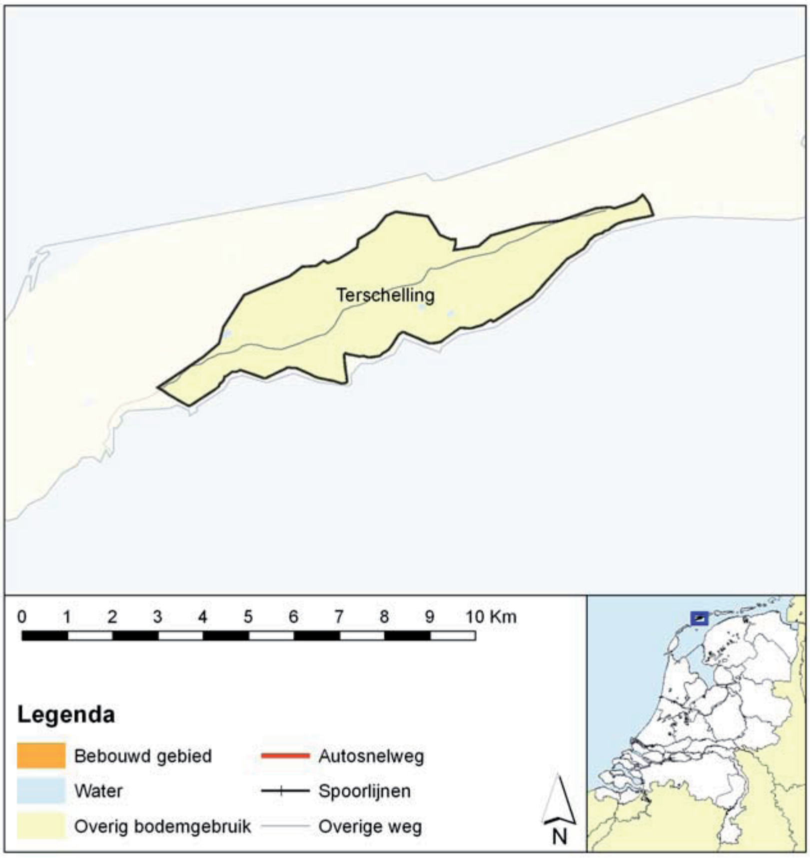


Figure B-1 Location of dike ring 3

The dikes are in category a. and have a combined length of approx. 26 km: 12 km dunes and 14 km dikes. There are two hydraulic structures in the dike, these are two drainage locks: the Nieuwe Sluis and the Liessluis.

The height of the ground surface on the Wadden Sea side is approx. AOL +0 m and quickly rises in the direction of the North Sea to a height of more than AOL +5 m. The dike ring area has approx.1900 inhabitants. In the area there are a number of villages, surrounded mainly by pasture. There is no industry or other intensive forms of land use.

Results, risks, consequences and probabilities
The economic risk for dike ring 3 amounts to € 0.1 million per year. The damage in the dike ring, calculated with the global method, amounts to € 160 million. This is an upper limit for the maximum damage in the dike ring area. The surface of the dike ring is relatively small and the Wadden Sea contains enough water to flood the entire dike ring. The calculated probability of flooding dike ring 3 is 1/1500 per year. It has been assumed in the calculated probability of flooding that the mud flats will add to the seepage length. The most important failure mechanism is 'non-closure' of the two hydraulic structures. The dike manager acknowledged this.

More insight into the reliability of the closing procedures could lead to a reduction in the calculated flooding probability, possibly to 1/10,000 per year. The economic risk is then reduced to € 0.016 million per year.

Dike ring 7 Noordoostpolder

Area description
Dike ring area 7 roughly encompasses the Noordoostpolder and lies largely in the province of Flevoland with small areas in the provinces of Overijssel and Friesland. The dike ring area is bordered on the south side by the Zwarte Meer and the Ketelmeer with the Ramspolkering barrier, with the IJsselmeer lake to the west. On the east side the area is bordered by the dikes along the Vollenhoverkanaal and the former sea dikes of the old country. The area of the dike ring is approx. 49,000 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/4000 per year.

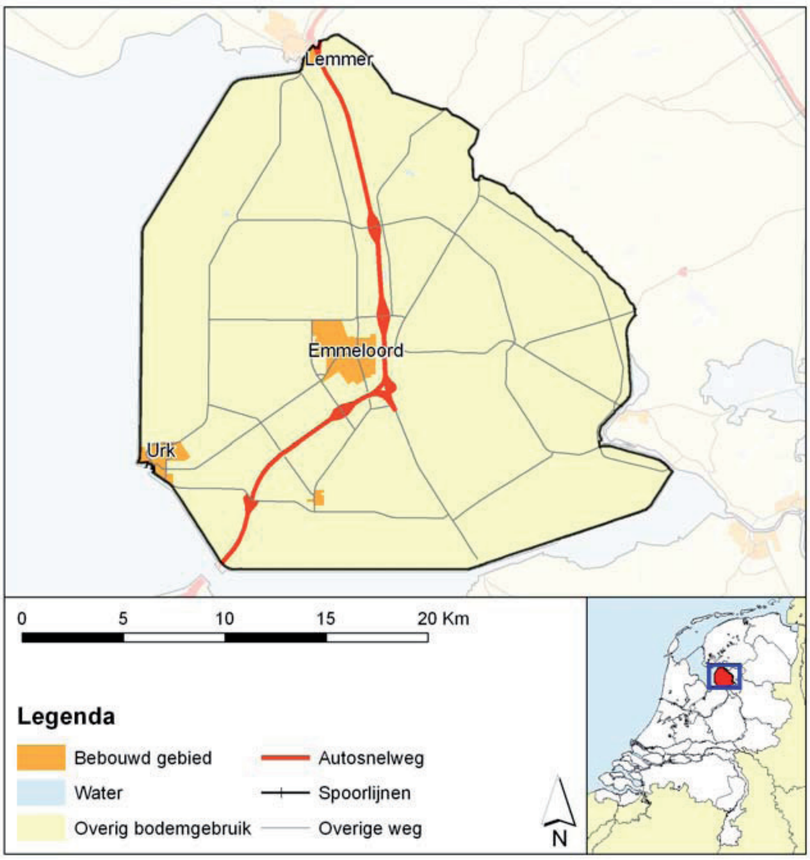


Figure B-2 Location of dike ring 7

The former island of Urk plays a particular role in the flood defences of this dike ring area. The old part of Urk is built on a higher area of boulder clay which makes up part of the flood defence. Because the height of this area from the hydraulic engineering perspective is more than adequate its flood defensive function was not included in the calculations.

The category a. dikes have a combined length of approx. 55 km. The dikes to the east of the polder are primary flood defences of type c. Because of the guard lock function of the Kadoelersluis these dikes can be cut off from the outside water (Zwarte Meer). There are 10 hydraulic structures in this dike ring: three cuts, three intake locks, two pumping stations and two navigation locks.

The Noordoostpolder is a predominantly flat area lying 4 metres below AOL on average. More than 60,000 people live in the dike ring area. The major residential towns in the area are Emmeloord and Urk. A large part of the dike ring area is used for agricultural purposes.

Results, risks, consequences and probabilities
For dike ring 7 the consequences were calculated with both the global method and the detailed method. The economic risk for dike ring 7 was determined with the **detailed consequences method** as € 2.1 million per year. The economic damage amounts to € 170 million to € 4,000 million, depending of the location of the breach. The victim risk depends on the location of the breach and varies from 0.006 to 1.6 per year. The lower limit is based on an unexpected flood in which no evacuation takes place. The upper limit is based on a predictable inundation in which an organised evacuation takes place. Various flood scenarios were tested for this dike ring using the detailed consequences method. From this it appeared that in many cases the dike ring would not completely fill up with water, because the water level would not rise higher than the water level in the IJsselmeer. With the **global consequences method** the economic damage amounted to € 9,000 million. The economic risk then amounts to € 10 million.

The flooding probability of dike ring 7 is mainly determined by the probability of structural failure of two hydraulic structures and amounts to 1/900 per year. In the knowledge that the results of the advanced testing of these hydraulic structures was not included, the dike manager also confirmed this picture.

The calculated flooding probability is small compared with other dike rings. Further investigation and the construction of a collision beam at one of the hydraulic structures can help to further reduce the probability of flooding to 1/3100 per year. This does not involve any significant investment costs. The economic risk, based on the results of the detailed calculation of the consequences, amounts to € 0.6 million per year.

Dike ring 10 Mastenbroek

Area description
Dike ring 10 is situated in the province of Overijssel. The dike ring area is surrounded by three different bodies of water. The stretch between Zwolle and IJsselmuiden lies along the IJssel, the stretch between IJsselmuiden and Genemuiden lies along the Zwarte Meer lake and the stretch between Genemuiden and Zwolle likes alongside the Zwarte Water. The dike ring borders on two connecting flood defences, the Spooldersluis and the Ramspol guard lock. The area is approx. 9400 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/2000 per year.

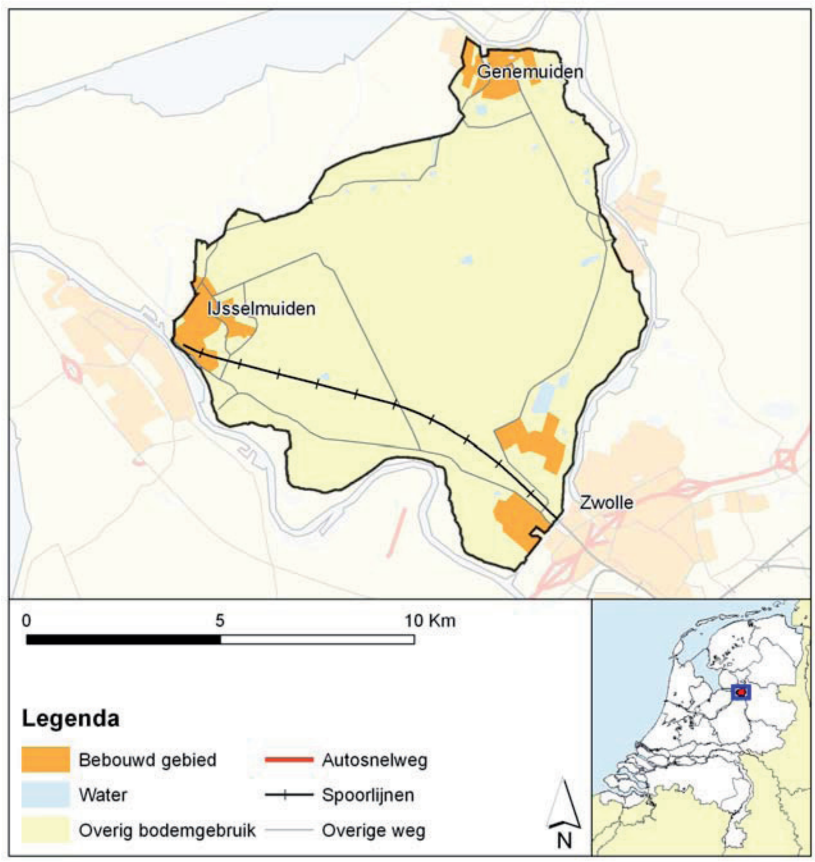


Figure B-3 Location of dike ring 10

Dike ring 10 is surrounded by category a. flood defences. The dikes are sand dikes with grass vegetation. The total length of the dikes is approx. 40 km. There are ten hydraulic structures in dike ring 10: two pumping stations, three locks and two intake culverts.

The deepest point of dike ring 10 lies north-east of IJsselmuiden. The ground surface there is AOL -3 m. The eastern and southern edges are at roughly AOL level.

The dike ring area is mainly in use as arable land (pasture) and has approx. 29,000 inhabitants. The main residential areas are IJsselmuiden, Genemuiden and that part of Zwolle which falls within the dike ring.

Results, risks, consequences and probabilities
The economic risk for dike ring 10 in the present situation amounts to more than € 12 million per year. The damage was calculated with the global method and amounted to € 1200 million. A probability of flooding greater than 1/100 per year was calculated for dike ring 10.

Weak locations analysis
The probability of flooding is mainly determined by two main weak locations: two dike sections where uplifting and piping are involved. In addition, there are six other weak dike sections where uplifting and piping play a role and one other weak dike section involving overflow and wave overtopping. The dike manager acknowledged the high probability of uplifting and piping, which was also discovered in the safety assessment. There was a feeling that due to the lack of good data and the conservative approach adopted the problems could be considerably overestimated. However, the dike manager did not agree with the large probability for overflow and wave overtopping.

With further investigation and strengthening measures if necessary for the two main weak locations, the probability of flooding can be reduced to 1/100 per year. An upper limit for the cost of implementing any strengthening measures is € 4.3 million. To further reduce the probability of flooding to 1/400 per year it also would be necessary to change the other weak locations. The economic risk would then be reduced to € 3 million per year. The upper limit for the costs in this case amounts to € 17.7 million. To arrive at the costs it was assumed that measures would be taken along the entire length of the dike sections. The possibility that the problems with piping as a result of the conservative approach may be considerably overestimated was also not taken into account.

Dike ring 13 Noord-Holland

Area description

Dike ring 13, Noord-Holland, is situated in the province of North Holland. This dike ring borders the North Sea to the west, the Wadden Sea to the north and the IJsselmeer and Markermeer lakes to the east. Indirect primary flood defences are situated where the dike ring borders on the Wieringenmeer (dike ring 12) and the Noordzeekanaal (dike ring 44). In these places the dike ring borders on dike rings with a different safety level. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/10,000 per year.

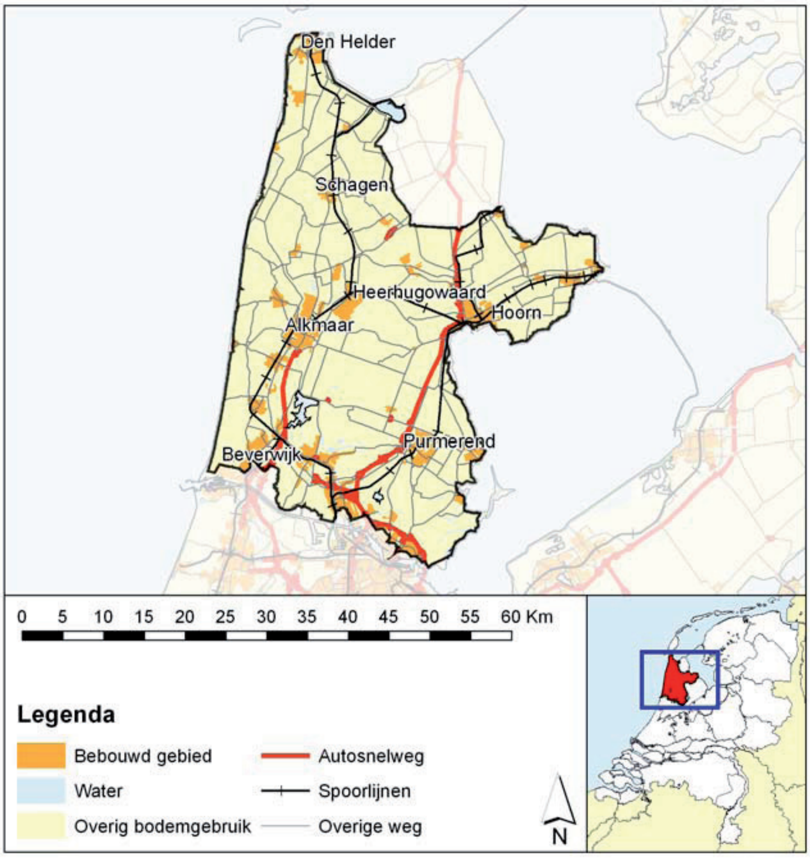


Figure B-4 Location of dike ring 13

The total length of the primary flood defences of dike ring 13 is approx. 250 km. The flood defences along the North Sea coast mainly consist of dunes (48 km). The Pettemer and Hondschbossche sea defences are situated in the dunes. The remaining flood defences consist of dikes and a few hydraulic structures. Of the 200 km in total of dikes approx. 55 km are in category a. and approx. 150 km in category c. At Westerland approx. 1 km of high ground forms part of the flood defence. This high ground falls in category c. There are approx. 110 hydraulic structures in the flood defence. Of these hydraulic structures 38 are in category a. and 72 in category c. Two tunnels traverse the flood defence. The area of the dike ring is approx. 153,000 ha.

The height of the ground varies greatly. In the west and north-west the ground surface is around AOL +0 m. In the centre the ground surface is sometimes lower than AOL -4 m. In the east, near Hoorn and Enkhuizen, the ground surface lies at around AOL -1.5 m.

The dike ring area has approx. 959,000 inhabitants and a major economic value. Parts of Amsterdam, Zaandam, Alkmaar, Heerhugowaard and other large towns lie within the dike ring. In the area around the Noordzeekanaal (North Sea Canal) there is a great deal of industry present, as there is on the edge of the large towns. In the north and east there is a lot of agriculture.

Results, risks, consequences and probabilities
The economic risk for dike ring 13 in the present situation amounts to more than € 116 million per year. The damage, calculated with the global method, amounts to € 58,000 million. This figure can be seen as an upper limit. In the global method it is assumed that the entire dike ring floods. This is a conservative assumption. Further to the results of the detailed flooding calculations for Zuid-Holland (dike ring 14) it may be assumed that not the entire dike ring will become inundated. There are two reasons which may be put forward for this:

- The volume streaming in as a result of a single breach would be too little to fill the entire dike ring up to the level of the lowest crest height (AOL +1.9 m). The duration of the wind set-up is too short for this. This applies from the IJsselmeer and Markermeer lakes as well as from the North Sea. In the global method the water depth and thus the damage is therefore overestimated.
- In the area there are various elements which can restrain the water. For example, old secondary flood defences, drainage waters and railway dikes. These elements divide the dike ring into compartments and will help to reduce the damage. Not much can be said in advance about possible flood patterns, because there are no flooding calculations for this dike ring area. Probably in the event of a flood it will spread compartment by compartment. As a result part of the dike ring area will remain dry.

The calculated damage is therefore an upper limit. On the basis of the results for dike ring 14 (Zuid-Holland) it would appear to be realistic to assume that this is an overestimate by a factor 10. It is recommended that more detailed flooding calculations be carried out for this dike ring.

The calculated probability of flooding for dike ring 13 is less than 1/500 per year. The dike manager confirmed the picture that the dikes which border on the Markermeer have stability problems and that in some places the dunes give a large probability of flooding. In several places repair work on the dikes was already in progress; this was not taken into account in the probabilities. The largest contribution comes from the Sas lock at Enkhuizen due to non-closure of this hydraulic structure.

Dike ring 14 Zuid-Holland

Area description
Dike ring 14, Zuid-Holland, is situated in the provinces of North Holland, South Holland and Utrecht. To the west the area is protected from the North Sea by the dunes. In several places in these dunes there are solid defences such as the dune base reinforcement at Ter Heijde, the beach foot reinforcement at Scheveningen and the dike at Katwijk. On the north side the area is bordered by the Noordzeekanaal, on the south side by the Nieuwe Waterweg, the Nieuwe Maas and the Hollandse IJssel and on the east side by the Amsterdam Rijnkanaal. The area is approx. 223,000 ha. According to the Flood Defences Act the dike ring area has an average exceedance probability of 1/10,000 per year.

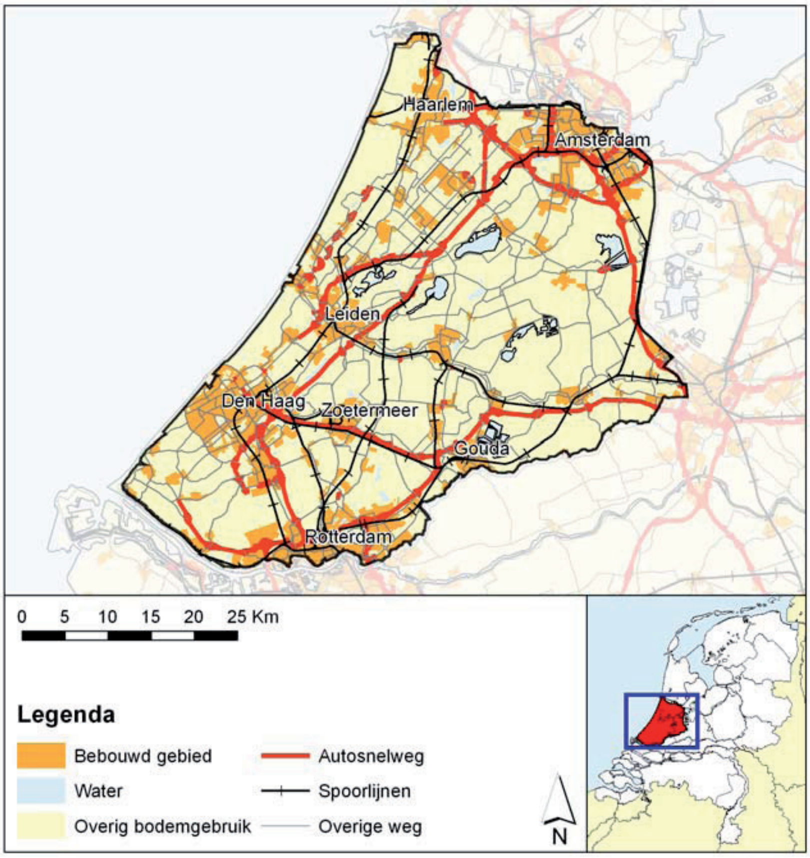


Figure B-5 Location of dike ring 14

The dikes and hydraulic structures along the Hollandse IJssel, the Amsterdam Rijnkanaal and the North Sea Canal are category c. primary flood defences. The total length of the category a. primary flood defences in dike ring 14 is approx. 95 km. In total there are 19 category a. hydraulic structures.

The elevation in dike ring 14 varies widely. The height of the coastal strip is AOL +0 m. The elevation of the Alexanderpolder, just to the north of Rotterdam, is lower than AOL –6 m in some areas. The Haarlemmermeerpolder too, where Schiphol Airport is situated, is lower than AOL –5 m. The dike ring area has approx. 3.2 million inhabitants.

The major residential towns in the area are Amsterdam, Rotterdam, The Hague, Haarlem, Leiden and Delft. There is also a lot of industry present and Schiphol Airport is situated in this dike ring.

Results, risks, consequences and probabilities
For dike ring 14 the consequences were calculated with both the global method and the detailed method. The economic risk for dike ring 14 was determined with the **detailed consequences method** as € 2.3 million per year. The economic damage amounts to € 280 million to € 37,000 million, depending of the location of the breach. The victim risk depends on the location of the breach and varies from 0.012 to 2.44 per year. The upper limit is based on an unexpected flood in which no evacuation takes place. The lower limit is based on a predictable inundation in which an organised evacuation takes place. In the case of South Holland the breach would be most likely to occur in the coast. The situation at sea cannot generally be predicted more than a day in advance and this does not allow sufficient time for a full evacuation of the threatened area. Particularly with multiple breaches from the coast, large areas with many inhabitants could be inundated. The damage and the number of victims will greatly depend on the breach scenario which will determine the area flooded and the characteristics of the flooding as well as whether evacuation is possible. Obstacles in the dike ring, such as secondary flood defences and old dikes, can prevent large areas of the dike ring from flooding.
With the **global consequences method** the economic damage amounts to € 116 million per year. The economic damage amounts to € 290,000 million.

The calculations resulted in a probability of flooding of 1/2500 per year for dike ring 14. This a relatively small probability.

Weak locations analysis
The main weak locations are the Scheveningen promenade where 'dune erosion' is involved and a dike section with uplifting and piping. There is also another weak location due to 'dune erosion' and two other weak hydraulic structures involving the 'not-closing' mechanism. The dike manager acknowledged this.

With further investigation and strengthening measures if necessary for the two main weak locations the probability of flooding can be reduced to 1/5000 per year. An upper limit for the cost of extending the seepage length is € 3.7 million. The basic principle here is that the entire dike section is tackled, even where the problem may not be involved. The costs of tackling the dune erosion at the other main weak location still has to be added to this: for the two other weak hydraulic structures where 'not-closing' is a factor, this can be adequately dealt with by taking procedural measures. This does not involve any significant investment costs. Although the probability of flooding after taking the procedural measures may be further reduced to 1/7000 per year. The economic risk amounts to € 0.8 million per year and the victim risk varies, depending on the location of the breach, from 0.004 to 0.9 per year.

Dike ring 15 Lopiker and Krimpenerwaard

Area description
Dike ring area 15, Lopiker and Krimpenerwaard, is situated in the provinces of Utrecht and South Holland. The dike ring area borders on the Lek and the Nieuwe Maas on the south side. To the west the area borders on the Hollandsche IJssel. And to the east it borders on the Amsterdam - Rijnkanaal and the Lekkanaal. To the north the area borders on dike ring 14, Central Holland, east of Gouda. The area of dike ring is approx. 32,000 ha. According to the Flood Defences Act the dike ring has an exceedance probability of 1/2000 per year.

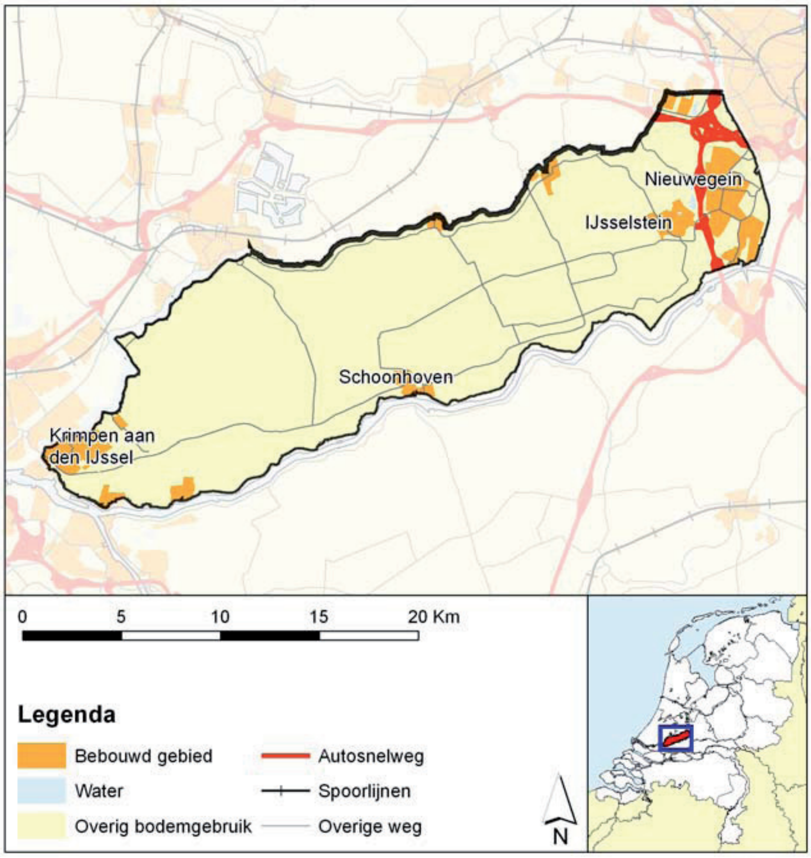


Figure B-6 Location of dike ring 15

Only the flood defences along the Nieuwe Maas and the Lek are in category a. The Hollandsche IJssel is separated from outside water by the Hollandsche IJssel storm surge barrier, the flood defences behind it are therefore in category c. The length of the category a. flood defences is approx. 47.5 km. The length of the category c. flood defences is approx. 48.8 km. In there area there are 20 category a. hydraulic structures and as far as is known, 5 category c. hydraulic structures.

The elevation varies from AOL +0 m in the east to AOL -5 m in the west.

The dike ring has approx. 196,000 inhabitants. The main residential areas are Nieuwegein, IJsselstein, Krimpen aan de Lek and Krimpen aan de IJssel. There are a number of smaller towns spread throughout the area. The land use is mainly agricultural. There are built up areas at the eastern and western extremities of the area.

Results, risks, consequences and probabilities
The economic risk for dike ring 15 in the present situation amounts to more than € 100 million per year. The economic damage was calculated with the global method and amounted to € 10,000 million. The flooding probability of dike ring 15 is greater than 1/100 per year.

Weak locations analysis
The cause of this large probability is mainly due to the dominant weak locations: not closing of the Koninginnesluis lock and sliding for one dike section. There are also another seven weak locations. The number of dominant weak locations established and other weak spots is fairly arbitrary. In this dike ring there is an almost continuous distribution of probabilities per dike section. It turned out to be impossible to give a clear boundary in the probability of flooding per dike section at which a level would be reached at which a further reduction in the probability of flooding could only be brought about through integral measures.

With further investigation and strengthening measures if necessary for the two dominant weak locations the probability of flooding can be reduced but still remains larger than 1/100 per year. If all the weak locations were to be tackled the probability of flooding would be reduced to 1/900 per year. The costs that this would involve are estimated at between € 9 million and 12 million. It is assumed that measures would be taken along the entire length of the dike sections.

Dike ring 16 Alblasserwaard and Vijfheerenlanden

Area description
Dike ring 16, Alblasserwaard and Vijfheerenlanden, is situated in the province of South Holland. The area lies in the transition from the rivers to the delta region. The dike ring area is bordered to the north by the Lek, to the south by the Upper and Lower Merwede and to the west by the Noord. The dike ring is closed by the Diefdijklinie. The area of the dike ring is approx. 39,000 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/2000 per year.

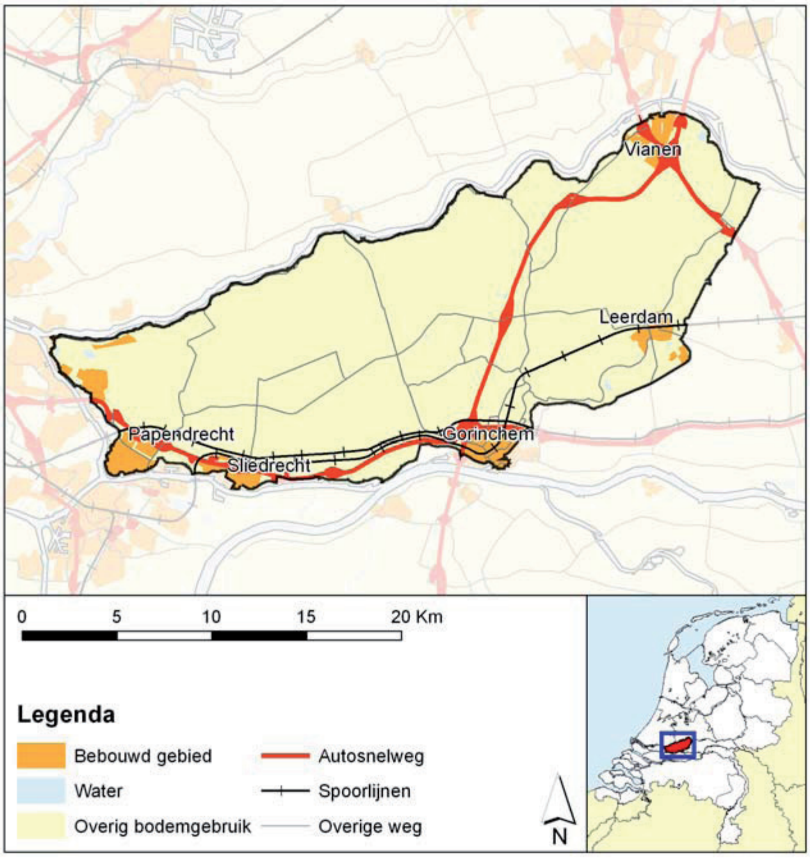


Figure B-7 Location of dike ring 16

84 km of the primary flood defences fall in category a. To the east the dike ring is bordered by a category c. flood defence. This category c. flood defence will only retain water if dike ring 43 floods. There are nine category a. flood defence hydraulic structures in the dike ring area.

The ground surface of the dike ring runs from AOL +0.5 m in the east to AOL -2 m in the west.

With the exception of the cities at the edge of this dike ring, the land use is mainly agricultural. The dike ring area has approx. 197,000 inhabitants. A number of large residential towns are situated in the dike ring, such as Gorinchem, Leerdam, Papendrecht and Alblasserdam. There are a number of smaller towns spread throughout the area.

Results, risks, consequences and probabilities
The economic risk for dike ring 16 amounts to € 48 million per year. The maximum damage was calculated with the global method and amounts to € €19,000 million. The dike ring area has no compartments and flooding from the rivers could last long enough to actually fill the entire dike ring with water. The water depth which could result is very large. There are no indications that the calculated damage amount could be lower.

According to the calculations the flooding probability for dike ring 16 is 1/400 per year. The main causes of the large flooding probabilities are the large probabilities calculated for uplifting and piping, heaving and structural failure of one of the locks. The manager did not think the high probability of uplifting and piping likely. However, seepage (welling) has been observed at high water levels. Further investigation can determine whether the probability of this is overestimated. The manager did subscribe to the result that the dikes are subject to stability problems due to heaving.

Dike ring 25 Goeree-Overflakkee

Area description
Dike ring 25, Goeree-Overflakkee, is one of the South Holland islands and is situated in the province of South Holland. To the west the dike ring area borders on the North Sea. The Haringvliet lies to the north, the Zoommeer is to the east and the Grevelingen to the south. The total length of the primary flood defences is approx. 96 km. The flood defence comprises approx. 26 km of category a. dikes, approx. 52 km category c. dikes and approx. 18 km of dunes. There are 15 hydraulic structures in the dike ring 10: six pumping stations, seven locks and two cuts. The area of the dike ring is approx. 22,000 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/4000 per year.

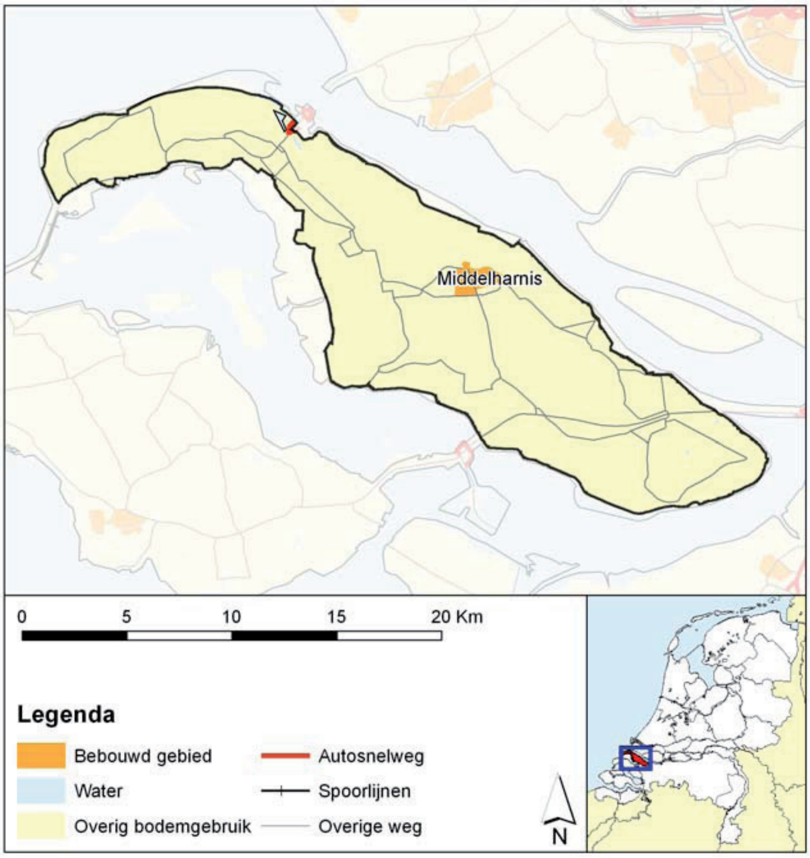


Figure B-8 Location of dike ring 25

The height of the ground surface varies around AOL 0 m. The ground surface in the dune area in the west is higher.

The dike ring area has approx. 46,000 inhabitants. There are no large residential areas. The inhabitants are spread over the island in small villages or, for example, in the slightly larger centres of Goedereede, Middelharnis and Oostflakkee. The land use in the dike ring area is mainly agricultural.

Results, risks, consequences and probabilities
The economic risk for dike ring 25 amounts to € 3 million per year. The maximum damage, calculated with the global method, amounts to € 3,700 million. This amount is an ample upper limit. In the calculation of the damage it was assumed that the dike ring would flood right up to the lowest crest level. This assumption is not correct for Goeree-Overflakkee because there are compartments in the dike ring which means that only some compartments would fill up. Furthermore, a large part of Goeree-Overflakkee no longer borders on the sea but on the Haringvliet and the Grevelingenmeer lake. These are protected against high sea water levels by the Delta Works. As a result the normative water level has in some places dropped by metres. The dike ring is unlikely to flood completely. The calculated damage and the economic risk therefore represent a wide upper limit.

The calculated probability of flooding of dike ring 25 is 1/1200 per year. The main causes are due to the large probability of uplifting and piping, damage to the asphalt dike revetment, the height of the Flaauwe Werk dike and, to a lesser extent, 'non-closure' of several hydraulic structures. It is not clear whether these actually are weak locations because there are large uncertainties in the data. In places where the dike manager did not expect there to be a large probability of uplifting and piping, these probabilities were not included in the calculation of flooding probability. For two sections of dike the calculations indicated a large probability of instability. During the safety assessment these dike sections were not approved for these reasons and measures to improve them are now being implemented. In the calculation of the flooding probability it was assumed that these measures had been completed.

Weak locations analysis
The flooding probability is largely determined by two weak dike sections where uplifting and piping make a large contribution to the probability of flooding.

Dike ring 32 Zeeuwsch Vlaanderen

Area description
Dike ring 32, Zeeuwsch Vlaanderen, lies in the province of Zeeland. The bordering waters are the North Sea and the Westerschelde (Western Scheldt river). The dike ring area crosses the national border and is defined by the following flood defences:

- The dike along the Westerschelde.
- The dike along the Schelde.
- The high ground in Belgium and Northern France.
- The sea defences formed by the dunes or dikes of Belgium, Northern France and the Netherlands.

The area of the dike ring is approx. 72,000 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/4000 per year.

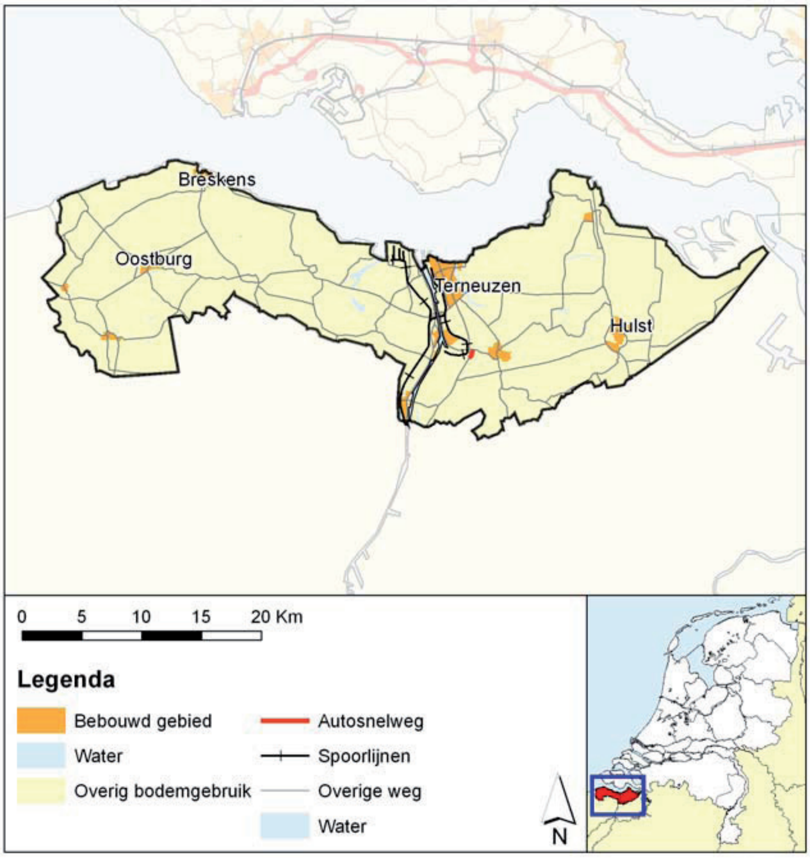


Figure B-9 Location of dike ring 32

The length of the category a. primary flood defences is 85 km, approx. 6 km of which is dune coast.

The ground surface lies at around AOL +1 m and hardly changes over the entire area.

The dike ring has approx. 106,000 inhabitants. The main towns in this area are Terneuzen, Sluis and Hulst. The main activity in the area is agriculture. At Terneuzen there is also an industrial area.

Results, risks, consequences and probabilities
The economic risk for dike ring 32 is greater than € 140 million per year. The damage, calculated with the global method, amounts to € 14,000 million. This is an upper limit. Zeeuwsch Vlaanderen is an area typified by many secondary flood defences. In the event of a breach of a primary flood defence the hinterland would flood compartment by compartment. The assumption in the global method that the dike ring would be filled with a flat water table up to the level of the lowest crest is therefore impossible. Furthermore the duration of a flood would be determined mainly by the duration of the wind set-up at sea. This is often so short that one single breach in the dike could not lead to the entire dike ring flooding. The calculated damage and the economic risk are therefore widely overestimated.

The flooding probability for dike ring 32 is greater than 1/100 per year. It turned out to be difficult to provide good calculations for dike ring 32, due to the variation in load and the complexity of the dike profiles. The flooding probability is largely determined by stability problems near a pumping station and close to the dikes. In the current round of testing the regional water board collected more information. Recently it appeared that the pumping station could be approved in the assessment. The data for the dikes is not yet available. The calculated probability may therefore be overestimated. It is clear that there is a real risk here because the dikes are steep and stand on weak layers in the subsoil.

Dike ring 36 Land van Heusden / De Maaskant

Area description
Dike ring 36 Land van Heusden / De Maaskant is situated in the province of North Brabant. Dike ring 36 lies along the Maas, between Boxmeer and Waalwijk. On the south-east side of North Brabant, where the diked Maas becomes the undiked Maas, the flood defence joins up with the high ground. The area of dike ring 36 is approx. 74,000 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/1250 per year.

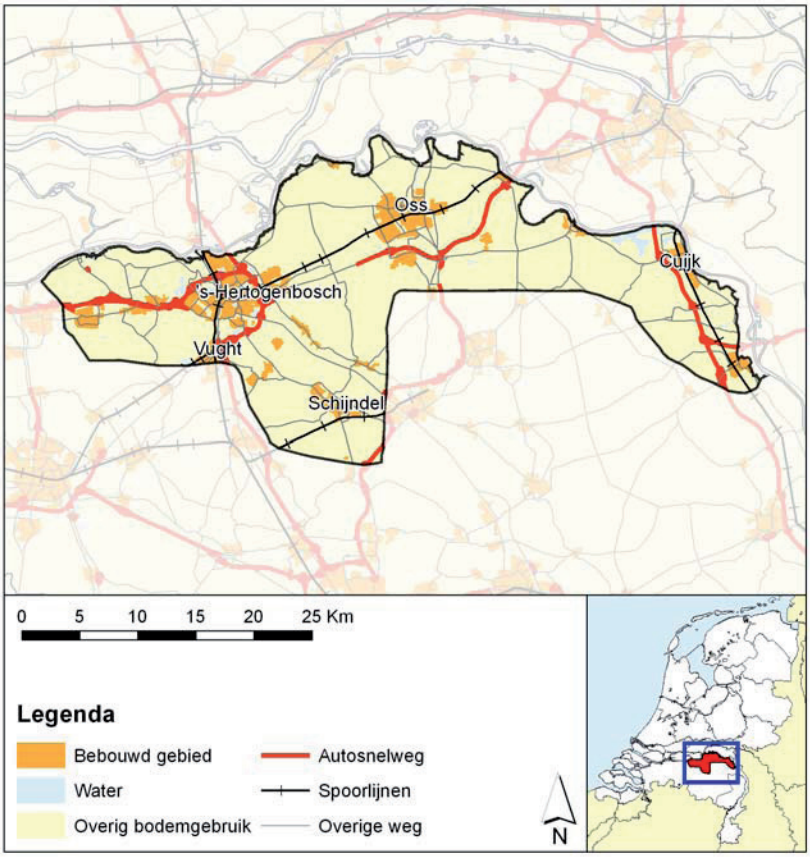


Figure B-10 Location of dike ring 36

All dikes and hydraulic structures in dike ring 36 fall in category a. The total length of the flood defences in dike ring 36 is approx. 100 km. There are 40 hydraulic structures in dike ring 36.

The main land use in the dike ring is agriculture (approx. 80%). About 10% of the land use is for nature/recreation and urban development. Dike ring 36 has approx. 407,000, inhabitants. The main residential areas are 's-Hertogenbosch and Oss.

Results, risks, consequences and probabilities
For dike ring 36 the consequences were calculated with both the global method and the detailed method. The economic risk for dike ring 36 was determined with the detailed consequences method and amounted to € 37 million per year. The economic damage amounts to € 60 million to € 7500 million, depending of the location of the breach. The victim risk

depends on the location of the breach and varies from 0.05 to 8 victims per year. The lower limit is based on an unexpected flood in which no evacuation takes place. The upper limit is based on a predictable inundation in which an organised evacuation takes place.

The calculations for dike ring 36 resulted in a probability of flooding greater than 1/100 per year.

Weak locations analysis
The flooding probability is largely determined by two main weak locations with a high probability of uplifting and piping. In addition, uplifting and piping play a role in 22 other weak dike sections, not closing on time for two other weak hydraulic structures, Raamsluis Grave and Uitwateringssluis Henriëttewaard, and the water retaining height of Keersluis Cuyck. The dike manager endorsed these results. There was a feeling that due to the lack of good data and the conservative approach adopted the problems with uplifting and piping could be overestimated.

The cause of the large economic risk is due to the fact that with most dike breaches a large part of the dike ring would be flooded. If uplifting and piping in the two weakest locations is further investigated and strengthening measures are taken, if necessary, the flooding probability could be reduced to 1/150 per year. The upper limit for the costs to achieve this is € 7.9 million. To achieve an even smaller probability of flooding of 1/220 it is necessary to tackle all the above weak locations. The upper limit for the costs in this case amounts to € 35.6 million.

It was assumed in the costs that the seepage length across the entire length of the dike section would be modified for both dike sections where uplifting and piping are involved. This upper limit also does not take into account the feeling that the problems with uplifting and piping could be overestimated due to the lack of good data and the conservative approach adopted, . These assumptions have a major impact on the costs. Depending on the assumptions, the costs of € 35.6 million could be reduced by as much as 80%. The economic risk with a probability of flooding of 1/220 per year amounts to € 15 million per year.

Dike ring 38 Bommelerwaard

Area description
Dike ring 38, Bommelerwaard, is situated in the province of Gelderland. The dike ring area lies between the Maas and the Waal and is bordered on the west side by the Afgedamde Maas. The primary flood defences which encircle the area have a combined length of approx. 65.6 km. The area of the dike ring is approx. 11,000 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/1250 per year.

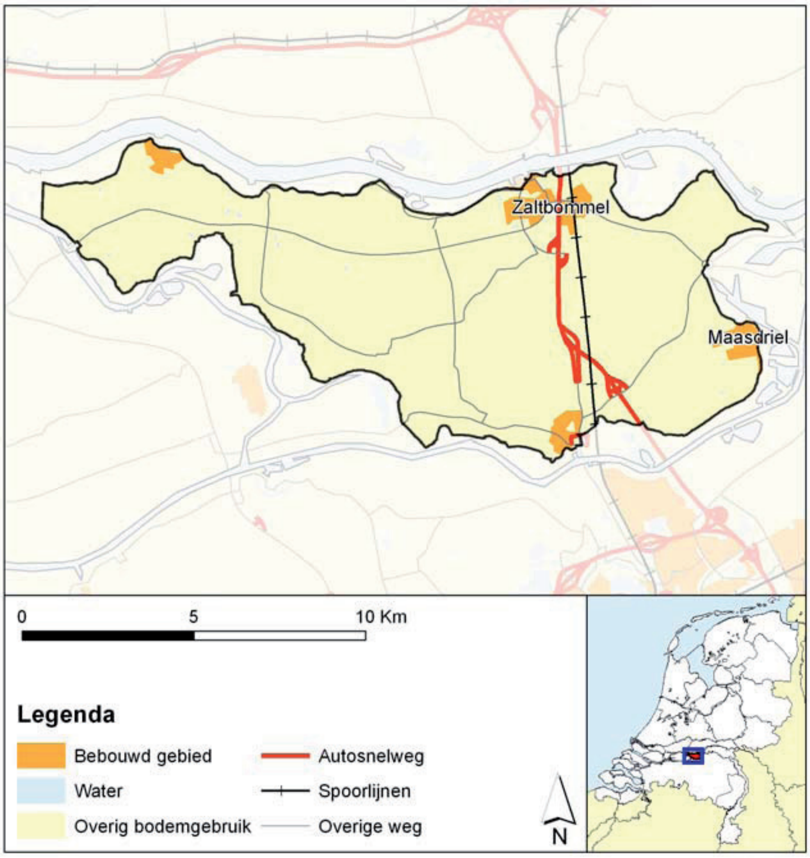


Figure B-11 Location of dike ring 38

The entire primary flood defence is in category a. The dike ring area has approx. 45,000 inhabitants. The main residential area is Zaltbommel. There are a number of other villages spread throughout the area.

The elevation of the area runs from AOL +3 m in the east to AOL +2 m in the west. Other than this there are no other major differences in terrain height in this area. The land use is mainly agricultural.

Results, risks, consequences and probabilities
The economic risk for dike ring 38 amounts to € 10 million per year. The maximum damage, calculated with the global method, amounts to € 2,600 million. This is not an upper limit. The area is bordered by the Maas and the Waal. The dikes along the Waal are 2 to 3 metres higher than along the Maas. In the calculation of the global consequences it was assumed that the dike ring would fill up with water up to the lowest

crest level of the dikes along the Maas. In the event of a dike breach along the Waal the water level would be 2 to 3 metres higher than for a dike breach along the Maas. The water would then flow through the dike ring area and ultimately, when the dike ring is full, flow back into the Maas again via the lowest point in the dikes along the Maas. Therefore it can make a major difference whether the flooding comes from the Waal or from the Maas. The calculated damage and the economic risk are not an upper limit. For this dike ring it is recommended that the consequences be looked at in more detail.

A probability of flooding of 1/260 per year was calculated for dike ring 38. The reasons are a high probability of uplifting and piping (particularly at two sites where there are sand strata under the flood defence) and non-closure and instability of hydraulic structures. The dike manager confirmed this picture and will further investigate whether the condition of the hydraulic structures needs improvement and what measures will be required for this.

Dike ring 41 Land van Maas and Waal

Area description
Dike ring 41, Land van Maas and Waal, lies in the province of Gelderland. A very small part of the dike ring area lies in the province of Limburg. The area borders on the Maas on the south side and on the Waal on the north. The high ground of the lateral moraine at Nijmegen forms the eastern boundary. On the west side the Maas and the Waal approach one another but remain separated by the connecting flood defences. The area of the dike ring is approx. 28,000 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/1250 per year.

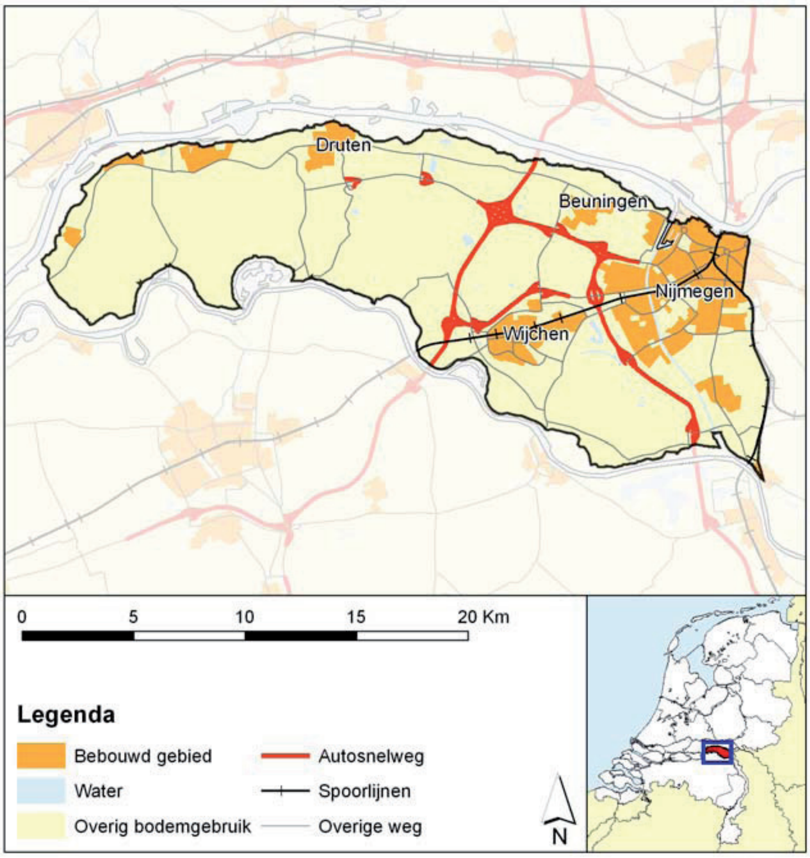


Figure B-12 Location of dike ring 41

The dike ring area has 85 km of category a. primary flood defences and 8 hydraulic structures: four locks, one pumping station and an effluent pipeline.

The dike ring area has approx. 242,000 inhabitants. To the east is an urban area with parts of Nijmegen and Wijchen. There are also a number of other reasonable size towns in the whole dike ring area.

The height of the ground surface runs from AOL +4 m in the west to AOL +10 m at Nijmegen. The lateral moraine is more than AOL +30 m in height. The east of the dike ring is highly urbanised. Mainly agriculture is found in the west.

Results, risks, consequences and probabilities
The economic risk for dike ring 41 amounts to more than € 64 million per year. The damage, calculated with the global method, amounts to € 6,400 million. This is not an upper limit. The area is bordered by the Maas and the Waal. The dikes along the Waal are 2 to 3 metres higher than along the Maas. In the calculation of the global consequences it was assumed that the dike ring would fill up with water up to the lowest crest level of the dikes along the Maas. In the event of a dike breach along the Waal, however, the water level would be 2 to 3 metres higher than for a dike breach along the Maas. The water would then flow through the dike ring area and ultimately, when the dike ring is full, flow back into the Maas again via the lowest point in the dikes along the Maas. Therefore it can make a major difference whether the flooding comes from the Waal or from the Maas. The calculated damage and the economic risk are not an upper limit. For this dike ring it is recommended that the consequences be looked at in more detail.

A probability of flooding greater than 1/100 per year was calculated for dike ring 41. The reasons are large probabilities for uplifting and piping and the non-closure and structural failure of hydraulic structures. The dike manager confirmed this picture.

Dike ring 42 Ooij and Millingen

Area description
Dike ring area 42, Ooij and Millingen, lies mainly in the province of Gelderland and partly in the German Nordrhein-Westfalen. The dike ring area lies on the Waal and the Rhine. On the south and west sides the dike ring area connects with the high ground of Nijmegen. The area of the dike ring is approx. 3400 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/1250 per year.

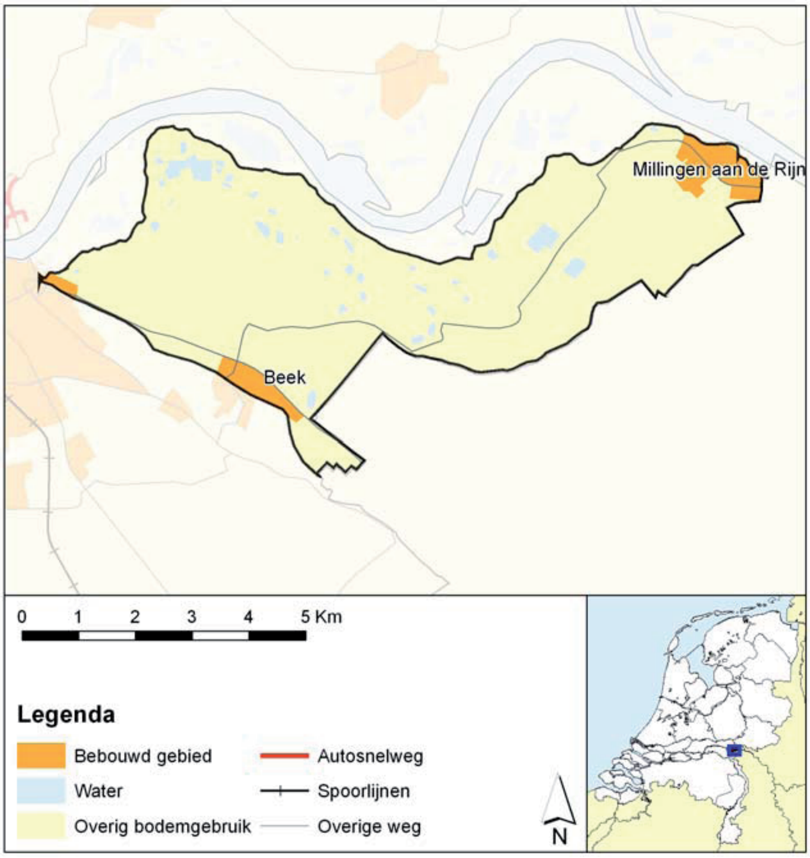


Figure B-13 Location of dike ring 42

The flood defence in the Dutch section has a length of approx. 18 km and is in category a. A hydraulic structure, the Hollandsch-Duitsch pumping station, forms part of the flood defence. This pumping station lies on the westerly point of the Ooij and Millingen dike ring area.

The east of the dike ring lies at AOL +11.5 m. Near Nijmegen the ground surface is at AOL +10 m. The dike ring is bordered to the south-west by the high ground of a lateral moraine. There are no other elevations or basins in the area.

The land use is mainly agricultural. In the west there is a modest nature reserve. The dike ring has approx. 14,000, inhabitants spread over the area. There are no large residential areas.

Results, risks, consequences and probabilities
The economic risk for dike ring 42 amounts to € 0.7 million per year. The damage, calculated with the global method, amounts to € 1,000 million. This is a slight underestimate of the actual damage which can occur. The reason for this is the fact that this dike ring, the Ooijpolder, would also be flooded as a sort of flood plain with the Waal if it were to flood from upstream. The flood plain would fill up with water after which the water level would be the same as the water level in the river. The water levels would then be higher than the dike heights. The water depths will therefore be larger than what was calculated with the global method.

A relatively small probability of flooding of 1/1400 per year was calculated for dike ring 42. In this dike ring overflow and wave overtopping is the indicative failure mechanism. The dike manager confirmed this picture.

Dike ring 43 Betuwe, Tieler- and Culemborgerwaarden

Area description
Dike ring 43, Betuwe and Tieler and Culemborgerwaarden, is situated in the province of Gelderland and the province of South Holland. The dike ring is bordered on the north side by the Nederrijn and the Lek, on the east side by the Pannerdensch Kanaal, on the south side by the Waal and Boven Merwede and on the west side by the Diefdijklinie. The Diefdijklinie is part of dike ring area 43, as well as dike ring area 16, Alblasserwaard and Vijfheerenlanden. The area of the dike ring is approx. 63,000 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/1250 per year.

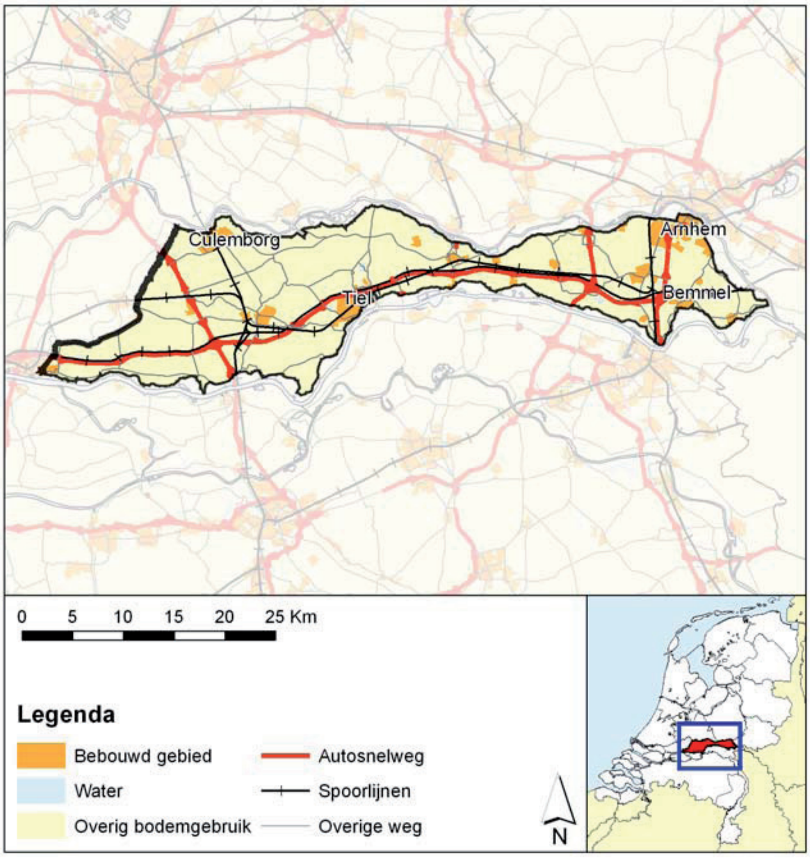


Figure B-14 Location of dike ring 43

The category a. flood defences are approx. 168.5 km long. The exception to this is the Diefdijklinie (approx. 24 km) which is in category c. There are 15 category a. flood defence hydraulic structures in total in the dike ring area.

The ground surface runs from AOL +11 m at the Pannerdense Kop to AOL +0 m near Gorinchem.

The land use in the dike ring is predominantly agriculture and fruit growing. The number of inhabitants in this dike ring is 299,000 people. There are several large residential areas in the dike ring such as part of

Arnhem, Lent and Geldermalsen. There are also numerous other smaller towns and villages.

Results, risks, consequences and probabilities
The economic risk for dike ring 43 amounts to more than € 180 million per year. The damage, calculated with the global method, amounts to € 18,000 million. This is a conservative value. The dike ring is long which means that in the event of a flood halfway along the water would never fully reach the area upstream. There is too little water available for this. There are also compartments in the dike ring which would reduce the damage.

A probability of flooding which greater than 1/100 per year was calculated for dike ring 43. Originally, relatively high probabilities were calculated for uplifting and piping. The reason for this was large uncertainties in the data. Further to discussion with the dike manager, who was not aware of the problems at the locations concerned, it was decided to leave this aspect out of the calculated probability of flooding. Other reasons for the relatively large flooding probability are structural failure and non-closure of some hydraulic structures. The dike manager agreed with this. Investigation of the soil structure could show whether there is indeed a risk due to uplifting and piping. The dike manager has since begun an investigation of the indicated hydraulic structure with stability problems.

Dike ring 48 Rijn and IJssel

Area description

Dike ring 48, Rijn and IJssel, lies in the province of Gelderland. The flood defence is approx. 52 km long and retains water from the Rhine, the Pannerdens Kanaal and the IJssel. The northern boundary is formed by the Oude IJssel. Montferland is situated in the dike ring. This is a lateral moraine which extends far above the normative water level. Germany is to the east of this dike ring, where another approx. 38 km of category d. flood defences are situated. The Floris project did not consider this flood defence. The area of the dike ring is approx. 29,000 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/1250 per year.

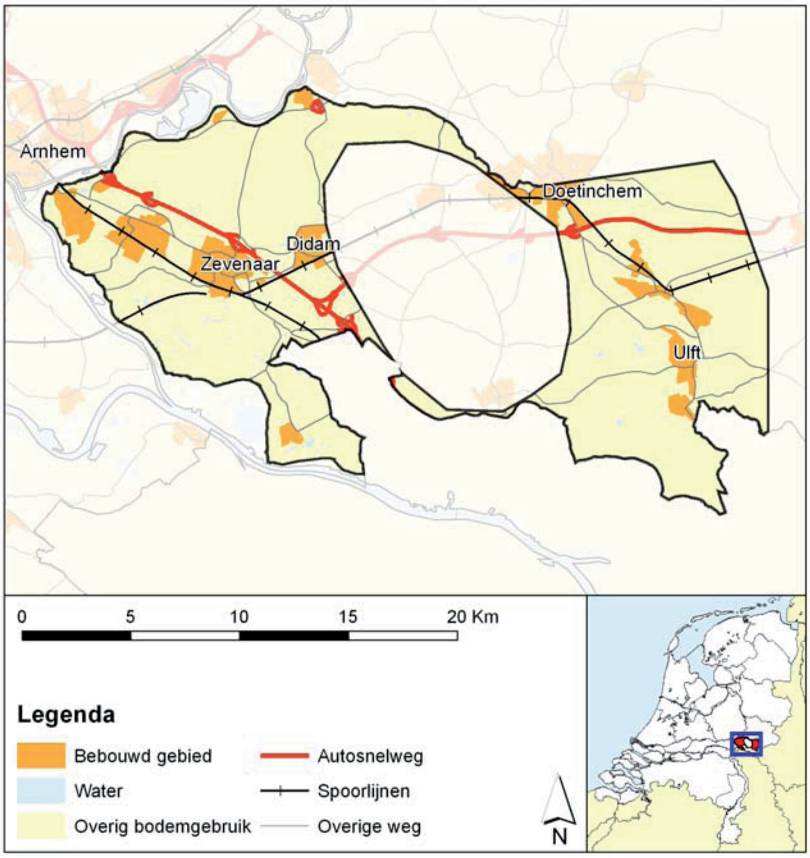


Figure B-15 Location of dike ring 48

The entire primary flood defence is in category a. There are 8 hydraulic structures in the flood defence: three pumping stations, three culverts, one cut and a former defensive hydraulic structure.

The elevation varies from AOL12.5 m at Lobith to AOL 8.5 m at Giesbeek. Montferland is the highest point at AOL +80 m.

The dike ring has 156,000 inhabitants. The largest residential area is Zevenaar. In the north, in the area of the lower lying parts of the dike ring, the land use is primarily agricultural.

Results, risks, consequences and probabilities
The economic risk for dike ring 48 amounts to € 34 million per year. The damage was calculated with the global method and amounts to € 6,800 million. This is an upper limit. In the event of flooding it is very likely that the entire dike ring will not fill up. There are compartments in the dike ring.

The calculated probability of flooding of dike ring 48 is 1/200 per year. This is mainly due to the high probability of uplifting and piping. In this case it would appear that this large probability cannot be put down to uncertainty about the soil data. Other causes for the relatively high flooding probability are structural failure of three hydraulic structures and non-closure of two hydraulic structures.

Dike ring 52 Oost-Veluwe

Area description
Dike ring 52, Oost-Veluwe, lies in the province of Gelderland and partly in the province of Overijssel. The area lies on the west bank of the river IJssel. To the north, west and south the dike ring area is bordered by the high ground of the Veluwe. The area of the dike ring is approx. 31,000 ha. According to the Flood Defences Act the dike ring has an average exceedance probability of 1/1250 per year.

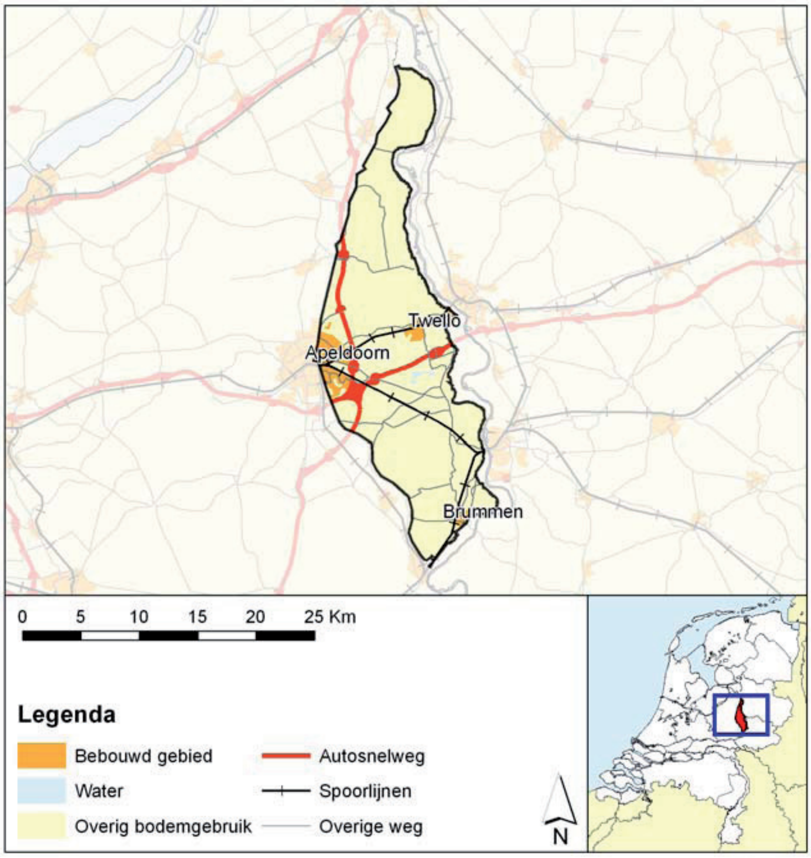


Figure B-16 Location of dike ring 52

The primary flood defences of dike ring area 52 are all in category a. and have a total length of approx. 65 km. The primary flood defences also include 12 hydraulic structures: six pumping stations, four locks and two cuts.

The level of the ground surface in the south is approx. AOL +10 m. The level of the ground surface in the north of the dike ring is AOL +1.5 m. To the north of Apeldoorn the dike ring forms a basin. The ground surface in the centre of the dike ring is lower than it is near the IJssel.

The land use is mainly agricultural. The dike ring area has approx. 105,000 inhabitants. The largest residential area is Apeldoorn.

Results, risks, consequences and probabilities
The economic risk is greater than € 31 million per year. The damage, calculated with the global method, amounts to € 3,100 million. This is an upper limit.

The calculated flooding probability of dike ring 52 is greater than 1/100 per year.

Weak locations analysis
The most significant contribution to the flooding probability comes from uplifting and piping for two predominant weak dike sections. In addition, uplifting and piping are involved for 14 other weak dike sections, overflow and wave overtopping affect three other weak locations and 'not closing' affects one other weak hydraulic structure. The dike manager confirmed the uplifting and piping to some extent. At high water seepage has been observed but in the second assessment the dike sections were approved for the failure mechanism of uplifting and piping. A different calculation method was used in the safety assessment than in the Flood Risks and Safety in the Netherlands (Floris) research project.

By investigating the probability of flooding of the two main weak dike sections and extending the seepage length, if necessary, the probability of flooding would be reduced to 1/100 per year. An upper limit for the cost of extending the seepage length is € 5.3 million. The basic principle here is that the entire dike section is tackled, even where the problem may not be involved. To further reduce the probability of flooding to 1/250 per year the 14 other weak dike sections with uplifting and piping, the three other weak dike sections with overflow and wave overtopping and the one other weak hydraulic structure with 'not closing' also should be further investigated and if necessary, the seepage length increased and the dike raised. The upper limit for the costs in this case amounts to € 31.3 million. If the probability of flooding were to be reduced to € 1/250 per year, the economic risk would amount to € 12.4 million per year.