Flood Risks and Safety in the Netherlands (Floris)

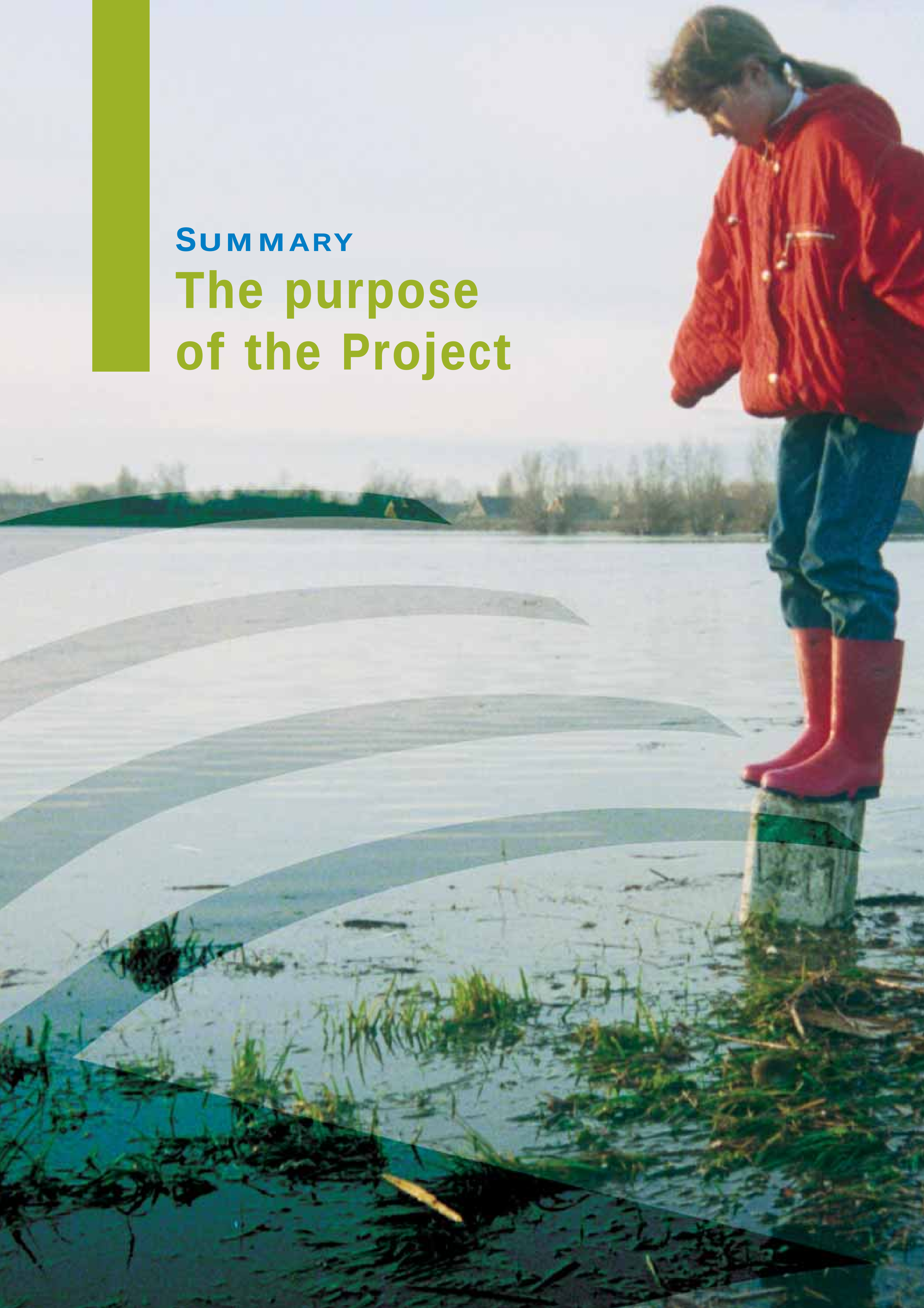
Floris study - interim report

Ministerie van Verkeer en Waterstaat

Content

SUMMARY

The purpose of the Project



The Flood Risks and Safety in the Netherlands (Floris) Project was initiated in 2001 at the request of the State Secretary of Transport, Public Works and Water Management. The purpose of the project is to gain an understanding of the consequences and the probability of flooding in the Netherlands. The underlying aim is that, apart from evaluating the probability of a certain water level being exceeded (which is the measure currently used to assess our dikes), other failure mechanisms are also taken into consideration. At the same time the potential consequences of flooding will also be investigated. The project was conducted by the Road and Hydraulic Engineering Institute of the Directorate-General for Public Works and Water Management, 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 development 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 loss resulting from various flooding scenarios for three dike ring areas. The consequences have been determined more globally for the remaining dike ring areas.

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 termed, can also initiate flooding: not just very high water levels, but also instability of a dike or failure to close a barrier 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 ring areas. The 16 dike ring areas were selected to give a representative view of safety in the Netherlands related to flooding. The calculations also show where the 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 engineering works. 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 risk. Further research may, in a number of cases, reduce the uncertainty, in which event the probability of flooding will also be lower. This research will take place in the next phase of the Flood Risks and Safety in the Netherlands (Floris) Project. Only then can the probability of flooding be established on a sound basis.

Consequences of flooding

The aim of the Floris Project is also to use the calculated consequences of flooding when deciding on strengthening of the water defences. From the study it appears that the most victims can be expected in the event of unexpected flooding. It is important to calculate various flooding scenarios to be able to improve the coordination of disaster preparedness plans.

The maximum economic damage in the event of flooding of a dike ring area 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 area was to fill up with water. It is however very unlikely that this will happen. For three dike ring areas 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 area would be inundated and how much damage this would result in. From these calculations it appears that in the most likely flood scenarios 'only' a part of the dike ring area would flood. Only in the rivers region would the dike ring area almost always become completely flooded. The average damage in South Holland amounts to roughly € 6 billion instead of the maximum damage of almost € 300 billion. The global method can therefore lead to huge overestimation of the damage, particularly for the larger dike ring areas which are divided into compartments by obstacles.

Probability of Flooding

The study shows that the probability of flooding in the 16 dike ring areas varies from 1/2500 per year in South Holland to more than 1/100 per year in a number of dike ring areas in the rivers region. These figures are only an indication of the probability of flooding and cannot yet be taken as absolutes. The method is not yet robust enough for that. The calculations do offer an opportunity to analyse what failure mechanisms have the most impact on the probability of flooding and where, relatively speaking, 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 ring areas the failure mechanism of ‘piping’ constitute the greatest threat. Here the water forms channels under the dike causing the dike to collapse. The great 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 location. 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. Emergency measures can be taken, such as covering the dike with textile and sandbags. The effects of this human intervention are not included in the calculation of the probability of flooding.

The failure mechanism of ‘not closing the hydraulic structures’ also led to a high probability of flooding in a number of dike ring areas. In almost all cases this was because the closing procedures were not properly defined. This threat 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.

Flooding risks

The risk of flooding in a dike ring area 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 ring areas ranges from € 0.1 to 180 million per year. In the three dike ring areas 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 flooding. In dike ring areas 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 larger because if there are floods, almost the entire dike ring area will be inundated with water. In most cases, other dike ring areas will 'only' partially flood.

Usefulness 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 ring areas 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 flood probability, but cannot 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 the uncertainty in the data. Further study in Rotterdam, for example, showed that the probability of flooding at the Boerengatsluis was much less.

The Floris project has reached the second development level for three dike ring areas. These are the dike ring areas 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 ring areas. As soon as the flood risks of all the dike ring areas 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 ring areas, along the coast or in tidal river areas.

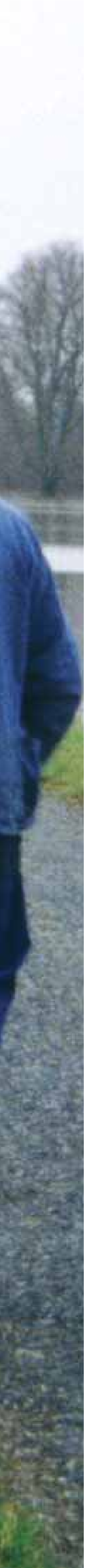
Development level three will be reached in the future when the flooding probabilities and consequences for all dike ring areas have been soundly determined, with an acceptably small margin of error. The flood risks of dike ring areas throughout the Netherlands can then be compared with one another. It 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 absolute values. Further research and development of the method could help to make the method more robust in the future.

For most applications the picture of the flood risks nationwide needs to be completed. Therefore it is recommended that the method also be applied to the remaining 37 dike ring areas. To obtain a proper estimate of the consequences a detailed method needs to be used for all dike ring areas. More attention should also be focused on how cost/benefit analyses can be carried out to deal with relatively weak locations. The study should continue, preferably coordinated from one central point to be able to compare all the results. The mechanisms of uplifting play a major role in the present flooding probabilities and deserver further investigation. The study needs to 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. Flood protection: a public issue



Is the Netherlands properly protected against flooding? And what is "properly protected"? These are public issues: it really depends on how much we are willing to spend. To be able to conduct this debate, the relationship between the cost of flood protection and what we want to protect needs to be clear. The Flood Risks and Safety in the Netherlands (Floris) project provides more insight into this.

1.1 Reasons for a study of the risks of flooding

There is no such thing as a life without risks. One of the risks of living in the Netherlands is that the country is vulnerable to floods. Because of major technological advances it is possible to make the flood probability very small. It is therefore not surprising that the Dutch no longer consider floods as a natural disaster, but as a disaster caused by humankind. It may never be possible to prevent flooding entirely, but people can largely determine for themselves to what extent they want to control the risk. This makes it possible and, indeed, necessary to make a conscious choice about the costs and benefits of high water protection. The benefits are fewer victims and less damage when flooding does occur.

The consequences of a flood largely determine how the flood risk will be assessed. The greater the consequences, the smaller we want to make the flood probability and the more we are willing to invest in high water protection. The present safety standards for water defences were derived on the basis of the size of the population and the economic importance of South Holland in the 1950s. For regions with fewer inhabitants and of less economic value, lower standards were set at the time. Since the 1950s the size of the population and economic importance has greatly increased throughout the Netherlands, particularly in the vulnerable, low-lying polders. The consequences of any flooding have therefore become greater. This was the reason for reviewing whether the Netherlands is still sufficiently protected against the consequences of a flood, even though the dikes have never been as high and as strong as they are now.

A flood can occur due to various causes. Each cause contributes to the probability of flooding. This makes calculating the probability of flooding very complicated. When the present standards were set, it was not even possible to do this. The present standard therefore does not reflect the probability of flooding, but an aspect of it. The standard assumes that extremely high water levels will be the main cause of a flood.

1.2 Aim of the Flood Risks and Safety in the Netherlands project

In the year 2000 the Dutch government decided to determine the probability and consequences of flooding throughout the Netherlands. The government wanted to have a clearer idea of where the relatively weaker locations are in the flood defences and the costs and benefits of investments made to improve these locations. The government also considers it important that the public has a better understanding of the probability of their area being hit by a flood. In 2000 the Technical Advisory Committee on Water Defences (TAW) developed a method for calculating the probability of flooding and, as a test, applied it to four areas. One of the results was that hydraulic structures, such as locks and cuts, form relatively weak locations in the water defences. The government decided to extend this study. The Ministry of Transport, Public Works and Water Management undertook to do this by setting up the Flood Risks and Safety in the Netherlands (Floris) project, together with the provincial authorities and the Water Boards.

The Floris project began in 2001with this goal: “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 locations in the dike rings and the risks of flooding can be determined.” Four routes were taken to achieve this goal:
1. determining the probability of flooding for all dike ring areas;
2. gaining an understanding of the problems affecting hydraulic structures;
3. gaining an understanding of the possible consequences of flooding;
4. obtaining an impression of the uncertainties and an indication of how to deal with them.

The task of the Floris project turned out to be ambitious. Despite the fact that the Netherlands is a front-runner when it comes to expertise on flooding, it is still difficult to turn complex flooding processes 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 in the right format, or at the right time. The method itself is also not fully developed.

During the project it was therefore decided to undertake the assignment in phases. During this first phase of the project the probabilities of flooding, consequences and risks were calculated for 16 of the 53 dike ring areas in total. The 16 dike ring areas were chosen such that together they would give a fairly representative picture of the situation in the Netherlands. The consequences of flooding were calculated at a detailed level for three dike ring areas. The consequences for the remaining 13 dike ring areas were roughly estimated.

Dike ring

A dike ring is a unbroken ring of water defences and high ground. The area protected by the dike ring is called the dike ring area. At the start of the study there were 53 dike ring areas in the Netherlands. In 2005 the Water Defences Act was revised, with new dike ring areas being designated along the Maas, south of Nijmegen. Ninety-five dike ring areas in total are now designated in the legislation.

1.3 Interim phase

The first phase, which has now been completed, should be seen as a step in a long term process (see appendix). This process began with the recommendations made by the Delta Committee in 1960 and, as the process develops further, will ultimately result in a thorough understanding of the flood risks throughout the Netherlands:

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 the dike ring and what failure mechanisms are responsible for this. The dike manager can use this sound information to set 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 ring areas. Once the probabilities of flooding are available for several dike ring areas in the rivers region, for example, this provides insight at this level into where the weakest links are throughout the entire rivers

region. In this way similar dike ring areas along the coast or the tidal river areas can be compared and priorities set about what measures to take and when.

Development level 3:
The final level provides robust values for flooding probabilities and the consequences with an acceptably small margin of error. This level is necessary to be able to carry out a cost/benefit analysis for the investments to be made in providing protection against flooding and 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 ring areas. The flood risks have been determined at the second level for three dike ring areas. 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.

1.4 Combined effort

The Road and Hydraulic Engineering Institute of Rijkswaterstaat (Directorate-General for Public Works and Water Management) was asked by the Ministry of Transport, Public Works and Water Management (Directorate-General Water) to coordinate the Flood Risks and Safety in the Netherlands (Floris) project. The Provinces and the Water Boards were also closely involved. They provided the data for the calculations of the probabilities and consequences for each dike ring. The Water Boards have thoroughly examined the results of the probability calculations and indicated whether or not the results make sense to them on the basis of their knowledge and experience in the area that they control. Given their responsibility for spatial planning and public safety, the Provinces mainly contributed to the calculations on the consequences of flooding and the discussion of the results.

Various parties have contributed to the development of methods: Rijkswaterstaat, universities and other centres of expertise, as well as specialist consulting firms. To share the newly acquired knowledge with the market, a number of selected consulting engineering firms were asked to carry out the calculations.

The former Technical Advisory Committee on Water Defences (TAW, now the Water Defences Expertise Network) carried out a quality audit and at various points gave advice on the set up of the study, the methods used and undertook an analysis of the results.

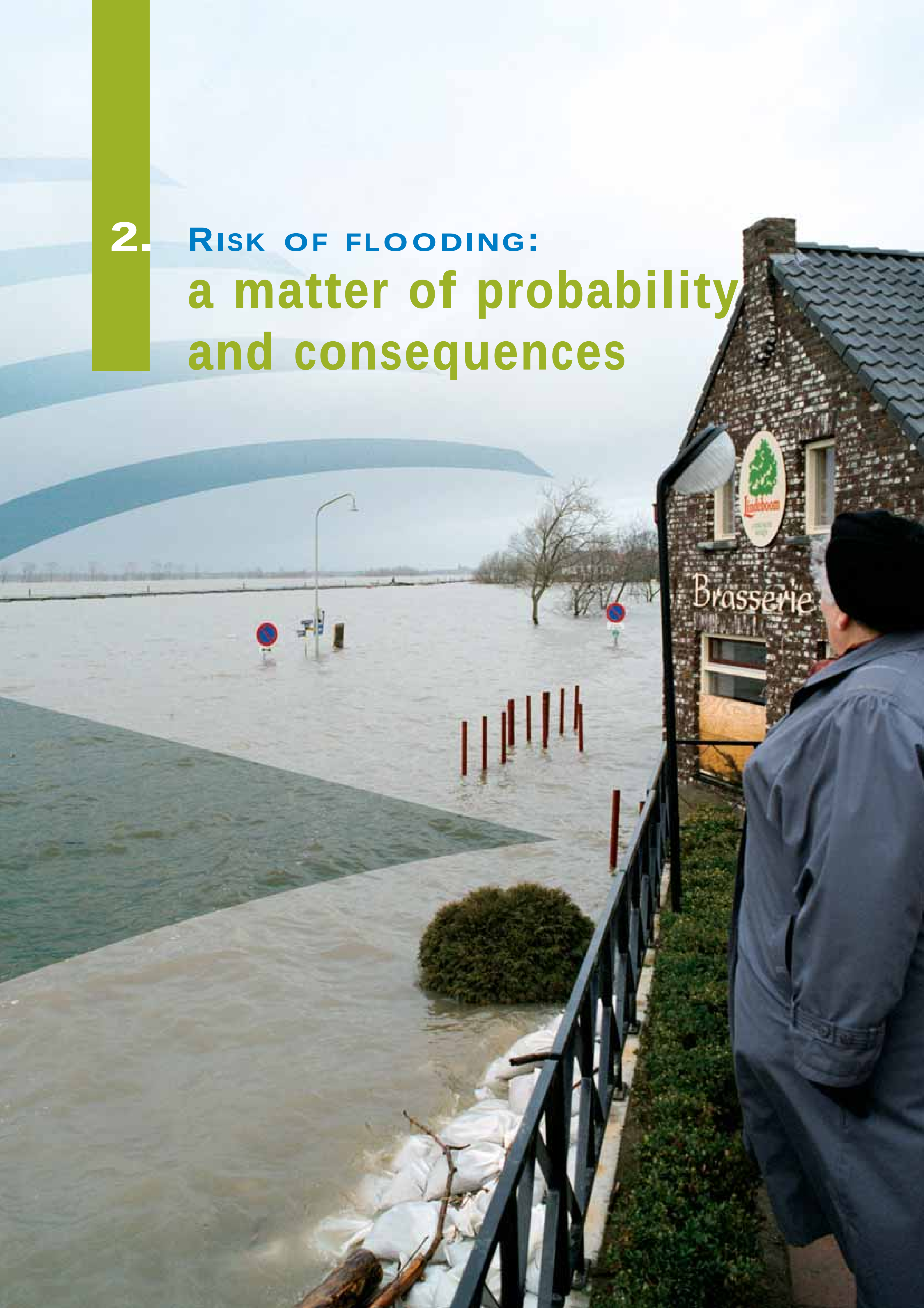
1.5 Schedule

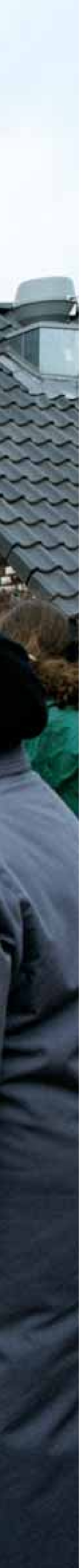
In the summer of 2005 the first phase of the Floris project was completed. This interim report summarises the main findings and also covers the applications which the Safety in the Netherlands (Floris) method can be used for.

The following topics will now be covered:
- background information on consequences, probabilities and risks;
- findings of the Floris project;
- application of the Floris method;
- conclusions and recommendations.

The main report of Flood Risks and Safety in the Netherlands (Floris) project gives, in addition to this interim report, a more complete overview of the methods used, the results and conclusions.

2. Risk of flooding: a matter of probability and consequences





The risk of flooding depends on the probability of flooding and the consequences of this flooding. The Flood Risks and Safety in the Netherlands (Floris) project has developed a new method for calculating the probability and consequences of flooding.

2.1 Risk of flooding

Viewed in the very long term, the risk of flooding is the average damage caused by flooding per year. The risk of flooding can be calculated by multiplying the consequences of a flood with the annual probability of a flood occurring. The risk is generally expressed in terms of the number of victims and a financial sum per year. The Floris project established the risk of flooding per dike ring.

2.2 Consequences of a flood

A flood can have various consequences:
- economic damage can occur;
- there may be victims;
- people may feel displaced and there may be social disruption;
- there may be damage to the landscape, wildlife and cultural heritage;
- there may be environmental damage caused by the dispersion of pollution.

A flood from the sea, the major rivers or the IJsselmeer can quickly take on the proportions of a disaster. The number of victims will depend on the number of people living in the area affected, the location of the breach, the speed at which the water rises and the evacuation capacity. Other factors may also play a role, such as the presence of compartment dams.

The economic damage and the damage to wildlife, the landscape and the environment largely depends on the land usage, the ultimate depth of the water in the flooded area and how long the flood lasts. The economic damage and the damage to wildlife and cultural heritage in the event of a salt water flood will be much greater than for fresh water. The greater the consequences of the flooding the greater the sense of displacement and social disruption will be.

2.2.1 Present method

The Delta Committee drew up the standards for water defences following the flood disaster of 1953. It estimated what the economic damage would be in the event of a sea flood in the Randstad (western conurbation). The committee also estimated to what extent the probability of flooding declines with investment in the water defences and what the effect of this would be on the flood damage. The committee then tried to find an optimum balance between the flood damage and the investments to be made in water defences. It reached the conclusion that this optimum could be achieved by setting a water level for the water defences along the Dutch coast with an exceedance level of 1/10,000 per year. For the coastal areas in Zeeland, Friesland, Groningen and Texel the committee considered a greater probability reasonable, because the size of the population was smaller and the economic assets were less in these areas than in the Randstad. The government adopted the proposed standards in the Delta Plan. At a later stage the Minister of Transport, Public Works and Water Management set a lower standard for the rivers region. Important considerations for this lower standard were that high water levels on the rivers can generally be predicted several days in

advance, so that evacuation is quite possible. Furthermore, flooding with freshwater river water causes less damage than salt seawater.

The consequences were thus originally taken into account when the present standards were set, but for most areas only qualitatively. Since then the size of the population and the economic value have grown considerably in the Netherlands. It is therefore, open to question whether these standards are still in proper proportion to the consequences. The present method for setting standards is, in practice, quite workable and easy to apply.

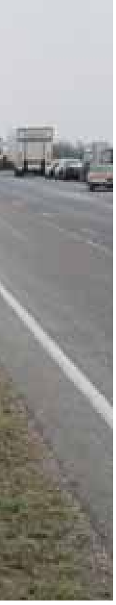
2.2.2 New Floris method

In the Flood Risks and Safety in the Netherlands (Floris) project two methods were used to calculate the consequences of a flood.
A detailed method was applied to the three dike ring areas: Noordoostpolder, Zuid-Holland and Land van Heusden/De Maaskant. Several flood scenarios were calculated for these dike ring areas. A flood scenario indicates the way in which the dike ring area will flood if a water defence fails at a certain location. The scenario shows how quickly the water rushes in, what part of the dike ring area will be inundated, how quickly the water rises and how far the water will ultimately rise. With this information it is possible to predict the potential damage and the number of victims in each scenario.
The Floris project also used a global method to calculate the consequences of flooding in these three dike ring areas. The global method was also applied to the other 13 dike ring areas. This method assumes that in the event of a flood the entire dike ring area will fill up to the level of the lowest dike. The results give an impression of the maximum damage which could result from a flood. Because in reality the entire dike ring area will not fill up in all situations, the global method generally overestimates the damage. It is not possible to determine the number of victims with the global method, because the speed at which the water rises cannot be calculated.

Economic damage

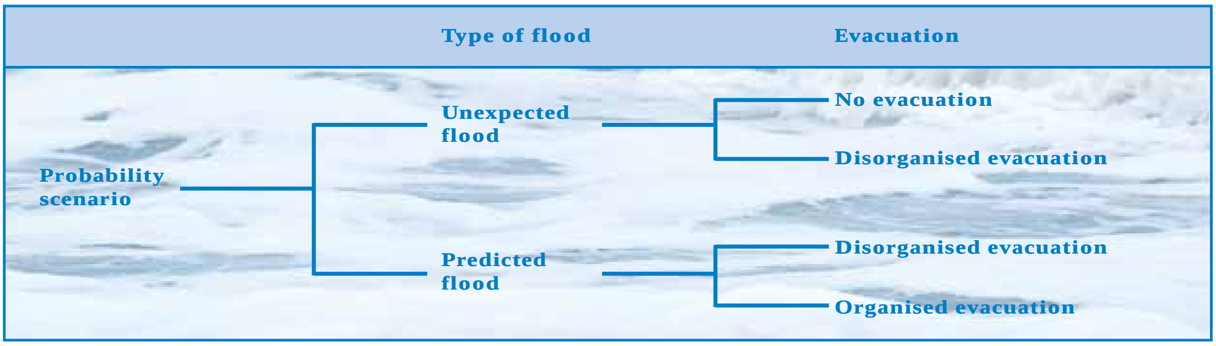
In both methods the damage is calculated for three categories:

direct material damage	damage which is caused to objects, capital goods and movable goods as a result of direct contact with water
direct damage due to business interruption	commercial losses due to interrupted production of businesses in the flooded area
indirect damage	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



Victims

The number of victims was also estimated for the three dike ring areas where the detailed method was applied. The number of victims mainly depends on the possibility of evacuation. If a flood occurs unexpectedly, there is less time available for evacuation than if a flood can be predicted a few days in advance. The better the evacuation is organised the more effective it will also be. The Floris project obtained an overview of the number of victims in four situations:



Whether a flood can be predicted or not depends on the cause. 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. In Floris these considerations were taken into account in determining the number of victims. When calculating the number of victims in the event of organised evacuation it was assumed that adequate disaster preparedness plans are available.

Other consequences

Methods were developed in Floris for determining the damage which a flood can cause to wildlife, the landscape and cultural heritage, as well as to the environment due to the spread of chemicals. To gain an impression of the scale of these consequences the method for natural and landscape features was applied to two dike ring areas and the method for damage to the environment was applied to one dike ring. The feelings associated with displacement and social disruption in the event of a flood were not investigated.

2.3 Probability of flooding

Possible causes of flooding

The water defences can never prevent flooding entirely. Various causes, also known as failure mechanisms, can initiate a flood. Each failure mechanism results in a certain probability of flooding. The probabilities of all failure mechanisms together determine the probability of a dike ring area flooding.

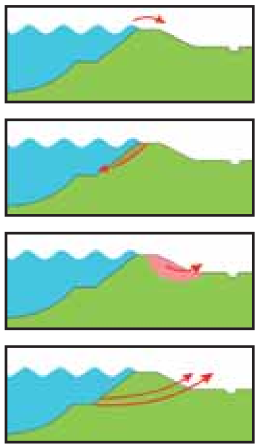
There are four important failure mechanisms for dike rings:

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;

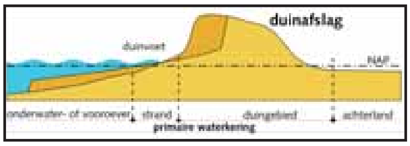
damage to revetment the dike facing (or revetment) becomes damaged by the waves, following which part of the dike is washed away;

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

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

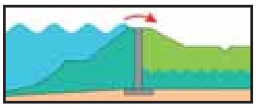


Dunes can fail due to:

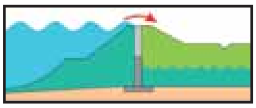


dune erosion during storms a large part of the dune may be washed away, and the sea can then break through;

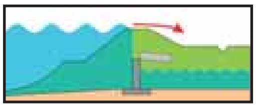
The hydraulic structures in the dikes, such as locks, can also fail causing the dike ring area to flood. There are three main failure mechanisms for engineering works:



overflow and overtopping the water level is higher than the top of the hydraulic structure and the water flows over it;



non-closure the hydraulic structure is not closed on time or fully and the water flows through it;



structural failure the hydraulic structure collapses.

2.3.1 Present method

The standards for primary water defences are laid down in the Water Defences Act. The standards reflect the probability that the water will rise higher than the normative water level which applies to the water defence ("exceedance probability"). 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 due to climate change, for example. On this basis the hydraulic boundary conditions that the water defences must meet in the next five years are set. The dike managers then test whether each section of dike meets these boundary conditions and reports the result to the Minister. 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.

Flooding risks abroad

The Netherlands applies considerably stricter standards than most other countries in the world. Even the legal status of the Dutch standards is exceptional. The Netherlands tailors the design of the dike much more closely to the standard, while other countries often "add on a bit extra" just be sure. In practice, the protection levels differ not as much as the standards would lead us to believe. The protection measures in the Netherlands focus mainly on reducing the flood probability, as in Flanders and Germany. Other countries, such as Great Britain, the United States and Japan, focus more on limiting the consequences of a flood. They do this, among other things, by discouraging building in risky areas. These countries place the responsibility for flood damage largely with the public, who can often insure themselves against flood damage.

2.3.2 New Floris method

In the Floris project all the above failure mechanisms were included in the calculation of the probability of flooding. First the probabilities per failure mechanism for each section of dike and hydraulic structure were separately determined. The overview of the probabilities per failure mechanism per dike section and per hydraulic structure indicates where the relatively weaker locations are within the dike ring. These probabilities are then combined for the entire dike ring to arrive at the total probability of flooding of the dike ring.

Previous research conducted by the Technical Advisory Committee on Water Defences showed that hydraulic structures could potentially constitute relatively weak locations in the water defences. The calculations, however, contain large uncertainties. The Floris project therefore devoted particular attention to assessing the probabilities of failure of the hydraulic structures. New methods were developed and applied for six types of hydraulic structures. Surveys were carried out for pipelines and longitudinal structures (such as quay walls).

The Floris project based the calculations of the probability of flooding on the hydraulic boundary conditions laid down by the Ministry of Transport, Public Works and Water Management in 2001. In the rivers region these conditions are stricter than they were in the past and the dikes in this area have not all be modified accordingly. For the coast it was noted that after 2001 the impact of waves in the future will be greater than had been expected. These new insights were not included in the Floris project.

The following effects were not included within the scope of the calculations:

• human intervention

If flooding is anticipated, people will take emergency measures such as raising the dike with sandbags or stopping seepage behind the water defences to combat piping. This can help to reduce the flooding probability. By how much, cannot be predicted. The human intervention factor was taken into consideration in the closing of hydraulic structures.

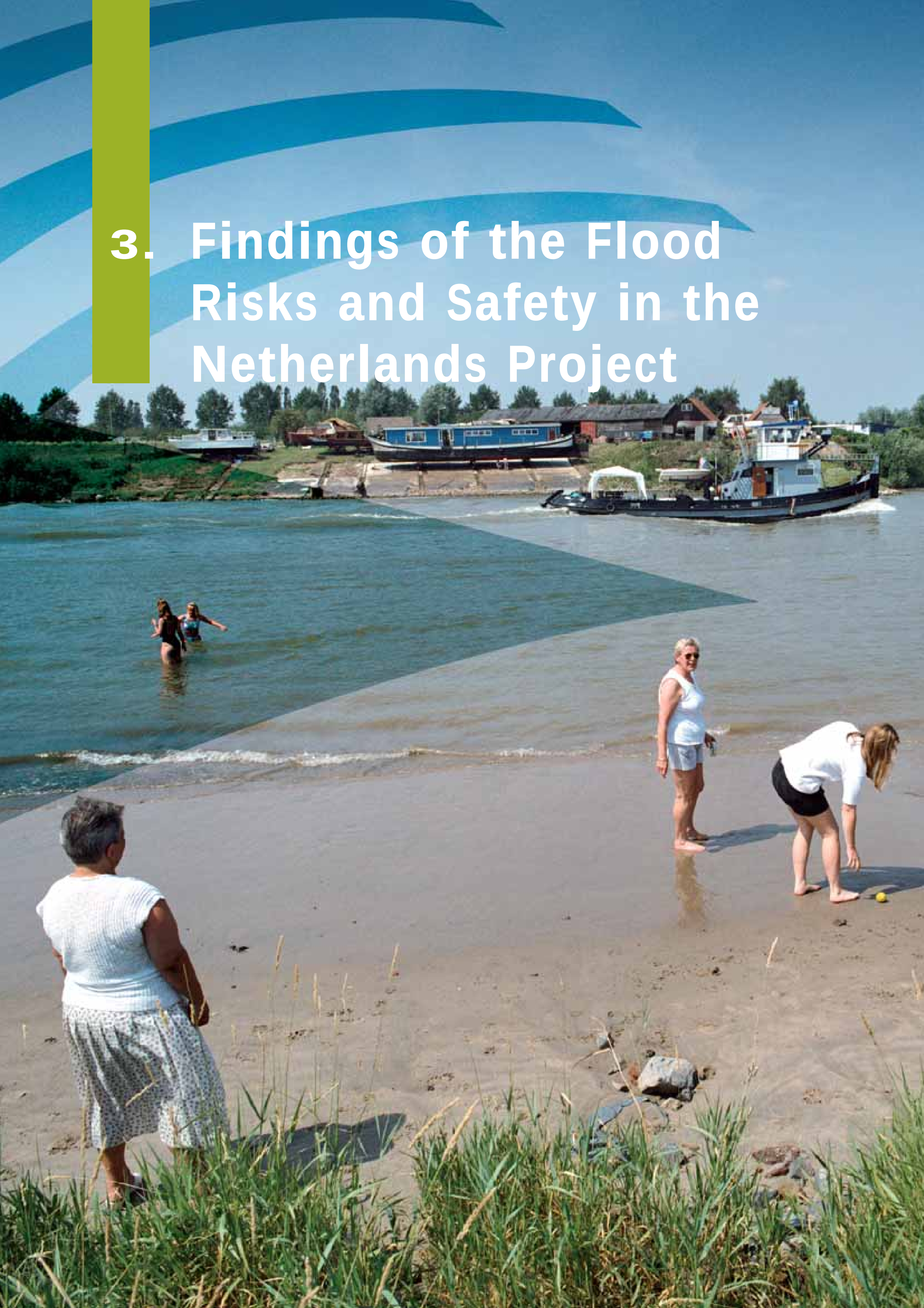
• system effect

Various events in the water system can reinforce or even curb one another. 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 area 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 than expected. As a result the probability of flooding will increase. The impact of system effects is difficult to predict.

• flooding of water defences in the categories b, c and d (see glossary).

The Floris project only calculated the flooding probabilities for category a water defences: dikes, dunes and hydraulic structures which provide direct protection against the sea, the major rivers or other large open waters. The water defences in other categories were not included. Category b water defences were not included because they do not form part of the water defences surrounding the dike ring areas. These water defences therefore contribute little to the flooding probabilities and the consequences of flooding in the dike ring area. The dike ring areas in category c were not included because there was often insufficient data available about the hydraulic load, the height and strength of these water defences. Category d concerns water defences abroad. Within the time frame and scope of the Floris project it was not possible to obtain sufficient information about these water defences.

3. Findings of the Flood Risks and Safety in the Netherlands Project



The Flood Risks and Safety in the Netherlands (Floris) project has determined the risk of flooding for 16 dike ring areas. The results have provided new insights into protection against flooding.

3.1 Selection of the dike ring areas

In the Floris project the consequences of flooding and its probability were calculated for 16 dike ring areas. The calculations apply to the situation in 2004. The project began with 6 dike ring areas, designated as the front runners. The remaining 10 dike ring areas were chosen such that together with the front runners, they provided a representative picture of the Dutch dike ring areas and reflected as many different characteristics as possible. The dike ring areas 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 on the Wadden islands. The dike ring areas chosen included ones in large and densely populated areas and smaller ones in areas with fewer inhabitants.

For three dike ring areas the consequences were calculated using a detailed method. Here too, three very different situations were examined: Noordoostpolder, Zuid-Holland and Land van Heusden/De Maaskant.

3.2 Consequences, probabilities and risks

3.2.1 Consequences of flooding

The consequences for the 16 dike ring areas were first calculated using the global method. The number of victims cannot be determined with this method. The calculated economic damage is the maximum damage, i.e. the scenario in which the entire dike ring area fills up with water to the level of the lowest water defence. This scenario is not conceivable for every dike ring. For three of the dike ring areas the consequences of flooding were also calculated using a detailed method. Here in various flooding scenarios it was analysed what part of the dike ring area would be inundated and how much damage this would cause. When the detailed method is used the consequences of flooding can be expressed in numbers of victims and the average economic damage.

The maximum economic damage in the dike ring areas ranges from several hundred million euros to almost three hundred billion euros in South Holland (tables 1 and 2). This damage would occur if the entire dike ring area were to fill up with water. From the detailed calculation of the damage in South Holland it appears that in the most likely flooding scenario 'only' part of the dike ring area would flood. Due to various obstacles, such as secondary defences and partition dikes, the flooding would often be limited to a small section of the dike ring. The average economic damage (approx. € 6 billion) in this dike ring area is therefore considerably lower than the maximum damage. This also applies to the Noordoostpolder. Only in the rivers region would the dike ring area become almost completely inundated in the event of a flood.

The conclusion is that the use of the global method can result in a huge overestimation of the damage, particularly for large dike ring areas which are divided up into compartments by obstacles. The detailed method gives a picture which more closely matches the actual situation. The detailed method also has the advantage that it provides insight into the most likely flooding scenarios and the way in which the dike ring area will flood in these situations. This information is very valuable for drawing up disaster preparedness plans.

The detailed calculations also give an impression of the number of victims in the event of a flood. From the calculations it appears that depending on the flooding scenario, there may be between a few dozen and thousands of casualties. Most are likely to occur if the flooding is unexpected and evacuation is not possible. In the flooding scenarios that would seem to be most likely in these three dike ring areas , timely evacuation may indeed not always be possible.

In the Floris project an indicative calculation was made of the damage which a flood could cause to wildlife, the landscape and cultural heritage (known as the natural and landscape features). The scale of the damage to these features depends on the duration of the flooding and the height of the water. It is expected that in the event of flooding, certain rare species may vanish forever. Cultural heritage sites could be irreparably damaged. In general, it appears that the damage caused by flooding with salt water would be much greater than with fresh water. The level of environmental threat posed by the spread of toxic substances was also ascertained. For this, the method developed was applied to the dike ring area Land van Heusden/De Maaskant. On the basis of this analysis no large scale environmental pollution is expected due to the release of substances from the companies surveyed.

3.2.2 Flooding probabilities

The calculated probability of flooding ranges from 1:2500 per year for parts of the Randstad western conurbation to more than 1:100 per year in the rivers region (see table 1). The calculations carried out for the Floris project are currently at development levels 1 or 2 (see section 1.3). The results give an indication of the flooding probabilities but cannot be seen as absolute values. The calculations do, however, provide the opportunity to analyse which failure mechanism contribute most in the flooding probability and where the weakest locations are in the dike ring.

The calculated probability of a flood due to high water levels (failure mechanism overflow and overtopping) is small in most dike ring areas compared with probabilities of other failure mechanisms. In the dike ring areas along the coast and along the IJsselmeer this probability is even considerably smaller than the present standard. This is in line with what would be expected because this failure mechanism is highly influential in the design of the water defences. The weakest links in the coast line are revealed in the calculated probability of failure of sections of the coastal defences but these are not critical to the calculated probability of flooding of the dike ring. This can be explained by the fact that the Floris project used the boundary conditions for 2001. After 2001 it was established that the wave load along the coast will increase in the future and, based on this information, the weak links along the coast have been identified.

Uncertainties in the data

The probability of failure mechanisms occurring cannot always be established with equal certainty. In some cases our understanding about the course of processes is not adequate or insufficient data is available. In the Floris project these uncertainties are, as far as possible, specifically expressed in the uncertainty margins (margins of error). Where this was not possible, our interpretation of the data was conservative (i.e. cautious). This is the method normally adopted in risk analyses and is often referred to as the "Maximum Credible Accident". The inclusion of uncertainties generally results in greater flooding probabilities and possibly an overestimation of the risks. Failure mechanisms which require detailed information about the structure of the subsoil, such as piping and the stability of hydraulic structures, are surrounded by uncertainties. Many dikes have been gradually raised over the centuries and extensive research is required to be able to find out what structural work was done. For a particular hydraulic structure it has been calculated that the probability of failure can drop from 1/500 to 1/50,000 if the structure of the subsoil is known and turns out to be favourable. Further research, however, may not always lead to a smaller probability.

In most dike ring areas the failure mechanism of piping results in the greatest probability of flooding. In the rivers region in particular, high probabilities were calculated for this failure mechanism. These high probabilities are partly due to the large uncertainties in the data about the subsoil under the foundations of the water defences. What is clear is that piping constitutes a real risk. It is known that this phenomenon caused dike breaches in the past. During the high water levels on the rivers in 1993 and 1995 the first signs of piping were seen in numerous places in the form of seepage and sand-bearing rising water behind the dike. At the time this did not lead to a breach because there was adequate intervention. The dike managers stopped the seepages by damming them with geotextile and sandbags at the affected sites. The effect of this type of human intervention is not included in the calculated probability of flooding because it is not possible to be sure that piping will always been spotted on time. The major uncertainties in the data and the exclusion of human intervention therefore generally leads to an overestimation of the probability of flooding. Further investigation of the sites in question is necessary to be able to determine whether the calculated high probability of flooding due to piping means that the water defence actually has relatively weak locations.

The "non-closure" failure mechanism for hydraulic structures also makes a major contribution to the probability of flooding of a number of dike ring areas. In almost all cases this is the result of closing procedures not being well documented and sufficiently practised. This probability can be quickly and cheaply reduced by having the procedures documented and practising them regularly. Some Water Boards have already started on this. At the start of the Floris project the probability of failure of hydraulic structures was still an unknown factor. The methods developed during the project mean that these probabilities can now be properly revealed.

Uncertainties in the method

When assessing water defences dike managers can use two types of methods to calculate the probability of piping occurring. If from the first, global method it appears that a dike section does not meet the requirements for piping, a new calculation is carried out using a more detailed method. This method requires detailed information on the subsoil, which is collected by an expert on the area concerned.
The Floris project has to rely on the detailed method because only this method provides the necessary calculation of probability. The vast length of water defences which the Floris project has to cover meant that it was impossible to have detailed survey data on the subsoil collected by local area experts. The data used therefore includes a fairly large uncertainty margin. Uncertainties can have a major impact on the probability calculations, which could explain the high failure probabilities calculated by the Floris project for piping.
In 2004 external experts, led by Professor Vrijling, undertook a review of the initial results of the Floris project. They concluded that the latest techniques had been used, except for piping. The advice of the experts was to investigate whether the calculations would lead to different results for the failure mechanism of piping if new, more detailed subsoil information was used. In this way it can be investigated whether uncertainties result in overestimation of the probability. This was tested for two locations where large failure probabilities were initially calculated for piping. Using more detailed information reduced the uncertainties and the calculations for these two sites resulted in considerably smaller probabilities of failure. To be able to apply the new method a great deal of information is required, e.g. on the soil stratification. This information is not available for most of the locations.

Importance of detailed knowledge of the area

To be able to interpret the calculated probability of flooding properly it is necessary to have a detailed knowledge of the area. For example, the Boerengatsluis, a lock near Rotterdam would appear to have a failure risk of 1/300 per year, which has a major impact of the total probability of flooding of the dike ring. Behind the lock however, there is a dike, so that failure of the lock would not immediately result in flooding of the dike ring area. The failure probability of a lock and a dike at the same time is only 1/48,000 per year, if the dike is also managed in the same way. For Terschelling too, the failure risks could be adjusted by adding local knowledge of the area. The calculations resulted in a failure probability due to piping of 1/600 per year. The extensive Wadden mud flats, however, in front of the dike would largely prevent piping. When this effect is taken into account, the calculations result in a failure probability of only 1/64,000. This thorough checking of relatively weaker locations was done for all 16 dike ring areas.

3.2.3 Flood risks

The economic risk is calculated by multiplying the probability of flooding by the economic damage in the event of a flood (tables 1 and 2). This economic risk is expressed as a sum per year. An economic risk of, e.g. € 10 million per year means that a sum of € 10 million per year should be set aside from public funds for compensation in the long term of the damage caused by flooding. The risk increases as the probability of flooding increases along with the consequences. The risks can be reduced by either reducing the consequences of flooding or by strengthening the water defences such that the probability of flooding becomes smaller. Appendix 2 presents an overview of the flooding risks per dike ring.

From the results of the detailed risk calculations it appears that the economic risk in the Noordoostpolder is similar to that in Zuid-Holland. The economic damage in the event of flooding may well be greater in Zuid-Holland than in the Noordoostpolder, but the probability of flooding in Zuid-Holland, however, is smaller. The spatial land use planning of Zuid-Holland (South Holland) greatly determines the scale of the consequences. In the most likely flooding scenarios the presence of compartments results in the damage remaining limited which is then reflected in the risk. In the rivers region the flood risks are relatively great. This is because both the calculated probabilities and the average damage are large.

Detailed calculations of the consequences were carried out for the flood risk of three dike ring areas (table 1). For the remaining dike ring areas the risk is based on global calculations of the consequences (table 2). The detailed calculations give a more realistic picture of the flood risk than the global calculations. The global calculations result in overestimation of the risk. This can be seen in the consequences and the risks for the Noordoostpolder, Zuid-Holland and Land van Heusden/De Maaskant, as shown in table 1 (detailed calculations) compared with the consequences and risks given in table 2 (global calculations).

Table 1 Flood risks calculated with the detailed method

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 2 Flood risks calculated with the global method

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.

3.3 Value of the figures

Sixteen dike ring areas at development level 1

All 16 dike ring areas have been covered at development level 1 (see section 1.3). The results are suitable for use in the management phase. In this phase the calculated values for the probability of flooding give an indication of the actual probability of flooding, but cannot yet been seen as an absolute value. It is possible to identify where the weakest locations are in the dike ring and which failure mechanism is responsible for this. The dike manager can use this soundly-based information to set priorities for the maintenance of a dike ring. For a number of relatively weak locations it is first necessary to investigate whether there is actually a large risk of failure or whether this is due to uncertainties in the data or the method used. Appendix 2 gives a first impression of the relatively weaker locations for each dike ring.

Every five years the dike managers (Water Boards) assess whether the water defences still meet the standards laid down in the Water Defences Act. Measures are only taken further to statutory safety assessment of the water defences. These tests were carried out by the managers for the first time in 2001. The relatively weak locations revealed by the Floris project were compared with the results of these tests and, in general, they largely agree. In 2006 the results of the second safety assessment will be released.

Three dike ring areas at development level 2

Three dike ring areas are at development phase 2 in the Floris project. These are the dike ring areas for which the consequences of flooding have been calculated in detail. The results can be used in the management phase. This makes it possible to compare the flooding probabilities and flood risks of similar types of dike ring areas. As soon as the flood risks of all the dike ring areas in the rivers region can be obtained at this level, this will provide an overview of the consequences of flooding and the weakest links in the entire rivers region. Priorities can also be set in this way for similar dike ring areas along the coast or in tidal river areas.

Prospects for further development

Development level 3 will be reached when in the future the flood risks for all dike ring areas has been established in a robust manner, with an acceptably small margin of error. The flood risks of dike ring areas throughout the Netherlands can then be compared with one another. It is necessary to reach this level to be able to make a national cost/benefit analysis of investments in protection against flooding and to be able to evaluate whether the present standards offer sufficient protection. Once this level has been reached, the total risk of flooding in the Netherlands can also be compared in absolute terms with other collective national risks.

4. Application of the Floris method

Having an understanding of the probability of flooding and the consequences of flooding offers new opportunities for coping with the risk of flooding. The Floris method makes it possible for the costs and benefits of investments in flood protection to be more carefully weighed against one another. The method also offers the possibility in the future for setting standards for high water protection. If the method is applied to all dike ring areas, it will also be possible to compare the flood risk in the Netherlands with other collective national risks.

4.1 Is the Netherlands sufficiently protected against flooding?

The water defences in the Netherlands have never been as high and as strong as they are now. But the property to be protected has also never been as valuable and the population so large as it is now. If the flood risks for all dike ring areas are revealed in detail, it can be assessed whether the risk of flooding is acceptable or not. It will then become clear how the risk changes as investment in flood protection is either reduced or increased. In this way it is possible to decide how useful it would be to invest in flood protection based on a cost/benefit analysis for society as a whole.

The Floris project made a start on the development of a method for a cost/benefit analysis. The method makes it possible to compare the cost of improving relatively weak locations in relation to the reduction in the economic risk. From this information it can be deduced at what level of investment and what probability of flooding an economic optimum can be achieved. The method is not yet fully developed. For example, the effects of climate change have still to be incorporated in the method and the cost calculations need to be more accurate.

4.2 Investments in the right place

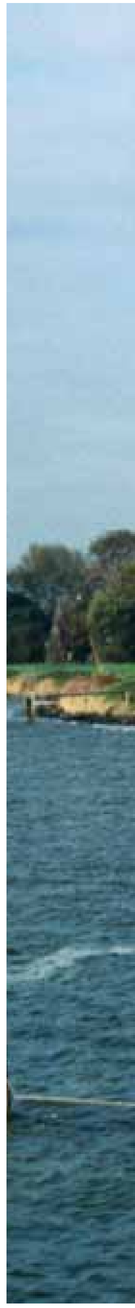
With the Floris method it is possible to get an impression of where investments in water defences will make the most contribution to reducing the risk of flooding. For example, it becomes possible to set well-founded priorities for the implementation of measures. This can be done at various levels of scale and will ultimately involve a political decision. The levels of scale are closely related to the development level in the method, as indicated in sections 1.3 and 3.3.

4.3 What is a good standard for protection against flooding?

The present standards for flood protection are almost 50 years old. The Floris method provides an opportunity to evaluate whether the standards are still in agreement with the present economic value and the size of the population. It is also an opportunity to explore whether other standards could perhaps offer a better measure of protection against flooding.

The advantage of the present standards for water defences is that it is fairly easy to test them. The drawback is that they provide no insight into the flooding probability or the risk of flooding. From the results of the Floris project it appears that the probability of flooding is greater than the present standards allow for. Because the current standards must be maintained per dike section, maintenance and investment may not always be carried out where they are most urgently needed or would be most cost-effective. For these reasons it has often been suggested that these standards should be redefined.

Already in the 1950s the Delta Committee wanted to express standards in terms of a maximum admissible probability of flooding. At that time, however, the mathematical techniques available were not sufficient for this. Using the method developed in the Floris project, this is now possible. A probability of flooding gives the public more insight into their situation than the present exceedance probability and moreover, provides an opportunity to undertake maintenance and investment in those places where it will contribute most to reducing the probability of flooding. In selecting the maximum admissible probability of flooding which will set the standard, it is useful to carry out a cost/benefit analysis, for which it is necessary to calculate the flooding probabilities of all dike rings. The main consideration is that the flooding probabilities, e.g., of the dike rings in the rivers region, must be coherent. Lowering the probability of flooding in one dike ring could automatically lead to the probability of flooding increasing in another dike ring. To be able to test a standard in the form of a probability of flooding, a feasible method has to be developed which takes this interdependency into account.



A step further would be a standard in the form of the flood risk, which combines the probabilities and the consequences. Changes in the spatial planning would have an immediate impact on the flood risk. For example, the development of a new industrial estate would increase the consequences of a flood. If, as a result, the flood risk of the dike ring area exceeds the standard, the choice would then be whether to reduce the probability of flooding or the consequences of flooding, or to apply a combination of both measures. The consequences could be reduced, for example, by improving the disaster preparedness or by taking area-related planning measures. In setting the level of the standard, room can be left for new developments, without such new developments immediately resulting in the standard being exceeded. The enforcement of a standard for the risk of flooding however, will be complex, because different parties are responsible for the consequences and the probabilities.

4.4 Disaster preparedness

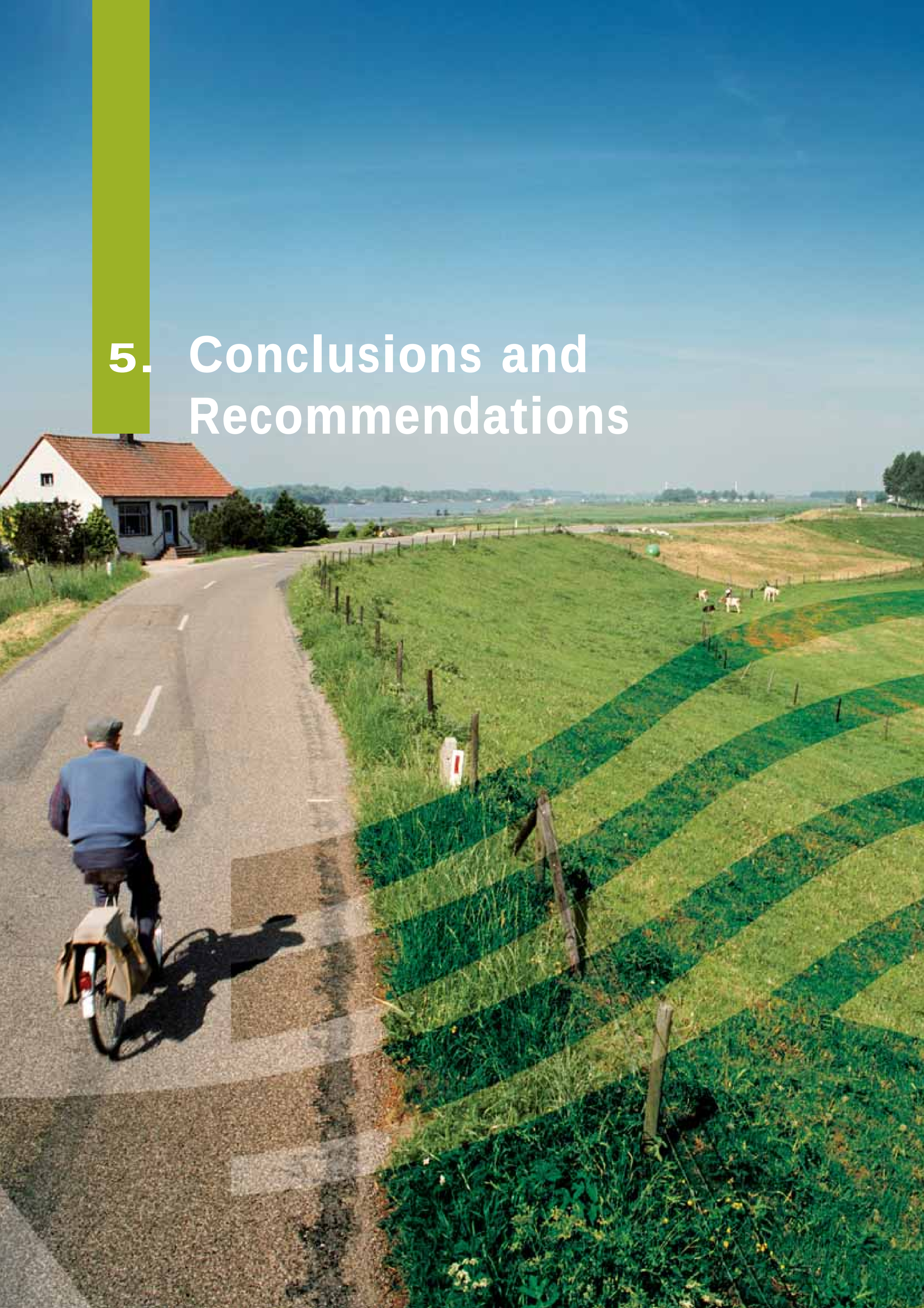
Having an understanding of the relatively weak locations is particularly important for disaster preparedness planning. Municipalities can take the most likely flood scenarios into account in their disaster preparedness planning and, at the same time, the options for evacuation, for example. The Water Boards can prepare more targeted emergency measures.

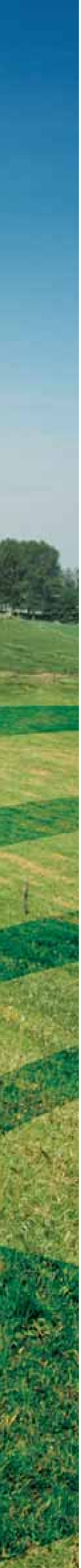
In 2006 central government will make a decision on the disaster management strategy for the major rivers. The knowledge gained from the Floris project could contribute to the debate on the strategy to be adopted and its implementation.

4.5 Improving understanding and cooperation

The application of the Floris project method requires specialist knowledge. The Water Boards and Provinces were involved in the analyses by collecting the necessary information and evaluating the analysis results. It was deliberately decided to involve several consulting engineering firms in carrying out the calculations. Experts from the former Technical Advisory Committee on Water Defences (TAW) advised on specific issues and provided a quality audit. The Floris Project Bureau made sure that the information gathered by the Provinces and Water Boards, which was done by various firms, was carried out in a similar fashion. The Floris project resulted in a huge volume of new data which had to be systematically processed. This has resulted in many new insights and a better understanding of flood protection.

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 water 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

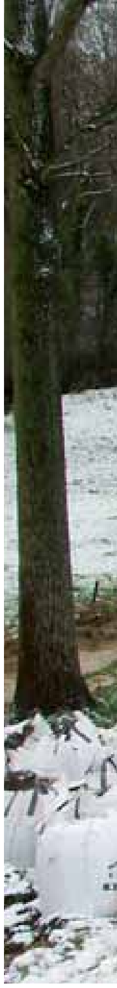
The Floris project is an intermediate step along a longer development pathway. The flood risks have been identified for 13 dike ring areas at development level 1. For these dike ring areas it is possible to trace the relatively weak locations in the dike ring and the reasons for them. The Floris project has reached development level 2 for three dike ring areas. The figures calculated for these three dike ring areas can be compared with the results of similar types of dike ring areas. 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 ring area varies from hundreds of millions euros to almost three hundred billion euros in parts of the Randstad western conurbation. This damage would occur if the entire were to be inundated 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 area would be flooded. Due to numerous higher linear elements in a dike ring area (e.g. embankments and railway lines) the flooding would very likely be limited to a small part 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 area almost always be completely inundated in the event of a flood. Depending on the flood scenario there could be anything between a few dozen and several thousand victims. The most victims may be expected if the flood is unexpected and evacuation is not possible. Due to the lack of practical data it will be almost impossible to reduce the uncertainties in determining the numbers of victims.

4. Flooding probability

The Floris study showed that the water 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 "piping" (where water seeps under the dike) and the failure to close hydraulic structures. These failure mechanisms are not included in the present safety standards but are included in the design testing.
In some cases the high probability of 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 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 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 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 unified method was also developed to be able to turn all water defences into data for input into models The loads from water levels, currents and waves were calculated in the same way for all dike ring areas. 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 piping and calculate the failure probability of several other water 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. In calculating the probability of flooding various uncertainties play a part, not least about the structure of the subsoil under the foundations of the water defences. An essential part of probability calculations is that the order of the uncertainty is specifically 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 by conducting further research, e.g. on the structure of the subsoil. In the next phase of the study particular attention will be devoted to this. 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 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 flood risks. To achieve this goal there was systematic knowledge transfer to the 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 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. Although it is open to question whether development level 3 can be fully realised.

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 ring areas. This will provide a basis for political and public debate on how to cope with flood risks and possibly a different safety standard. Continuation of the Floris project for the remaining 37 dike ring areas 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 ring areas using detailed flood scenarios. For the remaining dike ring areas 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 Water Boards and Provinces, using detailed flood scenarios for all dike ring areas.

4. The Floris project revealed that the mechanism 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 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 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 research 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 Water Boards concerned actively collect data on the subsoil, particularly through soil surveys. This is critical to a successful follow up study.

Glossary

5-year safety assessment
Periodic evaluation of the safety and strength of a dike ring. This means checking whether the condition of the construction at that moment 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 water defences.

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.

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

Dike
A body of earth which acts as a water defence.

Dike ring
Set of water 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 water 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 water 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.

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.

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

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

Flood risk
Consequences x Flooding probability

High ground
The naturally high areas of the Netherlands. These are designated in Annexe 2 to the Water 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 water defences on the downstream side of the dike ring area, plus 1m.

Hydraulic boundary conditions
The water levels and waves which the water defences can still safely withstand.

Load
The internal and external forces impinging on a structure (a water defence), or the degree to which a structure is subject to internal and external forces, expressed as a physical quantity.

Longitudinal structure	Structures in the longitudinal direction of the water defence, such as sheet piling, deep cut-off walls, coffer dams, erosion screens, mooring structures and quay walls.
Manager	The public authority responsible for the management of the primary or other water defence.
Normative high water	The design water level.
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.
Piping	The phenomenon in which a hollow pipe-shaped channel is created under a water defence due to the erosion process of a sand-bearing current (seepage).
Polder	A polder area discharging or draining into a body of water.
Primary water defence	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. Primary water defences can be subdivided into the following categories: category — description a — defence surrounding dike ring area, holds back water from outside c — defence surrounding dike ring area, does not hold back water from outside b — defence in front or connecting defence, holds back water from outside c — defence in front or connecting defence, does not hold back water from outside d — water defence situated abroad
Regional waterdefence	Non-primary water defences.
Rise in sea level	The increase in the average sea level relative to the Amsterdam Ordinance Level (AOL).
Safety standard	The standard which a primary water defence must meet, 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.
Seepage	The extrusion of groundwater under the influence of greater piezometric heights outside the area under consideration.
Tidal 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 upward water pressure is greater than the weight of the soil, as a result the overlying of soil is pushed up.
Upper river region	The rivers 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.
Water Defence	Artificial and natural elevations (or parts thereof) or high ground, including structures built in or on them, which have a fully or partly water defensive capability, and which are registered as such.

Appendix 1 Studies of the probabilities and consequences of flooding

1960 **Report of the Delta Committee**
The Delta Committee made proposals for the present standards for water defences and recommended including the probability of flooding and the consequences in the standards in the future

1977 **Report of the Becht Commission**
Further to the debate on strengthening the dikes along the major rivers, the Becht Commission recommended lowering the safety standard for the rivers.

1993 **Evaluation of the basic principles for strengthening river dikes (Boertien Commission)**
The Boertien Commission observed that in the rivers region the valuation of cultural heritage and natural features and the flooding risks had changed. Because of these changes and with a view to new technological and scientific insights the Commission proposed lowering the normative high water level for the rivers regions. The Commission also recommended maintaining the present standards and considering them to be the minimum standards.

1996 **Start of the "Marsroute" study**
The Technical Advisory Committee for the Water Defences started work on the "Marsroute" (marching route) research programme, the goal of which was to develop a safety approach based on flood risks.

1998 **Fourth Policy Document on Water Management**
Central government presented a new policy for the rivers: "room for the river". If the consequences of climate change were to be solved by raising the dikes, the consequences of flooding would only increase. Where possible the river should therefore been given more room to prevent water levels from rising.

2000 **Report "Flood Risks – a study of the probabilities and consequences"**
The Technical Advisory Committee for the Water Defences developed a method for determining the probability of a dike ring area flooding and tested it on four dike ring areas.

2000 **Report of the Water Management in the 21st Century (WB21) Committee**
The WB21 Committee concluded that the water management in the Netherlands is not in order and recommended that the safety standards be evaluated.

2000 **Cabinet review paper "Anders omgaan met water" (Living with water in a different way)**
The government announced that the public should have a better understanding of the probability of flooding. The government also wanted to have a clearer view of the weak locations in the flood defences and the costs and benefits of investments.

2001 **Start of the Flood Risks and Safety in the Netherlands (Floris) project**

2002 **Report of the Luteijn Commission**
The Luteijn Commission concluded that the designation of emergency overflow areas is useful and essential to limit the consequences of flooding in the rivers region.

2003 **Cabinet review paper Disaster management strategy: Flooding of the Rhine and the Maas (RBSO)**
The government announced that it would be investigating various ways of limiting the probabilities and consequences of flooding in the upper river regions, including a review of the safety standards.

2004 **Policy evaluation: safety policy**
The State Secretary of Transport, Public Works and Water Management asked RIVM to evaluate the safety policy for floods. RIVM confirmed that the present standards for the water defences are obsolete because the value of the economic property to be protected was now six times as high and the population had also increased.

2005 **Flood Risks and Safety in the Netherlands (Floris) project - Interim phase**
The flooding probabilities and the consequences of flooding were calculated for 16 dike ring areas in the Flood Risks and Safety in the Netherlands (Floris) project.

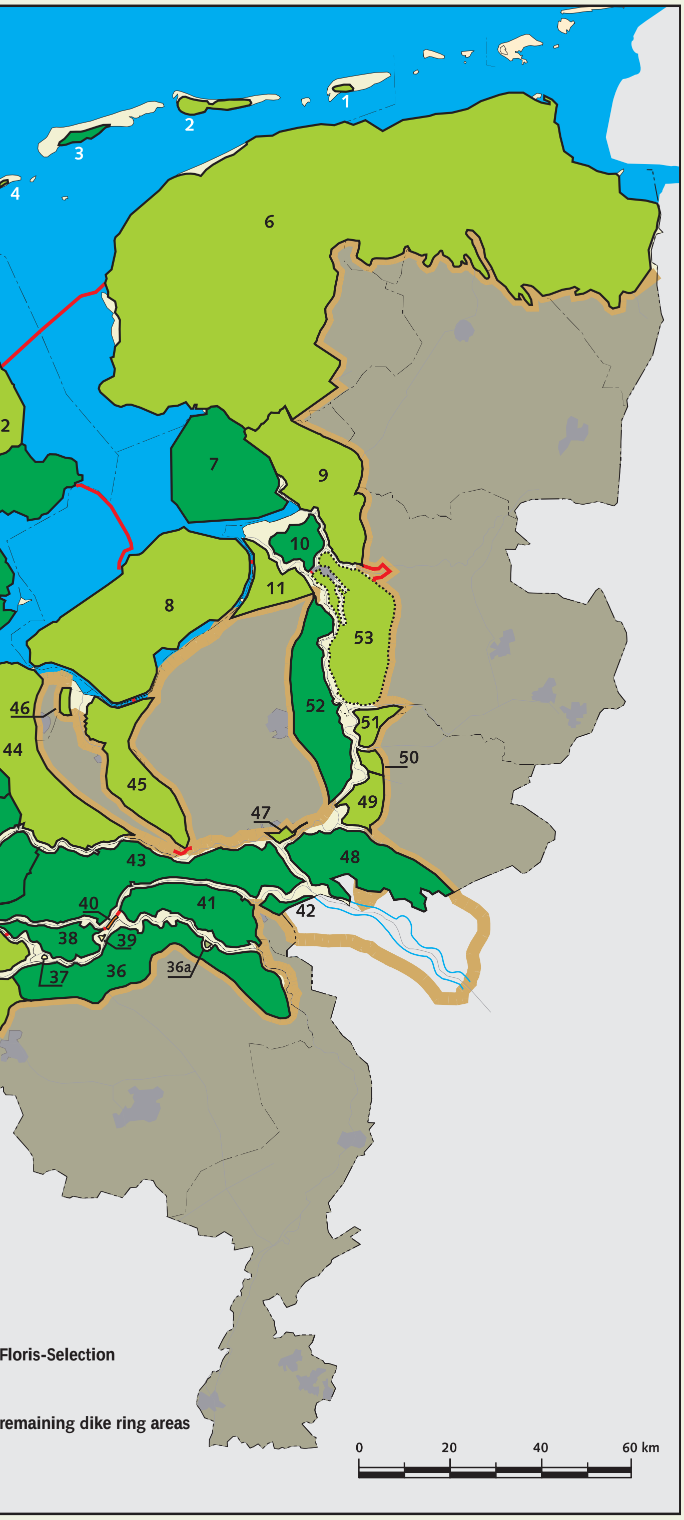
Appendix 2 Consequences, probabilities and risks per dike ring area

Here follows an overview per dike ring area of the consequences of a flood, the probability of flooding and the flood risk. For each dike ring area an analysis was made of where the weakest spots are and what measures could be taken to reduce the probability of flooding. The economic risk reduces in proportion with the flood risk. This information should be seen as a practical exercise and an example. The need for measures to be actually implemented must first be demonstrated by the statutory safety assessment of the water defences.

The maximum flood damage in the **Terschelling dike ring area (dike ring 3)** amounts to € 160 million when calculated using the global method. Together with a flooding probability of 1/1500 per year, this results in an economic risk of € 0.1 million per year. It has been assumed in the calculated probability of flooding that the mud flats will help to prevent piping. 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 flooding probability, possibly to 1/10,000 per year.

For the **Noordoostpolder dike ring area (dike ring 7)** the damage was calculated using the global and the detailed method. The maximum damage according to the global method amounts to € 9,000 million. Various flood scenarios were tested for this dike ring area using the detailed method. From this it appeared that in many cases the dike ring area would not completely fill up with water, because the water level would not rise higher than the water level in the IJsselmeer. Depending on the flood scenario, the damage ranges from € 170 million to € 4,000 million. The average damage amounted to € 1,900 million. Combined with a flooding probability of 1/900 per year this results in an economic risk of € 2.1 million per year. The number of victims in the event of a flood depends on the site of the breach and the degree of evacuation success, and ranges from 5 to 1400. The upper limit represents a situation in which no evacuation can be organised. This is a reasonable assumption given that the main cause of a flood in this dike ring area (structural failure of hydraulic structures) is sometimes, but not always, predictable in advance. The flooding probability of the Noordoostpolder is determined by the probability of structural failure of two hydraulic engineering structures. Advanced safety assessment of these structures, however, has not taken place. Knowing this the dike manager accepted this picture. The calculated flooding probability is small compared with other dike ring areas. Advanced testing of both structures will help to reduce the flooding probability to 1/3100 per year.

The maximum flood damage in the **Mastenbroek dike ring area (dike ring 10)** calculated with the global method, amounted to € 1,200 million. The calculated flooding probability is greater than 1/100 per year. The economic risk in the present situation amounts to more than € 12 million per year. For nine dike sections a larger probability of piping was calculated and for two dike sections a relatively large probability of overflow and overtopping. The dike manager was aware of the spots where piping may occur. These were also identified in the safety assessment. However, the dike manager did not agree with the large probability for overflow and overtopping. One of the two dike sections was therefore omitted from the calculation of the flooding probability. Further investigation of the structure of the subsoil may help to reduce the uncertainty surrounding piping, which could result in a lower calculation of flooding probability. Further to the safety assessment, physical measures may well also be taken to reduce the probability of piping. As a result the flooding probability could be reduced to 1/400 per year.



For **Noord-Holland (dike ring 13)** the flood damage was calculated with the global method. The maximum damage amounted to € 58,000 million. The global method can overestimate the damage for large dike ring areas. Noord-Holland is also divided into compartments, which means that the probability of the entire dike ring area being flooded is small. The maximum damage in combination with a flooding probability of just under 1/500 per year leads to an economic risk of € 116 million per year. The dike manager was aware that the dikes and dunes have a high probability of failure in some places. In several places repair work on the dike was already in progress. The probability of non-closure of the Sas lock at Enkhuizen also contributed to the high flooding probability.

For the **Zuid-Holland dike ring area (dike ring 14)** the damage was calculated with both the global and the detailed methods. The maximum damage under the global method amounted to € 290,000 million. Various flood scenarios were tested for this dike ring area using the detailed method. From this it appeared that in many cases the dike ring area would not fill up with water because, in these scenarios, obstacles in the dike ring area, such as the banks of drainage pools and old dikes, prevent large sections of the dike ring area from flooding. The damage varied, depending on the flood scenario, from € 280 million to € 37,000 million. The average damage amounted to € 5,800 million. Together with the relatively small flooding probability of 1/2500 per year this results in an economic risk of € 2.3 million per year. The number of victims in the event of a flood depends on the site of the breach and the evacuation success, and here ranges from 30 to 6100. The upper limit applies to a situation where no organised evacuation can be arranged. This is realistic given that 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 allows insufficient time for a full evacuation of the threatened area, particularly in bad weather conditions. In South Holland more extreme forms of flooding are also possible where large parts of the dike ring area flood. The number of victims and the damage will be considerably more in such cases. The probability of such extreme flood scenarios, however, is much smaller. The most important causes of flooding in this dike ring area are failure of the boulevard at Scheveningen, piping in one of the dike sections, and failure to close some hydraulic structures on time. The dike manager acknowledges this, with the exception of the dike section with a large probability of piping. By improving the relatively weak locations the flooding probability can be reduced to 1/7000 per year.

In the **Lopiker- en Krimpenerwaard dike ring area (dike ring 15)** the maximum damage, calculated with the global method, amounted to € 10,000 million. The calculated flooding probability is more than 1/100 per year. The economic risk therefore amounts to more than € 100 million per year. The flooding probability is heavily influenced by the large probabilities for non-closure of a lock, loss of stability due to uplifting, as well as piping. The calculated probability of piping is mainly due to uncertainty in the data. Further investigation may well lead to a smaller probability. By strengthening the relatively weak spots, the flooding probability can be reduced to 1/900 per year.

The maximum damage in **Alblasserwaard en Vijfheerenlanden (dike ring 16)** was calculated using the global method and amounted to 19,000 million. According to the calculations the flooding probability is 1/400 per year. The economic risk amounts to € 48 million per year. The main cause of the large flooding probability is the large probabilities calculated for piping. In addition, uplifting and structural failure of the locks also play a role. The manager did not think the high probability of piping likely. However, seepage has been observed at high water levels. Further investigation can show whether the probability of piping has been overestimated. The dike manager did subscribe to the result that the dikes are subject to stability problems due to uplifting.

The maximum damage in **Goeree-Overflakkee (dike ring 25)**, calculated with the global method, amounted to € 3,700 million. Together with a calculated flooding probability of 1/1200 per year, this led to an economic risk of € 3 million per year. The main causes of flooding according to the calculations were 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 relatively weak spots because the uncertainties in the data are great. In places where the dike manager did not expect there to be a large probability of 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 statutory safety assessment in 2001 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 has been assumed that these measures have been completed.

In **Zeeuwsch-Vlaanderen (dike ring 32)** the maximum flood damage calculated using the global method, was € 14,000 million. It turned out to be difficult to provide good calculations of the flooding probability for this dike ring, 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. For a second safety assessment of the water defences the Water Board collected more information, from which it appears that the pumping station could be approved in the second test. The data for the safety assessment of the dikes is not yet available. The calculated probability may therefore be an overestimate. It is clear that stability problems constitute a real risk here because the dikes are high and steep and stand on weak layers in the subsoil. The calculated flooding probability is greater than 1/100 per year. As a result the economic risk is greater than € 140 million per year.

For **Land van Heusden/de Maaskant (dike ring 36)** the consequences of a flood were calculated using the detailed method. The global method results in a maximum damage figure of € 18,000 million. Using the detailed method various flood scenarios were tested for this dike ring area. Depending on the flood scenario the damage ranges from € 60 million to € 7,500 million. The average damage amounted to € 3,700 million. The calculation results in a flooding probability of more than 1/100 per year. The economic risk is therefore € 37 million per year. The number of victims ranges from 5 to 800 and depends on where the breach occurs and the success of the evacuation. The upper limit reflects a situation where no organised evacuation takes place. This is a reasonable assumption given that the indicative failure mechanism in this dike ring (piping) can sometimes, but not always, be predicted on time. The flooding probability of Land van Heusden/de Maaskant is mainly due to the high probability of piping. The dike manager endorsed these results. When further research is done on this failure mechanism and strengthening measures are taken, if necessary, the flooding probability may be reduced to 1/220 per year.

The maximum flood damage in the **Bommelerwaard (dike ring 38)** was calculated with the global method. The maximum damage in this dike ring area amounted to € 2,600 million. The calculated flooding probability was 1/260 per year, the economic risk therefore amounts to € 10 million per year. The reasons for this relatively high flooding probability are a high probability of piping (particularly at two sites where there are sand strata under the water defence) and non-closure 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.

For the **Land van Maas en Waal dike ring area (dike ring 41)** the maximum flood damage, calculated with the global method, was € 6,400 million. According to the calculations the flooding probability is greater than 1/100 per year. The economic risk is, therefore, greater than € 64 million per year. The reasons for the calculated high flooding probability are relatively large probabilities of piping and for the non-closure and structural failure of hydraulic structures. The dike manager confirmed this picture.

The maximum flood damage in **Ooij en Millingen (dike ring 42)** was calculated using the global method and amounted to € 1,000 million. Together with the calculated flooding probability of 1/1,400 per year, the economic risk is € 0.7 million per year. In this dike ring overflow and overtopping is the indicative failure mechanism for a flood. The dike manager agreed with this picture.

For the **Betuwe, Tieler- en Culemborgerwaarden dike ring area (dike ring 43)** too, the flood damage was calculated using the global method. The maximum damage amounted to € 18,000 million. The calculated flooding probability is greater than 1/100 per year, and the economic risk is more than € 180 million per year. Originally, relatively large flooding probabilities were calculated for the failure mechanism piping. The reason for this was major uncertainties in the data. The dike manager did not think that these problems applied at the sites in question. Therefore it was decided to exclude this probability of failure in the calculation of the flooding probability. Investigation of the soil structure could show whether there is a risk due to the failure mechanism of piping. Other reasons for the relatively large flooding probability are the large probability of structural failure and non-closure of some hydraulic structures. The dike manager acknowledged this and has started an investigation of the hydraulic structure with stability problems.

For **Rijn en IJssel (dike ring 48)** the maximum damage, calculated using the global method, amounted to € 6,800 million. Together with a calculated flooding probability of 1/200 per year, the economic risk is € 34 million per year. The flooding probability is largely determined by the high probability of piping. In this case it would appear that this high probability cannot be put down to uncertainty about the soil data. Other causes for the relatively high flooding probability are the high probability of structural failure of three hydraulic structure and non-closure of two hydraulic structures.

In **Oost-Veluwe (dike ring 52)** the maximum damage calculated with the global method amounted to € 3,100 million. The calculated flooding probability is more than 1/100 per year. As a result the economic risk is more than € 31 million per year. The most significant contribution to the flooding probability comes from piping in a number of dike sections. Overflow and overtopping also play a role and, to lesser extent, non-closure of the Nieuwe Wetering discharge sluice. The dike manager confirmed some of this. At high water seepage has been observed but in the second safety assessment the dike sections were approved for the failure mechanism of piping. It is not expected that the flooding probability will drop as a result of further investigation of the soil parameters. Although the use of a detailed model for the calculation of the probability of piping could result in a more favourable estimate of the flooding probability. If, in addition to this, measures were to be taken in the dike section with the high probability of failure for overflow and overtopping, the flooding probability could be reduced to 1/250 per year.

Floris study - interim report

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