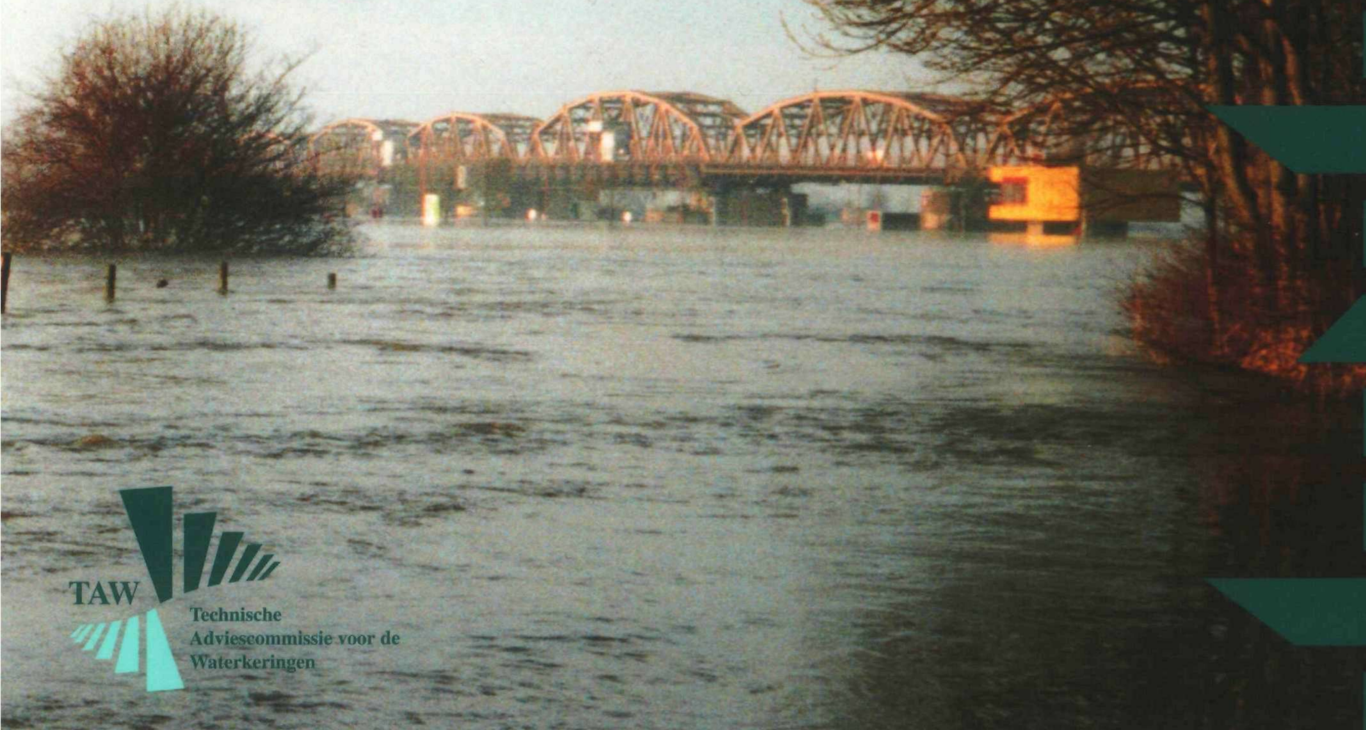
Flood Risks

A study on probabilities and consequences

From probability of exceedance to probability of flooding



TAW
Technische
Adviescommissie voor de
Waterkeringen

TAW

Technische Adviescommissie voor de Waterkeringen

Technical Advisory Committee for Flood Defence in The Netherlands

From probability of exceedance to probability of flooding

June 2000

Technical Advisory Committee for Flood Defence in The Netherlands

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To :
the State Secretary of the Netherlands
Ministry of Transport, Public Works and Water Management
Mrs. Drs. J.M. de Vries
PO Box 20901
2500 EX The Hague

Date
30 juni 2000

our reference
TAW 00.65

your reference

Subject
Risks of flooding

Dear Mrs. de Vries,

Over the past years, the Technical Advisory Committee for Flood Defence (TAW) has developed a method to calculate probabilities of flooding of dike ring areas. This method has been tested for its applicability in four parts of the Netherlands. I hereby present you the results, which are compiled in the document 'From probability of exceedance to probability of flooding'.

Research programme on flood risks: a study on probabilities and consequences
In 1992, TAW started the research programme 'Flood risks: a study on probabilities and consequences'. Its first results are now available. The Water Defence Act of 1996, the 4th memorandum on Water Management of 1999 and the national budget of 1999 already refer to this study.

The advice of the Delta Committee of 1960 formed the reason to initiate this research programme. The Delta Committee developed the foundations of the current Dutch safety approach against flooding. In those days, the committee noticed that a safety approach should preferably be based on flood risks, for which the probabilities and consequences of flooding should have to be mutually considered. Until 1992, however, the knowledge required to further develop this approach was not available. This is why the water defences in the Netherlands have been designed on the basis of a design water level: a water level corresponding with a certain exceedance frequency.

Probabilities of flooding versus probabilities of exceedance
The exceedance frequency is a standard for a high water level that a dike section should be able to withstand. The flood probability of an area is that the entire area will be flooded due to failure of one or several water defence works of that protected area. The differences between the proposed method to determine probabilities of flooding from the current approach (exceedance) is at three levels:

- the analysis of a entire dike ring instead of individual dike sections. In this way, the strength of a dike ring as a whole (consisting of dikes, structures and dunes) is determined;
- taking various types of failure mechanisms of a dike ring mutually into account. This is different from the current approach, in which the type of failure is dominated by the failure modes 'overtopping' and 'overflow of water';
- systematically and verifiably discounting all uncertainties in advance when calculating the probabilities of flooding. In the current approach, uncertainties are for the greater part discounted afterwards by including an extra safety margin.

First results of the applied method
The new calculation method was tested for four dike ring areas: Central Holland, Groningen-Friesland, the Hoeksche Waard, and the Betuwe, Tieler and Culemborgerwaarden. For the test calculations, a selection was made of dike sections and available information.
The pilots show that the method, works. They also show that a dike ring is not stronger than its weakest link. Through this new calculation method, it is possible to detect weak links in a dike ring, to improve water defences in steps, and to set the right priorities for water defence improvements. Furthermore, this method also shows the effect of gaps in our knowledge on water defences.
The result of the calculations can be interpreted as an action plan for the future; the calculated flood probabilities indicate the bottlenecks of the dike ring under consideration. These bottlenecks are ordered according to their significance. In this way, the available budget for improvement of water defences and for the development of knowledge can be efficiently invested.

The results also show that hydraulic structures require more attention, as there is insufficient knowledge on especially the actual construction of (older) hydraulic structures and on the reliability of their manual operation. This lack of knowledge is expressed in a higher calculated flood probability. Furthermore, hydraulic structures might also be a weak link in a dike ring. Therefore, the TAW advises to thoroughly investigate the hydraulic structures in the near future, as to determine the extent to which these structures may cause dangerous situations.
The TAW also advises to determine the probabilities of flooding of all 53 dike ring areas in the Netherlands in the coming years, as to identify possible weak links.

The TAW concludes that there is insufficient knowledge, especially with regard to uncertainties such as those caused by nature's caprices, uncertainties in models, and lack of data. By reducing these uncertainties, the differences between the calculated and the actual flood probability will become smaller. The TAW intends to pay more attention to this research in the coming years. The findings will be incorporated in the recommendations of the TAW to the water defence research programme of the Directorate-General for Public Works and Water Management.

Follow-up
With this report, the TAW concludes its first stage of the research programme 'flood risks: a study on probabilities and consequences'. In the coming years, the TAW and the other parties involved will -next to the attention on the probabilities of flooding of the nation's 53 dike ring areas- also investigate the damage assessment of possible floods. For this analysis, knowledge from many disciplines, such as economics, environmental planning, agricultural sciences, psychology, cultural history and nature conservation, will be required.

It is expected that in the course of this research, more insight will be gained into the probabilities of flooding of dike ring areas, and on the possible consequences of floods. By then, the (as indicated by the Commission itself) 'imperfect steps' of the Delta Committee in 1960 will be repeated with the help of the latest insights. Those insights will allow to develop a better overview of costs and benefits of flood protection measures. These measures might be in the field of strengthening water defences, lowering water levels and wave heights on the one hand, as well as in the field of restricting the consequences of floods due to technical and governmental measures.
With this approach, the TAW offers technical knowledge as a contribution to the ongoing socio-political discussion on the desired level of flood protection. The TAW sees it as its duty to assimilate this knowledge as to support an anticipating safety policy.

The result of this first research stage offers insights that are already applicable in practice. However, these results should not be considered as a further interpretation of article 3.2 of the Water Defence Act, which refers to the possibility in future of changing the current exceedance frequencies into actual flood probabilities. Based on the current results, the TAW can not yet advise positively on the use of the flood probability as a new standard for flood protection.

Summarising
The TAW has developed a method to determine the probabilities of flooding and has successfully tested its applicability in four dike ring areas. Based on the results, the TAW advises to calculate the flood probabilities of all 53 dike ring areas within the coming two years, and to further inspect the most critical hydraulic structures, as such an inspection will considerably increase the knowledge of possible weak links. Since the water defence managers will be required to supply information, I would like to advise you to discuss this item on short notice with them.
Over the coming two years, the TAW and other involved parties intend to establish a first assessment of the potential damage of floods for the entire country. In addition, the TAW likes to pay more attention to uncertainties, as to realise that the calculated probabilities of flooding reflect the actual chance of flooding more accurately.

I trust this advisory report will provide you with sufficient information on the TAW's first findings on 'Flood risks - a study on probabilities and consequences.'

Yours sincerely,

Ir. W. van der Kleij
Chairman of the Technical Advisory Committee for Flood Defence

Contents

1. Living in a Delta

Large parts of the Netherlands are located below the water level of the sea, the river or Lake IJssel. So here is always a flood probability. But how dangerous is this situation? This is difficult to say. Normally we feel very safe and secure but sometimes, especially shortly after a disaster, we feel that our Dutch way of living might be rather dangerous. In principle, dunes and water defences protect our country. Yet, this protection is never 100% safe; there is no such thing as absolute safety against flooding! The question is which risks of flooding are acceptable and which ones are not. This is an ever recurring socio-political question, which is, amongst others, fed by developments in knowledge. The research on probabilities of flooding offers new insights; this report describes the first results.

Due to its location, the Netherlands is always threatened by floods. Living in the delta of the Rhine, Meuse and Scheldt rivers involves risks, but has also enabled the Netherlands to develop itself into the main gate of Europe. In the past, river floods provided fertile soil and clay for brickworks. However, negative effects of floods, like the loss of goods and cattle and the danger of drowning belonged to the same reality. With increasing welfare and population density, the protection against flooding became more effectively. Since the Middle Ages, the building of dikes, quays and hydraulic structures has increased considerably.

Whether the protection against the water is sufficient, is a question that belongs to all times. Absolute safety simply does not exist. Safety is a feeling and is experienced differently for each activity. Experiencing safety in traffic, for instance, is rather different from that of floods. The extent to which we protect ourselves against floods is the result of a socio-political balancing of the costs (not only financial) and the expected benefits. In this process, subjective feelings and objective rationale are both involved.
In the different government's views on the advice of the Delta Committee in 1960 (safety approach), the Becht Committee (1977), and the Boertien 1 Committee (1992) on the river area, it can be clearly observed that political considerations, in which many interests are reflected, lead to a compromise rather than to a maximum protection level against flooding.

Since the danger of flooding is difficult to determine in advance, the political scene and society usually adopted a reactive approach: a (near) flood should not be repeated. The 1953 flood disaster in the southwest of the Netherlands resulted in major investments to improve the water defences. The high water stages in the main rivers in 1993 and 1995 once again drew attention to the risks of living in a delta; the water defences along the rivers were reinforced at an accelerated rate. It is expected that in 2001, the majority of the water defences will be strengthened and be brought to the safety standards of the Water Defence Act (1996). However, latest developments show that anticipating on future developments –instead of reacting to them- is becoming more and more practice. The initiative for the designation of overflow areas is a good illustration of this changed approach. Developments like the expected sea level rise, the higher river discharges and ever ongoing soil subsidence demand for such a pro-active approach. In such an approach, the increase of the interests and investments to be protected will have to be taken into consideration.

Knowledge on water and water defences is indispensable when considering the desired protection level against flooding. This advice report from the Technical Advisory Committee for Flood Defence, called 'From probability of exceedance to probability of flooding: offers insights, which are supplementary to the current safety approach that is based on exceedance frequencies only (see frame 1)[1].
In calculating the probabilities of flooding, the entire dike ring area (there are 53 in the Netherlands, see Figure 1) is considered instead of individual dike sections. The following aspects are the reason for proposing this new method:

- a dike ring as a whole determines the protection of an area rather than merely a dike section or a single structure[2];
- the proposed calculation method also takes equally account of the different failure mechanisms. After all, water not only can flow

over a dike. A dike may also collapse due to a weak subsoil or due to seeping water through a dike body, resulting in weakening the dike body and consequently sliding of the inner slope. Or a gate of a discharge sluice may not be able to close or the lock keeper might forget to close it;
- finally, uncertainties are taken into explicit consideration, by addressing them prior to the calculations, in a systematic and verifiable way.

This report 'From probability of exceedance to probability of flooding: a calculation method for probabilities of flooding' presents the first results of the calculations of the probabilities of flooding. The calculation of the flood probability for a dike ring area identifies weak links in the water defences and indicates how a step-wise improvement will contribute to a better protection against floods in the future. The report also discusses the meaning of knowledge gaps. This advisory report concludes the first stage of the TAW research programme 'Flood risks: a study on probabilities and consequences'. The TAW recommends follow-up studies to be initiated, as to continue the development of knowledge on water defences and to make this knowledge available for socio-political decision making.

Frame 1

The exceedance frequency of a water level is the probability that the design water level is reached or exceeded. The design water level is used to design a safe dike or hydraulic structure.

The flood probability is the probability that an area might be inundated, because the water defence around that area (the dike ring) fails at one or more locations.

[1] The safety approach on the basis of exceedance frequencies (Water Defence Act) and the method based on flooding probability focus both on primary water defences.

[2] Examples of hydraulic structures are sluices, pumping stations, cut-off structures, storm surge barriers.

2. Exceedance frequencies – the current safety approach

Dikes in the Netherlands are designed to safely withstand a certain water level. 'Safely' means that the water can not flow and the waves can not break over the dike and that the dike is sufficiently strong and remains accessible during design conditions. Therefore, when designing a dike section, the water level and the safety margins are both taken into consideration. This provides for extra crest level as well as strength. The exceedance frequencies - the standard - for Central Holland has been set at 1/10,000 per annum. The areas in the Netherlands do not all face the same exceedance frequency. This depends on the type of threat and the economic value of the protected area.

The current safety approach is mainly a practical oriented approach. Each dike section has been designed to safely withstand a certain water level. This water level is called the design water level. By means of standard for each dike ring area, an exceedance frequency has been defined by law. These exceedance frequencies vary from 1/1,250 to 1/10,000 per annum. This does not imply that when the design water level would be reached, the protected area would be inundated at once. Extra safety margins are built in, so that the final height and strength of a dike section is higher than strictly is required to exactly retain the design water level. In the design, the wave run up, the accessibility of the dike at high water stages and an extra margin for uncertainties are included as well.
Technical handbooks and guidelines are available for the design and construction of a dike. In these guidelines it is for instance indicated how the dike should be shaped, depending on the subsoil, soil structure, the loads, etc. These guidelines, however, do not guarantee that a dike would never fail at lower water levels than the design water level. Therefore, uncertainties are included partially afterwards (adding safety margins to the crest level) and partially in advance (natural fluctuations in the water levels).

In the nineteen fifties, the political choice of the exceedance frequencies for the Netherlands were defined on the basis of the advice of the Delta Committee (1960). This committee followed two approaches with taking Central Holland as basic standard:

- firstly it was investigated whether the water levels of 1953 could be exceeded. The conclusion was that there was no reason whatsoever to exclude the possibility of water levels of (at least) NAP[3] + 5 m at Hook of Holland (in 1953, the water reached a level of NAP + 3.85 m). A water level of NAP + 5 m represents an exceedance frequency of 1/10,000 per year;
- secondly, a study was made to the costs of greater safety in relation to the economic benefits. Based on the interests of the fifties, a financially optimal protection was established for Central Holland, whereby Central Holland would be inundated once every 125,000 years on average.

Both outcomes were related to each other by assuming that a water defence designed to safely retain a 1/10,000 water level, would probably only collapse at a 1/100,000 water level.

The final advice of the Delta Committee included a proposal to differentiate the protection level throughout the country in accordance with the (economic and other) interests of the areas to be protected.
Central Holland is the most densely populated area in the Netherlands, which is also threatened by the sea. In this area the largest investments have been made. It was therefore concluded that this area should as optimal as possible be protected against flooding. For other coastal areas of the Netherlands, larger exceedance frequencies were considered acceptable, due to their lower economic value. For the provinces of Zeeland, Friesland and Groningen, for instance, it was determined that dike sections could be 2 to 4 decimetres lower than in Central Holland, which corresponds with an exceedance frequency of 1/4,000 per year.

In a later stage, a standard was also set for the river area. The basic difference between floods from rivers and from the sea is that river water levels can be predicted well in advance: a matter of

[3] NAP Normaal Amsterdam Peil: Amsterdam Ordnance Datum, which is the refererence level at approximately Mean Sea Level.

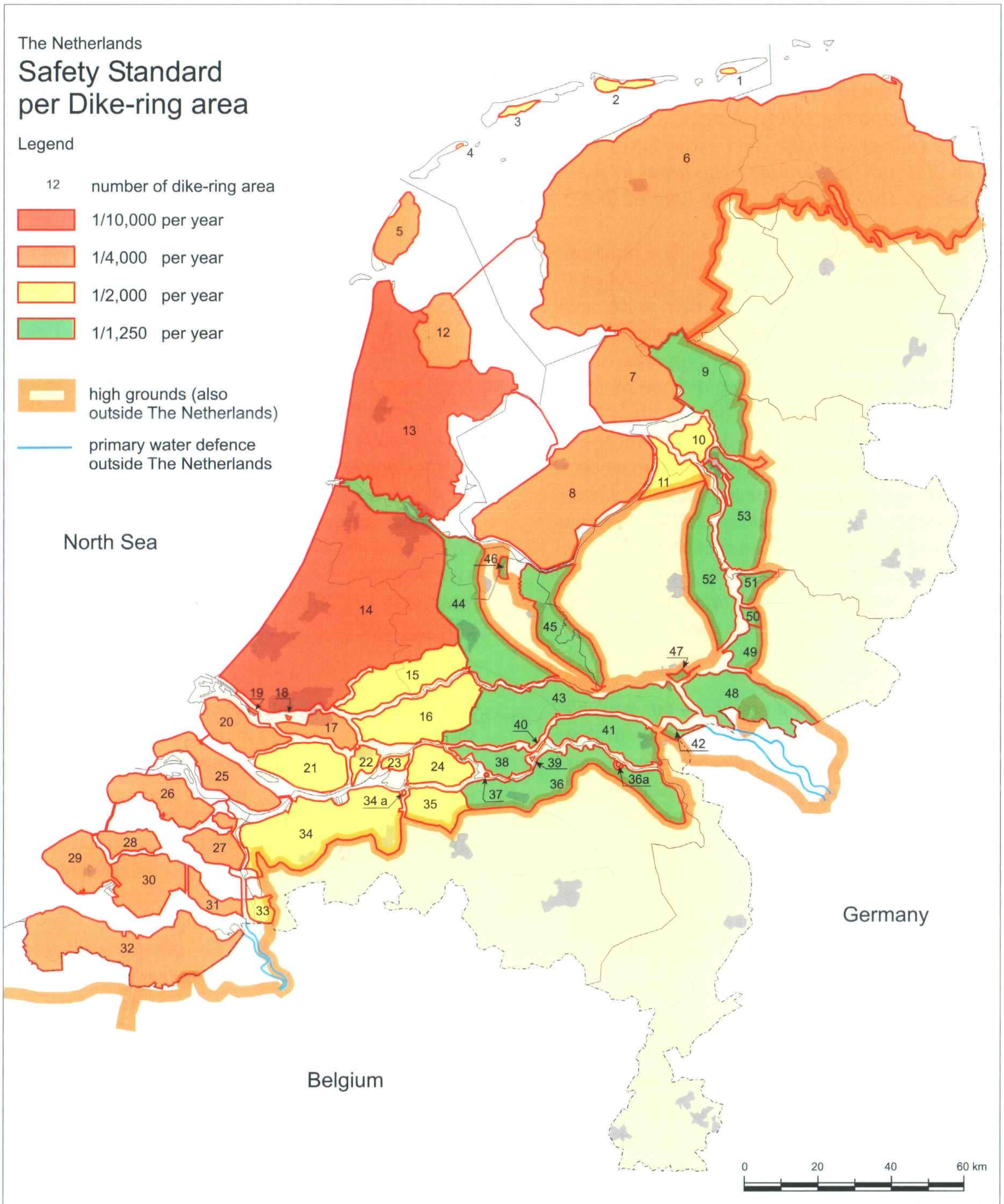


Figure 1 Dike ring areas and standards

days instead of a few hours in case of a sea flood. This allows for taking precautionary measures. In addition, fresh water floods create less damage compared to floods from salt water. And thirdly, in case of a breach, the resulting erosion channels will be less deep compared to those in tidal areas. Because of these three reasons, a slightly lower safety level of 1/3,000 for the river area was considered acceptable. In the intertidal area, where water levels are under the influence of both sea and river, a transition zone was proposed, with an exceedance frequency of 1/10,000 on the sea side and 1/3,000 on the river side.

In the nineteen seventies, the river dikes would be improved. However, strengthening (especially raising) the dikes up to the afore mentioned safety level, would result in a lot of damage to the landscape, nature and the region's cultural inheritance. The resulting social protest led to a reconsideration of the safety levels. Following the advice of the River Dikes Commission (the Becht Commission, 1977) the original standard of 1/3,000 was lowered to 1/1,250 per year. In this way it was possible to partially leave the area around the dike to be reinforced.
In the eighties, the river dike reinforcement programme stagnated again. This time it was caused by a decline in social consensus. The committee on testing different approaches of river dike strengthening (the Boertien Committee 1, 1992) advised to maintain the safety level at 1/1,250 per year. However, the committee also proposed to apply a different method for calculating the design water level. In this way, the design dike height could be lowered with 3-4 decimetres.

Figure 1 shows the exceedance frequencies for the various dike ring areas in the Netherlands, as laid down in the Water Defence Act (1996). The above mentioned developments show how socio-political decision making on the desired safety standards works and how the consideration of various aspects may change over time.

3. Probabilities of flooding

What are the mechanisms of inundation of an embanked area? Flooding may not only occur because of too high water levels (or too low crest levels), but also because of a collapse of a dike when its revetment is damaged, when a slope slide occurs, or when water seeps through or under a dike and thereby weakening it. In addition, hydraulic structures may not function or its gates remain open. When determining the probabilities of flood, all these failure mechanisms have to be taken into consideration. In addition, the flood probability is calculated for an entire dike ring area and not for a single dike section only. In this way, a better insight into the protected area can be obtained. Weak links in the dike ring become apparent and bottlenecks can be ranked from large to small. Uncertainties due to lack of knowledge can also be made explicit.

The method used to calculate probabilities of flooding mainly distinguishes itself from the current approach (exceedance frequencies) through:

- the transition from considering a dike section to a dike ring. This analysis results in the strength of an entire dike ring, which typically consists of dikes, hydraulic structures and dunes;
- taking equal account of all failure mechanisms of a dike ring;
- taking from the start of the calculations all uncertainties in a systematic and verifiable way into account.

The current safety approach is based on a design approach of individual dike sections. The calculation of the probabilities of flooding is based on the principle that 'a chain (dike ring) is as strong as its weakest link'. The calculated probabilities of flooding of an area is the arithmatic sum of all probabilities of failure of dike ring elements. In this approach, the weakest link has the greatest impact on the calculated outcome: the flood probability. The failure mechanisms taken into consideration when calculating the flood probability can be found in Frame 2 and Figure 2.

The calculated flood probability reveals all the weak links of the water defences of a dike ring. It also shows that not every weak link contributes in an equal manner to the total flood probability. Bottlenecks can be of lesser or greater importance and thus contribute less or more to the flood probability. This offers possibilities for a step-wise improvement of a dike ring, for instance by improving the dike crest or the dike body, by improving the construction of a hydraulic structure or its operation, or by reinforcing the dunes of the dike ring under consideration. The method is thus also a tool for analysing the bottlenecks themselves.
Addressing the weakest link firstly is the most beneficial measure to reduce the calculated flood probability. It thus becomes possible to prioritise: which part of the flood defence should be improved first and what can wait? This clarifies the difference with the current testing method, which does not focus on the coherence between and the prioritisation of bottlenecks.

Uncertainties in the calculation of flood probabilities
When calculating flood probabilities, several forms of uncertainty are, from the start, taken into consideration in advance in a systematic and verifiable way (see Frame 3).

Frame 2 Failure modes

The following failure modes were considered with the calculation of the flooding probabilities:

- Dike:
  - overflow and overtopping of water over the dike crest;
  - sliding of the dike inner or outer slope;
  - erosion of the dike revetment (e.g. grass, asphalt or basalt blocks), which might cause a breach in the dike;
  - piping, causing water to run under the dike and erosion of the dike body from within.
- Structure (like a sluice, pumping station):
  - overflow and overtopping of water over the structure;
  - the collapse of the construction or the foundation due to high water and waves, collision or an extreme settlement;
  - piping and seepage, water streaming under or along a hydraulic structure;
  - not closing a hydraulic structure on time, allowing water to flow in.
- Dune:
  - erosion under the influence of flow, wave action, wind or human action.

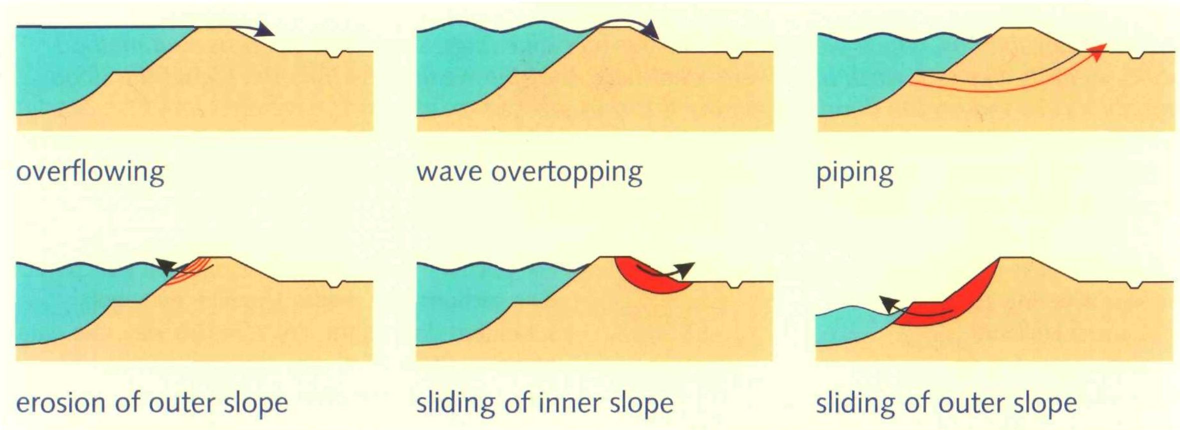


Figure 2 Dike failure modes

This is an important difference to the current approach of exceedance frequencies, which only considers one type of uncertainty in advance: the natural uncertainty in water level. After determining the height of a dike, a safety margin is added to include non-explicit uncertainties.

The calculation of the flood probability includes uncertainties in water levels, in strength, in the calculation model and the lack of long-term measurement data.

The calculated flood probability is always an approach of the actual flood probability of an area. As the uncertainties in the models and the statistics decrease, the approach improves in accuracy. Frame 3 shows the way in which uncertainties can be reduced. Knowledge development and an increase of the number of measurement data are thus important.

Frame 3

Uncertainties that are included in the calculation of the flooding probability:

- *natural uncertainties*. As just little is known about the behaviour of nature in time and space. The location and occurrence of storm surges can be predicted with an certain accuracy. However, these remain predictions. The thickness of a clay layer in the subsoil may differ from place to place. Its accuracy can be improved by intensified measurements, but uncertainties can never be reduced to zero. Other uncertainties (e.g. long-term developments) can hardly be reduced, if at all;
- *model uncertainties*. A calculation model is never an exact reproduction of reality, but just an approach. Models can be improved by verifying their outcomes with reality and thus be improved, thereby reducing this type of uncertainty;
- *statistical uncertainties due to lack of measurement data*. This is especially relevant when working with extrapolations, for instance to predict unusual water levels. This type of uncertainty can be reduced partially if more measurement data are available; but uncertainties will always remain.

4. Results of the four pilot calculations

The pilot calculations, which were carried out for four dike rings, show that the proposed method works. In each dike ring weak links were identified. And, the weaker the link, the higher the flood probability. To reduce the flood probability it is thus advised to address the weakest link first. Starting with the other links is usually of little use. Lack of knowledge leads to higher calculated probabilities of flood. For hydraulic structures both aspect are relevant: our knowledge is insufficient and these structures often are the weak links.

The probabilities of flooding have been calculated for four dike ring areas:

- Central Holland;
- Groningen-Friesland;
- Hoeksche Waard;
- Betuwe, Tieler- and Culemborgerwaarden.

These areas (see Figure 3) also differ in form of threat (from sea, river, lake or a combination of these), population, and economic activity. These differences explain the different protection levels. The question is whether the differences in the exceedance frequencies, determined for these areas, are of the same magnitude as the calculated flood probability (see Paragraph 4.3).

Figure 3 The four dike ring areas for which the pilot calculations were made

For calculating the flood probability, a selection of dike sections was made. The dike managers submitted data to the TAW. In this way, the data of nearly 30% of all dike sections were used in the calculations. These dike sections included those that were, by the dike managers, considered most vulnerable. To calculate the flood probability, use was made from models and data from the latest TAW Guidelines and Technical Reports. The same models are also used in daily design practice.

When describing the results, attention was paid to the weak links in the dike ring and to the effects of the lack of knowledge on the calculated flood probabilities. Uncertainties in strength, models and statistics were discounted in advance in a systematic and verifiable way.

4.1 Insights

Flood probabilities versus exceedance frequencies
The difference between the current safety approach and the investigated method implies that the exceedance frequency and the flood probabilities can not be compared directly. Approaching the water defence as a dike ring, taking all failure mechanisms into consideration and discounting uncertainties give the calculated flood probabilities a different meaning than the exceedance frequencies (see also Frame 1).

The method as a tool to analyse bottlenecks
The way of calculating the flood probability of all four areas shows that it is possible to detect weak links and to identify the extent of their effect on the flood probability. The calculation of the flood probability is thus a useful instrument for the detection and classification of bottlenecks. These bottlenecks can be of different nature. They may result from a weak spot in the dike ring, or from lack of knowledge or data. In the case of lack of

knowledge, further research must determine whether there actually is a problem. The method gives a search direction for solutions, where success can be obtained in a step-wise manner. It must be clear that solving the biggest bottleneck will have most effect on the lowering of the flood probability. This makes it a promising means for the management and the reinforcement of the water defences.

Hydraulic structures

Little is known about the underground construction of older structures, for instance if a sheet pile is present. A second element is that many structures are operated manually. These two elements lead to major uncertainties and thus to high calculated flood probabilities. In all areas, structures were identified as the weakest links. This does not mean that all structures are unsafe in reality; it either indicates that the knowledge is insufficient or that structures are actual weak links in water defences. If research proves that the structures are in good shape along with more certainty about the reliability of their operation, the calculated flood probability reduces. The calculation results should be seen as an incentive to submit the hydraulic structures for further inspection in the near future. This should preferably be realised in the official next testing round (2001-2006).

Figure 4 Failing structure at Delfzijl due to human error

Flood probability on the basis of data selection

Data submitted by the dike managers were used to calculate the flooding probability. For the pilot calculations it concerned a selection. This means that not all data of all dike sections, all structures and all dune cross sections were used. It is thus possible that not all the weak links have been included in these calculations, meaning that the calculated flood probabilities are actually too optimistic. However, this does not alter the principle of the gradual lowering of the flood probability by taking specific actions.

4.2 Flood probabilities per area

Central Holland

The dike ring of Central Holland consists of dunes, dikes and structures. The calculated flood probability is based on the chances of overtopping and overflow of water, the sliding or collapse of masses of soil of a dike section, piping, the failure of a dike revetment or grass slope, erosion of a dune and the chance of a failing hydraulic structure.

The reliability of the operating method of the pressure line at Monster is pivotal in the calculated probabilities of flooding for Central Holland. Should in case of an emergency the pressure line not close in time, water can flow into the hinterland, which could eventually lead to a modest flood. If human errors are minimal in the operation, for instance due to automatic operation or improved procedures, the flood probability for Central Holland amounts to 1/2,000 per year.

The calculation method shows that the next weak link in this dike ring is at Moordrecht, where sand-carrying wells may weaken the dike on the inside. Improving the dike or closing the storm surge barrier earlier in the Hollandse IJssel could deminish this bottleneck. This is reflected in the flood probability: assuming that the situation at Moordrecht has been improved, the calculated flood probability for Central Holland drops to 1/30,000 per year.

The calculated probability of 1/30,000 could be even further reduced if the narrow range of dunes of the Westland (especially at the village of Monster) would be wider. If this bottleneck is removed, the flood probability becomes 1/75,000 per year.

These three weak links have a great influence on the calculated flood probability of Central Holland. The step-wise approach learns that the largest bottleneck has to be improved first. Broadening the Westland dunes first has little effect on the flood probability, as long as the two other bottlenecks have not been addressed. Therefore the insufficient knowledge of the reliability of the operation of the pressure line at Monster should be tackled first.

Supposing that all weak links in the dike ring of Central Holland have been removed, the calculation method also provides information on the way in which the calculated flood probability can be reduced even further. In such case, the dike ring would have to be reinforced over its entire length.

Groningen-Friesland

Groningen and Friesland border on the Wadden Sea, Lake IJssel and higher inland areas. The dike ring consists of dikes and hydraulic structures, but there are no dunes. When calculating the flood probability of this area, the probability of overtopping and overflowing of water, sliding, piping and seepage, the failure of a dike revetment and the probability of failing hydraulic structures were taken into account. Again the effect of removing bottlenecks on the calculated flood probability can be observed clearly.

The Harlingen cut-off forms the main bottleneck. This is a cut through the dike for the railway. At this location there are chances of well formation. The calculated flood probability in Groningen-Friesland is also dominated by uncertainties with regard to structures (in this case their construction). Supposing that this problem is solved, the flood probability reduces to 1/4,300 per year. The flood probability is then determined mainly by the chance of too much wave overtopping of the Reiderwolderpolderdijk (along the river Dollard). The dike height is lower than elsewhere along the ring. Heightening the dike should remove this bottleneck. The calculated flood probability would drop to 1/9,000 per year.

The step-wise approach of the water defence improvement would imply that the Harlingen cut-off would be the first candidate for improvement, followed by locally enforcing the very low Reider-wolderpolderdijk. To further lower the calculated flood probability (weak links all removed) the dikes and structures in Groningen-Friesland will all have to be reinforced.

Hoeksche Waard

The Hoeksche Waard lies in the transition area between sea and river. The dikes and structures around the Hoeksche Waard were constructed when the influence of the sea was strongly present. The river Haringvliet was still in open connection with the sea and the Brielse Maas had not yet been dammed of. According to current insights, the dikes of the Hoeksche Waard are too high. Also in this case, the calculated flood probability consists of the chance of overtopping and overflow of water, sliding, piping and seepage, the failing of the dike revetment including grass and the failing of structures.

The calculated flood probability of the Hoeksche Waard is determined by the uncertainty whether the inlet structure at the Mariapolder is closed in time. Also for this structure, the reliability of manual operation is unknown; our knowledge is still insufficient. This is not only valid for the Mariapolder, but also for other structures in the Hoeksche Waard. In addition, there is the chance on sand boiling wells.
These are the only weak links in the Hoeksche Waard dike ring. Assuming that the structures work properly, the calculated flood probability amounts to 1/20,000 per year. The calculated flood probability is thus small and might become even smaller by reinforcing the dikes and structures along the entire dike ring.

Betuwe, Tieler- and Culemborgerwaarden

This dike ring is located in the river area. Within the scope of the Delta Plan for Large Rivers, the dikes were recently (in the last decade) improved. This dike ring consists of dikes and structures only. Here, the chance of overtopping and overflow of water, sliding, piping, failing of the dike revetment and structures determine the calculated flood probability. Also in this case, the calculation framework of the flood probability shows the weak links in the dike ring in a step-wise manner.

The only bottleneck in this dike ring is the uncertainty that sand boiling wells may occur at the inlet structure at Tiel. The chance that this would happen in reality is not known, as the underground construction is not sufficiently well known. If this problem would be solved, a calculated flood probability of 1/1,000 per year would be the result. Solving the problem requires two steps. Firstly, the knowledge gap on the aspect should be decreased, and secondly (depending on the results and information obtained) the inlet structure would have to be improved.

In this dike ring, it will only be possible to lower the flood probability by reinforcing all dikes and structures. The contribution of the other possible failure modes (unlike overflow) to the calculated flood probability is at least a factor ten times as small as the probability of overflow. This conclusion was to be expected, given all the dike improvements of the recent past. In this dike ring, there is no single dike section that can be considered a weak link, as all dikes are equally strong.

4.3 Comparison of probabilities of flooding with probabilities of exceedance

The four dike rings, for which the flood probabilities were calculated, are subject to different dangers of flooding due to their locations. These dangers range from threat from the sea, from river, possible flooding by fresh water or salt water, and different warning times. These areas also vary in terms of population and economic activity. The combination of the danger and the potential damage of floods thus varies per area. So there is sufficient reason to have different safety standards (exceedance frequencies) for these areas on the basis of the current safety approach (see Chapter 2).
It is now also possible to compare the calculated flood probabilities with the exceedance probabilities of these four dike rings. Assuming that the observed weak links have been eliminated, the comparison shows that the ranking order of the dike rings remains for the greater part intact. Only the dike ring of the Hoeksche Waard is an exemption. Its small flood probability can be explained by the too high crest levels of its dikes (see Paragraph 4.2).

4.4 The impact of sea level rise and higher river discharges

In the coming decades, it is expected that due to climatic change, the sea level will rise and river discharges will increase. To investigate the effects on the flood probability, calculations have been carried out for both cases. For two sections of dike ring Central Holland (one dike and one dune section), the flood probability has been calculated for a sea level rise of 50 and 100 centimetres per century. The effect of possible land subsidence has not been taken into consideration. For the dike ring area of Betuwe, Tieler and Culemborgerwaarden, the effects of an increased discharge of the river Rhine to 16,000 m^3/s (instead of the present 15,000 m^3/s) at Lobith were calculated.

Effect of sea level rise

From the two studied sections in Central Holland, the effect of a sea level rise was calculated for the failure mode 'water overflow' and 'overtopping'. For the dike section, a sea level rise of 50 cm means that the probability of failure increases with a factor 4. This multiplying factor becomes even 15 for a sea level rise of 100 centimetres. For the dune section, the sea level rise implies an increase in probability with a factor 2.5 and factor 6 respectively.

If calculations would have been carried out for the entire dike ring, it can be expected that the failure mode overtopping and overflow of water would be the dominating weak link of the dike ring. This also meets expectations, given the fact that the water defence was not designed for such high sea levels.

Effect of higher river discharges

The probability of failure for the failure mode 'overflow' has also been calculated for the dike ring areas of Betuwe, Tieler and Culemborgerwaarden for a river discharge of 16,000 m^3/s. In this case the calculated flood probability of the area increases from 1/1,000 per year at 15,000 m^3/s to 1/400 per year at 16,000m^3/s. The probability of overtopping and overflow of water dominates the flood probability at increased river discharges. The increase in probabilities of other failure modes is considered much smaller. The weak link of this dike ring is the height of the dikes in the case of higher river discharges, which was also to be expected.

5. Conclusions and recommendations

A chain is never stronger than its weakest link. This insight is the basis for the calculation method to determine the flood probabilities of dike ring areas in the Netherlands. The TAW can already formulate first recommendations on research and policy making. This does not imply that the research on 'Flood risks: a study on probabilities and consequences' is already finalised. This study concentrates on probabilities ánd consequences. Developing a method to estimate consequences of flooding is the next step of the TAW. Then it also will be possible to estimate the costs and benefits of the alternative measures.

Added value of flood probabilities

The outcome of this study on flood probabilities can be regarded as an action plan for the future and thus as a guide to pursue a more anticipating policy on flood defence. New insights have been obtained on the weak links of a dike ring and on the gaps in our knowledge. The calculated probabilities of flooding allow for making rankings for a step-wise improvement of water defences, whereas the available budget can be used more efficiently. The same holds for the development of knowledge on water defences. The findings of this study will be used in the TAW's annual advisory recommendations on the 'water defences' research programme of the Directorate-General for Public Works and Water Management.

Recommendations

Based on the results so far, the TAW recommends:

- to calculate the flood probabilities of all 53 dike ring areas in the Netherlands on short notice, as to create a first overview of weak links and knowledge gaps;
- to undertake research on the strength and operational safety of hydraulic structures, as they are the main source of observed uncertainties;
- to carry out research on the magnitude of uncertainties, so that the calculated flood probability better approaches the real probability of flooding.

Flood risks: a study of probabilities and consequences

When evaluating the acceptability of the flood probability of an area, the two crucial factors are the potential damage caused by flooding and the danger for the population. Back in the nineteen sixties, this insight was already acknowledged by the Delta Committee. Because of the available knowledge in those days, this committee could only come up with a differentiated safety approach, which was characterised by probabilities of exceedance.
The coming socio-political debate on the protection of the Netherlands against floods will again involve the same consideration of the social costs of safety measures and the expected benefits of reducing the probabilities of flooding: less damage.

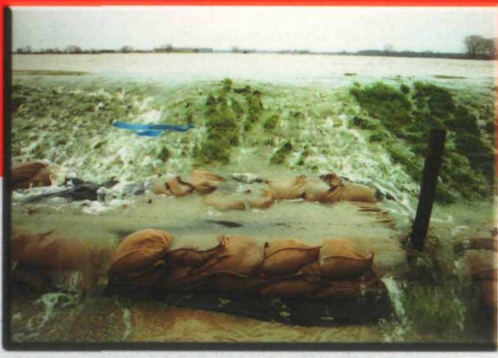
In the next stage of the research programme 'Risks of flooding: a study on probabilities and consequences', together with the relevant parties, the TAW intends to assess potential damage that would result from a flood. At that moment it will also be possible to calculate the costs and benefits of all alternative mitigating measures. These measures refer to research (inspection and testing, study and research), reinforcement and elevation of the water defences, lowering water levels and wave heights, as well as restriction of flood consequences by means of technical and administrative measures. Knowledge from disciplines, such as economics, environmental planning, agricultural sciences, psychology, cultural history and nature conservation will be necessary in this study. Investigations will be made into whether the probabilities and consequences of floods can be expressed in measures that are usual in other fields of risk management. This concerns individual risk, group risk and economic risk.

During the research, more insight will be gained into the probabilities of flooding in dike ring areas and the possible consequences of such floods. In fact by then, the conceptual steps as were initiated in an imperfect way by the Delta Committee (as indicated by the Commission itself) in 1960 can be repeated according to the latest insights.

Is the Netherlands safe enough?

The question whether the protection against floods in the Netherlands is sufficiently high is a question of all times, and will remain to be posed in future as well. With this study, the TAW provides knowledge that will be functional in answering these questions. The TAW feels it as its duty to supply such knowledge as to support an anticipating approach to the safety discussion.

The question as to whether the Netherlands is safe enough, which standard should be maintained, and whether the current safety approach still meets current standards, will have to be answered at political level.



In 1965, the Netherlands Technical Advisory Committee for Flood Defence (TAW) was inaugurated by the Minister for Transport, Public Works and Water Management. This committee was established as a reaction on the flooding of part of the city of Amsterdam as a result of a dike failure.

The TAW is now functioning for almost 4 decades. Its tasks have remained the same, namely:

- giving the Dutch Minister of Transport, Public Works and Water Management (asked or on own initiative) advice on matters concerning safety against flooding;
- preparing guidelines and technical reports for the dike managers (water boards), and;
- overall guidance of the ever needed research (on technical aspects of water defences as well as on the technical background of the safety approach).

To realise these tasks, the committee consists of representatives of the three governments levels that play a role in water defence (State, Provinces and Water Boards), and specialists from universities and private enterprise. An independent chairman and secretary at the water policy directorate of the ministry complete the TAW. TAW is advised by four committees: Technical affairs, Safety matters, River systems, Coastal systems.
TAW does not have an own budget; the Road and Hydraulic Engineering Institute from the Ministry carries out the work.

For questions on TAW's activities please contact the Road and Hydraulic Engineering Institute (DWW) of the Directorate-General for Public Works and Water Management.
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