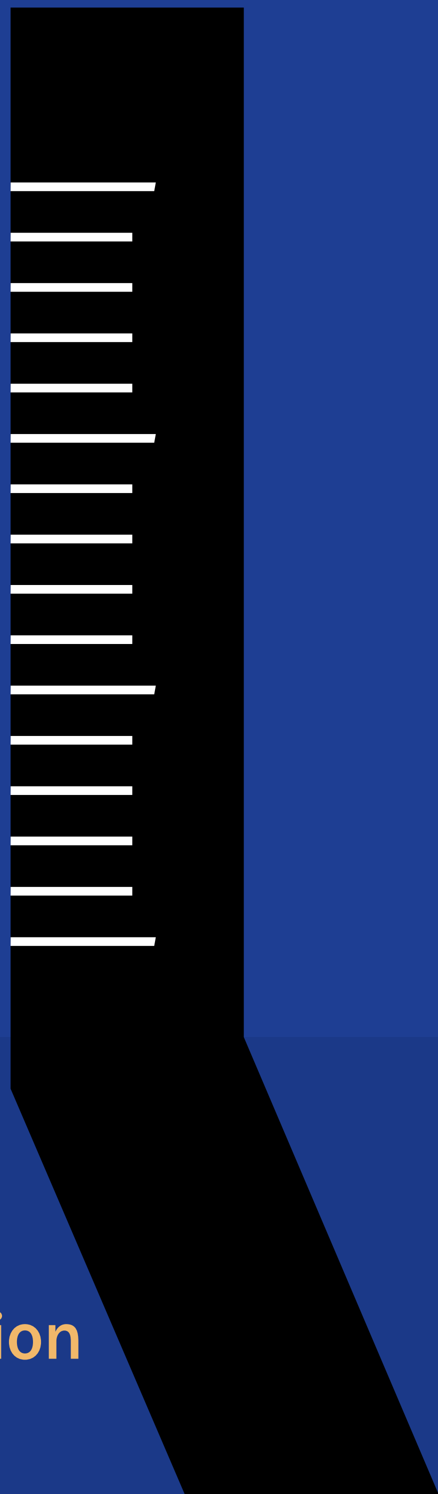

Fundamentals of Flood Protection

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December 2016
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Preface

7 November 2016 was a special day in the history of flood protection in the Netherlands. On that day, I closed the final weak link along our coastline, making the entire Dutch coast super-stormproof for decades to come.

But the job is not finished. Protection from flooding is never finished in a delta. Climate change is causing changes in the sea level and in river levels. We therefore need to take the next step. From January 2017 new standards will apply to our levees, dams and dunes. We will not only consider the probability of flooding, we will also take a very close look at the possible consequences, on the principle that everyone should receive the same basic level of protection from flooding.

The Expertise Network for Flood Protection sets out those new standards in this publication. It also gives an insight into the assessment, design and management of flood defences. The final chapter looks at crisis management. Even if all our primary flood defences comply with strict standards, the possibility of flooding can never be entirely ruled out.

All in all, 'Fundamentals of Flood Protection' gives experts and anyone else with an interest in the subject an excellent picture of how we are protecting our country. It tells the story behind the standards and technical reports, and that will help us continue to ensure our country is well protected from flooding in the future. I wish you all every success in these endeavours.

Melanie Schultz van Haegen
Minister of Infrastructure and the Environment

Hondsbossche sea defences near Petten.

Diefdijk levee at Schoonrewoerd.

Algerakering storm surge barrier at Krimpen aan den IJssel.

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Flooding at Tuindorp Oostzaan, January 1960.

01 Introduction

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Protection from flooding is vital for quality of life in the Netherlands, and is therefore subject to statutory regulation. *This chapter explains why protection is needed and why the fundamentals of flood protection have been established and updated.*

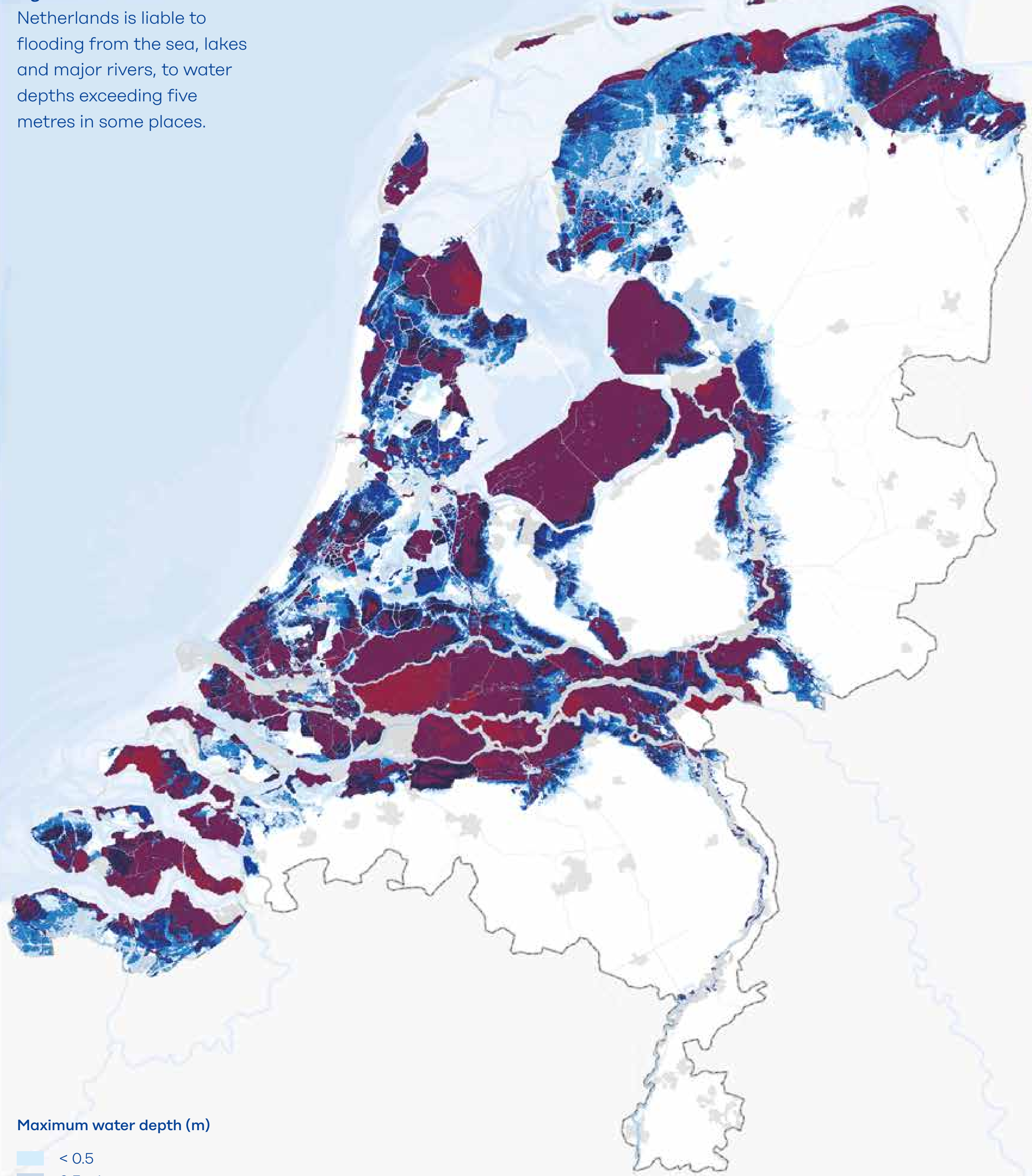


Figure 1.1 60% of the Netherlands is liable to flooding from the sea, lakes and major rivers, to water depths exceeding five metres in some places.

1.1 The importance of flood protection

The Netherlands has always lived with the threat of flooding. Protection from flooding is therefore vital if we are to be able to live and work in the Netherlands. Figure 1.1 shows which parts of the Netherlands are vulnerable to flooding: not only the part below sea level, but also those parts of the country that are liable to flooding at times of high river discharges. The government believes it is very important to prevent flooding. Protection from high water levels is therefore regulated in the Water Act (*Waterwet*), which provides a basis for permanent protection from flooding.

The Delta paradox

How we deal with the risk of flooding is a key subject of social and political debate. Hardly surprising, given the geographical circumstances of our country. The public debate on this issue will always remain current. Since the Middle Ages our country has built levees and created polders. Some wonder, however, whether the levees should now be heightened, and whether it would not in fact be better to give the rivers more room.

Some even question whether it will be possible to remain living in the lower-lying parts of the Netherlands, and whether it would not in fact be better to move the most important economic activities to higher parts of the country.

Like the Delta Commission 2008, the Expertise Network for Flood Protection (ENW) is convinced that the Netherlands – including the lower-lying parts of the country – will remain an attractive place to live and work in the future. This is referred to as the Delta paradox: despite the vulnerability to flooding, quality of life in the Netherlands is good. We will therefore have to continue investing in measures to keep the risk of flooding to an acceptable level. An understanding of the effectiveness of various measures is therefore essential.

Multiple layers of safety

Various types of measure can be taking to reduce the risk or consequences of flooding. This 'multi-layer' safety consists of three layers:

1. Prevention: measures to stop floods from happening.
2. Spatial design (mitigation): building our country in such a way that the consequences of flooding are limited.
3. Crisis management: measures that limit the consequences of flooding.

The Delta Programme[1] of 2014 concluded that prevention is the most important layer in the Netherlands, complemented by the other two. The government and parliament both endorsed this conclusion. However, we must continue to focus on spatial design and crisis management in order to limit current and future flood risks.

1.2 Purpose of the new fundamentals of flood protection

Revised fundamentals

The Water Act sets out standards for flood defences designed to preserve an acceptable level of safety in the Netherlands. These statutory norms need to be translated into practical measures. Uniform calculations and shared knowledge must for example be used to produce an assessment of the level of safety afforded by flood defences, or a design for a new or reinforced flood defence structure. The calculation methods and knowledge to be used for this purpose have for example been set out in guidelines and technical reports.

'*Fundamentals of Flood Protection*' encompasses all these documents. It describes the underlying principles of flood protection in the Netherlands: how the statutory norms have been devised and how they can be translated into assessment, design and management (see figure 1.2).

[1] The Delta Programme is a national programme in which central government, provincial and local authorities and water authorities work together, with input from civil society and the private sector. Its aim is to protect the Netherlands from flooding and provide sufficient fresh water, both now and in the future.

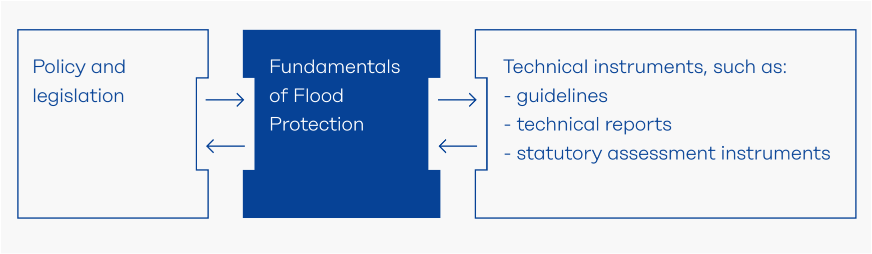


Figure 1.2 *Role of Fundamentals of Flood Protection.*

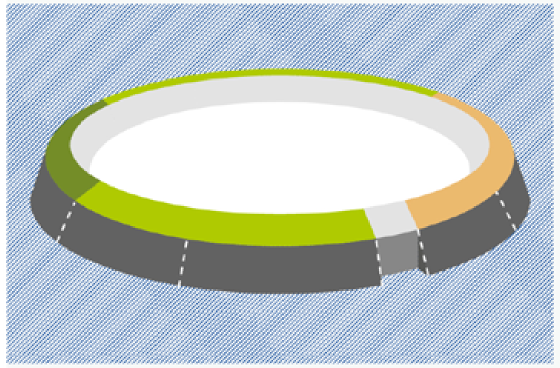
The first edition of 'Fundamentals', entitled *Grondslagen voor waterkeren* ('Fundamentals of Flood Defence') was published in 1998. There are now good reasons to publish a new edition. In 2015 the government decided to make fundamental changes to the requirements applying to protection from major flooding. The type of standard would change, as would the calculation methods used to assess and design flood defences. This prompted the revision of the Fundamentals.

This new version of the Fundamentals has a new title: *Fundamentals of Flood Protection*. This change is consistent with the trend towards considering not only flood defences, but also ways of reducing high water levels and waves through interventions in the surrounding area (such as creating more room for rivers).

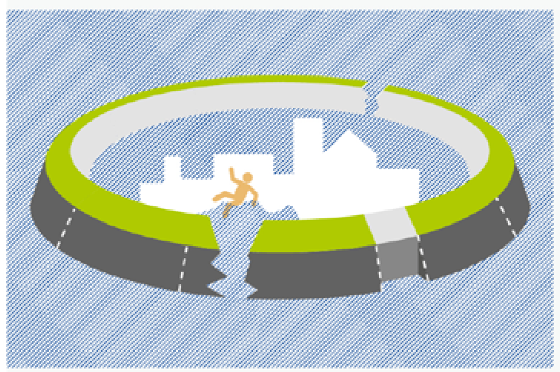
Fundamental change: the new standard

The new standard for flood defences is expressed in a different way. Until 2017 it was defined as a water level that must be safely guarded against, and as such the standard focused only on the hydraulic load. Though the strength of the flood defences played a major role, it was not explicitly reflected in the numerical standard. The new standard is expressed as a probability of flooding. This change was envisaged as long ago as 1996, and is also described in the *Fundamentals of Flood Defence*. The main reason for switching the focus to the probability of flooding is that it properly reflects the degree of protection from flooding. After all, the probability of flooding depends both on the hydraulic load (water levels and wave action) and on the strength of the defences (height, width, type of material etc.).

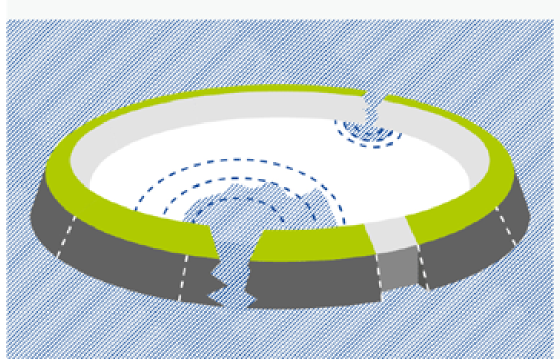
The new standard is based on the *risk* of flooding. Risk refers to both the probability and the consequences of flooding (see figure 1.3). The possible consequences have been identified more effectively than in the past, with a greater focus on fatalities and victims. For the first time, the loss-of-life risk has played an explicit role in the updating of standards for flood defences. The government has decided that the probability of loss of life due to flooding may not exceed 1/100,00 per year in all protected areas of the Netherlands.



Probability of flooding:
The probability of a breach is identified for each section of the levee system.



Impact of flooding:
The impact (damage and casualties) of any breach is identified.



Flood risk:
For every section of the levee system, the probability of flooding is combined with the associated impact. All the combinations together give the flood risk:
probability x impact = risk

Figure 1.3 Schematic representation of risk approach.

1.3 Intended readership, scope and reader guide

Intended readership

Fundamentals of Flood Protection is intended for a wide readership: both professionals working on the basis of guidelines and technical reports, and lay readers with an interest in the subject. This helps ensure that all concerned use the same language, thus improving communication. Since specialists will be using the book, use of some jargon is unavoidable. However, the terms used are explained as clearly as possible. There is some variation in terms of depth, and chapters 5 to 8 – particularly chapter 5 – are more specialist than the other chapters.

Fundamentals of Flood Protection is based on knowledge about flood protection available in 2016. Flood protection will continue to evolve in response to societal interests and decisions. Knowledge of high water events and flood protection also continues to develop, as do innovative techniques that can be used to improve safety or the monitoring of safety. The focus on safety is not expected to abate. In the opinion of the Expertise Network for Flood Protection, the answer to the question of *how safe is safe enough* does not lie in a calculation; it is an eminently societal and political issue. It is a matter of weighing up various interests, always cognisant of the fact that it is not technically feasible to reduce the risk to zero. These two factors mean that this new version of Fundamentals will also need updating at some future point.

Scope

Since prevention is the most important layer of flood protection in the Netherlands, this publication focuses mainly on layer 1 of multi-layer safety (see section 1.1). Prevention is therefore key. Layer 2, spatial design measures (mitigation) that limit the impact of flooding, is still under development, and this publication focuses little attention on this aspect. The concept is being worked out in a number of contexts, including the ‘Spatial Adaptation Delta Programme’, the ‘Water and Evacuation’ programme and the National Water and Flooding Information System Platform. Layer 3, crisis management, is however dealt with in this publication. This is because crisis management, and particularly the estimated effect of evacuation, has been incorporated into the new standard in the form of the ‘evacuation fraction’ (the proportion of the population that can be evacuated prior to a flood). The success of an evacuation depends in turn on flood forecasting, among other things, so it makes sense to focus on crisis management.

Reader guide

Three chapters in this book describe the background to flood protection. Chapter 2 begins with a description of the flood protection system in the Netherlands: the key elements of and responsibility for flood defence. Chapter 3 explains the technical and scientific background to the concepts of uncertainty, probability and risk. Chapter 5 looks at how the standard is translated into technical requirements.

The other chapters focus on activities (also known as processes) performed by the various authorities involved in flood protection (central government, water authorities, provincial and local authorities and security regions):

- setting risk standards (chapter 4)
- design (chapter 6)
- assessment (chapter 7)
- management and maintenance (chapter 7)
- crisis management (chapter 8)

In order to keep the publication accessible to a wide readership, the sources used have not been included in the text. A list of the most important references used as sources for each chapter is however given at the end of the book. The new Water Act (*Waterwet*) has not been included; readers can access the text at www.wetten.nl.

Fundamentals of Flood Defence, 1998.

02

Flood protection in the Netherlands

pp. 09—28

Roughly two-thirds of the Netherlands is vulnerable to flooding from the sea, major lakes or major rivers. Over the centuries, this vulnerability has led to a regulated system of flood defences that curb the threat of flooding where possible. *The choices made and the preservation of this system are the subject of this chapter.*

2.1 History

Today, much of the land in the Netherlands is intensively used, particularly in the regions near the rivers and along the sea coast. Many of these areas are low-lying. The potential consequences of flooding are much more serious than ever before. As a result of the efforts of our ancestors over a thousand years, the Netherlands is now a densely populated, highly developed, low-lying region where flooding could lead to great loss of human life, tens of billions of euros' worth of damage and disruption to society.

An extensive system of flood defences protects this low-lying land. The water that enters the Netherlands, carried by the major rivers that flow through it, is discharged as swiftly as possible into the sea when river levels are high, and retained for as long as possible when they are low. The water level in the IJsselmeer and the Markermeer is regulated, and sand replenishment ensures that the coastline remains fixed in a predetermined position. More than anywhere else in the world, flood protection here is controlled by institutions and regulations.

The course of the rivers and the influence of the sea have had a huge impact on the geography of our country. Initially, the inhabitants of this region sought higher ground on which to live. Around 2500 years ago they began actively to protect themselves from flooding, and were thus able to inhabit and exploit a larger proportion of the country.

Northern Netherlands

The earliest signs of flood protection can be found in the northern Netherlands. From circa 500 BC, hundreds of *terps*, or dwelling mounds, were created there. The inhabitants of the region also began to construct low earthen structures by piling up sods of clay. Local village and monastic communities built such structures, known as dikes, around small fields. From the twelfth century smaller dikes were connected, creating contiguous chains of flood defences: levee systems. Individuals and small communities were no longer capable of building and maintaining the levees, so water authorities were established in the Late Middle Ages. Nevertheless, flooding still occurred on various scales on a regular basis.

Rivers area

In the area through which the major rivers flow, the water system was highly dynamic. The course of the rivers changed quite frequently. The impact of this can still be seen in the soil structure along the rivers. One important step designed to afford more control over the course of the rivers was the digging of the Pannerden Canal in the early eighteenth

century, followed later by the Bijland Canal, which redirected a distributary of the IJssel river and the Pannerdensche Kop river bifurcation. From then onwards, the river Waal discharged roughly two-thirds of the water from the Boven-Rijn, and the Pannerden Canal roughly one-third. This has not essentially changed since that time.

Nevertheless, floods regularly occurred in the rivers area, so various measures were taken in the early nineteenth century: a number of spillways were constructed, rivers were straightened to increase the rate of discharge, the Meuse and Waal were separated, and levees were heightened. This considerably reduced the frequency of flooding in the region compared to previous centuries.

The last major flood in the rivers area occurred in 1926, when the rate of discharge at Lobith was the highest ever measured, at 12,850 cubic metres a second.

During the critical peak water levels of 1993 and 1995 maximum discharge rates of 11,000 and 12,000 cubic metres a second were measured. Since it could not be guaranteed that the levees would hold, the decision was taken to evacuate 250,000 residents. This prompted a programme of levee reinforcements (the Delta Plan for the Major Rivers) and a programme designed to increase the discharge capacity without any heightening of the levees (the 'Room for the Rivers' programme).

Zuyder Zee

The Zuyder Zee was created as a result of regular flooding and the erosion of the peat subsurface. Over the course of the centuries the Zuyder Zee flooded many times. The response was often to reinforce the levees, but sometimes a flooded area was simply abandoned to the sea. From the nineteenth century, ways of closing off and reclaiming the Zuyder Zee were studied, with the aim of creating more land. The prime mover behind the plan was public works minister Cornelis Lely. His plans resulted in the Zuyder Zee project, which was eventually implemented between 1920 and 1975. Initially the work had to be postponed when the First World War broke out, but the project gained more urgency due to the Zuyder Zee flood of 1916. Many levees around the Zuyder Zee breached, mainly causing material damage, although 16 people lost their lives on the island of Marken.

The construction of the Afsluitdijk causeway, completed in 1932, shortened the coastline considerably, transforming the Zuyder Zee into the IJsselmeer. Wieringermeer lake, the Noordoostpolder and the Flevopolders were created later in the 20th century.

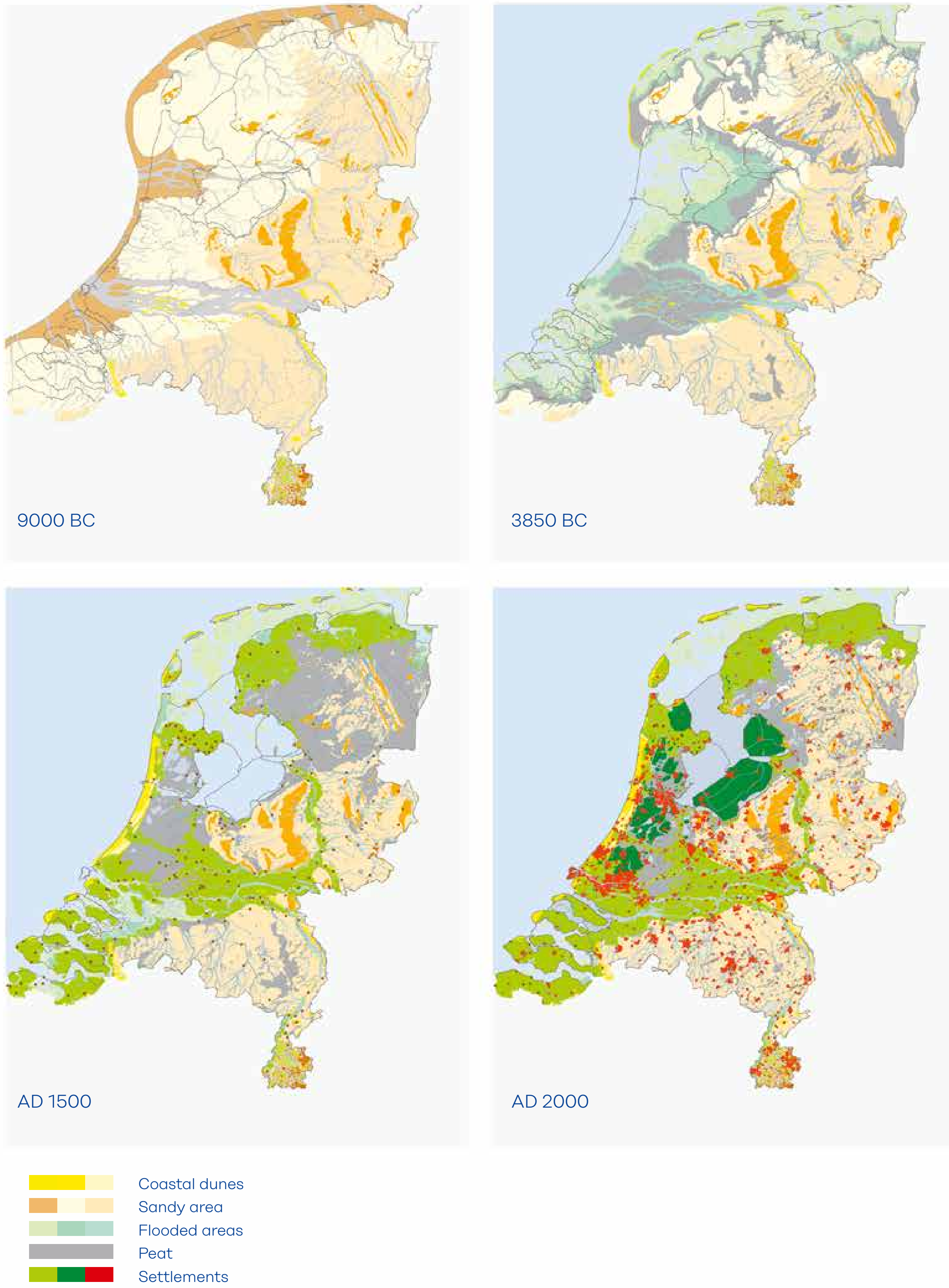


Figure 2.1 Changes in the Netherlands over time.

Coastal region

The construction of the Afsluitdijk causeway had a major impact on the position of channels and flats in the Wadden area, an impact that is still felt to this day. The region is part of the Dutch coast, which also consists of the closed coastline of Noord- and Zuid-Holland and the Zeeland delta. The entire Dutch coast, in turn, is part of a much larger system, extending from the cliffed coast of northern France to the northern German Wadden area. The Dutch coast features beaches and dunes, which are several kilometres wide in places. Some places are subject to structural erosion. Groynes and sand replenishment are used to respectively curb or counteract the erosion.

Southwestern delta

The southwestern delta has frequently been hit by flooding. This region is at risk from high tides and from high river water levels. The islands of Zuid-Holland and Zeeland have regularly changed shape. One of the best known floods is the Saint Elizabeth's Day flood of 1421, when levee breaches and flooding cause major devastation in Zeeland and Zuid-Holland, causing an estimated 2000 deaths.

The flood that determined current policy was the storm surge of 1953, which took the lives of 1836 people when some 2000 square kilometres of land were flooded. The Delta Commission was established immediately afterwards to draw up plans for preventing any such disaster in the future. The Commission recommended closing off a number of sea inlets, shortening the coastline by about 700 kilometres. The Delta Act was passed in 1958 in response to these recommendations, and work on the Delta Project commenced. The most innovative element of the project is the Eastern Scheldt storm surge barrier.

2.2 Flood risk management policy from 1953

2.2.1 Standards for primary flood defences

The recommendations of the Delta Commission provided the basis for safety standards to be enshrined in law. The Delta Commission proposed design high water levels that levees must be able to defend against. This was a simplified way of specifying safety requirements in terms of the probability of flooding which only took account of water levels. A flood defence structure should be able to safely defend against a certain peak water level. At the time, this represented a new way of thinking about flood defence. Whereas, in the past, levees had been heightened on the basis of the highest known local water level, from now on they would be reinforced on the basis of the probability that a certain design peak water level would be exceeded. It was no longer a matter of responding to

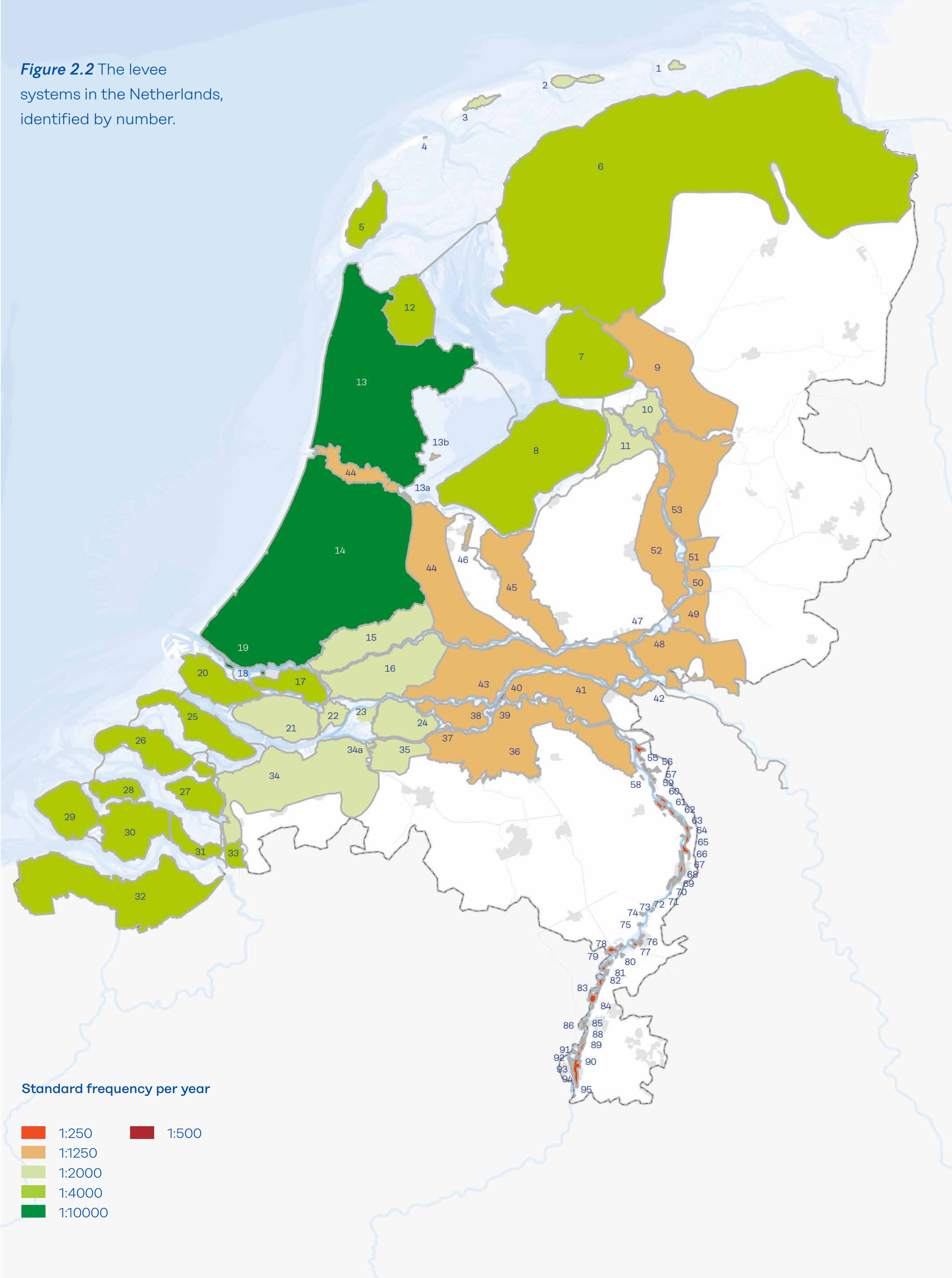


Figure 2.2 The levee systems in the Netherlands, identified by number.

flooding, but of taking a proactive approach based on statistical analysis. The Delta Commission underpinned the standards by balancing the costs of reinforcement against the reduction in flood risk. The impact of flooding would be greatest in the west of the country, and it was there that the strictest standards were proposed. Flood defences in the west would have to withstand water levels with an annual exceedance probability of 1/10,000. Lower standards were proposed for other parts of the country. The Delta Commission only considered the defences along the coast. It was not until later that other bodies, building on the ideas of the Delta Commission, set safety standards for the river levees. The standards proposed by the Delta Commission and subsequent commissions relate to primary flood defences, which afford protection against flooding from major bodies of water (or 'outer waters'[2]): the sea, the major rivers and the large lakes. Primary flood defences include levees, dams, dunes and structures forming part of them, such as cuts and locks.

Besides primary defences, the Netherlands also has regional defences along canals and man-made lakes. A breach in regional defences will generally have a smaller impact than a breach in the primary defences, though it can still have considerable consequences. The safety standards for these defences are set by the provincial authorities. Finally, the country also has many kilometres of flood defences with no specific status, for which no safety standards have been specified in national or provincial legislation.

Until 2017 the standards referred to entire levee systems: contiguous rings of flood defences and higher ground. Under the Flood Defences Act, and later the Water Act, each levee system had its own standard for exceedance probabilities of the design water level. In the new system, primary defences have been divided into one or more levee segments, each of which has its own safety standard. The same threat and more or less the same consequences in the event of a breach exist along the entire length of the segment. Figure 2.3 shows an overview.

[2] According to section 1.1 of the Water Act, outer waters are surface waters where the water level is directly impacted by storm surges, high surface water levels in one of the major rivers, high water levels in IJsselmeer or Markermeer lakes, or a combination of these. Volkerak-Zoommeer and Grevelingenmeer lakes, the tidal portion of the Hollandsche IJssel river and the Veluwerandmeren lakes are also classified as outer waters.

__Figure 2.3__
Levee segments in the Netherlands.

Starting in 2017 all primary defences border outer waters, with the exception of the Diefdijk, the only stretch of primary flood defences not to border do so. This historic flood defence structure, part of the Hollandse Waterlinie system of water-based military defences, was constructed to protect the Alblasserwaard polder against flooding from the Betuwe wetlands.

The condition of primary flood defences is regularly assessed, and reported to parliament. In this way, the Dutch government remains up to date on the state of the country's flood defences. If a flood defence structure no longer complies with the statutory requirements, measures have to be taken.

Diefdijk levee, the only primary flood defence structure not situated beside water.

2.2.2 Types of primary flood defences

Most primary flood defences provide direct protection from flooding. Some do so indirectly, by limiting the load on other flood defence structures situated further away. These are known as flood defences. One example is the Afsluitdijk causeway, which reduces the loading on the flood defences around the IJsselmeer. Storm surge barriers like the Balgstuw at Ramspol are flood defences. If such a defence structure fails, the hydraulic load on the primary flood defences beyond increases, so the probability of flooding also increases, though this does not necessarily mean that a flood will actually occur. There are various types of flood defences:

Dunes

Dunes are natural landscape features. They are formed by the wind from sand that washes ashore, in interaction with vegetation which captures and retains the sand. Stabilisation can be expedited or enhanced by planting marram grass. However, this vegetation is not intended, nor is it able, to prevent sand erosion due to wave action during high tides and surges. Dunes' role in flood defence depends entirely on the total mass of sand, which must be great enough to ensure that, when a storm erodes part of the dune, enough sand remains to protect the lower-lying land behind the dune belt from the higher sea level. Once the storm has passed and the water receded, the wind can start to build up the dune again. In view of this dynamic process, dunes require particular care in terms of management and maintenance.

Levees and dams

Levees and dams are artificial earthen structures. Unlike dunes, which are eroded by wave overtopping, levees should be able to withstand some overtopping, due to their smaller dimensions. Levees derive their erosion-resistance from the materials used to build them, such as clay covered with grass, stone cladding or asphalt. The shape of the basic earthen structure – often trapezoid in section – is characteristic of these structures. The flood protection capacity of the structure is determined by its height, its shape in profile and the ground on which it stands. Levees must be sufficiently resistant to shearing (stability) and watertight. Stability depends on the shear strength of the levee body and of the subsurface.

The dunes at Rockanje.

Church on Waaldijk levee.

Algerakering storm surge barrier at Krimpen aan den IJssel.

Special structure, Kampen.

Hydraulic structures

Protective hydraulic structures are installed to safeguard another function that intersects the flood defence. They include such structures as locks (IJmuiden) and storm surge barriers (Nieuwe Waterweg, Hollandsche IJssel) for shipping, pumping stations (Katwijk), sluices (Haringvliet) and storm surge barriers (Eastern Scheldt) to provide drainage, and cuts (Lobith) for traffic.

To allow the various functions to operate, hydraulic structures generally have one or more moving closure mechanisms. When closed, the mechanism transfers the forces working on it to the rigid part of the structure. The storm surge barrier in the Eastern Scheldt protects the land behind it, while still allowing tidal movements.

It is not always possible to draw a sharp distinction between the different types of flood defences and the elements that comprise them. A combination of a hydraulic structure and an earthen structure is also known as a water retaining structure. Such structures may reinforce, complement or completely replace earthen structures. Examples include sheet piling, cofferdams and retaining walls. They are also referred to as longitudinal structures. The connection between the water retaining structure and the adjoining earthen structure requires particular attention in the design process.

2.2.3 High grounds

Parts of the Netherlands – such as the Utrechtse Heuvelrug ridge, Drenthe and the Veluwe moorlands – are naturally high ground where the probability of flooding from the sea, lakes or major rivers is negligible. These areas do not depend on primary flood defences for their safety.

Until 2017 high grounds were regarded as part of the levee systems on which the standards were based. The northern and southern sides of levee system 45, which surrounds the Gelderse Vallei, are formed by the flood defences along the Randmeren lakes and the Rhine, while the western and eastern sides consist of the high grounds of the Utrechtse Heuvelrug ridge and the Veluwe moorlands. The standard applied to the entire levee system. Under the new system of levee segments, the situation has changed. Two different standards now apply to the protection of this one area, for the two levee segments along the Randmeren lakes and the Rhine (the Grebbedijk levee).

In addition, some high ground along the Limburgse Maas river has not been designated primary flood defences, though it does protect the areas beyond, and could be part of a levee segment. Such grounds are not the same as high grounds like the Veluwe moorland, as they are much smaller in scale and are by no means always naturally high grounds. Nevertheless, they are also referred to as high grounds. It has been decided that no standards should be set for very short segments, but that longer segments that may include high grounds should be designated.

Where a flood defence structure or levee segment adjoins high ground, there is a point from which it has a negligible bearing on the probability of flooding. Where precisely this point lies depends among other things on the potential water levels. If they change as a result of climate change or interventions affecting the river bed, this point can shift. There is also a chance that higher-lying areas will be lowered due to excavation, making them more vulnerable to flooding. It is important to monitor this, under the terms of the Earth Removal Act (*Ontgrondingenwet*), for example. The connection between a flood defence structure and high ground requires particular attention, and every effort must be made to prevent the protected area from flooding via the high ground.

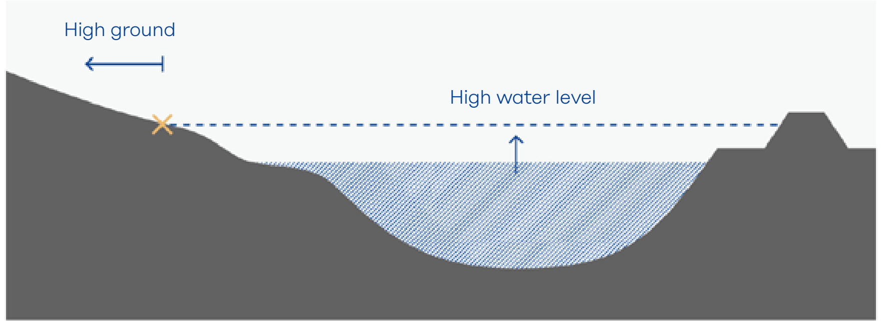
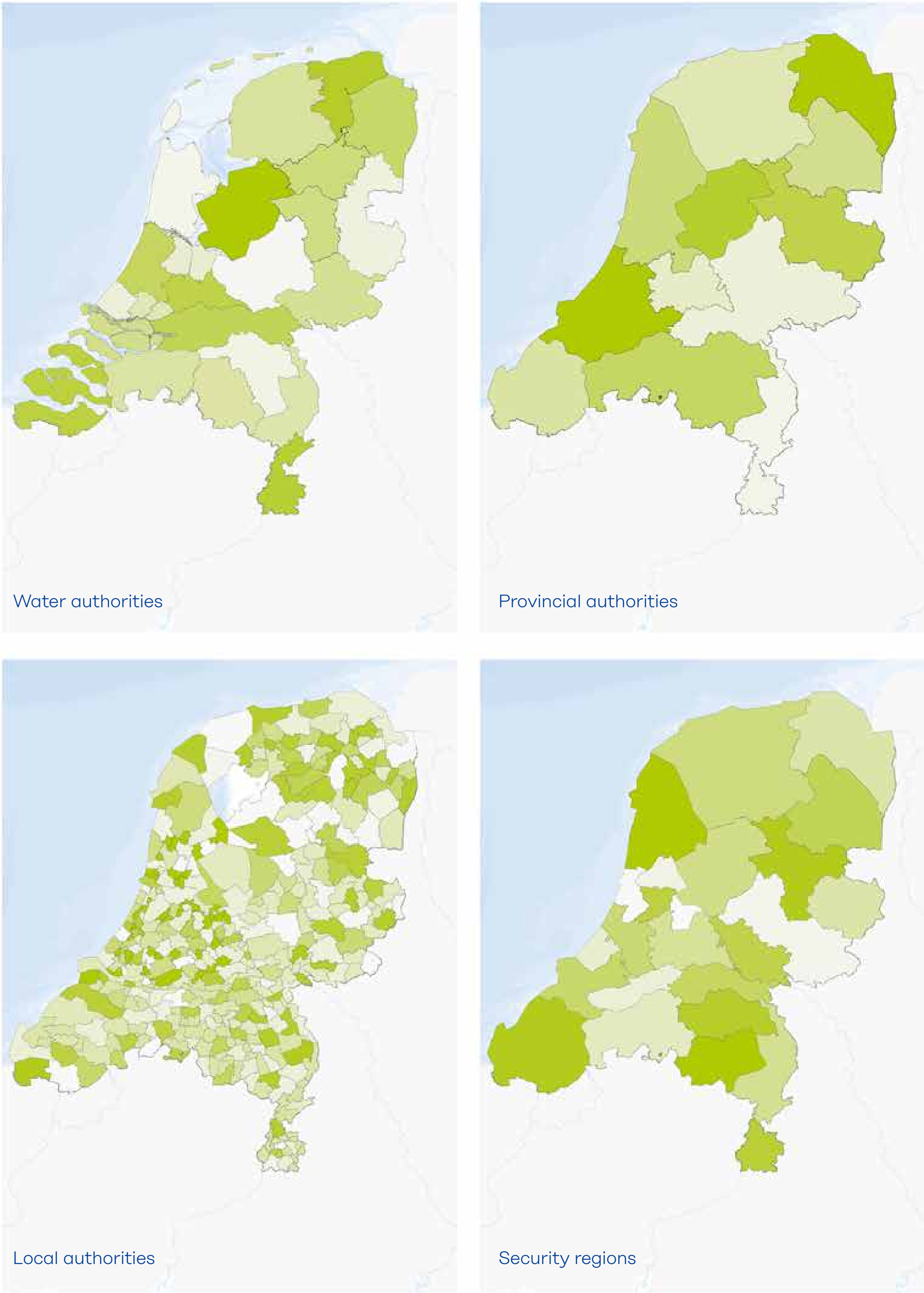


Figure 2.4 High ground.



2.2.4 Governance

Responsibility for flood protection in the Netherlands is shared by three levels of administration: central government, the provincial authorities and the water authorities. Local authorities play a role in spatial planning, representing other interests such as housing and transport, and in communicating with the public. The security region (in which the emergency services and administrative bodies collaborate on emergency response and the maintenance of public order and safety) plays a role in crisis management when there is a threat of disaster.

Since the signing of the administrative agreement on water management (*Bestuursakkoord Water*), responsibilities for water management have been allocated on the basis of 'decentralised where possible, centralised where necessary'. It has also been agreed that one single layer of administration, central government or the provincial authority, should be responsible for setting targets for water management, and for the associated rules, standards and policy. That layer will also monitor whether the implementing authorities are actually achieving the targets. There is always one regulatory authority and one implementing authority. Public works agency *Rijkswaterstaat* is the implementing authority for the main water systems (the sea, large lakes and major rivers) and the water authorities are the implementing authority for the regional water system (including water storage basins and polder waters). The water authorities are responsible for managing the majority of primary flood defences and the regional defences. *Rijkswaterstaat* manages a small proportion of the primary defences (including large defences such as dams and storm surge barriers) and a number of regional defences.

Water authorities

The water authorities manage the majority of primary flood defences, the regional system, including the regional flood defences, and are responsible for the quantity and quality of surface water. They are also responsible for waste water purification. Water authorities have an elected board and the power to issue permits and enforce regulations. They levy regional taxes to fund their work. The management and maintenance of primary flood defences is funded in its entirety by the water authorities. They can obtain grants under the flood protection programme for the reinforcement of primary flood defences. 50% of these costs are paid by central government, 40% by all the water authorities together, and 10% by the water authority that manages the flood defence structure in question.

Figure 2.5 The various layers of administration in the Netherlands all play a role in flood protection.

Provincial authorities

The provincial authority is responsible for organising the system of water authorities. It also plays a role in spatial planning and in managing the region. The provincial authority sets frameworks for the management of the regional water system, by designating and setting standards for the regional flood defences managed by the water authorities, for example. Given their potential impact on the physical environment, the provincial authority has the authority to approve or reject plans to reinforce primary flood defences. In exercising this power, it assesses whether the project plan complies with the law and is in the public interest. Finally, the provincial authority may also set further requirements concerning the preservation of high ground based on the Earth Removal Act or the Spatial Planning Act.

Local authorities

The local authorities are closest to the public and therefore play an important role in communication. They have both spatial and social responsibilities. Municipal spatial policy is set out in strategies and zoning plans. Flood defences are incorporated into these local authority zoning plans. A local authority also has responsibilities in the event of flooding, such as maintaining public order and safety, and protecting public health. It draws up a disaster response plan setting out how it plans to meet these responsibilities.

Security regions

The security regions are an extension of local government, in which various authorities and services responsible for crisis management work together. The chair of the security region has authority and administrative responsibility in the event of a disaster or crisis extending beyond the local area.

Central government

The ministry drafts legislation and rules for the management of the primary flood defences and the main water system. It also sets the standards for the regional flood defences managed by *Rijkswaterstaat*. The agency performs its task as manager of the main water system and flood defences on the basis of legislation, rules and standards. Along the sandy coast, *Rijkswaterstaat* is responsible for maintaining the position of the coastline, in accordance with the reference coastline approved by parliament. The Human Environment and Transport Inspectorate is responsible for supervising the primary flood defences and the non-primary flood defences managed by the agency.

2.2.5 Legislation

In a country as densely populated as the Netherlands, many things have to be regulated in legislation. Article 21 of the Dutch Constitution designates concern for the habitability of the country as one of the fundamental tasks of government. This responsibility as it relates to flooding is further specified in special legislation.

The Water Act, provincial ordinances and water authority *keuren* are of particular importance. The general policy on the major rivers (*Beleidslijn grote rivieren*) and the European Floods Directive also play a role.

The Water Act regulates the management of the water system, i.e. the flood defences, the surface water and the groundwater, and also focuses on improving compatibility between water policy and spatial planning. The Water Act is the basis for standards and requirements with which water systems must comply. The standards for primary flood defences are defined in the legislation itself. Standards for regional flood defences managed by central government are set by order in council, while standards for those managed by the water authorities are contained in provincial ordinances.

The manager of the primary flood defences (the water authority or *Rijkswaterstaat*) is responsible for guaranteeing protection from flooding by ensuring that the primary defences comply with the required safety level specified in the Water Act. The Water Act obliges flood defence managers to report on the condition of primary flood defences once every twelve years, and to indicate whether they comply with the statutory requirements. If the assessment indicates that measures need to be taken, the management authority must indicate which measures it regards as necessary. The Water Act specifies conditions under which a subsidy will be awarded to fund such measures. The legislation also obliges management authorities to conduct exercises in preparation for a disaster and to draft a disaster response plan and coordinate it with other management authorities. The Water Decree stipulates further requirements. Local authorities and security regions must also comply with certain requirements relating to crisis management, under the Security Regions Act (*Wet veiligheidsregio's*).

The EU Floods Directive has been incorporated into the Water Act. The Directive is an important international legal instrument allowing targets and measures for the reduction of flood risk to be coordinated with other partners in the same international river basin. One key principle of the Directive is that member states should not take any measures that increase the risk of flooding upstream or downstream (the solidarity principle). In contrast to many European Directives, the Floods Directive does not prescribe any specific targets or measures. Member states are however obliged to draft flood hazard and flood risk maps, indicating the hazard and risk associated with flooding. The member states must also draw up flood risk management plans that set out national goals and measures for reducing flood risk.

When a flood defence structure is built or reinforced, a number of other pieces of legislation come into play, including the Spatial Planning Act (*Wet ruimtelijke ordening*, 2006), the Expropriation Act (*Onteigeningswet*, 1851), the Housing Act (*Woningwet*, 1991), the Environmental Management Act (*Wet milieubeheer,* 1993), the Nature Conservation Act (*Natuurbeschermingswet*, 1998), the Flora and Fauna Act (*Flora- en faunawet*, 1998) and the Environmental Licensing (General Provisions) Act (*Wet algemene bepalingen omgevingsrecht*, 2010).

The Environment & Planning Act (*Omgevingswet*) is expected to enter into force in 2018. This legislation is designed to simplify and amalgamate the rules for spatial developments, making it easier to launch spatial development projects. Many other pieces of legislation will be incorporated into the new legislation, either partially or in their entirety. The whole of the Water Act and Environmental Management Act and parts of the Spatial Planning Act will be incorporated into the Environment & Planning Act.

03

Uncertainty, probability and risk

pp. 29—44

The concepts of uncertainty, probability and risk play a key role in the flood risk approach. These concepts are inextricably linked. Uncertainty is translated into probability; without uncertainty, the probability is zero or one. Risk refers to more than simply probability; it also encompasses the consequences of flooding. This might seem simple, but confusion can easily arise. ***The way in which uncertainty and probability are factored into calculations of flood risk and the probability of flooding has a major impact on the outcomes of such calculations. This chapter therefore explores these concepts in more depth.***

3.1 Uncertainty

Uncertainty exists when more outcomes are conceivable than can actually occur. It is for example uncertain whether a flood will occur during the coming year. The impact of any flood that does occur is also uncertain. It is for example uncertain whether an evacuation will proceed according to plan. Nor can we accurately predict how the flood will propagate in the event of a levee breach, or what the consequences will be.

Uncertainty comes in all shapes and forms. The scientific literature therefore contains many classifications of uncertainty and many methods for factoring it into calculations. In hydraulic engineering, a distinction is generally drawn between inherent (aleatory) uncertainty and uncertainty resulting from lack of knowledge (epistemic uncertainty). Aleatory uncertainty refers to *uncertainty arising from pure randomness* that cannot be reduced by further analysis or data collection (natural variability). Frequently cited examples include the uncertainty associated with the roll of a dice and seawater levels. Epistemic uncertainty refers to uncertainty resulting from a lack of knowledge, such as uncertainty as to the strength of levees. This can be reduced with further analysis or data collection.

Classifications such as these can give rise to philosophical questions. Are seawater levels really inherently uncertain? And is the outcome of the rolling of a dice actually inherently uncertain, or is prediction theoretically possible but impossible in practice because of the outcome's sensitivity to minimal variations in the casting of the dice? Is this not also the fundamental cause of the unpredictability of extreme water levels? These are not simple issues. Scholars have for example been debating Laplace's deterministic world view for centuries, as exemplified by the famous dispute between Einstein and Bohr concerning predictability in quantum mechanics.

Such philosophical issues are fortunately less relevant in practice. When making decisions it is above all important to know what uncertainties exist, how great they are, and whether in practical terms they can be reduced. The magnitude of a risk refers both to the size of the differences between the possible outcomes and to the likelihood of the various outcomes.

Uncertainties are caused to a large extent by natural variability, imperfect information and our inability to precisely model complex realities. This makes it impossible to predict what the future will bring. Several important examples are listed below.

Uncertainty about extreme weather

It is impossible in practical terms to predict how high the highest water level at a specific location will be over the coming year. At most, we can indicate the probability that a particular water level will be reached or exceeded (figure 3.1). This probability can be determined by statistical analysis of past annual peak water levels. We do not however have sufficiently long series of measurements to precisely describe the natural variability in the water level. Only limited series are available, covering perhaps a hundred years. We therefore have to extrapolate a long way to draw any conclusion about the seawater level with an exceedance probability of, say, 1/10,000 per year. Such extrapolations are necessarily surrounded by uncertainty. Furthermore, model calculations are needed to translate data on discharge rates into high water levels along a river. The models can approximate reality, but never reflect it perfectly. Again, this introduces uncertainty. The uncertainty associated with extreme water levels therefore has several causes.

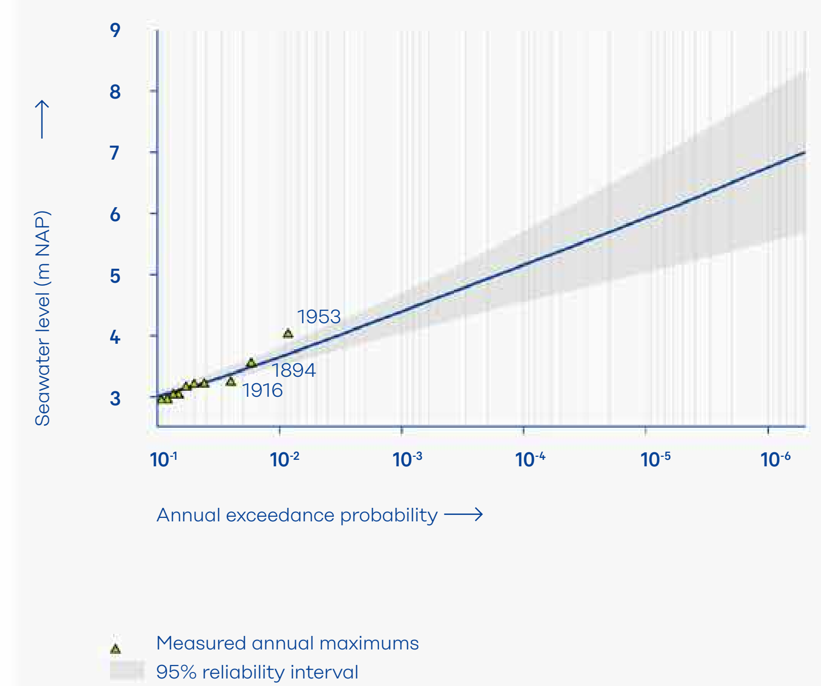


Figure 3.1 The annual probability that a certain water level will be exceeded.

Uncertainty about the strength of flood defences

In practice, the actual strength of hydraulic structures, dunes and levees is uncertain. A levee's capacity to withstand extreme water levels is for example determined to an important degree by the uncertain properties of the subsurface. The natural subsurface beneath a levee varies from one point to another. The soil consists of various layers, such as Pleistocene sand and river deposits (an example is shown in figure 3.2). Although this layered structure and the properties of the subsurface can in theory be precisely determined in all places, they remain uncertain until they have actually been measured. And even if they have been measured, they remain uncertain to some extent because of measurement uncertainties.

Our knowledge of the subsurface is based on measurements from boreholes and cone penetration tests, for example. Measurements are often taken dozens or even hundreds of metres apart. The properties of the subsurface are fairly well known at the point where the cone penetration test was performed, but they remain uncertain in between. This uncertainty is greater, the further the distance to the nearest coring or sounding location.

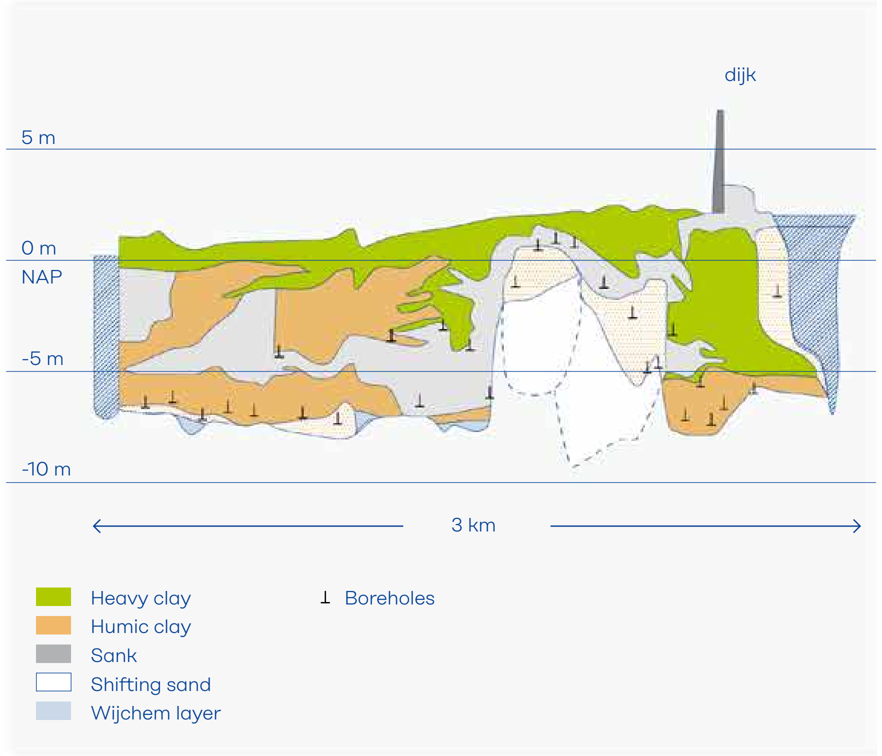


Figure 3.2 Diagram showing the stratigraphy identified by borehole surveys and cone penetration tests. Between the boreholes and test sites, the precise stratigraphy is uncertain.

Model uncertainty

Models are always a simplification of a complex reality. The outcomes of model calculations are therefore always surrounded by uncertainty. Figure 3.3 illustrates the relationship between river discharge and water level. It shows that the level calculated can differ from the level measured.

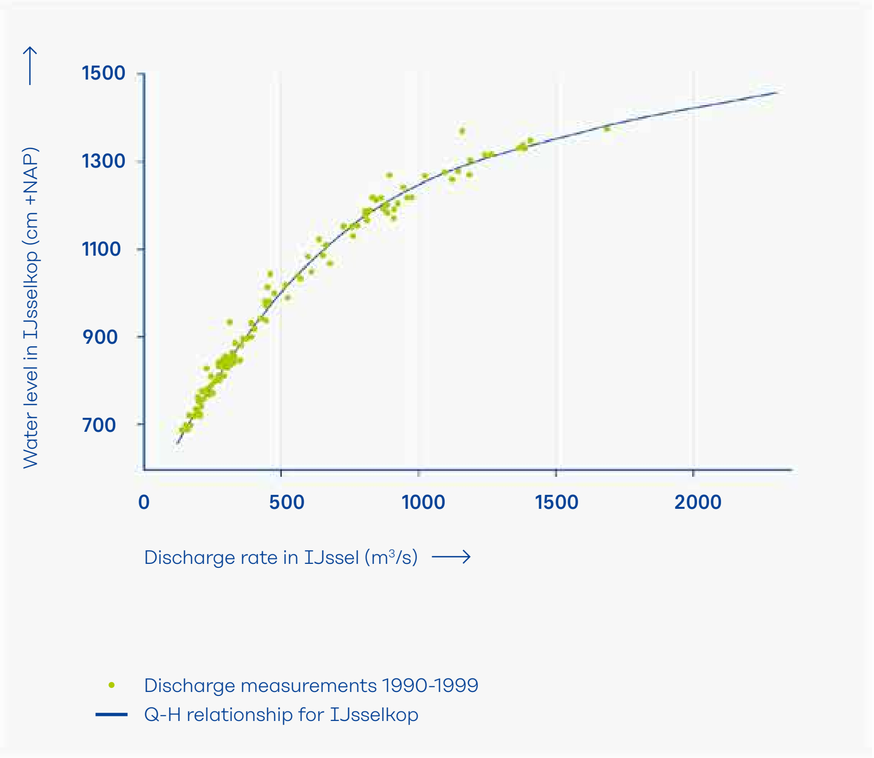


Figure 3.3 Illustration of model uncertainty: the uncertain relationship between river discharge and water level.

Uncertainty about the consequences of flooding

The consequences of flooding depend on many uncertain factors, such as the location of levee breaches, how the breach develops and the rate at which the water spreads through the affected area. The vulnerability of the people, buildings and infrastructure in the area is also uncertain, as is the impact of a flood outside the area directly affected, in terms of accommodating evacuees, for example, and the broader economic impact of the flood.

Even when extensive preparations have been made, it is uncertain whether the alarm will be raised in time, whether action will be taken in good time and whether the response will proceed according to plan. In practice, it often remains very uncertain whether emergency measures will be successful. During the storm surge of 1953 the region around Rotterdam narrowly escaped flooding, even though the Schielandse Zeedijk levee breached. Skipper Evergroen managed to sail his barge *De Twee Gebroeders* into the breach, allowing the hole in the levee to be repaired. It is difficult to imagine how this emergency action could have succeeded. If it had not, however, the damage and suffering in this area would have been immense, as the Schielandse Zeedijk protects several densely populated polders, the lowest-lying in the country.

De Twee Gebroeders barge in the breach in the Schielandse Zeedijk sea levee.

3.2 Probability

Since the standards for flood defences are defined in terms of the probability of flooding, the concept of probability plays a key role in Dutch flood risk management policy. Different views exist as to the meaning of probability. Two of the most important are the frequentist and the Bayesian interpretations (the latter named after Thomas Bayes, 1702-1761). In both, probability is a figure between 0 and 1. A value close to 0 corresponds with a small likelihood, and a value close to 1 with a large likelihood. There are however important differences between frequentist and Bayesian interpretations, which can easily give rise to confusion and misunderstanding as to the practical significance of flood probability standards.

3.2.1 Frequentist and Bayesian interpretations

According to the frequentist interpretation, a probability is the average number of times that a certain result is obtained in a long series of identical independent experiments. In this view, a probability is thus a relative frequency. The classic example concerns the throwing of a dice. There are six possible outcomes. By throwing the dice many times one finds that the probability of each outcome is 1/6. Determining the relative frequency of high water levels is more complex, however, because of the uncertainty due to lack of knowledge. The relative frequency of a particular high water level cannot therefore be determined with certainty. The probability of flooding itself is therefore uncertain according to the frequentist interpretation. It then becomes impossible to conclude with certainty whether the probability of flooding is lower than a particular standard. At most, one can determine the probability that a standard will be met.

According to the Bayesian interpretation, the probability of flooding is a measure of the likelihood that a flood will occur, given the knowledge at our disposal. The difference between inherent and knowledge uncertainty is irrelevant in the Bayesian interpretation, according to which the probability that a flood will occur is not uncertain; the probability is a measure of uncertainty. The probability is no longer, therefore, a physical property but a subjective 'degree of belief'. According to the Bayesian interpretation, a person can give only one answer to the question of whether the probability of flooding is lower than the standard. However, the probability estimates of different people can differ. In practice, such differences can be overcome by exchanging data, second opinions and the establishment of best practice.

3.2.2 Application in flood protection

When it comes to determining whether an adequate level of safety has been achieved, it does not in practice matter whether the uncertainty about the flood defence capacity of a levee is the result of inherent uncertainty or uncertainty due to lack of knowledge. The Bayesian interpretation has therefore been chosen as a basis for the risk analysis on which the standards and instruments for the design and statutory assessment of flood defences are based. This is in line with the approach used for years – both nationally and internationally – in the context of the Eurocodes for the design of buildings and infrastructure (see box in section 5.5.2).

The decision to use a Bayesian interpretation has a number of important practical consequences. The uncertainties arising from data constraints and lack of knowledge, for example, are expressed in the calculated

Flooding in the Sava river basin, Serbia, Obranovac 2014.

Flooding in the Chao Phraya river basin, Thailand 2011.

probability of flooding. This means that data collection and further investigation lead to a change in *the* (in fact *our*) probability of flooding. If the probability of flooding were regarded as a property of a flood defence system, this would of course be impossible. The probability of flooding is not an easily definable property of a flood defence structure, like its height, but a judgment based on knowledge of the structure. The probability of flooding is therefore also a measure of our uncertainty, as the probability depends on the knowledge and information available to us. For instance, our uncertainty about the flood defence capacity of a new dam, for example, declines dramatically once the reservoir has been filled. After it has been filled, we judge the probability of a breach to be considerably smaller as it is now successfully retaining a large body of water, though the properties of the dam have not changed at all.

This also means that a flood probability is not the same as the probability that a particular water level will be exceeded, leading to flooding. This would only be the case if we were able to know at exactly what water level the flood defence will breach. This is however uncertain in practice, because of our lack of knowledge about the subsurface, for example. As a result of this uncertainty there is a chance that the flood defences will breach even at a relatively low water level, but it is also possible that this will not happen until the water level is relatively high.

3.3 Risk

There are many different definitions of risk. In hydraulic engineering, flood risk is a concept that concerns both the possible impact of flooding and the probability that it will occur. It indicates the consequences, and also the probability of these consequences. Risk is often expressed as probability x economic damage. Risk is more than that, however. Flood risk can also be expressed in terms of other risk measures, such as societal risk (the probability that a large group of people will lose their lives) and individual risk (the probability that an individual will die). Which risk measure is preferable depends on the factors that determine how serious an imminent event is perceived to be. The Dutch approach considers three measures of risk: the annual expected damage, the individual risk and the societal risk.

A clear idea of flood risks and the extent to which measures can be taken to reduce them can support decision-making on flood risk management. Levee reinforcements, providing extra room for rivers, spatial interventions and crisis management and public readiness measures all impact on flood risk, albeit in different ways. By showing the impact of such diverse measures on the flood risk, it is possible to make consistent and comparable decisions. Which individual measures or combinations of measures are ultimately the most appropriate will not only depend on the effect on the flood risk, but also on the costs, and any benefits apart from flood risk management.

Flood risk can help with decisions as to whether the level of safety provided is adequate: whether it is an *acceptable risk*, in other words. The first Delta Commission assessed the acceptability of flood risks on the basis of cost-benefit analysis (economic risk). The Technical Advisory Committee on Flood Defences (the forerunner of the Expertise Network for Flood Protection) proposed that the resulting societal risk and individual risk also be used as criteria when assessing acceptability. All three types of risk played a key role in determining the flood probability standards (see also chapter 4).

Economic risk

Economic risk concerns the cost of risk bearing, expressed in euros, or in euros per year. In cost-benefit analyses economic risk is often equated with the annual expected value of the damage, the product of probability and damage. The idea behind this is that the government can efficiently spread the cost of any damage among all residents of the Netherlands. If this does not happen and everyone has to bear the cost of the damage they themselves sustain, the cost of risk bearing will often exceed the annual expected value of losses.

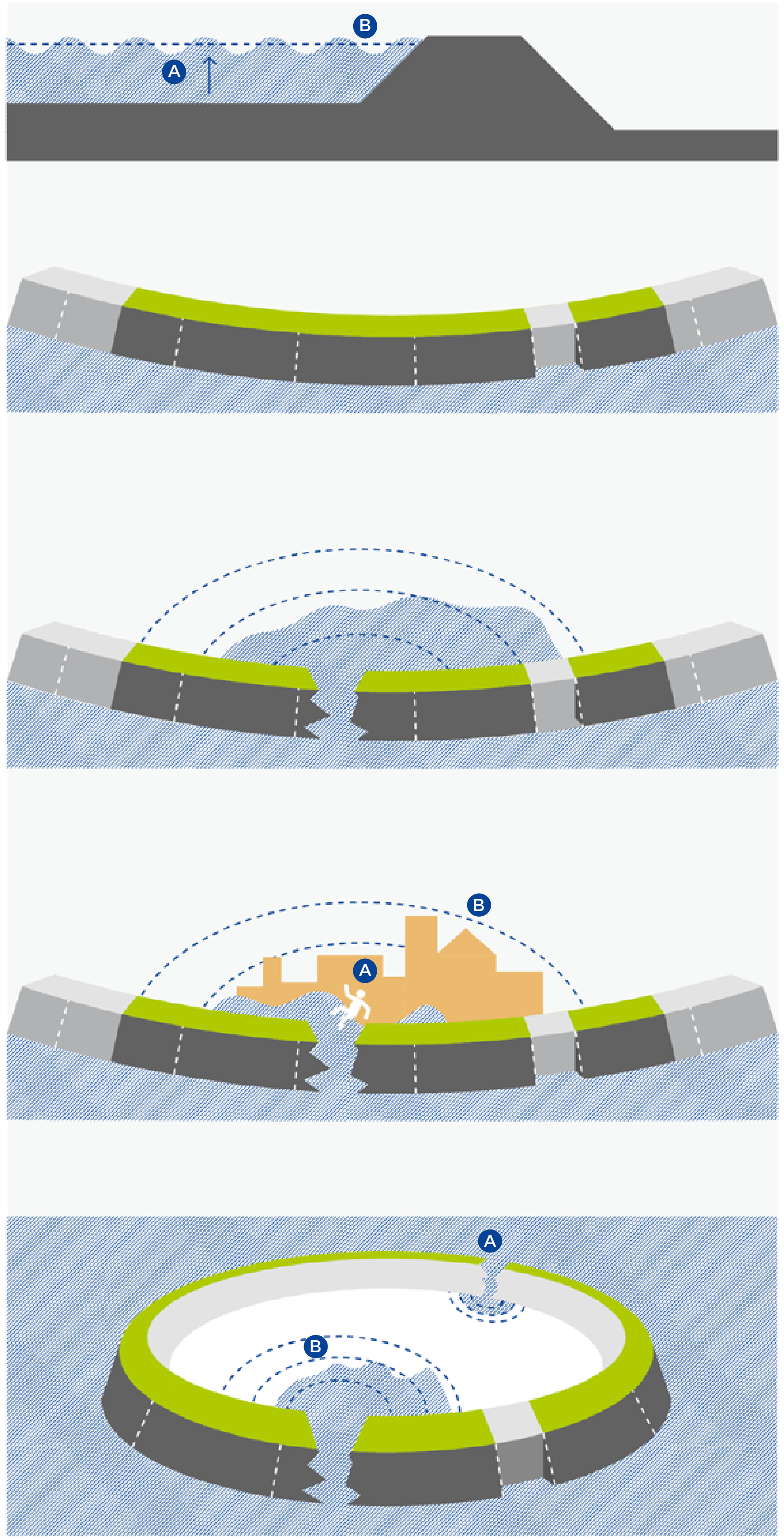
Societal risk

Societal risk is a measure of risk that provides an insight into the likelihood that there will be large numbers of casualties. This is important because disasters that cost many lives lead to great unrest and make people feel unsafe. A road accident with 20 casualties can dominate the news for days. This is not however true of the many accidents involving only a single casualty.

Individual risk

Economic risk and societal risk, and cost-benefit analyses, relate to population-wide risk. They do not provide any insight into the risks that individuals face, despite the fact that this is a factor in our assessment of the acceptability of risk. The local individual risk (LIR) is a measure of risk which expresses the probability that a person permanently present at a particular location will die as a result of flooding, taking account of the potential for evacuation. Setting a limit for local individual risk provides everyone in the Netherlands in regions protected by levees with a basic level of protection.

Figure 3.4 Numbers of casualties at different locations in the 1953 flood disaster.



01. Loads
A. Water level load
B. Wave load

02. Probability of flooding
The probability of failure in various parts of a flood defence.

03. Flood scenario
Depends on the rate at which the breach develops, the hydraulic roughness of the landscape and the stability of linear elements such as roads and regional defences.

04. Consequences
A. Number of casualties
B. Economic damage

05. Risk
Probability x impact = risk, for example:
A. High probability, low impact
B. Low probability, high impact

Figure 3.5 Steps in calculating flood risk.

3.4 Calculating flood risk

The probability that a flood defence structure will fail is determined by the probability of a particular load and the probability that the structure will not be able to withstand this load. A flood can occur in an almost endless variety of ways, depending on factors like the conditions in which it occurs, the location of levee breaches and the stability of linear elements in the landscape such as raised roads and railway lines. The impact of a flood depends on the vulnerability of the area affected and the decisions taken by members of the public and the authorities as the threat of flooding increases. The success of any preventive evacuation depends to a great extent on the time available and the conditions in which the evacuation must take place. Evacuation can reduce the number of victims, but traffic chaos in a low-lying polder could in fact cause many casualties in a flood. All these factors are uncertain, and we can only consider them in terms of probabilities. Combining all the possible effects (consequences) with their probabilities gives us a complete picture of the flood risk.

Calculating flood risk involves a number of steps (see figure 3.5):

01
Load

Determine the probability distributions of the loads to which different parts of the flood defences are subject. Different types of load can be significant, including water level or wave load, and also earthquake load, traffic load and the load of the structure's own weight. Consider the possibility that different loads might occur simultaneously.

02
Probability of flooding

For all possible loads, determine the probability that the defences will lose their water retaining capacity at one or more places, allowing flooding to occur. Take account of dependencies. Different parts of the flood defences are subject to the load cause by a high water level at the same time, which means there is a relatively high probability that they will breach simultaneously in the event of an extremely high water level.

03
Flood scenario

Determine the likely progress of any flooding that might occur. This is also known as a flood scenario. The scenario shows how the flood will propagate through the affected area, depending on the location of the breach, the rate at which it grows, the hydraulic roughness of the landscape and the stability of linear elements such as roads and regional flood defences. All these factors are uncertain. This uncertainty can be taken into account by assigning probabilities to the different scenarios.

The flood scenarios are regarded as a model for all possible ways in which a flood might occur. The sum of scenario probabilities is equal to the probability of flooding: the probability that something will go wrong somewhere, somehow. In general, a more precise picture of flood risk can be assessed, the more scenarios are defined.

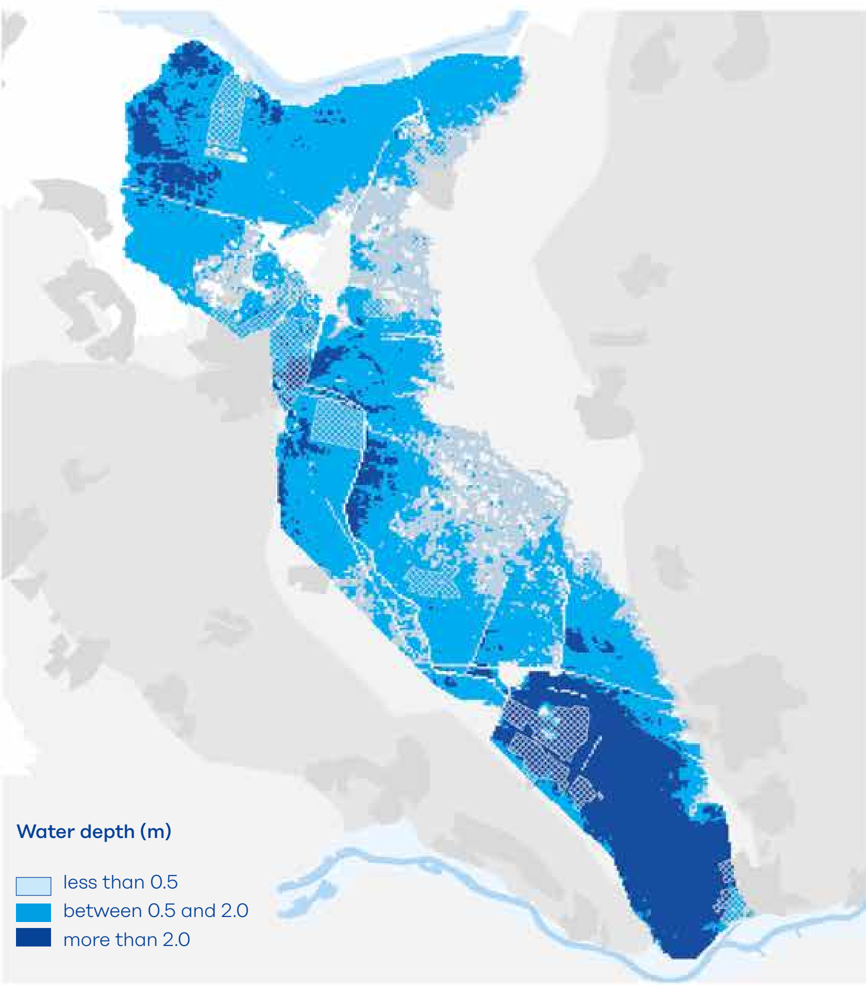


Figure 3.6 Example of a calculated flood pattern (Gelderse Vallei flooded by the river Lek).

04
Consequences

Determine the consequences in each flood scenario by combining the characteristics of the flood, such as the maximum water depths and the maximum rate of flow and water rise in the affected area, with data on the people and vulnerable objects present there. The number of casualties and, to a lesser extent, the damage, will depend on how far in advance the threat of flooding becomes apparent, whether a timely decision to evacuate is taken and whether the evacuation goes according to plan. Uncertainty concerning these factors can be accounted for in risk analyses by assigning probabilities to the various possible outcomes of evacuation.

05
Risk

Combine the probabilities of flooding with the consequences to obtain a picture of the risk. This can be done in various ways. First multiplying the probability of each scenario by the associated damage and adding together the outcomes gives an expected value of damage throughout the area. Performing this same calculation for smaller areas gives a spatial image of the expected value of damage. The probability that an individual will die as a result of flooding can be calculated in the same way. The local individual risk can be obtained by factoring into this calculation the probability that an individual is present in the area and has not been evacuated. To calculate the societal risk, the casualty numbers for each scenario must be ranked from low to high before calculating the cumulative sum of scenario probabilities. This gives the cumulative probability for each number of casualties. These values can then be expressed as a societal risk curve (FN curve).

A. Terp
B. Old levee
C. Railway line
D. Urban area
E. Industrial site
F. Farmland
G. Roads

Figure 3.7 The different elements that determine the scale of the impact of a flood.

04

From risk to standard

pp. 45—66

The Water Act that came into force on 1 January 2017 sets out new standards for primary flood defences. *This chapter explains how these standards have been defined, and what they mean.*

4.1 Acceptable risk

As we have said, the Netherlands has an extensive system of flood defences that protect people and property from flooding. Given the uncertainty as to the strength of and load on these defences, there is always a risk of flooding. The question is what level of risk is acceptable. This depends among other things on the cost of reducing the risk.

The risk of flooding can be managed in several ways. Firstly, the probability of flooding can be reduced by reinforcing flood defences or reducing the load, by widening the river, for example. Secondly, the scale of damage and the number of casualties can be influenced through spatial planning: not building in low-lying areas, for example. Thirdly, the consequences can be limited by ensuring there are good options for evacuation and crisis management.

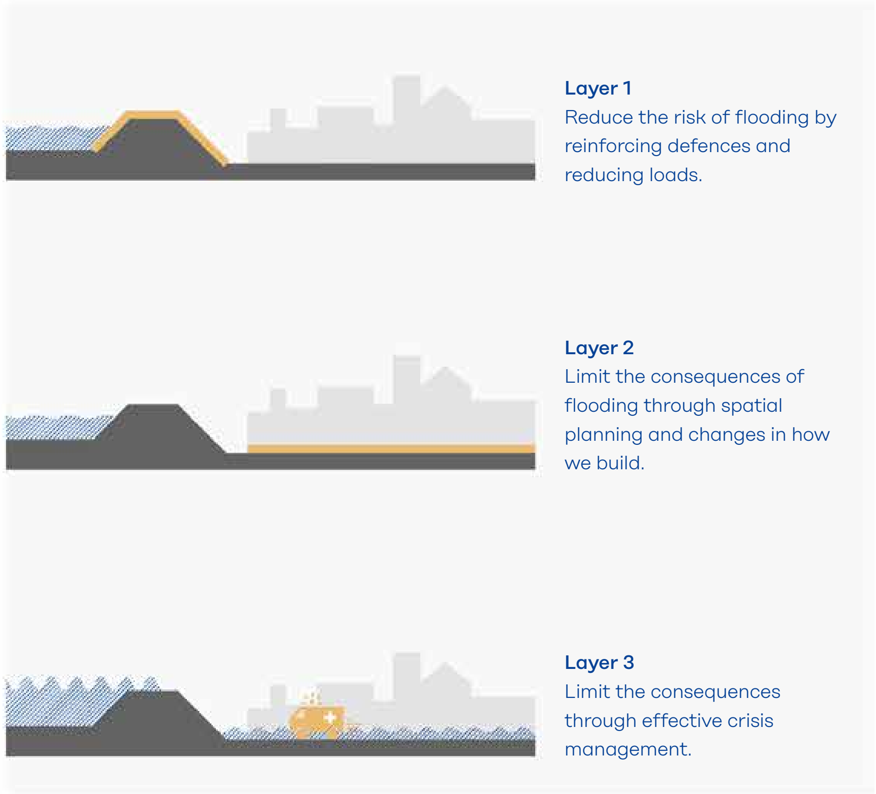


Figure 4.1 The different layers of safety.

Prompted by its history of flooding and by growing population pressure, the Netherlands decided many years ago to focus on preventing flooding by building flood defences. This does not however mean that there is no point in taking measures to limit the consequences; in the long term, a strategic decision to prevent an increase in the consequences of flooding could prove wise. However, in the Netherlands the most efficient way of reducing flood risk is almost always to reduce the probability of flooding. That is why the country has an extensive system of flood defences which are governed by legislation.

The standards in the Water Act are based on the flood risk deemed acceptable for areas protected by the primary flood defences. The standards for these areas are based on two principles:

A. Everyone should be able to rely on the same minimum level of protection: the basic level of protection, expressed as local individual risk (LIR).
B. Where the impact of flooding would be very high, a lower probability of flooding is appropriate, based on societal risk and a social cost-benefit analysis (SCBA).

[3] The Water Act does not stipulate any requirements concerning protection from flooding in unembanked areas.

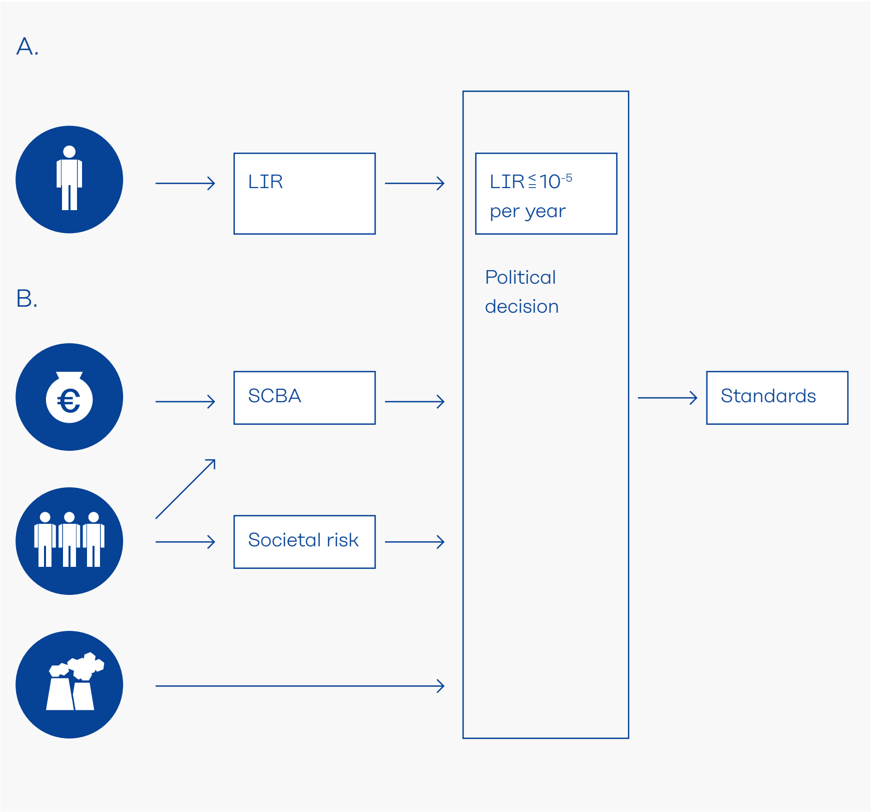


Figure 4.2 The principles underpinning the flood probability standards for primary flood defences.

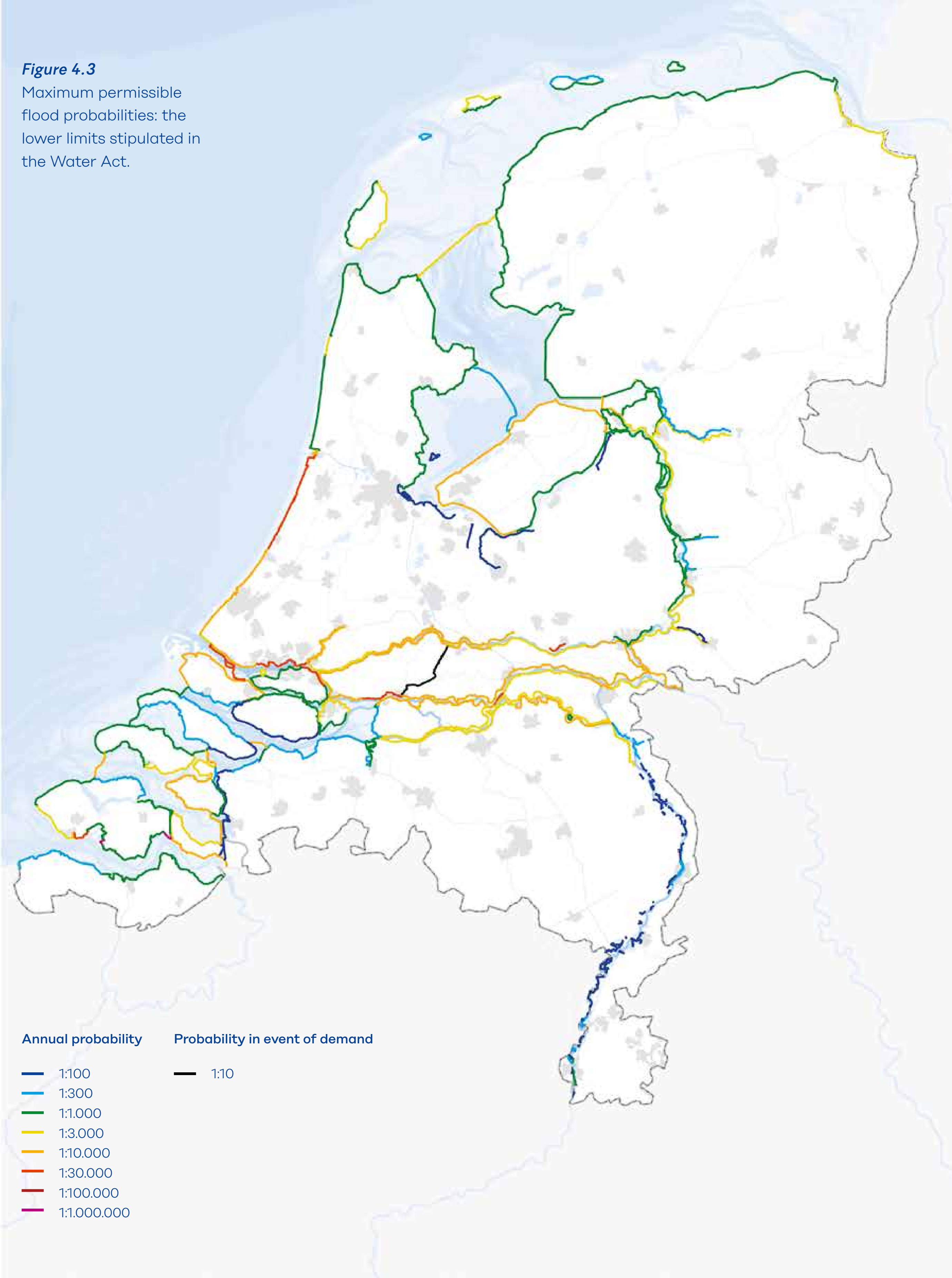


Figure 4.3
Maximum permissible flood probabilities: the lower limits stipulated in the Water Act.

Roughly speaking, the greater the potential consequences, the more stringent the standard. Major consequences can involve large numbers of casualties or economic damage on a large scale. The consequences can also be regarded as major if the flooding of certain objects such as Borssele nuclear power plant causes great social disruption.

The standards for levee segments range from 1/1000 to 1/1,000,000 a year. These standards give an almost equal risk in all parts of the Netherlands that are liable to flood.

The flood probability standards apply to levee segments. These are parts of the original levee systems. They have been defined on the basis of the area liable to flood and the scale of the damage. The dimensions of a flood defence structure are determined both by the standard and by the length of the segment. A total of 234 levee segments have been defined, ranging in length from 0.2 to 47 kilometres, with an average length of 15 kilometres. Each segment is defined in the Water Act using the national coordinates denoting where it starts and ends, and a map.

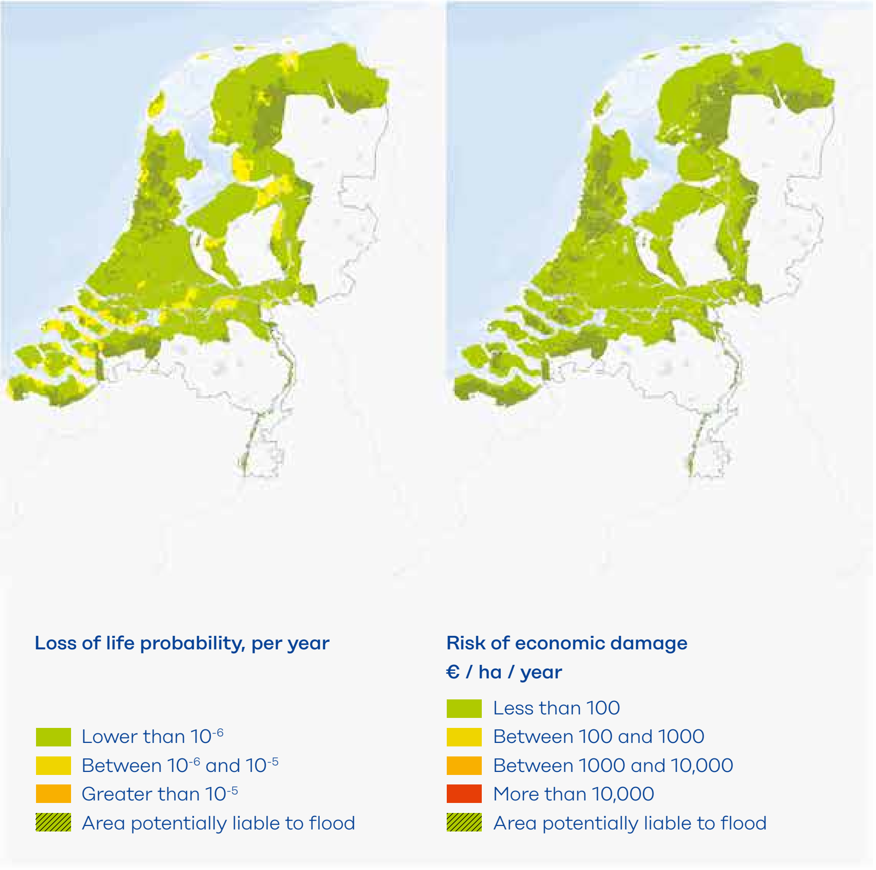


Figure 4.4
Local individual risk and economic damage if all flood defences comply with the requirements of the Water Act.

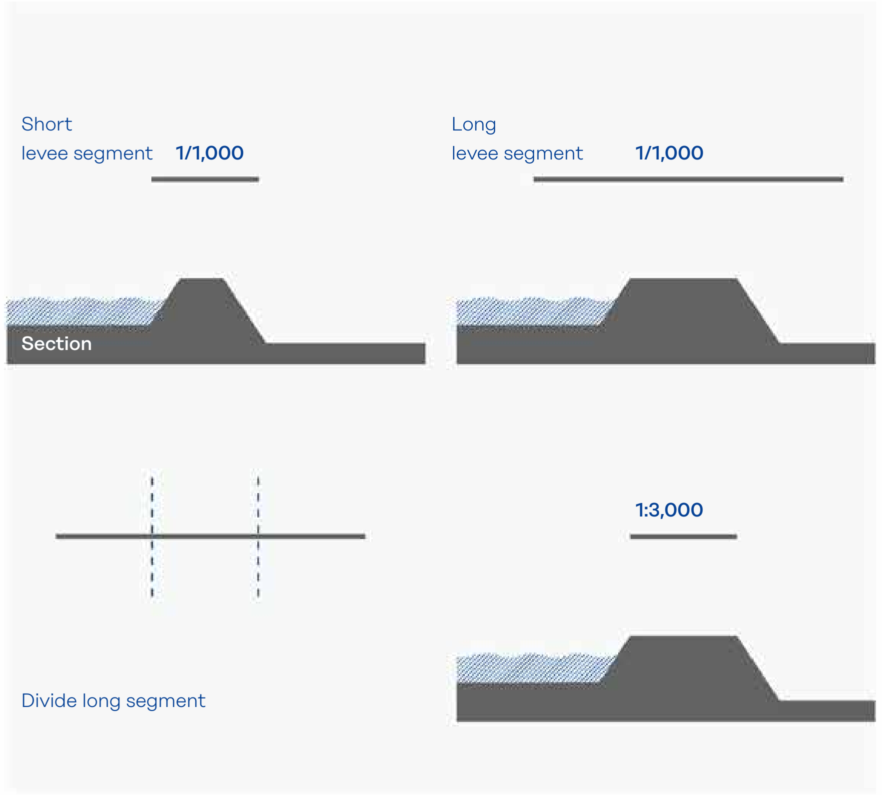


Figure 4.5 Schematic representation of the relationship between the length of a levee segment, the standard and the profile. A long levee segment subject to the same standard as a short segment will have a larger profile. Dividing the longer defence structure into a number of shorter segments means they will be subject to a more stringent requirement, though the profile will not change. Making the segments all more or less the same length improves the relationship between the level of the standard and the profile. NB: this applies only to the strength mechanisms.

4.2 Deriving standards

Standards are the result of a political process based on the results of risk calculations and a cost-benefit analysis. In many cases the results have been adopted, with due consideration of the uncertainty associated with the input.

4.2.1 Flooding in the Water Act

The Water Act sets out standards for the probability of flooding. But what exactly is meant by flooding? The Water Act applies to the primary flood defences along outer waters, not to the regional system. However, an influx from the outer waters will not always lead to flooding within the meaning of the Water Act. The failure of a lock gate that is part of a primary flood defence structure need not necessarily lead to substantial damage if the water can be accommodated in the water system behind the structure.

There are many different types of floods, with a huge range of consequences. In theory, different requirements could be set for different flood scenarios, depending on their likely consequences. But the Water Act

stipulates a single maximum permissible probability of flooding for each segment. This probability of flooding is defined as 'the probability of the loss of flood defence capacity in a levee segment causing the area protected by the levee segment to flood in such a way that fatalities or substantial economic damage occur' (section 1.1). Substantial economic damage is not defined because this depends on the local situation. In practice, the following criterion can be applied: if the average water depth in an area or neighbourhood with a single four-digit postcode (based on Statistic Netherlands' district and neighbourhood map) remains below 0.2 metres, flooding has not occurred. This criterion is based on experience, which shows that casualties and large-scale damage do not occur until local water depths exceed approx. 0.2 metres. It is possible to deviate from this general principle in specific situations, provided arguments can be presented in support of the decision.

4.2.2 Basic level of protection

To offer everyone the same minimum level of protection, it has been decided that the local individual risk (LIR) may not exceed 1/100,000 per year. The LIR is the probability that an individual will die somewhere as the result of flooding, and can be calculated as follows for each location:

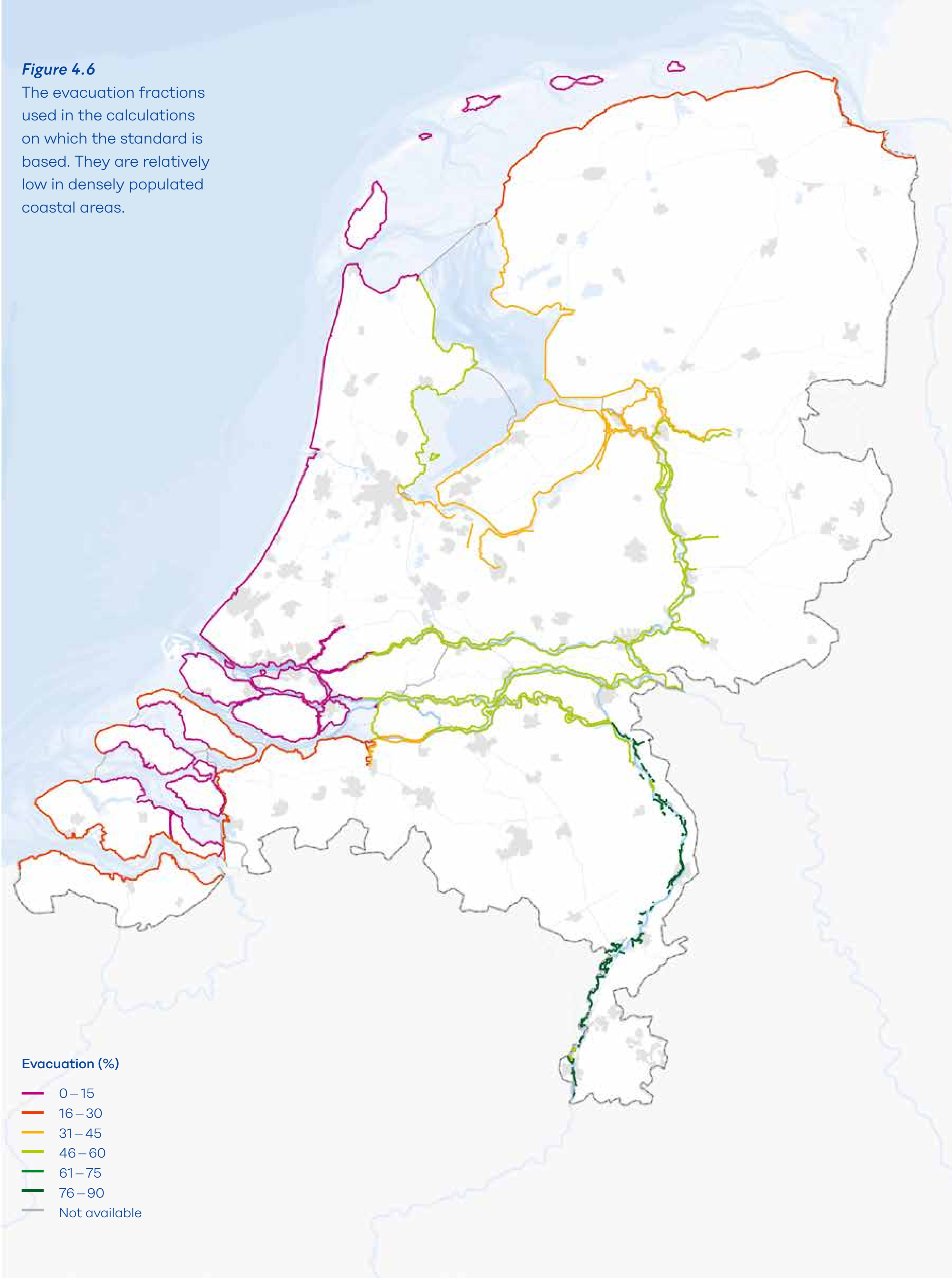
LIR = probability of flooding x mortality x (1- evacuation fraction)

Where mortality is the probability of dying in the event of a flood evacuation fraction is the proportion of the population which, on average, is evacuated from the threatened area before a flood occurs.

The required LIR of 1/100,000 per year can be translated into a maximum permissible probability of flooding if mortality and the evacuation fraction are known. The rate of rise and the maximum water depth are the main factors determining mortality. An evacuation fraction of 0.35, or 35%, means that 35% of people are out of the area before the flood (in other words: the probability that any resident has left the area prior to a flood is 0.35).

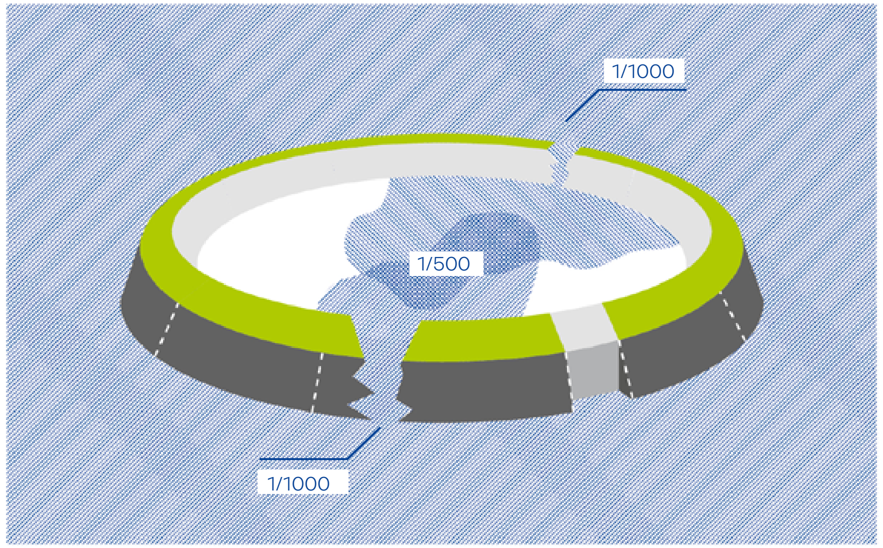
Mortality varies from place to place in the area liable to flood. The average mortality on the scale of neighbourhoods was considered when determining the required probability of flooding. A neighbourhood is an area with a single four-digit postcode (based on Statistics Netherlands' district and neighbourhood map). The neighbourhood at most risk in the flooded area determines the requirement applying to the levee segment. An area may be affected by flooding through several segments (see figure 4.7). This was taken into account when the standards for the probability of flooding were derived for the flood defences.

Figure 4.6
The evacuation fractions used in the calculations on which the standard is based. They are relatively low in densely populated coastal areas.



Leaving the area is referred to as 'horizontal evacuation' (in contrast to 'vertical evacuation', whereby people seek a safe higher place in the flooded area). The success of horizontal evacuation depends on the amount of warning, the distance to safety and the available road capacity. Since it is not possible to know beforehand how exactly the threat and the evacuation will proceed, evacuation fractions have been determined for several scenarios with varying warning times and degrees of success. One scenario that is always included is an unexpected flood with no possibility of evacuation. Expected values and bandwidths are derived from this range of evacuation fractions, and used to determine the standards.

Figure 4.7
If an area can be flooded through different levee segments, the probability that the area will be hit by flooding is greater than the probability of flooding from one of the individual segments.



Relationship between basic level of protection and probability of flooding

The loss of life probability in the event of a flood is based on flood calculations. Historical data show that the probability is around 0.01, but can increase to 0.1 in small, deep-lying polders that fill quickly in the event of a breach. A successful evacuation reduces the probability of loss of life:

*LIR = P flood * mortality * (1- evacuation fraction)*

Here, P flood stands for the probability of flooding. This means that the permissible probability of flooding compatible with the LIR of 10^{-5} per year depends on the probability of a successful evacuation and on mortality:

*P flood = 10^{-5} / mortality * (1- evacuation fraction)*

The table below shows several values of P flood at different mortality and evacuation fraction values.

Mortality		Evacuation fraction = 0	Evacuation fraction = 0.90
0.1	(small deep polders)	10^{-4}	10^{-3}
0.01	(large deep polders)	10^{-3}	10^{-2}
0.001	(shallow polders)	10^{-2}	10^{-1}

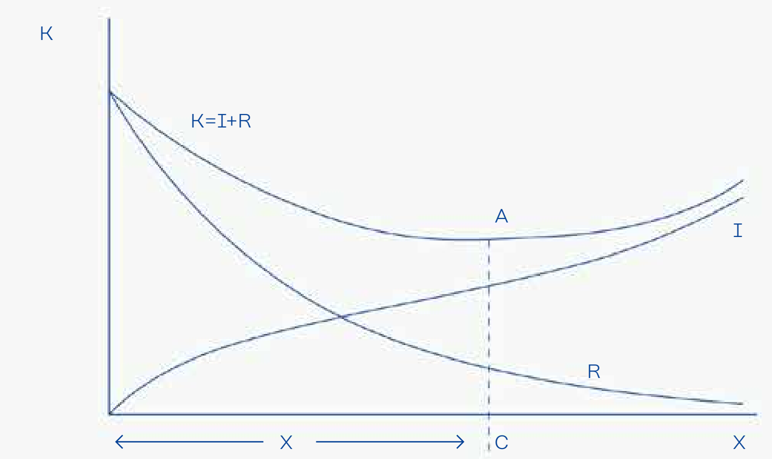
The table shows that the maximum permissible flood probabilities based on the basic level of protection are particularly stringent for deep polders. The basic level of protection determines the standard for around a third of the levee segments.

4.2.3 Cost-benefit analysis

A social cost-benefit analysis (SCBA) was performed to weigh the consequences of flooding against the costs of reducing the probability of flooding. This determined the optimum point, from an economic perspective, at which the flood defences should be reinforced, and on what scale. The optimum investment strategy is the strategy whereby the present value of the investment costs plus the economic risk is at a minimum. The calculation included various forms of non-material damage, including loss of human life, by expressing them in monetary terms.

The principle of cost-benefit analysis

More investment in the reliability of flood defences reduces the flood risk. The investments and the risk are the total costs to society. Minimising the total costs allows the optimum reliability of the flood defences to be identified. This principle was first put into practice by the original Delta Commission, and is schematically represented in the figure below.



K. Total costs
I. Investment costs
R. Risk costs

Figure 4.8 The basic principle of economic optimisation. The total costs (K) are equal to the investment costs (I) associated with improving reliability (here: heightening levees) plus the present value of the risk (R). The optimum lies at the point where the total costs (I+R) are lowest.

Coastal defences at Katwijk. Crest of levee hidden beneath sand visible thanks to basalt paving.

The *optimum* investment strategy is also associated with a certain progression in the probability of flooding over time. This takes the form of a sawtooth wave because the probability of flooding reduces immediately when a levee is reinforced, then gradually rises due to subsidence, increasing river discharge rates and sea-level rise. The scale of reinforcement (and thus the reduction in the probability of flooding after reinforcement) and the time until the next round of reinforcements are strongly influenced by the relationship between the fixed and variable costs of the exercise. If the fixed costs are relatively high, it is economically advisable to postpone a new intervention for as long as possible. If the fixed costs are relatively low, as they are along the sandy coastline, it makes more economic sense to make small interventions more frequently.

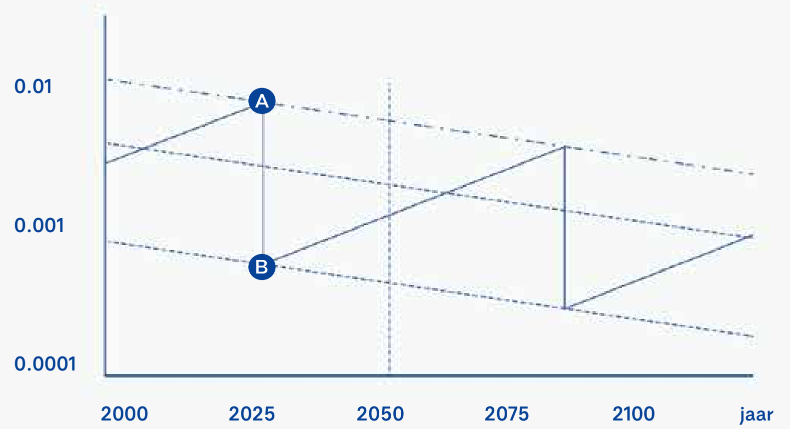


Figure 4.9 Trend in the probability of flooding when the optimum investment strategy is adopted.

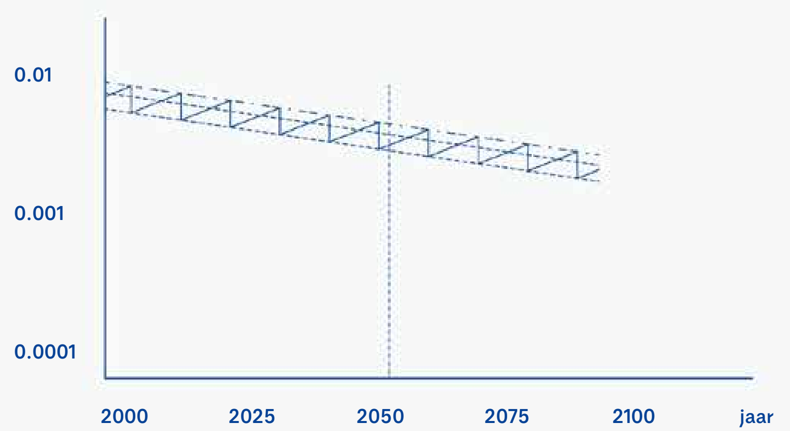


Figure 4.10 Trend in the probability of flooding when the optimum investment strategy is adopted if the fixed costs are relatively low: the time between investments is relatively short.

Since the consequences of flooding gradually become greater due to population growth and economic growth, from an economic point of view it makes sense to continually enhance the country's protection. The sawtooth pattern therefore shows a steady drop. The economically optimum probabilities of flooding are based on the results for 2050.

'Median probabilities' were calculated as part of the cost-benefit analysis: after this value is exceeded there is still sufficient time for measures such as levee reinforcement to be put into practice before the maximum permissible probability of flooding from an economic perspective has been reached. The median probability, which provides the basis for the 'alert value' in the legislation, varies from one levee segment to another, as does the maximum permissible probability of flooding.

Table 4.1 shows the parameters on which the SCBA was based. These values change over time, as a result of the discount rate, for example. This does not mean that the standards must immediately be altered, however. The principles on which the political decision concerning the standards is based, and the decision itself, are laid down in the Water Act. The periodic evaluation of the standards, once every twelve years in accordance with the Act, includes consideration of whether there is any reason to adjust the standards.

Everyone who lives in an area that floods will experience some form of harm as a result and is therefore referred to as a *victim*. The calculation of damage was based on an average sum of €12,500 per victim. This sum represents the non-material damage to the victim's property (loss of irreplaceable property such as mementoes) and the personal costs of evacuation (such as inconvenience and loss of income). The figure for the personal costs of evacuation is based on a survey of 'willingness to pay' and the assumption that an average one in five evacuees will actually become a victim. Since evacuations are a preventive measure, the number of evacuations exceeds the number of actual floods, and the number of

Table 4.1 Parameters for the SCBA which, together with the values for the basic level of protection, provide the basis for the standards. The standards are defined in the legislation and do not change in response to new insights concerning the parameters. However, the standard is periodically evaluated.

Parameter	Value
Discount rate	5.5% per year
Fatality	€ 6.7 million
Victim	€ 12,500
Year	2050
Economic growth	1.9% per year

evacuees is greater than the number of actual victims. Therefore, any changes to the standard of protection not only lead to a different probability of becoming a victim of flooding, but also to a different probability of being evacuated as a precaution – which may prove to have been unnecessary in hindsight.

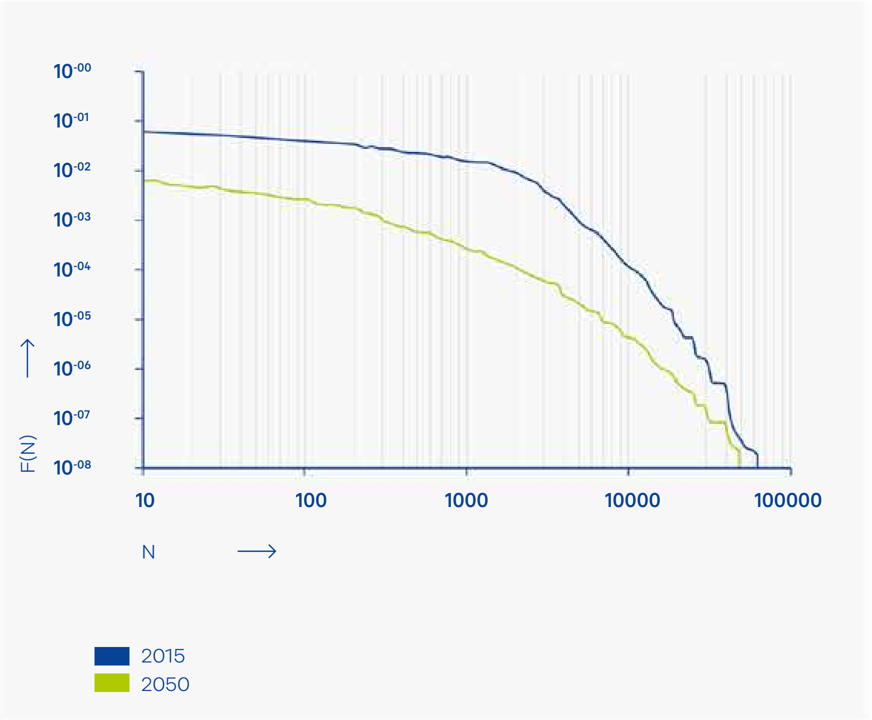
If the optimum probability of flooding resulting from the SCBA is smaller than that resulting from the basic level of protection, the SCBA probability will be used as the basis for the standard. Otherwise, the probability resulting from the basic level of protection serves as the basis.

4.2.4 Societal risk

The third factor underpinning the standard is societal risk (the probability of major loss of life). Assessment of the severity of societal risk is often based on a *risk-averse decision-making criterion*, which attaches increasing weight to greater numbers of casualties. A risk-averse decision-maker regards a risk as greater than would be expected on the basis of expected impact values.

Firstly, an assessment was conducted to ascertain whether the societal risk of flooding is restricted on an adequate scale at national level, because the total loss of life in the event of flooding is what counts, not the number of casualties per levee segment or location. The assessment was performed using an assessment framework developed by the forerunner of the ENW, the Technical Advisory Committee on Flood Defences. This framework gives ‘orientation values’ based on the potential benefits of different risks (such as climbing, smoking or living next to a factory) and the extent to which exposure is voluntary. Climbing is for example a voluntary risk, which means that a higher level of risk is acceptable than in the case of an involuntary risk. The calculated probabilities that there will be major loss of life can be compared with these values by showing them both in a graph. The societal risk is represented as an FN-curve, with the probability of N or more casualties. Figure 4.11 shows that if the flood defences comply with the new standards the probability of 10,000 casualties is approximately equal to 1/100,000 per year. A similar curve can also be produced for economic damage, in which case it is known as an FS-curve. The FN-curve lies within the bandwidth of the orientation values, leading to the conclusion that the standards for flood defences based on the SCBA and LIR provide a sufficiently low level of national societal risk.

Figure 4.11 Societal risk curve for the Netherlands. The horizontal axis shows the number of casualties and the vertical axis the probability that this number will be exceeded. The probability of at least 1000 casualties is currently 1/5000 per year, for example, according to the FN-curve.



The standards for six levee segments take into account the potential for relatively large numbers of casualties at these locations: segments 16-2 Alblasserwaard West, 14-2 Zuid-Holland Rotterdam Capelle, 16-1 Alblasserwaard Merwede, 19-1 Rozenburg, 20-3 Voorne-Putten Oost and 22-2 Eiland van Dordrecht Noord. These segments are all in the southwest of the country, in the transitional zone between major rivers and sea.

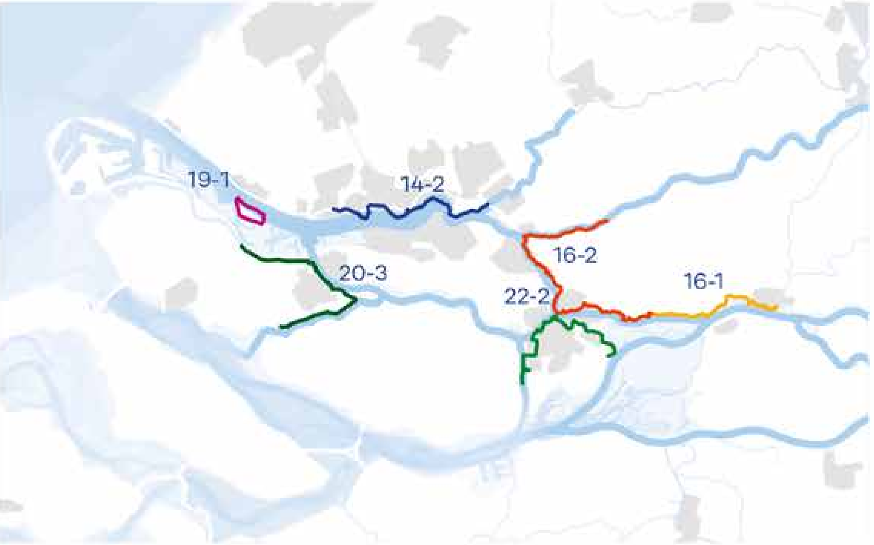


Figure 4.12 The six levee segments in the southwestern Netherlands where the standards reflect the large potential loss of life at these locations.

4.3 Standards for flood defences

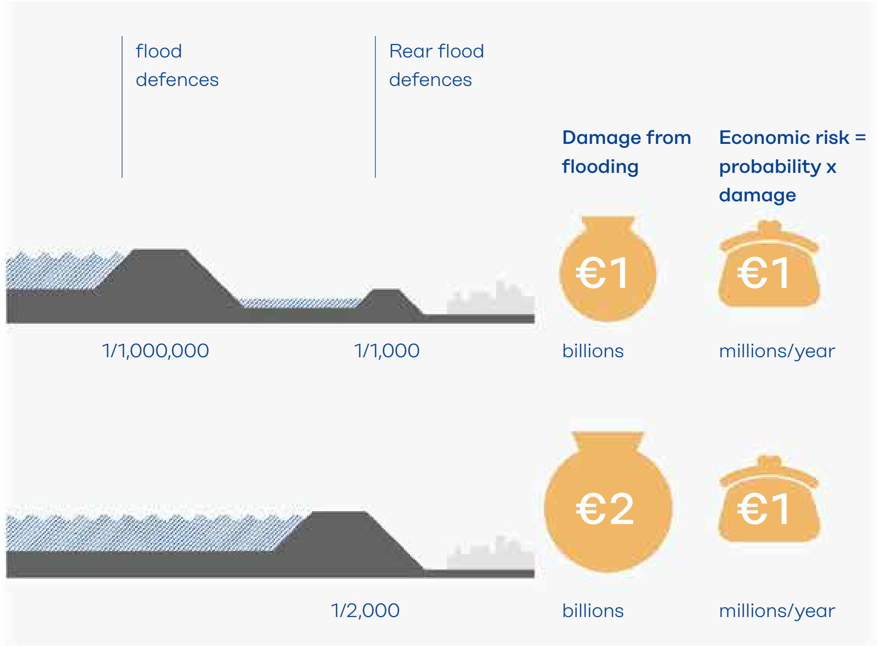
In several parts of the Netherlands protection from flooding is provided by a system of and rear flood defences (see also 2.2.2). Zuid-Holland province, for example, is protected by the Maeslantkering barrier which closes off the Nieuwe Waterweg in the event of high water levels at sea (flood defences) and by levees (rear flood defences). The areas around the IJsselmeer are protected by the Afsluitdijk causeway – a flood defence structure – in combination with the rear levees along the IJsselmeer itself.

The required level of reliability applying to a flood defence structure depends in part on the probability of extreme water levels occurring in the waters behind the levees. This probability determines the efforts required to comply with the flood probability standard applying in the hinterland. Where there is a system of and rear flood defences, therefore, flood risk can be reduced in two ways: by reinforcing either the flood defences or the rear flood defences. Ideally, the standards should apply to the entire system of and rear flood defences. This is a relatively complex matter, however, as an integrated cost-benefit analysis for the flood defences along the IJsselmeer shows. A simplified approach has therefore been adopted, whereby standards are first set for the flood defences and then for the rear flood defences.

The flood probability standards for the rear flood defences are based on the requirements for the flood defences applying in 2015. On this basis it was for example assumed that the Afsluitdijk causeway is so reliable that the effects of a breach or failure to close retaining structures would be negligible. Next, the requirements that the flood defences would have to meet to ensure that this assumption was valid were analysed. This was followed by an assessment of whether these requirements would place a disproportionately large burden on the flood defences. This was not found to be the case at any point.

A breach in a flood defence structure need not necessarily lead to immediate flooding. The Water Act does not therefore stipulate flood probability standards for flood defences. Instead, it defines required failure probabilities (see also section 4.4). Separate requirements have also been set for the probability that movable storm surge barriers will fail to close. Required failure probabilities per attempted closure make it simpler to assess the reliability of the closure process for these flood defences. In the case of other flood defences, management authorities and designers must derive required reliabilities for drainage facilities and locks, for example, from the failure probability standards in the Water Act.

Figure 4.13 Two solutions, with and without flood defences, which produce the same level of risk. Without flood defences the damage is greater because more water is able to enter the area.



Exceptional cases

Diefdijk

The Diefdijk levee is a compartmentalising flood defence structure which prevents water from flowing through the Alblasserwaard polder in the event of a levee breach upstream. Since this has a major impact on the flood risk, the Water Act specifies a separate requirement for the Diefdijk levee. This requirement is defined as the maximum permissible probability of flooding in the event of a load on this structure.

Flood defences along Volkerak-Zoommeer lake

Volkerak-Zoommeer lake has been designated a water retention area as part of the 'Room for the Rivers' programme. When actually used as such, the water level in the lake will be higher and the impact of any flood will be greater than if it were not used for water retention. When the standards were set a conservative assumption was made that in the event of flooding along Volkerak-Zoommeer lake, it would always be in use for water retention purposes. Nevertheless, this led to a standard for several segments with a probability of flooding that was relatively high in the event that the lake were being used to retain water. The Water Act therefore stipulates an additional requirement that the probability of flooding in the event of use for water retention may not exceed 1/10.

4.4 The different standards in the Water Act

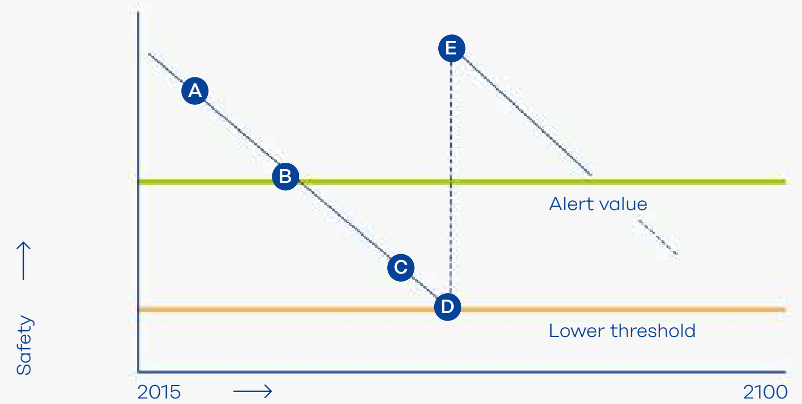
The Water Act stipulates different types of required reliability levels for flood defences:

- For segments providing direct protection from flooding the requirements are formulated in terms of probability of flooding. The probability of flooding is '*the probability of the loss of flood defence capacity in a levee segment causing the area protected by the levee segment to flood in such a way that fatalities or substantial economic damage occur*'.
- For flood defences such as the Afsluitdijk causeway, the requirements are formulated in terms of failure probabilities. In this context, failure probability is '*the probability of the loss of flood defence capacity in a levee segment causing a substantial increase in the hydraulic load on a rear levee segment*'.
- Additional requirements apply to the Ramspolkering, Hollandsche IJsselkering and Maeslantkering barriers and the Eastern Scheldt storm surge barrier in respect of the required failure probabilities per attempted closure.
- For the Diefdijk levee, a compartmentalising flood defence structure, the requirements have been formulated in terms of the probability of flooding in the event of a load on the levee.
- Additional requirements have been set for the flood defences along Volkerak-Zoommeer lake because of the possibility that it will be used for water retention purposes. These requirements have been formulated in terms of the probability of flooding in the event of use for water retention.

Two values are always specified for levee segments with a flood or failure probability, each of which has its own function:

1. Alert value. If the periodic statutory assessment finds that the probability of flooding for a levee segment exceeds this value, the Minister of Infrastructure and the Environment must be informed. Once the alert value has been reached, one of the conditions for subsidised measures has been met.
2. Lower threshold. This is the minimum probability of flooding or failure which the flood defence structure must be designed to prevent (article 2.2, paragraph 4 of Explanatory Memorandum). The lower threshold is the maximum permissible value for the probability of flooding or failure. Compliance with this value guarantees the basic level of protection.

Figure 4.14 The function of the alert value and lower threshold.



A. Safety declines due to increasing load as result of climate change and declining levee strength due to ageing.
B. Preparations for measures can commence as soon as alert value is reached.
C. Work on levee reinforcements commences.
D. Lower threshold
E. Safety level immediately after reinforcements.

One frequently asked question is: what is the annual probability that major flooding will occur in the Netherlands? It is not easy to give an answer. The individual probabilities applying to levee segments cannot simply be added together to determine the overall probability, because a very extreme natural event can impact on a large proportion of the Netherlands all at once. We can however say that the overall probability is greater than the highest probability of flooding for all levee segments. If we assume that the highest annual probability is 1/100, the annual probability of flooding occurring somewhere in the Netherlands is greater than 1/100.

The Water Act sets out various types of required reliabilities: probabilities of flooding, probabilities of failure, probabilities of flooding given a certain load and probabilities of flooding in the event of water retention. Methods of assessment and design are essentially the same for all these requirements. The following chapters refer only to flood probability standards in order not to complicate matters unnecessarily. The term probability of failure is used in this publication as a general indication of the probability of an extreme limit state being exceeded (this is not the definition used in the Water Act).

Old and new standards

It is not easy to say how stringent the old exceedance probability for each levee system was in comparison with the new flood probability standards based on levee segments because of the different definitions and spatial units used. The flood probability approach is based on the probability of a loss of *flood defence capacity* (resulting in flooding) and differs from the old safety philosophy based on the principle that the design water level must be safely withstood. The design rules in the old system were therefore largely based on criteria concerning the beginnings of levee failure, such as damage to the revetment.

In the 1960s the Delta Commission calculated an appropriate flood probability of 1/125,000 per year for levee system 14 Zuid-Holland, which was eventually translated into an annual exceedance probability for the water level of 1/10,000 per year. The flood defences were dimensioned in such a way that the probability of flooding was lower than 1/10,000 per year, possibly even in the region of 1/100,000 per year. The new maximum permissible probability of flooding for the segments in levee system 14 ranges from 1/3000 to 1/30,000 per year.

It is difficult to make a comparison, though it would appear that the requirements based on flood probability standards are in practice stricter for almost all segments than the old standards, mainly because the new standards explicitly take account of the length effect (see section 5.4). In the rivers area, the numerical standards are also much stricter.

The system based on exceedance probability standards for hydraulic structures and dunes, as laid down in the Hydraulic Structures Guidelines 2003 and the technical report on dune erosion, also strongly resembled the new system based on required failure probabilities. These requirements can be compared directly with the required failure probabilities associated with the new standards. The new requirements for dunes and flood defences consisting of hydraulic structures are the same or slightly less stringent.

05

From standards to technical requirements

pp. 67—90

How is it possible to assess whether a levee segment complies with a flood probability standard in the Water Act? This chapter considers this question. *Despite the complex subject matter, every effort has been made to make the text accessible to a wide readership, though some knowledge of statistical concepts is required.*

Waaldijk levee at Herwijnen.

5.1 Basic concepts used in reliability analysis

A required level of reliability imposes a maximum on the probability that a certain limit state will be exceeded within a certain period of time.

5.1.1 Limit states

A limit state is the transition between the desired situation, whereby the flood defences function properly, and a situation in which this is no longer the case. There are two types of limit state:

1. Ultimate limit state (ULS). The flood defence function of primary flood defences exceeds the ULS once there is a '*loss of flood defence capacity in a levee segment causing the area protected by the levee segment to flood in such a way that fatalities or substantial economic damage occur*' (Water Act, section 1, subsection 1). One example is flooding due to the breaching of a dune or levee when outer water levels are high. Another is flooding at relatively low outer water levels when the flood defence structure has been compromised by an earthquake or slide. NB: both the alert standard and the maximum permissible probability of flooding refer to the ultimate limit state of the flood defence function.
2. Serviceability limit state (SLS). This limit is reached when major deformation or damage occurs which, though it does not immediately lead to flooding, does necessitate measures. Examples are deformation of sheet piling causing buildings to be damaged, or damage to the revetment on a levee that does not cause the probability of flooding to exceed the required level.

5.1.2 Failure and breaching

Exceeding an ultimate limit state is also referred to as failure. Failure and breaching are not the same thing. Breaching refers to the loss of integrity or a major geometric change. A flood defence structure can fail without breaching. The water might for example overtop the structure, causing flooding, without a breach appearing in the structure. Conversely, a flood defence structure can breach without failing. Surface slide on the landside of a levee does not necessarily lead to flooding, for example. Of course repairs will need to be carried out, as such an event affects the structure's future flood defence capability.

5.1.3 Failure definition and residual strength

Models are used to assess the reliability of flood defences. Given the current state of the art, these sometimes reflect only some of the physical processes that ultimately lead flood defences to fail (= failure definition). The proportion of the strength overlooked in reliability analysis is referred to as the residual strength.

5.1.4 Reference period

A probability cannot be viewed in isolation from the period of time to which it refers. A probability of failure of 1/10,000 over a period of one year is not the same as a probability of failure of 1/10,000 over a period of 50 years. The time period to which a required failure probability refers is also known as the reference period.

The standards in the Water Act are based on a reference period of one year. This means that the probability of flooding must be sufficiently low in each individual year. Flood probabilities may not therefore be averaged out over periods longer than a year. This is an important difference from Eurocode NEN-EN1990 in which requirements refer to reference periods of 50 or 100 years. In that case, the failure probabilities per year may vary sharply, as long as the failure probability is sufficiently low over the entire reference period.

The reference period is not the same as the design working life of a new flood defence structure. If the required failure probability has been defined for a reference period of one year, the failure probability of the flood defence structure must be lower than the requirement in every contiguous period of one year throughout the structure's design working life.

5.2 Load and strength

In a reliability analysis the loads and strength properties, including uncertainties, are first analysed, and the loads and strength properties are then compared.

5.2.1 Load

The most important loads are generally the water pressure, the forces exerted on the flood defence by waves and the flow of water along, through or under the flood defence. A flood defence structure can also be subjected to loads as a result of traffic passing along a road on top of the structure, a collision or an earthquake. The relevant load properties can differ from one failure mechanism to another.

The loads at work on a flood defence structure set in motion all kinds of physical processes in the structure, such as stress and degradation. These changes are also known as load effects. One example of a load effect is the impact of high water levels on pore pressure in an earthen structure. A levee derives its stability from its shear strength, which in turn depends on the friction between the soil particles (the effective stress). Effective stress reduces as pore pressure increases, making the levee less stable. A similar phenomenon occurs in hydraulic structures, which derive their resistance to slide from friction, which reduces as a result of the upward pressure caused by high water levels.

The difference between a load and the associated effect is not always sharply defined. For example, a load effect can consist of a reduction in strength, such as the decline in the shear strength of soil caused by an earthquake.

The magnitude of a load on a flood defence over a particular period of time is uncertain. In practice, this uncertainty is caused to a great extent by the natural variability in sea levels, river discharge rates and wind speeds. But it also comes from a lack of knowledge, such as uncertainty about the unevenness of river beds and the relationship between wind speed and wave height. All these uncertainties together mean that, in practice, we can refer to load only in terms of probabilities (see also section 3.2). It is for example possible to determine a water level that (on average) will be exceeded only once every 100 years.

5.2.2 Strength

The strength of a flood defence structure is its capacity to resist the loads to which it is subjected. Examples of strength properties include the height of the flood defence and the friction angle in sandy levee material. The relevant strength properties may differ from one failure mechanism and load situation to another. The strength of a flood defence structure is rarely, if ever, precisely known. Uncertainty concerning strength can be expressed by assigning probabilities to the various potential strengths.

The strength of a structure is in principle determined using models for the purposes of design or assessment. These models are all to some extent based on simplifications. Some models simulate in detail the behaviour of the structure when subjected to a succession of loads, as in a computer programme that calculates the deformation of an earthen structure at every point in its profile. Empirical models and rules of thumb are also used, in which case no clear picture is given of the underlying physical processes. Other models describe the physics in simple terms, such as the Bishop model of slope failure. These models describe the essence of the physical process, but disregard a number of matters.

Which type of model is preferable will differ from one case to another. Generally speaking, a simple model will suffice at the start of the design process, and only later will a more refined model be needed. Empirical and simple physical models have the advantage that they are easy to use and the calculations easy to follow, though the model uncertainty is fairly high. If this uncertainty poses a problem, or the circumstances are too complex, then more advanced models may provide a solution. However, they often require detailed input. If this is not available, model uncertainty merely makes way for parameter uncertainty.

The input parameters of models are based on measurements and/or expert judgment. The uncertainties concerning inputs can be expressed in terms of probability by assigning to each parameter value a probability that indicates how likely it is that this value is the actual value. These probabilities can be adjusted on the basis of the observed behaviour of the flood defence structure. If, for example, a structure has withstood an extreme load, this might suggest that certain assumed unfavourable strength properties are less likely to apply than previously thought.

5.2.3 Relationship between load and strength

The relationship between the load on and the strength of a flood defence structure can be expressed by a limit state function. This function indicates for every possible combination of load and strength properties whether the structure will fail. A limit state function is often referred to as a Z-function. It has a negative value if the load is greater than the strength, so flood defence structure fails. The limit state function includes all dimensions, variables and parameters that express the strength of the structure and the load on the structure. In many cases the limit state function for a certain failure mechanism can be shown as the different between a strength and a load:

$$Z = R - S$$

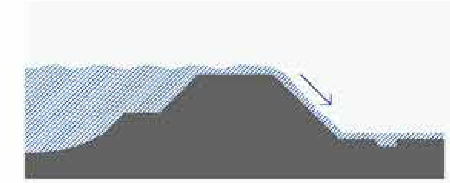
Where:
Z Limit state function
R Strength
S Load

The strength and the load in the above formula can be functions of different parameters. Limit state functions play a key role in reliability analysis. This is examined further in section 5.6.

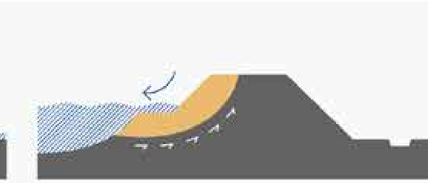
5.3 Failure mechanisms

Failure mechanisms in earthen structures

A flood defence structure can fail due to a number of causes. These causes are also known as failure mechanisms. Figure 5.1 shows potential failure mechanisms in earthen structures. The different failure mechanisms can impact on each other. Sliding of the landside slope can for example compromise the erosion-resistance of the slope. Interactions such as these must be taken into account when performing reliability analyses.



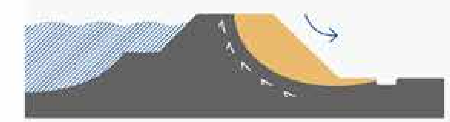
Overflow
Flooding caused by a water level higher than the crest, possibly in combination with overtopping. This can cause the structure to fail due to progressive erosion.



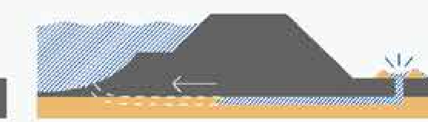
Macro-instability in waterside slope
Sliding of waterside slope when the outer water level falls sharply after a high water event (outward macro-instability).

Overtopping
Progressive erosion of crest, landside slope and/or toe due to the force of the water in the event of overtopping or overflow.

Micro-instability
Instability in the landside (or waterside) slope due to outward seepage through the structure.



Macro-instability in landside slope
Sliding of landside slope, either due to water pressure exerted against the structure and increased pore pressure in the subsurface, or due to infiltration of the overflowing water when high water levels are combined with overtopping.



Uplift and piping
Piping as a result of seepage through the subsurface, carrying sand particles with it and undermining the levee.

Erosion of waterside slope
Erosion of the waterside slope due to wave action or currents.

Figure 5.1 Failure mechanisms in earthen structures.

Failure mechanisms in dunes

Figure 5.2 shows the most important failure mechanism in dunes: dune erosion. Waves cause erosion of the waterside slope, causing part of the dune to disappear into the sea. If the dune erodes too far, it can no longer withstand the outer water, and flooding will occur.

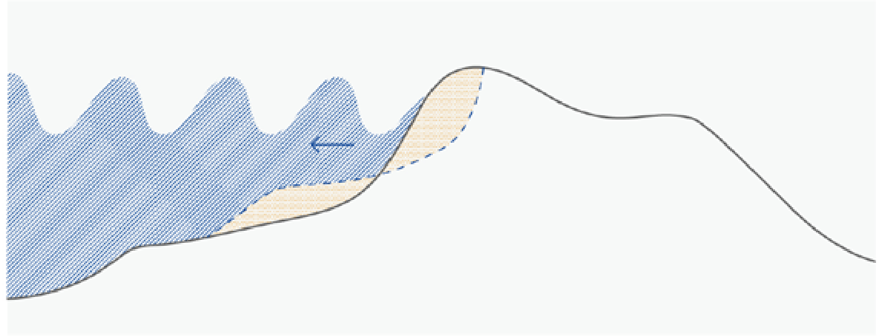


Figure 5.2 shows the key failure mechanism affecting dunes: dune erosion. Waves cause the waterside slope to erode as a result of which parts of the dune disappear underwater and are deposited on the beach or foreshore. If the dune erodes too far it will breach. It can then no longer hold back the outer water, and the hinterland will inevitably flood.

Failure mechanisms in hydraulic structures and special structures

Besides overflowing and overtopping, the following failure mechanisms are also important when it comes to hydraulic structures and other special structures:

- Structural failure of parts of the structure.
- General loss of stability in a hydraulic structure.
- Failure of transitional structures, as a result of internal erosion for example.
- Failure to close, or to close on time.

This last failure mechanism is very different from all the other mechanisms listed, as it not only involves the failure of materials, but also the behaviour of humans and machinery. Clearly, when moving parts fail, entirely different factors are at play.

Failure mechanisms and aggravating circumstances

Objects in, on or near a flood defence structure can increase the likelihood of the above failure mechanisms. A fallen tree whose roots have been ripped out of the ground can for example reduce the landside slope's resistance to overtopping. Posts or steps on a levee can cause locally higher flow rates in the event of overtopping, speeding up erosion at those points. Leaks or explosions in pipelines can adversely affect the strength and flood defence capacity of a structure. When assessing a flood defence structure, it is important to identify objects that might have a bearing on its reliability.

Historic water level gauging station built in 1874 on Waaldijk levee at Herwijnen.

5.4 Length effect and failure mechanisms in levee segments

Two phenomena have major implications for the failure probability of a levee segment: the 'length effect' and the interdependencies of failure mechanisms.

5.4.1 The length effect

Each segment consists of a contiguous series of flood defence structures such as levee sections, hydraulic structures and dune sections. These flood defence structures are the components of a series system, like the links in a chain. Figure 5.3 shows a fault tree that illustrates how different links (levee sections in this case) contribute to the failure of a segment. A levee or dune section is part of the segment where the load and strength are statistically homogeneous: the probability distributions of load and strength are the same throughout the section.

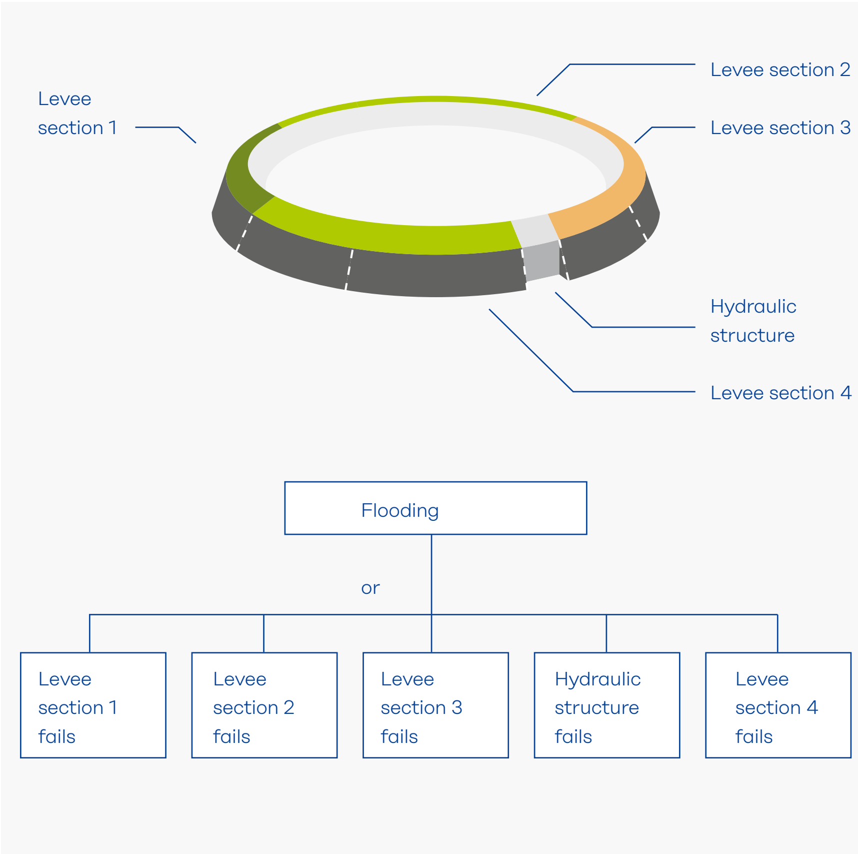


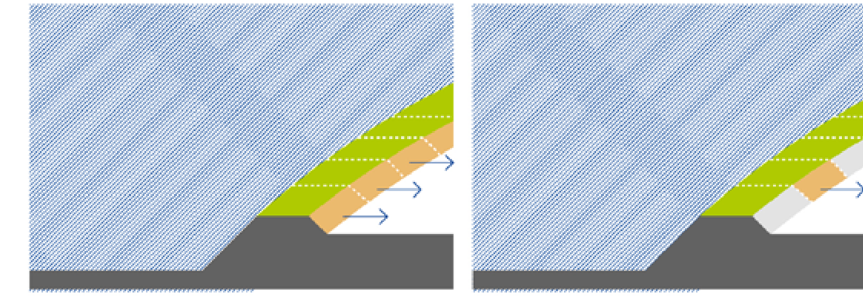
Figure 5.3 Fault tree

A chain is as only strong as its weakest link: if one link fails, the entire system fails. The probability of flooding in a segment is therefore equal to the probability that at least one link will fail. In practice, which link is the weakest is always uncertain. Nor is it certain just how weak the weakest link is.

The longer a levee, the greater the probability that there will be a weak spot somewhere. The probability that a long stretch of levee will fail at some point is higher than the probability that a segment will fail at one specific point. This is referred to as the length effect. That is why, at times of high water levels, patrols inspect levees to check whether there are any problems. The longer the distance a levee inspector covers, the greater the likelihood that he or she will find a problem somewhere, even though the probability of observing a problem remains the same at every step taken.

If the value of an important uncertain parameter is likely to vary sharply from point to point, the length effect is strong. In practice, the length effect is relatively strong for geotechnical failure mechanisms like macro-instability and piping. The uncertain, spatially variable properties of the subsurface are the determining factors in these failure mechanisms.

Figure 5.4 Illustration of the length effect: the probability that things will go wrong somewhere in a levee segment is greater than the probability that things will go wrong at one specific spot.



The length effect can be converted into the probability that a certain failure mechanism will lead to flooding somewhere in a segment as follows:

1. Divide the segment into sections with equal statistical properties.
2. Calculate the failure probability for each section on the basis of a representative cross-section.
3. Translate the failure probability for the representative cross-section into a failure probability for the entire section, taking account of the length effect. The length effect depends on the relative importance of the uncertain quantities, and thus differs from one section to another. The various uncertain quantities are not all equally spatially variable. For instance, the outer water level is the same over large distances, but the properties of the subsurface can change over short distances. The length effect is greater, the more important the uncertain variables that display strong spatial variability.
4. Combine the failure probabilities for the sections, taking account of the interdependencies (correlations) between sections.

Splitting sections does not produce a different failure probability at segment level, as the length effect also exists within levee sections. Dividing a long levee section into two creates two new sections, each of which has a smaller failure probability than the original longer levee section. The combined failure probability of the two smaller sections is however the same as the failure probability of the original levee section.

5.4.2 Failure mechanisms and their interdependencies

Any levee section, hydraulic structure or dune section can fail due to a variety of failure mechanisms. This is illustrated in the fault tree in figure 5.5. The probability of flooding is equal to the probability that at least one of the failure mechanisms will occur somewhere. This probability is less than the sum of the failure probabilities per failure mechanism, as the mechanisms are not entirely independent. The outer water level is for example the driving force behind many failure mechanisms.

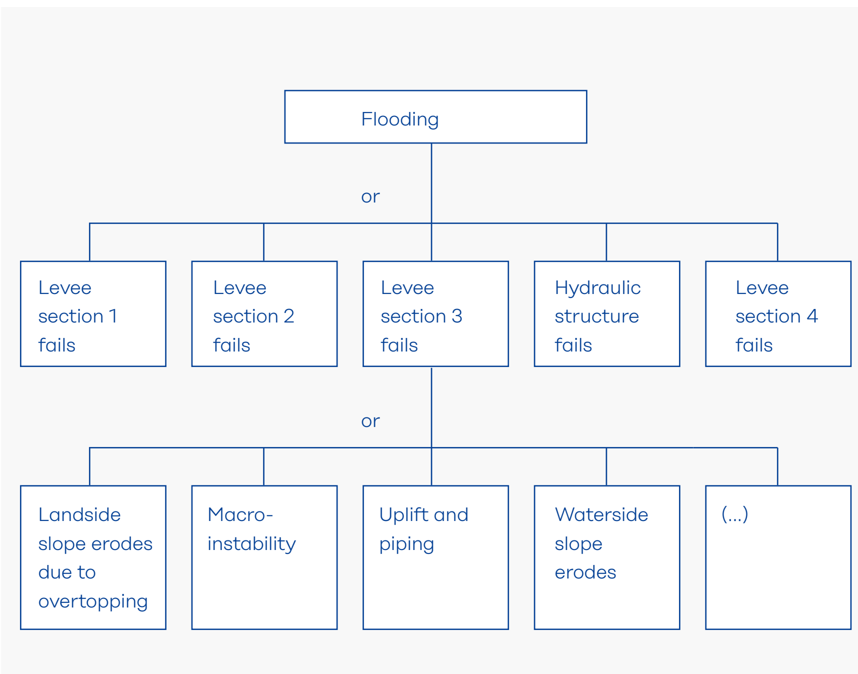


Figure 5.5 Detailed fault tree showing different failure mechanisms.

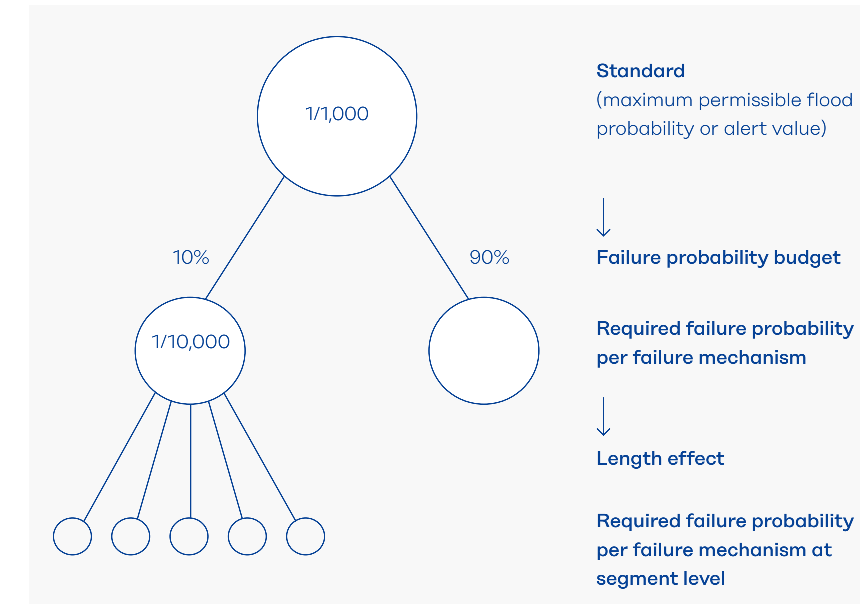
5.5 Required levels of reliability

A flood probability standard is a standard for the probability that a levee segment will fail somewhere, irrespective of the cause. Whether a levee segment complies with the standard can in theory be determined by calculating the probability of flooding for the segment. At this moment (2016), however, we do not have the techniques to calculate failure probabilities for all failure mechanisms and parts in a segment and combine them into a single probability of flooding. Probabilistic models are available for only a small number of failure mechanisms, so we are often forced to work with rules that indicate whether the failure probability associated with a failure mechanism is below a certain value for a representative cross-section of a levee section. In this case, a failure probability requirement is needed for the failure mechanism for each representative cross-section (cross-section level).

The required failure probability at cross-section level can be calculated using two steps (figure 5.6):

1. Determine a required failure probability per failure mechanism at segment level.
2. Translate the required failure probability at section level into a required failure probability for a representative cross-section.

Figure 5.6 From standard to required failure probability per failure mechanism for a representative cross-section.



5.5.1 Required failure probabilities at section level

Required failure probabilities for a failure mechanism at section level are determined by dividing a flood probability standard over different failure mechanisms. This is also known as failure probability budgeting. A failure probability budget denotes the potential relative contribution of each failure mechanism to the probability of flooding.

The failure probability budget can be allocated in various ways. The optimum budget might differ from segment to segment. If, for example, it is relatively expensive to take measures to prevent macro-instability, it might be wise to assign it a relatively large proportion of the failure probability budget to this mechanism, as this will give rise to relatively stringent requirements for the other failure mechanisms. The total failure probability, for all failure mechanisms together, must of course remain within a certain limit.

Standard failure probability budgets have been draw up for the Statutory Assessment Instruments 2017 which are important in semi-probabilistic analysis (see following section). An overview is presented in figure 5.7. It is

Hydraulic structures: requirements in the Water Act and Building Decree

Hydraulic structures for flood defence, such as locks, must not only meet the requirements of the Water Act, but also those of the Building Decree. The requirements in the Building Decree are set out differently from those in the Water Act. The former refer to the probability that an individual part of the structure will fail, while the flood probability standards in the Water Act cover the entire segment. The Building Decree requirements also refer to the failure probability over a period longer than a year – at least 15 or 50 years, for example – whereas flood probability standards cover one-year periods.

The Building Decree makes reference to the following regulations which specify required levels of reliability:

1. NEN-EN1990/NB for new buildings (Basis of Structural Design);
2. NEN8700 for rejection and alteration of existing structures.

Earthen structures with a flood defence function, such as levees, are not subject to the requirements of the Building Decree. Like the requirements in the Water Act, those in the Building Decree are based on a risk approach. This means that the greater the potential impact of failure, the stricter the requirements. NEN-EN1990/NB distinguishes three consequence classes. Each class has its own required reliability. This consists of a reliability index for the working life of the structure and an associated required failure probability (table 5.1). A reliability index of 4.3 (consequences class CC3) means that the probability of failure during the structure's working life may not exceed 1/120,000. The reliability index ß is directly linked to the failure probability.

NEN8700 stipulates required reliabilities for existing buildings (table 5.2), distinguishing between values for rejecting structures and ordering alterations. A distinction is also drawn between situations in which the wind load is dominant and cases where this is not so. NEN8700 has the same three consequences classes as NEN-EN1990/NB, but here the consequences class CC1 is divided into two: in class 1A people's safety is not at risk, while in class 1B it is at risk.

Table 5.1 Required levels of reliability for new buildings in NEN-EN1990/NB.

	Consequences of failure			
Consequences class	Chance of loss of life	Chance of economic damage	Reliability index for working life	Required failure probability for working life
CC1	None/small	small	β = 3.3	1/2,100
CC2	Considerable	considerable	β = 3.8	1/14,000
CC3	Very high	very high	β = 4.3	1/120,000

Table 5.2 Required levels of reliability for existing buildings in NEN8700. The required reliability indices for dominant wind load are shown in brackets.

Consequences class	Minimum reference period	Alteration	Rejection
CC1A	1 year	β = 2.8 (1.8)	β = 1.8 (0.8)
CC1B	15 years	β = 2.8 (1.8)	β = 1.8 (1.1)
CC2	15 years	β = 3.3 (2.5)	β = 2.5 (2.5)
CC3	15 years	β = 3.8 (3.3)	β = 3.3 (3.3)

always possible to deviate from these standard failure probability budgets in order to avoid unnecessarily restrictive requirements for certain failure mechanisms. It must however be borne in mind that only large shifts in the failure probability budget are of practical significance. An increase or decrease in a contributor to the failure probability budget by a factor two, for example, will have a barely perceptible impact in terms of levee dimensions. In practical terms, a 24% contribution has virtually the same significance as a contribution of between 10% and 50%. Adjustments are therefore only useful for failure mechanisms for which relatively small contributions have been reserved in the standard failure probability budget, such as for macro-instability and failure to close (both 4%).

All percentages in the failure probability budget add up to 100%. The interdependencies between two or more failure mechanisms influence the probability that at least one of these failure mechanisms will occur. According to the standard failure probability budget, the probability of failure in a segment due to overtopping or damage to the revetment must therefore be no greater than 24%+10%=34%.

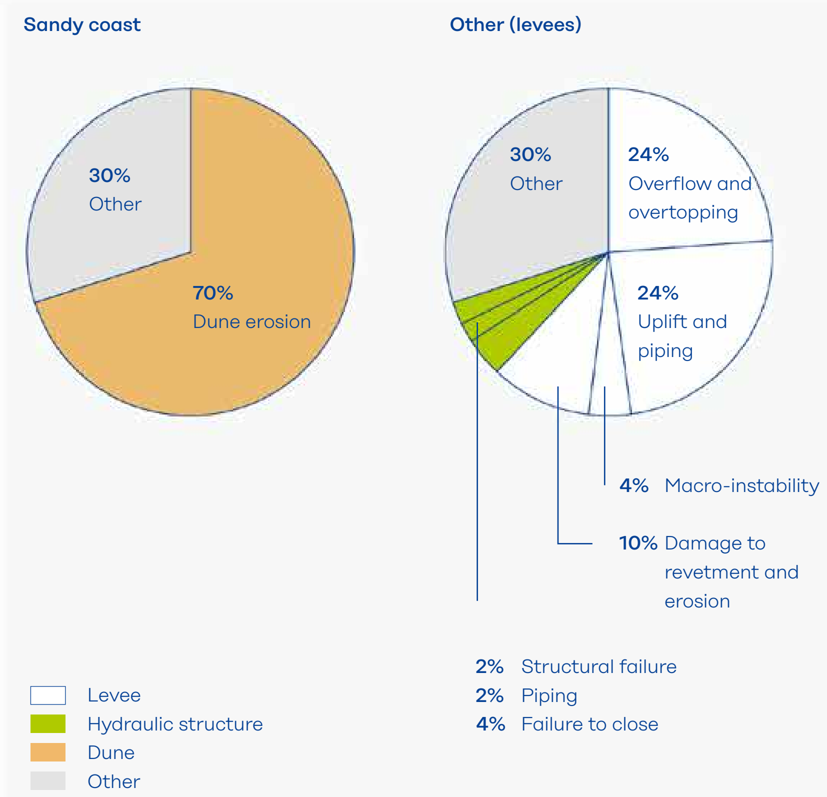


Figure 5.7 The standard failure probability budget consists of maximum permissible failure probabilities as percentages of the maximum permissible probability of flooding. This budget was used in the WBI2017 for the detailed assessment. The standard failure probability budget may be deviated from as long as the total does not exceed 100%.

5.5.2 Required failure probabilities at cross-section level

When translating a required failure probability at segment level to a required failure probability at cross-section level, the 'length effect' must be taken into account (see also section 5.4). The length effect differs from one failure mechanism to another. It is not therefore possible to first derive required failure probabilities at cross-section level and then divide them among the failure mechanisms in each segment, as it would then be unclear which length effect should be applied.

5.6 Methods of assessing reliability

How is it possible to assess whether a flood defence structure complies with a required failure probability? Both probabilistic and semi-probabilistic methods are available. These methods are closely related. They use the same required failure probabilities and the same models of failure mechanism models or limit state function. Both methods also take the same uncertainties into account. The difference lies in the way they deal with uncertainties. Deterministic rules are also still in use, though they are not suited to the flood probability approach.

Hondsbossche sea defences seen from the dunes at Groet.

5.6.1 Probabilistic methods

In probabilistic assessments failure probabilities are first calculated and then compared with required failure probabilities. The load on and strength of a flood defence structure are uncertain in practice. This uncertainty means there is a chance that the strength of the structure will prove inadequate over a certain period. The failure probability of a flood defence structure is the probability that the uncertain load will exceed the uncertain strength.

The failure probability per failure mechanism and levee section, dune section or hydraulic structure can be calculated as follows:

1. Assign probabilities of occurrence to all possible combinations of parameter values in the limit state function or Z-function (see 5.1 and 5.3).
2. Determine the probability of all combinations where Z is less than zero (i.e. the load is greater than the strength).

Figure 5.8 shows these steps. The contours show the probability density of all possible combinations of strength and load. The area beneath the total *probability mountain* is equal to 1. The area beneath the shaded section of the mountain is the failure probability.

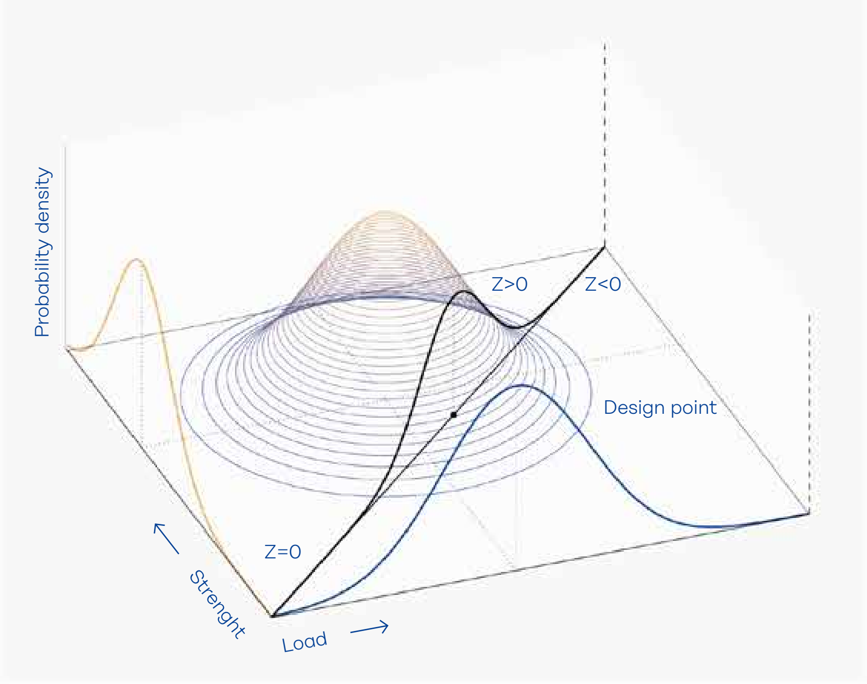


Figure 5.8 The failure probability and the joint probability density function of strength and load.


Casemate at foot of Diefdijk levee in Leerdam.


Buildings on the boulevard near coastal defence structure in Katwijk.

Fragility curves

A fragility curve shows the trend in the failure probability of a stretch of levee as a function of a load parameter such as the water level. The fragility curve differs from one failure mechanism to another and depends on the strength properties of the levee. The greater the uncertainty regarding the strength, the less steep the fragility curve. That is why the fragility curves for geotechnical failure mechanisms are relatively flat. The fragility curve for a failure mechanism like overflow or overtopping tends to be steep close to the design water level.

Combining the fragility curves for all failure mechanisms gives a fragility curve for the stretch of levee in question. This shows the probability that the structure will fail as a function of the water level, by whichever failure mechanism.

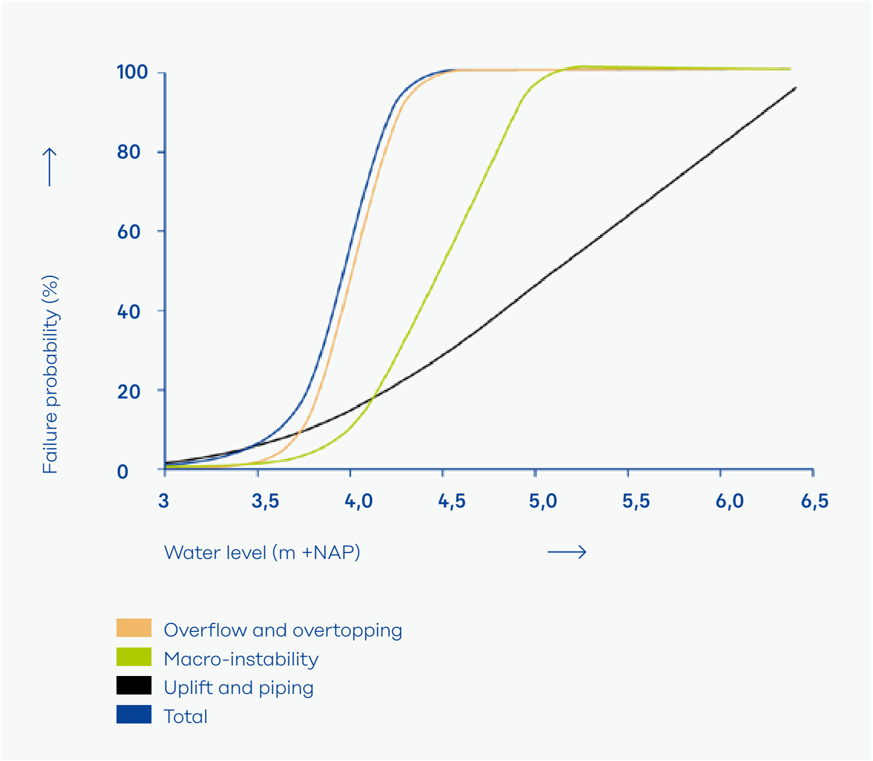


Figure 5.9 Example of a *fragility curve.*

5.6.2 Semi-probabilistic methods

In a semi-probabilistic assessment, design values rather than probability distributions serve as input for a failure mechanism model. A design value is a combination of a representative value and a partial safety factor. A representative value is a particular value of an uncertain quantity. Examples are a 5% quantile value, or a value with an exceedance probability of 1/10,000 per years. Then:

$$S_d = S_{rep} \cdot \gamma S$$
$$R_d = R_{rep} / \gamma R$$

Where:

S_d	Design value of a load variable
R_d	Design value of a strength variable
γS	Partial safety factor for a load variable
γR	Partial safety factor for a strength variable
S_{rep}	Representative value of the load
R_{rep}	Representative value of the strength

The partial safety factors are chosen in such a way that the failure probability is sufficiently low if the flood defence structure is satisfactory according to the semi-probabilistic assessment ($S_d < R_d$). In fact, a semi-probabilistic prescription is a simplified recipe for assessing whether a failure probability is sufficiently low.

Figure 5.10 shows the difference between probabilistic and semi-probabilistic reliability analysis. It shows a simple case with one uncertain load variable (S) and one uncertain strength variable (R). The failure probability P(S>R) must be lower than a certain required failure probability Preq. The design values of the load and strength, S_d and R_d, must be such that P_{req} as $R_d \geq S_d$ with sufficient certainty, as in figure 5.11.

A semi-probabilistic method is often easier to use than a probabilistic method. However, a semi-probabilistic assessment is often less accurate than a probabilistic one. Partial safety factors that have to be broadly applicable are sometimes relatively strict.

5.6.3 Deterministic methods

Finally, there are the classic, deterministic methods, which at first glance appear similar to the semi-probabilistic methods. These methods also involve inputting deterministic values for load and strength properties into a limit state function. An essential difference between deterministic and semi-probabilistic methods is however that in the former there is no explicit relationship with required failure probabilities.

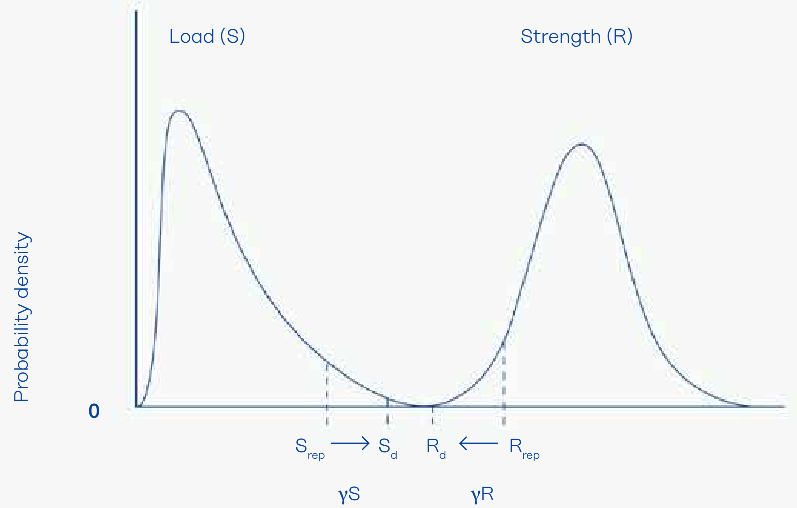


Figure 5.10 Schematic representation of the difference between a probabilistic and a semi-probabilistic assessment.

Deterministic rules are based on experience, or expert judgment. An example of a deterministic rule is Bligh's rule, which for a long time was used to assess piping in the Netherlands. Bligh's rule requires a minimum ratio of seepage length to differential head. The rule dates from 1910 and is based on the interpretation of failure events in brickwork dams with steel foundations in India. Although a semi-probabilistic prescription may have the same form, it would have to relate the minimum ratio to a required failure probability.

The classic, deterministic assessment and design rules will gradually be replaced by probabilistic tools and semi-probabilistic rules. It will take time to develop these, and the old deterministic rules will therefore remain in use for some time for some failure mechanisms.

06

Design

pp. 91—112

What goes into the design of a measure to reduce the probability of flooding? This chapter provides an insight into both the process and the procedures involved. All aspects of the previous chapters have a bearing on this. *It is the job of the designer to produce a coherent design based on these aspects that provides the required level of protection, caters in the best possible way for other functions and enjoys sufficient support.*

6.1 The design cycle

The starting point for the design cycle is a flood protection task, which might for example arise if the periodic inspection of a levee segment finds that it does not meet the requirements (see chapter 5). Measures to reduce flood risk can be taken on many different scales. First, the solution approach must be chosen; examples include:

- Reduce the hydraulic load by widening the river, for instance.
- Increase the strength by carrying out levee improvements.
- Take measures to limit the consequences, for example by presenting supporting evidence for the evacuation fraction to be increased.

The process of developing a package of measures to ensure the required safety level are met is referred to here as design. The resulting design must not only address the flood protection challenge ensuing from the provisions of the Water Act, it must also comply with other legislation and policy. This includes legislation on nature conservation, the cultural heritage, archaeology and landscape, and also compatibility with existing infrastructure and buildings. A design must also comply with all kinds of social criteria, such as minimum costs and minimum disruption during the execution of the work. Design involves both the creative process of generating appropriate solutions (design proper) and the technical details of these solutions (engineering).

There are large similarities between the assessment and design of flood defences for flood risk management purposes. Design follows broadly the same system as assessment. However, design must also take account of potential developments during the lifetime of the structure, whereas assessment is about the much clearer here and now. Hydraulic loads might for example increase due to climate change, and subsidence can also have an impact. In design, the requirements of stakeholders and local residents also have an important bearing on the process.

The design comes about in a cyclical process that proceeds from the general to the specific: from a draft design that mainly serves to determine the solution approach, to a preliminary design that provides clarity about the overall dimensions and incorporation into the existing situation, as well as sufficient information about the costs for a preference to be identified. The final or detailed design is then produced, indicating precisely what is to be built. A design plan is drafted, describing the construction process step by step. The design of measures to improve flood defences encompasses a broad range of activities: surveying requirements and wishes, gathering and analysing data, developing and considering alternatives and variations, discussing the pros and cons with stakeholders, working up a preferred alternative, dimensioning the structural elements, applying for construction permits and deciding on funding and construction. As can be seen in figure 6.1, which shows the cyclical design process, the words *specify*, *analyse* and *verify* appear repeatedly. These things occur at every step of the design process, at the appropriate level of abstraction. Eventually, this results in a solution that has been constantly verified to ensure all elements comply with the statutory requirements, technical requirements and the requirements and wishes of stakeholders.

Figure 6.1 shows a schematic representation of the design process for flood defence improvements. In practice, the design process must be arranged in such a way that it suits the specific stretch in question, the scale of the flood defence problem, the various stakeholders and potentially linked projects.

A design must always meet a whole range of requirements and wishes. For example, it must not only comply with the requirements of the Water Act, it must also fit into the existing context, perhaps with a road along the top of the structure, and buildings on or near it. Combining the flood protection challenge with other desired developments in the area can often create added value. Management and maintenance must also be considered in the design process. In this respect, it is important to take the entire life cycle of the measure into account.

Installing self-floating flood defences in Spakenburg.

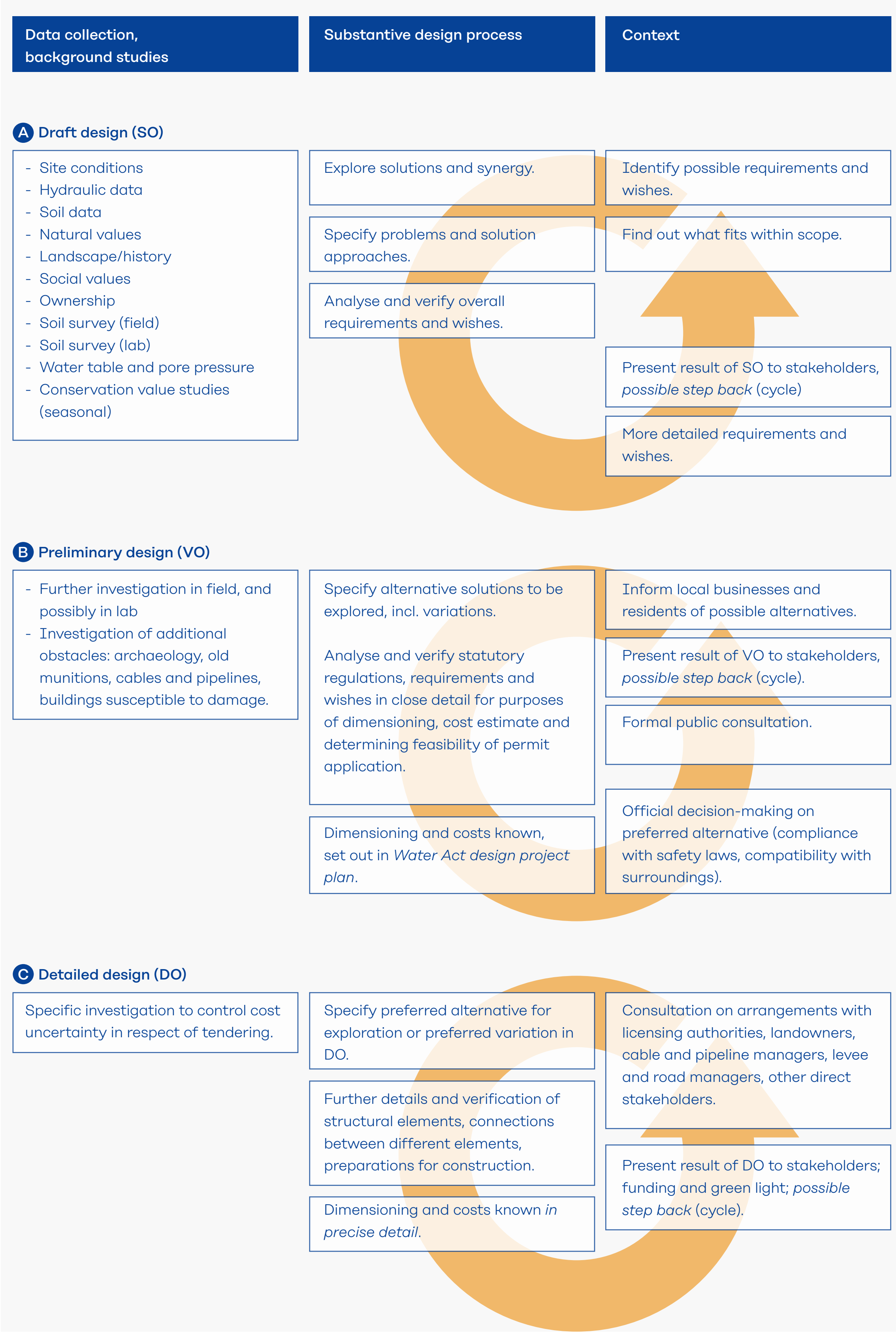


Figure 6.1 Design process for flood defence improvements.

6.2 Design verification: does the design meet the requirements?

Design verification involves assessing whether the envisaged solution meets the requirements. Assessment in relation to the standards in the Water Act and Buildings Decree is first considered below, followed by assessment in light of other social requirements.

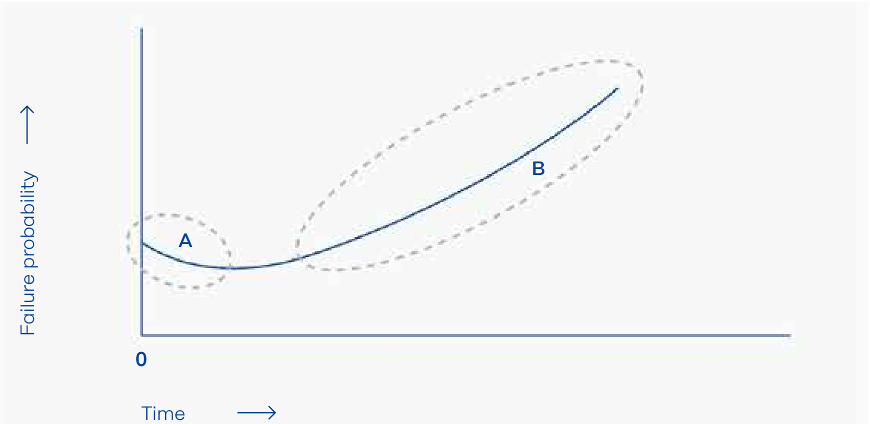
6.2.1 Statutory requirements

The standards in the Water Act are the basis both for assessing existing flood defences and for designing new flood defences and other solutions. The flood probability in a segment must be less than or equal to the maximum permissible flood probability specified in the Water Act (the lower limit) every year. As explained in chapter 5, the standards have been set with a view to 2050, though this date is not relevant when a solution is being designed. Whether designing for an envisaged working life of 10 years or 100 years, the same standard applies.

The optimum design working life is the working life at minimum cost, given the standard in the Water Act and taking account of other requirements and interests. The working life depends to some extent on the ratio of fixed to variable costs associated with future reinforcement or replacement. This, in turn, depends on the flexibility or scalability of the measure. If the fixed costs are relatively high, as with major levee reinforcements in urban areas, it makes economic sense to design for a long working life. Regular reinforcement of flood defences would not then be efficient. Things are different if the fixed costs are relatively low, as with sand replenishment or partial reinforcement of flood defences (e.g. reinforcement of a small section of revetment), in which case it makes more sense to carry out smaller, more frequent reinforcements. The optimum working life will not necessarily be the same for all parts of a levee segment or structure. For instance, the optimum working life of a moving part will often be shorter than that of pile foundations. In the past, a design working life of 50 years has often been used for levee improvements, and 100 to 200 years for more complex constructions like hydraulic structures.

If the load on a flood defence structure increases, due to relative sea-level rise for example, or its strength declines as a result of processes such as ageing and settling, the failure probability will gradually increase over time. The failure probability of a new or reinforced flood defence structure may reduce in the initial period after reinforcement, perhaps because physical processes occur that enhance its strength, such as the dissipation of (excess) pore pressure, and consolidation of the grass cover. Uncertainty about the strength may also reduce if the performance of the new structure indicates that certain strength properties are better than initially assumed, perhaps because it has actually withstood a certain load. This too will reduce the failure probability. The result of the upward and downward influences on the failure probability produces what is known as a bathtub curve (see figure 6.2).

This means that it can take some time before a flood defence structure is at 'full strength'. This temporary deficit in strength can be counterbalanced to some extent through good timing, for example by ensuring that consolidation takes place outside the season when high water levels are likely to occur, and by introducing temporary management measures. It can however prove very costly to demand that a flood defence structure found to be unfit for purpose must comply with the standards in the Water Act during or immediately after reinforcement. Enforcing such a demand would drain the resources available for other reinforcement measures. The Expertise Network for Flood Protection therefore regards a higher probability of flooding over a period of up to four years as acceptable, if it prevents excessive costs. The probability of flooding may not however exceed the probability of flooding immediately prior to the reinforcement in any year during this period.



A. Strengthening effects and proven strength dominate.
B. Climate change and ageing dominate.

Figure 6.2 Illustration showing bathtub curve: in the initial years the flood probability declines, then increases again due to climate change and ageing. In reality, the process is more variable because loads differ in summer and winter, for example.

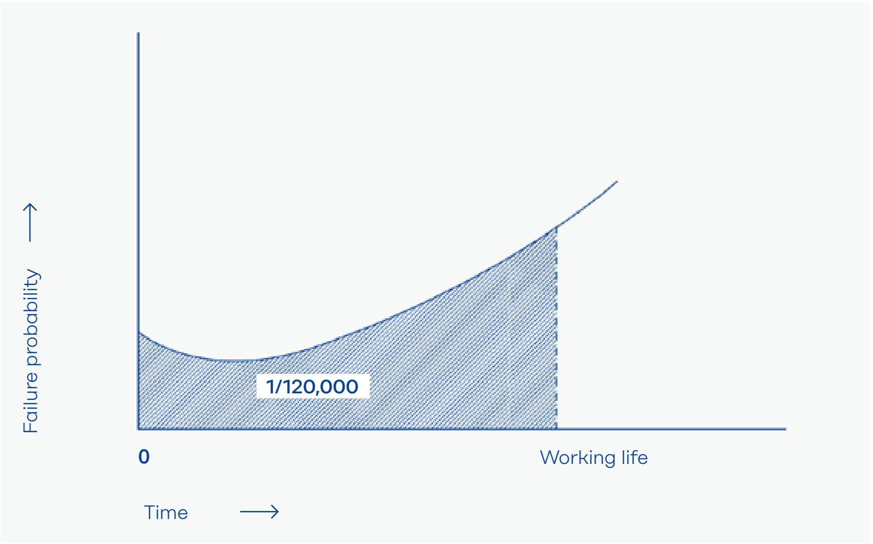
Hydraulic structures: design requirements in Buildings Decree

Hydraulic structures must not only comply with the standards in the Water Act, but also with the requirements in the Building Decree, as set out in Eurocode NEN-EN1990/NB (see also box in section 5.5.1). Unlike the standards in the Water Act, the requirements in Eurocode NEN-EN1990/NB apply to reference periods of longer than a year, generally equivalent to the working life of the structure. This means that the probability of failure during the envisaged working life must be smaller than the required failure probability. The area under the bathtub curve in Figure 6.3 approximates the failure probability in the period considered.

Incidentally, this is officially only the case if the annual probability of failure and non-failure in previous years is also shown on the vertical axis. In practice, the difference between a probability of failure in the event of no failure in previous years, and a probability of failure following no failure in previous years is very small, however.

Figure 6.3 shows the bathtub curve for a design based on consequences class CC3 in the Eurocode (ß=4.3, required failure probability 1/120,000) and a reference period equal to the working life.

Figure 6.3 Illustration of a design based on Eurocode consequences class CC3: the probability of failure during the working life is equal to 1/120,000 (ß=4.3)



The Water Act does not specify any particular required level of reliability for the design. It does however indicate what minimum requirement a levee segment must meet, and each segment must be periodically assessed on the basis of this requirement. To prevent a reinforced flood defence structure from immediately exceeding the standard, the design must take account of the changes that will occur over time, such as ageing and relative sea-level rise. It has been found in practice that developments in knowledge and the introduction of new models can lead to changes in the perceived reliability of a flood defence structure. All these changes are surrounded by uncertainty. As a result, uncertainty also exists as to when exactly a reinforced flood defence structure has to be reinforced again or replaced. If the designer is relatively optimistic regarding the uncertainty as to the future situation, there is a large probability that the structure will not make it to the end of its envisaged working life as it will have to be designated unfit for purpose before that point. If the designer is relatively pessimistic regarding these uncertainties, there is a good chance that the structure will exceed its envisaged working life. The crux of the matter is therefore to strike the right balance, for elements of the structure, or for the structure as a whole. A review and identification of arguments in support of the uncertainties considered in relation to the design working live is therefore an essential part of the design process.

The load on a flood defence structure may be greater than assumed in the design, or the structure might turn out to be less strong than previously thought. The designer and manager of the structure are wise to anticipate these possibilities, by adapting the design or taking emergency measures, for example. If the emergency measures are part of the package of measures introduced to ensure the structure complies with the standard, they must be guaranteed. If the structure complies with the standard without emergency measures, they will be supplementary, and not required to ensure compliance.

This explains why the freeboard, which was used in the past in the exceedance probability approach, no longer features in the flood probability approach. A freeboard over and above the required crest height would reduce the probability of flooding below the level required by law.

6.2.2 Other design requirements

A flood defence structure often has to perform other functions besides its role in protection against flooding. For example, a road often runs along the top of the structure, or it includes a lock to allow vessels through. Requirements can be set out for each of these functions, relating to both use and reliability. A lock chamber must for example have a certain minimum width (user requirement) and comply with the structural safety requirements (required reliability level).

Requirements concerning reliability may be related to both ultimate limit states and the serviceability limit states. A road on top of a levee, for example, may be damaged by a slide (when an ultimate limit state is exceeded) or become temporarily inaccessible due to overtopping (in which case a serviceability limit state is exceeded).

Requirements of other functions and serviceability limit states do not stem from the standards in the Water Act. These requirements may therefore deviate from those in the Act, which only sets requirements in terms of '*the probability of the loss of flood defence capacity in a levee segment causing the area protected by the levee segment to flood in such a way that fatalities or substantial economic damage occur*'. Requirements relating to other functions and serviceability limit states are generally based on other legislation and regulations, such as the Building Decree and the Machinery Directive.

It should be noted that the probability of a levee becoming inaccessible, for example, may be far greater than the probability of a levee breach. A levee must remain accessible for maintenance, inspection and repair. However, these activities do not take place in extreme circumstances. Only if a flood defence structure has to be accessible in order to close off a cut, for example, is the required accessibility based on the flood probability standard.

6.3 Reducing the flood probability

The flood probability can be made smaller either by reducing the hydraulic load or by increasing the strength of the structure, or a combination of the two.

6.3.1 Reducing the hydraulic load

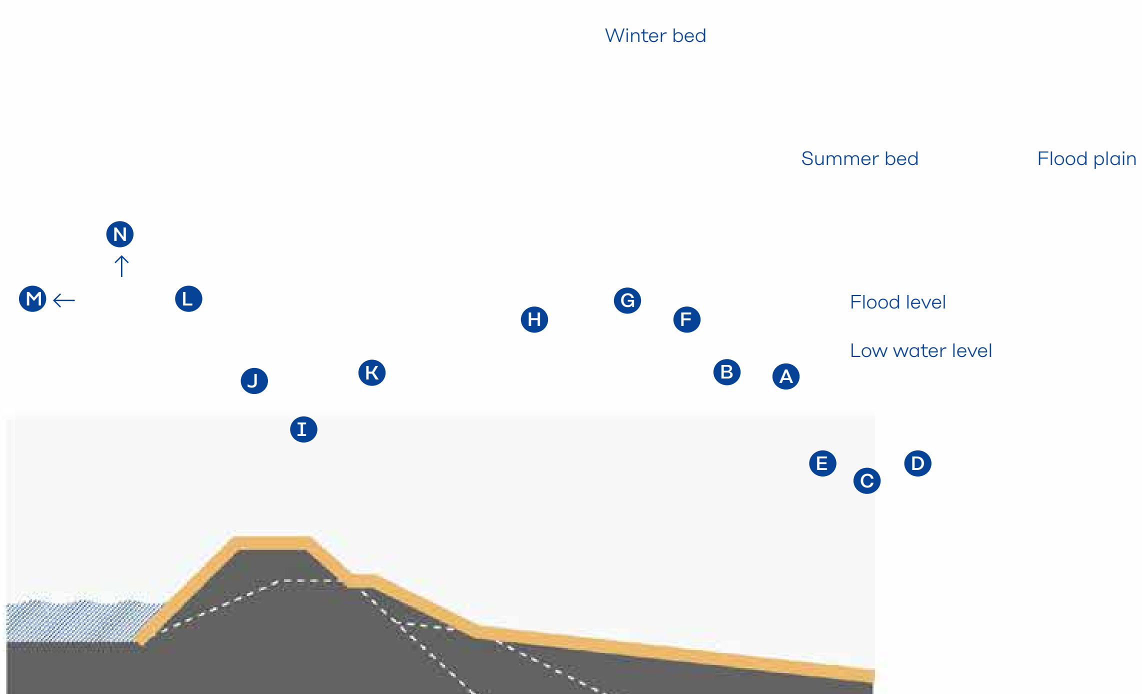
The hydraulic load on flood defences can be reduced in various ways. This section highlights three examples: river widening, installation of breakwaters and use of pumping stations.

Waaldijk levee at Vuren.

River widening

Measures in this category focus on increasing the river's discharge or storage capacity to lower the water levels that the flood defences have to withstand. Typical measures involve excavating or lowering flood plains, relocation of the levee, digging secondary channels and flood channels, and deepening the summer river bed.

Figure 6.4 Potential measures in river cross-section.



A. Narrow summer bed
B. Lower groynes
C. Dredge summer bed
D. Add sediment
E. Apply solid layer
F. Create wildlife-friendly banks
G. Remove summer embankments
H. Create secondary channel
I. Lower flood plain
J. Create nature conservation zone
K. Remove raised areas guaranteed free of flooding
L. Reinforce levees
M. Move levees
N. Raise levees

External reinforcement

It is a general principle of policy in the Netherlands that the discharge capacity of the rivers may not be reduced. It has been found in practice that strict application of this principle has led to a reluctance to perform external reinforcements on flood defences. An external levee reinforcement has barely any impact on discharge capacity, however. The Expertise Network for Flood Protection therefore advises that such measures be given full consideration as a potential alternative and should not be dismissed out of hand.

Lowering the water level by widening the river requires much more excavation work than reinforcing a levee. The nature of the required excavation work is also different, and on the whole this measure often entails more spatial interventions. In many cases, it may serve other development goals in or near the area where the river is widened, such as enhancing the opportunities for recreation by making the area greener and more dynamic. This means that, when river widening measures are designed, the necessary management and maintenance measures during the design working life must be considered, in order to prevent flow-restricting vegetation from counteracting any benefits of lowering the water level, for example. If the option of digging a secondary channel is selected, the costs and ecological impact of the maintenance dredging required to keep the channel open must also be considered.

Breakwaters

Breakwaters can be an effective way of reducing the wave loading on flood defences. They can be made of stones, though planting vegetation or heightening the foreland can also be effective. In all cases, required management must be considered. Whether breakwaters are an efficient solution will also depend on their potential for serving other purposes.

Water level management using drainage sluices and pumping stations Drainage sluices can be useful for managing the water level over a large area. The sluices in the Afsluitdijk causeway, for example, have a major bearing on the water level in the IJsselmeer region. Pumping stations can also help reduce the probability of extreme high water events, if they have sufficient capacity relative to the volume of outer waters threatening the flood defence structure. The pumping station at IJmuiden, for example, helps keep the Amsterdam region safe from flooding. If gravity-assisted drainage becomes more problematic as a result of climate change, for example, additional pumps can be used to enhance the pumping station's capacity.

Foreland and ledger

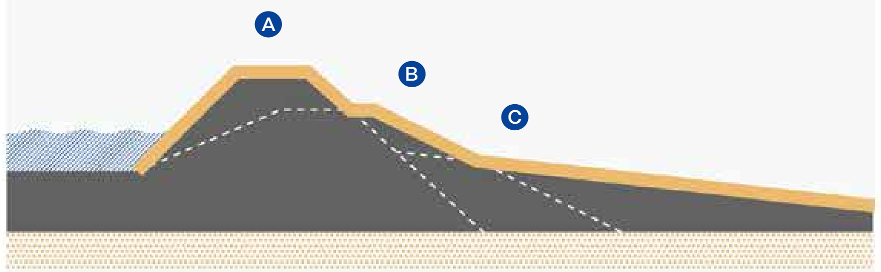
The flood probability approach is based on the principle that the foreland is taken into account in the calculation of loads. If the foreland is expected to remain present even under extreme conditions, it can be factored in ('*assess what is actually present*').

If the foreland plays an important role in reducing the probability of flooding, operational management (duty of care) is needed to ensure that it is monitored and maintained. The management authority can specify the flood protection importance of the foreland in the ledger, though this is not strictly necessary. If the foreland is managed by another party, it is useful to make arrangements for its maintenance.

6.3.2 Increasing strength

How the strength of a flood defence structure is increased will depend to a large extent on what type of structure it is: dune, earthen structure, hydraulic structure or special flood defence structure (see section 2.2.2). This section looks at the most common type: the flood defence levee as an earthen structure. Such flood defences are relatively cheap, made of natural materials, sustainable and are easily expanded. The composition of the soil (subsurface), dimensions (including the height and slope) and the revetment determine the levee's resistance to failure. Figure 6.5 shows an example of a levee profile.

The required protective height of a flood defence structure is determined by a number of factors. Overflow and overtopping damage the revetment and erode the underlying clay layer, and can thus potentially cause a breach. These mechanisms also have a negative impact in terms of sliding in the top layer and macro-stability (see figure 6.5).



A. Overtopping (greater height, less steep slope, rougher slope)
B. Stability (less steep slope on landside, widening of levee base)
C. Uplift and piping (heavier top layer and longer seepage length)

Figure 6.5 Example of the design of the levee profile based on three failure mechanisms. The thick orange line envelopes the solutions to the three failure mechanisms, and shows the design profile.

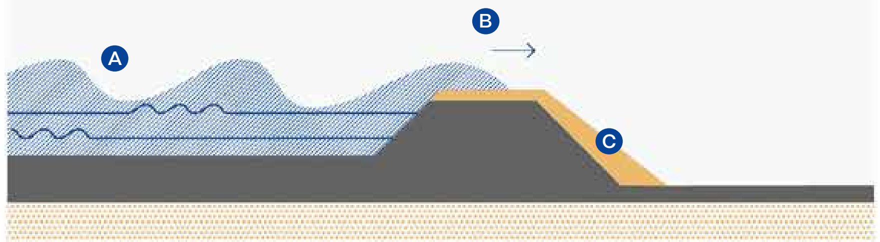


Figure 6.6 The critical overtopping rate is the link between load (water level and waves) and strength (erosion and stability). The required height depends on the local water level (determined by river discharge, sea water level, lake water level, shower oscillations, seiches, wind surge, failure probability of storm surge barrier) and wave runup (determined by wave height, wave duration, levee profile).

A. Various water level/wave combinations contribute to the probability that a critical overtopping rate will be exceeded.
B. Critical overtopping rate
C. Levee design includes extra height for:
   1. Higher water levels and waves due to climate change
   2. Subsidence (drainage, tectonic)
   3. Settling of subsurface after new soil applied.
   4. Compaction of newly applied soil.

There is not always enough room to make levee profiles entirely of earth, for example when there are buildings, watercourses or other obstacles that are expensive or impossible to move. In such situations the flood defence structure will have to be strengthened using methods that take up very little space, such as steel sheet piling or concrete walls, or specific soil strengthening or anchoring techniques. Drainage systems can reduce groundwater pressure in the structure, allow the soil to retain more strength.

6.4 Integration into surrounding environment

There will often be many existing functions, or desired functions, in the vicinity of a location where a measure needs to be taken. Physical meas-ures that reduce the probability of flooding can also serve other purposes. Indeed, nowadays it is regarded as desirable that flood risk management be combined with other functions. This is nothing new, however. Flood defence structures built in the past also generally perform several func-tions. Many river levees, for example, are also roads, pasture for sheep or the main thoroughfare through a village.

Multifunctional flood defence structures require a greater focus on reliabil-ity, as the other functions may conflict with the flood defence function. Management requires particular attention. Various stakeholders will be involved with a multifunctional defence structure, with goals other than protection from flooding.

Entrance to underground car park in coastal defence structure, Katwijk.

Wishes and requirements concerning other functions give rise to design criteria that differ from those for flood risk management. These criteria will need to be reconciled in the design, without any concessions to statutory requirements (such as those in the Water Act and the Building Decree).

Multifunctionality can impact on the costs of future interventions and thus on the design working life. Examples of multifunctional solutions include the Boompjes, an important through traffic route in Rotterdam; the promenade in Scheveningen; the flood defences in Kampen; the underground car park located in a flood defence structure in Katwijk and Voorstraat in Dordrecht.

Every design must also fit in with the surrounding landscape or urban fabric, with a view to the preservation and development of the landscape, wildlife habitats and the cultural heritage. The dune landscape is almost always accorded very high value and river levees are increasingly coming to be appreciated as features that define the look of the landscape and can be used to improve the quality of the environment. One obvious key element in the design of these lengthy structures is their continuity. Keeping this intact requires specific solutions for local facilities for transport, business and leisure activities, for example. Variations in building style, by contrast, are rarely perceived as undermining the continuity of the levee. This indicates that the scale of the different elements on and beside the levee is important. Special structures can be designed to preserve landscape values.

Integration into the surrounding environment might give rise to certain preferences concerning the steepness of the slopes, bends or straight stretches in the levee or preservation of characteristic locations. There may also be a preference for widening on either the landside or the waterside. The box on the following page briefly explains the role of levees in the rivers landscape.

Role of levees in the rivers landscape

There have been major changes in the way levees are integrated into the rivers landscape over the past few decades. The table below presents a summary (taken from H+N+S, 2015). The final column lists the ambitions for future levee improvements, as set out in Rivierenland water authority's 'Spatial Quality Handbook'. Ambitions concerning the longitudinal continuity of levees and co-use closer to the levee have undergone particularly radical changes. Three main principles have been distilled:

1. **The current trajectory should serve as the basis (length profile).**
2. **The levee should appear compact and the varied landscape of the levee zone should *touch the levee* (cross-section).**
3. **Particular attention should be focused on a number of locations requiring customised solutions.**

When designing levees, technical considerations must be reconciled with ambitions concerning the landscape.

	Pre-1970	1980's reinforcements	1990's reinforcements	Ambition for levee improvement
Position in landscape	Levee as part of riverbank landscape. Landscape features close to levee (seepage quays, ditches, *wielen* etc.)	Levee as autonomous element, linear feature in landscape.	Levee as independent element with changeable profiles and relationship with adjacent landscape.	Levee remains independent element, but with greater focus on continuity and 'readability' of levee as a whole.
Use	Use close to levee, often up to crest.	Levee as independent element. Landscape and use at distance. Relatively large number of buildings demolished.	Use slightly closer to levee, thanks to maximum compactness of levee profile. Lots of scope for customised solutions.	Use close to levee again. Management partly by users.
Attitude to improvement		Robust and rectilinear where possible, embankments where no space available, and old levee no longer functional. Outward relocation considered. Buildings purchased and demolished.	Sophisticated design. Integration of great variety of assumed qualities leads to broad range of location-specific solutions. No outward relocation, or only in combination with secondary channel.	Austere and efficient. Well-integrated, clear and 'readable' levee, with 'no frills'. Focus on number of unique ensembles and places like spillways, Fort Vuren etc. No outward relocation, or only in combination with secondary channel.
Profile		Slope 1:3 Height ave. >9m NAP Crest width 6m	Waisted slopes Height >8m NAP Crest width 6m High support benches.	Compact profile, earthing up of surface.

Table 6.1

6.5 Impact mitigation

Flood risks can be limited by reducing the probability of flooding (stronger flood defences), but also by reducing the potential consequences of flooding. The pattern of flooding following a levee breach determine these consequences, and that in turn depends on the layout of the surrounding area. The success of the crisis management operation also determines the consequences, such as the number of people successfully evacuated when flooding is imminent (the evacuation fraction). This was taken into account when the standards in the Water Act were set.

Impact mitigation measures do not automatically comply with the requirements of the Water Act, which are of course defined in terms of flood probabilities. However, flood probability standards can be relaxed if mitigation measures are put in place. Any such decision must be taken by the Minister.

To assess whether a *smart combination* of prevention and impact mitigation measures (cf. section 7.24) affords the same *level of protection* (cf. section 7.24, subsection 6) as the flood probability standard, the principles also underlying the standard must be applied. This is vital in order to allow proper comparison of the risk. Using a different victim model or discount rate, for example, can cause the required level of protection to turn out more or less stringent without any impact mitigation measures being taken.

Whether a *smart combination* leads to savings can be determined by identifying the investment costs associated with levee reinforcements, load reduction measures and the *smart combination* in order to achieve the intended *level of protection* over a certain period. For the sake of comparison, all options must be calculated for the same period, or annual costs must be calculated.

6.6 Procedures for levee design

6.6.1 Points for consideration in design procedure

1. The design must lead to a Water Act project plan:
   a. for a safe flood defence structure
   b. that is well integrated into the surrounding area
   c. and in which the environmental impact has been taken into consideration.
2. Stakeholders must be informed and have the opportunity to submit their views and any official objections.
3. There must be sufficient financial cover for the construction of the flood defence structure (and any combined projects).
4. The final decision on construction must come with legal safeguards.
5. Eligibility for construction permits and changes to zoning plans is vital.

Designing a flood defence structure is not only a matter of engineering. The importance of the structure in keeping the area safe from flooding – or at least minimising the likelihood of flooding – means it affects many stakeholders, including the local population and the land they live on, the authorities that represent them, the body that will manage the structure, the body funding the work, those who are responsible in the event of an emergency, environmental interest groups and regulators.

These stakeholders must be involved in the design process at some point, in order for the flood defence structure to be designed in accordance with the Water Act, to integrate it into its surroundings, to take account of other local interests, and to ensure that the reinforcements are funded and that the structure will be adequately maintained over a certain period.

The key steps in the procedures are:
1. Establishing that an area needs better protection (generally following an assessment).
2. Inclusion in a programme for flood defence improvement (organisational and financial framework).
3. Announcing the initiative to local residents, businesses and authorities and exploration of potential for combining it with other initiatives.
4. Identifying solution approaches to be explored (what is to be done, what is not).
5. Assessing the environmental impact.
6. Developing alternative solutions (within spatial and financial frameworks).
7. Flood defence structure management authority selects preferred alternative (after consideration of environmental impact and cost).
8. Regulator and funding body/ies take decision.
9. Final appeals (Council of State).
10. Formal adoption of plan, issuing of permits and necessary amendments to zoning plan.
11. Construction.

All these steps involve consultation and provision of information for administrators, officials and the public. Each of these stakeholders may seek the advice of experts.

6.6.2 Mandatory environmental impact assessment

The Environmental Impact Assessment Decree under the Environmental Management Act stipulates that environmental impact assessment (EIA) may be made mandatory for flood defence structure reinforcements.

The party initiating the reinforcements must notify the competent authority of its plans in good time. For flood defences, this is generally the provincial authority. The notification must include an assessment of the environmental impact of the construction or reinforcement, indicating whether it is significant. If so, the initiating party must draft a memorandum describing the planned activity, the scope of the intervention and the environmental impact, plus the level of detail to which this impact has been identified in the plans.

The competent authority will then issue guidance that may include additional requirements for the study. Generally speaking, the competent authority will seek the advice of the Commission for Environmental Impact Assessment.

The party initiating the plans will draw up an environmental impact statement (generally a *draft memorandum/EIS or project memorandum/EIS*) detailing the flood defence structure design, measures to mitigate the environmental impact and proposed measures to offset any negative environmental effects. The memorandum must be approved by the competent authority after consultation with the Commission for Environmental Impact Assessment.

Environmental impact assessment includes notification, information and participation procedures which can be combined with the Water Act procedure in various ways. An EIA procedure is always mandatory if the intervention is to take place partially in an area (e.g. a wildlife conservation area) where 'appropriate assessment' is required. The party initiating the plans may also institute a voluntary EIA procedure to show how environmental effects have been considered in the design, the eventual choice of measure and the decision.

6.6.3 Levee reinforcement project plan in accordance with Water Act

The *Water Act project plan* is central to the planning of the construction or improvement of a flood defence structure. The authorities concerned decide on the basis of this plan whether to approve the aspect for which they are responsible. The plan summarises the information required for such a decision, with reference to background studies.

Based on the need for and benefit of the measure, the plan describes the current situation and the changes that the intervention will bring about. It contains the most relevant information for the decision-makers involved and any parties that will benefit or suffer damage, and details how this will be compensated for (one key element is land acquisition).

The plan also describes any positive and negative effects, including environmental effects, and measures to mitigate them or compensate where necessary.

The plan also looks ahead to how the work will be performed and to responsibilities in the operational management phase. This includes the formal registration of the position and form of the structure intended for flood defence in the management authority's ledger.

The party initiating the plan indicates in the *Water Act project plan* how it intends to share responsibility and collaborate with other organisations involved in the construction and operational phases.

07

Continuous focus on flood protection

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This chapter explores the daily practice of flood protection. The key here is management: all activities designed to prevent flooding, such as inspection, maintenance, licensing, enforcement and periodic safety assessments. *The focus of this chapter is the management of flood defences.*

7.1 Management

The management of flood defences is part of the authorities' duty to provide protection from flooding. It encompasses all activities required to ensure that the functions of flood defences are in continuous compliance with the appropriate requirements. From society's point of view, it is also desirable that environmental aspects be considered.

The major rivers are also actively managed for shipping and flood protection. *Rijkswaterstaat* maintains and operates diverting structures and dams to safeguard the drainage and removal of water, ice and sediment. The agency also keeps the winter bed in good shape, maintains secondary channels and vegetation, and assesses user functions, to guard against impoundment of water, for example. *Rijkswaterstaat* controls the water levels in the large lakes using sluices and pumping stations.

Coastline maintenance

The coastline of the Netherlands features a great deal of natural morphological variation. Some parts are subject to erosion, while on other stretches of coast sand accumulates. In 1990 it was decided that the coastline should be *maintained dynamically*, which involves combating structural coastal depletion along the entire Dutch coastline (with the exception of the tips of some of the Frisian Islands) by means of sand replenishment. These efforts are part of the coastline maintenance programme. The position of the reference coastline (BKL) is the benchmark for coastal maintenance. The coastline is assessed against this benchmark every year. The position of the BKL was determined in 1990 and locally adjusted in 2001 and 2012. Figure 7.1 shows the basic coastline of Schiermonnikoog.

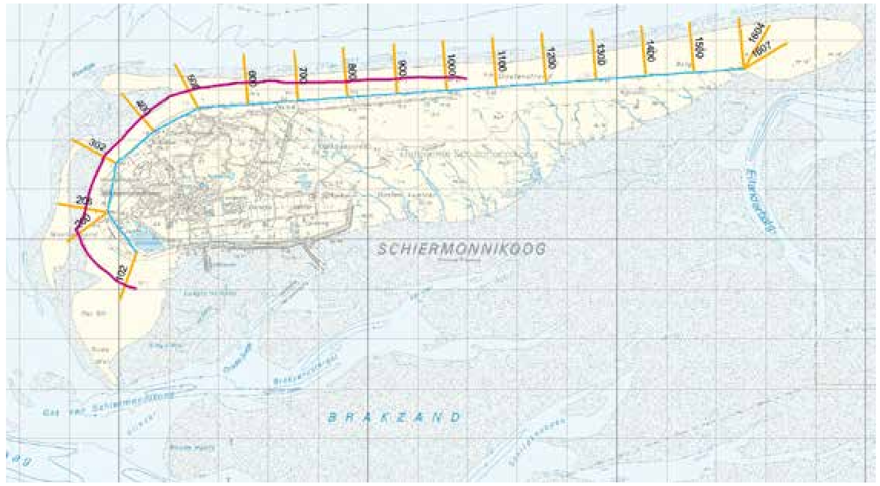
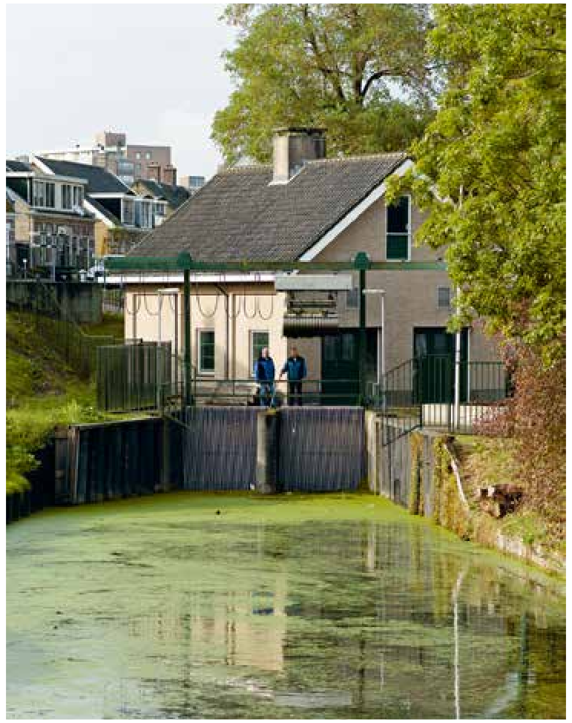


Figure 7.1
Basic coastline of Schiermonnikoog (in red).

'Management of' and 'responsibility for'



Maintenance work on the pumping station on the Schielandse Hoge Zeedijk sea levee in Capelle aan de IJssel.

The Water Act distinguishes between 'management' of the water system by water authorities and central government, and 'responsibility for' other tasks such as waste water purification and musk rat control by water authorities, or rainwater collection by local authorities (chapter 3, section 1 of the Water Act).

The Water Act defines management as measures by the authority concerning one or more individual water systems or parts therefore designed to prevent and where necessary limit major flooding, localised flooding and water shortages.

The allocation of responsibility for management to central government (Rijkswaterstaat) is based on article 3.1 'management of surface waters' and article 3.2 'management of flood defences' of the Water Decree under the Water Act. Responsibility for management is allocated to water authorities by provincial ordinance, generally referred to as the 'management regulations' of the water authority in question.

As such, management is a government responsibility. The powers associated with this responsibility are not associated with ownership. A management authority may own parts of the water system, but this is not necessarily the case.

Each year, the position of the current coastline (MKL) is calculated for each profile on the basis of the position of the beach and the upper part of the foreshore. The rule of thumb used in the calculation focuses on the sand volume around the average low water line. The section examined is bordered at the top by the dune foot. The lower boundary and the dune foot are equidistant from the average low water line.

The coastline for assessment (TKL) is decided on the basis of the trend in MKLs over several years and expressed in metres relative to the RSP, a line measured alongshore which is used as a reference for cross-shore profiles. Any sand replenishment operations are taken into consideration. Comparison of the TKL and BKL reveals whether the standard is being met. Allowing the *coastal base* to rise with predicted sea-level rise is another aspect of coastline maintenance. Sand replenishments are performed every year, involving approximately 12 million cubic metres of sand, to maintain both the coastal base and the coastline.

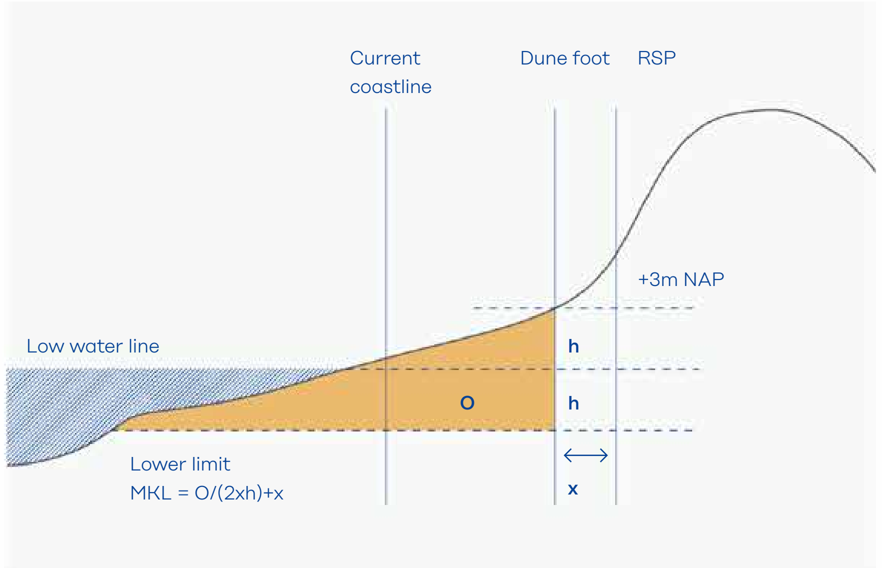


Figure 7.2
Rule for calculating the current coastline (MKL).

Management of flood defences

Management of flood defences is designed to guarantee safety both now and in the future, both in normal circumstances and in emergencies. Three types of management activity can be distinguished:

1. Firstly, each levee segment is assessed every twelve years to determine whether it still complies with the standard in the Water Act. If not, measures such as reinforcements will be needed.
2. Secondly, flood defences are regularly inspected. Maintenance is carried out where necessary. Inspection and maintenance also includes musk rat control.
3. Thirdly, licensing and enforcement are used to ensure that other uses of flood defence structures do not give rise to undesirable situations. The safety of the flood defences is paramount. Examples of other uses include underground cables, pipelines and housing.

Inspections (levee monitoring) are also carried out in exceptional situations, such as high water events, and measures are implemented where necessary.

Different types of management can be combined in practice. This is often the case with hydraulic structures, where functions associated with sluice gates and/or shipping generally dominate day-to-day activities. The authority responsible for this is often also responsible for managing the flood defence function, those these responsibilities may lie with other authorities. If so, coordination will be needed between the authority managing the flood defence structure and the water authority and/or waterway management authority as regards daily maintenance and operations (testing closure mechanism, for example).

Duty of care and statutory assessment

The management authority has a statutory duty to guarantee protection from flooding by ensuring that primary flood defences comply with the safety requirements, and for carrying out any necessary management and maintenance activities to ensure this is the case. This is referred to as a 'duty of care'. This duty of care includes licensing and enforcement. The Human Environment and Transport Inspectorate (ILT) monitors whether this duty of care for primary flood defences is being adequately discharged, on behalf of the Minister of Infrastructure and the Environment. It does so under the terms of the Primary Flood Defences Duty of Care Framework, which stipulates process requirements.

A poorly maintained levee may still comply with the standard, and an outstandingly maintained levee may in fact fall short, if for example the hydraulic load has increased over time. Periodic assessments therefore remain vital to establish whether the flood defences are still compliant. The Water Act stipulates that such assessments must be performed once every twelve years.

7.2 *Keur,* ledger and management register

The *keur*, the ledger and the management register are important tools for the management of flood defences. A *keur* is the term water authorities use to denote a byelaw that regulates the protection of flood defences, watercourses and associated hydraulic structures. In accordance with the Water Act the flood defence structure management authority ensures that a *keur* is adopted and that a technical management register is opened.

The *keur* is essentially a set of prohibited and mandatory actions. The prohibited actions are intended to prevent the flood defence capability being compromised due to the activities of third parties. Some of the prohibited activities may be carried out under licence, with an exemption or water permit issued under the Water Act. Licence applications are assessed on the basis of the water authority's policy rules. The licensing authority must set out the considerations and criteria on which its decision to grant or withhold the licence has been based. Mandatory actions generally involve maintenance obligations by third parties which are often associated with ownership. An exemption may be granted under certain circumstances.

The ledger sets out the required properties for flood defences, such as their orientation, shape, dimensions and structure. The ledger at any rate identifies features necessary for the flood defence structure to comply with the standard in the legislation. The dimensions, including the height, are particularly important in this respect. A ledger includes a map detailing the position of flood defences and the zones they protect.

A ledger contains two profiles: the management or maintenance profile and the clearance profile for the next 50-100 years. The details will differ from one management authority to another.

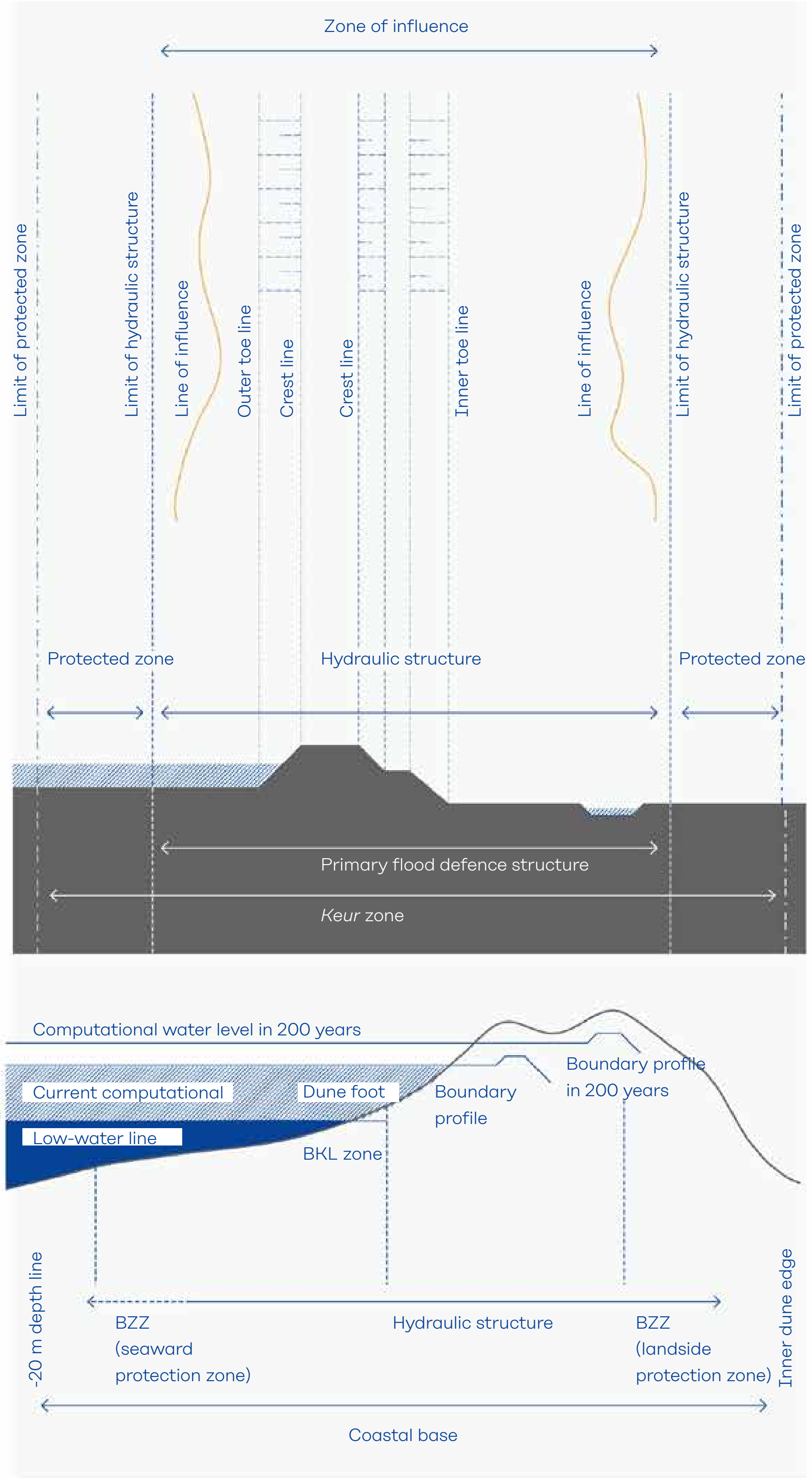


Figure 7.3 Examples of water authority *keur* zones.

The water authority describes in a technical management register the details of the structure that are relevant for the preservation of its flood defence capabilities and its actual condition. Unlike the ledger, the register contains current data on the structure.

Protected zones are strips of land that border on the flood defence structure and are needed to prevent damage caused by extraordinary burdens such as resource extraction activities, seismic surveys and explosions in pipelines. The flood defence structure and the protected zones together are all covered by the keur. The ledger contains details of how the various prohibited and mandatory actions actually apply in the situation on the ground. The ledger, which is required under the Water Act, is generally combined with the ledger that the water authority must compile under the Water Authorities Act (*Waterschapswet*) containing information on those who are responsible for maintenance, and what their maintenance responsibilities entail (section 73, subsection 2). It also provides practical details of the maintenance obligations relating to the actual situation.

In practice, flood defence structure management authorities use other names for the various zones in the area subject to the keur.

7.3 Inspection and maintenance

One important aspect of management is inspecting flood defences to obtain an idea of their condition. The following four steps are important:

1. Observation: gathering and recording information on the state of the flood defence structure, such as any damage to the grass cover.
2. Diagnosis: assigning value to the information gathered, such as assessing whether any damage poses a problem in terms of safety.
3. Prognosis: estimating likely developments in the state of the structure. Might a defect develop into a safety issue?
4. Operation: determining measures – physical and/or administrative – on the basis of the previous steps.

Day-to-day or corrective maintenance is carried out when unpredictable damage occurs to the flood defence structure. Daily maintenance cannot therefore be scheduled in advance. Examples of day-to-day maintenance include filling holes and cracks, repairing stone revetments, reseeding bare patches in the grass cover, removing fallen trees, repairing holes dug by animals and repairing fencing.

Regular or preventive maintenance involves recurrent activities that are planned on an annual basis. Safety is paramount, but management bodies also combine measures associated with wildlife conservation and recreational use with their regular maintenance activities. Examples include mowing the grass cover, removing root growth and thistles, pruning trees, collecting litter and flushing drains.

Major maintenance work involves adapting the structure within the existing ledger profile. This needs to happen from time to time as ageing processes such as settling and subsidence can impair the quality of the structure. Since such processes are predictable, major maintenance can be scheduled in advance. Examples include replacing the entire shoring, relaying a stone revetment, reprofiling the slopes and sowing a new grass cover.

Levee reinforcements involve changes to the flood defence structure extending beyond the existing ledger profile. This is not regarded as maintenance. Levee reinforcements are mainly carried out in response to the periodic statutory assessment of the structure.

Relaying a stone revetment, 1991.

7.4 Periodic safety assessment

Every twelve years the flood defence structure management body reports to the Minister of Infrastructure and the Environment on the general structural condition of the primary flood defences (under section 2.12, subsection 1 of the Water Act). The authority responsible for the major rivers also reports to the minister every twelve years on the extent to which these rivers comply with the ledger applying to them. This guarantees that politicians and administrators remain aware of the flood defences.

The assessment of safety is based both on alert values and on maximum permissible flood probabilities (Water Act section 2.2), hydraulic loads (Water Act section 2.3) and technical guidelines (Water Act section 2.6). Further rules for determining hydraulic load and strength, and for assessment methods are set by ministerial order. These rules form part of the statutory assessment instruments (WBI).

The Human Environment and Transport Inspectorate (ILT) monitors primary flood defences on behalf of the Minister of Infrastructure and the Environment. The ministry defines the assessment instruments and procedure in consultation with the water authorities. Final responsibility lies with the minister.

The statutory assessment is concerned with the predicted condition of the flood defence structure on a predetermined reference date, not with the structure as recorded in the ledger. The reference date is generally the last year of the assessment period. This means that the assessment is based on:

1. The expected levee profile on the reference date.
   The current levee profile must be corrected for the settling and subsidence expected to occur up to the reference date.
2. The predicted condition of the entire structure or parts thereof on the reference date.
3. Other uses.
   The assessment must take account of the influence of objects not associated with flood defence and of other forms of use.

The situation in the field provides the starting point for these three aspects of the assessment. Measurements taken on the reference date allow the ‘predicted situation’ on the reference date to be verified and adjusted if necessary.

Predicted situation on reference date

The statutory assessment includes an estimate of the condition of the flood defence structure on the reference date. This also takes account of the fact that the structure will be in a worse condition than expected at times of excessive loading. The failure probability of an asphalt cover will, for example, increase sharply during a high water event due to undetected or unrepaired cracks, which reduce strength. The likelihood of this is considered when calculating the failure probability.

Frequent inspection and rapid intervention can reduced the probability that a structure will be in worse condition than expected during high water loading. It may be that the failure probability implications of a scenario in which the structure is damaged, not repaired in time and subsequently fails can be reduced to negligible proportions by management and maintenance measures. If these implications cannot be reduced sufficiently, because this would require almost continuous inspections or interventions under extreme conditions, for example, structural measures such as levee reinforcements will be needed.

Measures required in connection with statutory assessment must in principle be paid for by the flood defence structure management body concerned, with the exception of reinforcement measures necessitated by changes to the standard, a change in hydraulic loads or a change in the statutory assessment instruments. Any such measures are eligible for subsidies and will form part of the Flood Protection Programme (HWBP).

The HWBP is a rolling programme. This means that flood defence structure management bodies have the opportunity to submit projects every year if the assessment has revealed that the alert value has been exceeded. The HWBP works on the basis of multi-annual programming, as not all projects can be carried out simultaneously. The programme is updated every year. The aim is for all primary flood defences to comply with the new standards by 2050.

08

Crisis management

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Crisis management involves preparing for potential flooding, responding to the threat of flooding and taking action after flooding has actually occurred. T*his chapter explores the role of crisis management in the risk approach, and the organisation of crisis management.*

8.1 Crisis management and flood risk

Fundamentals of Flood Protection defines crisis management as all measures and arrangements intended to prevent flooding during emergency conditions, and to minimise the potential effects of flooding. This includes forecasting high water levels, performing inspections during high water events, implementing emergency measures, issuing warnings, crisis communication and organising evacuations. In the event of major flooding as a result of a breach in primary flood defences, the scale and impact are so great and the probability so small that emergency services and crisis teams are not equipped or staffed to deal with them.

However, by using the rescue equipment available and providing information, crisis management organisations can help reduce the number of victims and other consequences by issuing timely warnings, increasing people's readiness and conducting evacuations. It may also be possible to prevent some of the economic damage. Since major flooding cannot be predicted until shortly before it occurs, crisis management when a high water event is imminent must be based on the infrastructure, buildings and organisations on the ground, and on people's knowledge and skills.

The effect of crisis measures is uncertain and depends heavily on the situation at hand. Actions and their effectiveness can only be discussed in advance in terms of probability. High water predictions are for example uncertain and, in the event of a threat, it is not clear whether, where and how a flood defence structure will fail. Human behaviour can sometimes unintentionally exacerbate the situation, for example if people end up trapped in a location that is more at risk due to a failed attempt to evacuate or flee the situation. Indeed, an evacuation can in itself cause great economic harm.

Crisis management cannot eliminate all risk, but it can reduce it. This was taken into account when the standards for primary flood defences were set. For example, the influence of preventive evacuation was considered in the loss-of-life risk when determining local individual risk and societal risk (see chapter 5). The economic damage caused by unnecessary evacuation was also taken into account when the economically optimum standards for flood defences were derived. The weaker the flood defences, the greater the chance that an evacuation will need to take place. The Water Act does not make any requirements concerning rescue capacity or other measures to limit the consequences. Crisis management does require continuous attention, however.

Evacuating the rivers area in 1995. Some 250,000 people and almost all the livestock were evacuated because the probability of a levee breach was regarded as excessively high. The discharge rate in the Rhine at Lobith was approx. 12,000 m3/s. The river levees were reinforced immediately after this event, as part of the Delta Plan for the Major Rivers.

Preparations for flooding are generally based on scenario analysis, whereby one specific scenario is considered in detail. Such analyses provide an insight into the effect of management measures on the progress of the disaster, given the selected scenario. These insights are important when it comes to preparing for disaster, though the possibility of other flood scenarios must also be taken into account, as well as the fact that the time between warning and the actual breach is very important when it comes to crisis management. Scenario analysis is not however directly suitable for assessing the effectiveness (including cost-effectiveness) of crisis management measures, because the probability of disaster also has a bearing on effectiveness. In the Netherlands, the establishment and maintenance of a large crisis management organisation for flooding would not be very cost-effective because of the small probability that a flood disaster will actually occur. This also explains why, in practice, the focus is on the most effective possible deployment of existing emergency services capacity.

Waalbandijk levee at Ochten, where a monument commemorating the narrowly averted disaster was unveiled in 2016.

8.2 Organisation of crisis management

Crisis management in the event of major flooding involves interaction between several organisations, each of which has its own responsibilities. Roughly speaking, we can distinguish between the functional and administrative columns. The functional column consists of organisations concerned with water, such as the Ministry of Infrastructure and the Environment and the water authorities. The administrative column is made up of organisations concerned with general administration, such as the Ministry of Security and Justice and the security regions.

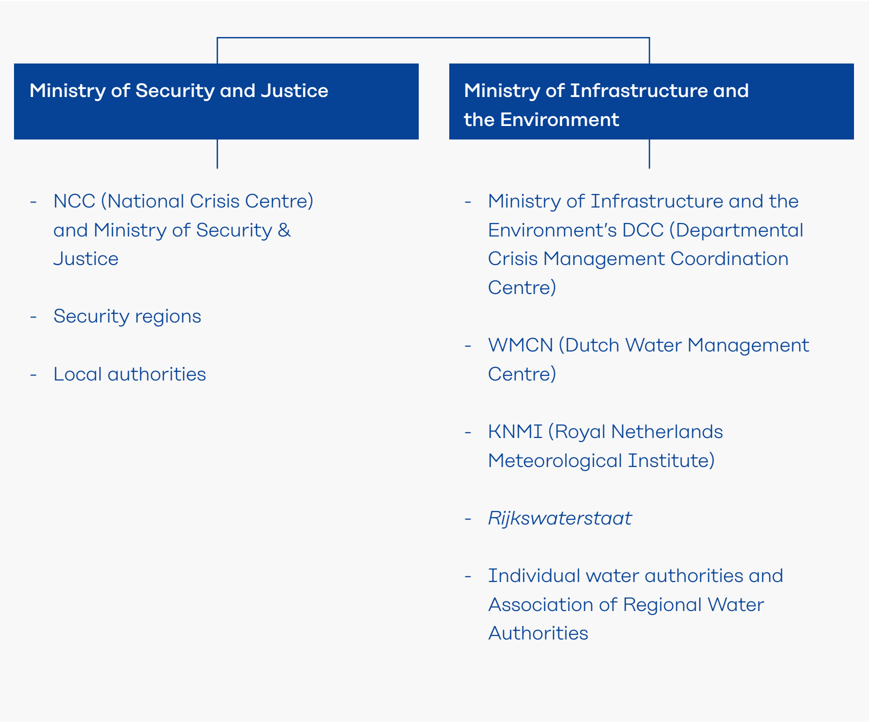

Figure 8.1 Crisis management in the event (or threat) of major flooding involves interaction between the water column and general administration.

Multi-layer Safety and the Safety Chain

In the worlds of crisis management and flood protection different terms are sometimes used to denote similar concepts. In flood protection, 'multi-layer safety' (see chapter 5) is used to arrive at an efficient mix of measures. In the world of crisis management, this is also referred to as the 'safety chain'.

The term 'safety chain' can easily lead to misconceptions, as the flood protection chain is not in fact as weak as its weakest link. The importance of crisis management depends to a large extent on the probability of flooding. Where there is a relatively small risk of flooding, investments in crisis management will be less cost-effective than in situations where there is a relatively large probability of flooding. Preventive measures thus have a major impact on the cost-effectiveness of measures targeting spatial design and crisis management. This explains why the term 'multi-layer safety' is deliberately used in flood protection policy.

The following organisations and teams are involved:

- **NCC: National Crisis Centre**. National coordination in the event of a crisis or disaster is in the hands of the NCC. The National Crisis Coordination Consultative Committee (LOCC) translates policy into operations. In the event of a crisis the ministries responsible and other crisis management partners meet under the auspices of the NCC to support ministers in their decision-making. The NCC keeps the authorities informed during crisis situations, and is available 24/7.

- **DCC: Departmental Crisis Management Coordination Centre**. Every ministry takes measures in its own field to tackle disasters and crises. Each has a coordination centre for the purpose. The Ministry of Infrastructure and the Environment's DCC is responsible in the event of major flooding. If several ministries are involved in tackling a crisis, the national crisis structure comes into operation.

- **LCO: National Flood Threat Coordination Committee**. The LCO is responsible for providing accurate information for early warnings of enhanced flood probabilities and updates on which areas are at risk. *Rijkswaterstaat*, the KNMI, the water authorities and the Ministry of Infrastructure and the Environment's DCC collaborate in the LCO.

- **WMCN: Dutch Water Management Centre**. The WMCN informs and advises the national and regional water authorities as to expected water conditions in extreme situations such as drought, major water pollution and imminent flooding. The Dutch Water Management Centre works closely with the KNMI, *Rijkswaterstaat*, the water authorities, security regions and the Ministry of Infrastructure and the Environment's DCC. They coordinate national water management and crisis response.

The lagoon behind the Hondsbossche sea defences.

- ***Rijkswaterstaat* regional services**. These regional organisations act on the WMCN's forecasts, closing storm surge barriers, for example.

- **Security regions**. The security regions and the local authorities are jointly responsible for decisions with a bearing on public order and security, including in the event of measures that have an impact on public life. The security region provides information to various stakeholders in the event of imminent flooding, including farmers, energy companies and the healthcare sector. Floods are often so large-scale that they cross municipal boundaries. Indeed, the area under threat or actually affected may even cover several security regions.

- **Water authorities**. One important responsibility of the water authorities during high water events is to provide information on the strength of the flood defences, and emergency work on the structure, such as placing sand bags on the crest of a flood defence structure. To keep the structure intact for as long as possible, the chairman of the water authority has special powers to institute measures to reinforce flood defences in the event of a threat.

Dike guard and dike brigade

To remain informed of the current state of the flood defences during a high water event, each water aurhtority has a 'dike guard' (professionals) or a 'dike brigade' (trained volunteers). The team inspects the structure and passes on its observations to action teams, which may inform operational and policy teams, depending on the seriousness of the situation. Measures are taken in response to the problems observed. The crisis teams assign responsibility for the management and emergency measures and coordinate their implementation. The water authority may carry out the measures itself, or it might have a standby arrangement with a contractor or other party, such as the Ministry of Defence (to which it submits a request for assistance). It is important to take account of the fact that people may need to be deployed for a long time, and to organise relief and sufficient food and drink. Fatigue among professionals and volunteers must also be considered.

8.3 Forecasting and alerts

High water forecasts are vital for informing the public in time when there is a threat of high water levels and for taking timely measures. Forecasts are issued and made public by *Rijkswaterstaat*, both on its website and in high water reports.

A high water forecast is not a flood prediction. The strength of the levee also has a major bearing on whether flooding occurs. Nor is it certain under what conditions flooding will occur. The Water Act no longer sets any requirements as to the water level that must be safely withstood. The higher the water level, the greater the probability that a flood defence structure will actually fail. This can be illustrated using fragility curves (see box in chapter 5). When using fragility curves in crisis management, the uncertainty of the high water forecast must always be borne in mind. The actual water level may after all differ from the high water forecast.

The uncertainty associated with high water forecasts increases, the longer in advance they are issued. Forecast uncertainty depends both on the water system and on the location. The uncertainty is inherent in the system to some extent, but it also depends on the availability of monitoring data and the quality of the models used. Roughly speaking, more uncertainty is associated with forecasts of extreme water levels along the coast and in lakes than in the rivers. A high water level is more difficult to predict in the Meuse than in the Rhine.

Figure 8.2 shows how long in advance a flood warning can be issued. Generally speaking, high water warnings can be given a day earlier than ten years ago, as research has enhanced knowledge in the meantime.

When there is a threat of flooding the Dutch Water Management Centre (WMCN) issues a warning or an alert, in response to the expected exceedance of a predetermined criterion, such as the water level or the discharge rate. To make clear the threat to all concerned, the WMCN uses a colour code. The code is shown in table 8.1, along with examples of the levels used for several coastal locations.

The Minister of Infrastructure and the Environment sets alert levels for primary flood defences every six years. If it expects the alert level to be exceeded, the body responsible for managing a flood defence structure will set the disaster plan and the necessary disaster response plan in motion. It is important that the upscaling criteria take account of the actual strength of the flood defences, as well as the predictability of various failure mechanisms.

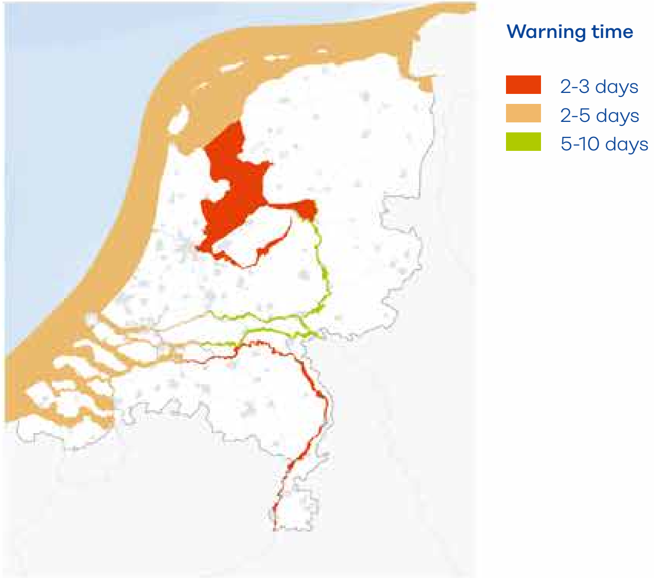

Figure 8.2 Warning times for high water along the coast, rivers and lakes.

Table 8.1 Colour coding used in communications to indicate different threat levels.

	Vlissingen	Hook of Holland	Den Helder
	Water levels in m relative to NAP		
Code green Regular daily water management. Pre-warning phase	3.10	2.00	1.70
Code yellow - Water levels expected to be higher in some places. - Water managers take standard measures. User functions on and beside water, such as shipping and activities in flood plains or other unprotected areas may be restricted.	3.30 Frequency: 1.3 x per year	2.20 Frequency: 3.5 x per year	1.90 Frequency: 2 x per year
Code orange - Threat of high water expected to increase. - Water managers take further measures. If necessary, major measures are prepared. User functions on and beside water restricted. Flood defences may sustain slight damage.	3.70 Frequency: 1/5 per year	2.80 Frequency: 1/5 per year	2.60 Frequency: 1/6 per year
Code red - Serious and exceptional situation in water system (expected). - Major emergency measures might be taken. Damage may occur. National security could be at stake.	4.10 Frequency: 1/25 per year	3.65 Frequency: 1/100 per year	3.45 Frequency: 1/100 per year
Extremely high water levels	5.30 Frequency: 1/4,000 per year	5.10 Frequency: 1/10,000 per year	4.50 Frequency: 1/10,000 per year

Management and emergency measures

In the event of high water levels the manager of the flood defence structure will attempt to prevent flooding, by closing off cuts, for example, inspecting the structure and, if necessary, taking extra measures such as placing sandbags. A distinction can be drawn between management measures and emergency measures. A management measure is part of the flood protection system, and is aimed at achieving the required flood probability. The efficacy of such measures must be clearly guaranteed, with regular emergency drills for example. A risk analysis can identify how management measures can contribute to reducing the risk. Alerts, mobilisation and implementation are particularly important in this respect.

If measures do not enjoy this level of guarantee, they are emergency measures, which are not taken into account in the periodic statutory assessment of flood defences.

Security regions' protocols also set out upscaling criteria linked to the various phases of the Coordinated Regional Incident Response Procedure (GRIP). GRIP phases denote the involvement of strategic and tactical teams for general management. The level of upscaling also depends on the impact of the threat. The security column can alert the public on the basis of high water reports and information and advice from the water authority.

8.4 Public information

Public information includes both risk communication and crisis communication. Risk communication aims to raise awareness of risks associated with water, and provide information on potential action. Crisis communication occurs in the event of an imminent or actual flood. In such circumstances, public communication uses various media and resources. The authorities attempt to provide clear and consistent messages in the event of a threat to safety.

Local authorities inform residents and companies about risks in the area. Information on local risks can be found on risk maps. The Water Decree also stipulates that flood risks must be shown on maps, in accordance with the EU Floods Directive (ROR). The Decree also requires risk maps to be updated at least once every six years. The Ministry of Infrastructure and the Environment and the water authorities provide information on potential action to raise awareness of risks associated with water. The National Water and Flood Information System (LIWO) provides information for professional users on how to prepare for the consequences of flooding.

In the event of a flood threat or actual flooding, the authorities must provide regular updates on the situation. The security regions provide information about possible actions, and have arrangements with radio stations which act as emergency broadcasters. Special websites such as www.crisis.nl and channels like 'NL-alert' also provide information. However, the authorities do not have the exclusive right to provide information; the traditional media and social media also disseminate information and images.

8.5 Handling claims

After a flood, the question of who will pay for the damage always arises. In the Netherlands, the Disasters and Serious Accidents (Compensation) Act (*Wet tegemoetkoming schade bij rampen en zware ongevallen*, WTS) comes into effect if central government designates a flood a national disaster. The WTS was introduced in 1998 to allow central government to reimburse victims for a large proportion of the damage suffered. It has been declared applicable on five occasions since 1998 following localised flooding after extreme rainfall and embankment breaches in Wilnis and Limburg.

In almost all countries the government pays the costs of flooding, sometimes with the help of a disaster fund, and often using insurance companies as intermediaries. Damage resulting from flooding in the Netherlands is not covered by standard insurance, mainly because of the cumulation of damage in the event of major flooding.

Flooding at Tuindorp Oostzaan in January 1960; levee breach along Midden Zijkanaal H.

Further reading and references

The Water Act can be found on wetten.overheid.nl/BWBR0025458. Other legislation referred to in this publication can also be found on this website (in Dutch). The list of references includes the main sources which the authors used when compiling the Fundamentals. It also lists several general works of reference and reports. The list is not comprehensive.

Interesting websites:

www.enwinfo.nl has all advisory reports published by ENW concerning current issues associated with flood protection.

www.helpdeskwater.nl/onderwerpen/waterveiligheid/primaire has all documents pertaining to the assessment and design of flood defences.

www.deltacommissaris.nl contains information on the Delta Programme.

www.uvw.nl has information on the Association of Regional Water Authorities. Water authorities are responsible for managing flood defences, regional water management and purification of waste water.

www.stowa.nl contains information from the Foundation for Applied Water Research (STOWA), the centre of expertise for regional water managers in the Netherlands. STOWA develops, gathers and disseminates the knowledge needed to allow water management authorities to deal with the challenges they face.

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Figure 2.1 is a reworking of figures from: P.C. Vos, Origin of the Dutch coastal landscape. Long-term landscape evolution of the Netherlands during the Holocene, described and visualized in national, regional and local palaeogeographical map series. Barkhuis, Groningen, 359 pp. 2015.

Figures 2.2, 2.3, 2.5, 3.6, 4.3, 4.4, 4.6 and 4.11 are reworkings of figures commissioned by RWS from Deltares.

Figure 3.2 is a reworking of a figure from the report: Erodibiliteit en kans op het ontstaan van zettingsvloeiing als maat voor stabiliteit van oevers, onderwatertaluds en rivierbodem van de Lek, Utrecht University and Deltares, November 2011.

Figure 3.3 was made by RWS.

The photograph on p. 23 comes from the Drents Overijsselse Delta water authority.

The photograph on p. 35 is from the National Archives/Spaarnestad Collection/ANP.

The photographs on p. 37 and p. 38 are from Royal HaskoningDHV.

Figure 3.4 is from the Watersnood Museum in Ouwerkerk www.watersnoodmuseum.nl

Figure 4.8 is a reworking of a figure in the report by the Delta Commission, 1960: p. II.2-4.3.

Figure 4.12 comes from the report Achtergronden bij de normering van de primaire waterkeringen in Nederland, Ministry of Infrastructure and the Environment, August 2015.

Figure 4.13 is a reworking of a figure from the report De normering van primaire waterkeringen van de (voormalig) categorie b, Ministry of Infrastructure and the Environment, June 2016.

The overview on p. 99 comes from: HNS, Handreiking Ruimtelijke Kwaliteit, May 2015, commissioned by Rivierenland water authority.

Figures 7.1 and 7.2 come from: RWS, Kustlijnkaartenboek, 2016.

Figure 7.3 comes from Hoogheemraadschap Delfland and Rivierenland water authority.

The photograph on p. 121 is from the RWS image library.

The photographs on p. 126 were taken by Jan Rikken.

Figures 8.2 and 8.3 are reworkings of illustrations in the Landelijk Draaiboek Hoogwater en Overstromingen, 2015.

Book credits

Fundamentals of Flood Protection was written by a project team, on behalf of the Expertise Network for Flood Protection (ENW), in the period October 2015 – September 2016. The team members were:

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- Martin Nieuwjaar (Waternet)
- Dr. Ilka Tánczos (RWS)

The study was overseen by a focus group whose members were:

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The Expertise Network for Flood Protection's four working groups – ENW Kust, ENW Rivieren, ENW Veiligheid and ENW Techniek – commented on the draft version of this document:.
Don de Bake (ENW coordinator), Michel Tonneijk (RHDHV, chapter 6) and Dr. Bas Kolen (HKV lijn in water, chapter 8) also contributed to the text.

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The Expertise Network for Flood Protection (ENW) is a knowledge network for flood protection specialists. Its most important task is to advise public organisations with responsibilities for flood protection on guidelines and technical reports, current issues and innovations.

Waaldijk levee at Vuren.

Protection from flooding is vital for quality of life in the Netherlands. The Water Act therefore sets out standards for flood defences. Water authorities and Rijkswaterstaat ensure that the primary flood defences they manage comply with these standards. This requires practicable, uniform methods of calculation that can be used to assess the safety afforded by existing flood defences, and new flood defences in the design stage. Of course sufficient knowledge and experience of applying the methods are also needed. It is therefore vital that bodies managing flood defences, knowledge institutions and industry share their knowledge and experience.

The methods and knowledge needed for this purpose can be found in regulations, guidelines and technical reports. *Fundamentals of Flood Protection* describes the principles behind flood protection in the Netherlands. It covers issues like how to deal with uncertainties and how to derive technical requirements, as well as various aspects that play a role in the design of flood defences, continuous protection from high water levels, and crisis management.

Fundamentals of Flood Protection has been written by the Expertise Network for Flood Protection (ENW) at the request of the Ministry of Infrastructure and the Environment, and replaces the 1998 publication *Fundamentals of Flood Defence*. The ENW hopes that *Fundamentals of Flood Protection* will help enhance understanding of what goes into protecting the Netherlands from flooding.

Gert Verwolf
Chair, ENW