Flood control in the Netherlands

A strategy for dike reinforcement and climate adaptation
This brochure provides information on the strategy taken by the Rijnland Water Control Board to secure flood safety within the Rijnland District. Although the best possible care has been taken in preparing this brochure, formal policies and company objectives have been established in the Water Management Plan 4 (2009). For regulations and legislation, reference is made to the Rijnland ‘keur.’
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Living below sea level

Dike of the Haarlemmermeer boezem canal, alongside the Lisserpoelpolder
Sixty percent of the surface area of the Netherlands is at risk of flooding — along canals, rivers and lakes. We work and live on the beds of lakes that we’ve pumped dry two centuries ago. Dikes and levees and continuous pumping prevent these lakes from refilling. We’ve built cities on peat beds that would sag if it wasn’t for dikes and levees to keep this water-rich substrate saturated and stable. Our beaches and sand dunes absorb the forces of a rising sea that would overflow an otherwise flat land. To offer protection against such floods, the Netherlands is divided into 53 dike ring areas. The urban agglomeration of the western Netherlands, for example, is encircled by one solid ring of dikes and dunes: Dijkring 14. These ‘primary’ compartments contain polders, each surrounded by smaller dikes and levees. These are the regional flood defences, built to prevent flooding from the ‘boezem’: the smaller rivers (the Oude Rijn and Gouwe) and the main channel system of the Rijnland District. Should a breach occur in the primary defences, the regional defences provide evacuation routes and limit the spread of the water.

Safety is and has always been the number one priority of the Rijnland Water Control Board. Protection against flooding is a prerequisite for living and working in this part of the Netherlands. The Rijnland District stretches between The Hague and Amsterdam (45 km) and from Haarlem to Gouda (50 km). Over 1.3 million people live, work, travel in this area, which is separated from the North Sea by a line of sand dunes not even 1 km wide in places. Climate change, sea level rise and soil subsidence set boundary conditions for water management in the 21st century. The flood defences must be high and strong enough to withstand the changes that face us. To improve flood defences within its area, the Rijnland Water Control Board will implement a number of measures in the coming years. This brochure provides information about these measures. Residents directly affected by the measures will be addressed separately.

The water control boards maintain the correct water level in ditches and canals. Surplus water is pumped through these ditches into canals and rivers and then out to sea. During dry periods in summer, river water is allowed inside to compensate for evaporation and salinization of groundwater. The water control boards manage and maintain the dunes and dikes so that they are strong enough and in good condition.
Together with the provincial governments, the water control boards of the western Netherlands are now assessing whether the regional flood defences meet new, stricter safety standards. Flood defences that do not meet the required safety level must be improved, both in anticipation of climate change and to keep our system of levees up-to-date.

In 2008, Rijnland began testing of all dikes and levees for height and stability – and plan for the necessary improvements. Our district has 1280 kilometres of dikes and levees, equivalent to about 9 percent of all the secondary flood defences in the Netherlands. The Rijnland area is one of the most densely populated and industrialised regions in the world. Here also lies the national airport, in one of the deepest polders at almost 5 metres below the sea level. All urgent and at-risk dikes, totalling about 150 kilometres, will be prioritised for improvement in the coming years. Work on our dikes will continue on a large scale up to 2020 at least. The total programme will cost about 300 million euros, which will be paid in taxes by the people living in the Rijnland area. With this large investment and proper maintenance, the condition of the water system is assured for the next 30 years. Economic, social and ecological interests in the western Netherlands are substantial and growing. A regional flood therefore will have a disruptive effect on society as a whole. The advice of the Delta Committee, the government’s advisory board on flood safety, to be prepared for large changes on a time scale of 50 to 200 years, corresponds with the mission of the water control boards. Dikes, levees, and dunes make the characteristic Dutch vistas. They are flood defences and the basis of our prosperity and future.
Flood control in the Netherlands - Rijnland

The Hekslot between Haarlem and Spaarndam
A diagram of the Rijnland area. In dry periods (top) fresh water is allowed in from the Hollandse IJssel to compensate for evaporation and salinization of groundwater. In wet periods the pumping stations at Katwijk, Gouda, Halfweg and Spaarndam return the surplus water to sea.
Why make dike improvements now?
Increased economic activity, with more property and lives in vulnerable areas than ever before, requires ever higher standards for our flood defences. To be prepared for the changes that we are faced with, the safety levels currently provided by our dikes and levees are tested. This fits in with a wider range of measures commissioned by national authorities. For example, river beds are widened and deepened to accommodate higher water levels within the ‘Room for the River’ programme (Ruimte voor de Rivier). Along the coast, ‘weak links’ in our beach morphology have been identified and are currently strengthened.

Land use and climate adaptation

Regular maintenance of dikes and levees is a part of our core business. All 1280 kilometres of dikes and levees in the Rijnland area are inspected annually. The inspectors cover the dikes on foot, initially in the spring and, in the case of a long spell of dry weather, many parts again in the summer. The resulting repairs guarantee a high level of security. But this is not enough. Dry summers will be more frequent this century. Peat dikes will dry out and may break under the pressure of the water in a canal. A season will be too dry in one year and too wet in the next. Extreme rainfall events (‘peak precipitation’) appear to occur in the coastal area in recent years, perhaps as a result of warming North Sea surface water. On either side of the Oude Rijn, the river running centrally through the area, soil subsidence is taking place at a rate of over a centimetre each year. By the end of the 21st century, this will have produced an uneven decrease in the elevation of the ‘boezem’-canal system and surrounding polders of more than a metre. Urbanization has disrupted the hydrological cycle. The total built-up or asphalted area in the Netherlands has doubled since the Second World War and will increase again by some 25% in the years to come. This reduces the natural water storage capacity and speeds up surface run-off.

In the Netherlands, flood control and safety are a statutory task of water control boards under authority of national and provincial governments. Private parties and municipalities are required to have spatial developments tested with our water management plans. The consequences of a flood are much greater today than ten or fifty years ago. Following the flooding disaster of 1953, during which more than 1800 people died, the Delta Committee produced a cost-benefit analysis of reinforcement of the primary flood defences, i.e. along the coast and major rivers. Investments required to limit the flood risk are plotted against the direct economic damage. And the value of commodities in the area behind the dike (homes, infrastructure and businesses) continues to change. A flood will also cause substantial indirect damage, for example from the failure of electricity stations, which can easily be out of use for months. When lives potentially are going to be in danger, we need to plan for timely evacuation.
The whole of the Netherlands (here shown upside down) is roughly the same size as the Mississippi Delta and half the state of Louisiana (right). Rijnland equals the size of the area between Sacramento and San Francisco, where Dutch engineers are currently helping to reinforce about 1250 km of peat dikes.

<table>
<thead>
<tr>
<th>Safety level</th>
<th>Direct economic damage (million euro)</th>
<th>Water level probability per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0 – 8</td>
<td>1/10</td>
</tr>
<tr>
<td>II</td>
<td>8 – 25</td>
<td>1/30</td>
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<tr>
<td>III</td>
<td>25 – 80</td>
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<td>IV</td>
<td>80 – 250</td>
<td>1/300</td>
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<tr>
<td>V</td>
<td>&gt;250</td>
<td>1/1000</td>
</tr>
<tr>
<td>rivers</td>
<td>primary defences</td>
<td>1/1250, 1/2000</td>
</tr>
<tr>
<td>Dijkring 14</td>
<td>primary defences</td>
<td>1/10 000</td>
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Classification of the polders of the western Netherlands into safety classes is based on the calculated economic damage.
Safety levels and differentiation

After hundreds of years, the Dutch water system has become finely tuned. The water level in the Rijnland ‘boezem’ is always at or near 0.60 metres below the Amsterdam Ordnance Level (NAP), which roughly corresponds with mean sea level around AD 1700. The maximum safety level for levees is a 1/1000 chance (‘once in a thousand years’) that the dike will overflow. The City of London is protected at the same level of ‘Low Probability.’ For comparison, the exceedance risk for Dijkring 14 in the western Netherlands is once in 10,000 years. Diked areas along the Meuse River may overflow once every 250 years; once in 1250 years along the Rhine and other major rivers. The exceedance risk relates to the occurrence of extreme water levels that a dike may have to withstand. Because the dike will be designed to also hold this maximum water level, the actual probability that a dike fails is even smaller. In contrast, contingency plans describe the ‘flood risk’ of an entire diked area, considering all possible failure mechanisms that may cause a flood.

On the basis of a risk analysis prepared by the water control boards, the provinces of Noord-Holland, Zuid-Holland and Utrecht have set a safety standard for every polder. Five safety classes and corresponding ‘boezem’ dike heights have been determined by the Association of Provincial Authorities (Inter Provinciaal Overleg IPO). To limit the number of polders with varying safety levels, Rijnland has recommended that class 3 (1/100) will be the lowest class for its region. This standard implies that society accepts – in theory – a risk of flooding once every hundred years. In reality, the ruling perception is that the government has eliminated the flood hazard.
Counting down: the Alexanderpolder (1865-1874) northeast of Rotterdam, for many years the lowest point in the Netherlands but now surpassed by soil subsidence further north.
Water management in a man-made landscape

Dutch policies on flood safety focus on ‘resilient designs’ and use of natural processes. The stability of our coastline, for instance, is ensured by providing sand supplements that are redistributed by coastal currents. The construction of dikes, land reclamation and groundwater management, however, has transformed the western Netherlands into a patchwork of ‘cultural landscapes.’ The containing forces of levees and dikes are especially important at the borders between these landscapes, between elevated, water-saturated peat areas and deep polders.

The water control boards were put in place to ensure proper water management and facilitate the use of the land. Many of the waterways and ditches were created to drain marshy plains, for transport of peat and to make the area inhabitable. The water control boards are the first democratic institutions of the Netherlands, remaining pretty much the same throughout the centuries. The autonomous collection of water taxes has always prevented dike maintenance from becoming dependent on political preference or instability, as indeed it was during the late Middle Ages. Rijnland was the first water authority to be established. It originates back to 1248, when a complex of dikes and drainage sluices was constructed along the River IJ to improve flood safety (see plate on page 48). The collaborative effort required to maintain this system also marks the start of the Rijnland Water Control Board. In the twelfth century, the Oude Rijn River sanded up at Katwijk. Surrounding towns and the city of Leiden suffered from high water and floods. Storms and waves from the IJ estuary rolled in through the Haarlemmermeer. As in today’s situation, population growth and changing land use patterns meant that the risk of an incident rapidly increased. As with the Delta Project, following the disaster of 1953, and the improvements currently being made to the flood defences, the drainage and construction of windmills demanded large investments.
The Rijnland area contains about 950 km of ‘boezem’-dikes (red), which contain the main waterways, and over 300 km of the smaller polder levees (yellow). This elevation map shows the division of the area into deep polders (dark blue), peat meadow areas (light blue), and the sandy soils bordering the coastal dunes and Oude Rijn river channel. Only the yellow and green areas lie at or above sea level.
Soil subsidence: 7.6 km³ of water are removed each year to keep the Dutch polders dry — more than the capacity of the whole of the IJsselmeer, the former Zuiderzee (5.2 km³). Using steam-driven and electric pumping stations, a polder was drained in the nineteenth century within five years. Thus, the Haarlemmermeer was created (1852). Peat exploitation, begun in the Middle Ages, has resulted in soil subsidence of over four meters in some places. This peat extraction produced areas of deep polders, surrounded by peat dikes. Drainage and compaction (and oxidation) of the subsoil is still causing subsidence of over a centimetre a year in the remaining peat areas. This will add more than a metre to the depth over the next century, relative to the current sea level, requiring a greater effort to remove surplus water and to ensure adequate defences.

Drive ways are supported by poles but the yards have been heightened in anticipation of soil subsidence.

Red indicates maximum peat oxidation and soil subsidence of at least 1 cm per year.
The state of our flood defences
The strengthening of a 1500 metres-long stretch of dike near the village of Rijnsaterwoude marks the start, in the spring of 2008, of large scale dike improvements to be undertaken over the next ten years. The dike protects a small, densely populated and almost five metre deep polder bordering the Braassemermeer, a wide lake. It has been heightened and reinforced to meet the required safety level and cope with wave run-up across the lake.

Testing regional levees
The Rijnland register of flood defences contains the dimensions and exact location of all dikes and levees in the district. The register provides the formal frame-of-reference for everything dike-related. Over a period of five years (between 2007 and 2012) Rijnland assesses the strength and stability of the entire 1280 kilometres of its dikes and levees. For about 800 km this will be done through detailed analysis of the soil composition and the groundwater level within and beneath the dike. Field research, laboratory shear tests, and model calculations contribute to the assessment. An initial inventory shows that at least a quarter of the territory, i.e. 300 kilometres, will require reinforcing. About 500 kilometres (partially overlapping) are not as high as we would like to see.

The large-scale construction work on dikes will also affect the roads and traffic on and near the dikes. Many roads in the Rijnland area run over the dikes. Municipalities may determine themselves, based on theodolite-measured elevations, whether or not a dike requires heightening. The guideline to be followed is that boezem dikes must lie at NAP -10 cm or 50 cm above the standard level of our main canal system (NAP -60 cm). Polder dikes must be a minimum of 40 cm above the water level in the ditches. In some areas, the peat subsoil is subsiding at a rate of one centimetre a year. To compensate for the sagging effect, dikes will be made up to 50 cm higher than necessary in areas of subsidence. The water-blocking height of a dike is as much as its impermeable clay layers. Sand and rubble may lie on top of this, but do not contribute to the damming properties of the flood defence. To plan efficiently, we organize dike improvements and road constructions together with the relevant municipalities.

Construction works
We currently estimate that there are 300 kilometres of improvement works with a moderate to high priority. At-risk sections are identified through visual inspection, height measurements, and the detailed assessment of strength and stability. Dikes which score poorly in terms of height but which are strong and stable will be included in the regular maintenance cycle. Annual maintenance will be intensified, to cope with the extra work. The real improvements in flood safety are to be made by strengthening and reinforcing dikes.

Negative results of the testing programme, the weak areas, are carefully analyzed to identify what strengthening exactly will be needed. If, for example, a section of a dike is found to be unstable because the polder ditches lie too close to the dike, then we fill the ditches and leave the dike alone. We tailor the work to the situation. Following dike reinforcement, a dike will be as wide and ‘robust’ as necessary. A ‘robust’ dike is designed to meet future require-

A diagram demonstrating groundwater flow within and beneath a dike, with the subsurface composition to a depth of about 15 metres. A layer of clay has been applied on the inner (polder)-side of the dike to increase stability.
ments and not too sensitive to coming changes in conditions. If there is no space to widen the dike, we need to take to the much more expensive option of steel sheet piling. Dikes alongside lakes and other water bodies with wave run-up are to be heightened by an extra 20 cm on average. Ecological embankments (gentle slope, planted with reed) will be created as much as possible, for healthy waters and to break the swash.

Particular attention is paid to peat dikes in the Rijnland area. These are often peat remnants that were left to facilitate peat excavation in past centuries. Peat dikes can become unstable while drying out during the summer. These dikes often form the boundary with deep polders and a breach could have serious consequences. Increasing the height to meet long-term objectives in one go would only lead to increased subsidence on the soft peat subsoil. We find that adding clay to a maximum of 30 cm will yield an optimal life span of 10 to 20 years. Adding a little at a time – the approach taken for centuries – has resulted in steep embankments. The intention now is to widen the dikes at their base and take it from there.

We aim to improve flood defences at a rate of 30 kilometres a year. An improvement project is expected to run for an average of 3.5 years. Because we started in 2008, we expect the first 30 kilometres will be completed at the end of 2011. Of course, projects do not always run as smoothly as planned. This is a new and ambitious programme for all parties involved, for the Water Control Board, the engineering firms and local residents. There are several complicated procedures on licence enforcement, as well as European Union directives on archaeology (since 1992) and ecology (2000). Although we expect a slow start, we should soon pick up speed. Every year until 2012, the most urgent sections will be clustered for reinforcement.

Who does what?
The national government is responsible, together with the water control boards, for the stability of the coastline and the ‘primary’ flood defences. Safety against flooding became a statutory task through the Flood Defences Act (Wet op de Waterkering) in 1995. The act describes what is to be done and by whom. The task of maintaining the regional defences lies completely with the water control boards. This responsibility also covers the financial aspects. The Water control boards manage the dikes and implement policies to facilitate this work. Rijnland also does small maintenance on the dunes, such as planting (marram) grass or adding sand or clay following a storm. Daily maintenance of dikes and levees, i.e. mowing, is the responsibility of the owner of the land. The provinces formally set the safety standards and provide supervision to ensure that the Water Control Board meet these standards. Rijnland does have some room to manoeuvre. We take into account the needs and expectations of stakeholders in the area. Because time and resources are limited we choose and prioritize what we do, what we don’t do, and how we do it.

Rijnland has been commissioned by the provinces North Holland and South Holland to test all flood defences and, where necessary, to improve them before 2015. If a dike does not meet the required standards, the safety situation in the adjacent polder
A levee is designed to carry a maximum weight (see: Guidelines, p. 59).

Failing of a polder levee at Wilnis during a summer drought in 2003.

Collapse of a levee in the US.
is compromised. To fix this, we investigate all options. The Provincial Authorities, ‘Ordinance on flood defences in the western Netherlands’ (Verordening Waterkeringen West-Nederland) states that the Water Control Board is authorised to construct, reinforce or move a dike (Article 11). The decision to accept and execute a particular plan for these activities is made by the Chair (‘dijkgraaf’) and supervisors (‘hoogheemraden’) of the board. Residents and stakeholders may then submit their opinions of the draft plan. The Plenary Meeting of the Council (‘Verenigde Vergadering’), our democratically elected directorate, will take the submitted opinions into consideration when deciding on the final reinforcement plan.
Reinforcement of dikes surrounding the Groote Westeindsche Polder, here by the A4 motorway, will start by the end of 2009.
Reinforcing a dike usually involves stabilising the dike by widening it (top). This requires polder ditches to be filled and moved. Heightening and reinforcing a dike in a built up area where there is little space available for widening necessitates expensive technical solutions (centre: before reinforcement, below: after reinforcement).
Growing with the sea level

Much of the western Netherlands was deposited in the past 6000 years as a tidal plain. The sea and rivers frequently flooded the land and elevated it with the sand and clay they left. Because the tide coming in has much more energy than the retreating water, sand is transported from the sea to the coast. In this way, thousands of years of daily tides left deposits of sand in the channels and branches of the rivers. The first settlers on this low-lying territory were frequently forced to leave their land to the mercy of the water and built higher-lying refuges and later dikes. As a result of draining and diking the land, the polders have been starved from clay or sand for about a thousand years.

Only when the sea level rise began to level off, did the Dutch coast stabilise and develop. The first beach ridges, now beneath the town of Rijswijk, are about 5500 years old. This ancient coastline runs from Noordeinde Palace through the Rijnland area to the Stompe Toren church in Spaarnwoude. Recent archaeological research shows that the coastal ridges were once grown over with oak woodland and that settlements existed in the dune valleys, with farms and arable land, as early as the seventh century. It is this phenomenon, the creation of the coast by the sea, which makes the Netherlands fairly resistant to climate change today. The steady rising sea level and large amounts of sand available from the North Sea have resulted in growth of the coast from the year A.D. 1000 onwards. The wind blew the sand across the dry beach to form dunes, so that at the time the inhabitants of the area were more concerned with fighting the shifting sand than the water. The Kennemer dunes, between Haarlem and Velsen, were blown to reach heights of 50 metres above sea level. While these dunes formed, the coastline extended seaward by between one and two kilometres, as a result of which we are now protected from several metres of sea level rise.

Climate change: the Netherlands in 2100

To be prepared, Rijnland takes into account the worst possible climate change scenario. Climate by definition is variable and defined from time intervals of 30+ years. As a result, model predictions for the coming 100 or 200 years differ considerably. We ourselves are not agreed, either, on what should be 'enough,' but prefer to play it safe. Worldwide, sea levels will rise by about 80 centimetres over the next century, probably increasing to a maximum of two metres by the year 2200 due to ongoing thermal expansion of the oceans and melting of glaciers (www.realclimate.org). The Delta Committee estimates a rise of the relative sea level (relative to our country) between two and four metres by 2200, but this includes at least a metre of soil subsidence. To give an idea of the extent of the changes we are faced with: the last time the sea level rose by three metres it took over 3000 years! The extensive protection measures and hydraulic structures implemented after the flooding of 1953 have been designed to limit the risk of a
flood from the sea to once in every 10,000 years. That is the entire geological period since the last Ice Age. Technically, the western Netherlands is prepared for a perfect storm, the likes of which have never been seen before in this part of the world. Within the secure walls of the primary flood defences, dikes and levees ensure that water management can be regulated with sufficient flexibility to adapt to the environmental changes.

For regional water management, the primary consequence of the sea level rise is that surplus water must be pumped up higher to remove it. Climate change affects the water system in the form of higher peak precipitation and increased storm surge from stronger winds. The Netherlands has a temperate maritime climate influenced by the North Sea and Atlantic Ocean. Rainfall is distributed fairly evenly throughout the year with average annual precipitation between 700 and 800 mm. Higher sea water temperatures are expected to result in a more frequent occurrence of extreme precipitation throughout Europe, and therefore greater river discharge. Each meter rise in sea level also means that the water level in the lower reaches of the rivers, including the Hollandse IJssel and the Lek, will rise just as quickly. The dikes that presently confine our rivers must therefore be heightened (from 4.5 to 5 m) and broadened to meet the new standards.

The white line shows the rise in sea level along the Dutch coast since the last Ice Age. Each point represents a difference in elevation and the corresponding laboratory age (C-14 radio-isotope age) ‘Before Present.’ The growth of our coastline was established through geological research carried out by Jelgersma (1979); Van de Plassche (1982); Denys & Baeteman (1995) and Beets & Van der Spek (2000).
4 What is the risk?

Vereenigde Binnenpolder between Haarlem and Spaardam
Historically, spatial planning in the western Netherlands has relied on flood defences. A cost-benefit analysis of risk and damages in a polder decides the size and shape of our dikes. New residential areas have been built in many deep polders in recent years. Because investments and population density increase, the consequences of a dike breach are constantly changing.

Calculating the consequences of a dike breach
The flood risk is the chance that a flood takes place, multiplied by the resulting damage. Places with the highest chance of flooding and the most severe damage therefore have the greatest flood risk. Advanced computer models are used to calculate and visualize what happens when a dike in the Rijnland area gives way. This has been done for over one hundred locations in our district, to ascertain the flood patterns resulting from a particular dike breach. Water may rise unexpectedly fast or change direction due to obstacles, for instance a highway or a residential area. The damage often depends on the duration of a flood, the maximum water depth (inundation depth) and the land use. The exercise demonstrates how the consequences of a dike breach vary according to the location. Some places are barely touched, whilst elsewhere in the polder the damage can total hundreds of millions of euros. Parts of a polder may experience no flooding at all, despite a dike breach, because the water flows into other, lower-lying areas. Conversely, some locations are almost always flooded in case of a dike breach.

The flood risk assessment takes into account future spatial developments and the effects of soil subsidence. Flow patterns calculated for the current situation will change in the next half century. Some areas that are now at limited risk of flooding may have a higher risk in the future. The chance of a breach could increase, as could the consequences. Where there is now a field, there may be a residential area in thirty years time. What is the sustainability of improvement works on a time scale of thirty, fifty or a hundred years? What are the possible consequences of soil subsidence, sea level rise and changing precipitation patterns? To what extent do the natural characteristics of the area (alluvial ridges or peat areas, for example) provide limitations and opportunities in terms of flood safety? To protect our security and enable economic investments, dike reinforcement is at present the first and best measure available.
Calculating risk and damage

To determine the current and future flood risk, various dike breaches have been modelled using the Rijnland ‘Calamity Information System’ (Calamiteiten Informatie Systeem CIS). The CIS programme was developed in 2006-2007 to support the Water Control Board should a dike breach occur. The chosen technology and the underlying principles conform to national standards, on the one hand in that they ensure comparison of results, on the other hand in that national standards are based on the best available knowledge. Using the High Water Information System Damage and Casualties Module (HIS-SSM Schade en Slachtoffer Module), the expected damage and number of casualties as a result of a flood in a particular area was calculated. The method has been developed for the Directorate for Public Works and Water Management (Rijkswaterstaat) and is also used for the primary flood defences, i.e. the coast and major rivers.

CIS calculations are made using the hydrodynamic Sobek 1D/2D computer model. When constructing the CIS, Rijnland carefully evaluated the positions of two hundred dike breaches. The base map in the system is the AHN (Actual Height model of the Netherlands at www.ahn.nl). Any inaccuracies in this map are therefore also incorporated in the calculated flood patterns. Much effort has been made to ensure that the AHN is indeed actual and has its best resolution of centimetres. The model assumes a breach at during a water level 25 cm above the baseline of -0.6 m, i.e. at NAP -0.35 m. The model outcome was tested with the field knowledge of the Water Control Board. The 2100 scenario is calculated using an indicative water level of 0 m NAP. Raising the water level in the Rijnland boezem could be one measure to cope with sea level rise.
Future scenarios

Two scenario’s have been considered to assess risks in the near and not-so-near future. These regard the year 2050, when adjustments presently made to the system of dikes and levees expire, and the year 2100, when the effects of sea level rise and soil subsidence are going to be felt. Many areas in Haarlemmermeer are designated for housing, and major soil subsidence is expected around Gouda and Boskoop in particular. In places where there are no foreseeable changes in spatial planning or soil stability, the situation will remain stable in the near future. For the year 2100, rising sea level, soil subsidence, and intensified precipitation events will require a substantially bigger pumping effort. In time this could be overcome by setting the maximum water level at 0 metres NAP rather than the current -0.60 metres – obviously with enormous consequences for dikes and bridges. The increased drop between the channels and the polders will increase the effect of a dike breach in 2100. As changes in spatial planning are uncertain on this time scale, they are not included in the long term analysis. Calculation of a scenario for 2100 is primarily meant to get an idea of the scale of changes in the coming century.

### Damages calculated for every single polder and concomitant safety classes (see table on page 12)

N.B.: Rijnland is working to ensure that all dikes, where necessary and possible, meet Class 3 standards at a minimum.
5 Flood maps and area-specific measures
The Rijnland Water Control Board manages dune areas, deep polders, lakes, and an extensive region with peat meadows. Each of these areas has a specific use. Roughly speaking, the water system can be broken down into three components: the clayey polders, the peat areas and the sandy subsoil. It is therefore necessary to come up with a tailored approach that minimalises damage in each of these areas. Across our district there are large, differential changes in soil subsidence and precipitation. For each of these areas this chapter presents an example of the likely approach.

Haarlemmermeer and the deep polders
The Haarlemmermeer is a dry-milled lake bed at about -4.5 m below sea level. The soil of this large polder consists of clays and is fairly saline because of sea water penetrating from underneath. The Haarlemmermeer is of great economical importance as the national airport, Schiphol, and the urban areas of Hoofddorp and Nieuw Vennep are located within it. There are several business parks and greenhouse farming areas. One elevated, 60 kilometre-long canal and shipping way surrounds the polder. The inner ring of the canal dike meets the highest regional standard: class 5 (1/1000 security level). A flood in this area would have national economic consequences.

Nieuw Vennep and Schiphol Airport
Modelling of flooding patterns in the Haarlemmermeer indicates that the area to the west of Nieuw Vennep is very sensitive to flooding. It is a low-lying area and water quickly flows into it if a flood occurs anywhere around the polder. The north-eastern part of the polder, around the town of Badhoevedorp, and the southern area around the A44 motorway (near Abbenes) are also sensitive to flooding. Schiphol Airport is less likely to be flooded and the runways appear sufficiently elevated to stay dry in the case of a flood. The surroundings of the airport will only flood if there is a breach directly to the east of the terminals.

Flower district
There are a number of small, deep polders (-3 m to -1.5 m NAP) to the west of the Haarlemmermeer, bordering the Ringvaart canal dike. The consequences of a breach in the area between the towns of Lisse and Hillegom are very limited. This area is relatively high, so that the flooded area would be small.

Simulation of progress of flood in the Lisserpoel Polder. See photograph on page 4.
The ‘dike risk map’ shows where the greatest damage takes place in simulated dike breaches (colours correspond to the IPO classification scheme). The maximum inundation depth (dark blue) is 1.75 m.

The Haarlemmermeer ‘flooding frequency map’ shows how often certain areas flood in simulated dike breaches. The redder the area, the more often they flood.
The Lissepoel polder to the south of Hillegom as at risk because this polder would be partially under water in just six hours. After 24 hours, the water depth will have risen to an average of over two metres. The focus is therefore on durable, strong flood defences in this area.

**Comparison of the current situation and the medium to long term**

Soil subsidence in the Haarlemmermeer is very limited. Spatial planning developments, i.e. housing, will therefore determine the extent of the damage in the near and not-so-near future. Large housing projects have been planned for the area around Nieuw Vennep and are also being investigated in the south-west of the polder. The current calculated damage for the Haarlemmermeer totals about 3.5 billion euros. The damage in the future situation will increase dramatically as a result of growing investments and population – unless land use in the polder will be ‘flood-proof’.

Current dike improvements are directed at providing a high level of safety (1/1000) for the next 30 years. Already, we work towards a ‘smart’ water management for this region. Spatial planning could incorporate low sandy mounds (‘terpen’) on which we situate new housing projects. Sand quickly absorbs excess rain water. Designated reservoir areas could accommodate excess water. Electric and communication infrastructure should be elevated or at least moved to higher floors. In the most futuristic scenario, multi-purpose ‘super dikes’, with room for housing and businesses on top, will surround an undulating landscape.

*Flooding and damages in the MT-polder (Gouda area) following a polder dike breach (cross) are only 5% of those resulting from failure of a boezem dike. Rapid response (right) further reduces damages (p. 40).*

*Over the next fifty years, soil subsidence will increase (red) or decrease (green) inundation resulting from a breach in the boezem system around Gouda, to a maximum of 150 cm locally.*
Evaluation of current flood risk assessments

All polders in the Rijnland District have been classified based on the calculated direct damage or the property in the polder. This method follows a simple and practical approach, which we refine here using flood mapping computer models. These models take into account the speed of inundation and ponding of water in the lowest parts of the polder.

The original (IPO 1998-2004) approach assumes that all the water in the boezem system flows into the polder. However, the Water Control Board trains to limit the water flow in the case of a dike breach. This was demonstrated when a polder levee failed at Wilnis in the summer of 2003. Wooden boarding had caused the levee, consisting of layers of peat and clay, to dry out during a warm spell. The strength of the levee was thus reduced to a level that it no longer balanced the pressure of the water in the polder canal. According to the IPO method, the damage resulting from this breach should have been 200 million euros. In fact it was much lower, thanks to the rapid and effective response by the Water Control Board of Amstel, Gooi and Vecht. The actual damage totalled about 20 million euros, and most of this resulted from dikes and embankments subsiding as the water pressure in the canal dropped. Because this was only a polder canal, there was relatively little water behind the dike.

The IPO method assumes that a breach in a dike will flood a polder entirely. Therefore, a single height and strength standard is applied to the whole length of the dike ring surrounding the polder. In reality, a part of the polder will flood immediately. The rest will at first inundate to a reduced depth, depending on the location of the dike breach and the emergency measures taken. Our modelling study helps identify the most vulnerable parts of a polder, to ensure that the proper mitigating measures can be implemented. The flood mapping models of the ‘Calamity Information System’ (CIS) are used by the Water Control Board to draw up contingency plans and be prepared in case of a dike failure.
Gouda and the peat meadow areas
The south-eastern area of the Rijnland consists of peat lands and meadows, primarily used for horticulture and the dairy industry (cattle). Rivers border this area: the Gouwe, the Oude Rijn, and the Hollandse IJssel. The average ground level height is about -2.0 m NAP and there is significant soil subsidence: over a centimetre a year as a result of oxidation and settlement of the peat. As a result, by the end of the century, the A12 motorway (already undulating from uneven subsidence) will lie almost a metre lower than at present. In the centre of the study area lies the deep Middelburg & Tempel Polder (MT polder). This polder has an average depth of about -5 m NAP and is surrounded by polder levees. These are peat remnants that were left to facilitate peat excavation in this region in past centuries.

The MT polder is very sensitive to flooding from a breach in the boezem system. At any location a breach in the river dikes by the Oude Rijn or the Gouwe would result in flooding in the polder. The average inundation depth could reach two metres. The best preventative measure is to ensure that all dikes surrounding the rivers are in a good state. The polder ditches that surround the MT polder do not hold as much water. A breach of a polder levee would therefore cause ponding of certain areas at most. Although the area around Gouda is not very sensitive to flooding, the average inundation depth is large; 1.5 metres. The damage resulting from a breach near Gouda could therefore reach 250 million euros.

Medium to long term
Spatial planning in the area around Gouda and Boskoop is not expected to change very much in the near and not-so-near future (AD 2050). However, the effects of soil subsidence are dramatic. It is expected that soil subsidence will cause a change in flow patterns by 2050. One important finding is that water will no longer flow into the lakes of the Reeuwijkse Plassen. The urban area of Bodegraven and Reeuwijk will therefore, compared with the current situation, be faced more often with problems as a result of precipitation. As a result of soil subsidence, the average inundation depth increases at many locations, including the MT polder. Contrary to the current situation, the urban area of Bodegraven could also flood due to a dike breach in 2050.

Long term
Soil subsidence in the area around Gouda and Boskoop will increase in the long term (AD 2100). To investigate the effects of this soil subsidence together with a possible increase in boezem water level, two calculations have been carried out for this area: a breach near Gouda and one in the south-eastern part of the study area. These calculations demonstrate the scale of these changes: damage resulting from a dike breach in the south-eastern part of the area would increase from 2 million to 50 million euros.

Zoetermeer and urban surroundings
The situation between the urban areas of Zoetermeer and Voorschoten is complicated by its system of watercourses and dams. In contrast to a polder, the urban water system, with its sewerage, viaducts, etc. is closely knit. As a result flooding and drainage are less predictable. A practical solution for Zoetermeer could be to build a ‘safety valve’ into the dike between the water in the Zoetermeerse Plas (Lake) and the adjoining Zoetermeerse Meerpolder. By lowe-
Aerial photographs and laser measurements provide a detailed picture of the height differences along a dike, here the Haarlemmermeer canal dike.

Map showing flooding in the area between the A4 motorway and Zoetermeer.
ring a section of the dike here, the water would flow into the polder and not reach Zoetermeer. The use of overflow polders is one way of quickly discharging excess water from the boezem system. It is an emergency measure that is not taken lightly, because it presents the danger of serious damage to the dike system (p. 41 ‘Smart Drainage’).

There are a number of smaller, deep polders in the area (-4.0 to -5.0 m NAP). A large section of the Gecombineerde Starrevaart- en Damhouder polder along the A4 motorway is very sensitive to flooding. The average inundation depth is deep, possibly up to 3.5 metres. Although the largest part of the polder is not built on, the town of Leidschendam is situated in the south-western part, where the largest inundation would take place. To drain this water, the flow under the A4 motorway should be facilitated. A water storage location is being designed in the Nieuwe Driemans polder, between the A4 motorway and Zoetermeer. Clever constructions such as tilting doors could drain the water to this polder.

Map showing flooding in the area between the waters of the Braassemmermeer and the Kagerplassen, between the towns of Roelofarendsveen and Leiderdorp (bottom left). The maximum water depth is dark blue (3.50 m). The A4 motorway runs through the middle of the polders (see p. 16 for reference).
Background information

Mitigating measures
Flood control relies first and foremost on dikes and dike reinforcement. This is the first link in the ‘safety chain’. However, should there be a breach of some kind, emergency measures are in place to limit the effects of a flood.

Drainage A stable water level in the boezem canals is an important condition for the stability of dikes and embankments in the Rijnland area. Pumping stations ensure that the water level remains at around -0.60 m NAP. Construction of extra pumps has increased the capacity of the pumping station at Katwijk by 60 percent, to 94 m³/s. This will control the amount of water within the system of regional flood defences for the next fifty years. Maximum pumping will draw water away from a breach.

Compartmentalisation Compartmentalisation of the canals of the boezem system is a measure that limits the amount of water entering the polder. On each side of the breach doors, partitions, or beams can be closed. These works are present at more than 60 locations in the district. Thus, Rijnland can be divided into nine compartments. Contractors are stand-by at all times with clay and blocks of stone.

Subdivision of an area Subdivision of an area is a permanent measure that prevents the whole polder from being flooded should a breach occur. An example of this is a motorway that lies higher than the surrounding area and so divides the polder into compartments, or the use of the Liniedijk in the Haarlemmermermeer. Modelling studies demonstrate that for Rijnland this is not a very effective measure. It is difficult to distinguish between high-value and low-value areas and area compartments are usually too rough to be able to make the required separation. It may, however, be useful to concentrate high-value land use areas more in the future so as to be able to better protect these areas.

Property protection Property protection is a measure to protect a specific, valuable part of the polder. The construction of a small dike or flood wall around critical objects such as electricity substations can be effective. Flooding simulations show that, in many cases, an elevation of 0.5-1.0 metres is enough to significantly reduce or even to remove the chance of flooding. ‘Retrofitting’ and flood proofing existing urban areas will however entail a large investment, because roads, tunnels, sluices and bridges will have to be adapted. Residential areas, business parks or airports may be offered extra protection by raising the ground level of the whole area (prior to construction).
Smart drainage  Steering water to the least sensitive part of a polder or to a storage basin where it can do little damage is an effective measure, certainly in combination with compartmentalisation of the canals. The use of overflow polders is one way of quickly dis-charging the water storage basin. It is an emergency measure, not taken lightly, because it presents the danger of serious damage to the dike system. A dike breach will cause water levels in the storage basin to drop quickly, while the dikes have been designed to remain standing under pressure from aside. A drop in the water pressure can cause many dikes ‘upstream’ to become instable and collapse. The sudden drainage and movements in the subsurface may damage foundations and cause the subsiding of buildings and neighbourhoods.

Multiple-purpose use  Vulnerable areas in the dike system can be made so ‘robust’ that the dike will never fail and can be used for several purposes. A ‘giant dike’ with a crest width of 30 metres and a very gentle slope can provide opportunities for traffic or housing on top.
6 Dike management and enforcement
To protect the dikes and facilitate maintenance, Rijnland has developed, over the past centuries, rules and by-laws which are embedded in national and provincial legislation. The water control boards have far-reaching statutory powers to fulfil their primary task: ensure flood safety. Moreover, as a formal authority, Rijnland is obliged to enforce its own legislation. Climate change and tighter provincial standards, in combination with an ageing dike system make this more urgent than ever before. Dikes will be both heightened and substantially widened. This will have repercussions in one way or another for thousands of homes in the Rijnland area. ‘Not in my backyard’ will sometimes be a first reaction. The Water Control Board will do all it can to tailor the work to the situation.

Legislation
For permits and licences, Rijnland refers to its keur, which sets out provisions on cables and piping, constructions, plantings, roads, etc. on or near levees (www.rijnland.net/regelgeving/keur_beleidsregels_regionale_keringen). The underlying policy focuses on the maintenance and protection of existing flood defences. Legislation ensures that policy is enforced fairly: in similar situations the same rules apply to all residents in the area. Only in this way can safety be effectively guaranteed. Strict rules apply in the core zone along the centre line of the dike. The core zone effectively guarantees the water blocking properties of the dike. On either side of the core zone is a protection zone. The protection zone guarantees the free standing stability of the dike.

Before dike improvements are executed, the enforcement officers prepare an inventory of the core and protection zones in the area. What have licences been granted for, and what not? What fits in with policy and can be legislated? What does not fit in with policy but can be legislated anyway, as an exception? Where will we enforce legislation? Once we have a good idea of the work that needs to be carried out on a dike and the effects this will have on the local residents and users, the Water Control Board informs all interested parties of the plan. This may take place, for example, at a residents’ meeting or ‘round the kitchen table’. Residents and users are informed, often as early as the assessment phase, about the project and the purpose and necessity of the improvement work. Residents and local authorities work together in this way to come up with the best solution for all involved.

Cables, pipelines, buildings, and larger vegetation all influence to some extent the water-tight properties or the stability of a dike. Assessment and enforcement are meant to take these aspects into account. Based on the keur of 2006, cables and pipelines are not permitted within the core zone. That gas and water present a certain danger was demonstrated in January 2004, when a pipe leak caused a 15 metre dike section to collapse, forcing the evacuation of residents.

Licences and compensation
Licences from the Water Control Board are required for all activities taking place in the core and protection zones of dikes and levees. These licences are controlled by our enforcement officers. Existing, undesirable situations, such as pipelines running through dikes or trees planted on dikes, are now tolerated until work needs to take place on that particular part of the dike – as long as this does not present any
Causes of dike leaks

• Water flow through peat or sandy layers under the dike. Groundwater flow and seepage is recognisable by the sand it carries with it and by cracks in the clay layer on the inside of the dike.

• Many dikes have rubble and sand applied prior to construction of a road. Water at high levels may move through this porous rubble underneath the road, and thus overflow the dike. (In the past, dikes in and around polder meadows were often constructed using rubble.)

• The digging activities and tunnels of muskrats and rabbits can undermine the stability of a dike.

• Cables and pipelines in the dike negatively influence the water blocking properties of the dike, because seepage water will flow along these lines. Gas and water pipes can leak and, in the case of gas, can even explode.

• Abandoned inlet or drainage pipes have sometimes been left behind in the dike. These must be filled and sealed.

• Roots and rotting plant remains can produce empty spaces in the dike, resulting in piping and leakage.

• Large cattle (horses and cows) is too heavy and will damage a dike (see picture below).
danger. As a consequence, the dike improvement programme will result in many changes. Sewerage pipes and electricity may need to be moved, building constructions or trees on a dike may no longer be permitted once the dike has been heightened. Naturally, a tree will be spared if the risk it presents to the dike is acceptable. Trees will be relocated if this can be done without damaging the tree and if it can be carried out at a reasonable cost.

We work to prevent the landscape from being unnecessarily affected. However, to be able to reinforce the dikes and continue to broaden them over the coming century, space must be earmarked now. Legally, damage or nuisance resulting from dike maintenance is considered an acceptable societal risk. Dike maintenance and improvement are foreseeable. And following the dike improvement, we will regularly return to the area to carry out maintenance. In the case of dike widening and widening of the protection zones, we consider both the consequential loss and the difference in the value of the land in the old and the new situation.

In case a municipality decides to start building in a previously empty polder it needs to consult the Water Control Board first. A housing project may result in a polder requiring a higher safety level. The dike will then need to be improved. The 'perpetrator’s principle' applies in such cases, meaning that the initiator,

\[
\begin{align*}
\text{CORE ZONE} & \quad 0.5 \times 1.5 = 0.75 \text{ m} \\
\text{PROTECTION ZONE} & \quad 0.9 \times 3 = 2.7 \text{ m}
\end{align*}
\]

The core zone is the width of the dike (in this case 5 m) between the vertical intersection with the outside water and the groundwater (inside the dike). The core zone ensures water blocking. The protection zones of 15 m on either side of the core zone ensure that a stable earth body remains should there be an excavation next to the dike.
After heightening small fences and wooden jetties return.

Buildings, plants, cables and pipes do not return (below).
whether it be a local authority of private developer, must make sure that safety is organized and continued. Changing land use is an important reason to review flood safety now.

A particular situation exists outside the flood defences (beach, lake borders and river sides) where the government has no direct responsibility. As recommended by the Delta Committee, the government’s advisory board on flood safety in the long term, the protection costs that are induced by building on floodable locations will have to be carried by those responsible for the investments.

Difficult situation: homes and trees on a dike.
Haarlem and the original sluice complex near Spaarndam 1:28,000 (Floris Balthasar & Balthasar Florisz. van Berckenrode, coloured copper engraving 1615)
Disaster management
Much time and effort is spent on testing and reinforcing our dikes and coastline. Every year they are inspected on foot. We make significant investments to keep our flood defences in good condition. To be forewarned of threats from outside our district, we rely on science and technology. Storm surges are predicted by the meteorological office with advance warning of 12 to 24 hours. Peak discharges from the Rhine River can be predicted more than a week ahead. Storm doors in the Hollandse IJssel southwest of Gouda will be closed when the storm surge at the coast amounts to NAP +3 metres or NAP +2.25 in the river (the dike crest lies at 4 to 4.5 m). The last time this happened, November 2007, the sea level rose to +3.20 m. At this stage, the emergence organisation is raised to preparedness level 2 of 4.

Things can go wrong. The collapse of a dike will pose a threat, but also the release of a dangerous chemical. We have therefore drawn up contingency plans, detailing what we must do in the case of an emergency. The Public Works Act makes it compulsory for Rijnland to have a fixed emergency plan available. This can be found (in Dutch) on our website (www.rijnland.net). The emergency plan describes the actions to be taken in the case of each type of emergency, including spills from the waste water system and droughts.

Recent floods, not just in New Orleans but in England too, have forced us to face the facts. The importance of a good contingency plan was proven during the large flood in New Orleans, where a plan was found wanting. In the Netherlands, this has provided an extra impulse to prepare and train for possible floods. After all, although the chance of a flood may be very small, we must still know how to act in an emergency situation. For this purpose, the national government has set up a Flood Management Taskforce (Taskforce Management Overstromingen, TMO). The taskforce is entrusted with ensuring that from 2009 the Netherlands is better prepared for possible flooding. At what moment should we make evacuation compulsory and who will decide that? Will the roads have sufficient capacity, and when will the electricity fail? All stakeholders: local authorities, provinces, ministries and the water control boards incorporate the findings of the TMO into their own contingency plans.

Emergency response organisation
Practice has demonstrated sufficiently that it is not possible to prevent flood disasters altogether. While we critically re-assess our dike system, mitigation planning is directed at limiting future losses. Spatial planning as a whole will be considered in relation to flood safety. Higher lying roads are prepared to serve as evacuation routes. At lower lying locations, a home that stands on poles or even floats when water levels
are rising may last through a flooding of the area. The emphasis, however, remains on prevention: on building and strengthening the flood defences.

Depending on new developments, an emergency plan is to be revised once every four years. The value of an emergency plan is increased through training and drills. Training, instruction and a drill programme ensure that a high level of knowledge and experience in dealing with emergency situations is built up and maintained.

Rijnland exercises with the emergency plan for flooding once a year. It stocks necessary resources such as emergency pumps, telephones and other materials to be fully prepared. The water control boards are required to report the results of these drills to the provinces. Rijnland has also drawn up agreements with sub-contractors and other support services to help with manpower and materials: heavy machinery, clay, stones. To close a breach of 80 metres to a height of 5 m, 3000 m$^3$ of filling is needed! We maintain active contact with regional emergency services (the police, fire service and ambulance service) and other partners that will play a role in dealing with disaster.

We regularly carry out drills so that we know what to do in the case of a flood. It is important that you also know what to do prior to and during a flood.
What can you do in the event of a flood?

**Preparation**
- Make sure you have a radio that works on batteries (or a dynamo).
- Tune in to the regional emergency channel.
- Make sure you have emergency provisions.
- Think about where to go if you need to leave your home.
- Look for an alternative route to get there, as roads will be jammed in the event of an evacuation.

**If there is the possibility of a flood**
- Listen to the emergency channel on the radio.
- Follow the instructions of the local authorities and emergency services.
- If there is time, move valuable items upstairs.
- Open or remove inside doors.
- If possible, protect your home against water using sand bags and barriers.
- Look around to see if there are other people who need help.
- Ensure you have enough food and water in the house for at least three days (four litres of water per person per day).

**In the event of an evacuation**
- Follow the instructions given by the local authorities.
- Take your emergency provisions with you.
- Close outside doors and windows.
- Follow the routes indicated.
- Community shelter will be provided, though you may go to friends or family.
- Tell your local council where you are staying.
- If it is not possible for you to leave, contact the emergency services.
- Turn off gas, water and electricity.

**If you can't evacuate**
- Move to the upper floors in your house and take your battery radio and emergency provisions with you.
- Make sure you can't get trapped in the attic.
- If the water reaches your house, turn off gas and electricity.
- Ensure you have extra clothing and blankets and enough food and water for at least three days (four litres of water per person per day).
- Keep up to date with the situation on the radio and listen to the instructions given by the authorities.

More information can be found at the following websites:

Filling and placement of sandbags
Guidelines
The activities described so far in this brochure concern improvements that focus on ensuring the future safety and strength of the water system. Such improvements include enlarging or extending the flood defence or other changes, such as adding sheet piling.

In addition to this, the Water Control Board also works all year round at maintaining the flood defences. Inspection officers walk over every dike and levee in spring, before the grass starts to grow. They use a laptop computer with a GIS-program and GPS-positioning to record damage and necessary maintenance. Smaller jobs they will immediately forward to construction companies. Bigger jobs they will forward to the main office, to be discussed with engineering firms and if necessary included with the improvement program. Daily maintenance, such as mowing the grass, is carried out by the owner of the land.

Common maintenance activities are:
- repairing areas damaged by water flowing through the dike
- adding material to the base of the dike, below water level
- raising low areas and repairing small wet areas at the lower edge of the dike
- repairing existing facing
- repairing leaks by applying clay
- applying temporary barriers in a water storage basin ditch

This excavator weighs 8 tons
Completed reinforcement at Rijnsaterwoude (2008)
Dike basics: dimensions

Register height:  
Boezem levee = NAP -0,10 m (around lakes NAP 0 m)  
Polder levee = water level + 40 cm

Minimum width 1.5 m  
Construction 10-30 cm above register height, depending on soil compression and desired longevity

Inside slope  
A clay fill of more than 30 cm reduces the stability of the levee and requires a new design

Foot

Dike basics: maintenance

Max loading 8000 kgs

Max loading 20,000 kgs

Grass cover prevents erosion of clay layer

Drainage pipes may reduce water pressure below clay cover

Top  
Leave vegetation
Shorelines of the Haarlemmermeer between 1531 and 1740 on scale 1:40,000 (Melchior Bolstra, coloured copper engraving 1740)
Bijlage: onderhoud
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Opposite page: coloured copper engraving on the oldest map collection covering the Rijnland District (Floris Balthasars & Balthasar Florisz. van Berckenrode, 1615). The year 1255 (in Roman numerals) here refers to the establishment of the Rijnland Water Control Board.