PBL Netherlands Environmental Assessment Agency

CLIMATE ADAPTATION IN THE DUTCH DELTA

Strategic options for a climate-proof development of the Netherlands

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PBL Netherlands Environmental Assessment Agency

Deltares
Enabling Delta Life

Knowledge for Climate

climate changes spatial planning

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- *Overstromingsrisico's en droogterisico's in een veranderend klimaat. Verkenning van wegen naar een klimaatbestendig Nederland* (Klijn et al. 2010).

Climate changes Spatial Planning Programme and Knowledge for Climate:
- *Naar een klimaatbestendig landelijk gebied* (Van de Sandt & Goosen 2011);
- *Building the Netherlands climate proof. Urban areas* (Van de Ven et al. 2011);
- *Beleids- en rechtswetenschappelijke aspecten van klimaatadaptatie* (Driessen et al. 2011).

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PBL Netherlands Environmental Assessment Agency is the national institute for strategic policy analysis in the field of environment, nature and spatial planning. We contribute to improving the quality of political and administrative decision-making by conducting outlook studies, analyses and evaluations in which an integrated approach is considered paramount. Policy relevance is the prime concern in all our studies. We conduct solicited and unsolicited research that is both independent and always scientifically sound.

Preface

The PBL Netherlands Environmental Assessment Agency was asked by the Ministry of Infrastructure and the Environment to investigate options for climate-proofing spatial development in the Netherlands. In 2009, the PBL presented its first report 'Roadmap to a Climate-Proof Netherlands'. That report set out the main challenges for adapting to climate change and indicated the types of policies needed to tackle these challenges. This PBL study elaborates on the first report and presents possible strategies for climate-proofing the Netherlands. Much of the supporting research that underlies the proposals presented here was carried out by Deltares and the Climate changes Spatial Planning and Knowledge for Climate research programmes.

The Delta Programme was launched last year under the leadership of the Delta Commissioner, (www.deltacommissaris.nl/english/organization/deltacommissioner/). In 2010 and 2011, the Delta Programme focused on analysing the main national and regional bottlenecks with respect to safety against flooding and freshwater availability. The final reports on these issues were published at the same time as the Dutch version of this PBL report Climate Adaptation in the Dutch Delta (Een Delta in Beweging), on 21 September 2011.

In this report, the PBL has set out the first steps to be taken in working up strategic adaptation options. For four complex topics we have analysed how the Netherlands could adapt to the expected changes in climate: flood protection; freshwater supplies; rural areas, ecosystems and biodiversity; and urban areas. Special attention was devoted to the uncertainties surrounding climate change, the possible adaptation options and the related governance challenges.

From the analysis of possible strategic adaptation options, it became apparent that at a national level the country faces several fundamental choices with significant consequences for its future spatial development. For the most part, these choices can be worked up in more detail within the Delta Programme.

Professor Maarten Hajer

Director of the PBL Netherlands Environmental Assessment Agency


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KEY MESSAGES

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Climate Adaptation in the Dutch Delta
Strategic options for a climate-proof development of the Netherlands

Key messages

- **Unbreachable dykes and managing new development in the Rhine-Meuse floodplain will make the Netherlands safer and more climate-resilient**
  Flood risk in the Netherlands can be structurally reduced if the Dutch Government not only acts to reduce the *probability* of flooding, but also to reduce the possible consequences of flooding. An effective way to achieve this is to reinforce the dykes to create so-called Delta Dykes (‘unbreachable dykes’), especially in areas with the highest concentrations of population and fixed assets. Building unbreachable dykes will reduce the dangers and impacts of flooding to such an extent that there is little need for adjustment to built-up areas behind these dykes in order to reduce the *consequences* of flooding (flood-resilient building). Because the consequences of flooding are always less damaging when areas are protected by unbreachable dykes, the Netherlands would then also be less sensitive to climate change and unexpected, more extreme conditions. In addition, areas must be reserved in the Rhine-Meuse floodplain for managing the consequences of potentially higher river discharges in the future, combined with higher sea levels, in the longer term. This will require management of new spatial developments in the riverine areas.

- **Climate-proofing freshwater supplies will require a more flexible water system and better use of the water in the Rhine**
  It is expected that climate change will lead to more frequent and longer periods of water deficit during the summer months. Making better use of the water in the Rhine may compensate for shortages in the freshwater supply. In addition to the option of

increasing the water reserves in the IJsselmeer (as previously proposed by the Delta Committee), changes to the management of the New Waterway is an interesting alternative, to make more fresh water available. This would be effective because about 80% of all the water in the Rhine is discharged through the New Waterway into the sea – even in dry years – to counteract salt water intrusion. Doing this more effectively, in other words with less water, will release more fresh Rhine water for other uses, such as the irrigation of agricultural land. Moreover, there are various possibilities for making regional water systems more flexible, thus, temporarily curbing demand for water in dry years. The main options are those of optimising water management practices and water management authorities taking a more flexible approach to salinity standards.

- **Climate-proofing ecosystems and biodiversity will require revising the strategy behind the National Ecological Network**
  Climate change increases the risk of biodiversity loss in the Netherlands. This, in turn, reduces the chances for the Netherlands to meet international nature conservation and restoration obligations, in the longer term. Biodiversity levels can be maintained in the face of climate change if nature conservation policies focus more forcefully than at present on increasing the spatial connectivity of nature conservation areas, improving environmental and water conditions, and creating room for natural processes. For the internationally important habitats in the low-lying areas of the Netherlands, this will involve strengthening spatial connectivity in the coastal dunes, the peat marshes and the Rhine-Meuse floodplain, and restoring natural processes in the Wadden Sea, the south-west delta area and the coastal zone. Greater spatial connectivity and restoration of the natural hydrological dynamics is also required in forest and heathland ecosystems. Climate-proofing ecosystems and biodiversity, therefore will require revision of the government strategy for the National Ecological Network.

- **Implementation of climate-proofing measures in urban development today may considerably reduce costs for tomorrow**
  Phenomena associated with climate change, such as urban flooding and water shortages, the retention of heat in built-up areas (heat build-up) and drought, may vary considerably in nature and scale, from city to city and from neighbourhood to neighbourhood. Climate resilience is hardest to achieve in highly urbanised areas. These areas contain the largest proportion of hard surfacing, causing more heat build-up and urban flooding, whereas the space available for mitigating measures is more limited. A broad range of measures is available for use at various scales, from individual buildings and streets to neighbourhoods, districts and whole cities. Structural measures, such as the construction of parks, canals, ponds, thermal energy storage and modified sewerage systems, can be implemented in new developments and urban restructuring projects. The key players for such adaptations at neighbourhood or city scales are municipal councils and real estate developers. The most appropriate measures in existing urban areas are adaptations at the scale of individual buildings or streets, such as insulation, green roofs and adapting street paving for water retention. The key actors at this scale are housing corporations,

companies and private property owners. Urban areas are constantly changing: new homes, offices and infrastructure are built, neighbourhoods and business estates are restructured and sewerage systems replaced. If municipal authorities, developers, housing corporations and private owners consistently incorporate climate resilience into their investments in the built environment and urban facilities, the additional costs of climate adaptations can be minimised. Municipal authorities are the most suited to play a leading role in coordinating and managing these adaptations. The opportunities to incorporate climate resilience into planned and new investments in urban areas in regions experiencing growth are different to those in areas that are in decline.

- **A clear division of responsibilities between central government and other parties**
  Central government has the overall responsibility for tasks such as spatial planning, freshwater supplies and flood protection. In decentralising these responsibilities, central government must create preconditions and enabling mechanisms for municipal authorities, water boards, provincial government and citizens to adapt to climate change, primarily in the areas of urban climate resilience and freshwater supply. This means that central government must indicate exactly where the limits of its responsibility of care lie and what investments in climate adaptation it expects from other government authorities, the business community and citizens. Central government must also be alert to the need to embed climate adaptation into its decision-making process on the funding of spatial investments.

SUMMARY

SUMMARY

ONE

Introduction

Setting

The Netherlands form a delta where four European river basins meet and flow into the North Sea, namely those of the Rhine, Meuse, Scheldt and Ems (Figure 1). The quantity and quality of the Dutch national waters, therefore, are heavily influenced by the land use and water management in the upstream countries Germany, Switzerland, Austria, Belgium, Luxembourg and France. The Netherlands is a country consisting largely of man-made water bodies. Low-lying areas are made habitable with man-made constructions, such as dykes, sluices and pumps, and major alterations to the natural morphology and hydro-dynamics of water courses. Benefiting in many ways from its location in the delta, the Netherlands has the highest densities of population, industry, livestock and transport in Europe. However, this situation also means that the Netherlands is vulnerable to the consequences of climate change:

- 26% of the area of the Netherlands lies below sea level (up to 7 metres) and about 60% of the country is susceptible to flooding, either from the sea or the rivers;
- The flood-sensitive areas are densely populated and account for about 70% of the country's GDP;
- Further urbanisation is expected over the coming decades and a million new homes will be built, primarily in flood-sensitive areas (PBL, 2007), increasing the risks to fixed assets two- to three-fold, depending on the rate of economic growth (Figures 2 and 3);
- Although in normal, or even dry years freshwater availability is not a bottleneck, future water availability is expected to be reduced by climate change and risks of water shortage will increase, depending on water demand in the Netherlands and water management in upstream countries.

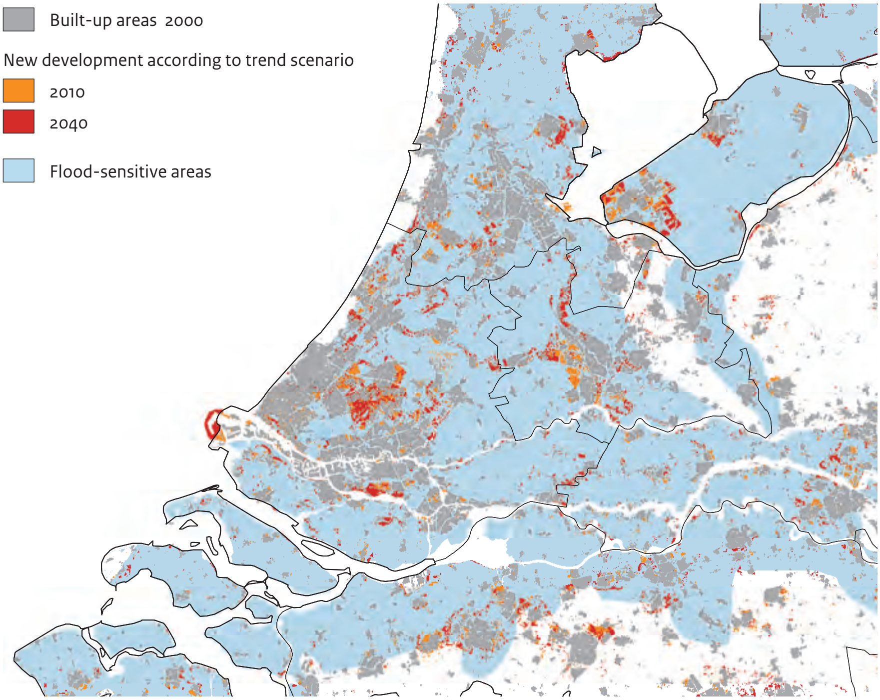
Figure 1
Geography of the Netherlands focusing on the most important national waters

Source: PBL

The deltaic national water system encompasses rivers of four river basins, large lakes in the north, and both freshwater and salt water bodies in the south-western part of the delta.

Over the past few hundred years, the Dutch Delta has undergone continual change and adaptation, both in terms of the demands made by the geographical system and the demands and capacities of a society that has itself been continually changing. Although surrounded by many uncertainties (see Appendix), the expected changes in the climate,

Figure 2
Built-up areas in flood-sensitive areas



Source: PBL (2007)

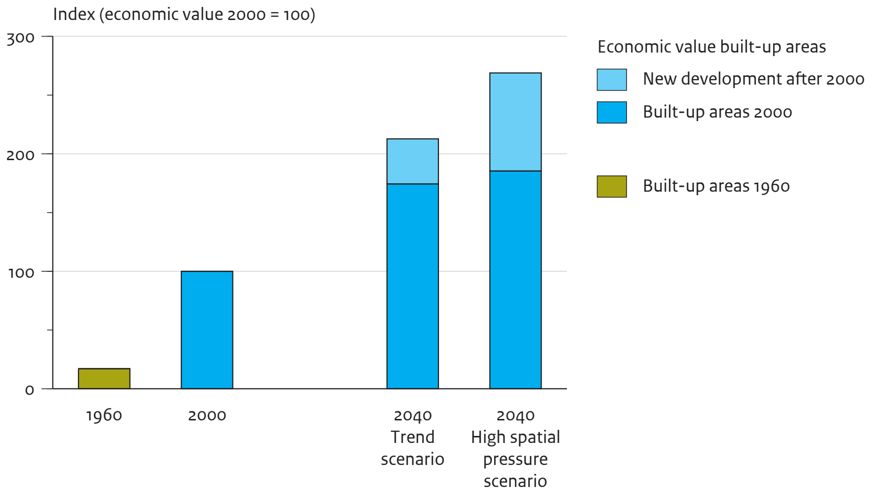
Planned urbanisation in the low-lying parts of the Netherlands. A million new homes are expected to be built over the coming decades, resulting in a substantial expansion of the urban area.

in combination with the expected economic and social developments, make it necessary to reconsider the future spatial development of the Netherlands and investigate how to reduce its vulnerability to a wide variety of impacts: sea level rise, changing river discharges and precipitation patterns, more frequent and extreme periods of drought and possibly also extreme temperatures and changing patterns of health-related risks (allergies, distribution of vector-borne diseases).

Towards a climate-proof spatial strategy

The Dutch Ministry of Infrastructure and the Environment (I&M) asked the PBL Netherlands Environmental Assessment Agency to indicate strategic options for a climate-proof development of the Netherlands. The government seeks a better

Figure 3
Potential economic damage in flood-sensitive areas



Source: PBL (2007)

Due to autonomous growth and new urban development, the potential damage in the areas at risk of flooding in the Netherlands will increase two- to three-fold in the period up to 2040.

understanding of the vulnerability of the country to climate changes, over the shorter and longer term, and how to reduce this vulnerability through structural measures and spatial development, combined with sectoral or technological measures.

In 2011, the Delta Programme was launched, under the leadership of the Delta Commissioner (http://www.deltacommissaris.nl/english) (Text box). In 2010 and 2011 the Delta Programme focused on analysing the main national and regional bottlenecks with respect to safety against flooding and freshwater availability. The final reports on these issues were recently published (http://www.deltacommissaris.nl/english/topics).

In support of further policy development, the PBL has set out the first steps to be taken in working up strategic adaptation options in this report (in Dutch: Een delta in beweging). For four complex topics, we analysed how the Netherlands could adapt to the expected changes in climate: flood protection (Chapter 2); freshwater supplies (Chapter 3); rural areas, ecosystems and biodiversity (Chapter 4); and urban areas (Chapter 5). Special attention was devoted to the uncertainties surrounding climate change (see Appendix), the possible adaptation options and the associated governance challenges (Chapter 6).

The Dutch Delta Programme

Following an advice by the second Delta Committee (Deltacommissie, 2010) in 2011, the Delta Programme was launched (Deltacommissaris, 2010). The Delta Programme (*Deltaprogramma*) is aimed at creating a safe and attractive Netherlands, now and in the future. By way of the Delta Programme, the Dutch Cabinet seeks to ensure that there is certainty about flood risk management and sufficient supply of fresh water, in the long term, acknowledging both socio-economic developments and climate change. Apart from protecting people, animals and goods, this is also a purely economic necessity. The damage and suffering caused by a flood in the Netherlands could be incalculable, which is why Cabinet wants to forestall such a disaster. In addition, water shortages are also damaging.

The Delta Programme is a national programme, involving the Dutch Government, provinces, water boards and municipalities. Social organisations, knowledge institutes and the business community are actively involved, as well. The Delta Programme is directed by the Delta Commissioner (*regeringscommissaris*), appointed by Cabinet. Based on the Delta Commissioner's proposal, Cabinet has opted for a realistic and adaptive approach.

Five delta decisions for 2014
Preparing decisions for a climate-proof development of our delta is the main task of the Delta Programme. The Delta Commissioner is meant to submit five guiding 'delta decisions' on flood risk management and freshwater supply to the Dutch Cabinet in 2014, to be embedded in the next National Water Plan (2015). These five delta decisions concern:

1. Updating safety standards for primary flood defence systems;
2. A freshwater strategy that should guarantee a sufficient and long-term water supply in the Netherlands;
3. Long-term water level management for the IJsselmeer, with a focus on freshwater supply in the Netherlands and the safety task in the area;
4. Protection of the Rhine-Meuse floodplain;
5. A national policy framework for the (re)development of built-up areas.

Knowledge and innovation

Part of the Delta Programme is the joint development of knowledge, in the next few years, in support of the required decision-making. As consistency and integration of sectoral scientific knowledge is of great importance for developing a cohesive set of solutions, the following research lines have been set up:

- A number of scenarios to be used for all research in the Delta Programme;
- An evaluation system that will enable comparison of all possible solution strategies;
- A Delta model with which to carry out (some) of the underlying calculations.

The Delta Programme is committed to strengthening the relationship between knowledge and innovation. Along with water technology and maritime technology, delta technology is part of the so called Key Area Water areas, in which the Netherlands plays a leading international role. Innovation, therefore, is doubly rewarding given that it not only serves the needs of the Delta Programme, but also stimulates the Dutch economy.

Controlling flood risk

Unbreachable dykes and management of new development in the Rhine-Meuse floodplain will make the Netherlands safer and more climate-resilient

Flood risks are increasing

About 60% of the land area of the Netherlands is susceptible to flooding from the sea or from the rivers. Not all the areas are equally vulnerable; areas with the highest concentrations of population and fixed assets face the greatest risks. For the future, flood risks are expected to increase further as sea levels rise and river discharges increase. If no adaptations are made, climate change will lead to a greater *probability* of flooding, which increases the flood hazard. The possible consequences of flooding are increased mainly by the rising levels of investment in fixed assets and the growing population concentrations in the most flood-sensitive areas (Figures 1 and 2); this, in turn, raises the level of *vulnerability*.

In 1953, the last major flooding disaster occurred in the south-western part of the Netherlands, with over 1800 casualties. After this disaster, the first Delta Committee was installed to set out new flood safety standards for areas vulnerable to flooding. Since this first Delta Committee (1960), Dutch flood protection policy, based on the proposed flood safety standards, has been geared primarily to the prevention of flooding and, therefore, is based essentially on managing the chances of flooding (Ten Brinke et al., 2008). In the National Water Plan (VenW 2009a), the Ministry of Infrastructure and the Environment announced a revision of the policy on flood risk management. The new policy will not only seek to prevent flooding, based on the chances of flooding, but also – more than before – will seek to control the consequences if flooding does occur (unexpectedly). The new strategy will explicitly address ways to reduce the risk of casualties and social disruption as well as economic damage.

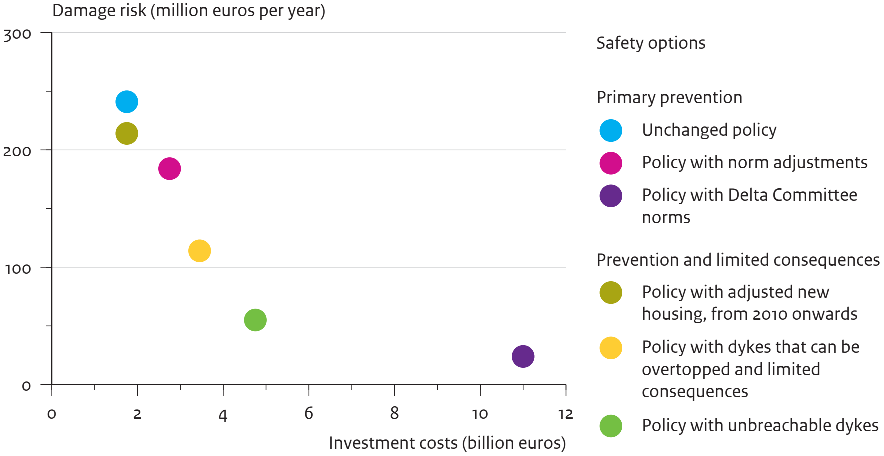
Options considered

To obtain an initial indication of the costs and effects of various strategies for the 2010–2040 period and building on the analyses in PBL (2008), the following options were compared:

- Option 1: a continuation of current policy; in other words, maintaining all the flood defences according to the current flood protection standard.
- Option 2: all new building development in the 2010–2040 period is to be located outside the flood-sensitive areas, combined with maintaining current levels of protection. This option assumes that diverting development to other locations involves no additional costs. Comparing Option 2 with Option 1, therefore, shows the reductions in flood damage risk that can be achieved by a policy of redirecting development.
- Option 3: where justified on grounds of cost-effectiveness, additional investments are made in raising safety standards. However, current safety policy remains the guiding principle, with an emphasis on prevention and the use of conventional dykes. The report ‘the Netherlands in a Sustainable World’ already identified the dyke rings for which raising the protection level would be cost-effective (see also Klijn et al., 2010). This was later confirmed in a study by Kind (2008).
- Option 4: further differentiated safety levels in the Rhine-Meuse floodplain, coupled with the use of overtoppable dykes, extended river floodplains and with steering urban development towards areas where the risk of damage and casualties are lowest. In this strategy, the safety level of the dyke rings with the highest concentrations of population and fixed assets is structurally increased. At the same time, areas on the Rhine-Meuse floodplain are reserved for managing potentially larger peak river discharges, in the longer term (when sea level rise means the current measures under the Room for the River programme are no longer sufficient). This option can be seen as a logical extension of the Room for the River and Living with Water strategies.
- Option 5: the use of unbreachable dykes in strategic locations and where they are cost-effective (Silva and Van Velzen, 2008; Klijn et al., 2010). Under this option, therefore, the dyke rings near flood defences with the highest population concentrations (De Bruijn and Klijn, 2009) and those in the Rhine-Meuse floodplain are protected by unbreachable dykes (Klijn et al. 2010). In this option, as an exploratory exercise, half of all the flood defences in the relevant dyke rings are reinforced to create unbreachable dykes, and it is assumed that the damage and casualties in the event of flooding will be reduced by 50% to 90% (Klijn et al., 2010).
- Option 6: a general raising of the safety standards for all dyke rings by a *factor of 10*, with the use of conventional dykes (Klijn et al., 2010).

Options 1, 2, 3 and 4 have already been worked up in some of our previous studies (PBL, 2008; Ligtvoet et al., 2009); Options 5 and 6 were added to this new analysis. The options require different levels of investment and have different outcomes regarding

Figure 4
Indication of investment costs and damage risk related to flooding, 2020 – 2050



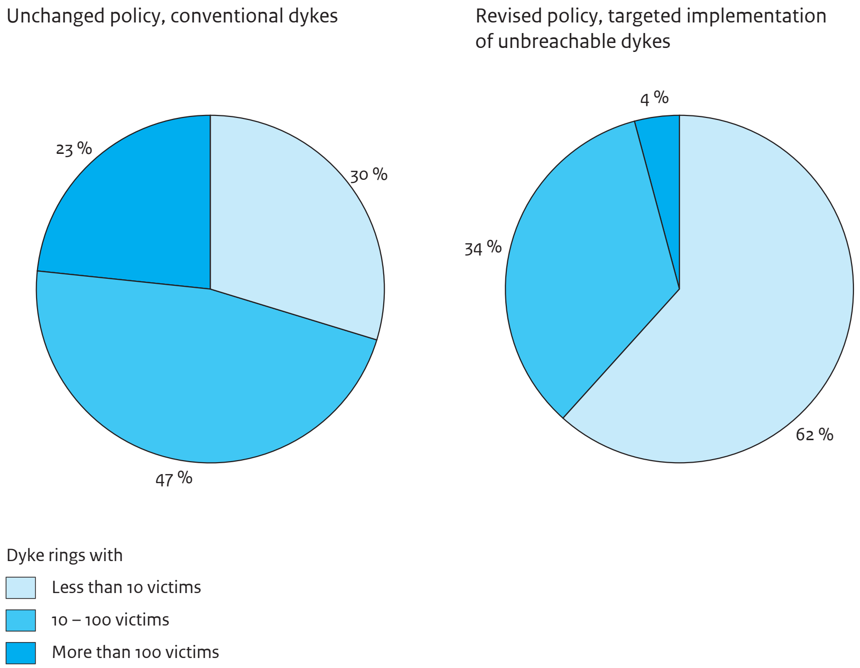
Source: Klijn et al. (2010)
Policies on dykes that can be overtopped and extended floodplains, and on unbreachable dykes, all lead to a considerable reduction in flood damage.

economic damage and casualties, the consequences for spatial development, and sensitivity to the rate of climate change and associated extreme conditions (PBL, 2011). For all options it was assumed that the maintenance backlog will be rectified in the period up to 2015, so that flood defences and dykes meet all the current legal standards (Waterwet, VenW 2009b). A number of options will turn out to be cheaper if the necessary investments are combined with the works to be carried out under the Flood Risk Management Programme to complete this overdue maintenance.

Unbreachable dykes are effective in minimising the consequences of flooding
Managing peak discharges (Option 4) and the construction of unbreachable dykes in strategic locations (Option 5) are expected to lead to a considerable reduction in the risks of flood damage (Figure 4). Also, the number of dyke rings at which flooding could cause an immediate, large number of casualties is significantly reduced when these are protected by unbreachable dykes (Figure 5). The construction of unbreachable dykes will sharply reduce the risk of damages and casualties, because although these dykes can be overtopped, much less water will flow into an area – considerably reducing the speed at which such an area becomes flooded as well as reducing the depth of the flood waters. Thus, the consequences of flooding would remain limited (Figure 7).

Figure 5

Estimated number of victims per dyke ring



Source: Klijn et al. (2010)

The construction of unbreachable dykes is expected to lead to a considerable reduction in the number of dyke rings within which flooding could claim large numbers of casualties.

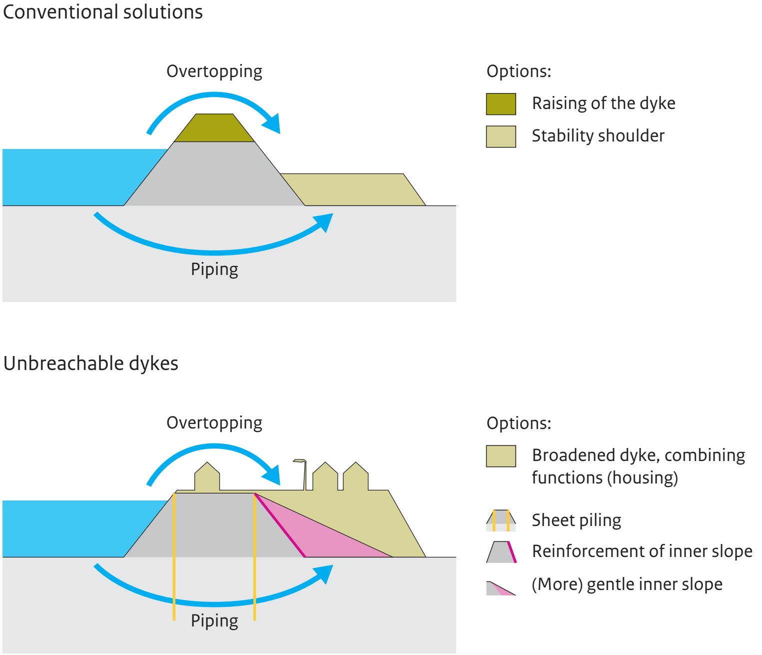
The option of raising safety levels for the whole of the Netherlands by a factor of 10 with the use of conventional dykes (Option 6) gives the lowest damage risks, but this option is by far the most expensive. Although the probability of flooding is smaller in this option, the possible consequences would still be great if flooding would occur, with numbers of casualties equalling those under the present situation (Figure 5, left panel). If, from 2010 onwards, all new builds were to be restricted to areas outside flood-sensitive areas (Option 2), the reduction in damage risk would be only slight. This is because most investments in real estate and infrastructure are located in already built-up areas, and areas of new builds would be limited by comparison (Figure 3). Because the possible consequences of flooding are so much smaller in the option of managing peak discharges (Option 4) and in that of constructing unbreachable dykes (Option 5), these options also are less sensitive to climate change and unexpected extreme conditions.

Conventional and unbreachable dykes

The National Water Plan announced the investigation of the possibilities of applying so-called Delta Dykes (unbreachable dykes). This type of dyke carries the virtual certainty that it will not collapse, not even under the most conceivably extreme conditions (Figure 6). Delta Dykes, already applied in Japan and the United States, can be built in various shapes. The Japanese constructed very broad versions (several hundreds of metres wide) with houses and roads built on top of them (this concept, however, was not based on flood hazard only, but foremost on the earthquake hazard, which can have a strong destabilising impact on dykes that have been built too narrowly). Yet, it does not necessarily involve a complete new concept of dyke construction. Less far-reaching options are to reinforce existing dykes, for example with revetments, sheet piling or creating a less steep inner slope. These less drastic options also demonstrate that the difference between an unbreachable dyke and a conventional one is not so much a difference in applied concept (the present Dutch dykes are already supposed to hold at exceptionally extreme conditions), but rather a difference in construction. Although, from an efficiency point of view they perform better than conventional dykes, in the sense of yielding a larger risk reduction per euro invested, they need additional investments over the present legally required budget for reinforcement. Still, there are several good reasons to apply them at certain locations. If flooding is limited to overtopping instead of breaching, flood exposure is reduced, considerably. The number of fatalities is believed to drop by one or two orders of magnitude. Certain predefined locations that are most at risk behind the dykes are obvious spots for implementation of Delta Dykes (Figure 8). A 50% fatality risk reduction is to be expected when applying Delta Dykes along only 200 kilometres of the 3500 kilometres of flood defences in the Netherlands. Moreover, these dykes would reduce the necessity for radical spatial measurements to reduce flood exposure, which are not only rather costly, but also administratively difficult to realise in these densely populated areas.

Compared with a strategy of revising safety standards on the basis of cost minimisation (Option 3), lowering the risks within all dyke rings (Option 6) is a costly measure. Selective use of Delta Dykes (unbreachable dykes), whether or not combined with controlling flooding, is more effective (Options 4 and 5; Text box). The additional costs of making dykes unbreachable make such strategies more expensive, but they do deliver the greatest reduction in risk per euro invested. The additional costs of unbreachable dykes can be limited if these works can be incorporated into the restructuring of urban areas along rivers and the coast (multifunctional dykes), or combined with the implementation of the Flood Protection Programme, bringing all flood defences up to standard.

Figure 6
Options for dyke reinforcements

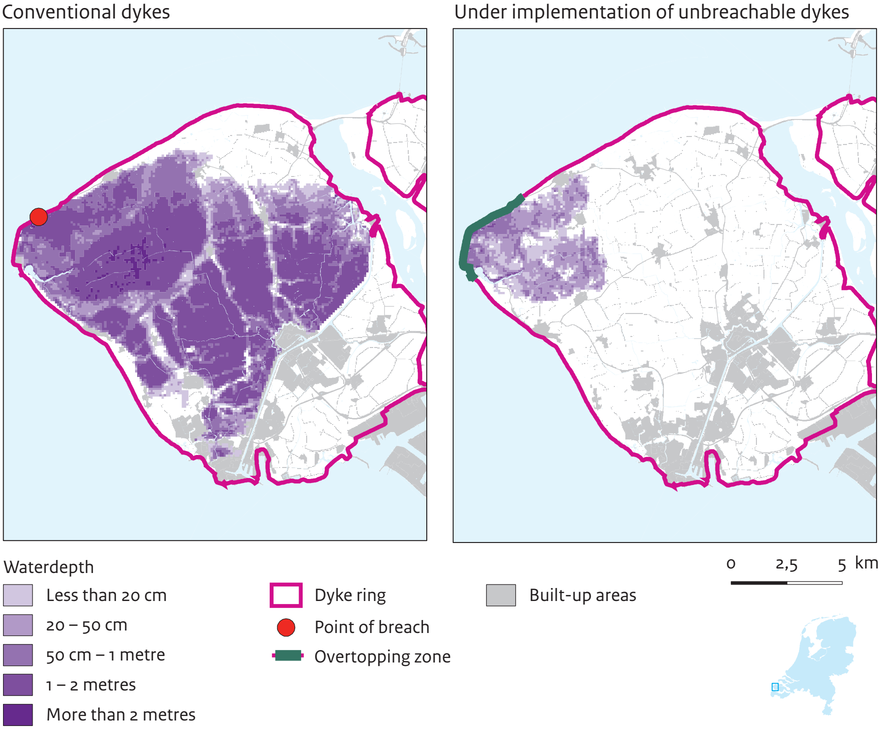


Source: PBL

Conventional dykes can be made more robust and less vulnerable to various failure mechanisms (e.g. piping, erosion from overtopping) by strengthening and broadening them or through sheet piling or other structural elements.

Because the impacts of flooding would be far less serious with unbreachable dykes (Figure 7), the need for adjustments to the built-up areas themselves in order to reduce the possible impact of flooding, is smaller. Under current policy, which is geared primarily to reducing the probability of flooding using conventional dykes, it is necessary to steer building and rebuilding activities in such a way so as to minimise the consequences of flooding (flood-resilient building). However, adjusting the built-up area and spatial development patterns will not be easy, as the major part of the built-up area and infrastructure of the future is already in place (Figures 2 and 3). Therefore, it will take many decades before flood-resilient building methods will have made urban areas any safer. Nevertheless, because the consequences of flooding will be structurally reduced if unbreachable dykes are constructed, the Netherlands will become much safer once these dykes are implemented, as well as less sensitive to climate change and unexpected more extreme conditions.

Figure 7
Flooded area and flood levels for conventional and unbreachable dykes (at Walcheren)



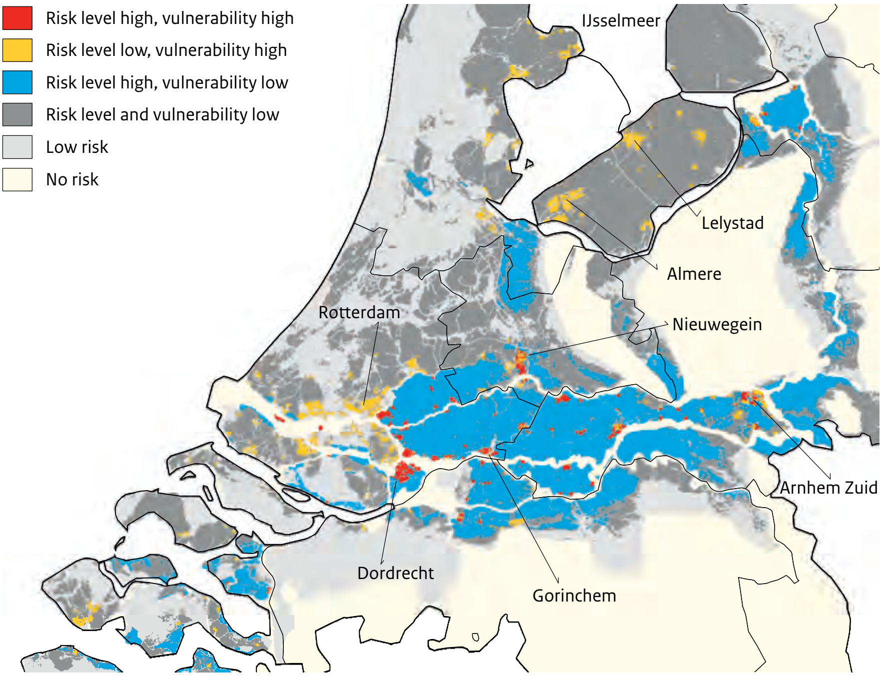
Source: Stijnen (2008)

Extent of flooding in the case of conventional and unbreachable flood defences (Walcheren, south-west Netherlands).

Managing new development in the Rhine-Meuse floodplain

In the Rhine-Meuse floodplain, open land areas must be reserved to accommodate potentially higher river discharges in combination with higher sea levels, in the longer term (see Appendix). The measures taken in the present Room for the River programme by the Ministry of Infrastructure and the Environment will then no longer be adequate (Ligtvoet et al., 2009). Maintaining these open areas in the Rhine-Meuse floodplain does not mean that these areas cannot be used: buildings can de designed to minimise their vulnerability to flooding; for example, by building on raised areas or on stilts, and farming can also continue and recreational areas be developed, possibly linked to the conservation and restoration of internationally important riverine habitats and river landscapes. This implies that spatial development management is needed, especially in built-up areas in the Rhine-Meuse floodplains, where open land areas for future flood

Figure 8
Flood risks



Source: De Bruijn and Klijn (2009)

Not all areas are equally vulnerable; the consequences of flooding are greatest in areas with the highest concentrations of population and fixed assets. The construction of unbreachable dykes at these locations will deliver the greatest benefits.

management options must be kept available. When combined with the implementation of Delta Dykes on hotspot locations (Figure 8), this means that the need for management and adjustment of spatial development remains restricted to riverine areas.

Governance challenges

Implementation of unbreachable dykes in the most vulnerable locations (compare Figure 8) will take time to accomplish. If limiting casualty risks and the consequences of flooding are to be fully included in flood protection policy, drawing up the details, administrative decision-making and informing the public about the implementation of this policy will all take considerable time. Given the potential safety benefits and the complexity of this task, taking the time for a careful and thorough planning process would seem to be more than justified. This study has revealed an important correlation between the choice for unbreachable dykes and the need to adapt the structure of urban areas behind these dykes, to reduce the consequences of flooding. Coordination will be needed between the Safety and New Build and Restructuring sub-programmes of the Delta Programme, and the development of regional safety strategies.

It can be expected that an investment strategy based on an adapted flood protection policy will also result in different investment needs. As the details of the strategy are worked out, a clearer picture may emerge of the extent to which the backlog of maintenance works can be combined with the construction of unbreachable dykes at strategic locations or with other developments.

THREE

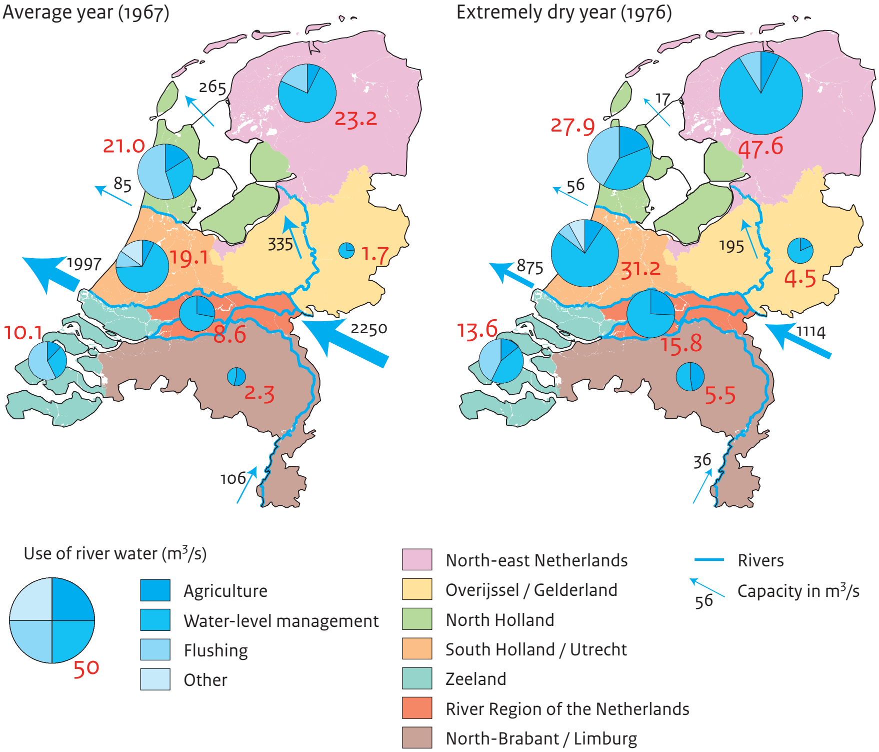
Freshwater supplies

Climate-proofing freshwater supplies will require a more flexible water system and better use of the water in the Rhine

Water availability will probably decrease

When viewed from an annual perspective, the Netherlands has a water surplus; water deficits occur during the summer, when evapotranspiration exceeds precipitation. During the summer months, about three-quarters of the Netherlands is supplied with additional water from the national waterways, which include the rivers Rhine and Meuse and the IJsselmeer (Figure 9). In the summer, the river Rhine is by far the most important source of fresh water for the Netherlands. Parts of the more elevated regions with sandy soils in the east and south of the country and a few of the islands in the south-west delta rely entirely on precipitation and regional groundwater reserves for their water supply. In normal and dry summers – the latter occur about once every ten years – these water resources are usually sufficient to meet demand. However, in extremely dry summers – which occur about once every 60 to 100 years – the available water resources may be insufficient, as was the case in 1976. Climate change is expected to increase the frequency of periods of drought during summer (see Appendix), which will also lead to increased risks of water deficits. Water deficits can lead to drought and low water levels, amongst other things, affecting shipping, agriculture, urban groundwater levels, and natural habitats. Drought can also result in salinisation and reduced water quality, because less water is available in the rivers and the IJsselmeer to supply regional and urban water systems. Peat dykes have also proven susceptible to drying out during periods of extreme drought, and high river water temperatures may impose restrictions on the amount of cooling water that power plants are allowed to discharge, in turn leading to constraints on the energy supply.

Figure 9
Distribution and use of river water



Source: Deltares

Even in extremely dry years, about 80% of the fresh water in the Rhine flows unused via the New Waterway (Nieuwe Waterweg) into the sea. It can then only be used to combat salt water intrusion.

Options considered: water demand and water supply

The future availability of water can be managed by regulating the supply of water from the national waterways and the demand from regional water systems. Broadly speaking, there are two policy options:

- *Limiting regional demand for water.* Current levels of water supply and current distribution of water across the national waterways remain the same. This means that this task will mainly rest the shoulders of the regions and the water-hungry sectors, when climate change leads to increased demand or increased water shortages (see also Section 3.2). The amount of water available for new economic activities will then be limited.
- *Increasing the supply of water by the national waterways.* The supply of water by the

Table 1
Indication of potential reduction in water demand by regional water systems, based on various regional water studies

Source	Research area	Research topic	Potential reduction in water demand
Lobbrecht (1997)	Delfland	Optimisation of water intake	50%
Van Kruiningen et al. (2004)	North Holland	Flexible saline levels of surface waters	>80%
Ten Voorde (2004)	Hollands Noorderkwartier	Optimisation of water intake	50%
Velstra et al. (2010)	Hollands Noorderkwartier	Optimisation of water intake	50%
Van Bakel et al. (2010, 2011); Velstra et al. (2009)	Netherlands	Flexible saline levels of surface waters	90%
Turlings (2007)	Haarlemmermeer	Effects of not flushing water systems	>50%
Klomp (2010); Velstra et al. (2009)	Netherlands	Additional water retention in freshwater lenses	>50%
Van Bakel and Stuyt (2011), Stuyt (2006)	Netherlands	Tolerance of crops to saline soil moisture (precision agriculture)	>50%
Balendonck (2011)	Netherlands and international	Optimisation of agricultural use of soil moisture (precision agriculture)	10–60%

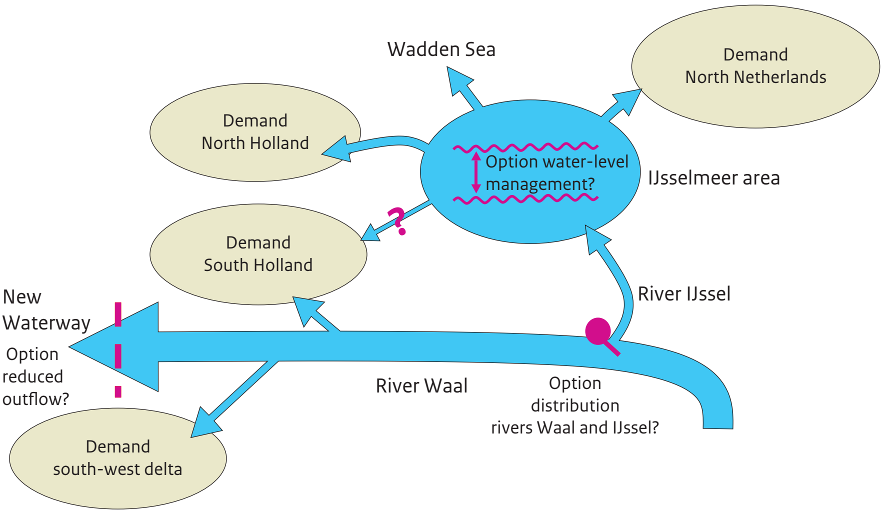
Source: PBL (2011)

national waterways is increased during the summer, to a greater or lesser degree, making more fresh water available over the coming decades to compensate for the unfavourable effects of climate change and/or for the growth in economic activities that use water. Consideration can also be given to expanding the supply of water to areas not yet supplied with water (Figure 9).

Curbing regional demand for water through more flexible water management
Water from the national waterways is used mainly to maintain water levels and for flushing regional water systems to maintain water quality and control salinity levels (Figure 9). During dry periods, the demand for water from regional water systems can be curbed by taking a more flexible approach to water management (Table 1).

Water is required mainly for maintaining water levels and flushing regional water systems (to control salinisation and improve water quality). Less than 5% of the water demand is for direct agricultural use (irrigation). The demand for water can be reduced by temporarily taking a more lenient attitude to meeting the sometimes very strict

Figure 10
Supra-regional freshwater analysis



Source: PBL

Two important ways of increasing the supply of fresh water from the national waterways are reducing the discharge of fresh water through the New Waterway and allowing greater fluctuations in water level in the IJsselmeer.

salinity standards. A temporary increase in salinity in parts of the regional water systems will not necessarily have significant adverse effects on agriculture. For valuable salt-sensitive crops, such as greenhouse horticultural crops, increasing use is already being made of separate water supplies to ensure the required water quality, thereby decoupling water supply from the regional water system. This alternative is not economically feasible for arable production, which uses water on a much larger scale. However, most arable crops have a higher salt tolerance than quality crops, and research has shown that temporary increases in the salinity of surface waters does little damage, because the salt hardly penetrates into the soil. However, a higher salt content reduces the suitability of the water for irrigation. Grassland, which covers a large part of the lower lying areas of the Netherlands, is also quite tolerant of more saline water. On the islands in the south-west delta, the demand for water can also be reduced substantially by altering the management of the groundwater ('salt water lenses') and taking a more flexible approach to water management. Although further research is needed, various regional studies suggest that considerable efficiency savings can still be made through regional water management (Table 1). The provincial councils, water boards and the agricultural sector have an important role to play in defining the options in the various areas in more detail, during the further planning and implementation of the Delta Programme.

Table 2

Indication of the supply–demand ratio by 2050 for the IJsselmeer

	Unit	Current situation	15 cm additional water-level fluctuation	30 cm additional water-level fluctuation
Water-level fluctuation in the summer	Centimetres	20	35	50
Average annual supply/ demand (W+ 2050)	Percentage of demand met	97.7	98.3	98.2
Supply/demand in extremely dry year (W+ 2050)	Percentage of demand met	72	78	85

Source: Meijer et al. (2010)

Water supply: making better use of the water in the Rhine offers prospects for an adaptive strategy

Two important ways to increase water supply from the national waterways are: i) increasing the amount of usable water resources in the IJsselmeer by allowing a greater fluctuation in water levels, and ii) reducing the discharge of fresh water through the New Waterway (Figure 10).

At the moment, there appears to be little need for substantial changes to the water-level regime of the IJsselmeer. By 2050, assuming the present water-level regime, as well as a continuation of current land uses and the W+ climate scenario, in an extremely dry year (occurring once every 100 years) about 70% of the water demand could be met. With a limited additional water-level fluctuation of 30 cm, in a similar year, 85% of water demand could be met (Table 2).

Given the uncertainties, consideration may be given to allowing the possibility of a limited additional fluctuation in water level. The costs of this would appear to be limited, but a balance needs to be struck with the possible negative impacts on natural habitats located outside the dykes, the recreational areas and shipping (Meijer et al., 2010).

With greater fluctuation in water levels, also more water becomes available, but the costs also rise sharply. For example, a one-metre rise, in line with the recommendations of the Veerman Commission, will require an investment of about 4.4 to 6.5 billion euros, whereas occasionally lowering the water level of the IJsselmeer will cost substantially less, at around 1 billion euros (Van Beek et al., 2008). The question, though, is at what point such major investments would be cost-effective. Klijn et al. (2010) conclude that

Source: Rijkswaterstaat

Management of the water system in the areas of the New Waterway could be a key element in the supply of fresh water in the Netherlands. If the amount of water from the river Rhine, used to prevent intrusion of salt water from the sea, could be decreased, a substantial amount of additional fresh water would become available for other uses.

major interventions and raising the water level by as much as one metre will not be cost effective in the near future: the costs outweigh the avoided agricultural damages.

The amount of available fresh water can be increased by making better use of the water in the Rhine system. Large volumes of fresh water flow through the Rhine and the New Waterway. Even in dry years, more than 800 cubic metres of fresh water per second flow through the New Waterway to the sea, which corresponds with about 80% of the amount of Rhine water entering the Netherlands (more than 1100 cubic metres/second; Figure 9). If the salinisation of the New Waterway can be counterbalanced by just part of this flow of fresh water, the problem of salt water intrusion in the lower stretches of the Rhine could be solved and more fresh water would become available for use in the west and south-west of the Netherlands. Possible variants of such a regime to reduce salinisation are step-wise reductions in the depth of the New Waterway (which is now more than 20 metres deep, up to Rotterdam), constructing groynes (permanent or temporary), temporary partial closure in extreme dry years, or installing underwater barriers or pneumatic barriers. However, little is known about the actual effects of these measures on the intrusion of the saline wedge (Van Beek et al., 2008).

It is important to compare costs, effects and flexibility of the options for the New Waterway and the IJsselmeer when developing the freshwater strategy in the Delta Programme. To give an indication of the amounts of water in these two regions: a one-metre change in the IJsselmeer water level, during six summer months, would provide the equivalent of less than 10% of the amount of water that is discharged through the New Waterway, even in extremely dry summers, such as that of 1976. The amount of water in the Rhine, therefore, may be sufficient – depending on the rate of climate change – to allow a gradual build-up of freshwater resources and, thus, avoid overinvestment. If large volumes of water could be abstracted from the New Waterway, it may be possible in dry periods to adjust the distribution of river water between the Waal and the IJssel to increase flows into the IJsselmeer. Under this option, no investments would be needed for large water-level fluctuations in the IJsselmeer.

Governance challenges: coordination between Delta Programme areas

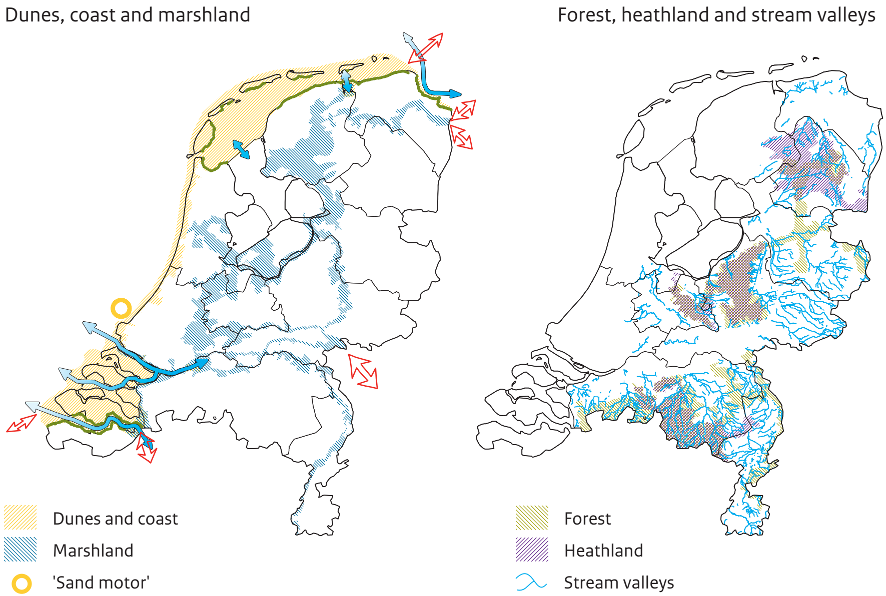
With regard to freshwater supply, our analysis has revealed a close correlation between the different areas within the Delta Programme: the IJsselmeer (water level ordinance), the Rhine estuary (effectiveness of measures to counter salinisation), the river Rhine (discharge distribution between the IJssel and the Waal) and the south-west delta (fresh versus saline water) (cf. Figure 10). The water level ordinance for the IJsselmeer could be set independently, but long-term decisions will also depend on the possibilities in the Rhine estuary for taking a more effective approach to preventing salinisation of the New Waterway and the possibilities for the Rhine system to alter the distribution of river water during dry periods. In the area around the New Waterway, the possibilities for making more effective use of the water in the Rhine will also have a considerable bearing on a national level on the development of a long-term freshwater strategy. To make a proper assessment of which approach to take, it will be necessary to identify substantively coherent and consistent options from a national perspective, and estimate the costs and benefits of these options.

Ecosystems and biodiversity

Climate-proofing ecosystems and biodiversity will require revising the strategy behind the National Ecological Network

Under current policies ecosystems and biodiversity will not be climate-proof
Environmental and nature conservation policies have been successful in increasing the adaptive capacity of biodiversity. Environmental pressures on biodiversity have decreased and nature conservation areas have been expanded and linked together. Despite this improvement, water table drawdown, eutrophication, acidification and fragmentation remain significant problems for the conservation of habitats and biodiversity, even after the completion of the planned National Ecological Network. Climate change adds an extra dimension to these problems: climatic zones are shifting and disturbances, such as higher temperatures, extreme precipitation events and periods of drought, will occur more frequently. Shifts in species ranges and in the life cycles of plants and animals are already visible in the Netherlands and are expected to increase. The effects of water table drawdown on nature conservation are already noticeable and make these areas even more vulnerable to drier periods and fires. The government intends to revise plans for the National Ecological Network, to acquire land for ecological restoration only sporadically, and not to create the previously planned robust links. In the short term, these decisions appear to have only limited consequences for the Netherlands' ability to meet its European obligations. Over the longer term, however, it is expected that ecosystems and biodiversity will be unable to fully adapt to climate change. This means that the risk of biodiversity loss will increase; in turn, reducing the chances that the Netherlands will meet its international nature conservation and restoration obligations, in the long term.

Figure 11
Possible nature areas suitable for climate adaptation



Source: PBL (2010)

Restoring natural processes in the coastal zone, connectivity between marshland in lowland areas and along rivers, and between forest, heatland and stream valley ecosystems in sandy regions are important for reducing climate risks.

Climate-proof ecosystems and biodiversity: greater spatial connectivity, better environmental and water conditions and room for the operation of natural process

The risk of biodiversity loss, and consequently not meeting international obligations, would be reduced if elements of Dutch nature policies were revised. Biodiversity levels can be maintained if efforts are directed at expanding and linking together protected areas, both within the Netherlands and internationally, increasing the heterogeneity of habitats and landscapes, and improving environmental and water conditions to create more space for natural processes to operate. This will also require international (European) coordination.

The ecosystems in the low-lying areas of the Netherlands are of international importance

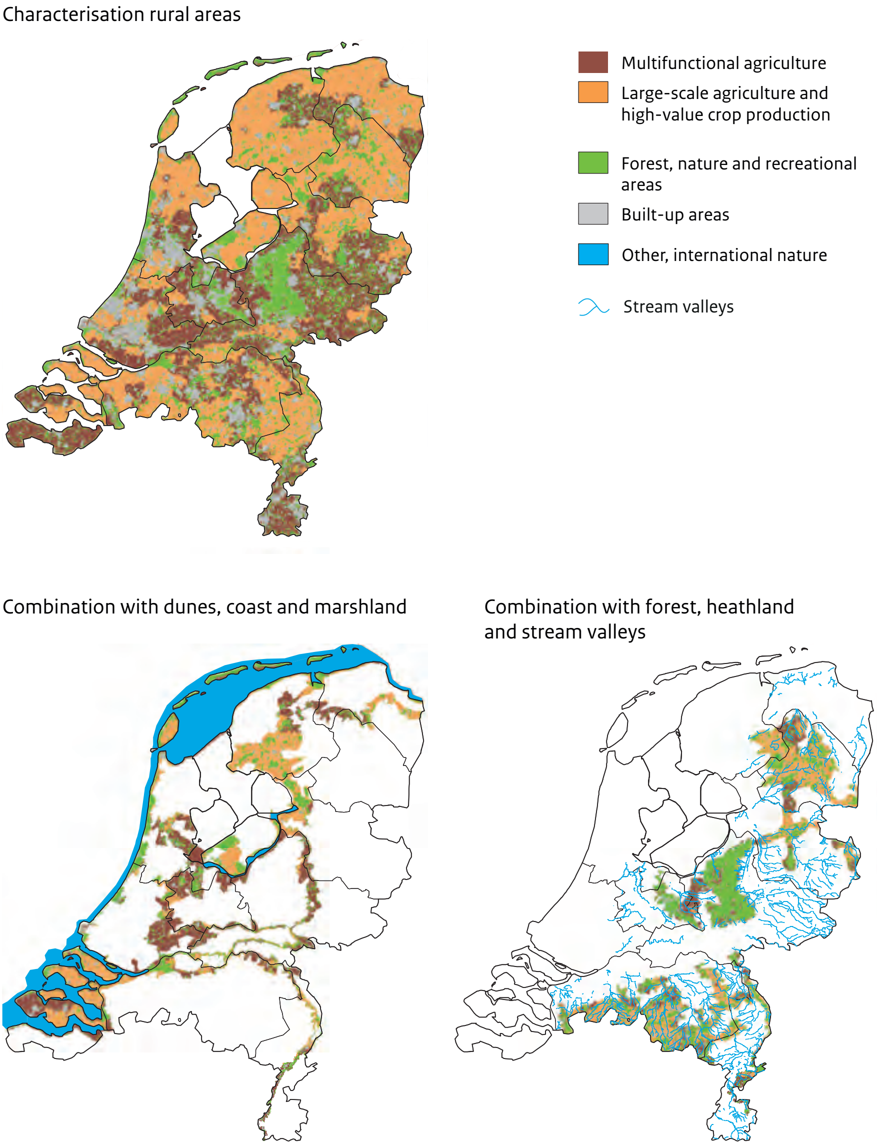
The Netherlands has an important international responsibility for ecosystems typical of lowland deltas: the tidal areas, the Wadden Sea, dune systems, salt marshes and salt meadows, and mires and fens in the lowland areas and along the rivers. Given this responsibility, the obvious course is for the Netherlands to adopt an internationally oriented adaptation strategy for these areas. For terrestrial ecosystems, this will involve strengthening the spatial connectivity of the dune systems, the peat marshes and the Rhine-Meuse floodplain (Figure 11). In the Wadden Sea, the south-west delta and the coastal zone, the adaptive capacity of ecosystems and biodiversity can be strengthened by restoring natural processes, such as erosion and sedimentation, and restoring the freshwater/saline gradients. As all the main water systems are Natura 2000 areas and fall within the Delta Programme, the future climate resilience of ecosystems and biodiversity will depend heavily on the choices made in the Delta Programme relating to flood protection and the availability of fresh water. It is also important that these decisions leave room for natural processes and the restoration of dynamic freshwater/ marine interactions in the south-west delta.

For the ecosystems characteristic of the more elevated regions of sandy soils (forest, heathland and stream valleys; Figure 11), greater coordination and compatibility is needed between nature conservation, water management and agriculture. More favourable conditions for forests, heathland and stream-valley ecosystems can be created by linking these together more effectively and restoring the natural hydrological dynamics (such as groundwater levels, groundwater seepage and stream flow dynamics). These measures can be integrated as much as possible into the development of diversified farming with adapted water management and lower fertilisation regimes (Figure 12). The prime responsibility for these areas rests with the provincial councils, the water boards, the agricultural sector and nature conservation organisations.

National waters within the Delta Programme: all Natura 2000

The national waterways contain important areas of international conservation value: the Wadden Sea, the IJsselmeer, the Rhine-Meuse floodplain, and the south-west delta (compare Figure 1). Large parts of these areas are Natura 2000 sites. The vision for landscape and ecosystem quality in the various areas will have an influence on the choices to be made about flood protection and freshwater supplies. Central government's responsibilities for ecosystem quality and biodiversity in the national water bodies are the development of more naturally functioning shoreline systems, the restoration of natural (gradual) salinity gradients and making weirs, locks and sluices passable for migrating fish. The construction of dams and sluices has heavily compartmentalised the water system and large parts of the tidal areas have disappeared (Zuiderzee, south-west delta). Obvious examples are the IJsselmeer Dam, the Haringvliet Dam, the locks at IJmuiden and the weirs in the rivers. These dams, locks and weirs restrict the possibilities for the exchange of water between water systems and form barriers for migratory fish. The artificial water regime has also led to a large reduction in the area of shores and banks, while the absence of natural fluctuations in water levels, which create wetter conditions in winter and dryer conditions in summer, has led to a reduction in the ecological value of these areas.

Figure 12
Various potential combinations of nature and agriculture



Source: Agricola et al. (2010); Vonk et al. (2010)

Multifunctional agriculture provides the best option for combinations with nature conservation and development. Important areas for these combinations are located in the western peat-marsh areas and in the floodplains.

At the national scale, several fundamental decisions have to be made about the IJsselmeer, the south-west delta and the Rhine-Meuse floodplain:

- *The IJsselmeer: water-level management versus shore areas and facilitating fish migration.* The issues to be addressed in the IJsselmeer region are the incompatibilities between fluctuations in water level in the interests of freshwater supplies (see also Chapter 3), the conservation and development of marshland and shores, and the possibilities for improving fish migration between the IJsselmeer and the Wadden Sea. The area of marshland in the IJsselmeer and Markermeer is very small (just a few per cent of the total area) and the quality and development of the area will depend to a large degree on the future fluctuations in water level and whether or not the area of marshland is expanded; for example, by creating foreshores or broad sloping shoreline zones in combination with improved flood protection. A considerable rise in water level would remove the current shore areas unless the physical layout of the shore zones is altered. However, a gradual lowering of the water level during the summer would stimulate shore development.
- *The Wadden Sea: natural processes and improved safety.* The natural processes in the Wadden Sea can contribute to flood protection through the creation of shallows and salt meadows just off the coastline. Salt meadows are a valuable part of the Wadden Sea ecosystem and, in the form of an extended foreshore outside the dykes, can help to increase flood protection. A gradual saline gradient from saline to fresh water also benefits the natural ecological processes at work in the Wadden Sea. Permanent salinity gradients can still be found in the Ems–Dollard tidal zone. The gradual salinity gradients in the IJsselmeer and Lauwersmeer have disappeared following the closure of the area by the IJsselmeer Dam. The task here is to improve the exchange and migration of species between the various systems, within the constraints of the existing situation.
- *South-west delta: saline versus fresh water.* The issues regarding ecological quality in the south-west delta are the incompatibilities between restoring the dynamic interactions between saline and freshwater environments characteristic of tidal systems and the provision of fresh water for agricultural use on the delta islands. The saline dynamics in the south-west delta can be restored on a significant scale (Haringvliet, Grevelingenmeer, Veerse Meer, Volkerak-Zoommeer). The Haringvliet is the most important link between the North Sea and the Rhine and is crucial for fish migration. The water quality in Grevelingenmeer, Veerse Meer and Volkerak-Zoommeer is continuing to decline as a result of the closure of the sea arms and the loss of the hydrological dynamics in the region, which not only affects ecological quality in the area, but also its recreational value. In Chapter 3 was established that, in principle, more water can be obtained from the Rhine if the salt water intrusion in the New Waterway can be countered more efficiently. As the delta becomes more saline, this Rhine water could then be transported to the delta islands; for example, by pipeline, in the same way that water from the Biesbosch is transported to Tholen. The supply of fresh water to these areas, therefore, would not appear to be a limiting factor. However, the desirability and feasibility of such an approach will eventually to a large extent depend on the possibilities for optimising freshwater management on

the islands themselves and the costs and financing of importing water to the islands (public, private or a combination of both).

- *The Rhine-Meuse floodplain: coupling the conservation of open space with long-term flood protection?* The issue to be addressed in the Rhine-Meuse floodplain is whether the open space can be maintained in order to accommodate river discharges, in the longer term. As the river landscape and its freshwater marshes are important elements for the development of climate-proof ecosystems (Figure 11), the areas along the rivers Waal and IJssel present interesting opportunities for combining these two goals. This will require steering future development towards appropriate locations (Chapter 2).

Governance challenges: climate-proofing ecosystems and biodiversity requires revising the government's vision and strategy

Enabling the development of climate-proof ecosystems and biodiversity, in the long term, will require changes to various elements of the national nature policy. Central government will not only have to adopt an appropriate policy vision, but also a coordinating and supervisory role, because what is at stake is the international and supra-provincial spatial connectivity of ecosystems. For the major hydrological systems, which all belong to the European Natura 2000 network of protected areas, there remains an important coordinating task for the Delta Programme and the Ministry of Economic Affairs, Agriculture and Innovation.

FIVE

Urban areas

Implementation of climate-proofing measures in urban development today may considerably reduce costs for tomorrow

Climate-proof cities: the challenges vary considerably from neighbourhood to neighbourhood

Climate change will increase the likelihood of river flooding, urban flooding, drought and water shortages in urban areas, as well as heat stress in extremely hot summers, because of heat build-up in urban areas. Heat stress poses a health hazard to already vulnerable groups in the population, such as the old and chronically ill, and can also affect labour productivity. Flood defences in the Netherlands are designed to withstand extreme situations occurring once in every 1,250 to 10,000 years, and droughts are likely to occur only once in every 10 (dry) years, or 60 to 100 years (extreme droughts). Severe heat stress occurs more frequently (heat waves), and peak precipitation events causing urban flooding at various places across the Netherlands occur several times a year. The effects of climate change and, thus, the nature of the measures required to ensure a climate-proof urban environment, vary considerably, depending on the form and layout of each district or neighbourhood. The potential damage or nuisance depends to a large degree on the type, density and quality of the buildings, the presence of public green spaces, such as parks, gardens and trees in streets, the presence of water bodies, such as ponds and canals, and the state of repair of the sewerage system. Climate proofing is hardest to achieve in highly urbanised areas, because the proportion of hard surfaces is highest there, leading to a more rapid build-up of heat, while the available room for mitigating measures is limited.

Source: ANP/Jan Luursema

The growing frequency of peak rainfall events increases the probability of flooded drainage systems in urban areas. Unfavourable street layouts (full-width speed ramps or other raised paving, lowered pavements, limited height differences) can also contribute to increased urban flooding.

Urban areas are constantly in development: new housing, offices and infrastructure are being built, existing neighbourhoods and business estates are restructured and sewerage systems are replaced. If adaptation to climate change is consistently taken into account in all new investments in urban areas, the additional costs of these measures can be reduced and even minimised, and in some cases they even may involve no additional cost at all.

Enough effective measures are available at the scale of individual buildings, streets, neighbourhoods and cities; flexibility of implementation at neighbourhood and city levels is limited.

Measures of climate adaptation in urban areas can be implemented at various scales: those of individual buildings, streets, neighbourhoods and cities. Adaptations to buildings and streets – such as building insulation, green roofs and modified paving for water retention – can be carried out relatively quickly because of short lead times. Such measures decrease heat stress in buildings and in many cases can be combined with energy saving measures. Key actors at this level are housing corporations, companies and private property owners. Structural spatial adaptations at neighbourhood or city levels, such as the construction of parks, ponds and water features, planting street vegetation, building thermal energy storage systems and adapting sewerage systems,

Table 3

Effects of possible measures to increase climate resilience of urban areas

	Flooding outside the dykes	Improve urban drainage systems	Minimise heat build-up	Minimise drought	Combination with: OEQ[1]	Combination with: Energy saving	Flexibility in implementation[3]
Building							
Orientation to sun			+			+	Low
Insulation			+			+	High
Green roofs			+			+	High
Air conditioning			+			-	High
Adjust threshold height		+					High
Raised buildings	+	+					Low
Floating buildings	+	+					Low
Neighbourhood							
Improve existing water system		+					Low
Water retention in street		+			-		High
Water retention under street		+					Low
Create ponds		+	+		+		Low
Upgrade sewerage systems		+		(+)[2]			Low
Separate sewerage system (sewage and surface water)				+		+	Low
Hydrological isolation				+			Low
Create parks		+	+		+	?	Low
Street vegetation			+		+	?	Low
Build thermal storage systems			+			+	Low
Safe refuge	+						Low

	Flooding outside the dykes	Improve urban drainage systems	Minimise heat build-up	Minimise drought	Combination with		Flexibility in implementation[3]
					OEQ[1]	Energy saving	
City							
Green networks		+	+		+	?	Low
Blue networks		+	+	+	+	?	Low
Escape routes	+						High
Public information	+	?	?	?			High
Warning system	+	?					High

Source: based on Van de Ven et al. (2010)

[1] *OEQ: outdoor environmental quality*

[2] *Where sewers have an unintended drainage function*

[3] *Structural measures: low flexibility; process of installation and layout: high flexibility*

Legend

+	Positive effect
-	Negative effect
?	Unknown effect
Blank	Neutral effect
(olive green)	High flexibility
(yellow)	Low flexibility

Source: Jacqueline van Eijk

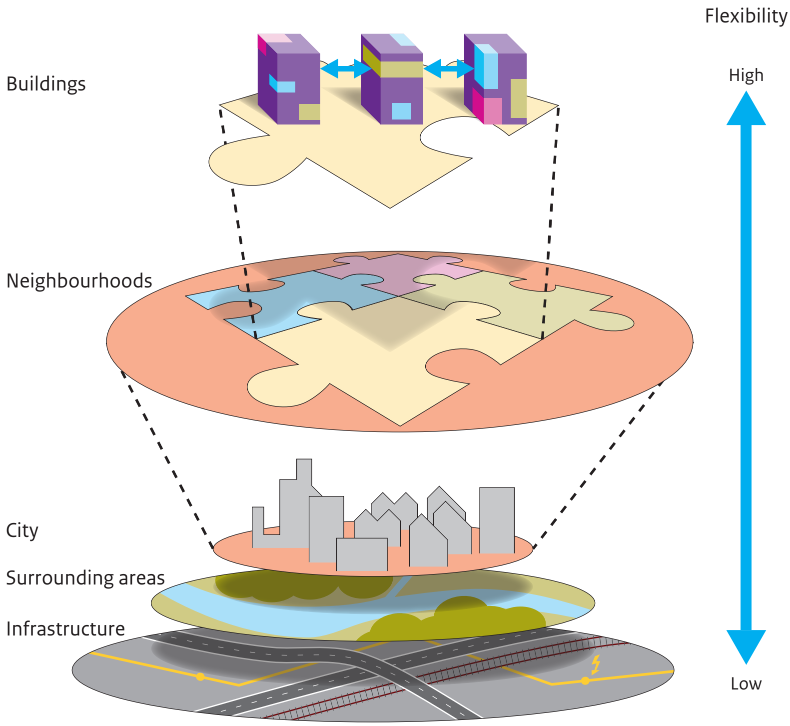
Introducing green structures, street planting, ponds and watercourses raises the quality of the urban environment and also helps to reduce heat build-up and the likelihood of urban flooding.

are more profound interventions in the urban fabric and involve longer lead times. These measures, therefore, cannot be flexibly deployed. Key actors for such measures are municipal councils and real estate developers. The opportunities for responding to climate change vary according to the type of urban area. New developments and urban restructuring areas offer the widest range of possibilities. The more limited options are found in existing neighbourhoods where no restructuring will occur within the next few decades, but only replacement, maintenance and renovation works are carried out. The measures that can be taken in these neighbourhoods will be restricted mainly to adaptations to buildings and streets. Much more radical measures can be taken in new-housing areas and in urban restructuring projects. This also accounts for the differences in the opportunities to respond to climate change in urban areas between growth regions and regions in decline.

Climate proofing also improves the quality of the urban environment

Structural measures to prevent heat stress and urban flooding are more effective when combined with general measures to raise the quality of and amenities in the urban environment, such as ponds, canals, parks, trees in streets, low-energy housing, creating 'green' and 'blue' networks in the city, and connecting these to the surrounding countryside. Such synergistic measures are compatible with the government's

Figure 13
Various scales for adaptation measures within the urban environment



Source: PBL

There are many ways to approach climate-proofing of urban development, on the various scales, and many actors are involved in the planning and implementation. This requires close cooperation between the various social actors and a clear division of responsibilities between government, public parties, private companies and citizens.

ambitions set out in the recently published National Policy Strategy for Infrastructure and Spatial Planning (I&M, 2011).

Governance challenges: allocation of responsibilities and integration of climate change in planning and decision-making

Encompassing different scales and a wide variety of actors, integrating climate-proofing in urban development is a complex challenge (Figure 13). Central government and the provincial and municipal authorities each have their own responsibilities in climate-proofing urban areas, while many private parties (housing corporations, companies and private citizens) play a part in urban development. But who is responsible for which of the effects of climate change? Under current legislation, municipal authorities have the prime responsibility, along with the provincial authorities and water boards. Central government has an important task in giving direction to the municipal and provincial authorities and water boards via legislation (such as the Building Decree and guidelines for the amount of green space per person) and national spatial planning decisions. The flexibility of response to climate change at city level is limited. The scope for action on this scale is restricted to new housing and urban restructuring projects, the creation of green space and water elements, the construction of thermal energy storage systems, and the renewal and replacement of sewerage systems and other infrastructure. There are considerable opportunities for integrating climate adaptation into existing plans for new development and improving the quality of urban areas. Failure to exploit these opportunities entails the risk of underinvestment.

Municipal 'climate-proofing plans' are a potentially interesting tool for gaining insight into the what needs to be done to make cities climate ready. These plans can clearly identify the scale of the task at hand, the options available, and the responsibilities that municipal councils take on themselves and those they delegate to businesses and local residents.

Challenges in governance

A clear division of responsibilities between central government and other parties

National government has the overall responsibility for tasks, such as spatial planning, freshwater supplies and flood protection. In decentralising this responsibility, central government must create the preconditions and mechanisms to enable lower-tier authorities (provincial and municipal authorities, water boards), citizens and companies to adapt to climate change, primarily in the areas of freshwater supply and climate-proofing cities. Central government should clearly state exactly where the limits of its responsibility of care lie and what investments in climate adaptation it expects from other government authorities, the business community and citizens. These other actors can then decide on the measures they wish to take and what investments in buildings and infrastructure they should make.

Facilitate and stimulate climate-inclusive decision making

In addition to a clear vision on responsibilities with respect to the challenges of climate proofing the Netherlands, the national government also has the responsibility of providing a suitable legal framework, a customised decision-making mechanism, as well as financing mechanisms that facilitate climate inclusive decisions on investments. The existing legal instruments for the policy fields of water, spatial development, housing, nature and environment can be used for adaptation to climate change, but, in actual practice, the opportunities are not fully appreciated, yet. Moreover, in the planning phase, possible solutions for climate-proofing may be blocked by the inflexibility of existing financing mechanisms (Driessen et al., 2011).
National government can take various steps in order to stimulate the embedding of climate adaptation in the decision-making process for financing physical investments,

Source: Hollandse Hoogte/David Rozing

Each intervention in the spatial development and layout of an area presents an opportunity to increase its climate resilience. To exploit these opportunities, the requirement of climate proofing needs to be addressed early on in the design and planning process, and must be embedded in the assessment and financing mechanisms.

such as cost recovery, equalisation arrangements, and creating a market for climate services. Making climate adaptation a standard consideration in urban governance can be supported by introducing policy plans for climate-proofing on municipal level, as well as incorporating the long-term perspective into existing decision-making processes.

Integration of climate-proofing development in the National Policy Strategy for Infrastructure and Spatial Planning

The National Policy Strategy for Infrastructure and Spatial Planning (I&M, 2011) sets out the government's vision on spatial development for the Netherlands. An important topic is the further decentralisation of spatial planning policy. The policy strategy refers to climate change and states that decisions about freshwater supplies and flood protection are being prepared as part of the Delta Programme. However, the possible spatial consequences of climate-resilient development are not mentioned. Our study has revealed that integrating a climate proof development into spatial planning policy can have significant spatial consequences. This implies the need for early strategic decisions on issues, such as the use of unbreachable dykes and the protection of the most vulnerable areas of the country, management of new development in the Rhine-Meuse floodplain and in urban areas, spatial and physical adaptations to make ecosystems and biodiversity resilient to climate change, and the distribution of fresh

Source: ANP/Hans Steinmeier

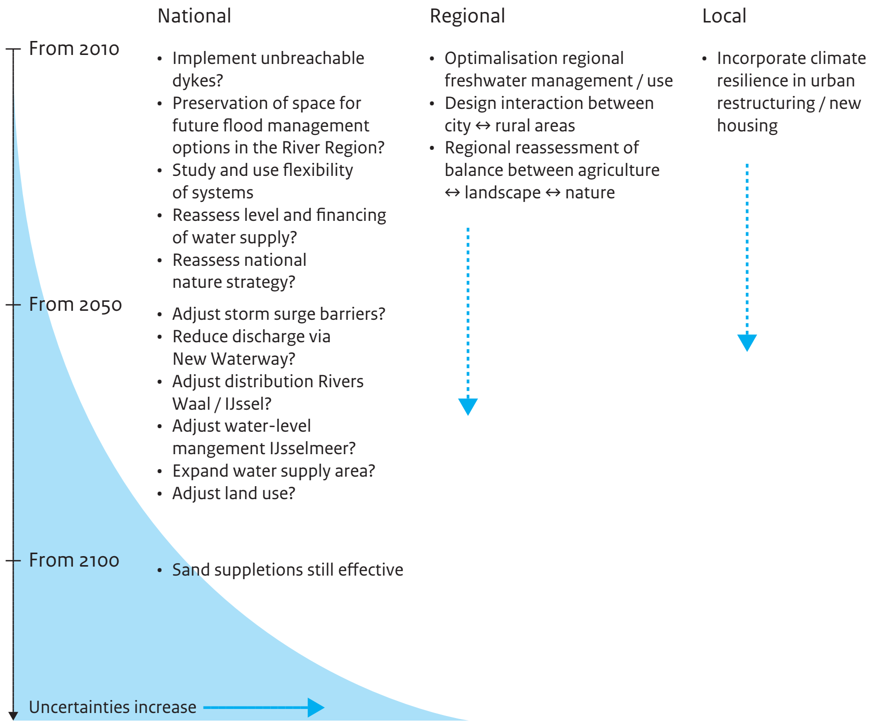
'More room for the river' will remain an option for protecting cities, such as Deventer, from river flooding. Maintaining or expanding areas reserved for water retention in the floodplain landscape will require strategic management of new developments.

water in relation to its use in the regions. Decentralised decisions on urban development in the River Region over the coming years, for instance, may already hamper future options of flood management in these areas, and decisions on nature development without incorporating the possible effects of climate change, after all, may reduce the effectiveness of investments.

Given the relatively slow pace of physical development, these topics deserve explicit attention over the coming years. For each development or spatial intervention, consideration can be given to how it can best be made climate ready. A start can already be made with preparing developments for the possible effects of climate change by placing such measures onto the existing policy agenda at various spatial scales (Figure 14).

Figure 14

Choices for climate adaptation



Source: PBL

The coming years, by joining in and being coupled to the current policy agenda, possible climate changes can be anticipated.

Appendix

Changing climate in the Netherlands

As in the rest of the world, the climate in the Netherlands is changing and further changes are projected for the coming decades and centuries. The Royal Netherlands Meteorological Institute (KMNI) has drawn up four possible scenarios for the future, reflecting differences in global temperature increase (in line with most global climate model projections) and whether or not atmospheric circulation patterns above western Europe will change. In these four scenarios, the climate is represented by many indices relating to both mean and extreme climatic conditions (Table A1). Some of these future changes are more uncertain than others. Annual precipitation, for example, may increase or decrease, whereas many other indices, such as sea level rise and temperature, differ between the scenarios mainly in the magnitude of expected change.

Sea level rise

Similar to many other deltas in the world, the expected sea level rise is of prime importance for the long-term safety of the Netherlands. Since 1900, the sea level along the Dutch coast has risen by 20 centimetres. If the rate of rise does not increase, the sea level may rise a further 20 centimetres by the end of this century. However, the future rise in sea level is surrounded by large uncertainties. Our understanding of the functioning of the earth's climate system and the melting of the ice sheets is still incomplete, future greenhouse gas emissions remain uncertain and the climate models themselves contain many uncertainties. The KNMI scenarios indicate a sea level rise of between 15 and 35 cm by 2050, and between 35 and 85 cm by 2100 (Table A1). Others have explored possible rates of sea level rise based on worst-case scenarios for temperature rise and the melting of ice sheets. The PBL (2007) suggested a worst-case sea level rise for the Netherlands of 1.5 metres per century, while the Delta Committee (2008) presented high-end estimates of between 65 and 130 cm for the period up to 2100 (Figure A1).

Precipitation and river discharges: marked changes in the '+ scenarios'

The historical precipitation deficit shows considerable variability and no clear trend has yet been identified (KNMI, 2009b). The average deficit over the 1906–2006 period was 144 mm, annually; 1949 and 2003 were dry years (deficits around 230 mm) and 1976 was an extremely dry year (360 mm deficit) (Klijn et al., 2010; KNMI, 2009b). The KNMI scenarios from 2006 show an increase in the summer precipitation deficit, but the size of the change differs considerably between scenarios (Table A1); the increase is slight in the G and W scenarios, while the greatest increase is expected in the W+ scenario. In the W+ scenario the average deficit may rise to 220 mm, annually, by 2050 (+50% compared

Table A1

Climate scenarios for the Netherlands: projected changes up to 2100

2100		G	G+	W	W+
Worldwide increase in temperature		+1 °C	+1 °C	+2 °C	+2 °C
Change in air circulation		No	Yes	No	Yes
Annual average	Average temperature NL	+1.8 °C	+2.5 °C	+3.5 °C	+5.1 °C
	Average precipitation	+6%	-2%	+13%	-4%
	Reference evaporation	+6%	+12%	+12%	+24%
Winter	Average temperature	+1.8 °C	+2.3 °C	+3.6 °C	+4.6 °C
	Coldest winter day within a year	+2.1 °C	+2.9 °C	+4.2 °C	+5.8 °C
	Average precipitation	+7%	+14%	+14%	+28%
	Number of wet days (>0.1 mm)	+0%	+2%	+0%	+4%
	Ten-day precipitation total that will be exceeded once every ten years	+8%	+12%	+16%	+24%
	Highest average daily wind speed	-1%	+4%	-2%	+8%
Summer	Average temperature	+1.7 °C	+2.8 °C	+3.4 °C	+5.6 °C
	Hottest summer day within a year	+2.1 °C	+3.8 °C	+4.2 °C	+7.6 °C
	Average precipitation	+6%	-19%	+12%	-38%
	Number of wet days (>0.1 mm)	-3%	-19%	-6%	-38%
	Daily precipitation total that will be exceeded once every ten years	+27%	+10%	+54%	+20%
	Reference evaporation	+7%	+15%	+14%	+30%
	Precipitation deficits in very dry years in mm (now about 352 mm)	366	397	381	440
	Repeating times of very dry years in years (now ones in 71 years)	52	31	40	20
Sea level	Absolute rise	35-60 cm	35-60 cm	40-85 cm	40-85 cm

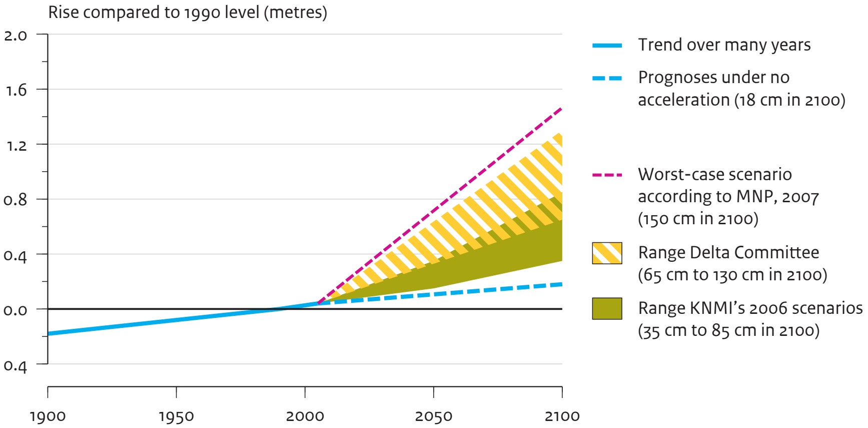
Source: KNMI (2009b); annual figures have been calculated by the PBL

with the last century) and to even more than 290 mm, annually (+100%) by 2100 (KNMI, 2009b). Figure A2 compares the maximum precipitation deficit for 2050 according to the two warm scenarios with the long-tem average over the 1981–2010 period.

Winter and summer river discharges change

Based on an analysis of the KNMI scenarios, Kwadijk (2008) showed that average river discharges in winter and early spring are expected to increase (Table A2). Levels of future summer and peak discharges still remain uncertain. They could remain more or less the same as today or – in the scenarios with structural changes in air circulation patterns – may decrease substantially (up to 40% in W+) (Van Beek et al., 2008; Kwadijk, 2008).

Figure A1
Sea level rise



Source: PBL (2007)

Based on the KNMI scenarios, a sea level rise of 35–85 cm may be expected by 2100. Other studies, based on worst-case scenarios, give a possible sea level rise of 65–130 cm (Delta Committee, 2008) or a maximum of 1.5 metres.

Over the last century, no significant trends in extreme river discharges from year to year have been found.

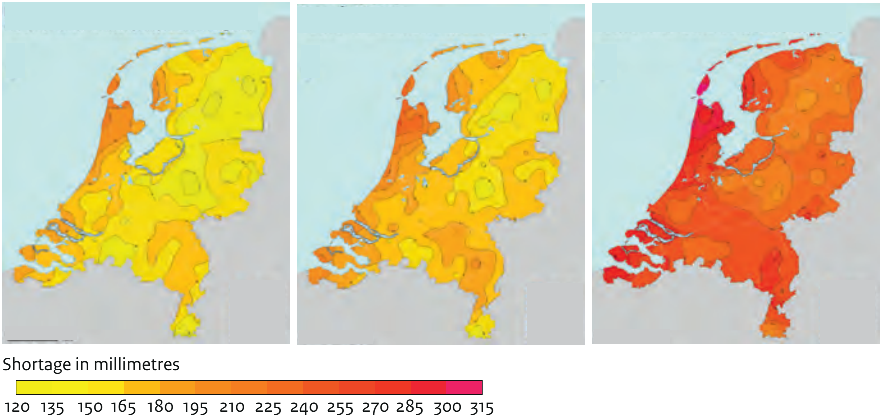
Tipping points; how much climate change could we withstand?

Studies on the impact of climate change and sea level rise usually take climate change scenarios as their starting point. This classical approach answers the question of 'What is climate change according to scenario x?'. A different approach is the concept of 'adaptation tipping points'. Adaptive tipping points are reached if the magnitude of change is such that the current management strategy can no longer achieve its objectives. Beyond the tipping points, an alternative adaptive strategy is needed. The tipping point approach answers the question of 'How much climate change could we withstand?', in addition to others, such as 'What are the first issues that we will face as a result of climate change?' and 'When could these first issues be expected to emerge?'. The expressed uncertainty about the period during which the existing strategy would be effective, was found to be useful by policymakers (Kwadijk et al., 2010).
Analysis of the adaptive capacity of the Netherlands in relation to tipping points presents a mixed picture (PBL, 2009). The risk of flooding has been studied the most. It appears that protection from flooding by the sea could be ensured using the available methods and expertise, even in the worst-case scenario of a 1.5-metre increase in sea level per century (e.g. PBL, 2007; Ligtvoet et al., 2008; Deltacommissie, 2008). However, it is likely that beyond the tipping point structurally different types of measures would

Figure A2

Maximum precipitation shortage (median)

Average over many years (1981 – 2010) | Warm scenario (W; around 2050) | Warm scenario under changed air circulation (W+; around 2050)



Source: KNMI (2009b)

Especially in the most warm scenario with a two-degree temperature rise by 2050 (KNMI W+ scenario), the precipitation deficit increases strongly over the whole of the Netherlands.

be needed, in the course of this century; for instance, having additional land area available and taking certain measures in the river region, in order to control peak discharges during the winter (compare Table A2).

A critical issue of climate change, for the Netherlands, is that of freshwater availability. With a further temperature increase and a growing deficit in precipitation (KNMI, 2006), this could lead to seriously increasing water shortages around 2050, in case of the dry W+ scenario (RWS and Deltares, 2008).

Apart from the issue of freshwater availability, the agriculture, energy and transport sectors, in principle, would be able to respond adequately to gradual climate change. This reason for this is that necessary changes in crop production and agricultural systems and replacement of infrastructural facilities all have a relatively short reaction time, compared to the gradually occurring climate changes. The agricultural sector is primarily anxious about increasing risks of pests and diseases and an increase in weather extremes. The urban areas and the transportation and energy networks are also vulnerable to the disruptive effects of weather extremes. In view of the importance of transportation networks and of energy to the functioning of society, further analysis of our vulnerability and possible measures to counter this vulnerability, would be desirable.

Table A2

Projected changes in the climate scenarios on the hydrological system in the Netherlands

2100		**G**	**G+**	**W**	**W+**
Worldwide increase in temperature		**+1 °C**	**+1 °C**	**+2 °C**	**+2 °C**
Change in air circulation		**No**	**Yes**	**No**	**Yes**
Annual average	Average discharge river Rhine	+6%	-8%	+12%	-12%
	Average discharge river Meuse	+6%	-10%	+14%	-11%
	Frequency of exceedance of the current maximum safe discharge levels of the river Rhine (=16,000 m^3/s) (now once every 1,250 years)[1]	250 year			50 years
	Frequency of exceedance of future maximum safe discharge levels of the river Rhine (=18,000 m^3/s) (now more than once every 4,000 years)[1]	1250 year			250 year
Winter	Average discharge river Rhine	+14%	+12%	+27%	+22%
	Average discharge river Meuse	+9%	+6%	+18%	+11%
Summer	Average discharge river Rhine	+0%	-24%	+1%	-41%
	Average discharge river Meuse	+5%	-20%	+11%	-26%

Source: Kwadijk (2008)

[1] *Frequency of exceedances are estimations, assuming also measures in upstream areas of the river Rhine . Without such measures, the frequency of future exceedances will be substantially further apart. The maximum discharge of 18,000 m^3/s is unlikely to become exceeded at all (Kwadijk, 2008).*

Nature is already changing (PBL, 2010), and irreversible effects due to temperature increases can already be observed in some freshwater ecosystems, such as the IJsselmeer (RWS and Deltares, 2008). Consequently, with continuing climate change, achieving current policy targets of nature conservation will become increasingly difficult. Although knowledge about the long-term effects of climate change on species and ecosystems is still limited, knowledge is available about possible measures to strengthen nature's ability to adapt to climate change (Chapter 4). The possible risk of increases in epidemics and pests to people, animals and crops is uncertain, but the adaptive capacity with respect to these risks appears to be limited. Additional research into the possible control of such pests and diseases would be desirable, especially in view of the potential magnitude of societal impacts.

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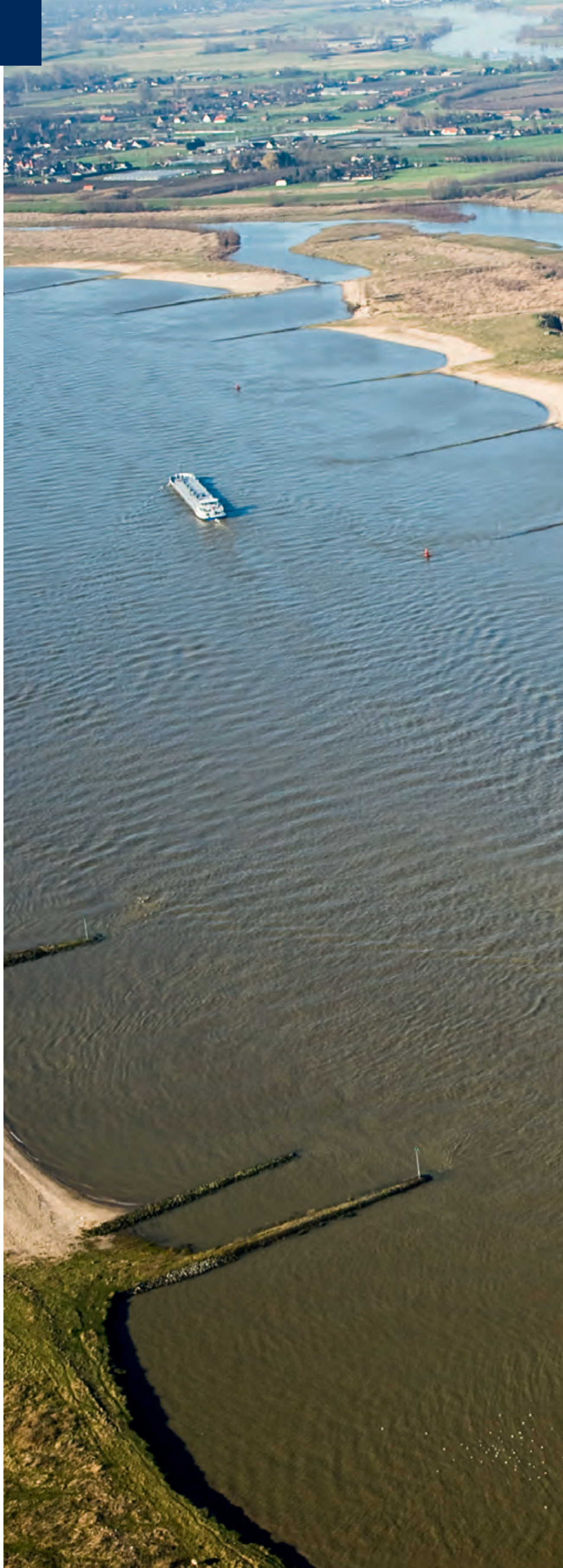
The Dutch Delta is vulnerable to the possible consequences of climate change, such as sea level rise and higher river discharges. In this report, the PBL Netherlands Environmental Assessment Agency presents options for a coherent and effective strategy for a climate-proof Netherlands, with respect to flood protection, freshwater supply, nature and urban development.

This report shows that, in principle, the Netherlands will be able to adapt well to climate change, but that certain structural choices will need to be made. These choices concern the possible application of unbreachable dykes, reservation of land area in the river region, and the option of freeing up more fresh water by making adjustments to the New Waterway. Furthermore, to enable a better response from nature to climate change, the spatial coherence between nature areas has to be increased. Future additional costs could substantially be reduced by taking into account today climate-proofing requirements of tomorrow.



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