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FLOOD RISK ASSESSMENT AND POLICY IN THE NETHERLANDS

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This paper introduces water safety policy in the Netherlands. Water safety considerations are important for water investments, spatial planning and insurance. In order to prevent floods, investments in flood prevention present opportunities that can benefit society by lowering the expected damage of relevant flood scenarios. From an economic perspective, flood damage includes physical damage, production loss, and economic loss resulting from the interruption of communication, infrastructure and trade relations.

The Dutch Ministry of Transport, Public Works and Water Management estimates the number of victims, physical damage and production loss of relevant flood scenarios using a comprehensive flood damage model. However, floods tend to have long-term, indirect effects on labour, housing and product markets as well. The resulting problems in these markets can decrease welfare. The assessment of indirect economic effects of floods appears to deserve improvement.

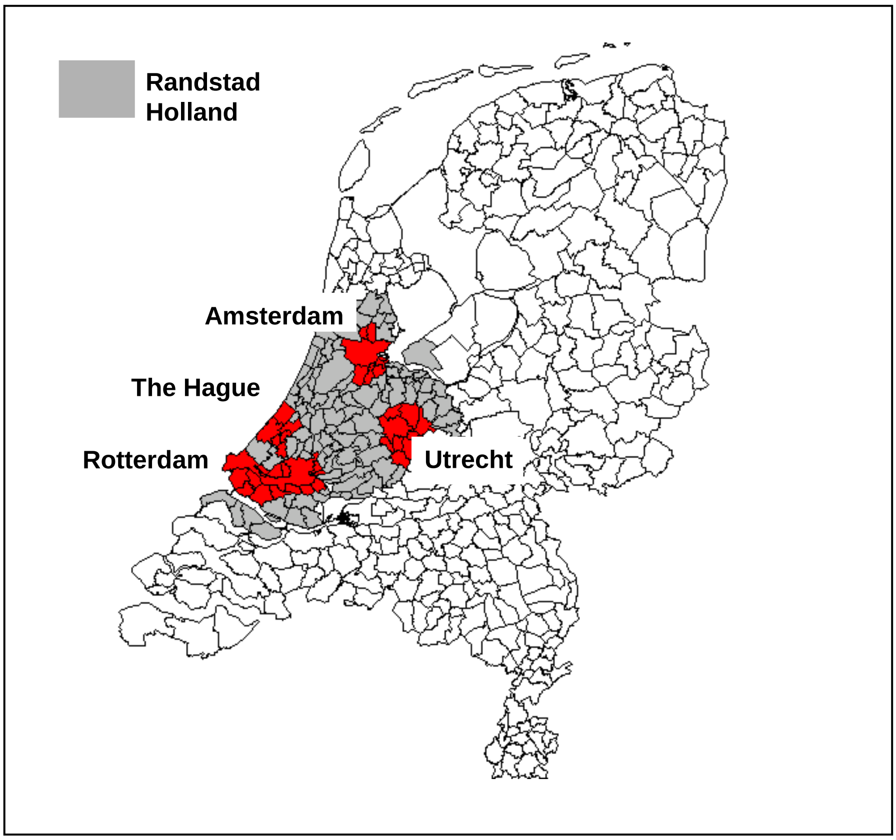
A case study investigates the Greater Rotterdam area. A spatial computable general equilibrium (SCGE) model for the Netherlands, known as RAEM (for Ruimtelijk Algemeen Evenwichts Model or Regional Applied General Equilibrium Model), is applied to assess both physical and indirect effects of relevant flood scenarios in the Rotterdam region. Indirect effects of floods on housing, labour and capital markets can account for about 15% to 55% of total flood damage. These gradually decrease after a flood has occurred, and the detrimental effects subsequently disperse throughout the country. Regions whose economic sectors are comparable to those of the flooded region appear to experience slight economic benefits, because they take over the production loss in the affected region's specialised sectors.

Introduction

The Netherlands comprises about 40 000 square kilometres of surface area, two-thirds of which is located below sea level. This area comprises the largest four Dutch cities: Amsterdam, Rotterdam, The Hague and Utrecht. These cities (collectively named Randstad Holland) represent the spatial core of the Dutch economy and feature the country's so-called main ports: Schiphol Airport and the Rotterdam harbour. These ports are considered of vital importance to the economy. About 6.7 million people live in the economic core, earning over EUR 250 billion (EUR 38 700 per capita) in 2007 (Manshanden *et al.*, 2009; OECD, 2007). The total capital stock below sea level is roughly estimated at EUR 1 800 billion (Deltacommissie, 2008).

The Netherlands has experienced numerous major floods. The last major flood occurred in 1953, causing 1 853 fatalities and about EUR 0.7 billion of direct physical damage (Botzen and Van den Bergh, 2008). In 1993 and 1995, the areas around the Rhine and Meuse rivers were nearly flooded. Recently, the so-called Delta Commission (Deltacommissie) published policy recommendations for flood protection in the twenty-first century in the face of climate change and its possible consequences for the Netherlands (Deltacommissie, 2008).

Figure 1. Location of Randstad Holland and its core cities within the Netherlands



Source: TNO.

This paper deals with flood-risk assessment and policy in the Netherlands. In Section 2, current policy in the Netherlands is discussed, stressing the importance of indirect effects of floods in *ex ante* policy making. Section 3 discusses how economic effects of floods can be estimated. Section 4 describes a case study of the Greater Rotterdam region. Section 5 concludes.

Policy background

Climate change is commonly divided into two research and policy fields, the first being mitigation and the second adaptation. The first discipline deals with strategies for reducing the pace of climate change by reducing carbon emissions. Adaptation deals with ways to adapt to the effects of climate change and is of central interest to the Dutch authorities. The Netherlands has a long tradition of protecting its land area from the sea and rivers, its water management boards (*Waterschappen*) being the oldest governing bodies in the country.

In the context of adaptation, climate change involves two types of cost that are expected to decrease societal welfare: the costs associated with damage resulting from climate change and the costs associated with preventing the consequences of climate change. One of the decisive elements in the latter cost category in the Netherlands is the increased probability of floods, especially in urban areas with low elevation levels. Optimal water safety policy minimises the sum of the two associated cost categories: the cost associated with preventing floods and the cost resulting from floods (Eijgenraam, 2005).

The following subsections describe water safety policy, spatial policy and insurance issues from a flood risk perspective. A common factor in these three policy fields is a strong tendency to focus on limiting probabilities of flooding while relying on innovative yet expensive technical solutions, as well as limited integration of water safety within other policy disciplines. The attention for cost-benefit considerations, the potential contribution of private insurance to efficient reduction of flood risk as well as *ex post* evacuation and recovery policy is relatively limited.

Water safety policy

The damage associated with floods is expected to increase due to climate change as well as (predominantly) future economic growth. Flood risk can be described as the annual flood probability multiplied by the expected damage floods will cause in the inundated region. Flood probabilities are used to define the legal minimum safety standards of dikes. Water management authorities (mainly the water management boards and national government organisations) are assigned the task of keeping the protection levels above these minimum requirements. A relatively new phenomenon is managed re-alignment. This entails providing rivers with more space to retain water, thereby lowering the likelihood of floods in times of high water discharge. These policies, dating back to the high waters of 1993 and 1995, are believed, together with traditional dike construction, to offer the best way of dealing with the expected increase in flood probability due to climate change. The main objectives of managed re-alignment initiatives were greater water system resilience, improved coherence between water policy, nature conservation and spatial planning, and the involvement of relevant stakeholders.

Flood risks differ among so-called dike rings (comprehensive protection system areas), according to population density and capital stock. The Netherlands consists of 53 dike rings. Flood probabilities per dike ring were first identified by the Delta Commission in 1960. This commission was installed to evaluate flood policy as a response to the catastrophic flood of 1953. The resulting flood probability norms were between 5 and 100 times stricter than those prevailing before the flood of 1953, with return periods between 500 and 10 000 years. By international comparison, these norms can be considered relatively strict. For example, in the United Kingdom, return periods of 1/100 are applied (Pearce and Smale, 2005).

Table 1. Flood risk norms and estimated actual flood risk 2005 and 2020 (dike rings not matching the norm in bold), risk = 1/estimate

	Dike ring	Legal norm	Actual estimated probability 2005	Current policy estimate 2020
1	Schiermonnikoog	2 000	5 000	5 000
2	Ameland	2 000	5 000	5 000
3	Terschelling	2 000	5 000	5 000
4	Vlieland	2 000	5 000	5 000
5	Texel	4 000	10 000	10 000
6	Friesland en Groningen	4 000	10 000	10 000
7	Noordoostpolder	4 000	5 000	10 000
8	Flevoland	4 000	5 000	10 000
9	Vollenhove	1250	**1 000**	2 000
10	Mastenbroek	2 000	2 000	5 000
11	IJsseldelta	2 000	2 000	5 000
12	Wieringen	4 000	10 000	10 000
13	Noord-Holland	10 000	10 000	20 000
14	Zuid-Holland	10 000	100 000	20 000
15	Lopiker- en Krimpenerwaard	2 000	**1 000**	5 000
16	Alblasserwaard en Vijfheerenlanden	2 000	**500**	5 000
17	Ijsselmonde	4 000	100 000	20 000
18	Pernis	10 000	20 000	20 000
19	Rozenburg	10 000	20 000	20 000
20	Voorne-Putten	4 000	**500**	10 000
21	Hoeksche Waard	2 000	20 000	5 000
22	Eiland van Dordrecht	2 000	2 000	5 000
23	Biesbosch	2 000	**200**	n/a
24	Land van Altena	2 000	**1 000**	5 000
25	Goeree-Overflakkee	4 000	10 000	10 000
26	Schouwen Duivenland	4 000	10 000	10 000
27	Tholen en St. Philipsland	4 000	10 000	10 000
28	Noord Beveland	4 000	10 000	10 000
29	Walcheren	4 000	10 000	10 000
30	Zuid Beveland west	4 000	10 000	10 000
31	Zuid Beveland oost	4 000	10 000	10 000
32	Zeeuwsch Vlaanderen	4 000	10 000	10 000
34	West-Brabant	2 000	5 000	5 000
34a	Geertruidenberg	2 000	5 000	5 000
35	Donge	2 000	5 000	5 000
36	Land van Heusden/de Maaskant	1 250	**1 000**	2000
37	Nederhemert	1 250	**1 000**	n/a
38	Bommelerwaard	1 250	5 000	2 000
39	Alem	1 250	**1 000**	n/a
40	Heerewaarden	500	500	n/a
41	Land van Maas en Waal	1 250	**500**	2 000
42	Ooij en Millingen	1 250	5 000	5 000
43	Betuwe, Tieler-en Culemborgerwaarden	1 250	**500**	2 000
44	Kromme Rijn	1 250	100 000	50 000
45	Gelderse Vallei	1 250	100 000	100 000

Table 1. Flood risk norms and estimated actual flood risk 2005 and 2020 (dike rings not matching the norm in bold), risk = 1/estimate (*continued*)

	Dike ring	Legal norm	Actual estimated probability 2005	Current policy estimate 2020
46	Eempolder	1 250	2 000	2 000
47	Arnhemse-en Velpsebroek	1 250	50 000	50 000
48	Rijn en IJssel	1 250	10 000	5 000
49	IJsselland	1 250	500	5 000
50	Zutphen	1 250	1 000	5 000
51	Gorssel	1 250	500	5 000
52	Oost Veluwe	1 250	2 000	2 000
53	Salland	1 250	1 000	2 000

Source: Deltares

In a 2005 inspection, a number of dike rings could not be proven to fulfil the legal safety requirements (about 25% of the water defence system was judged to have insufficient or uncertain safety levels in terms of return periods). Extensive maintenance and improvement is planned for the period until 2020. Many dike rings are therefore expected to show improvement with respect to their respective safety levels. Still, the effects for Dike Rings 23 (Biesbosch), 37 (Nederhemert), 39 (Alem) and 40 (Heerewaarden) remain unknown.

In 2008, a new Delta Commission identified policy options for the twenty-first century in response to expected climate change, advocating a tenfold increase in return period criteria for dikes, as well as the use of 1.3 metres expected sea-level rise as a reference for the year 2100 (Deltacommissie, 2008). An agreement was signed between the central government and water boards to improve the protection level so as to meet safety requirements by 2015.

Multiplying flood probabilities by expected flood damage results in estimations of flood risks. Expected flood damage is based on current practice in cost-benefit analysis, for which a comprehensive standard is used in the Netherlands. Evaluation of costs and benefits according to this standard is compulsory for national transport investments (Ministry of Transport, Public Works and Water Management, 2000). Economic effects of flooding are divided in a manner similar to the standard for cost-benefit analysis, featuring direct physical effects, direct production effects and indirect effects, respectively.

Direct effects are the first-order effects of floods. Direct effects of flooding scenarios are physical damages based on replacement costs. Direct production effects concern loss of value added due to flooding. Indirect effects are second-order effects due to flooding on product, labour and housing markets. These effects only affect societal welfare if a flood results in a change in market imperfections, *e.g.* when a housing market in a neighbouring region of the inundated area clears because of a flood.

Spatial policy

Flood risk depends on spatial planning in various ways. First, the way river water discharge is accommodated is important for flood probability and damage. The high waters of 1993 and 1995 showed that the approach until then was not sufficient to deal with extreme water discharges. A different approach was chosen, mainly entailing that rivers should be provided space. Moreover, anticipation of risks should govern policy instead of having policy react to water problems as they occur (Brouwer and Kind, 2005).

This has led many water boards to identify water retention areas, mainly in agricultural environments. Generally, identifying these areas has not caused major spatial problems. However, in urban areas like Rotterdam and Dordrecht, it is not always easy to deal with flood risk while simultaneously preserving urban and heritage space, as in the case of the old centre of Dordrecht next to the mouth of the Hollandsch Diep. Furthermore, spatial planning by the central government has not integrally incorporated future climate change, identifying local bodies of government as the main stakeholders in urban planning. It is not clear whether this rather dispersed way of governing urban policy takes sufficient account of the risk of floods. For example, new built-up areas have been constructed in areas located six metres below sea level, such as the Zuidplaspolder area east of Rotterdam.

Second, urban planning determines the amount of value that is protected by dikes. The Scientific Council for Government Policy (WRR) has indicated that economic growth is a central source of future flood damage for this reason (WRR, 2006). Future land use accommodation is highly determinative of damage in relevant flood scenarios. In economic and spatial scenario studies for the Netherlands (WLO, 2006) Geographical Information System (GIS)-based maps of future land use for 2040 are used for both a trend scenario and a high-growth scenario. This map system is called Ruimtescanner. In the trend scenario, the bulk of future urban development will occur in the flood-prone area of Randstad Holland. Some alternative development scenarios were identified. These entail mainly refraining from building new housing in dike rings with high flood probabilities, shifting investment to higher elevated areas in the Netherlands (predominantly to the east of the country), and offensive protection of the economic core in Randstad Holland by extending the coastline 5 kilometres westward (MNP, 2007). From an economic point of view, the third scenario appears the most promising, as economic cores appear geographically constant over time, implying that moving economic activity out of the core incurs high societal cost. Reducing flood probability appears preferable to decreasing potential flood damage below sea level.

Still in question, however, is what the relative influence of future climate change on flood damage will be. Water speed and maximum water depth in inundated areas are the principal determinants of damage. Sea and river level rise can be protected by higher and wider dikes, but the risk of floods will never be eliminated. Floods will eventually feature increased water speed and depth. Sea-level rise and river discharge are therefore important determinative factors for flood damage.

Other determinative factors include such considerations as land subsidence in the west of the country and dependence on water safety spatial policy in neighbouring countries, especially Germany. Land subsidence occurs in the north of the Netherlands because of gas drilling, and in the west of the country because of agricultural exploitation of peat soil. The subsidence can range up to 1 or 2 centimetres per year, which in the long term adds significantly to flood damage. A related problem is that subsidence necessitates improvement of dikes, which in itself causes subsidence.

Dutch water discharge norms are currently stricter than those in Germany. Given Germany’s current water safety policy, extreme high water discharges will cause floods in the Ruhr area before they occur in the Netherlands, and all the water involved will be prevented from reaching the Netherlands. Increased severity of the norms in Germany would have consequences for discharge patterns in the Netherlands, encouraging the governments involved to co-ordinate relevant flood policies.

Insurance

Flood protection is considered a public good, since no individual can be excluded from enjoying its benefits. Moreover, flood protection is universally beneficial: up to a certain point, flood protection for one individual does not take away from its usefulness for others. Individuals are typically reluctant to pay for flood protection, making it difficult for private firms to provide it. Flood protection is completely provided by central government and water boards in the Netherlands. Flood risk cannot be privately insured, as the central government compensates flood damage based on legislation, crowding out private market initiative (Botzen and Van den Bergh, 2008). Comparisons of protection options to insurance options present a rather new element in Dutch water safety evaluation. Comparing protection cost, expected flood damage and insurance premiums (should insurance be possible) can help to illuminate optimum policy choices.

The main reasons why private insurance companies avoid insuring flood damage appear to be incomplete measurement of expected damage (which insurance companies need to determine insurance premiums), the existence of a large number of dependent risks due to the spatial composition of the Netherlands, and the possibility of moral hazard (for example, new real estate in areas far below sea level) (Pearce and Smale, 2005). On the other hand, no realistic scenarios exist in which the whole of the Randstad Holland region floods, limiting the size of dependent risks. Moreover, insurance of flood damage can contribute to sharing risks among a multitude of policy holders and providing citizens with incentives to reduce losses of eventual floods. Insurance entails the contractual right to compensation, whereas current government compensation depends on public pressure and political preferences, which can be considered quite arbitrary (Botzen and Van den Bergh, 2008).

Assessing economic effects of floods

Assessing the economic effects of floods has only been partly successful in forecasting potential flood damage. The range of future changes in flood risk caused by expected climate change, economic development and spatial planning appears large, indicating the existence of large knowledge gaps and uncertainty concerning the impact of relevant future trends. Despite the obvious importance of future economic growth (WRR, 2006), it remains unclear whether future climate change or economic growth will cause the largest increase in monetary flood risk (Koops *et al.*, 2008).

Whereas direct effects of floods are well documented and assessed, indirect effects are usually derived applying fixed coefficients to direct effects. Effects such as the aforementioned depression on real estate prices due to adaptive expectations, effects of government-initiated recovery plans and labour market effects are usually not explicitly and independently assessed, focusing the modelling exercise on interruption of supply and demand of intermediary goods in regions close to the flooded area. This appears strange, since indirect effects can have dramatic consequences at the regional and local level. Tentative studies also point to persistent decreases in real estate value in regions after floods (Daniels *et al.*, 2006). Secondly, expected indirect effects are important determinants of *ex ante* policy. For example, the indirect effect of interrupted transport and communication networks is important for determining evacuation and recovery plans. Moreover, recovery initiatives by the central or local government can exert a large influence on post-flood regional economic development.

For complete assessments of flood damage, multiple steps have to be taken. A first step involves assessing expected climate change for the Netherlands, including resulting weather patterns. Secondly, weather pattern forecasts will have to be translated into physical effects on dike-ring areas, resulting in changes in flood probabilities for areas on a regional scale. A third step deals with translating expected economic and spatial development into expected damage. Once these steps are taken, relevant flood scenarios (Ministry of Transport, Public Works and Water Management, 2006) can be modelled and run to calculate expected annual flood risk change. However, all these steps involve considerable uncertainty with regard to future development (Jonkhoff, 2008).

Direct effects

Direct effects are mainly the first-order effects of floods: victims and damage to property as production loss. Assessment of direct effects is based on the standard flooding information system used by Dutch water authorities, called *Hoogwater Informatie Systeem*. Its damage and victims module (*Schade en*

Slachtoffer Module or HIS-SSM) estimates the damage that might occur due to a flood with a variable rate of water flow and water depth based on flooding scenarios (Ministry of Transport, Public Works and Water Management, 2006). This system also shows the weakest links of a dike ring, as well as potential damages from flooding and the effects of different policy options. HIS-SSM takes into account all sorts of physical damages and fatalities, providing detailed and comprehensive overviews of direct effects of floods. However, the HIS-SSM system assumes a linear increase in indirect effects based on direct effects.

HIS-SSM has been applied to evaluate large national research projects. Water boards, provinces, ministries and economic policy boards like the Central Planning Bureau are frequent users of the information system, which is maintained by the directorate for roads and water constructions of the national infrastructure management institute Rijkswaterstaat (RWS-DWW).

HIS-SSM provides the user with approximations of damage of floods featuring different water depths, speeds of water flows and speeds of water level increases. The model uses 100 by 100 metre rasters to provide geographically detailed projections. For any given raster and economic item, a maximum damage amount is available. The damage function then calculates the percentage of maximum damage that will occur based on the relevant flood scenario. The model uses very detailed datasets as information sources with regard to land use, infrastructure, housing, employment and locations of firms by sector.

The flooding scenarios HIS-SSM uses consist of Geographical Information System (GIS) raster information. Types of flood damage are provided consistent with national cost-benefit practice, identifying the following types of damage:

- *Direct damage*: damage to economic objects, capital goods and moving goods because of contact with water;
- *Production loss*: direct damage due to business loss where production is interrupted;
- *Indirect damage due to production loss*: damages to companies involved in supply and demand outside the flooded dike-ring through loss of sales, plus damage due to loss of supply and demand infrastructure based on travel-time losses.

However, some damage categories are excluded from the HIS-SSM system. The main components are recovery cost, interruption of energy and communication, welfare loss in land, labour and housing markets, and numerous non-priced effects such as injuries, non-tangible damage, societal disruption, loss of environmental values, and environmental damage (Jonkhoff *et al.*, 2008). Recovery cost, energy and communication interruption and welfare loss in land, labour and housing markets are indirect effects, which can be assessed separately.

Indirect effects

Indirect effects concern second-order, rather long-term effects of floods. These effects include the effect on product, labour, housing and land markets, commuting, and public recovery initiatives. Spatial computable general equilibrium (SCGE) modelling can be used to assess the indirect effects such as supply chain changes outside the affected region, labour market adjustment, migration, real estate price changes, and the effects of government responses to floods.

SCGE models are typically comparative static equilibrium models of interregional trade rooted in micro-economic theory, using utility and production functions with substitution between inputs. These models are part of the New Economic Geography (NEG) school (Fujita, Krugman and Venables, 1999) and have been around for less than a decade.

The RAEM model is a spatial general equilibrium (SCGE) model for the Netherlands. It models the Dutch economy for 40 NUTS3 (Nomenclature of Territorial Units for Statistics, in French *nomenclature d'unités territoriales statistiques*) regions and 15 economic sectors. For all regions and sectors, the complete economic system is modelled with markets for production, labour, capital, consumption, investments, housing and trade. The circular flow of income results in interdependency of all markets. The model consists of a micro-economic basis where equilibrium demand meets supply under rational behaviour of economic agents. The RAEM model consists of three economic agents: households, firms and the government. Households and firms in each region and sector are modelled by a representative agent. For each region and sector, all individual agents act according to the representative agent. That means that for each region and sector, all firms and households are identical. The government is a special economic agent. Like other economic sectors, the government sector purchases goods and services from different economic sectors. But the government also collects taxes and pays benefits to the unemployed, and finances infrastructure projects. An extensive description of the technical details of the RAEM model is given in Ivanova *et al.* (2007).

Figure 2. The Netherlands divided into 40 NUTS3-regions for assessment of indirect effects

1. Oost-Groningen	21. Agglomeratie Haarlem
2. Delfzijl en omgeving	22. Zaanstreek
3. Overig Groningen	23. Groot-Amsterdam
4. Noord-Friesland	24. Gooi en Vechtstreek
5. Zuidwest-Friesland	25. Aggl. Leiden/Bollenstreek
6. Zuidoost-Friesland	26. Aggl. 's-Gravenhage
7. Noord-Drenthe	27. Delft en Westland
8. Zuidoost-Drenthe	28. Oost-Zuid-Holland
9. Zuidwest-Drenthe	29. Groot-Rijnmond
10. Noord-Overijssel	30. Zuidoost-Zuid-Holland
11. Zuidwest-Overijssel	31. Zeeuwsch-Vlaanderen
12. Twente	32. Overig Zeeland
13. Veluwe	33. West-Noord-Brabant
14. Achterhoek	34. Midden-Noord-Brabant
15. Arnhem/Nijmegen	35. Noordoost-Noord-Brabant
16. Zuidwest-Gelderland	36. Zuidoost-Noord-Brabant
17. Utrecht	37. Noord-Limburg
18. Kop v. Noord-Holland	38. Midden-Limburg
19. Alkmaar en omgeving	39. Zuid-Limburg
20. IJmond	40. Flevoland

Source: TNO.

The RAEM model uses input from the HIS-SSM model to assess indirect effects of floods. The RAEM model has been designed and applied for policy evaluation of investments in infrastructure in the Dutch national cost-benefit analysis framework (see *e.g.* Snelder, Koops and Ivanova, 2008). Cost-benefit analysis following this framework is compulsory for evaluation of major investments in infrastructure (Ministry of Transport, Public Works and Water Management, 2000). An NEG model, such as the RAEM model, is recommended to calculate indirect effects in Dutch transport investments (Ministry of Transport, Public Works and Water Management, 2004). Indirect effects are additional costs and benefits for producers and consumers because of the direct benefit on the transport market. In order to qualify as an additional indirect effect and not a passed-on direct effect, some kind of market imperfection or interaction with countries abroad should exist (Oosterhaven *et al.*, 2005). Examples of market imperfections are taxes and benefits, limited labour mobility, economies of scale, product differentiation and knowledge spillovers.

The RAEM model can be used to model floods as disinvestments in the economy, resulting in estimations for the total damage of floods as well as indirect effects: recovery cost, energy and communication interruption, and welfare losses on land, labour and housing markets. However, a distinction will have to be made between the short, intermediate and long term to obtain a full view of indirect effects.

The initial RAEM model calculates indirect effects concerning:

- supply and demand for firms outside the inundated area
- loss of transport connections
- loss of energy, water and communication networks
- feedback effects on labour and housing markets

However, to identify indirect effects in a comprehensive way, the model input can be expanded. First, since floods influence the availability of land to a large extent with only few substitutes, land should be explicitly added to the production process assessment, apart from labour and capital.

Secondly, capital can be subdivided in fixed and flexible capital. Firms' capital stocks comprise flexible capital, which can flow freely to alternative production locations, while part of the capital (mostly the physical capital stock) is fixed. Considerable differences exist between sectors in their relative shares of flexible and fixed capital, and some sectors are able to respond more smoothly to floods than others. The greater the adjustment capability of a sector, the lesser the extent of flood damage. In general, services sectors adjust more easily to floods than agriculture and manufacturing sectors. Tangible fixed assets as well as stocks are considered fixed capital, while intangible fixed assets, short- and long-term liabilities, shares and liquid assets are part of flexible capital.

Third, a housing market can be added to the model, assuming the housing stock to be exogenous. A flood constitutes a shock leading to an exogenous decrease of the housing stock in the affected region, negatively impacting household utility.

Fourth, a distinction can be made between short-, medium- and long-term equilibrium. RAEM enables calculation of effects in the short term (until one year after a flood), medium term (one to three years after the flood) and long term (over three years after the flood). In the short term, no adjustment mechanisms like the ones identified above occur. For example, households in the affected area lose their dwellings, and unemployment occurs due to production loss. In the medium term, labour and housing markets find new equilibriums due to adjustments in commuting and migration by affected households and firms. In the long term, (fixed) capital markets find new equilibriums as firms reconsider their investments.

The input for the RAEM model is derived from the following damage components in the HIS-SSM model:

- **Loss of capital**: direct damage to firms per sector is derived from HIS-SSM. Loss of capital as a production factor causes less production, as well as lower efficiency of production. However, in RAEM, firms can apply land and labour as substitute production factors.

- **Land use**: Based on the relevant flood scenario, the amount of land use per function that is lost is known. Subsequently all land with water depth over 1 metre is assumed to be lost for functional use. Similarly to capital loss, land use loss leads to decreased production as well as lower efficiency of production while substitution options for firms exist.

- **Housing**: HIS-SSM provides the loss in housing stock. Inundated dwellings were assumed to be permanently withdrawn from the total housing supply in RAEM.

- **Labour**: HIS-SSM calculates the number of victims floods incur. These are all assumed to be part of the labour force, reducing a region's labour force by equal numbers.

RAEM generates results in terms of total effects and indirect effects per region in Euros.

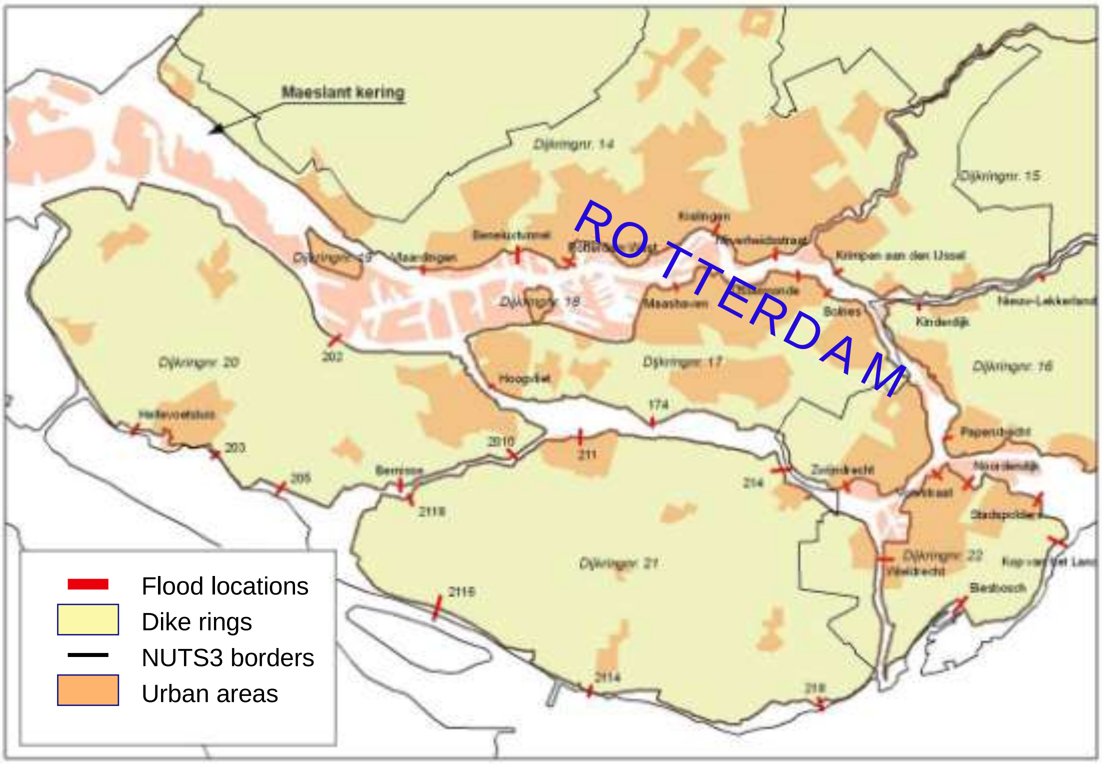
Case: Greater Rotterdam

Case description

The Greater Rotterdam area is located in the southwest of the Netherlands to the south of the urban Randstad Holland region. Greater Rotterdam comprises the city of Rotterdam (600 000 inhabitants) and its neighbouring communities (Vlaardingen, Schiedam, Capelle, Ridderkerk, Dordrecht, Barendrecht, Spijkenisse). Nearly 10% of the Dutch population (about 1.5 million people) live in the area. The region features some polders with elevations of as low as 6 metres below sea level, notably to the northeast of Rotterdam. The region also has the largest harbour in Europe. The urban areas are protected from the sea and rivers by major water defence works like the Maeslantkering – a removable dam in the mouth of the harbour. Normally, the dam is open, but in extreme weather, it can be closed. The Maeslantkering forms the finishing project of the Delta works (Deltawerken) initiated after the major flood disaster in 1953. So far, the dam has been closed only once.

To estimate the damage of floods with HIS-SSM and RAEM, about 25 floods in the Greater Rotterdam area (see the red bars in Figure 3) were simulated. The locations of the simulated floods are based on Ministry of Transport, Public Works and Water Management (2006). In this study, an inventory is made of the weak parts of dike rings in the Netherlands. At the weak points, the dikes were assumed to fail. The total damage, the number of victims and the flooded area for each flood were calculated applying HIS-SSM. For each dike ring, about six floods were simulated. For the estimation of the short-, intermediate- and long-run economic damage of the floods with the RAEM model, we assume an average flood for each dike ring based on the HIS-SSM results. Also, it was assumed that the flood took place in 2008 and a flood period of two months. The results concern a total of seven dike rings (Dike Rings 14, 15, 16, 17, 20, 21 and 22).

Figure 3. Overview of flood simulations in the Greater Rotterdam area



Source: TNO.

Results

In this section, results are illustrated for Dike Ring 15 (Lopiker-en Krimpenerwaard) east of Rotterdam. We refer to the appendix for the results of the other dike rings. Based on HIS-SSM, the total damage of an average flood in Dike Ring 15 is EUR 3.2 billion. More than 95% of the damage in HIS-SSM is physical damage. Economic damage (production loss in the flooded area and indirect effects) is rather limited. The RAEM model calculates the economic damage during and after the flood. To avoid double counting of economic effects during the flood, we only take RAEM results for economic effects into account for the total flood damage. The addition of economic effects in the intermediate and long run leads to an increase of total flood damage by over 50% (to EUR 4.9 billion). A flood leads to permanent loss of production factors and a re-allocation of the production process, causing permanent loss of welfare.

Table 2. Total damage of an average flood in Dike Ring 15 in 2008, in million euros

Damage category	HIS-SSM	RAEM	Total (HIS-SSM+RAEM)
Physical damage	3.074	x	3.074
* housing	1.833	x	1.833
* infrastructure and public works	590	x	590
* business sites	652	x	652
Economic damage during flood period	133	163	163
Economic damage in intermediate and long run (years 2009-2100)	x	1.670	1.670
Total damage	**3.207**	**1.833**	**4.907**

Note: [a] x = not calculated.

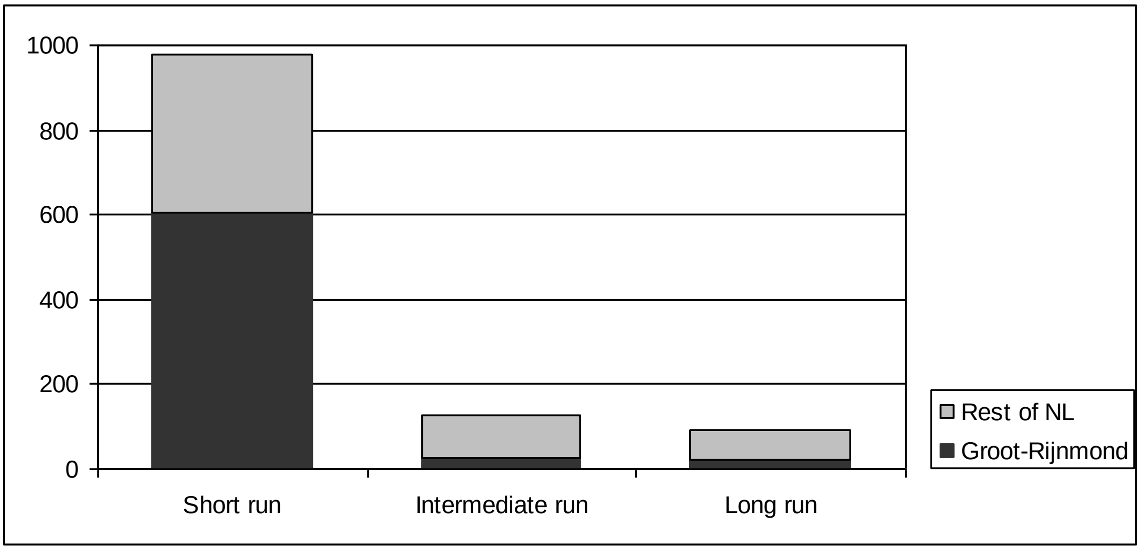
Source: TNO.

The economic damage in the intermediate and long run is calculated by the net present value of the estimated damage per year, applying an annual discount rate of 5.5%. The discount rate is based on the Dutch standard for cost-benefit analysis (Ministry of Transport, Public Works and Water Management, 2000), which is currently 2.5%, plus a risk premium of 3%. The intermediate run is assumed to last three years, in this case the years 2009, 2010 and 2011. The long run is assumed until 2100, so for the long run, we take the 2012-2100 period.

The direct effects of an average flood in Dike Ring 15 amount to EUR 3.2 billion, which is inclusive of economic damage (production loss) during the flood. Indirect effects add another EUR 163 million of economic damage during the flood (in the other Dutch regions), as well as nearly EUR 1.7 billion in the intermediate and long term, with total damage estimated EUR 4.9 billion. It should be emphasised that these results apply to an average flood scenario. Many differing flood scenarios exist (Ministry of Transport, Public Works and Water Management, 2006). The total damage of floods can amount up to tens of billions of Euros (Jonkhoff *et al.*, 2008).

In Figure 4, the distribution of economic damage between the flooded area (region Groot-Rijnmond) and the rest of the Netherlands is shown. The distribution is based on the welfare of households measured by equivalent variation. Equivalent variation is the monetised utility difference for households and is a commonly used welfare measure in a general equilibrium framework (Koops *et al.*, 2008). On the short run, 62% of the damage occurs in the flooded region Groot-Rijnmond. More than 35% of the damage ends up in the regions that did not directly suffer from the flood. Examples include residents of non-flooded regions who work in Groot-Rijnmond, or firms that buy or sell goods and products in Groot-Rijnmond. In the intermediate and long run, the regional distribution of the damage disperses over the Netherlands. Groot-Rijnmond has a share of about 20% to 25% of the total damage in the intermediate and long run.

Figure 4. Annual economic damage of an average flood in Greater Rotterdam (Groot-Rijnmond) area in the short, intermediate, and long run; divided into flooded region and rest of the Netherlands, in million Euros

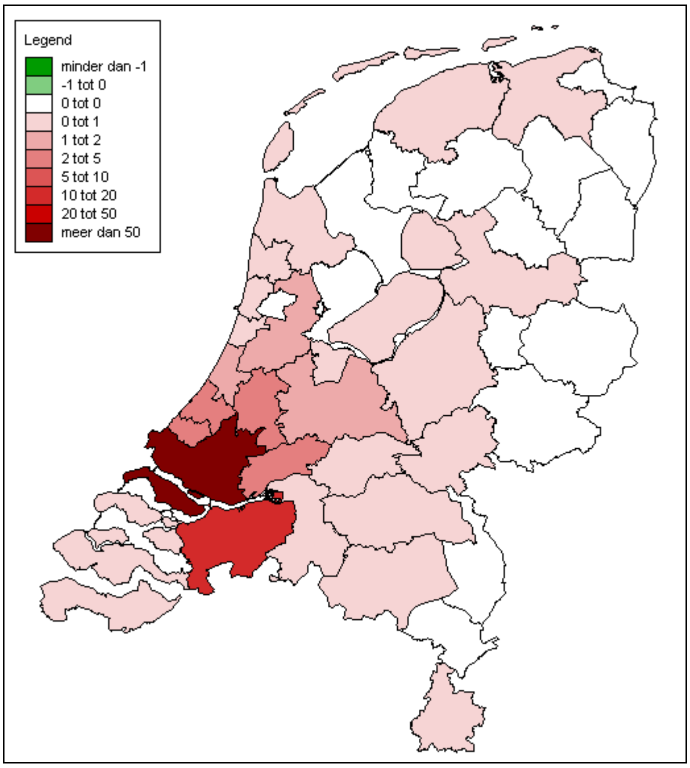


Source: TNO.

In the following figures, the regional distribution of flood damage is given for all regions. About 62% of total welfare loss is allocated in Groot-Rijnmond (Greater Rotterdam). Also West Noord-Brabant (12.8%) and other nearby regions like Delft and Westland (4.6%), Zuidoost Zuid-Holland (3.3%) and Oost Zuid-Holland (3.2%) experience welfare losses. A share of the inhabitants of these regions commute to the flooded area and are temporarily out of work. Trading partners of firms in the flooded area also face welfare loss because of loss of demand and/or intermediate inputs.

Figure 5A shows that adjustments in the labour and housing market result in a decrease of annual flood damage of 85% to 90%. Flood damage in the short run, *i.e.* the economic damage of a flood in Dike Ring 15 that would last for a whole year, is EUR 978 million. Adjustments in the capital market lead to an additional decrease of annual economic damage of about 15%.

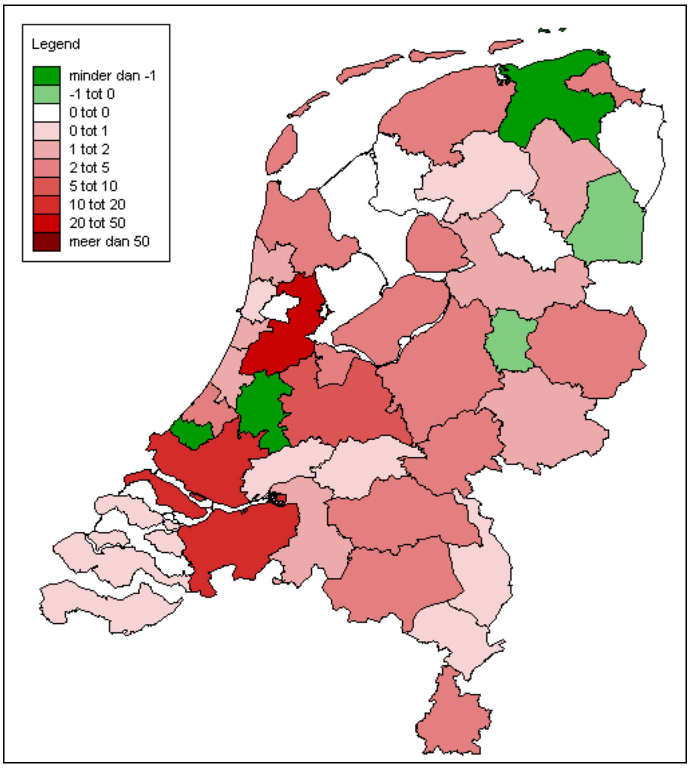
Figure 5A. Percentage regional distribution of flood damage of a flood in Dike Ring 15 in the short run (Netherlands = 100%)



Source: TNO.

In the intermediate run (figure 5B), some regions benefit from the flood because of distribution effects, albeit marginal. The regions of Delft and Westland and Oost Zuid-Holland, two small regions near Groot-Rijnmond, show the largest benefits (just over 1% of total national damage). In the intermediate run, the labour and housing market will be cleared. Production restarts in the flooded area (with loss of capital and land). People can decide to migrate or commute to other regions. The competitiveness of regions close to the flooded area increases and a demand shift takes place.

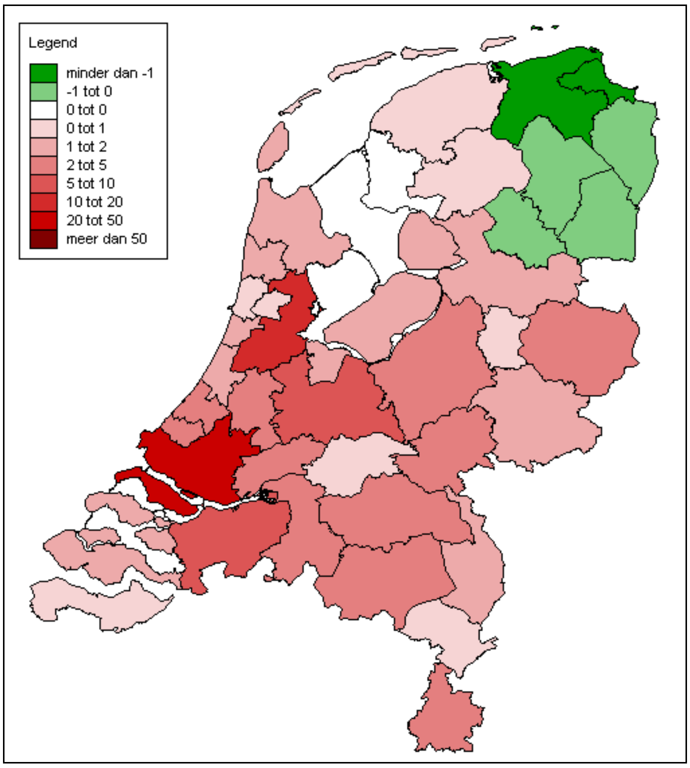
Figure 5B. Percentage regional distribution of flood damage of a flood in Dike Ring 15 in the intermediate run (Netherlands = 100%)



Source: TNO.

In the long run (after capital adjustments, figure 5C), all regions close to the Groot-Rijnmond region experience welfare loss. The northern part of the Netherlands benefits, albeit only slightly. The main reason for this is that chemical and harbour activities in Groot-Rijnmond move to the north of the country. Both the northern regions and Groot-Rijnmond have a large chemical cluster and sea harbours. The loss of production factors in Groot-Rijnmond leads to a lower return on investment of capital in this region. However, the size of the welfare gains in the benefiting regions remains small. About a quarter of total welfare loss in the long run takes place in the flooded region Groot-Rijnmond.

Figure 5C. Percentage regional distribution of the flood damage of a flood in Dike Ring 15 in the long run (Netherlands = 100%)



Source: TNO.

The results need a few qualifications, since two assumptions may lead to an over-estimation of total economic damage. First, it was assumed that all damage to production factors is permanent and irreversible. Input for the RAEM model consists of loss of capital, labour, land and dwellings. The loss of labour is based on the number of victims and can be considered irreversible. However, the loss of capital is over-estimated because we do not take the natural depreciation of capital into account. Second, we assume that all dwellings in the flooded area will be demolished. This appears unrealistic, because a share of the houses can probably be recovered.

Bearing these considerations in mind, the results show that taking explicit account of indirect economic damage after the flood may lead to a significant increase of the total damage estimate. The exercise shows that total damage of HIS-SSM increases by 15 to 55%, depending on the location and size of the flood. A larger size of the flood and/or an economically more important flooded area results in a larger increase of total damage.

Concluding remarks

Climate change has uncertain consequences for countries of low elevation like the Netherlands. It is therefore imperative to gather as much reliable information on possible effects of phenomena like floods induced by climate change. Complete assessment of the effects of floods is beneficial for *ex ante* policy with regard to water safety, spatial planning, insurance, as well as *ex post* evacuation and recovery strategies. Focusing policy on *ex ante* flood probability reduction may ignore uncertainties inherent in future flood risk. Simultaneously, a focus on the physical damage of floods may lead to under-estimations in total damage projections because intermediate and long-term economic damage after the flood period are not explicitly assessed.

We argue that due to loss of production factors, capital, land and labour and due to loss of dwellings, a permanent loss in welfare occurs that differs according to the way regionally interdependent markets function. Simulations for flood scenarios in the Greater Rotterdam area show that total damage estimated by the HIS-SSM model increases by 15% to 55%, depending on the location and size of the flood. For the Randstad Holland region, flood damage ranges from a few million to tens of billions of Euros. A flood can be regarded as a spatial disinvestment leading to regional re-allocation of economic activity. Households can choose to migrate or search for new job opportunities. Firms can choose to re-allocate capital investments. This way, the welfare effects of floods are tempered in the intermediate and long term, and the damage becomes increasingly regionally dispersed. Regions other than the affected area can even experience small positive welfare effects, depending on sector likeness with the inundated region.

The regional component in indirect effects estimation allows for improved spatial planning of built environments, for example when dealing with decisions to build in areas below sea level. Although policies to relocate economic activity to areas outside the Randstad Holland region do not appear economically sound, relocation of housing initiatives within the cities comprising Randstad Holland seems promising. In this respect, further integration of water policy and spatial policy is required.

Complete assessment of the damage inflicted by floods is also necessary for insurance purposes. Insurance can provide improved risk-sharing opportunities between those at risk, limiting moral hazard by offering citizens incentives to reduce their own flood risks. However, a full understanding of the damage associated with floods is necessary so that insurance companies can forecast their potential effects under worst-case scenarios. Insurance companies use worst-case damage assessments to evaluate the degree to which risks can be insured, and comprehensive assessment of potential flood damage contributes to better insurability of flood risk. Since it is currently not possible to insure flood risk in the Netherlands while government puts an emphasis on citizens' own responsibility, this topic deserves more policy attention.

Further research is needed on the time span of floods, the impact on real estate values, adjusted (migratory) behaviour of individual households and firms and the effect of public recovery plans. The adjustment behaviour of economic agents after a flood is highly uncertain. However, it has a large impact on the regional economic welfare effects of a flood and hence on *ex ante* policy evaluation. Further research should contribute to answering the following questions. Do households and firms change their attitude towards flood risks after a flood? How do they adjust their economic behaviour? What will firms do with long-term investments in vulnerable flood areas? And finally, what is the additional damage when government recovery investments do not take place or are delayed?

APPENDIX A: RAEM SCGE RESULTS FOR ALL DIKE RINGS

In Table A1, the RAEM results are given for seven dike rings in the Greater Rotterdam area. The short-run results for RAEM are given in the first column. In the last column, the net present value of the short-, intermediate- and long-run results are presented. It is assumed that the flood takes place in 2008 and lasts two months. The intermediate run takes three years.

Table A1: Total economic damage of an average flooding scenario for each dike ring in 2008, in million Euros

Dike ring	Total economic damage during flood [a]	Total economic damage 2008-2100 [b]
Dike Ring 14	-73	-2 979
Dike Ring 15	-163	-1 833
Dike Ring 16	*-118*	*-926*
Dike Ring 17	-6	-72
Dike Ring 20	-2	-25
Dike Ring 21	-7	-54
Dike Ring 22	*-36*	*-534*

Notes: [a.] Flood period is two months. [b.] Based on the net present value of annual damage in the period 2008-2100 and a discount rate of 5.5%.

Source: TNO.

In Table A2, the annual damage is shown on the short, intermediate and long run for all dike rings. Based on the results of Table A2, the net present value of Table A1 is calculated.

Note that RAEM did not solve the long-run results for Dike Rings 14, 16, 20 and 21. For these dike rings, it is assumed that the long run damage of a flood is 85% of the intermediate run results of the same dike ring. This percentage is based on the results for Dike Rings 15, 17 and 22.

Table A2: Yearly damage of an average flooding scenario for each dike ring in the short run, intermediate run and long run, in million Euros

Dike ring	Short-run damage	Intermediate-run damage	Long-run damage [a]
Dike Ring 14	-440	-176	x
Dike Ring 15	-978	-107	-85
Dike Ring 16	-2.831	-195	x
Dike Ring 17	-36	-4	-3
Dike Ring 20	-11	-1	x
Dike Ring 21	-43	-3	x
Dike Ring 22	-859	-113	-104

Note: [a.] x = RAEM did not solve.

Source: TNO.

Notes

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