PROJECT
A09 Financial arrangements for disaster losses under climate change

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Adaptation cost in the Netherlands: Climate Change and flood risk management

Climate change is expected to increase the frequency and severity of flooding in the Netherlands. The question is whether the Netherlands can adapt to increasing flood risk and whether the adaptation cost are acceptable.
The Netherlands is a densely populated country with approximately 16.5 million inhabitants. Approximately 9 million inhabitants live below sea level. This paper provides estimates of the adaptation cost of flood protection under various climate change scenario's.

Many low-lying parts of the Netherlands have been reclaimed from former lakes (usually referred to as 'polders') and are protected by so called 'dike rings' along the main rivers and coastal areas. The lower part of the Netherlands is divided in 53 of such dike rings (Figure 1). A dike ring is also a separate administrative unit under the Water Embankment Act of 1995. The latter aims to guarantee a certain level of protection against flood risks within each dike-ring area. For example, a dike ring with a safety norm of 1/10,000 has been designed in such a way that it can withstand a flood with a probability ('return period') of 1/10,000 years. Safety norms have been determined after a major storm surge in 1953 (van Dantzig, 1956)[1]. They reflect both the number of inhabitants and the economic value of assets within a dike ring; the more people and economic


Residential area and harbor in Delfzijl bordering the Eems river.

values to be protected by dike infrastructure, the higher the safety standard. The safety norms of dike rings vary in between 1/10,000 and 1,1250 throughout the country (Figure 1)[1]. [2,3]

Climate change is expected to increase the probability of flooding and hence dike reinforcements are needed to maintain the safety standards as required by law. Aerts et al. (2008) have calculated by how much flood probabilities may increase due to (combined) effects of sea level rise and increased river discharges. Depending on the location of the dike ring the flood probability may[4] increase with a factor 10 with each 50 to 80 cm sea level rise. For example, the largest dike ring around the cities of 0Rotterdam, The Hague and Amsterdam has the highest safety standard of 1/10,000 years. A sea level rise of 70 cm would increase the probability of flooding to 1/100 years.

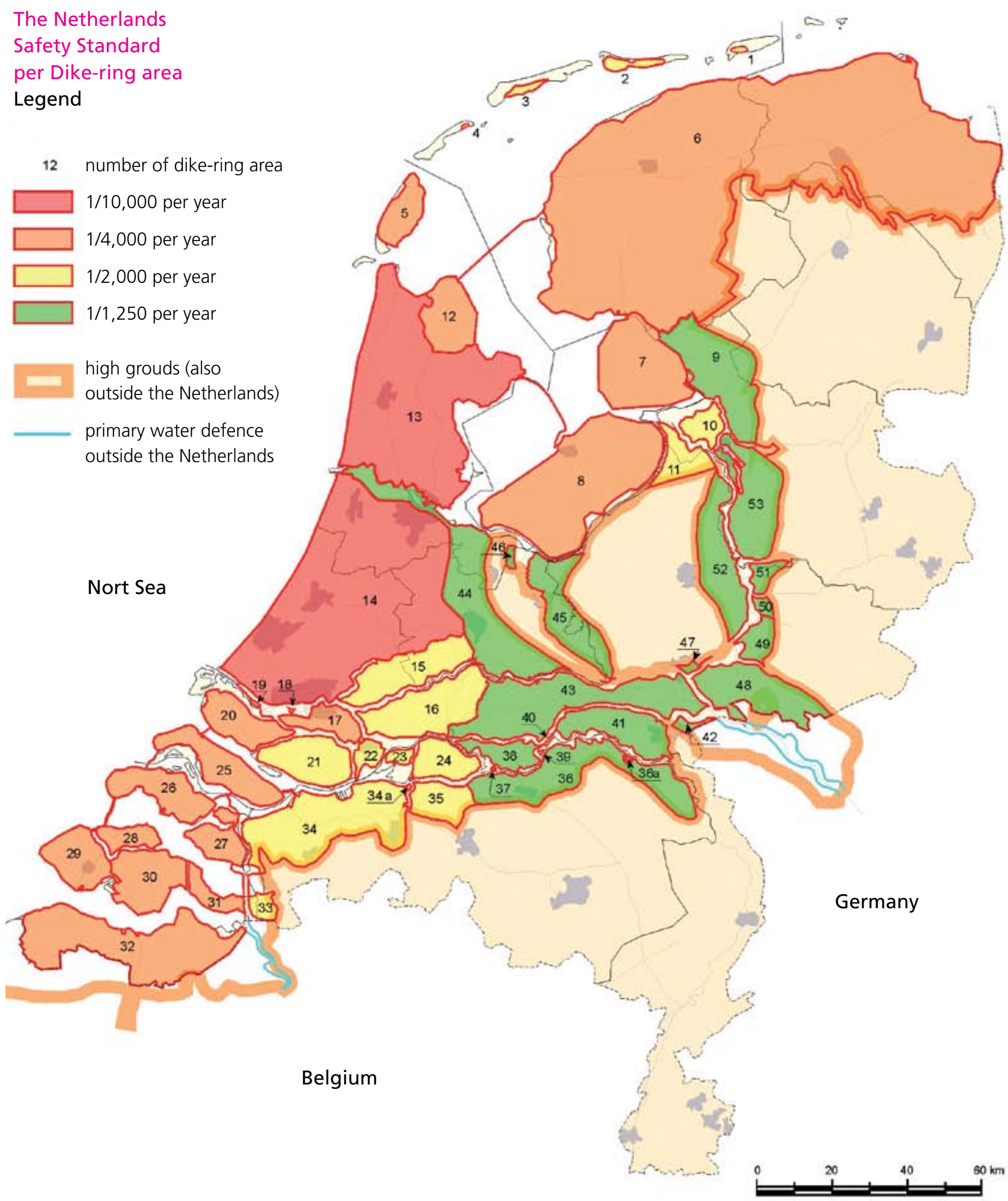

FIGURE 1:
a. Safety standards of dike ring areas in The Netherlands (left). b. Location of The Netherlands at the lower end of the rivers Meuse and Rhine(Right)

Apart from the effects of climate change, future projections show a gradual upward trend in house construction. In particular, by the year 2040 about 500,000 to 1,500,000 new houses will be constructed. Even if future flood risk defined as probability times damage are maintained at a constant level through heightening dikes, the potential damage of a flood is expected to increase. Therefore, it has been argued that an effective climate change adaptation policy should not only concern the reduction of flood probabilities with barriers but should also consider a wide range of adaptation options[5]. For example, measures could be implemented that reduce the vulnerability of buildings to flooding and thereby limit damage once a flood occurs[6]. Moreover, financial arrangements, such as insurance, could be promoted to compensate flood victims and heighten risk awareness[7].

An assessment of the development of the flood risk over time was made in Aerts et al.[4]. Flood risk is defined as probability multiplied with damage. Figure 5 shows the relative influence of climate change and urban development on flood risk. >

Potential flood damage may have double again at end of the 21st century.

Development of flood risk in the Netherlands

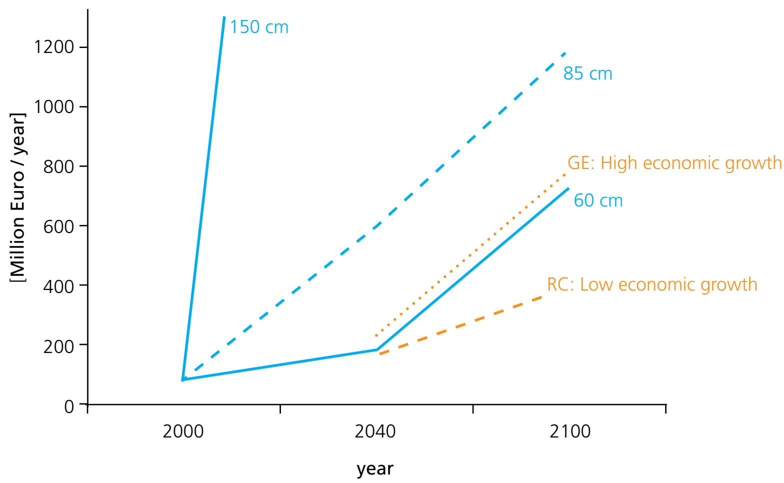

FIGURE 2.
The relative influence of sea level rise (60 cm and 150 cm in 100 years) on flood risk compared with the influence of urban development (according to the two scenarios, RC and GE)

TABLE 1.
Costs of dams and storm surge barriers of the Deltaworks (Aerts et al., 2008)

Construction costs	Year in operation	Million Dutch Guilders	Net present value 2007 million €	Lifetime in years	Scenario Sea level rise in cm
Storm Surge barrier Hollandse IJssel	1954	33	98		
Haringvliet barrier	1961	586	1,464	150	20
Brouwersdam	1961	141	353	100	
Hellegatsplein and Volkerak sluices	1961	191	477		
Grevelingen dam	1961	66	165		
Storm Surge barrier Oosterschelde	1986	5,500	3,850	200	20
Compartmentworks	1984	1,069	1,604		
Canal through Zuid-Beveland	1984	610	915		
Maeslant storm surge barrier	1997	990	545	100	60
Europoort barrier and Hartel barrier	1997	460	253		
Total costs of the Deltaworks		**8,195**	**8,925**		

The influence of the sea level rise and high urban growth (GE scenario) is approximately the same, as long as the rate of sea level rise does not exceed 60 cm per century. For both trends, either a 60 cm per century sea level rise or the GE scenario, the risk in the year 2100 is about seven to eight times greater. A sea level rise of 85 cm causes a risk increase of a factor of one hundred to two hundred for the respective RC and GE scenarios, assuming that no preventative measures are taken.

Costs of climate change adaptation

An important aspect of the Dutch flood protection system is the Deltaworks. The catastrophic flood event of 1953, led to the implementation of the Deltaworks, which are a series of dams, sluices, dikes, and storm surge barriers constructed between 1958 and 1997 in the Southwest of the Netherlands. The aim of the Deltaworks was to improve flood protection by shortening the Dutch coastline, thus reducing the number of dikes that had to be raised. With over 10,250 miles of dikes (1,500 miles designated primary dikes and 8,750 miles as secondary dikes) and 300 structures, such as sluices and bridges, the project is one of the most extensive engineering projects in the

	Scenarios				
Year	2040	2100	2100	2100	Far future
Sea level rise (cm)	24 cm	60 cm	85 cm	150 cm	500 cm
Max discharge river Rhine [m^3/s]	16,700	18,000	18,000	18,000	18,000
Max discharge river Meuse [m^3/s]	4,200	4,600	4,600	4,600	4,600
River works	Costs in billion €				
River widening Rhine	2.7	5.5	5.5	5.5	5.5
River widening Meuse	1.3	4.2	4.2	4.2	4.2
Dike reinforcement	0.2	1.8	2.6	6.1	36
Coast	Costs in billion €				
Beach nourishment Holland	1.9	6.4	9.1	16.0	25
Beach nourishment Waddensea	1.1	3.8	5.4	9.6	Unknown
Beach nourishment Westerschelde	0.1	0.4	0.6	1.1	Unknown
Coastal dike reinforcement	1.9	2.3	2.6	3.4	8
Total	9	24	30	46	>80

TABLE 2.
Costs of flood management investments under different climate change scenarios [billion] excluding the costs of upgrading the current Dutch flood protection system

world. The Deltaworks reduced the length of the dikes exposed to the sea by approximately 400 to 450 miles or 640 to 700 kilometres. In most cases, building a barrier or a dam was much faster and cheaper than reinforcing existing dikes. The total cost of the storm surge barriers of the Deltaworks are presented in Table 1.

Given the trends in increasing flood risk, different flood management strategies were explored by the government. In 2008, a special commission presented a new Delta Plan for the future addressing the issues of climate change. The strategy is following the current Dutch water management approach, which focuses on limiting the probability of flooding through the use of flood defences, such as dikes, beach nourishment, and storm surge barriers.

Table 2 shows the costs of additional flood protection measures under different climate change scenarios. These are costs for 3500 km of dikes, the nourishment of 450 km of beaches and widening of the main rivers. The Royal Dutch Meteorological Institute (KNMI) provided climate change projections for the years 2040 and 2100 for the Netherlands[8]. Each climate change scenario consists of a combination of projected sea level rise and maximum discharges of the rivers Rhine and Meuse. Table 2 provides the different combinations. For the year 2040, maximum discharges of the rivers Rhine and Meuse were set to 16,700 and 4,150 m3/s respectively. Maximum discharges for the year 2100 were projected as 18,000 and 4,600 m3/s. Note in this respect that in the current climate 16,000 m3/s is the discharge value of the river Rhine that has a probability of 1/1,250 years. In other words, dike rings with a current safety standard of 1/1,250 can withstand a flood peak of the river Rhine with a discharge of 16,000 m3/s. Different sea level rise scenarios (up to 500 cm) have been used to calculate the effects on flood probabilities. Note, however, that the maximum sea level rise scenarios provided by the KNMI project 85 cm in the year 2100.

The total costs for adaptation vary between 9 billion and over 80 billion euro. These are estimates

without upgrading the current Deltaworks storm surge barrier system. The costs expressed as a percentage of GDP are expected to be limited to 0.1% to 0.2% assuming a maximum sea level rise of 85 cm in 2100. The latter scenario is officially used by the government as the maximum sea level rise. Nevertheless, sea level rise will continue to increase after 2100 and large infrastructure investments should address the long-term sea level after 2100.

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