Dutch coasts in transition

Pavel Kabat, Louise O. Fresco, Marcel J. F. Stive, Cees P. Veerman, Jos S. L. J. van Alphen, Bart W. A. H. Parmet, Wilco Hazeleger and Caroline A. Katsman

The Netherlands has a long and varied history of coastal and river flood management. The anticipation of sea-level rise during the twenty-first century has renewed the push for sustainable solutions to coastal vulnerability.

The Netherlands is a densely populated country situated primarily in coastal lowlands. The Dutch coast, which is entirely along the North Sea, is 350 km long. At present, nine million residents of the Netherlands live in the coastal areas — vast regions at an elevation below sea level. Roughly 65% of the country's gross national product — about €400 billion — is generated in this region; the harbours and airports scattered throughout the lowlands are vital to the country's infrastructure and serve as important international transport routes for people and goods. Furthermore, the coastal lowlands host a number of the country's goods and services industries. Although this key region is protected by dykes and dunes along the coast, future sea-level rise could put it at risk.

Flood protection standards

The need for flood protection is etched on Dutch collective thinking. In 1953, a storm surge broke through the dykes and inundated the southwest coast with metres of water. Property destruction was devastating and over 1,800 people were killed. The Dutch central government immediately set up a committee — the (first) Delta Committee — to chart a course of action to prevent future disasters. The committee recommended a series of engineering works to protect low-lying areas, including the closure of several sea inlets, and made plans to reinforce and expand many of the dykes. The implementation of these recommendations fully began during the second half of the twentieth century, resulting in the construction of large and numerous levees and dykes that radically altered the appearance of the southwestern Netherlands.

Thus the existing standards for coastal flood protection date back to the 1960s and are based on the statistical likelihood of large storm surges as assessed at that time. However, as revealed in the 2006 audit conducted by the Ministry of Transport, Public Works and Water Management, between 24 and 56% of current coastal defences do not even meet the old standards (see Fig. 1). And of course, the number of people and the value of the property that need to be protected from flooding has grown steadily.

A changing climate and the anticipated rise in sea level will only add to the challenges faced by the aging flood defence system. The Dutch government not only recognized the growing vulnerability of

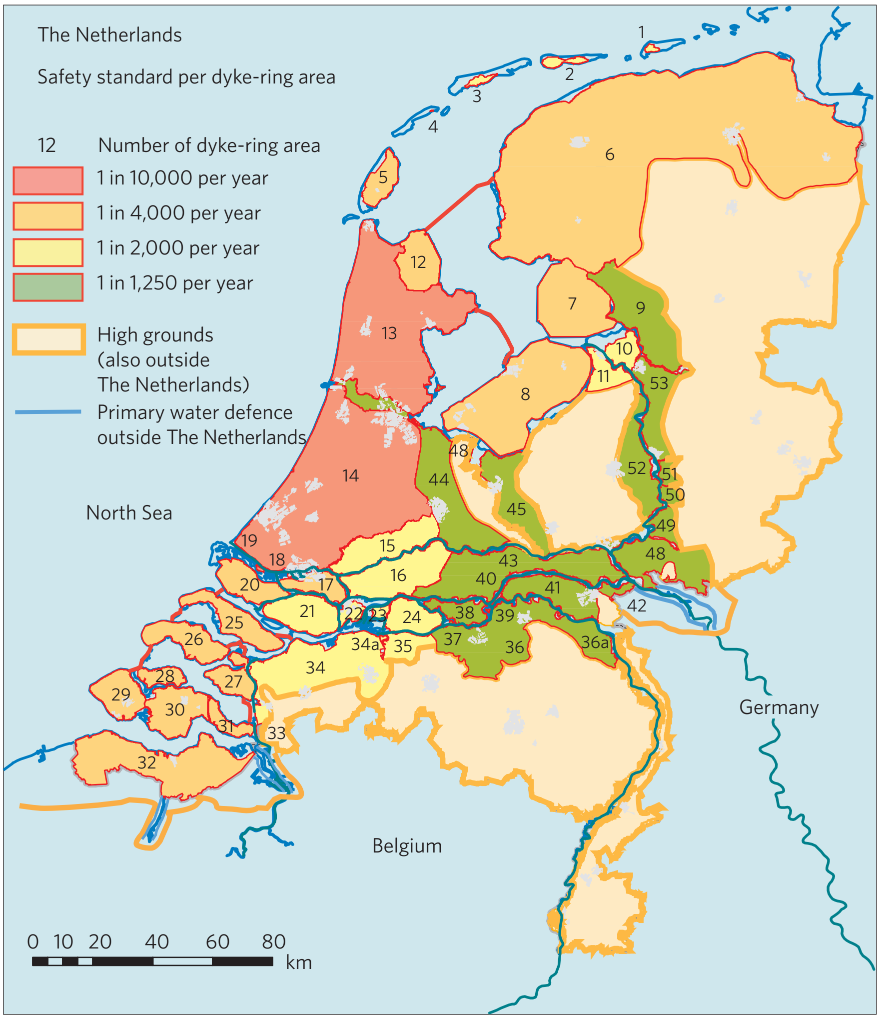

Figure 1 | Flood safety standards of dykes in The Netherlands. The current level of protection ranges from a flooding probability of 1 in 1,250 per year inland to 1 in 10,000 per year along the coast.

the lowlands, but also the opportunity to capitalize on re-shaping and updating the water management system to 'climate-proof' the Netherlands[1]. In 2007, the Dutch government therefore established a new Delta Committee to develop strategies for the sustainable development of the coast throughout the twenty-first century[2]. The committee was given a broad mandate to assess medium- and long-term scenarios involving the entire coastal and river system, and to develop region-specific recommendations. The committee's ultimate goal was to determine what needed to be done so that the Netherlands could continue to thrive well into the twenty-first and twenty-second centuries.

Sea-level scenarios

Although partly outdated, the original Delta Committee recommendations had strong and well-thought-out basic flood-protection standards based on economic optimization. The resulting engineering works protected coastal areas from floods with an occurrence probability of 1 in 10,000 for a given year, and riverine areas from floods with an occurrence probability of 1 in 1,250 per year (Fig. 1). The new Delta Committee started from the same thresholds, also recommending raising the flood protection levels of all dyked areas by a factor of ten.

Over the past century, relative sea level along the Dutch coast has risen by about 20 cm, a value that is similar to estimates of global sea-level rise[3]. The Intergovernmental Panel on Climate Change (IPCC) projects a further rise of between 0.18 and 0.59 m globally by 2100. To ensure that the flood protection measures can withstand high values of sea-level rise, a study — based on the IPCC high emissions scenario (SRES A1FI) — was initiated to provide an up-to-date, plausible upper-limit scenario of climate and sea-level projections for the Netherlands. High-end estimates of ice discharge and regional effects, such as local thermal expansion and coastal subsidence, place the upper limits of relative sea-level rise for the Netherlands at 0.65 to 1.3 m in 2100, excluding gravitational effects. By 2200, high-end estimates increase to 2.0 to 4.0 m of sea-level rise[4].

An integrated vision

Starting from the projections for climate change and sea-level rise, and in combination with its own vision of sustainable future development, the Delta Committee has presented an integral strategy for the long-term protection of the Dutch Rhine/Meuse delta and North Sea coast. They have also made recommendations for the development of the coast and the Dutch hinterland[5]. The strategy moves beyond basic water safety: the integrated approach also includes provisions for freshwater supplies, the preservation of natural and recreational areas, and sustainable energy.

Figure 2 | 'Building with nature'. Beach nourishment is one alternative approach to engineering in flood management along the Dutch coast.

The committee has incorporated two cornerstones of flood protection: 'building with nature' and 'room for the river'. The 'building with nature' approach moves away from engineered coastal protection structures such as levees and surge barriers, relying instead on beach nourishment and growth (Fig. 2). Indeed, whenever possible, they call for removing existing structures to restore natural estuary and tidal regimes while still protecting against flooding.

They also recommend that additional land be preserved from development along the Rhine and Meuse rivers, to accommodate increased river inundation. To ensure a continuous supply of fresh water, they suggest raising the level of Lake IJsselmeer by up to 1.5 m by 2100, to create a freshwater reservoir for the Netherlands and for possible freshwater export to southern Europe, which may be at increased risk of drought at the end of the century.

This advice was adopted in its entirety by the Dutch Cabinet, and a new Delta Act and Delta Programme are being prepared. This legislation will provide a legal, administrative and financial framework to begin full implementation of these recommendations. Yet although the importance of such measures to perceptions of flood safety is indisputable, these measures are not without cost. Projections of future climate change, and the attendant sea-level rise, are not absolute; the Dutch public, and their elected policymakers, tend to see climate change as a threat to prosperity, rather than to personal and societal safety. The Delta Committee has tackled this public perception by presenting the key challenges as opportunities for a sustainable and innovative economy.

Financing coastal protection

The proposed modifications will come at a price. The Delta Programme will cost up to €1.6 billion per year until 2050 when the cost is anticipated to drop to a minimum of €900 million per year, not including maintenance and management costs, which could add an additional €1.2 billion per year. But there are rewards for these expenses. Although not in the initial budget, the Delta Programme includes an optional €100 to 300 million per year for additional beach nourishment. As well as flood protection, the committee predicts that under the nourishment regime, the northern coast would expand seaward by about a kilometre, creating land for beach reserves, nature and recreation. Such additional activities could bring the total cost of the project, including maintenance, up to €3.1 billion per year up to 2050 — about 0.5% of the current Dutch gross national product.

In comparison, the potential cost of doing nothing could reach €3.7 trillion across the entire country[5], and even the cost of a single dyke failure could range from €10 to 50 billion. It is unlikely that the entire low-lying coastal area would be flooded, but a dyke break in a densely populated area would cause massive property loss and damage. The recommendations have an added financial flexibility: the infrastructure modifications and growth can be made in a stepwise fashion, and are designed so that they can be readily upgraded if scenarios for future sea-level rise change.

An unexpected opportunity

Unsurprisingly, these relatively costly suggestions have become a source of occasionally heated public, political and academic debate. Yet even with existing uncertainties about future climate, economically viable and responsible investments into adaptation measures in the water safety sector and beyond can be made in the Netherlands. These measures call for innovative solutions and technologies in our struggle against the rising waters. We thus propose that rather than being a financial burden, coastal protection can be seen as a push to boost technological innovation, and to invest in the development of long-lasting and sustainable infrastructure. We, and the Delta Committee, suggest that for the Netherlands, climate change can be an opportunity for societal and economic growth and evolution, moving the country into a sustainable future. ❐

Pavel Kabat[1], Louise O. Fresco[2], Marcel J. F. Stive[3], Cees P. Veerman[4], Jos S. L. J. van Alphen[5], Bart W. A. H. Parmet[6], Wilco Hazeleger[7] and Caroline A. Katsman[7] are at the [1]Wageningen University and Research Centre, PO Box 47, 6700 AA Wageningen, The Netherlands, [2]University of Amsterdam, PO Box 19268, 1000 GG Amsterdam, The Netherlands [3]Delft Technical University, PO Box 5048, 2600 GA Delft, The Netherlands, [4]Bracamonte BV, Postweg 11, 6561 KJ Groesbeek, The Netherlands, [5]Ministry of Transport, Public Works and Water Management, PO Box 17, 8200 AA Lelystad, The Netherlands, [6]Ministry of Transport, Public Works and Water Management, PO Box 20904, 2500 EX Den Haag, The Netherlands and [7]Royal Netherlands Meteorological Institute (KNMI), PO Box 201, 3730 AE De Bilt, The Netherlands.*
**e-mail: Pavel.Kabat@wur.nl*

References

1. Kabat, P., Van Vierssen, W., Veraart, J., Vellinga, P. & Aerts, J. *Nature* **438,** 283–284 (2005).
2. http://www.deltacommissie.com/
3. Church, J. A. & White, N. J. *Geophys. Res. Lett.* **33,** L01602 (2006).
4. http://www.deltacommissie.com/doc/deltareport_full.pdf
5. Aerts, J., Sprong, T. & Bannink, B. (eds) *Attention to Safety* (*Aandacht voor veiligheid* in Dutch) (Klimaat voor Ruimte, 2008); available at <http://www.klimaatvoorruimte.nl>.

Additional information

This article is based on the deliberations and final advice of the Delta Committee (see http://www.deltacommissie.com/en/advies).

Land waters and sea level

Dennis P. Lettenmaier and P. C. D. Milly

Changes in continental water stores, largely human-induced, affect sea level. Better hydrological models and observations could clarify the land's role in sea-level variations.

Understanding the causes of contemporary sea-level rise is a prerequisite for projecting future changes in sea level. The main contributions to the current rise in global mean sea level of about 2 to 3 mm yr^{-1} are thought to come from the loss of land-based ice masses such as ice sheets, ice caps and mountain glaciers, and from the thermal expansion of the oceans[1]. These contributions are sufficient to explain the observed rate of sea-level rise within the uncertainties of the constituent estimates[2]. However, the uncertainties in both contributions are large enough to leave room for a significant additional source of sea-level rise (or, less likely, a sink) that could account for several tenths of a millimetre per year. A number of proposed mechanisms[3] could reduce continental water mass and thereby explain any relatively small missing source of sea-level rise[2]. These mechanisms could also markedly affect any acceleration or deceleration of sea-level rise.

Land loses water

As a simple consequence of mass conservation, the ocean surface rises when the continents lose water. For example, wetland drainage entails deliberate reductions of water storage[4], urbanization can suppress groundwater recharge and thereby lower the water table[5], and extraction of groundwater by pumping (sustainable or not) reduces aquifer storage. Increasingly deeper seasonal thaw of soil above permafrost might promote drainage of the newly activated part of the soil profile[6], which can contain large deposits of ground ice. "Disappearing Arctic lakes"[7] — though contributing little mass on their own — provide evidence that thawing activates drainage pathways at the landscape scale. On the other hand, reduced seasonal freezing of the soil surface could also enhance infiltration of water into soil and increase soil-water storage, particularly where permafrost is absent.

Each of the aforementioned effects could reasonably generate a sea-level change on the order of 0.1 mm yr^{-1}. However, quantitative estimates of the contributions of these mechanisms to rising sea levels are based on speculative global extrapolations of uncertain local observations and data.

Land gains water

One well-defined negative contributor to sea-level rise results from the sequestration of water in man-made surface-water reservoirs (Fig. 1). Near the middle of the twentieth century, the sequestration of water in reservoirs depressed rates of sea-level rise by more than 0.5 mm yr^{-1} on a decadal timescale. More recently, the rate of impoundment of water in reservoirs has slowed (and perhaps, we speculate, has even changed sign). The implied rapid change in the role of reservoirs is a result of two processes: a slow-down in the construction of dams and a gradual infilling of existing reservoirs by sediments, such that their water volume slowly declines. (Reservoir sedimentation affects sea level by the infilling process