Planned Adaptation in Design and Testing of Critical Infrastructure: The Case of Flood Safety in The Netherlands

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ABSTRACT

In the Netherlands, dykes and other primary water defence works are assets that are essential to keep the society and economy functioning, by protecting against flooding from sea and rivers due to extreme events. Given that 55% of the country is at risk of flooding, primary water defence works belong to its critical infrastructure. Many factors influence the risk and impact of flooding. Besides physical factors (e.g., landscape design, climate change) also socio-economic factors (e.g., population, assets) are important. Given that these factors change and feature complex and uncertain behaviour in past and future, the design and regulation of this critical infrastructure will have to be flexible enough to be able to deal with such changes. 'Planned Adaptation' refers to regulatory programmes that plan for future changes in knowledge by producing new knowledge and revising rules at regular intervals. This study describes the emergence of the next generation of Dutch primary water defence infrastructure, which through the stepwise implementation of Planned Adaptation for design and testing of primary water defence works in the mid-1990s has moved beyond the Delta Works approach of 1953 and subsequent unplanned adaptations. This has prepared the ground for the recent introduction of Adaptive Delta Management, which makes an integral part of the new Delta Plan for the Netherlands that was published on 16 September 2014 and which is also analysed in this study.

Keywords: Water Defence Works; Critical Infrastructure; Dealing With Uncertainty; Planned Adaptation; Delta Plan

INTRODUCTION

After the coastal flooding disaster of 1953, the Netherlands embarked on a major multi-decade civil engineering effort to increase the protection against storm surges through the Delta Works and strengthening of the coast (dunes and dykes) – high safety standards were set in this process (e.g., for some parts of the country, protection against 1 in 10,000 year events). Also peak river discharges were re-assessed and river dykes were raised. While a significant amount of knowledge about the necessary heights and strengths of dunes and dykes was generated during that period, no system was put into place to systematically refine and update this knowledge and the resulting 'hydraulic requirements', engineering standards that correspond to the set safety standards, for the different locations along the coast. In 1989, when the Delta Works were considered to have nearly reached their completion, a five-year cycle of re-assessment of the safety of the primary water defence works was proposed along with continuous research funding to generate the required knowledge updates in a planned manner rather than in the ad hoc manner of earlier decades. The first cycle started in 1996 and the fourth cycle will run from 2017 (the cycle length has changed from five to six years to twelve years). The fourth cycle will be based on the new safety standards that have been proposed in 2014 and that will make use of renewed test and design criteria. This study argues that this system, which operates under the Water Act, has become fairly successful in generating new knowledge and making corresponding changes in the hydraulic requirements. For instance, new knowledge about wave heights along the coast have led

to significant investments in the heightening of coastal defences, and new insights into dyke failure mechanisms (in particular, 'piping') have led to a fundamental restructuring effort for dykes. Furthermore, by introducing a new risk-based approach to flood safety and a monitoring and evaluation programme that can lead to revisions of the new approach at regular intervals, science, engineering and public policy have been brought closer together in the new Delta Plan for the Netherlands that was released on 16 September 2014.

In this study, the Dutch science/engineering–policy process for setting safety standards and translating them into engineering standards for primary water defences is examined. We investigate to what extent we can see Planned Adaptation happening in this process. The term 'Planned Adaptation' is used to describe two features of a policy process: [a] there is a prior commitment to subject an existing policy to *de novo* re-evaluation and [b] systematic effort is made to mobilise new factual information for use when the re-evaluation takes place.[1]

THE PERIOD BEFORE THE WATER DEFENCE ACT (1916–1995)

It took a long time before the knowledge needed to give the Netherlands protection from sea inundations started to become gathered in a systematic manner. After the flooding in 1916, for instance, a *Rijkswaterstaat* (Directorate-General for Public Works and Water Management) committee had studied whether such flooding could happen again and concluded – based on knowledge available then – that that was not the case. This 1916 judgement was not revisited until 1938, when a civil engineer in *Rijkswaterstaat*, Johan van Veen, just could not believe that no new knowledge had become available that would make a re-assessment worthwhile. He initiated a study of existing dykes and found that these did not suffice by far, largely because of local factors that had not been taken into account. This led to the *Viereilandenplan* (Four Islands Plan) of 1938, which mapped out where higher or new dykes where needed and where dams should be built. It was not immediately implemented, but – as is typically the case in the Netherlands – first a committee was formed, the *Stormvloedcommissie* (Storm Surge Commission).

By the 1940s it had become clear to engineers from *Rijkswaterstaat* and the Storm Surge Committee that many dykes were still too low and too weak to withstand the severe storm surges that were likely to come. During the Second World War a lot of land had been put under water on purpose by both the Germans and the Allied Forces. In the Battle of the Scheldt for example, in October/November 1944, the island of Walcheren at the mouth of the West Scheldt remained in German hands and to break their defence sea dykes were bombed. After the war the Dutch were able to quickly regain the land (sometimes after surmounting huge technical difficulties) and they started to believe more and more that many desired physical and social changes in the Netherlands could be effected by choosing the right government policies and engineering approach ('*maakbaarheid*'). A plan by van Veen was even presented to close off most of the delta and reduce the coastline to the length it had in the year 800. This would lead to a significant amount of new land and a high level of safety. This plan did not get enough support within *Rijkswaterstaat*, though. He was even fired as secretary of the Storm Surge Commission. Still, the implementation of his Four Islands Plan was continued with the closing of the Den Briel Meuse in 1950.

But the Netherlands were too late with raising and fortifying all the dykes for which this was deemed necessary according to the Storm Surge Commission. The knowledge that was available about the risks had not been acted upon soon enough; the country was 'slapped in the face'. In February 1953, a storm surge disaster occurred, generally known in the Netherlands as 'The Disaster'. Though the number of casualties was not very high as compared with earlier disasters (1,836 people drowned as compared to tens of thousands in earlier floods in the 1500s for instance), the effects were traumatic – at the individual level, for the Netherlands as a country, and for the coastal engineering profession.[2] Very quickly after this disaster the first Delta Commission was installed and came up with a drastic reaction: the *Deltaplan* (Delta Plan) which in the end would turn out to take more than three decades to complete. This plan was a somewhat weakened version of the earlier plan proposed by van Veen for a complete closure of the Dutch coast. In 1955, the first Delta Commission proposed protection levels in connection with the *Deltaplan*. This made it possible to calculate the 'hydraulic requirements' for each segment of primary water defence (for instance, the once in ten thousand years combinations of water heights, that is sea level plus tide plus storm surge) and waves that the dykes in Holland are required to withstand; the hydraulic requirements are technically formulated as boundary conditions somewhat away into the water from the water defence work.

1 McCray, L. E., Oye, K.A. & Petersen, A. C. *Technol. Forecast. Soc. Change* 77, 951–959 (2010).

2 Bijker, W. E. *Soc. Stud. Sci.* 37, 143–151 (2007).

Over the 20th century there have been large, *unplanned* changes to the methods for determining hydraulic requirements. Before The Disaster of 1953 the norm for the height of a water defence work was determined by adding to the highest observed water level a fixed additional height: 0.5 or 1 m. For dykes exposed to waves more would be added. Already in 1939, the Storm Surge Commission pointed out that this method was fundamentally wrong; statistically speaking there could always be a higher water level than the highest level observed and also sea-level rise was contributing to higher water levels. The Disaster of 1953, which was caused by a combination of high water and structural failure, proved the correctness of this conclusion, which until then had not been adopted by the governments involved (the national government, the provinces and the water boards). The Delta Commission, in its final report of 10 December 1960, advised to create a national system of flood protection based on well-founded norms and guidelines. For Randstad Holland, the Delta Commission advised to base the design of water defence works on a water level of NAP (Amsterdam Ordnance Datum) + 5 m at Hoek van Holland, a seaward point, and corresponding levels elsewhere along the coast. These water levels match the storm surge water levels for which the chance that they are exceeded is 1:10,000 per year, on average. In addition, the first Delta Commission advised to take into account a *relative* sea level rise (that is, including the geological land subsidence effect) of 0.2 meter per century for the life span of the designed water defence work. The first Delta Commission also offered practical guidance on how designs could guarantee defence against the mentioned storm surge water levels: for example, by stating that 2% of the waves that can be expected for the indicative water level may run over the water defence work. Several years later, the *Technische Adviescommissie voor de Waterkeringen* (Technical Advisory Commission for the Water Defence Works) would be charged with further developing technical guidance.

THE INTRODUCTION OF PLANNED ADAPTATION WITH THE WATER DEFENCE ACT (1995)

In December 1995, the *Wet op de waterkering* (Water Defence Act) was accepted. This act provided both a statutory basis for the safety levels adopted after the 1955 Delta Commission proposal and a five-year review cycle of the hydraulic requirements associated with those fixed safety levels. In 2009 the act has been transformed without any substantive changes – except for a change in cycle length to six years, see below – into a part of the new Waterwet (Water Act). The main reason for introducing planned adaptation was that with the completion of the Delta Works, if not a system of Planned Adaptation were introduced, the safety of Dutch water defence could gradually deteriorate and the Dutch could become ‘slapped in the face’ again by a major catastrophe. One must remember here that 55% of the Netherlands is at risk of flooding from sea and rivers. Now that the safety levels set in 1955 had been met at the end of the 1980s, these safety levels have to be maintained. Dutch policy documents often stipulate that a deterioration of safety levels should ‘never occur’ anymore. In the aftermath of the Delta Works, the research funding and research infrastructure could continue to be used for Planned Adaptation, which may trigger small or large water defence engineering projects depending on how the standards evolve.

The proposal for the Water Defence Act was sent to Parliament by Minister Neelie Smit-Kroes (the later European Commissioner Neelie Kroes) in April 1989. There were some discussions surrounding the Act related to role of the national government and the distribution of costs over different actors. But there was no discussion at all about the need for scheduled reviews of the hydraulic requirements. In the Netherlands, the government and all actors involved in water defence policy and regulation just did not want a repeat of being too slow to respond to changing conditions and emerging knowledge now that the *Deltaplan* had been fully realised. Surely, The Disaster of 1953 and the drastic multi-decade response to it constitute an example of Unplanned Adaptation. When this effort was nearly finished, all relevant actors involved in coastal and river defence shared the concern that mismatches between actual and required defence might gradually develop. In order to prevent this from happening, the Dutch government said a system should be put in place that would guarantee *both* a regular updating of hydraulic requirements *and* other safety criteria and a regular test of whether the water defence works satisfy all the safety criteria. As a corollary, the government took up to allocate a larger fraction of research money spent on water defence engineering research for providing the knowledge needed to better calculate the hydraulic requirements and other safety criteria. In due time, a targeted research program would be set up, directly connected to the review cycles. Thus, Planned Adaptation was introduced in Dutch flood safety management.

When one introduces Planned Adaptation, one has several options for designing the processes securing the regular updates of the policy. One option is to monitor continuously and lay down in an agreement or convention what the thresholds for the most critical criteria are and what actions logically follow from reaching these values, e.g. adjusting safety standards or underlying criteria. In this option there is no a priori fixed cycle length; adjustment is considered

when the conditions justify the efforts involved. Another option is to fix the cycle length. At regular intervals all relevant data are analysed to determine if an update of safety levels or of underlying criteria is necessary. In this option obviously one has to choose a cycle length. In the Water Defence Act the frequency of re-assessing the hydraulic requirements was synchronised with the frequency of safety 'testing', where officials actually go out and assess the safety of existing structures by following an assessment protocol – this regular testing was the other major innovation introduced with the Water Defence Act. Both frequencies were set at once every five years. In the Explanatory Memorandum of 1989 this period was presented as a compromise between staying up-to-date with respect to guaranteeing the safety norm (new research can be well expected to deliver and corroborate new insights in just a few years' period) and being able to incorporate changes in requirements into the planning of water defence works maintenance (for the latter, policy makers in coastal defence typically prefer changes in hydraulic requirements less than once in a decade).

THE DELTA PROGRAMME AND ADAPTIVE DELTA MANAGEMENT (2014 DELTA DECISIONS)

In 2008, the second Delta Commission was installed. After one year it published its proposal and was abrogated. The commission advised, amongst other things, to establish a 'Delta Programme' uniting all levels of government and focusing on water safety and fresh water supply. This was done and the Delta Programme was tasked to focus on the *prevention* of a disaster, thus breaking from the past where big interventions were most often *reactions* to a disaster. The programme started in 2010, is led by a government commissioner and has an annual budget of 1 billion euro. While the Delta Commission had focused on the urgency to prepare for climate change, climate change became less central to the Delta Programme: in effect, it became one of the elements that established the necessity to deal with the Dutch Delta now.[3]

Based on a significant amount of targeted research, the Delta Programme has proposed new, regionally differentiated safety standards in September 2014: everyone living behind dykes and dunes in the Netherlands can count on a protection level of 10^{-5} or higher by 2050:

"The Delta Commissioner proposes that a risk-based approach be applied in water policy. This means taking into account the risk of flooding and the ensuing consequences. He is also proposing new standards for flood defences. These new standards are aimed at reducing the risk of death due to floods anywhere in the Netherlands to 1:100,000 (0.001 per cent) a year. A higher level of protection will apply in certain places where many casualties or significant economic loss could occur, or where "vital infrastructure" could be disrupted and affect the whole country (for example, the gas hub in Groningen). The aim is for all primary flood defences to meet the new standards in 2050."[4]

These risk-based safety standards will subsequently be translated into the corresponding hydraulic requirements for the re-assessment cycle that starts in 2017 and will be enforced under the Water Act. The Delta Plan (or, more precisely, 'Delta Decisions') of 2014 also proposes Planned Adaptation with a frequency of 12 years, when each time a full assessment will be made to whether the hydraulic requirements need to be adjusted if the underlying assumptions have changed materially – the safety standards themselves had not changed since 1955 and the new uniform risk-based standard may be expected to be kept more or less constant for the next few decades too.

The approach of Planned Adaptation also guides the way the new Delta Program frames 'Adaptive Delta Management' in the light of the projected sea-level rise and changes in river run-off associated with climate change over the 21st century and beyond, as well as other (socio-economic) developments:

"A key principle of the proposed Delta Decisions and preferential strategies is that it should also be possible to take additional measures in the long term (after 2050) to address the challenges following from climatological and socio-economic developments. The options for these are ready. These have been included in the adaptation paths of the preferential strategies." [5]

There are three significant examples of Adaptive Delta Management decisions where given the uncertainties options for after 2050 are consciously kept open through spatial policy, thus at some cost (even these costs are to be minimised). Both the options themselves and keeping them open are subject to planned re-assessments based on new knowledge that will be gathered in the future. The three examples of the options are:

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3 Zegwaard, A., Petersen, A. C. & Wester, P. *Climatic Change* (in press).

4 Delta Commissioner, *Delta Programme 2015*, web announcement (Delta Commissioner, The Hague, The Netherlands, 16 September 2014); available at www.deltacommissaris.nl/english/delta-programme/delta-programme-2015

5 Delta Commissioner, Delta Programme 2015 (Delta Commissioner, The Hague, The Netherlands, 16 September 2014); available at www.deltacommissaris.nl/english/delta-programme/publications

- to allow the winter water level in the IJsselmeer region to rise with the sea level to a limited extent;
- if necessary, to change the discharge distribution across the Rhine distributaries;
- to use Rijnstrangen as a retention area.

The basic philosophy behind Adaptive Delta Management is to choose strategies and measures that can give the Netherlands flexibility in the way they respond to new measurements and insights, by stepping up efforts if necessary or changing strategy, while already having everything at hand (see, e.g. Figure 1).

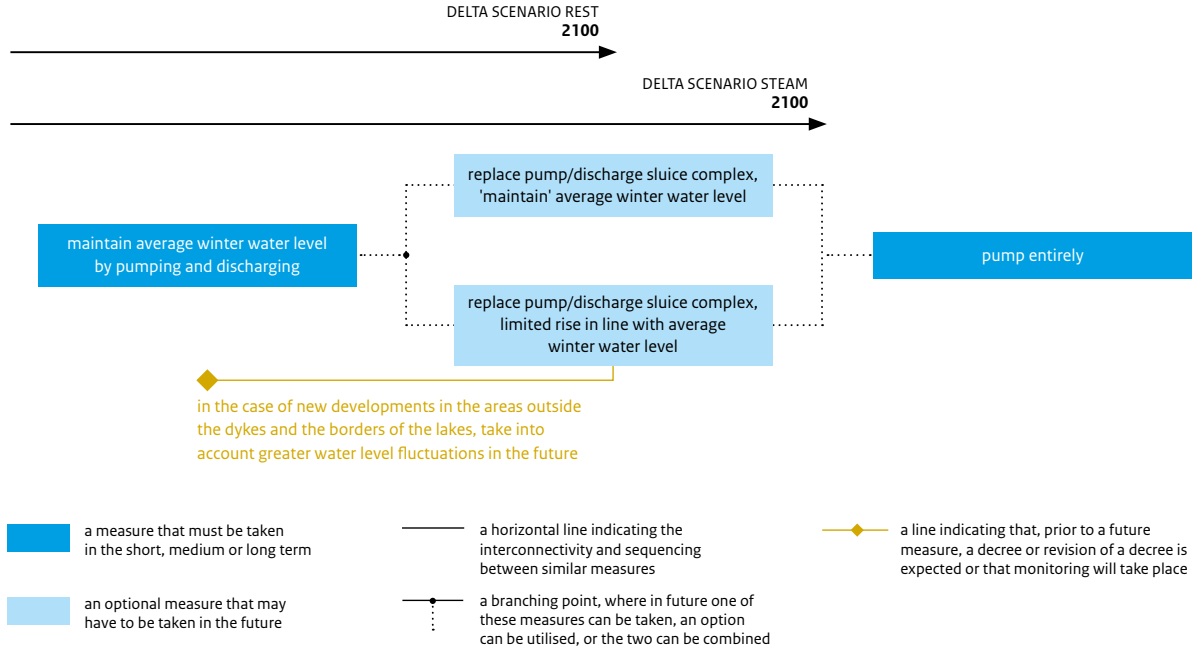

Figure 1. ***IJsselmeer region, adaptation path for preferential strategy for flood risk management***

Finally, Adaptive Delta Management will require proper monitoring of effects and, based thereon, regular evaluation of the strategies followed. Therefore, the Delta Commissioner will direct the development of a monitoring and evaluation system that matches with the adaptive and area-based approach advocated by the new Delta Plan.