10. Lessons of past disasters and preparedness actions to cope with future hydrological extreme events in the Netherlands

Marcel Marchand[1], Mark de Bel[1], Herman van der Most[1], Cees van de Guchte[1] and Niels Vlaanderen[2]

[1]: Deltares, Delft, the Netherlands; [2]: Ministry of Infrastructure and Water Management, the Netherlands.

niels.vlaanderen@minienw.nl and cees.vandeguchte@deltares.nl

Summary

The Netherlands, being a low-lying delta of the rivers Rhine, Meuse and Scheldt, have grappled for centuries in coping with water-related disasters - floods originating from both storm surges and high river discharges. Projected climate change scenarios learned the country to prepare for even more frequent and more intense extreme events. We realized the need for new solutions: automatically heightening the levees to protect against flooding was no longer a sustainable solution. We had to change the system we worked with for centuries and broaden its goals.

The Netherlands revisited their safety standards for protection against flooding, now incorporating a risk-based approach. We introduced nature-based solutions like “Room for the River” to enable higher river discharges and the “Sand Engine” for beach nourishment to complement traditional engineering for protective disaster resilient infrastructure. The Netherlands embraced system thinking to future proof the country, and we incorporated cultural and ecological values into adaptive decision making.

The Netherlands has proven it can shift the fundamentals of its strategy to prepare for a changing climate. Essentially, we have addressed the synergies between the agendas of water-related disaster risk reduction and climate adaptation in a coherent way, both of which are essential in reaching the integrated goals of the nation’s long-term vision for sustainable development. The narrative behind is being described below.

10.1Historic disasters and near disasters

The Netherlands have a long history of flood disasters, the responses to which have shaped much of the flood management infrastructure as we know it now. Two major disasters in the last century stand out for the way the Dutch handles protection against flooding. The first one, in 1916, caused widespread flooding due to a large number of dike breaches along the inner sea called “de Zuiderzee”. Although there were only 19 fatalities, it led to the closure of this sea by a 30 km long dam: the “Afsluitdijk”. The second disaster happened in 1953, when a storm surge hit the south-western part of the Netherlands and again caused a huge number of dike breaches (more than 150) that led to the inundation of 1650 km^2 of land. Besides 1853 fatalities the damage was estimated at 680 million euro or 10% of GDP at that time. This traumatic event brought about the installation of the first Delta Commission that advised the government to close off most of the delta estuaries with barriers so that the coastline that needed to be protected was significantly shortened. It was the start of a huge undertaking that became known as the Dutch Delta Works.

In more recent years two (near) flooding events acted as a wake-up call realizing that even after the Delta Works the Netherlands was still quite vulnerable to flood disasters. Due to heavy rainfall in 1993 the rivers Rhine and Meuse had to cope with very high discharges. Floods along the Meuse in Limburg caused extensive damage and in some places people needed to be evacuated. In 1995 the waters in these rivers rose again at danger level prompting the authorities to evacuate 250,000 people and around 1 million livestock. Luckily the dikes did not breach, and no casualties or major damage was recorded. These incidents combined with worries about higher peak levels that can be expected due to climate change made the government aware of the need for new safety measures.

Before describing these measures and policies it is important to have a better understanding of the specific nature of the country's flood hazard and vulnerability. The Netherlands is a low-lying delta, where three large rivers, the Rhine, Meuse and Scheldt, discharge into the North Sea. Without the present dikes and other flood protection measures, approximately half of the country would be regularly flooded. Until approximately a millennium ago, land freely accreted and eroded because of the dynamic behaviour of the sea and the rivers. The local population lived on the higher land or on artificial mounds, protected by a simple dyke. Over the centuries the people gradually reclaimed more and more land by building new dikes and creating so-called 'polders': low-lying areas prevented from flooding by a dike constructed around it (Gerritsen, 2005). Due to soil subsidence within these polders most of the land became lower than the sea level.

Basically, flood hazards in the Netherlands primarily originate from the sea and the rivers. Although the temperate climate precludes the occurrence of hurricanes or typhoons, strong gales that come from the Northwest can cause the sea to rise to high levels, especially due to the funnelled shape of the southern part of the North Sea. Because during the 1953 storm the time of the surge peak coincided with the time of spring-tide high water, the total water-level reached heights that, in many locations, exceeded those recorded ever before (Gerritsen, 2005).

The storm surge had a return period of one in hundred years, similar to the danger level river stages in 1995. But in this case heavy rainfall in the river catchments of Rhine and Meuse, in combination with melting snow, were the main causes of the high river discharges. The maximum discharge at Lobith (the place where the river Rhine enters the Netherlands) measured approx. 12,060 m3/s, only 5% less than the highest ever recorded discharge from 1926 (TAW, 1995). A big difference between the two events is the fact that during the 1953 disaster, people were completely surprised by the rising waters, which had its peak between 03.00 and 04.00 on Sunday morning. At that time the radio had been off the air for hours and would remain so for several more. Private telephones were not yet widespread, and the islands were isolated during the night, after the ferry boats had stopped. Moreover, all but a few people were in bed (Gerritsen, 2005). In contrast, the 1995 high water levels were predicted 2 days in advance and early warnings were given with high frequency to local waterboards and rapidly installed regional crisis centres (TAW, 1995).

10.2Responses

The people in the Netherlands have a long history of fighting against the water. For a long time, the primary response after a flood would be to heighten the dike to the height of the highest recorded high water plus a safety level of approx. half a metre (Battjes & Gerritsen, 2003). Only 17 days after the 1953 disaster took place the Delta Committee was installed. Its task was 'to develop measures, in order that such a disaster could not happen again'. Besides advising the government on taking up the Delta Plan, involving huge investments in closing off all estuaries but one, this Commission also introduced the first version of 'risk informed decision making'. It calculated through a cost-benefit analysis the optimal safety levels for different parts of the country, based on a combination of probability of occurrence and potential impact. Areas that are highly populated and having huge economic importance, such as North- and South Holland (with cities such as Amsterdam, Rotterdam and the Hague) would need to have a safety level of 1:10,000 years. Whereas other coastal areas with lower population densities would get a safety level of 1:4,000 years against storm surges. Areas liable to river floods could do with even lower safety level of 1:3,000 years (later adjusted to 1:1250 years), because of the longer lead time for early warning and the fact that freshwater does less damage than seawater.

The decades that followed were characterized by an optimism that coastal and geotechnical engineers would once and for all solve the flood risk. Based on the safety standards large flood protection projects were carried out. In 1996 the Flood Protection Act marked a conclusion of this period: the technical safety standards became statutory and all flood protection structures were to be tested against these standards every 6 years. Strict safety standards, dedicated forms of governance (including taxation), regular safety assessments and sound engineering have yielded a well-protected country. The flood prone areas are safeguarded from flooding by approximately 3800 kilometres of primary flood protection structures of which about 90% are managed by regional water authorities, whereas the remaining structures are managed by the national water authority (Rijkswaterstaat, part of the Ministry of Infrastructure and Water Management) (Jorissen et al., 2016). The primary flood protection structures are found along the major rivers, large lakes, estuaries and the coast. Most primary flood protection structures are dikes. In addition to this, also structures such as locks, gates and (storm surge) barriers are used. Along the coast the dunes provide a natural protection against flooding.

Especially after the near-flooding in 1995 people started to realize that the flood risk can never completely be reduced. Rising concerns of climate change and sea level rise, combined with the Katrina disaster in the USA in 2005 made people aware that, despite having the highest flood safety standards in the world, there always remains a risk and – more importantly – that strengthening dikes is perhaps not the only or best solution. Besides, also the ecological consequences of higher dikes and damming estuaries became a factor that could no longer be denied. Presently, decades after finalization of the Delta Works, each enclosed former estuary has specific environmental problems, which mainly result from lack of connectivity, reduced tidal flows and disrupted sediment balance (Van Wesenbeeck et al., 2014). Although the most important water related value is still safety, the ecological quality is currently deemed much more important than during the engineering era (Van der Brugge, 2009).

One of the most conspicuous examples of this paradigm shift is the “Room for the River” project. Projections of a plausible increase of 30% in flood discharges in the Rhine River due to climate change triggered new studies on how to cope with this increased flood risk. Instead of raising the levees it was decided to give more room to the river. This would substantially lower flood levels and sustain a more attractive environment, both urban and natural. More space for rivers was officially adopted by the Netherlands government to achieve the required safety level for the river systems. It became the guiding principle for climate change adaptation along the major rivers.

The “Room for the River” program had a budget of more than 2 billion Euro and consisted of 39 different projects, located along all the main branches of the river Rhine. The first machines started digging in 2007 and the whole program was finished in 2015, within anticipated budget and time limits. The overarching idea is to give the rivers back the space that was taken during the past centuries when floodplains became occupied by industries and residential areas. At many locations along the rivers cities expanded and reduced the floodplain area. Bottlenecks were thus created and resulted in increasing water levels during high river discharges. Besides the main goal of flood protection, the program also explicitly considered co-benefits: the spatial quality, amenity and nature values of the river landscape. Especially, the program focused on:

- Increasing the landscape diversity between river branches,
- Strengthening the openness of the river with its characteristic waterfronts,
- Conserving and developing the scenic, ecological, geological, cultural and historic values,
- Improving the environmental quality, and
- Promoting the use of the main navigable waterways.

Meanwhile, people became aware that climate change could have far reaching consequences for the flood safety as well as for the fresh water supply of the entire country instead of only for the main rivers. Sea level rise and salinity intrusion, combined with an autonomous land subsidence (on average 1 mm/y, with a maximum of about 5 mm/y at certain locations) and socioeconomic development would on the long run pose great challenges to the entire water infrastructure. This prompted the Government to embark on an ambitious Delta Programme in which national, regional and local authorities prepared key decisions, developed strategies and implemented measures, in close cooperation with the public, stakeholders and knowledge institutions.

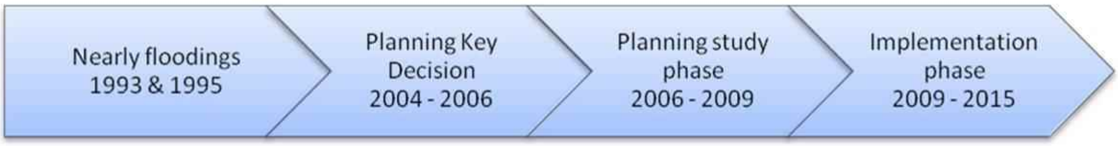
One of the novelties of the Delta Programme is that key decisions and regional strategies have been developed with a long-term perspective, i.e. a time horizon up to 2100. This long-term perspective stimulates the combination of investment agendas of different policy fields or authorities. In addition, it helps to anticipate on climate change gradually by making future-proof decisions on capital investments in infrastructure, flood defences and the built environment. On the other hand, this long- term perspective introduces uncertainty about the future conditions for which these measures must be designed.

Hence, the idea of climate change adaptation was introduced by using scenarios, models and adaptation pathways. To tackle uncertainty, four so-called Delta Scenarios presented the “corner flags of the playing field of plausible futures”. Each scenario combined climate change (rapid or moderate) with socio-economic development (growth or decline). The climate change parameters were downscaled from the IPCC AR5 and elaborated for the Netherlands (KNMI, 2014). Socio-economic parameters described the future size and spatial distribution of population and land use and constituted basic data for flood risk potential and fresh water demand. The Delta Scenarios presented a framework for checking the performance of the strategies under different future conditions.

10.3 Anecdotes and specific cases

Stakeholder participation in the “Room for the River” program

Not surprisingly it took several years of studies, planning and deliberations before measures were implemented. It first started with a number of studies and research activities, which concluded that the traditional way of flood protection (larger dikes) would take up much space and would affect the beautiful river landscape, that the urban squeeze would require more fundamental solutions and that due to climate change the rivers will have to convey more and more river discharge. Studies pointed out several locations where extra room could be created and in the year 2007 the Dutch government approved the Room for the River program that included 39 locations were measures would be taken.



Since such a large-scale program has a national interest, it was the central government that decided on the policy to give more room to the rivers. A Planning Key Decision (PKB) was formulated, that outlined the locations and types of measures. However, for the overall implementation of each of the 39 projects, local governments (municipalities) and stakeholders had to become involved as well. Many parties have interests because they own land along the river, have a house there or use the floodplain as recreational area. These people live in the area every day, so it is important that they are content with the new situation. Therefore, much attention was given to information and consultation meetings with local administration and stakeholders, which was a relatively unique and new approach.

Figure 10.1 Local inhabitants discussing a Room for the River project

The local government worked closely with the inhabitants of each project location. All the stakeholders tried to find a solution for the main question: "how do you want to achieve the required reduction of the water level?" From the beginning it was clear for everyone that the general objective of the program, i.e. reducing water levels at high discharges, was not negotiable. But the type of measures, their exact location and implementation was open for discussion. In this participative planning process solutions were found where all parties were satisfied with.

During this process the role of information and knowledge is crucial. Both national and regional authorities, municipalities and individual citizens proposed around 700 local measures that could help reducing the water levels. Each of these measures would have secondary impacts and different costs. A Decision Support System, called the *Planning Kit* was especially developed to handle such a huge amount of information and proved to be successful in supporting joint planning with stakeholders (Van der Most et al., 2017). Underlying the tool are advanced scientific, cause-effect models. These remain hidden to the users of the tool. Users can add measures to the existing situation of a river area in an intuitive manner, directly relating to their normal perception. They can for instance lower a dam or remove an obstacle. The tool visualizes the results of such interventions, again, in an intuitive way, e.g. showing the effects on natural quality and water levels. In this way, stakeholders – ranging from authorities to citizens – can jointly evaluate different strategies for adaptation in a river area, without being burdened with interpreting the results of the underlying models.

From flood exceedance chances to flood risk

Up till recently, Dutch flood protection policy was based on a flood exceedance approach. After the disastrous coastal flooding in 1953, flood defences were designed and maintained on an exceedance frequency of extreme flood levels. It was assumed that failure results from overtopping and that a flood covers the entire land behind the dike. Based on this approach a flood protection system of dikes, dams and dunes was realized up to a design frequency of 1/10,000 for the coastal area and 1/1250 for the rivers. Despite this high level of protection, a small probability of flooding always remains, the so-called residual risk. Flooding in Central Europe in 2002 and in New Orleans in 2005 illustrated the large scale of damage and disruption of modern society when flooding does occur. Therefore, and also prompted by the European Floods Directive (EU, 2007) that prescribed all European countries to develop flood policies based on a risk-based approach, Dutch policy started to change to a real risk-based approach, explicitly including the consequences of flooding in policies and preparing measures to reduce these consequences by spatial planning, building codes and disaster management (Van Alphen, 2014).

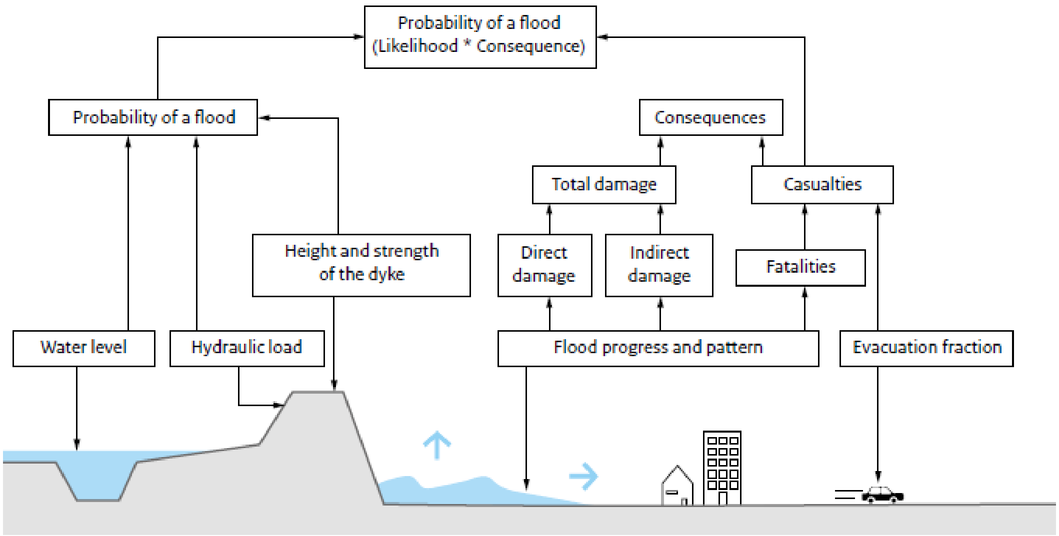


Figure 10.2 Elements of the Netherlands' integrated flood risk management approach: Risk as a result of flood probability (determined by hydraulic load and defence strength/height) and flood consequences (damage and casualties, determined by flood characteristics, buildings and evacuation success) (Source: Van Alphen, 2014).

The new risk-based approach, which was announced in the new National Water Plan 2009-2015, (MinIenW, 2009) involved a fundamental change in the type and level of flood protection standards. New knowledge on failure mechanisms of flood defences, inundation patterns, damage and casualty functions and powerful computer simulations enabled analyses with detailed information on the probability and consequences of floods. Besides including several dike failure mechanisms (such as macro-stability and piping) which could lead to flooding, also a cost-benefit approach (CBA) was used that provided insight in both the potential damage of a flood and the cost of raising the dikes. To this end two studies were carried out: a cost-benefit analysis, to determine the economically most efficient flood protection standards (Kind, 2011) and a study on the location specific casualty risk for individuals and societal groups (Beckers and De Bruijn, 2011). In the CBA study the costs of protection were compared to damages of infrastructure and loss of production from businesses in order to derive economically optimal flood protection standards. The damage calculations included intangible damages like damages to nature, landscape and cultural heritage and the impact on humans from loss of life. The study on casualties was based on the ambition to provide a basic safety level for each person from the risk to perish in a flood event. Eventually the Parliament decided that this safety level should be 1:100,000 per year for each individual.

Based on these studies location specific flood risk standards were proposed in which the legal flood risk standard was set to be the lowest probability between the two results, i.e. every individual is protected to the local individual casualty risk, which can be increased when economic damages warrant a higher protection. The resulting current legal standards for flood risks in The Netherlands are presented in figure 3. The innovative approach taken has been awarded with the Franz Edelman award.

Figure 10.3 Flood standards in The Netherlands (https://waterveiligheidsportaal.nl/#/nss/nss/norm)

Furthermore, the concept of multi-layered protection has been applied in deriving the safety standard. In this concept the flood control infrastructure forms the first layer, followed by a second layer that would reduce the damage through spatial planning. The third layer consists of efficient contingency plans in case of emergencies, including eventual evacuation.

These concepts and approaches resulted in economically efficient flood protection standards for different parts of the Netherlands that significantly differed from the previous standards, now ranging from 1/300 per year to 1/1,000,000 per year. It is expected that through these new standards an additional 1152 km of dike length needs to be strengthened, on top of the 748 km that was already needed based on the old standards. In order to complete the task of improving these 1900 km by 2050 it would require upgrading more than 50 km per year and an annual budget of €360 million (Jorissen et al., 2016). On the benefit site, these new standards would reduce the potential economic damage with a factor of 20 whereas the probability of 1000 fatalities due to a flood will be reduced by a factor 45 (Van Alphen, 2014).

Risk perception

Although the scientific formulation of a risk as probability times consequence seems very logical and rational, this is not the same as how people perceive risk. It is generally acknowledged that there is a discrepancy between how risks are formally quantified and how people perceive risk and whether they accept risk. Firstly, people distinguish between risks from natural hazards and hazards caused by human activities. Natural hazards are accepted more easily. Secondly, in the common perception, the consequences of events are not only easier to grasp but are also more important than their probability. The consequences are therefore given more weight in the judgement of risk. This means that people judge one hundred fatalities with a 1/100 per year probability as being worse than 1 fatality every year. Furthermore, in their actual behaviour, people take into account the personal advantages of running a certain risk. This also explains why people accept comparatively high risks in traffic, and in smoking cigarettes. In the context of flood risk management, personal gains are seldom obvious.

A research project a couple of years ago in the Netherlands showed that only a minority of respondents among the 3000 households and 200 business enterprises that were interviewed regard flooding as a likely event. The public has a great trust in the current flood defence system and in the authorities' ability to maintain this system. However, when it comes to assigning regionally differentiated standards for flood protection, a different picture emerged: there were strong adversaries of differentiation, whereas for others differentiation was viewed as a logical consequence of differences in the values to be protected. One way out of this dilemma is to base the new safety standard on the principle that every inhabitant should have a maximum allowable probability of drowning due to a flood (Local Individual Risk, LIR) of no more than 10^{-5} per year (i.e. once in 100,000 years), which is comparable with norms for other external risks such as safety against industrial calamities (which lies in the range between 10^{-5} and 10^{-6}). This is what the Delta Commission advised the Government.

Evacuation in 1995

It would turn out to be the largest evacuation in the Netherlands since the second World War. More than 250,00 people and 1 million of livestock were evacuated from areas behind the river dikes to higher places. After all, if the dikes had actually been breached, many places in the protected floodplain would have been submerged to about five meters and with a tremendous speed. At least the first two floors of many houses would have been flooded. It requires little imagination that such a decision was a hard one to take by the authorities. Evacuating such large number of people requires a lot of logistics and creates a disruption of normal life and economic activities. The decision was compounded by the uncertainty of the strength of many dike sections. The civil authorities had to rely on the expert judgement of waterboards and the national water management agency ("Rijkswaterstaat") who in many instances could not give a pertinent answer. Clearly, there were signs of potential failures, such as piping (the development of erosion channels under a dike) and seepage of water behind the dike. Although the waterboards could not guarantee the stability of the dikes, it didn't mean that these would breach. Based on previous experience of the waterboards and external advice from geotechnical experts the responsible dike manager had to make a judgement. It was evident that in such cases the boundaries of science and societal acceptance were reached and dealing with such uncertainties was extremely difficult (TAW, 1995).

It also proved to be a stress-test for crisis communication and organisation. All waterboards had to work with regional and provincial crisis coordination centres, that consisted of municipalities, provincial authorities, the police and fire brigade. Such centres had to rely completely on the technical judgements of the waterboards, but sometimes it proved difficult for them to accept these because of the earlier mentioned high level of uncertainty of the dike strength. Furthermore, the public opinion was sometimes biased by the media (television and newspapers) the information of which was sometimes misinterpreted. For instance, pictures of overtopping summer levees created alarm, whereas such is a normal phenomenon that occurs every winter (TAW, 1995). Eventually a combination of emergency measures to strengthen the weakest sections (Figure 4) and bold decisions by the authorities for preventive evacuation turned out for the best.

Figure 10.4 Emergency repair during high water at Ochten, The Netherlands in 1995

10.4 Good practices and lessons

The near-disaster in 1995 provided many a lesson for Dutch flood management. First, it proved risky to fully depend on dikes as the main measure for disaster risk reduction. Disaster preparedness, crisis communication and evacuation plans are also badly needed. Therefore, the Ministry of Security and Justice (responsible for disaster management policy and frameworks) has drafted safety region specific agreements to improve disaster management planning and response, especially on the supra-regional scale. These arrangements will be monitored, in parallel to the six-year evaluation of the flood defences (Van Alphen, 2014).

Secondly, more knowledge to assess dike strength and failure mechanisms is indispensable for a better risk assessment, also in emergency situations. Recent research includes piping experiments at laboratory scale, but also full-scale experiments using the “Smart Dike”, a unique international test facility with the aim of conducting systematic experiments and integrating and validating dike and sensor technology. Also, a Wave Overtopping Simulator has been used to perform destructive tests on inner slopes of real dikes in order to measure the erosion resistance against overtopping waves from severe storms. The results of these experiments already revealed a wide range of erosion processes, thus deepening our understanding and guiding the improvement of current models. Based on the knowledge gained, handbooks for design of dikes and guidelines for stability assessment for existing dikes have been rewritten.

Furthermore, working with nature instead of against it by giving the river the space it needs would provide a sensible addition to building stronger dikes. Although the direct response to the 1995 high waters was a “Delta plan” for the river dikes to immediately strengthen the most critical dike sections, already the Technical Advice Commission for Flood Control mentioned in its evaluation report in the same year that “levees alone are not enough” (TAW, 1995). By constricting the river in a narrow space waters will rise higher and the remaining floodplain will continue to accumulate sediment, whereas the land behind the dikes gradually subsides. Heightening the dikes is only a temporary solution. “Room for the River” would prove a much more resilient climate change adaptation strategy.

Since 1995 our knowledge on the climate change impacts on the Dutch water infrastructure has significantly increased and indicates that flood risk management will be a never-ending effort. Rising sea levels and increasing high river discharges, fiercer downpours and possibly increasing storminess will challenge the safety of the low-lying lands in which the great majority of the population lives. This necessitates a recurrent assessment whether the existing flood management strategies are still sufficient. A long-term perspective with ex-ante risk analyses, using climate scenarios and adaptive delta management, as the Delta Programme showed, seems the best strategy to cope with these challenges. With the end of the technical lifetime of many post-war structures approaching in the coming decades, reconstruction of aging infrastructure becomes an important driver for adaptation. The Delta Programme tries to frame these short-term investment agendas within a future perspective, seeking an optimum between “too much too early” and “too little too late”. Adaptation paths identify where a change of strategy is still possible, and how to avoid “lock in” situations (Haasnoot, 2013).

At the same time the Delta Programme took a pragmatic approach by including institutional, financial and legal components: there is a Delta Act that formed the legal basis of the programme, a Delta Commissioner who is an independent high-level government official supervising the programme and a Delta Fund of around 1 billion Euro per year that provides stability in financial resources. This budget covers the costs for operation, maintenance and reconstruction in (primary) flood protection, national water management and fresh water supply but excludes the regional water management tasks, the costs of which are primarily paid through local taxation (Jorissen, 2016). This latter budget is several times larger than the Delta Fund and is partly spent by the waterboards, the role of which cannot be overestimated.

Indeed, the waterboards have proven to be of paramount importance in disaster risk reduction since more than 8 centuries. Their mission is “*Dry feet and clean water*” and forms an indispensable link between the national/regional government and civil society. Because of their local presence they play a pivotal role in water governance. In fact, they are among the oldest forms of local government in the Netherlands, some of them having been founded in the

13th century. As of 2019 there are 21 water boards in the Netherlands. From time to time their existence is challenged as some say that the work can also be done by the provincial government. However, their unique focus on water management and the fact that taxes are paid by the inhabitants solely for that purpose make them highly valuable, and it shows that flood risk reduction is a matter of the utmost importance for Dutch society that does not require political debate.

With more than 65% of its Gross National Product being produced below sea level, the Netherlands has a unique position in the world. This explains the high safety standards against flooding that no other country has. With all the risk reduction measures in place the Dutch are well prepared for the upcoming challenges that climate change will bring, at least for the next 50 to 100 years. However, idleness would be misplaced, as recent history has shown. Given the uncertainty around sea level rise, for instance, a tipping point at which present safety measures would not be sufficient, could arise earlier than anticipated. Therefore, studies into the consequences of more extreme sea levels than currently used in the Delta scenarios are being conducted, as the Dutch do not want to be taken by surprise again.

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