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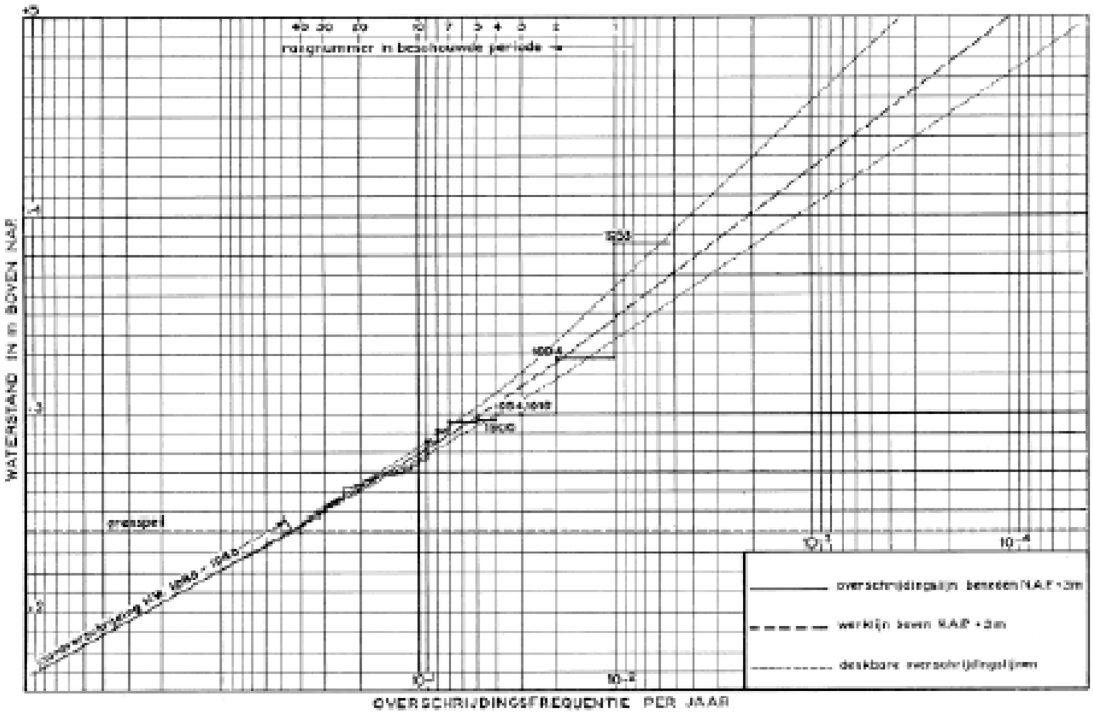
The development of the Dutch Flood safety strategy

Mark Z. Voorendt*



December 11, 2015

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THE DEVELOPMENT OF THE DUTCH FLOOD SAFETY STRATEGY

- technical report -

Mark Z. Voorendt

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Cover page: graph from the Delta report, part 1 (1960)

PREFACE

This technical report has been developed as part of my research on the 'evaluation of multifunctional flood defences'. The research is part of the programme on 'integral and sustainable design of multifunctional flood defences' which is subsidized by and being carried out in commission of the Dutch Technology Foundation STW. This programme is one of the 'perspectief' programmes that are organised within consortia of research institutes and users. The research programme consists of several projects in which various aspects of multifunctional flood defences are dealt with. These include technical aspects (strengths and loads), safety philosophy, governance, architecture and financial aspects. For details of the programme, one is referred to the project proposal (see the information on www.flooddefences.nl).

The current project on structural evaluation is being carried out under supervision of promoter prof. drs.ir. Han Vrijling and with help from ir. Wilfred Molenaar, dr.ir. Jarit de Gijt and dr.ir. Klaas Jan Bakker, all working at Delft University of Technology. The research project is externally supported by Witteveen+Bos (especially ir. Paul Ravenstijn and ir. Gerben Spaargaren), Arcadis (dr.ir. Marco Veendorp and dr.ir. Hessel Voortman), Deltares (dr.ir. Meindert Van, ir. Han Knoeff and ir. Harrie Schelfhout) and STOWA (ir. Henk van Hemert). I also got much support from many (other) employees of the Department of Hydraulic Engineering of Delft University of Technology, especially prof.dr.ir. Bas Jonkman, prof.dr.ir. Matthijs Kok, prof.dr.ir. Marcel Stive, ir. Ad van der Toorn, ir. Henk Jan Verhagen, dr.ir. Paul Visser. All their support is highly appreciated! Especially Henk Jan Verhagen is acknowledged for critically reviewing this report.

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Mark Voorendt
Delft, December 11, 2015

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1

Introduction

The Netherlands are located in a deltaic area where the rivers Rhine, Meuse, Scheldt and Ems flow into the North Sea. Rivers, sea and land formed a dynamic system, which ever more interfered with the intentions of the inhabitants of the low countries for spatial occupation. Without protective measures the inhabitants of the low countries had to cope with regular floods and resulting loss of lives and goods. The first inhabitants of the Frisian land (in the north of the Netherlands) settled down on higher plains, but this came to an end when, due to climate change, these plains became flooded ever more frequently.

In the first century AD Pliny the Elder, a Roman author and natural philosopher visited the Netherlands and characterised a pitiful country, where

> *... two times in each period of a day and a night, the ocean with a fast tide submerges an immense plain, thereby the hiding the secular fight of the Nature whether the area is sea or land. There this miserable race inhabits raised pieces ground or platforms, which they have moored by hand above the level of the highest known tide. Living in huts built on the chosen spots, they seem like sailors in ships if water covers the surrounding country, but like shipwrecked people when the tide has withdrawn itself, and around their huts they catch fish which tries to escape with the expiring tide. It is for them not possible to keep herds and live on milk such as the surrounding tribes, they cannot even fight with wild animals, because all the bush country lies too far away.* (Gaius Plinius Secundus, 78)

As a result of the floods, from the sixth century before common era, most people moved south to the Drents Plateau, or they started to create dwelling mounds, to elevate their dwellings to a height less prone for floods. Incidentally more rigorous measures were attempted: already in the first or second century BC, at the Frisian town of Peins (in the municipality Franeker), a dike was constructed of which a 40-meter section has been discovered. These soil structures, however, could not prevent the regular flooding of large areas of land. Around 1000 AD, dikes started to be constructed on a larger scale. Monks were responsible for the construction of these dikes, among others those of the monastery of Aduard, in the Dutch province of Groningen (Bosker, 2008).

The obligation to maintain dikes had already been regulated in the Middle Ages: regulations for farmers and landlords were established in farmstead systems (*verhoefslagstelsels*), by-laws (*keuren*) and ledgers (*leggers*)[1]. These regulations were later on incorporated by the water-boards, which were made responsible for the supervision of the flood defences. By-laws and ledgers are legal documents up to present date. The by-law of a water-board is a collection of legal regulations applying to rivers, brooks, ditches and flood defences that are administered by the water-board, but also by other parties. These regulations are complementary to the present Water Act.

This technical report sketches the main development of the flood defence system in the Netherlands. It concentrates on the establishment of the flood safety level and flood risk reduction strategies. First developments in the study of loading and soil properties until 1960 are described in Chapter 2. The storm surge of 1953 accelerated the process towards a more scientifically based approach. The philosophy of the Delta Committee is explained in Chapter 3. After the publication of the Delta Report in 1960, it lasted until 1996 until the policy was incorporated in a law. The developments in this period are described in Chapter 4 and the legislation of the safety standard can be found in Chapter 5. Newest developments are described in Chapters 6 and 7.

[1] Ledgers are legal documents that contain information on the functional requirements and maintenance duties regards hydraulic works like water courses, flood defences, catchment areas and corresponding structures. They also contain specific information on the status of channels and flood defences, dimensions and shapes of hydraulic works, position and dimensions of maintenance strips and protecting zones along water courses and flood defences (Website Waterschap Brabantse Delta, 2012)

heights upon local circumstances and experience (van der Ham, 2003a).

Pieter van Bleiswyk, who became grand pensionary (*raadspensionaris*) of Holland, wrote his dissertation at Leiden University in 1745 in Latin language (the original title was *Specimen Physico Mathematicum inaugerale de Aggeribus*), which is the first dissertation that we know of treating the design of dikes on basis of a scientific approach. Van Bleiswyk reasoned that the acting water pressure should be resisted by a reactive load from the soil body, equal in magnitude but opposite in direction (van Bleiswyk, 1778). He, however, at that time did not have knowledge of the numerical relationship between vertical and horizontal soil pressures. His work was of high importance to the awareness of the people involved in the design and maintenance of dikes. However, the Latin language was an obstacle for many people, so dr. Jan Esdré translated this work into Dutch and gave it the title *Natuur- en wiskundige verhandeling over het aanleggen en versterken der dyken* (Physical and Mathematical dissertation on the construction and reinforcement of dikes) and expanded it with clarifications and exemplifications. This work was published in 1778. Some illustrations of this work are depicted in Figure 2.1.

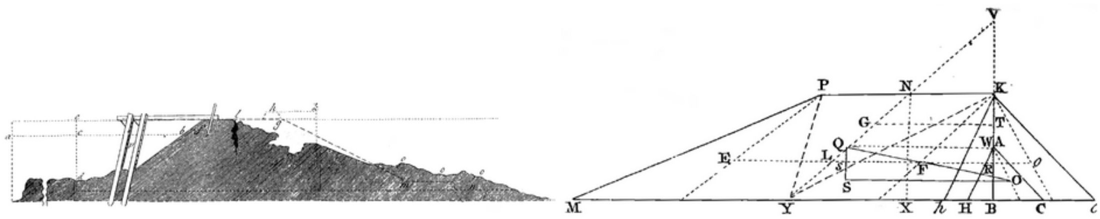

Figure 2.1: Two illustrations form the dissertation of van Bleiswyk (1778)

It was the French engineer Charles Augustin de Coulomb who developed an advanced theory to quantify horizontal soil pressures. In 1773 he addressed the Academy of Science in Paris with an essay *sur une application des regles des maximis et minimis a quelques problemes de statique relatifs a l'architecture*[1]. He introduced the concepts of active and passive soil pressures (Coulomb, 1776). At that time, the friction concept was known thanks to engineers like Sébastien de Vauban, Pierre Bullet, Bernard de Bélidor and Pierre Couplet des Tortreaux. Coulomb added the cohesion term. Later on, the theory has been expanded by William Rankine for soil at motion, by J. Jaky for soil at rest and by Müller & Breslau for soil adjoining inclined walls (Rankine, 1857), (Jaky, 1948), (Müller-Breslau, 1906). Also further developments in the study of soil mechanics in the Netherlands, boosted after a train accident in Weesp, advanced the knowledge on dike design[2].

Improvement in the estimation of loading was achieved by studying the characteristics of water loads. Mathematicians like Daniel Bernouilli, Leonhard Euler, Jean-Baptiste le Rond d'Alembert and Pierre-Simon Laplace reached results in the field

[1] 'On the application of the rules of maxima and minima to certain statics problems relevant to architecture.'

[2] In 1918 a passenger train derailed near Weesp, because of liquefaction of the railway embankment towards the Amsterdam-Rijn canal over a length of 95 metres. This was caused by the extensive rain in the preceding time and the poor state of the railway dike.

of hydrodynamics that are relevant up to present date. These results, however, were purely mathematical and had major restrictions for the application to real problems. Hydraulicians like Antoine de Chézy and Robert Manning (flow resistance in pipes) and Henry Darcy (groundwater flow) obtained more useful results, albeit using empiric methods.

In the twentieth century, theory and empiricism were better combined, initially by model tests where certain aspects could systematically be studied. The relation between scale models and reality was further studied by scientists like Froude, Reynolds and Mach. Professor Jo Thijsse propagated scale model tests and he was the first director of the Dutch Hydraulic Laboratory (founded in 1927). Ir. Johan van Veen, who was employed at the Study Department of Estuaries, Lower Rivers and Coasts (*Studiedienst van de Zeearmen, Benedenrivieren en Kusten*), of *Rijkswaterstaat* (the Dutch governmental agency for public water works, *RWS*), studied sedimentation and sand transport, but later also tidal movements for which he developed a new calculation method (Vreugdenhil et al., 2001), (van der Ham, 2003a). In some special cases, these tests could be simulated by simple calculation models. It also appeared possible to apply knowledge from other disciplines, specifically the analogy of electrical currents through a network. It was namely Hendrik Antoon Lorentz who applied and improved this analogon for hydraulic engineering. He schematised the Waddenzee and Zuiderzee as a system of tidal channels and applied the one-dimensional flow models of Saint-Venant and the quasi-linear system of partial differential equations of Riemann (Lorentz, 1926). Lorentz, together with Thijsse also replaced the quadratic hydrodynamic friction by a linear friction. In this way Lorentz derived the long-wave equations for tidal movements in shallow water.

Further study of the characteristics of water loads was carried out for the construction of the Closure Dam (*Afsluitdijk*) which is described in the following section.

Uncertainties in loading and resistance have to be dealt with in a technical design, which results in a certain reliability (safety) of flood defences. The desired reliability, or safety level, of a flood defence system can be estimated on a scientific base, called a safety philosophy. The description of the establishment of the Dutch safety philosophy is the object of the remainder of this report. Theoretical backgrounds are not explained in this technical report.

2.2 THE FIRST HALF OF THE TWENTIETH CENTURY

Because of the ever extending scientific knowledge, the design of flood defences has been much improved over the last century in the Netherlands. Two major floods have boosted the developments: the flood of 1916 and the flood of 1953.

The first event, the flood of 1916, prompted construction of the Closure Dam (which was completed in 1932). A scientific approach was chosen for the design of this dam: A study of tidal currents and the influence of the planned dam has been conducted by professor Lorentz. Also wave overtopping has been further analysed at that time. The Lorentz committee still based the crest height of the *Afsluitdijk* on the highest observed water level, based on experience. This only changed after the floods of 1953, when the Delta Committee reported on a method to base the required crest hight of flood defences upon statistics of water levels, which was the base for the design of the Delta Works and other flood defences in the Netherlands.

Meanwhile, in 1920, *Rijkswaterstaat* had found that also the condition of coastal defences in South-Western Netherlands was not satisfactory: The dikes were not high and stable enough to protect the land in case of a North-Western storm in combination with a spring tide. Later that same year the closure of the estuaries was proposed as a solution. This would namely shorten the coast line considerably, which would much better protect the land against high water levels and meanwhile counter the intrusion of salt water (van de Ven, 1993).

The committee that had studied the storm surge of 13 and 14 January 1931, assumed that the highest observed wind set-up of 2,80 m at Hoek van Holland was the highest possible and that an according water level of NAP + 3,40 m at Hoek van Holland should be taken into account. The probability in a year that this level would be exceeded was estimated at 1/68. The committee based this conclusion on measurements during 30 years (1887-1917), see figure 2.2, where a double linear scale was used (van de Sande Bakhuyzen et al., 1920). Later on, with help of statistical analyses of water level measurements, higher levels appeared possible.

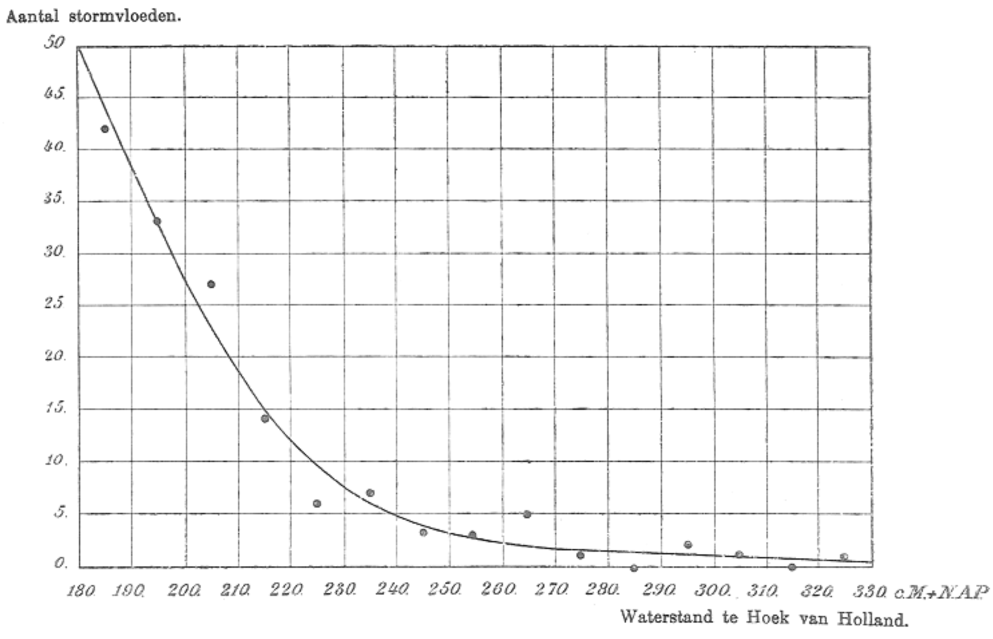

Figure 2.2: Storm occurrences between 1887 and 1917 at Hoek van Holland (van de Sande Bakhuyzen et al., 1920)

In 1939 Johan van Veen, a well-known Dutch hydraulic engineer working for the Dutch ministry for water works (Rijkswaterstaat), wrote an alarming report about the state of the Dutch South Western Delta. He stated that the storm surge levels could be much higher than had been assumed until then. His employee ir. Pieter Wemelsfelder studied the statistical patterns of storm surge levels, which he was able to extrapolate to extreme values. After he had published his alarming findings in De Ingenieur, 3 March 1939 (Wemelsfelder, 1939), the Storm Surge Committee (*Stormvloedcommissie*) was instated to estimate future possible water levels in the lower river areas.

Wemelsfelder had analysed registrations between 1888 and 1937, in which period 35 287 high water levels were measured. Wemelsfelder only considered high waters above the mean level of NAP + 0,88 m, about 17 500 measurements, because the lower values have no meaning in this respect. He calculated per water level (with steps of 0,10 m) how many times on average that level was exceeded per year. He drew the result in a graph on logarithmic scale to better include the very low numbers corresponding to high values of extreme water levels, see figure 2.3, line A. In line B a correction was done for succeeding measurement points that are co-related by the same storm event. For higher water levels both lines coincide.

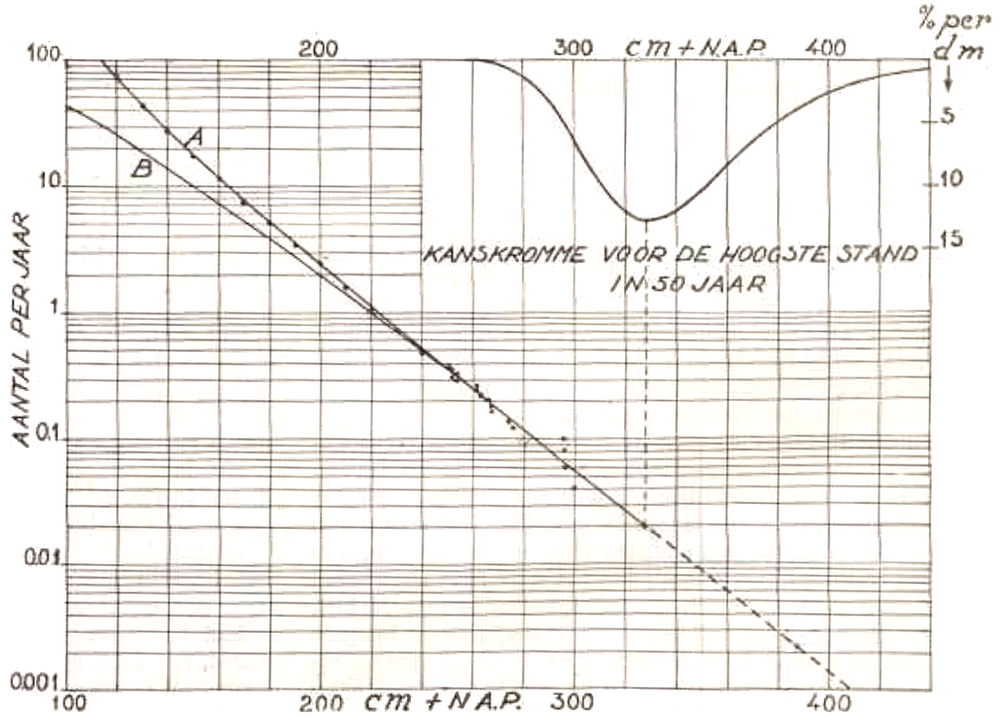

Figure 2.3: The relation between high water level and occurences per year, as found by Wemelsfelder (1939)

Wemelsfelder assumed a logaritmic relation between exceedance frequency and water level and was able to find a mathematical expression for the probability of exceedance. With this article Wemelsfelder demonstrated that higher water levels were much more likely to occur than assumed until then. For instance, if one would be sure for 90% that a structure resists the occurring water levels, it should be dimensioned for an extreme water level of NAP + 4,08 m and not NAP + 3,28 m, which was at that time the highest known water level for Hoek van Holland.

With help of his statistic relation, by the way, Wemelsfelder was also able to define a 'storm surge level'. Storms are related to wind speeds of 8 or more on the scale of

Beaufort. These speeds occur with an average frequency of 0,5 per year. With help of the found relation between exceedance frequency and water levels, the corresponding water level, i.e. the storm surge level, can be found. Consequently, the likelihood of occurrence of a storm surge in a certain year can be calculated.

Based on the analysis of Wemelsfelder, the Storm Surge Committee estimated the boundary conditions applying to flood defence structures for the year 2000 AD, accepting water levels that could be exceeded with a frequency of 1/300 per year. These storm surge levels were considerably higher than the observed levels until then. For Hoek van Holland the design storm surge level was thus estimated at NAP + 4,00 or NAP + 4,05 m, while the highest observed level was NAP + 3,28 m. The committee also calculated design crest height of dikes further away from the coast. These design heights would have required reinforcement of many of the present dikes, unless it would have been decided the close-off estuaries.

The Storm Surge Committee made some reservations regarding their calculations, because of uncertainties that were not yet resolved. The design levels of the Committee were nevertheless used for new dikes and existing dikes that had to be reinforced in Noord-Brabant since 1940. It indeed appeared that the crest height had to be increased considerably.

Plans were also made and executed for the closure of some branches of the lower rivers and estuaries. For example, the Brielse Maas and the Botlek were closed-off (realised in 1950). The purpose of these early closures was predominantly to reduce salt intrusion from sea (Deltacommissie, 1960b).

In its 1942 report, the Storm Surge Committee concluded that most dikes in the Northern delta area were indeed unreliable. Two years later it also appeared that most dikes in Zeeland were too low. It is often said that due to the Second World War not much was done to improve the flood safety situation in the coming years[3]. Van der Ham however mentions that *Rijkswaterstaat*, water boards and local authorities were very well aware of the bad conditions of the flood defences, but had refrained from acting adequately. In 1946, now in a secret document 'Overview Main Flood Defences of Zeeland', *Rijkswaterstaat* again reported that almost 60 kilometres of dike did not meet the requirements and some very weak spots had a height deficiency of 1,30 metre (van der Ham, 2003b), (van der Ham, 2007).

Unfortunately, as often, a disaster had to occur before action was taken to improve the bad condition of the flood defences. This is described in the following chapter.

[3]The closure of the gaps in the sea dikes of Walcheren, made in 1944 by allied forces to inundate this island as a military strategic measure, was a major challenge which took away the attention from other weak spots that had not yet led to failure.

3

PHILOSOPHY OF THE DELTA COMMITTEE

On 1 February 1953 a storm surge caused 67 dike breaches in the South Western part of the Netherlands, resulting in the flooding of 165 000 hectare of land. As a result more than 72 000 individuals had to be evacuated, 1836 individuals perished[1] and the economical losses amounted 1,5 billion guilders in the Netherlands[2]. This disaster resulted in a renewed awareness of the dynamics of living in an estuarine area. Per 18 February 1953 already a state committee had been appointed by the Minister of Transport, Public Works and Water management, mr. Algera (the Storm Surge Committee was meanwhile implicitly abolished because its secretary, Johan van Veen, had been dismissed from this function by a rivalling director-general). This 'Delta Committee' advised the minister on the measures that were needed to prevent future flood disasters[3].

The Delta Committee, according to its assignment, studied what flood safety level should be established and how this should be accomplished. The committee gave its first advices in May 1953, giving answer to the 'how' question: to heighten the dike of the island of Schouwen and to close-off the Hollandse IJssel with a storm surge barrier. Later on, the committee advised to close off the Eastern Scheldt, the Grevelingen estuary and the Haringvliet as well. The next advice comprised the execution of the 'Three Islands Plan': the connection of Walcheren, Noord- and Zuid-Beveland by damming of the Veerse Gat and the Zandkreek. The fifth and last advice, presented in 1957, contained further considerations on the closure of the estuaries. The advices were formalised in the Delta Act of 1958, after approvement of Dutch House of Representatives (*Tweede Kamer der Staten-Generaal*) and the Senate (*Eerste Kamer der Staten-Generaal*) and signing by Queen Juliana[4].

[1] The storm also caused casualties outside the Netherlands: 307 in the United Kingdom and 22 in Belgium.

[2] The Delta Report mentions an amount of considerably more than 1,1 billion guilders. 1,5 billion guilders is mentioned by (Toussaint, 1998). Van Dantzig mentions 1,5 to 2,0 billion guilders (van Dantzig, 1956).

[3] The dike breaches were closed and the flooded land was reclaimed and drained before the winter of 1953/1954 commenced

[4] The Delta Act fell due on 28 September 2005 and was succeeded by the Act on the Flood Defence of

The committee followed three steps in its reasoning to find an acceptable safety level:

1. A study of high water levels in the past;
2. A study to find what storm surge levels can be expected in future;
3. The execution of a cost-benefit analysis to find an optimum between investments in flood protection and obtained risk reduction. This leads to a desired design crest height of flood defences.

These steps are explained in more detail in the following sections.

3.1 Step one: Historical study of water levels

The first step of the study of the Delta Committee was to find the highest storm surge level reached in the past. The storm surge of 1953 reached a level of NAP + 3,85 m at Hoek van Holland, which was the level of the normal astronomical tide (NAP + 0,81 m) plus a 'storm effect' of 3,04 m. The 1953 storm surge level was considered to have an average exceedance frequency of about 1/250 per year[5].

It appeared that the water level of the 1953 storm surge exceeded all recorded water levels until then. The top level of 1953, NAP + 3,85 m, exceeded the second-highest level of 23 December 1894 (NAP + 3,28 m) with more than half a metre. The most severe storm surge since 1800 occurred on 4 February 1825, when an area of 370 000 m^2 was flooded, almost three times as much as in 1953. The maximum water level at Hoek van Holland in 1825 is not known, because no measurements were done there at that time, but the committee concluded that it can be assumed for sure that a storm surge like in 1825 would not have reached the level of 1953 (even if the sea level rise since 1825 would be taken into account)[6].

It turned out to be difficult to find out whether storm surges that occurred earlier than in 1825 were more severe than in 1953. Extensive description of the floods of 1421 (Saint Elisabeths Flood), 1570 (All Saints Flood), 1686 and 1775 are available, but water levels were not measured at that time. The committee, yet, did not have the impression that these water levels exceeded the level of the storm surge of 1953.

The circumstances during that storm surge, however, could have been worse. In the Delta Report it is mentioned that more unfavourable circumstances could have caused an additional water level elevation of 1,15 m. An internal note of Bart van der Pot of the Dutch contractor HBM explains that this 1,15 m consisted of four components (van der Pot, 1977):

1. The main contribution to this additional elevation comes from the astronom-

21 December 1995.

[5] Mentioned frequencies are: 1/222 per year (Deltacommissie, 1960a), 1/250 per year (RWS and KNMI, 1961) and 1/300 per year (Deltacommissie, 1960a)

[6] For Texel, almost 200 km North of Hoek van Holland, the levels of 1825 and 1953 were comparable, but there they were considerably lower than in Hoek van Holland.

ical tide: 0,44 m should be added to the water level reached in 1953 because it was not as high as it could have been during the storm surge. Two days before the storm surge (i.e., on 30 January 1953, 0:44 h) it was full Moon, which caused spring tide in Zeeland with a delay of about $2\frac{1}{4}$ days. This means that on 1 February 1953 a spring tide occurred in Zeeland, but it was not an extremely high one. This was caused by the distance between Moon and Earth, which was maximum on 1 February 1953 (the Moon was in its so-called apsis) so the gravity of Moon and Earth was minimal.
2. The water level could have been an additional 0,30 m higher, if the course of the storm depression of 1 February 1953 would have been the most disadvantageous for the water levels along the Dutch South-Western coast.
3. If the maximum wind set-up would have coincided with the astronomical tide, the water level would have been another 0,21 m higher.
4. Resonance of the maritime basin, finally, could have worsened the case with 0,20 m.

These effects, which could have aggravated the disaster, are presented in table 3.1.

Effect	**Resulting elevation**
maximum tide	0,44 m
'optimal' course of the depression	0,30 m
coincidence of max wind set-up and astronomical HW	0,21 m
resonance of the maritime basin	0,20 m
total	1,15 m

Table 3.1: Additional effects that could have raised the extreme water level at Hoek van Holland in 1953

Adding these 1,15 m to the reached level of NAP + 3,85 m at Hoek van Holland, this results in the 'basic level' of NAP + 5,00 m, which was finally chosen as a starting point for the Delta Committee. This level was calculated excluding effects of future closure dams and other interventions, and also did not include effects of chart datum subsidence or water level fluctuations of short periods.

RWS and KNMI (1961) describe that the discharge of the rivers Rhine and Meuse was lower than the usual winter average: only 67% of the average Rhine discharge (measured at Lobith) and 80% of the average Meuse discharge (near Lith). This implies that the water level of the lower rivers could have been higher than in 1953. If the storm surge op 1 February would have coincided with the high discharge of 1941, the river levels would have been 0,13 to 0,50 m higher, depending on the location. For Hoek van Holland, however, this river level elevation is not of any influence as the water levels were measured at sea.

The physical approach described in this section, however, is criticised because any of the parameters that together constituted the 'storm effect' might have been still more unfavourable. The Royal Dutch Meteorological Institute (textitKoninklijk Nederlands Meteorologisch Instituut, KNMI) carried out studies that showed that considerably higher storm surge levels are physically possible. In fact, it appeared that it would not be possible at all to predict a water level that cannot be exceeded.

3.2 STEP TWO: STATISTICAL ANALYSIS

As a second step, the Delta Committee tried to estimate what storm surge levels could be expected in future. As already told above, in 1939 Johan van Veen, and his employee ir. Pieter Wemelsfelder found that the storm surge levels could be much higher than had been assumed until then. In the statistical approach of Van Wemelsfelder, it is acknowledged that no maximum storm surge level can be found, but the likelihood of exceedance decreases considerably with the height of the water level. The exceedance frequency of extreme water levels could be found by extrapolation of a series of water level measurements, far beyond the observation range. It should be mentioned here that the measuring period considered by Van Wemelsfelder was long compared to other countries in the world, but it was not long enough to obtain a good accuracy for modelling the tails of the water level distribution over time.

Like already explained in the previous section, the Delta Committee assumed a water level of NAP + 5,00 m at Hoek van Holland as a basic level for further considerations. To find the corresponding exceedance frequency of this basic level, extrapolation of the found trend was necessary. Because of the uncertainties of the course of this line above NAP + 3,00 m, the Delta Committee had asked the Mathematical Centre in Amsterdam, with help of the Dutch Meteorological Institute, to assist. *Rijkswaterstaat* meanwhile started studying the problem. The water level records of *Rijkswaterstaat* between 1888 and 1956 were studied by the Mathematical Centre (represented by David van Dantzig) with aid of the Royal Meteorological Institute for making the selection of relevant data. Van Dantzig found that the disadvantage of the approach of Van Wemelsfelder (inaccurate modelling of the tails of the distribution) could be resolved by assuming an extreme value distribution of the water level, like the exponential distribution.

For the statistical analysis data of all storm surges with a wind set-up during high water of 1,60 m near Hellevoetsluis were selected from the complete data set. This was followed by a reproduction of the related weather conditions and depression lanes. In this way the area, or 'window', above the North Sea in which all these depressions passed could be estimated. Hoek van Holland was consequently chosen as a representative station for the Netherlands, insofar as it concerns the behaviour of severe storm surges. Then a selection was made of the high water levels at Hoek van Holland with a wind set-up of minimal 0,50 m and a depression lane through the corresponding window. These conditions were considered to be a potential threat. Then the data set was restricted to the months November, December and January because of reasons of representativeness and only one measurement point was included per storm surge. This set of selected data was extensively analysed by the Mathematical Centre. It advised to use an exponential distribution with a exceedance frequency line that intersected a water level of NAP + 5,13 m at a frequency of 10^{-4} per year.

After the Mathematical Centre had presented its results, the Delta Committee consulted representatives of this institute and the Department of Water Management (*Directie Waterhuishouding en Waterbeweging*) of *Rijkswaterstaat*. It was agreed upon to assume a work line as indicated in figure 3.1: the thick line, whith a bend at around NAP + 3,00 m. This graph shows the highest 30 storm surges plus the 40th surge. The relation between exceedance frequency and water levels is given by an exponential function (in accordance with the study of Wemelsfelder (1939)) which results in a straight line when plotted on a logarithmic scale like in figure 3.1.

It should be noticed that there is a bend in this line, just above NAP + 3,00 m. The Delta Committee justifies this in its report by stating that notwithstanding the fact that there are arguments to assume that the exceedance line above NAP + 3,00 m could deviate to lower water levels than indicated by a straight line (downward deviation), that assumption was not supported by measurements. On the contrary, a deviation towards higher water levels was considered more likely, because of some highest measurement points. The presence of these highest measurement points was statistically not demonstrable, but if a larger class of distributions would be used as a base for the adoption of a exceedance line to the measurements, a considerable upward deviation would be obtained (Deltacommissie, 1960b). Van Dantzig gives a possible explanation for the bend: he suggests that the highest storm surges are caused by storms of a different type than lower surges, which could cause a kink in the trend line (van Dantzig, 1956). Due to all uncertainties, the Delta Committee warned to use the exceedance graph only with 'great caution' (Deltacommissie, 1960a).

After having initially agreed upon the workline as indicated in figure 3.1, the Mathematical Centre did some further calculations, resulting in higher levels than NAP + 5,00 m for an average exceedance frequency of 10^{-4} per year. After some more discussions with *Rijkswaterstaat* the Centre finally stated that it considered the level of NAP + 5,00 m 'not entirely unacceptable', though on the low side, as an estimate for the entirely statistically determined height with an exceedance frequency of 10^{-4} per year.

It should be noticed that the relation between water level and exceedance frequency was found with help of measurements during long periods, but the reached level in 1953 was not included in this calculation. This omission is in line with the remark of Wemelsfelder, that 'the generic shape of a frequency curve should not include the highest, the one but highest and the two but highest levels' (Wemelsfelder, 1939). The highest measurements, namely, cannot be expected to be situated on the frequency curve, because the distribution of measurements becomes wider if the frequency decreases (Deltacommissie, 1960a).

The question then was what exceedance probability would be suitable as a criterion. Any chosen criterion is bound to be subjective, but anyway the Delta Committee preferred to include possible flood consequences in the estimation of an acceptable safety level. The committee considered a probability that an individual would die because of a flood reasonable, if this was 1% in a lifetime, or approximately 1% per 100 year. This is the exceedance probability that corresponds with the level of NAP + 5,00 m at Hoek van Holland according to the exceedance line preferred by the Delta Committee (Deltacommissie, 1960a) (Valken and Bischoff van Heemskerk, 1963).

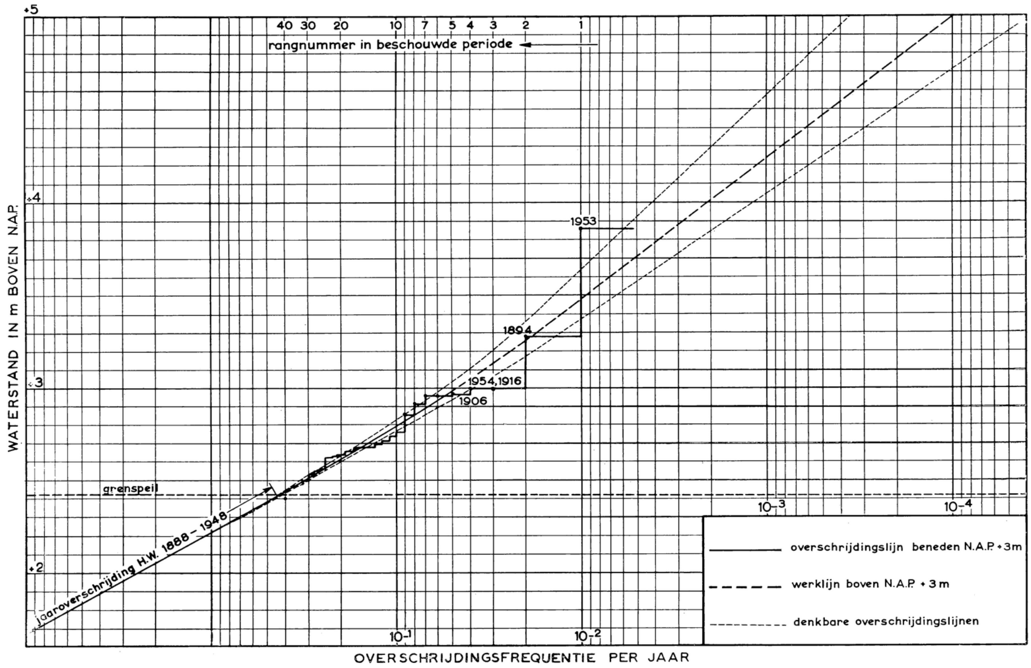

Figure 3.1: Water level exceedance line at Hoek van Holland from measurements between 1859 and 1958 (Deltacommissie, 1960a)

In 2014, Henk Jan Verhagen of Delft University of Technology performed an analysis of 150 years of storm surge data at Hoek van Holland (from 1863 to 2013). He used the Peak over Threshold method with a lower boundary of NAP + 2,25 m, assuming an exponential distribution. Subsequent peaks that were obviously related by the same storm event were reduced to single data points. All data were corrected for a relative sea level rise of 0,22 m per century. Assuming a straight line through these points, plotted in a log-linear graph, the 1953 storm appears to have an exceedance probability of 1/390. The water level corresponding to an exceedance probability of 1/10 000 appears to be slightly less than NAP + 5,00 m, namely about NAP + 4,84 m (figure 3.2.

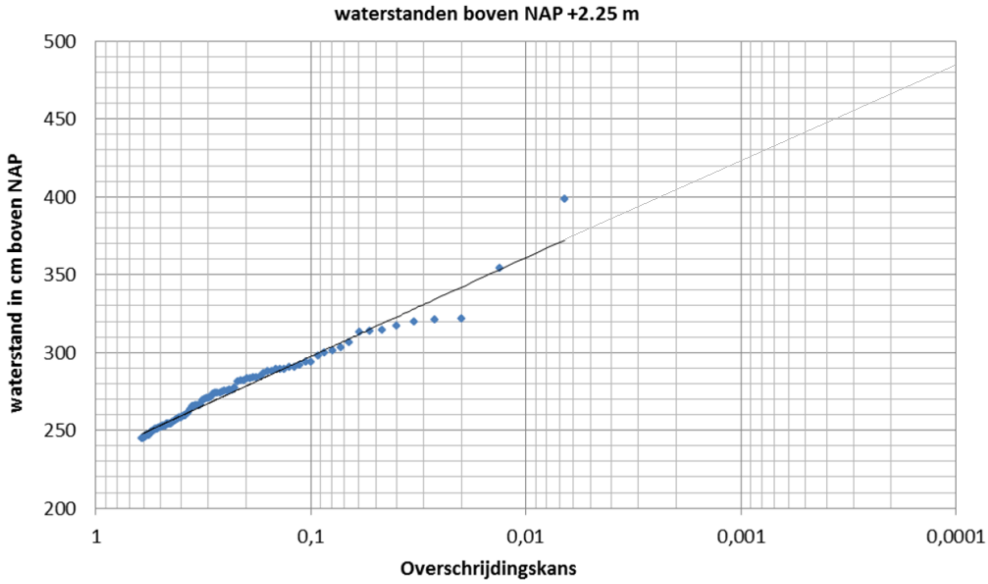

Figure 3.2: Water level exceedance line at Hoek van Holland from measurements between 1863 and 2013 (Verhagen, 2014)

3.3 STEP THREE: ECONOMETRIC OPTIMISATION

Because the selection of a design level on basis of physical or statistical considerations appeared to be necessarily subjective, it was attempted to approach the problem on a joint economic and statistical basis. The Delta Report therefore contains an econometric calculation, in which investments in protective measures are balanced with the therewith obtained flood risk reduction[7]. This is the third step in the approach of the Delta Committee. The backgrounds were delivered by a contribution of Van Dantzig and Kriens (Deltacommissie, 1960a).

To estimate the risk reduction, Van Dantzig used the estimate of the Central Bureau for Statistics (*Centraal Bureau voor de Statistiek, CBS*) of $24 \cdot 10^9$ guilders for capital goods and sustainable consumptive commodities in central Holland (dike ring 14)[8]. This value was the magnitude of the consequences of a flood in case of complete loss of capital goods. Not included in this value were production deprivations and to a much lesser extent also losses of infrastructure administered by the national authorities were left out. Social disruption and loss of lives were also not taken into account. On the other hand, there were also some over-estimations made in the econometric calculation: they consisted of partially preserved commodities in higher situated areas and partial preservation of productivity of the population. The net effect of this over- and underestimation was that no adjustment in the estimation of the economic value of the area was done.

By suitably varying the elements of uncertainty, it appeared possible to find maxi-

[7]For the obtained risk reduction the Committee considered the present value of the imaginary insurance premium that would be required to cover the remaining flood risk for the area behind the flood defence.
[8]In 2005 it was estimated at $290 \cdot 10^9$ euro (Rijkswaterstaat, 2005).

mum and minimum values for the combined costs of dike reinforcement and consequences per design level. The according lines can be found in figure 3.3. The real economic optimum lies somewhere between these two lines. The intermediate design level can be chosen as the optimum in such a way that the deviations from both lines are equal (indicated in the figure by $a_2 = b_2$). This will minimize the deviation from the real economic optimum as much as possible.

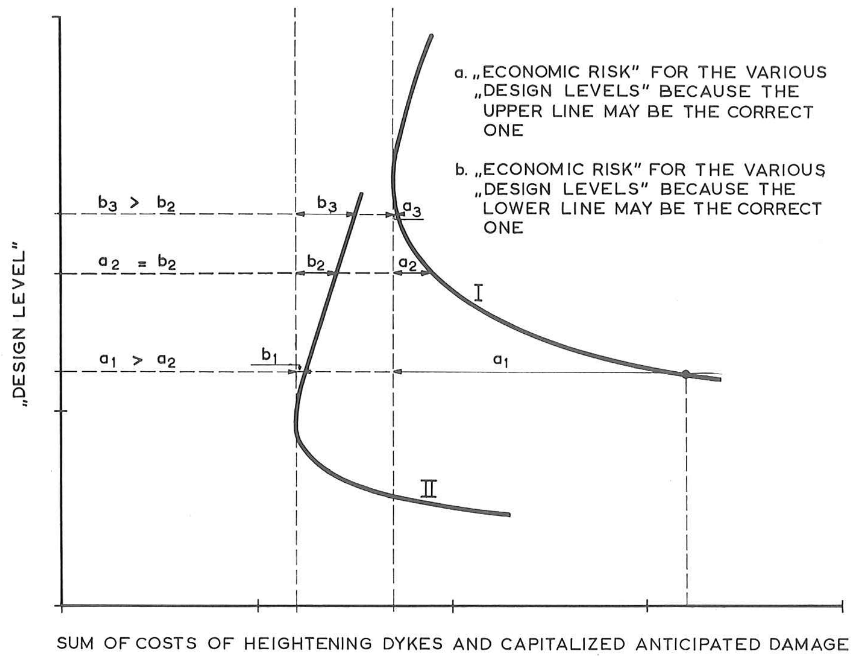

Figure 3.3: Minimum and maximum economic optimum (Valken and Bischoff van Heemskerk, 1963)

It was then calculated by Van Dantzig that if the complete economic loss would occur with a probability of failure in a year of 1/125 000, it would balance with the investments in risk reduction by flood protection, which were estimated 150 million guilders per year (net present value). After application of these dike reinforcement measures the flood risk, defined as the probability of occurrence of a flood in a year multiplied with the insured value, was estimated at 13,5 million guilders. This corresponds with a design water level of NAP + 6,00 m at Hoek van Holland, called the disaster level (*ramppeil*).

The calculations to find this optimum protection level, however, contain many uncertainties. To start with, only a tentative estimation could be made of the costs of reinforcing dikes on an extensive scale, constructing new dikes and carrying out other flood protection projects and of the capitalized expenditure of maintenance. Also the magnitude of possible consequences of a flood was extremely difficult to estimate. This was caused by the fact that economic developments had to be forecast, but also by the big differences in impact of floods. Furthermore, the selected rate of interest is an uncertain factor for the capitalization of the margin of damage. Yet, the uncertainties of extrapolation of the frequency curves are much bigger. Next to that, also the selection of the critical failure mechanism (wave run-up / overflow) introduces uncertainties because many factors are then not taken into account (for instance those connected to dike construction). It was borne in mind that the population would grow, as well as economic development and numerous other imponderables (such as human suffering, loss of life, and disruption of daily life) (Valken and Bischoff van Heemskerk, 1963).

Van Dantzig was reluctant to express the value of human life in monetary units, because of ethical reasons. He considered to make a comparison with investments that were made in society to reduce other kinds of risk, or to look at the insurance benefits in case of loss of life, but these ideas appeared to lead to unacceptable or insignificant results. So, Van Dantzig refrained from quantifying the value of human life. The same applies to cultural values. To nevertheless somehow include non-economical values, the Van Dantzig proposed to multiply the total economic value of a protected area with a factor to include not-economic values. He considered a multiplication factor of 2 'certainly not too high'.

The economic considerations mentioned in this section would be valid if a large number of risks could be insured on this basis. This, in fact, is not applicable to the present case and the next flood will have a considerable influence on the outcome of the calculations. This is one of the weakest points of these econometric calculations. Notwithstanding the somewhat arbitrary outcome of the econometric approach, it gives a more insight in the involved factors than the previous described steps alone (Valken and Bischoff van Heemskerk, 1963).

The Delta Committee, at the end, did not support the outcome of the advice of Van Dantzig: Due to lacking numerical insight in failure mechanisms it appeared impossible to determine the probability of failure of a dike. It also appeared that the assumption of a disaster with complete loss of goods in case of exceedance of the design level was overdone. The Delta Committee also disagreed upon the way in which Van Dantzig included non-economical losses in his analysis. It did therefore not adopt the advice to multiply the economic losses with a factor two to account for the loss of lives, because it was already assumed that a dike failure would result in maximal damage (RIVM, 2004).

The committee finally made a switch from a *failure* probability criterion of 1/125 000 (with a corresponding disaster level of NAP + 6,00 m) towards an *exceedance* probability of 1/10 000 (and corresponding 'design level' of NAP + 5,00 m) at the reference location of Hoek van Holland. The committee did not adopt the disaster level as a design level, as proposed by Van Dantzig, because exceedance of the design level would after all not immediately result in maximum damage (Deltacommissie, 1960b). A difference of opinion had arisen between the Delta Committee and Van Dantzig, on exactly this issue. Van Dantzig stated that the committee would once regret its too low standard (RIVM, 2004). The committee admitted that a maximum storm surge level could not be estimated, so the probability of a disaster remains, what ever storm surge level would be selected as a base for reinforcement of primary flood defences. The committee recognised that other considerations could lead to higher safety standards, but it was of the opinion that flood risk should not be regarded isolated, but in relation to other types of risks. In that respect the committee considered the proposed base levels related to a 1/10 000 exceedance probability a acceptable limit for the risk of storm surges. Moreover, levels based on a 1/10 000 norm would obtain a safety level as much as 30 times higher than the storm surge level of 1953. (Deltacommissie, 1960b).

The Delta Committee thus found a probability that a water level would be exceeded in an arbitrary year of 1/10 000 acceptable. It was then, finally, calculated whether the investments needed to accomplish this safety level could be afforded by the Dutch state. The investments in flood protection for the first 20 to 25 years were estimated at 2,0 to 2,2 billion guilders in total, or 100 to 125 million guilders per year, assuming that construction works would take about 20 to 25 years. One year of investments equals about 10% of the economic damage caused by the storm surge of 1953, which can be afforded in a short term without severe disruptions. Compared to the total of 27,6 billion guilders of total national expenditures in 1955, the protection of the Netherlands at the indicated level would cost 0,5% of these expenditures, which was considered affordable and acceptable (Deltacommissie, 1960b).

3.4 BASIC LEVELS OUTSIDE HOEK VAN HOLLAND

The Delta Committee thus proposed the exceedance probability of 1/10 000 as the safety level for Holland. As was explained in the previous sections, this safety level was based on a mix of controlling both economical and death risks. The Delta Committee reasoned that a larger flood probability was acceptable for areas with less population density and higher ground levels (the north of the Netherlands) or smaller sub-areas (the south-western part of the Netherlands) and the West Frisian Islands. For the north and the south-western part of the Netherlands a 2,5 times higher exceedance probability was considered acceptable. Along the rivers also a higher flood probability was accepted, also because extreme river levels can be forecast well in advance (up to a few days), in contrary to coasts where storm surge levels can only be predicted a few hours in advance. Moreover, fresh river water causes less damage than salt sea water. Finally, river dike breaches are not exposed to scour due to tidal variations.

For the reference location of Hoek van Holland water level corresponding to the exceedance probability of 1/10 000 was NAP + 5,00 m, but this level differs along the coast and tidal inlets. *Rijkswaterstaat*, after consultation of the Mathematical Centre and the Dutch meteorological institute (KNMI) drew up exceedance frequency lines for various locations along the coast. The slope of the exceedance probability lines of stations at other locations than Hoek van Holland was assumed to be almost equal to the relation found for Hoek van Holland for the range between 10^{-3} and 10^{-4} per year. From these exceedance probability lines the basic water levels of these locations were derived. Design levels to be used for the determination of the crest level of flood defences are derived from these basic levels, taking into account whether or not a flood defence protects vital or extremely high economic interests. The design level could thus be higher or lower than the determined basic level (Deltacommissie, 1960b).

The Delta Committee had estimated the basic levels for a large number of measurement station along the Dutch coast, but recommended to determine these levels with more accuracy when more measurement data would be available. This additional study, carried out some 30 years later, resulted in a report that was published in 1993 (van Urk, 1993). For the renewed estimation of basic water levels the work method of the Delta Committee was applied in a fine-tuned way. Information of the water level measurements was interpreted now for all measuring station separately. Enough data were available now to also calculate the levels for the Western Waddenzee, instead of doing interpolations[9]. The result of this study was a lower set of basic levels compared to the Delta Committee report, especially for the western Waddenzee (for Hoek van Holland it did not change).

[9]The Delta Committee did not possess over long series of measurements for this area because of the construction of the closure dam for the Zuiderzee in 1932.

4

THE SECOND HALF OF THE TWENTIETH CENTURY

After the publication of the Delta Report in 1960 and the adoption of flood protection levels in the Dutch Law (Act on the Flood Defence) in 1995, some developments are worth wile mentioning. These developments are treated in this section. The following section will relate on how the Flood Defence Act of 1995 was composed.

In 1956, while the Delta Committee was drafting her report, also the safety standard for the Dutch rivers was being established. This was done on request of the Province of Gelderland, which had asked the Minister of Traffic and Water Management, mr. J. Algera, what the design level for river dikes had to be. In his reply letter of 1956 the Minster answered that for the Rhine a design discharge of 18 000 m^3/s at Lobith is considered very safe (which formulation implied that it did not have to be implemented too tightly). This was calculated using the same statistical method as the Delta Committee and the design level corresponded with an average exceedance frequency of 1/3000 per year (Algera, 1956),(RIVM, 2004),(Van Heezik, 2008). This safety level was maintained until 1977 when the Committee on River Dikes (*Commissie Rivierdijken*, also called the *Commissie Becht*, named after the chairman) came up with another safety level. Meanwhile, in the period between 1956 and 1977, the responsible authorities had not succeeded in improving the dikes up to level, which became apparent when the Committee on River Dikes had analysed that 450 km of river dikes did not comply to the 1/3000 norm (Yska, 2009).

This Committee on River Dikes was reinstated in 1975 to find out whether the design Rhine discharge of 18 000 m^3/s at Lobith needed to be revised for the design of flood defences along the rivers. The committee was also assigned to indicate how stakeholder participation could be optimised. These stakeholders become more influential due to societal changes. Next to flood protection, values of landscape, nature and culture ('LNC-values') had to be taken into account. These values came under the attention of policy makers since 1969 and from 1973 active protests were organised against dike reinforcements. Societal engagement was growing and civilians ever more intervened in governmental policy. For example, a group of students from

Utrecht squatted two dike houses as a starting point for the revolt against dike improvements. Several organisations were set-up to mobilise the population for protest manifestations (Yska, 2009).

The difficulties of the improvement of a built-on dike had become clear in Brakel and Sliedrecht in the 1970s, where simply removing houses and trees appeared not to be societally acceptable any more. Dike improvement in the town of Brakel along the Waal required the removal of 140 houses and the historical town hall. Because the scrupulousness of the municipal administrators was called in question, the inhabitants and pressure groups (like the *Stichting Natuur en Milieu*) organised opposition against the dike improvement plans that did not take LNC-values into account. Despite the fact that most of the plans to demolish the houses were carried out after all, the conflict of Brakel appeared to be a turning point.

Similar problems arose in Sliedrecht, along the Beneden-Merwede, where start has been made to systematically study non-traditional possibilities of improving multifunctional dikes (Huis in 't Veld et al., 1986). Dike improvements still appeared technically possible, but the entire process appeared much more complex than before. Protests appeared to be more successful than in Brakel. Reference is made to Voorendt (2015) for background information on the Sliedrecht project. The dissertation of Heems and Kothuis (2012) extensively describes societal developments and discourses related to flood protection in the Netherlands.

So, the Committee on River Dikes deliberately took LNC-values into account to find optimal solutions. It assumed that the failure probability of river dikes was equal to the exceedance probability[1] and used a cost-benefit analysis to compare three alternatives. This way of reasoning was called *uitgekiend ontwerp* (sophisticated design) and resulted in flood defences that just met all safety requirements. The Committee finally finally advised a design discharge at Lobith of 16 500 m^3/s with a corresponding average exceeding frequency of 1/1250 per year.

The draw-back of this sophisticated design was that accordingly constructed dikes did no meet the requirements any more after the slightest change of boundary conditions[2]. As a result, many of the just reinforced dikes failed the next official assessment. To avoid this problem, a robustness height surcharge is included nowadays in the calculation of the crest height of river dikes.

Ideas to integrate LNC-values in flood protection measures were further elaborated in Stork Plan (*Plan Ooievaar*) that appeared in 1987. The aim was to revive the complete biotic river system in relation to societal activities like agriculture, shipping, safety, mineral extraction and recreation. The plan was made by scientists of various disciplines[3]. Water retention and nature development were propagated in the river forelands and river courses should be restored as much as possible to their natural state. This plan was the start of a new thinking about rivers and could be conceived

[1] This differs from the Delta Committee, which assumed a factor of 12,5 between both probabilities.

[2] boundary conditions tend to become more severe: higher water levels, larger river discharges, higher waves.

[3] The authors were Dick de Bruin, Dick Hamhuis, Lodewijk van Nieuwenhuize, Willem Overmars, Dirk Sijmons and Frans Vera.

as a predecessor of the later ’Living Rivers’ and ’Room for the River’ projects.

Notwithstanding these plans to involve LNC-values in sophisticated flood defence design, not much had happened in practice. This, amongst others, was demonstrated by the fact that hundreds of trees were planned to be demolished for dike inprovements in Neerijnen along the Waal and Zutphen along the Gelderse IJssel, so tensions between dike reinforcers and LNC-activists persisted. For that reason in 1992 the Committee Assessment Starting Points River Dike Reinforcement (*Commissie Toetsing Uitgangspunten Rivierdijkversterking*) was established to again consider the safety standard, related to the changes in society. The chairman of this committee was C. Boertien and because he also chaired another committee, this committee is often referred to as the Boertien 1 Committee.The Boertien 1 Committee based its advice (the final report was only 12 pages) on a scientific study carried out by WL/RAND and concentrated on the situation of the Rhine delta.

The Boertien 1 Committee advised to base the flood safety level on the following elements:

- individual flood risk
- economic damage in case of a flood
- disruption of society in case of a flood
- damage of dike reinforcement to LNC-values
- costs of dike reinforcement

Of these aspects, individual risk and economical damage were the most important.

The design river discharge at that time was 16 500 m^3/s at Lobith corresponding with an exceedance probability of 1/1250, but one of the extrapolation methods used by WL/RAND resulted in a design discharge of 15 000 m^3/s. The Committee Boertien 1 adopted this lower discharge as the new standard, mainly to reduce dike reinforcements and preserve LNC-values. The report of WL/RAND mentions that the economical value has increased considerably since 1977, but the appreciation of LNC-values had grown too in the same period. The norm of 1/1250 was considered too low by WL/RAND considering the economic risk, but for the sake of LNC-values a higher norm was not advised (Walker et al., 1993).

The attitude of *Rijkswaterstaat*, the Province of Gelderland and some Water Boards gradually changed, resulting in better involvement of stakeholder interests in the plans for dike reinforcement. The dikes with trees near Neerijnen and Zutphen became pilot projects for the new approach. By applying steel sheetpile walls in the dike, only 19 of 1900 trees in the dike near Zutphen had to demolished. After these pilots, the same approach was used for other river dikes.

Despite these pilot projects and concentration on accomplishing the Dutch delta works, attention to the state of river dikes diminished and the maintenance and safety level of these dikes was not optimal in the second half of the twentieth century. High river water levels of the Rhine, Waal and Meuse in 1993 and 1995 almost lead to a catastrophe. In 1993 the Maas flooded on many places in Limburg, affecting 6000 houses and causing 8000 inhabitants to be evacuated. Also the water in the

Rhine delta reached high levels. The discharge of 1995 almost led to dike failures and 200 000 inhabitants of river areas had to be preventively evacuated (Yska, 2009).

The 1993 and 1995 high river discharges attracted societal attention and brought flood protection back to the political agenda. The events of 1993 led to a strong call for dike reinforcements, which was the occasion to instate the Committee Maas Flood (*Commissie Watersnood Maas*), better known as Committee Boertien 2. This committee now concentrated on the situation along the Maas, because the Boertien 1 Committee just had given advice on the Rhine delta. Boertien 2 advised a protection level of 1/250 for existing dwellings and 1/1250 for newbuilt-on areas along parts of the Maas that were not protected by dikes[4] (Yska, 2009).

Luckily the river dikes did not breach in 1995, but the high discharges induced the formulation of a new policy on flood defence (Delta Act for the Major Rivers). Dike improvements were then executed with high priority so that they could resist a Rhine discharge of 15 000 m^3/s at Lobith and 3650 m^3/s for the Maas. These governing discharges have been increased to 16 000 m^3/s and 3800 m^3/s respectively due to findings of the assessment round in 2001. Figure 4.1 shows a graph with exceedance probabilities of water levels of the Rhine at Lobith. Two trend lines are drawn in this graph: one including and one excluding the discharge peaks of 1993 and 1995.

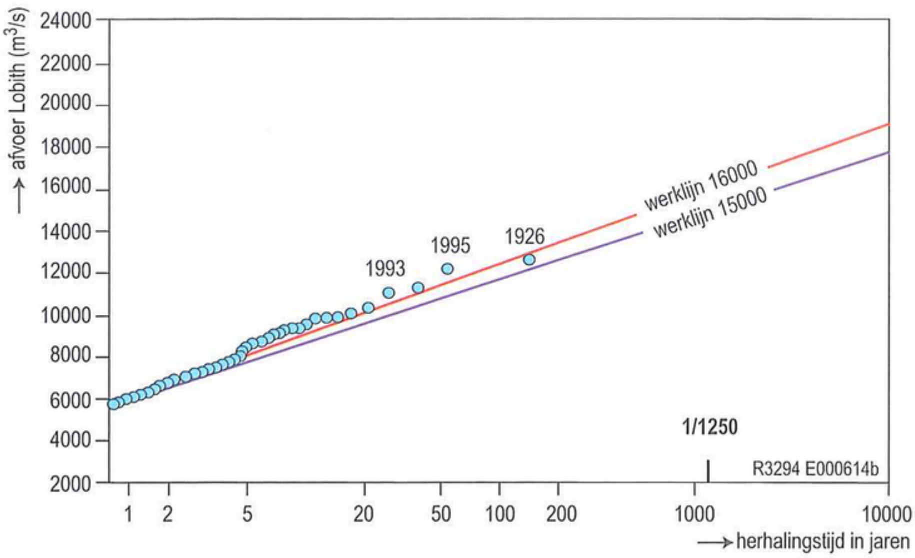

Figure 4.1: Governing high water discharge line before and after the discharge peaks of 1993 and 1995 (RIVM, 2004)

The changes in normative river discharges advised by several committees is summarised in table 4.1.

The aim of the Delta Act for the Major Rivers was the reduction of the administrative and legal complexity of improvement works. The intention was to improve 148 km of dikes and construct 143 km of quays before the end of 1996.

[4] In the Flood Defence Act, which was enacted in 1995, some of the secondary dikes along the Maas got the status of primary flood defence.

	Tot 1953	Delta-commissie 1/3000 per jaar		Becht 1/1250 per jaar		Boertien 1/1250 per jaar	HR2001 1/1250 per jaar
			Toeslag		Toeslag		
Bovenrijn bovenstrooms Lobithse Overlaat	13500	18000		16500		15000	16000
Bovenrijn benedenstrooms Lobithse Overlaat	12000						
Waal	8250	11250	150		0	9500	10133
Pannerdensch Kanaal bovenstrooms Kandia	3750	6750	350		75	5500	5867
Pannerdensch Kanaal benedenstrooms Kandia	5000						
Nederrijn-Lek	2700	3950	250		50	3250	3467
IJssel	2300	2800	250		25	2250	2400

Table 4.1: Advised normative river discharges (RIVM, 2004)

To preserve the characteristic fluvial landscape, the Dutch government has launched the 'Room for the River' programme, where spatial quality has become an important aspect, next to flood protection[5]. The idea of this programme is to restore the 'original' course of the river and to make better use of the winter bed, or to enlarge it, to create more space for high discharges, which reduces the high water levels. The problem of properly using the Dutch winter beds was that they were meanwhile used for other purposes (industry, agriculture), so that their primary function as a buffer for high discharges had passed into disuse. The Room for the River Programme therefore comprehended the clearance of the winter beds by clearing forelands from brickyards and clearing bridge approaches of roads and rail roads, as well as creating retention areas and excavation of channels in the winter bed. The project was projected to be completed ultimo 2015. Removing industry and agriculture from the forelands has a negative consequence, though, because of the economic impact of the disappearance of these activities. Forelands are, notwithstanding the fact that they are situated outside the protected areas, also in favour for habitation, but also houses outside the dike are unwanted objects in the Room for the River projects (van Gerven, 2004). Figure 4.2 shows a schematic presentation of dike repositioning measures to create more room for rivers.

In 2000 the Committee Watermanagement 21st Century, WB21 (*commissie Waterbeleid voor de 21e eeuw*) was appointed to give advice on the adjustments of the national flood protection system needed to cope with climate change. The committee

[5]This characteristic landscape actually is a result of flood protection measures, but this fact is often neglected.

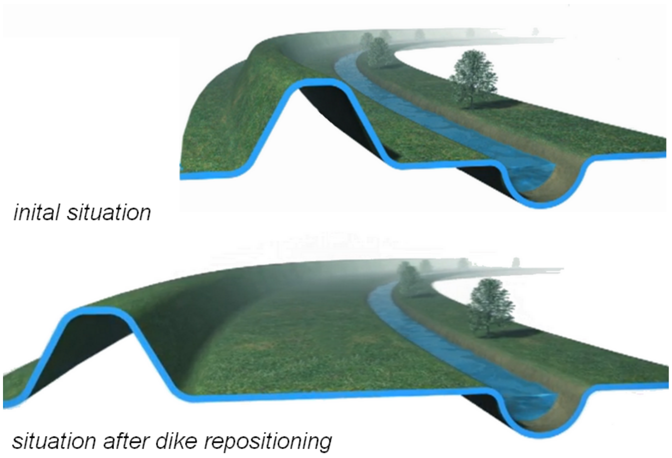

Figure 4.2: Schematic presentation of dike repositioning measures - notice that the proportions are far from realistic (www.ruimtevoorderivier.nl)

advised to top-off discharge peaks by first retaining water, then holding it in separate areas and finally discharging it towards the sea. For primary flood defences the committee advised to make a change from an exceedance probability to a risk approach. It also advised to set up standards for regional flood defences. Both last advices were not worked-out by the committee.

The possibility of inundating specific areas of land in a controlled way to save other parts from flooding during extreme circumstances was elaborated by the Committee Inundation Areas (*Commissie Noodoverloopgebieden*) (2000-2001). The advice of this committee did not include the required safety level to be obtained by these measures, but some areas were allocated to be deliberately flooded in case of extremely high water. Because of the heavy resistance against these plans, and calculations that showed only very small water level reductions as a result of the inundation areas, not much has been done with this advice (Yska, 2009).

5

Legalisation of the safety standard

The Delta Act, enforced in 1958, contained regulations regarding the closure of sea-arms en reinforcement of flood defences, but did not specify minimum required safety levels. These levels were however derived by the Delta Committee and published in its interim report of 1955. These recommended levels were used for the calculations of the dimensions and costs of the structures of the Delta Works. It was the common design practice of *Rijkswaterstaat* since the appearance of the reports of the Delta Committee to use their recommended safety level (a critical water level related to a specific exceedance frequency). This is reported in several documents of *Rijkswaterstaat*, like (Rijkswaterstaat, 1969) and (Rijskwaterstaat, 1972).

The advise of the Becht Committee to base dike reinforcements along the river on water levels related to a discharge of 16 500 m^3/s (discharge of the Rhine near Lobith) was agreed upon by the House of Representatives in 1978. The design standards of the Becht Committee and the Delta Committee appeared to overlap for the intermediary area. Therefore it was concluded that the safety standard for areas enclosed by flood defences had to based upon water levels related to natural phenomena with only one probability or occurrence. This lead to the establishment of design water levels after discussion with the peoples' representatives in 1993. The normative water levels for the Meuse as proposed by the Becht Committee were established at the same time. Later on, safety standards for the dikes around the IJsselmeer were proposed by the TAW.

When the end of the Delta Project and the river reinforcements came into sight, the flood safety of other flood-prone areas had to be taken care of. As most efforts since 1953 were aimed at protection along the coast and the main rivers, the improvement of other flood defences fell behind. Moreover, the Delta Act was about to fall due, so a new law up at national level was needed. It was namely felt that flood protection was one of the fundamental tasks of the government, conform article 21 of the Dutch Constitution. That is the reason why the Flood Defence Act (*Wet op de Waterkering*) was prepared by a workgroup chaired by Ir. Tjalle de Haan.

The draft law, including an elucidation, was presented to the Dutch Council of State (*Raad van State*) on 25 July 1988, which issued an advice on 19 April 1989. This advice was presented to HM Queen Beatrix on 13 June 1998. An adapted version of the draft law and elucidation was thereupon sent to the members of the House of Representatives on 23 June 1989. It was discussed there with the Minister of Transport, Public Works and Water Management (*Verkeer en Waterstaat*), ms. N. Smit-Kroes. Because of all the questions of the representatives, some aspects had to be given a second thought. The resulting document, a Memorandum in Reply (*Memorie van Antwoord*), was sent by the new Minister, ms. J.R.H. Maij-Weggen, and received by the representatives only on 12 April 1994. There were two reasons for this late reply. First, the decentralisation of granting subsidies to administrators of primary flood defences had to be finished before the Flood Defence Act would be effectuated. Second, the results of the points of departure for the river dike reinforcements had to be evaluated. The Boertien Committee had namely issued a report on this, which was discussed with the representatives on 27 April 1993.

The near river floods of 1993 and 1995 resulted in a sense of urgency, which offered the minister a possibility to quickly put forward the Flood Defence Act, especially because the Act also gave directions for financing the Boertien Committee measures.

The Flood Defence Act defined 53 dike ring areas: areas entirely surrounded by flood defences or higher land areas, related to one safety standard. The division in dike rings was gradually developed by *Rijkswaterstaat* in the 1980s in cooperation with the provinces and water boards. In 2006 the dike rings along the Maas in Limburg and eastern Brabant were added, resulting in a list of 100 dike rings in total.

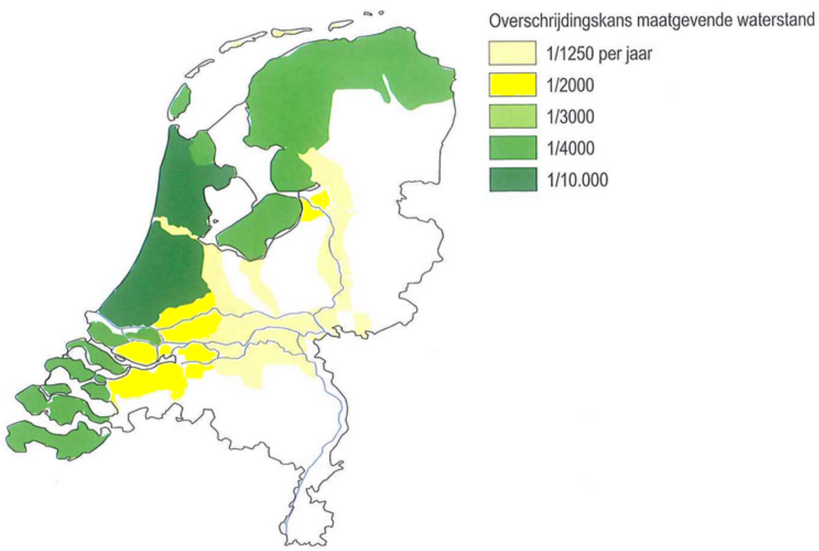

Figure 5.1: Normative exceedance probabilities as stipulated by the Flood Defence Act (RIVM, 2004)

The normative exceedance probabilities for dike rings along the cost and lakes as proposed by the Delta Committee were adopted in the Flood Defence Act. A map of the Netherlands with the normative exceedance probabilities is shown in figure 5.1.

The normative exceedance probability for upper rivers was set at 1/1250, like advised upon by the Becht and Boertien committees. For transitional zones between upper and lower rivers, and for the IJsselmeer, the normative exceedance probability was fixed at 1/2000. The correctness of the choice of the normative levels was only verified in 2005 when the failure probabilities were calculated (RIVM, 2004), (Rijkswaterstaat, 2005). Design water levels were derived from these normative exceedance frequencies.

Other recommendations of the Delta Committee, like over-topping volume criteria, were laid down in guidelines of the Technical Advisory Committee for the Flood Defences *Technische Adviescommissie voor de Waterkeringen, TAW*. The Flood Defence Act also stipulated that the quality of the primary flood defences should be checked every five years.

6

THE VEERMAN COMMITTEE 2008

The Dutch government set up a new delta committee in 2008 to give advice on the feared consequences of 'rapidly' changing climate change on the Dutch coast and its hinterland. The committee, officially called the 'State Committee for Sustainable Coastal Development', was chaired by mr. Cees P. Veerman, former Minister of Agriculture and further existed of a secretary and eight members, of which two had a hydraulic engineering background.

About the reason of its establishment, the committee mentions in its final report that it has been concluded *that a regional sea level rise of 0,65 to 1,3 m by 2100, and of 2 to 4 m by 2200 should be taken into account. This includes the effect of land subsidence. These values represent plausible upper limits based on the latest scientific insights. It is recommended that these be taken into account so that the decisions we make and the measures will have a lasting effect, set against the background of what can be expected for the Netherlands. For the Rhine and the Meuse, summer discharge will decrease and winter discharge will increase due to the temperature increase and changed precipitation patterns. Around 2100 the maximum (design) discharges of the Rhine and Meuse are likely to be around 18 000 m^3/s and 4600 m^3/s, respectively. The design discharges at that moment were 16 000 m^3/s and 3800 m^3/s. A rising sea level, reduced river discharges in summer, salt water intrusion via the rivers and ground water, all put pressure on the country's drinking water supply, agriculture, shipping and those sectors of the economy that depend on water, for cooling or otherwise.*

The mandate of the Veerman Committee 2008 was broader than that of the Delta Committee, that was primarily concerned with hydraulic engineering works 'to counter an acute threat'. The new committee came up with recommendations to avoid disasters in centuries to come. The concept was to 'work with water' to improve the quality of the environment. This should also offer excellent opportunities for innovative ideas and applications. The idea was also to let 'new forms of nature' arise and to use water to produce food and generate energy and to use flood defences for roads. The Committee summarized its ambitions in the question: *How can we ensure that future generations will continue to find our country an attractive place in which to live and work, to invest and take their leisure?*

The report of the Veerman Committee 2008 has been presented on 3 September 2008 (the cover of this report is shown in Figure 6.1). Water safety is the core of this report, including flood protection and securing fresh water supplies. Flood protection is aimed at prevention of flooding, so avoiding casualties and damage to economy, landscape, nature, culture and reputation. The task, however, also comprises interactions with life and work, agriculture, nature, recreation, landscape, infrastructure and energy. Flood protection and sustainability are the two pillars that form the base for the strategy for future centuries.

Figure 6.1: Cover of the report of the Veerman Committee 2008

According to the report, *the recommended measures are flexible, can be implemented gradually and offer prospects for action in the short term. Their implementation will allow the Netherlands to better adapt to the effects of climate change and create new opportunities. The recommendations made must be sustainable: their implementation must make efficient use of water, energy and other resources, so that the quality of the environment is not merely maintained but even improved.*

The Veerman Committee has formulated twelve main recommendations for the short and medium term. One of the recommendations was to raise the overall flood protection level with a factor 10, in some areas even more than this. The level of the IJsselmeer (exclusive the Markermeer) should be raised with 1.50 metres.

It was further recommended to base the decision of whether to build in low-lying flood-prone areas on a cost-benefit analysis. Because of the advantages of probabilistic design and the meanwhile improved calculation possibilities (thanks to the programme Safety Netherlands Mapped (*Veiligheid Nederland in Kaart, VNK*)), the Committee recommended to follow an approach based on risks, in stead of governing water levels with certain exceedance frequencies. Failure of flood defences, dikes in particular, is after all not only covered by overflow or overtopping, but also by other mechanisms, like piping and slide-offs, which was also clearly demonstrated by the peat dike failure in Wilnis, Netherlands, in 2003 and during the floods in New Orleans, Louisiana, caused by hurricane Katrina in 2005. A second advantage of the risk approach is that it supports the prioritisation of dike improvements: the biggest risks can be identified and remedied first, which can lead to more effective investments. A third advantage of the risk approach is that special solutions like multifunctional dikes can be better assessed (Vrijling, 2012).

The committee also stated that new development in unembanked areas should not reduce the river's discharge capacity or the future water levels in the lakes. The building with nature principle was propagated for the North Sea coast and the influence of the beach nourishments along this coast on the adaptation of the Wadden Sea area to sea level rise should be monitored and analysed in an international context.

Furthermore, sand nourishment should counter the reduction of tidal movements in the Eastern Scheldt because of the storm surge barrier and the Western Scheldt should remain open so that enforced dikes around this estuary provide the required protection. A re-arrangement of the Krammer-Volkerak Zoommeer, the Grevelingen and possibly also the Eastern Scheldt should provide temporary storage of river water when the discharge to the sea is blocked by closed storm surge barriers. The committee also suggested to combine flood protection, fresh water supply, urban development and nature development in the Rijnmond area in an open system, which can be closed when needed. Extreme discharges of the Rhine and Meuse would then have to be re-routed via the south-western delta.

As regards the major rivers area, the committee recommended to implement the Room for the River (*Ruimte voor de Rivier*) and Meuse works (*Maaswerken*) programmes without further delays.

The costs of the implementation of the new flood protection programme until 2050 was estimated at 1,2 to 1,6 billion euro per year, and 0,9 to 1,5 billion euro per year in the period 2050 - 2100. Coastal flood protection is mainly provided by beach nourishments. If this method would be intensified so that the coasts of the Netherlands grow say 1 km in a seawards direction, thus creating new land for such functions as recreation and nature, it would involve an additional cost of 0,1 to 0,3 billion euro per year[1]. The financial means must be secured by a Delta Fund, under administration of the Minister of Finance. The Delta Fund should be supplied with a combination of loans and transfer of (part of) the natural gas revenues. It was also recommended to make national funding available and drafting rules for withdrawals from the fund.

The organisation of flood protection was recommended to be strengthened by providing a cohesive national direction and regional responsibility for the implementation and by initiating a permanent Parliamentary Committee on the theme.

The new flood protection programme has been embedded, financially, politically and administratively, in a new Delta Act. This Act has been promulgated in 2009. An outline of the Act is presented in the following section.

[1]Amounts in euro at 2007 price levels, including Dutch Value Added Tax (BTW).

7

Developments in the 21th century

An incitement for a more interdisciplinary design approach was formed by some complications that were not predicted during the design of the Delta Works: Environmental problems gradually originated, such as large amounts of blue algae, lack of oxygen and the decline of sand banks and fish migration in the closed-off estuaries (Programmabureau Zuidwestelijke Delta, 2009).

Water-boards were given more rights to prevent unsafe construction plans of municipalities. From 2003 these local authorities were obliged to check their destination plans with respect to safety against floods (Spatial Planning Act). These plans consequently were checked by the provinces, who approved or disapproved them. The Dutch government in 2008 decided to further decentralise competences and abolished the provincial check. This made the water-boards entirely dependent on the judgement of municipalities (which, after all, have more, possibly conflicting, interest than only the protection against floods). This situation has worsened by the Dutch government in 2010 by empowering the Crisis and Recovery Act (*Crisis- en herstelwet*) to reduce delay of construction plans in order to stimulate the economy. This temporary act will probably be made permanent in 2014. One of the Dutch political parties (D66) in 2010 even proposed to move the competences and responsibilities of the water boards to the provinces.

On Monday 29 October 2012, the Dutch liberal party (VVD) and the labour party (PvdA) presented a coalition agreement with far-reaching consequences for the water boards. Both political parties indicate that they strive for an administrative division of the Netherlands in five districts with a closed economy, replacing the present provinces, and forming municipalities of at least 100 000 inhabitants. These parties also agreed upon combining the water boards with these five national districts[1]. Meanwhile the water boards will have to merge mutually until ten to twelve are left.

Since 2009, the safety level against flood is assigned to dike sections and is regulated by law (Water Act, *Waterwet* 2009). This act comprises eight former acts:

[1]This is quite remarkable, because this measure was not part of the election programmes of both parties.

- Water Management Act (*Wet op de waterhuishouding*)
- Act on the Pollution of Surface Water (*Wet verontreiniging oppervlaktewateren*)
- Act on Polluted Sea Water (*Wet verontreiniging zeewater*)
- Groundwater Act 1981 (*Grondwaterwet*)
- Land Reclamation Act 1904 (*Wet droogmakerijen en indijkingen*)
- Flood Defence Act,1996 (*Wet op de waterkering*)
- Act on the Management of the Structures of the Ministry of Waterways and Public Works [*Wet beheer Rijkswaterstaatswerken* (the 'wet' parts of it))
- Water Control Act ('wet' parts) 1900 (*Waterstaatswet*)

The Flood Defence Act was completely adopted in the Water Act without changes in content, but al articles were rewritten and moved to various parts of the Water Act. The Water Act additionally prescribes that the minister should specify what hydraulic boundary conditions should be taken into account to calculate the assessment levels [*toetspeilen*]. The water-boards have to check every six years if their flood defences still can function if the water will reach the test level.

Other relevant acts and regulations are/were:

- Water Control act 1900 (*Waterstaatswet*)
- Rivers Act 1908, 1999 (*Rivierenwet, Wet beheer Rijkswaterstaatswerken*)
- Water Board Act 1991 (*Waterschapswet*)
- Provincial Regulations
- Spatial Planning Act 1962 (*Wet op de ruimtelijke ordening*)
- Expropriation Act 1857 (*Onteigeningswet*)
- Environmental Management Act 1993 (*Milieubeheerwet*)
- Soil Protection Act 1986 (*Bodembeschermingswet*)
- Pollution of Water Surface Act 1971 (*Wet verontreiniging oppervlaktewateren*)

(Weijers and Tonneijck, 2009)

In case of multifunctional flood defences, also the following acts are relevant:

- Act on City and Village Renewal (*Wet op de stads- en dorpsvernieuwing*)
- Housing Act (*Woningwet*)

The Dutch Water Act stipulates that the responsible Minister takes care of the establishment and publication of technical guidelines for the design, management and maintenance of primary flood defences (article 2.6). To comply with the law, requirements should be formulated with respect to the retaining height, reliability of closure means (acceptable volume of water flowing through) and the strength and stability of hydraulic structures. The technical guidelines serve as recommendations for those responsible for the management and supervision. Strict compliance with these guidelines is not obligatory, because that would reduce the possibilities for optimal custom-made measures. It is, however, recommended to follow the guidelines, because they are considered to contain the best generally accepted technical knowledge.

The Dutch policy to reduce flood risk with help of retention areas has become more pliable. The Dutch National Water Plan 2009-2015 mentions that retention areas (*noodoverloopgebieden*) have been successfully applied in the past in vulnerable downstream areas. The spillways, however, have not been used for many decades, while these areas have been developed so that renewed use of during high water is disputable. In the past years it has been investigated to what extent and at what locations specifically equipped retention areas could be used. Initially three areas were selected: Rijnstrangen and the Ooijpolder for the Rhine and the Beersche Overlaat for the Meuse. The reservation of the selected areas for the Rhine have been withdrawn. In the cabinet point of view 'Rampenbeheersing Overstromingen' (2006), the Beersche Overlaat has been reserved for the safety of Den Bosch and the A2 highway. The available research results, however, do not sufficiently support the effectiveness of retention areas. The Dutch cabinet therefore decided not to equip the Beersche Overlaat as a retention area (Ministerie van Verkeer en Waterstaat, 2009).

The assessment of flood defences presently takes place on basis of the flood safety standards proposed by the first Delta Committee. The present safety level is said to be too low at present (2014), because of an increase of the number of inhabitants in a dike ring (doubled in South Holland) and the economic value (fivefold increase in South Holland) since the Delta Committee had calculated its optimum safety level. The Delta Committee 2008 therefore recommended to increase the protection level of the entire Netherlands with factor 10 (Deltacommissie 2008, 2008). The outcome of two studies carried out by Deltares in 2011, the societal cost-revenues analysis (*maatschappelijke kosten-batenanalyse, MKBA*) and the loss of life risk analyses (*slachtofferrisicoanalyses, SLA*), however, did not support this recommendation. In the new policy, only three areas deserve extra attention: the area in between the big rivers, parts of the Rijnmond-Drechtsteden region and Almere (Atsma, 2011).

The Veerman Committee 2008 proposed to elevate the level of the IJsselmeer with 1.50 m, but this has already been revoked in the Delta Programme 2013. It appeared that, because of the ingenuity of the Dutch water system with its many regulatory possibilities, the fresh water storage can be sufficiently enlarged without raising the water level that much, in combination with a flexible level control during summer. A water level rise of 0.20 m of the IJsselmeer and Markermeer, anticipating a period of drought in summer, would be sufficient to prevent salt intrusion until 2050, in combination with a water level lowering of 0.10 m during droughts. Pumping stations will probably be necessary in future to discharge superfluous water from the IJsselmeer into the Waddenzee.

7.1 THE ASSESSMENT OF DUTCH FLOOD DEFENCES

According to the Water Act (article 2.12, first member), the Dutch primary flood defences have to be periodically assessed, with a minimum frequency of once per 12 years. Originally, the assessment frequency in the Flood Defence Act of 1996 was once per five year. This five-year period was based upon two considerations. First, it was reasoned that the flood defence and the characteristics of the threatening outer water would not drastically change within this period. Therefore it was expected that possible shortcomings could be detected and repaired in good time. Second, after five years there would still be sufficient actual knowledge within the organisation of the maintaining authority regarding the actual problems of the previous period. This assessment period was reduced to once per six years in the Water Act of 2009 and in 2013 it was further reduced to once per 12 years (Government, 2013). The knowledge to judge the resistance against extreme water levels and waves has been laid down in the Regulations Safety Assessment (*Voorschrift Toetsen op Veiligheid, VTV*). The regulations contain calculation rules that have been formulated based upon many years of research on the loads on and strength of flood defences. There are nevertheless some knowledge gaps regards extreme circumstances. To cover these uncertainties, the assessment method makes use of safety factors (Vrijling, 2012).

Since the Flood Defences Act became effective in 1995, three assessment rounds have been carried out. The results are presented in figure 7.1. During the first round in 2001, only insufficient retaining height has been considered as a failure mechanism and only primary flood defences were assessed. During the second round in 2006, also other possible failure mechanisms have been taken into account. The result of a rise in the length of rejected dike stretches is therefore not surprising. The subsequent flood defence reinforcements since 2007 were organised in the High Water Protection Programme (*Hoogwaterbeschermingsprogramma, HWBP-2*) drawn up by the Dutch state and 22 water boards. The improvement task comprised 370 km of dikes and 18 engineering structures. The extent of stretches with 'unknown' result in the second assessment round, because of lack of data, was still very high, which is remarkable ten years after the effectuation of the Water Defence Act, so one of the goals was to reduce this category with 50% (Ministerie van Infrastructuur en Milieu, 2011). For the third assessment round, the policy was adopted to denominate all not-rejected flood defences as 'satisfactory', including the defences with 'unknown' status.

The third national assessment of primary flood defences over the period 2006-2011 nevertheless resulted in rejection of about one third of the dikes (1225 kilometre) and 335 engineering structures. Now also type c flood defences have been assessed, of which 80% was rejected[2]. As a result, the new High Water Protection Programme (*nieuw Hoogwaterbeschermingsprogramma, nHWBP*) has been set up, in which 744 km of dikes and 264 engineering structures will be improved. The budget for the nHWBP is lower than for the HWBP, although the nHWBP is by far bigger a task than previous programmes, so it is necessary to execute the nHWBP improvement programme faster and more effective than usual. The aim is to increase the improvement rate from 25 km/year (programmes until HWBP) to 80 km/year (2016). This is extra challenging because projects become more complex, leading to longer preparation periods which urges to follow an integral and project based approach (Samenwerk-

[2] Flood defences of category c are part of a continuous system of flood defence (dike ring), but do not directly retain outer waters.

ingsverband kennis- en innovatiestrategie nHWBP, 2012).

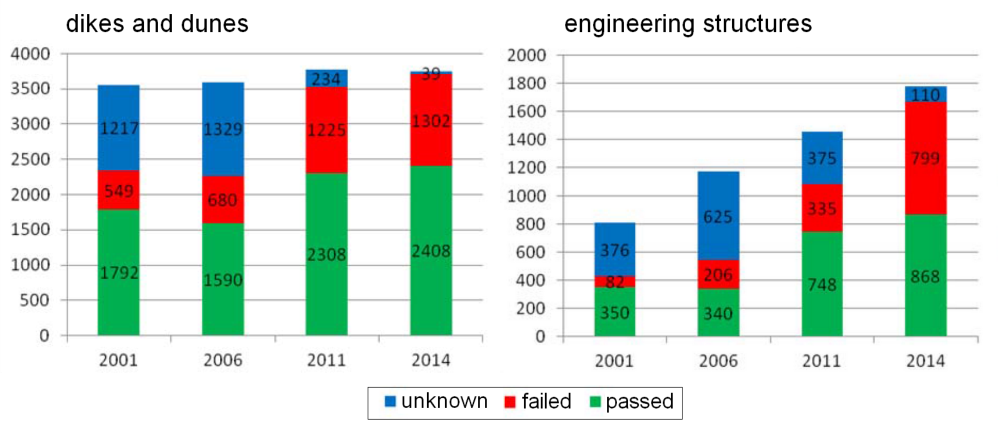

Figure 7.1: Results of the national assessments of primary flood defences in the Netherlands (Ministry of Infrastructure and Environment, 2014)

In the Governmental Arrangement Water (*Bestuursakkoord Water*) of 2011 it was agreed upon that the fourth national assessment of primary flood defences would be postponed until there is clearness about the actualisation of the standard and related assessment and design armamentarium. It was also decided to extend the third assessment for flood defences for which no judgement could be given. This extended assessment started on 30 March 2013 and concerned 234 kilometres of flood defences and 375 engineering structures. After this extended assessment, only 39 km of dikes and 110 engineering structures needed further investigation. In 2014, about half of the rejected flood defences have been planned to be upgraded as part of the High Water Protection Programme 2 (*Hoog Water Beschermings Programma 2*), the Room for the River programme and the Meuse Works programme. The flood defences that have failed the third assessment and the extended third assessment will be upgraded as part of the new High Water Protection Programme (*nieuw Hoog Water Beschermings Programma, nHBWP*). During the extended third assessment the supervision of the assessment moved away from the provinces towards the Inspection Surroundings and Transport (*Inspectie Leefomgeving en Transport, ILT*), of which the clearness, pragmatism and expertise were acknowledged by the administrators of the flood defences. However, there was a desire for better exchange of knowledge regarding assessments (Kraak and Zandstra, 2014).

7.2 THE MULTI-LAYERED FLOOD SAFETY APPROACH

The present approach of multi-layered safety (*meerlaagsveiligheid*) was introduced by the Dutch Ministry of Public Works in the National Water Plan 2009-2015 (*Het Nationaal Waterplan*), which is the successor of the Fourth Memorandum on Water Management (*Vierde Nota Waterhuishouding*) of 1998. In the Delta Programme 2014 this multi-layered approach was presented as a projected 'delta decision'.

The multi-layered approach aims at reducing flood risk. This can be achieved by reducing the probability of flooding, or by reducing the consequences of floods. Reduction of the probability of flooding is achieved by flood preventive measures, which are comprised in the first level. Reduction of consequences can be achieved by sustainable spatial planning measures (layer 2) or by disaster management (level 3). This section gives backgrounds of the considerations to introduce this policy.

In the past, the Dutch flood defence strategy focused on prevention of flooding. This prevention was accomplished with help of flood defence structures. In the new Dutch policy, this approach has been extended with two other 'layers': spatial solutions measures (layer two) and crisis management (layer three).

The motivation for more attention to the second and third layer is given in Chapter 4.1 of the National Water Plan:

> *Omdat de kans op een overstroming nooit helemaal is uit te sluiten, moet de aandacht in de toekomst niet alleen gericht zijn op het voorkómen van overstromingen (preventie) maar ook op het beperken van slachtoffers en schade bij een mogelijke overstroming en het bevorderen van herstel na de overstroming. Denkbare maatregelen liggen in de sfeer van ruimtelijke planning waarbij rekening wordt gehouden met de overstromingsrisico's en de werking van de rampenbeheersing (evacuatie, rampenplannen). Naar aanleiding van de kabinetsreactie op het advies van de Commissie Luteijn (augustus 2000) om de veiligheid te verbeteren, zijn maatregelen als noodoverloopgebieden en compartimentering in beeld gekomen.*
>
> *Bij het beperken van de gevolgen van een mogelijke overstroming gaat bijzondere aandacht uit naar het beschermen van vitale infrastructuur zoals energie- en drinkwatervoorziening, en telecom en ict. Deze kunnen als gevolg van een overstroming buiten gebruik raken. Bovendien zijn veel van deze objecten juist tijdens een overstromingsramp cruciaal om maatschappelijke ontwrichting zoveel mogelijk te beperken.*[3]

Some historical events caused this shift in thinking about flood protection. The Dutch Delta Works were about to be finished, when the Dutch big rivers (Rhine, Meuse, Waal) caused floods in 1993/95. This led to a change in thinking about flood management: there appeared to be more ways to deal with floods except for preventing them with help of permanent structures. The new strategy aimed at giving the rivers

[3]Attempt of a translation of this fuzzy Dutch text: *Because the probability of flooding can never be completely excluded, the future advertency should not only concentrate on avoiding floods (prevention), but also on reducing the numbers of casualties and material losses in case of an eventual flood, and to promote recovery after a flood. Possible measures reside in the sphere of spatial planning, taking into account the flood risks and the operation of disaster management (evacuation, disaster planning). In consequence of the response of the cabinet on the advice of the Committee Luteijn (August 2000), to increase the safety, measures like emergency catchments and compartmentalization came into sight. Regards constraint of the consequences of a possible flooding, special attention should be given to the protection of vital infrastructure, like energy and drinking water supply, and telecommunication and ICT. They can become dysfunctional as a result of the flooding. Moreover, many of these objects are crucial, especially during floods to prevent societal disorder as good as possible.*

more space, which was implemented in the project Room for the River (*Ruimte voor de Rivier*). This strategy was successed by the multilevel Safety approach, that considered alternative protection measures next to prevention. The flooding of New Orleans in the United States of America after Hurricane Katrina called into mind the severity of the impact if the flood prevention fails. Dutch history and examples from other countries show that there is an abundance of flood management measures that potentially might ease this impact of flooding. The multilevel safety approach allows floods, but compensates this with other measures than prevention (Hoss, 2010). The three layers will be explained in more detail in the following sections.

The multilevel safety concept is heavenly disputed at the moment. It seems that new policy makers with lack of historical and hydraulic engineering background are trying to reinvent the wheel, neglecting centuries of technological and societal progress (van Belzen, 2012). In the past, for example, the Dutch have stopped building on mounds, because of increasing need for space. They discovered a more efficient way to protect against floods. At present, building on mounds is part of the multilevel policy again (Kolen et al., 2011). On the other hand it can be observed that flood protection policy is nowadays being discussed at different conceptual levels and involving more disciplines and interests. This is a new development which requires a different approach. It can sometimes be confusing if one is not aware of the differences in conceptual level, which easily leads to misunderstandings and controversies.

At the moment, the second and third layer are already being applied, next to the first layer. Based on some examples it can be concluded that measures to reduce the probability of flooding (first layer) and non-expensive measures of risk management (third layer) can be cost-effective. Physical measures in spatial planning (second layer) are less or not cost-effective. These measures, however, could be justified if other values than the present become prevalent, and society is willing to pay extra to accomplish these other values. The thus acquired insights can be used to distinguish and compare more and less effective measures or strategies.

Presently there are only clear requirements prescribed by law for the first layer and protective measures in the second and third layer are still optional. There are only process requirements for the second and third layer, but what the result of these requirements should be, is unclear. This means that for these layers, the contribution to flood protection does not have to be quantified. Moreover, risk reduction through the second and third layer is practically rather problematic, because of the strict requirements in the first layer. A three-layered approach can only be functional if there is a framework by law, based upon a societal cost-benefit analysis making use of a risk approach (Kolen et al., 2011).

Frauke Hoss studied the three-layered approach for her MSc graduate work (Hoss, 2010). She stated that applying the multilevel safety approach would lead to unintended and negative side-effects, which were identified as critical properties. By changing the flood exposure, namely, people will respond differently to flood risk and the intensity and vulnerability of the population will change. Moreover, the measures to reduce the exposure can change flood characteristics and thus alter the performance of flood management measures. These effects are relatively small, but it should nevertheless be prevented that new flood management measures worsen the flood characteristics at another spot. She also concluded that measures aiming at the vulnerability have the least interaction with the system, which will lead to an optimum of vulnerability. This implies maximum damage.

Hoss also made clear that the cost-efficiency of the entire multilevel safety system heavily depends on the initial flood risk. After all, any additional measure reduces the probability of an event causing a smaller loss. Therefore, every multilevel safety measure that is added to an existing one, is less cost-efficient. The introduction of multilevel safety also changes the serial flood defence system into a parallel system, which might increase the transaction and administrative costs considerably. Another drawback of the temporary measures of the third layer is that they are less reliable than permanent measures of layers one and two.

It can generally be said that the smaller the total flood risk, measures with a lower geographical scale of implementation are better. For the Dutch situation this implies that applying measures other than prevention, is mainly appropriate to address deviations in local risk at the scale of urban districts. Spatial planning and crisis management are not found to be cost-efficient for scales larger than that.

The main conclusions of this study (Hoss, 2010) are:

- A flood defence system heavily based on dike rings does not lend itself to implement the multilevel approach. This approach would only be cost-efficient if it eliminates local differences in risk.
- Introducing redundancy to flood safety by means of multilevel safety is an alternative to only building flood defences (strengthening the strongest link).
- The cost-efficiency of any flood management measure depends on the initial safety level. This interaction between the individual measures might make it more effective to turn to other measures instead of continuously intensifying the implementation of one measure.
- To implement multilevel safety effectively it is necessary to know that different measures address different key parameters of risk and show different side-effects.
- Policy-making needs to be risk-based to make multilevel safety relevant. Right now most flood management policies are based on prevention and thus on failure probabilities. To supplement those policies with loss-reducing measures, as multilevel safety proposes, policy-makers need to be authorized to base their policies on the risk approach to flood management.

Also the Dutch Expertise Network for Flood Protection (*Expertisenetwerk Waterveiligheid, ENW*) contends that in Dutch circumstances with a very high safety level provided by primary dikes being part of dike rings, the multilevel safety approach has very limited surplus value. If prevention (dikes) would fail, a flood and consequently economic losses will be the result. Of course, states ENW, disaster management should be well arranged, but investing in disaster management in stead of in improving flood defences is not cost-effective. ENW therefore does not favour exchangeability of between levels. Flood defence is not a matter of additional measures, but of alternative measures, which especially in times of economical recession should be taken into account. An economic assessment of an optimal distribution of scarce means over the various layers will give the right answer. Investments in the second and third level could only be efficient in a limited number of cases: frequently flooded areas lying outside dike rings, deltas abroad, local risk concentrations inside dike rings, inconvenience in urban areas and very expensive bottlenecks in urban dike improvement projects (Expertisenetwerk Waterveiligheid, 2012) (Vrijling, 2012). The multi-layered approach could also be useful in case of failure of secondary flood defences, or as strategy to cope with abundant rainfall.

It has been pointed out that the chain-approach of the multilevel safety policy suggests that every chain must be fulfilled to prevent a broken chain (leading to flooding). The tendency to fulfil every layer/chain to a high extent is stimulated by the fact that the care for the separate chains has been put under the responsibility of various authorities. Each authority pursuits to optimally take care of its own chain, but this leads to a too high emphasis on crisis management, which can easily be decided upon at the expense of more effective investments in prevention (Jongejan et al., 2008).

In an interview in Dutch newspaper De Volkskrant of 26 January 2013, however, minister Schultz van Haegen of 'Infrastructure and the Environment' stated that The Netherlands are badly prepared for flood disasters and that she is working on an ambitious programme to prepare The Netherlands for such disasters. A programme for evacuation of the Dutch people is being prepared, but its effectiveness is considered to be rather limited. Schultz van Haegen therefore urges to apply innovative ways to build and deal with water, like districts with floating houses, putting low lying urban areas on quays and create room for the river. According to her, building with help of nature provides better protection than technological measures that combat nature. She confirmed these statements in her letter of 26 April 2013, addressed to the chairman of the Dutch Lower House. A few months later, they were incorporated in the Delta Programme 2014 (Deltacommissaris, 2013).

7.3 CHANGE TOWARDS A RISK-BASED APPROACH

The Delta Committee recommended the exceedance probability approach as flood safety standard, but realised that this was not ideal because dikes can also fail due to other failure mechanisms than only wave overtopping or overflow. The Committee therefore already recommended to make a switch towards a complete failure probability, or risk-approach, when knowledge and techniques would be sufficiently advanced to do this (Deltacommissie, 1960a). A risk based design enables possibilities to distinguish between dike stretches within a dike ring. This allows for diversification of the standard within a dike ring: Stretches with higher risks can be more improved than less vulnerable stretches. The risk approach also allows for better estimation of the contribution of the diverse structural parts to the flood defence function. Together with concepts like the multi-layered flood safety policy this allows for integration of flood protection and urban development.

Also the Committee River Dikes (*Commissie Rivierdijken*, better known as the textitComittee Becht), which advised the Minister in 1977 on the upper rivers policy, realised that a dike could in practice very well be able to retain the design water level, but at the same time it could not be excluded that a dike would fail at lower levels due to other failure mechanisms. It was acknowledged that it was a problem that there was no clear sight on the actual flood probability of a polder. In response to this advice the Advisory Board of the Water Council (*Raad van de Waterstaat*) advised to consider whether it would be possible to come to a standard based upon a risk analysis of all involved aspects. Consequently, in 1979, a workgroup 'Probabilistic Method' of the Technical Advisory Committee on Flood Defences (TAW) was installed to advise the Minister on this topic (TAW, 1985). In June 1990 a CUR/TAW report on the probabilistic design of flood defences was issued (CUR, 1990).

As already mentioned, the Delta Committee 2008 also recommended to switch to an an approach based on risks (Deltacommissie 2008, 2008). The project organisation 'Safety Netherlands Mapped' (*Veiligheid Nederland in Kaart, VNK*) made a flood risk analysis, based on failure probabilities of dike segments. This organisation was an initiative of the Ministry of Infrastructures and the Environment, the Union of Water Boards [*Unie van Waterschappen, UvW*], and the Inter-provincial Consultation Association (*Interprovinciaal Overleg, IPO*). VNK performed the calculations for 55 dike ring areas in the Netherlands and for 3 dike rings along the Meuse river in Limburg. The calculations were completed at the end of 2014.

The central issue of the fifth edition of the delta programme consisted of a proposal for new flood defence standards based on a combined failure probability of all failure mechanisms rather than on exceedance frequencies. This edition was offered to the Dutch House of Representatives at Budget Day, the third Tuesday in September 2014. The Delta Commissioner proposes an individual risk 1/100 000 everywhere in the Netherlands. A higher protection level will be ensured at places where many casualties or enormous economic losses are expected, or where vital infrastructure is at stake with large consequences for the entire country. It is expected that the new standards will be enforced by law in 2017 and it is strived for that all primary flood defences comply to the new standards in 2050. Figure 7.2 presents a geographical map with the old and new standard next to each other.

The standards as prescribed in the WTI2006 are being re-established as well as the related assessment and design tool-kit. These new tool-kits are expected to be available in 2017 and then most of the present standards and guidelines will become invalid. At the moment (2015), a new tool-kit for the assessment is being prepared: the Legal Assessment Tool-kit 2017 (*Wettelijk Toets Instrumentarium, WTI 2017*). This will be used for the fourth national assessment Dutch primary flood defences in 2017, from which the results are expected in 2023.

To prevent that projects that are presently realised will be rejected in 2023 according to the WTI2017, *Rijkswaterstaat* issued a 'Guide designing with flood probabilities (Rijkswaterstaat, 2014). This guide, together with the 'Background report design

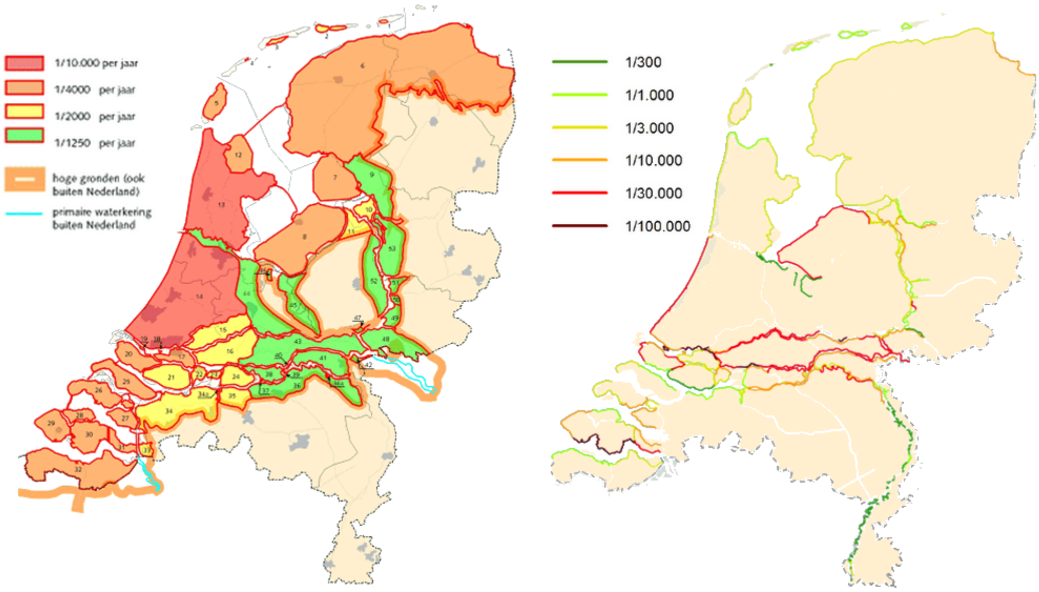

Figure 7.2: Old (left) and new (right) flood safety standard (failure probability) in the Netherlands

tool-kit 2014', forms the design tool-kit per 1 January 2014 (OI2014). This is the tool-kit that, according to the new High Water Protection Programme (nHWBP) should be used for the reinforcement of flood defences that were rejected during the third national assessment of flood defences. The administrator can choose between the present standard and guidelines or the OI2014 for the design of new flood defences, but to avoid early rejection according the new WTI2017, it is wise to choose for the robust approach of the OI2014.

The approach of the OI2014 comprises a flood probability norm per dike trajectory. This flood probability norm is divided into failure probability portions (*faalkans-ruimten* in Dutch) per failure mechanism. These failure probability portions are based upon the results of the VNK2 project.

It is important to know the meaning of some key words to interpret the new approach. The definitions are given below.

The *rejection probability* is the likelihood of flooding for which the costs of investments balance the benefits (flood risk reduction expressed in economic losses). This is the maximum allowable flood probability and it is used as a rejection criterion for the assessment of flood defences.

The *optimal design probability* is a failure probability that is determined with help of a life cycle costing (LCC) approach. Economical considerations are the basis of this optimal design probability. The optimal design probability is stricter than the rejection probability, in order to account for an increase of the flood probability.

The *mid probability* (*middenkans* in Dutch) is a probability in between the rejection probability and the optimal design probability. The mid probability for a certain year is defined as the average of the economic losses in between two successive investments, divided by the losses in that year. When the mid probability is exceeded by the actual probability, it will last about 20 years until the maximum allowable flood probability is exceeded. This 20-year period (*besteltijd* in Dutch) can be used for reinforcing the flood defence. An example of the temporal development of the discriminated probabilities is presented in Figure 7.3.

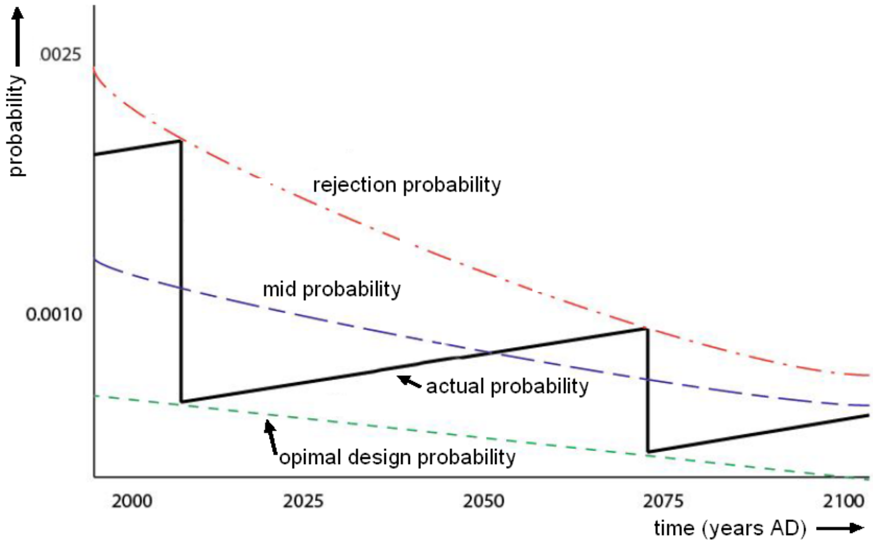

Figure 7.3: temporal changes of the probabilities described in WTI2017 (after Jongerius (2016))

The official standardised probabilities are middle probabilities. The design flood probabilities are often a factor two or three higher than this middle probability. The design criterion is determined by stating that the actual flood probability should not exceed the rejection probability at the end of the (design) lifetime of the flood defence. The optimal design probability can deviate to a higher extent from the middle probability for specific cases, like for engineering structures with very high adaptation costs, or a long design life time. The rejection probability is higher than the present standard, so in fact the new policy legalizes actual failure probabilities (probabilities in between the mid probability and the rejection probability) that are rejected at present (2015).

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