# 1

# The 1953 Great Flood

*[. . .] en in alle gewesten wordt de stem van het*
*water met zijn eeuwige rampen gevreesd en gehoord.*

Hendrik Marsman (1899–1940) in “Herinnering aan Holland”

*[. . .] and in every county the water’s warning of*
*more catastrophes heard and heeded.*

Translated by Michael Longley (from *Wavelengths: Various Translations*, Longley, M. and Morgan, J., Enitharmon, 2009)

## 1.1 The Night of January 31, 1953

On Saturday, January 31, 1953, around 18:15 local time, at the end of the evening news, every radio listener in The Netherlands heard the message below from the Dutch meteorological service (KNMI):

*Boven het noordelijke en westelijke deel van de Noordzee woedt een zware storm tussen noordwest en noord. Het stormveld breidt zich verder over de noordelijke en oostelijke Noordzee uit. Verwacht mag worden dat de storm de hele nacht zal voortduren. Daarom werden vanmiddag om half zes de groepen Rotterdam, Willemstad en Bergen op Zoom gewaarschuwd voor gevaarlijk hoogwater.*

Translated:

Over the northern and western parts of the North Sea, a strong gale rages from between northwest and north. The storm field is extending further north and east over the North Sea. It is expected that the storm will continue the whole night and given this fact, this afternoon at 17:30 the areas of Rotterdam, Willemstad and Bergen op Zoom have been warned of dangerously high water.

The experts of the KNMI, who had been monitoring the storm depression since Friday, became increasingly worried about potential consequences for the coastal areas of The Netherlands. This refers first to Zeeland, the southwest delta area which also borders on Belgium. A further area at high risk is the southwestern part of Holland, which contains the main shipping harbor Rotterdam. The northern part of the 20.5 km New Waterway canal linking the North Sea to Rotterdam’s harbor is known as Hoek van Holland (Hook of Holland). Only two days before it had been a full moon, with the possible consequence of a so-called spring tide (“springvloed”). In combination with an expanding severe storm already reaching force 10 and more, and taking a direction straight to the coasts of Zeeland and Holland, expert expectations for an extremely high tide for the coming night increased.

Concerning the above radio message we would like to add a comment. During those ominous days, the KNMI meteorologist Klaas Rienk Postma (1913–2005) was on duty. For the above radio message at the time, there were only two official formulations available that were allowed to be wired as a warning, namely “flink hoogwater” (seriously high water) and the chosen “gevaarlijk hoogwater” (dangerously high water). Postma would have preferred to communicate the not allowed “zeer gevaarlijk hoogwater” (very dangerously high water).

Today, more than 60 years on, the population of a region at risk can (and does) get ample information on possible catastrophic weather conditions, through radio and television news, both screened almost continuously, and of course through the omnipresent internet and social media. Furthermore, today’s storm predictions typically have a pre-event time lag of about 4 to 5 days with rather precise predictions of intensity, storm duration, storm path and geographic landing. KNMI did an excellent job in recognizing the threat but failed in getting its message sufficiently through to the people of Zeeland and Holland. In those days, risk communication was technologically underdeveloped.

In 1953 media warnings were extremely restricted; essentially only one warning was given, which was probably missed by many people. After 00:00 that night, no further warnings were transmitted to the population until 08:00 that Sunday morning, February 1. As every night, the radio program ended that Saturday midnight with the Wilhelmus, the Dutch National Anthem. The consequences were disastrous. People in Zeeland and Holland, who for centuries have been aware of the threat posed by living near the sea, went to bed trusting the existing dikes. That night the storm battered the coast with ferocious power. The ensuing seawater surge toppled the first dikes at around 02:00 Sunday morning, well before the expected high tide of 05:00. About one hour later, numerous other dikes along the coast of Zeeland and Holland started to collapse, and the resulting flooding was enormous; see Figure 1.1. Events had taken their course. In The Netherlands alone, 1836 people died that night with most of the deaths occurring in Zeeland. Across the east coast of the UK, the coast of West Flanders (Belgium) and at sea, at least a further 500 casualties had to be added. In total, 9% of total Dutch farmland was flooded, 30 000 animals drowned and 47 300 buildings were damaged of which 10 000 were destroyed.

**Figure 1.1** Left: The 1953 great flood in Zeeland and Holland. Right: The area flooded where we have additionally pointed out the location of Hoek van Holland. Sources: Herman Gerritsen (left) and Wikimedia Commons (right)

How severe was the 1953 flood from a historical perspective? Zeeland and Holland have experienced several other major storms in the past. By name, historically the most well-known ones are the so-called Saint Elisabeth flood of November 19, 1421 and the All-Saints flood of November 1, 1570; see Figure 1.2. Estimates for the number of fatalities of the latter storm stand above 20 000.

**Figure 1.2** Left: Flood marks in the delta area of Zeeland. Right: The Saint Elisabeth flood of November 19, 1421, Master of the Saint Elisabeth panels. Sources: Herman Gerritsen (left) and Wikimedia Commons (right)

About a third of The Netherlands lies below sea level, with about two thirds being prone to flooding. The lowest point of The Netherlands, standing at minus 6.76 m, is Nieuwerkerk aan den IJssel (after a merger, now referred to under its new name Zuidplas). It is situated about 10 km northeast of Rotterdam. Under such extreme topographic conditions, an understanding and communication of (especially) flood risk is highly relevant and "living with risk" becomes very tangible. Historically, the protection of the country by coastal as well as river dikes has always been of eminent importance. Below we will give a brief discussion of the world famous Delta Works project, which finds its origin in the 1953 flood event. First however, let us define what we understand by the above "minus 6.76 m". For that, one clearly needs a proper gauge. In the case of The Netherlands, this is the NAP = "Normaal Amsterdams Peil", a well-defined North Sea average level, also referred to as the Dutch National Ordnance level; see Figure 1.3. NAP is also officially the zero level within the European Union. Storm surges and low/high geographical points are always recorded and communicated relative to the NAP. In the case of the 1953 flood, the highest water level reached at Hoek van Holland was 3.85 m above NAP whereas for Zeeland this was 4.55 m above NAP.

Many accounts of the 1953 flood are available and on several occasions, commemoration days have been organized. You should therefore have no problem in finding relevant sources, for example start by searching "Rijkswaterstaat, 1953" to find the website of Rijkswaterstaat, the Dutch Directorate-General for Public Works and Water Management. Before discussing in some more detail the Delta Works, we would like to add two stories, one is fiction, and the other one corresponds to reality. As already stated above, because of its geographic location, sea protection always has been a key aspect of daily life in The Netherlands, as also becomes clear from the country's name. Consequently, several books treat the topic in a direct or an indirect way. A well-known example of the latter is Dodge (1866). In this book, the author tells the famous story of how a boy saves his village from flooding by plugging a hole in a dike with his finger. Whereas this yields a wonderful, even metaphorical, story, during the

**Figure 1.3** Left: NAP, the zero level of The Netherlands and the European Union in the NAP Visitors Centre of the City Hall of Amsterdam; Guus Balkema is pointing his finger at the official NAP zero-level marker and Paul Embrechts is climbing the stairs to find out how far the sea level stands above NAP in Vlissingen at that moment in time (January 20, 2006). Right: Dutch boy saving Haarlem from flooding by putting his finger in a crack of the dike, according to the story told in Dodge (1866). Sources: Authors (left) and Enrico Chavez (right)

1953 flood an event occurred not too far removed from the above story. Indeed, during the storm, some seamen were able to close a breach in an important dike in southwest Holland by first maneuvering and then grounding their boat, De Twee Gebroeders (The Two Brothers), in the already sizable gap. By doing so, they prevented a large, densely populated area near the city of Rotterdam from flooding, and as such no doubt saved many lives; see Figure 1.4. In memory of this act of courage, near the site of the event, a statue was erected with the title “Een dubbeltje op zijn kant” which in the Dutch language means a very rare event symbolized by a small coin (“een dubbeltje”) being tossed and landing on its edge.

## 1.2 The Delta Works

It is important to realize that The Netherlands in the early fifties of the last century was struggling with logistic consequences and rebuilding efforts in the aftermath of World War II. This may also have contributed to the deterioration of some of the dikes along the west coast. In any case, very soon after the 1953 flood, the government took swift action. Already on February 18, 1953, the Delta Committee was set up by the Minister of Transport and Waterways in order to examine “which hydraulic engineering works should be undertaken in relation to those areas ravaged by the storm surge, (and) also to consider whether closure of the sea inlets should form one of these works.” The Committee produced its first findings in May of the same year, together with a more specific report (standing at only seven pages) about one year after the catastrophic event, on February 27, 1954. This report led to the by now famous Delta Plan and the resulting Delta Works. It is important to understand that the Delta Plan was highly ambitious in proposing (of course in several stages) a fully new coastal protection as compared to “just strengthening and raising” the existing dikes. As

**Figure 1.4** Plugging a hole in a dike near Nieuwerkerk aan den IJssel with the boat De Twee Gebroeders. Source: Historical Society of Nieuwerkerk aan den IJssel

stated in Gerritsen (2005): “Until the middle of the twentieth century, a dike was largely characterized by its height. Very little was known about the factors influencing its strength or failure mechanisms. [. . .] The dike height was simply the height of the highest recorded high water plus a safety level of approximately half a meter.” Whereas a combination of statistical analyses based on historical data combined with the strengthening of individual (typically smaller) dikes still played a very important role, the Delta Plan contained in particular the construction of major new dams and barriers (13 in total) across the southwest delta area of The Netherlands; see Figure 1.5.

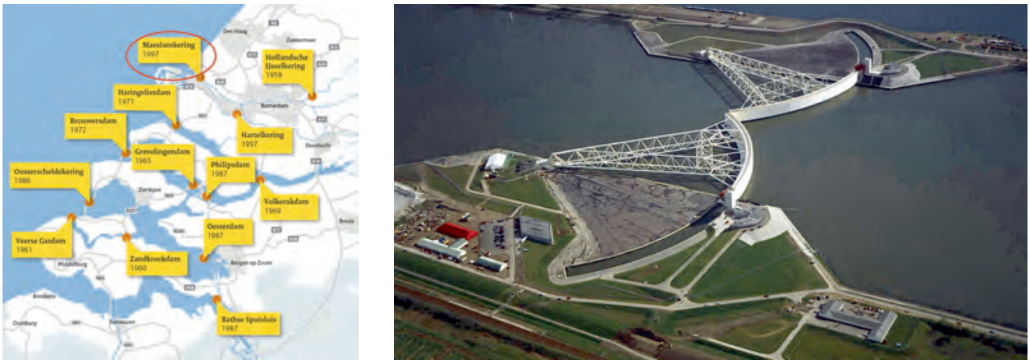

**Figure 1.5** Left: The original 13 storm dikes and barriers from the Delta Works. Right: The Maeslantkering when closed. Sources: © Rijkswaterstaat (left) and Watersnoodmuseum (right)

Construction started with the “Stormvloedkering Hollandse IJssel” (Number 1, already inaugurated in 1958) and included, as main engineering highlights, the “Oosterscheldekering” (Number 9, 1986) and the “Maeslantkering” (Number 13, 1997). The latter consists of two moveable gates, each arm reaching in length the height of the Eiffel Tower; see Figure 1.5. They are designed to protect the important harbor of Rotterdam and its surroundings. The flood barrier at the Oosterschelde warrants a more detailed discussion; see Figure 1.6. The delta area of the Oosterschelde in Zeeland suffered the highest number of casualties during the flood. Original planning started in 1960, initially aiming at a fully solid dam closing off the delta area. This section of the Delta Works, however, took 26 years to complete, far more than any other section and at a considerably higher cost than that originally estimated. The main reason was that, early on, pressure from the local fishing industry as well as an increased environmental awareness caused a fundamental rethinking of the original plans. Prevention of the free in- and outflowing of seawater would destroy the rich delta fauna and flora and impair the livelihood of many people. By 1975, a solution was reached consisting of a 9 km barrier with 62 moveable steel gates that would close as soon as the sea level at a well-defined point along the coast reached 3 m above NAP. In 1953, at that particular location, the level stood at 4.20 m above NAP; see Figure 1.6. There is a further triggering event for the closure of the barrier, namely when the sea level at a line between Stavenisse and Wemeldinge, well within the Oosterschelde, reaches 1 m above NAP.

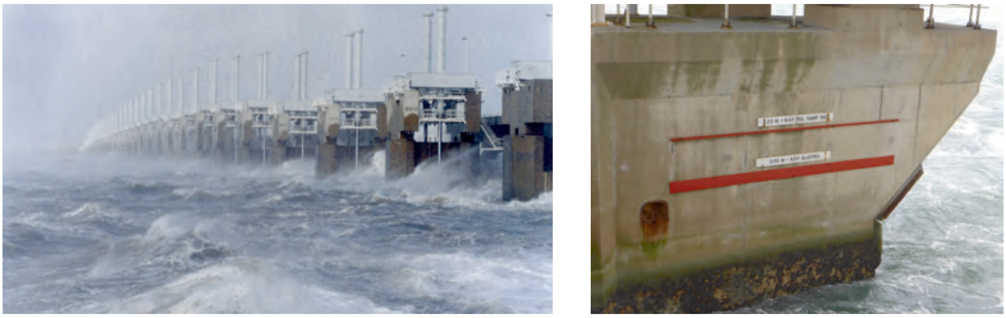

**Figure 1.6** Left: The Oosterscheldekering at Neeltje Jans. Right: Its 3 m and 4.20 m storm-surge markers. Sources: Watersnoodmuseum (left) and authors (right)

Since inauguration, individual moveable barriers and gates, as part of the Delta Works, have been closed on average once a year. It takes about 1.5 hours to close the sluices. On Wednesday, January 3, 2018, Rijkswaterstaat closed all main storm-surge barriers (five in total) on the same day. The American Society of Civil Engineers included the Oosterscheldekering in its list of The Seven Wonders of the Modern World. We highly recommend visiting its construction, which includes a museum reviving the 1953 events, at Neeltje Jans, halfway along the dam. Famous became the official opening words spoken on October 4, 1986 by Queen Beatrix of The Netherlands: “De stormvloedkering is gesloten. De Deltawerken zijn voltooid. Zeeland is veilig.” (The flood barrier is closed. The Delta Works are completed. Zeeland is safe.) Of course, in a way the Delta Works will never be completed. Mechanical deterioration and corrosion, changes in the topography of the sea floor and possible adjustments because of climate change have to be monitored carefully. We will return to these issues in Section 9.5.2. Over centuries, the Dutch have learned to live with the sea both as a friend and as an enemy. As a “friend”: the nearness to the sea contributed importantly to the Dutch Golden Age in the seventeenth century. Its struggle against the recurring storm events led to engineering knowledge now reaching out all over the world. The latter, the “enemy” part, is explicitly recognized in the title “Fighting the arch-enemy with mathematics” of the interesting paper by Laurens de Haan (1990).

Of course, the above brief description of the Delta Works cannot come close to doing justice to the multitude of scientific and engineering innovations that went into the (current) completion of the works. In the sections to follow, we shall touch upon some of the statistical, economic and political discussions which entered into the Delta Plan. The communication of risk will play an important role.

## 1.3 Inside the Delta Plan

Early on, Dutch scientists (mathematicians/statisticians, economists, engineers) paid attention to flood hazards. An early report concerning the north of The Netherlands is known under the name of the Lorentz Report, written in 1918. Hendrik Antoon Lorentz (1853–1928) was a mathematical physicist who received the Nobel Prize in Physics in 1902; his scientific work turned out to be crucial for Einstein’s relativity theory. The 32 km long Afsluitdijk created the large fresh water IJsselmeer. It was built over the period 1927–1932. As reported in Kruizinga and Lewis (2018): “The Lorentz Committee’s work combined state-of-the-art hydrographic modeling of the impact of a new dam on seawater flows with a historical analysis of previously recorded wind speeds and water levels. Based on these data, which the committee itself admitted [were] incomplete, it was suggested that the new Afsluitdijk should be raised by an additional meter to between 7.5 and 7.8 meters above NAP.” This scientific approach, for the first time presented in the Lorentz Report, became the hallmark of Dutch dike constructions. The success of the Afsluitdijk was confirmed during the 1953 flood; though battered, the dike did not give way.

In June 1953, the mathematician and statistician David van Dantzig (1900–1959) accepted the invitation to contribute to the by now famous *Delta Report*; it contains several appendices, some of which we will highlight later on. The original Dutch version of the final report (Deltacommissie, 1961) was signed off by all committee members on December 10, 1960. For a version in English of Part 1, containing the main conclusions and recommendations, see Delta Committee (1962). The full report also contains a contribution by Jan Tinbergen, the Dutch economist who in 1969 was to be awarded the first Nobel Memorial Prize in Economic Sciences. He became one of the founding fathers of the field of econometrics. The key scientific paper, underlying van Dantzig’s analysis for the Delta Committee, is van Dantzig (1956). His important input to Deltacommissie (1961) appeared, in Dutch, under the heading of “The contributions of the Mathematical Center (MC) on storm surges” as Part 3, Contributions II.1–II.5. It was worked out with several collaborators from the MC, in particular J. Hemelrijk, J. Kriens and H. A. Lauwerier. These scientific additions to the Delta Report, referred to as the *van Dantzig Report*, were officially published in September 1960, more than a year after the premature death of David van Dantzig on July 22, 1959. In his foreword to the van Dantzig Report, the then director of the Mathematical Centre, J. F. Koksma, wrote “His death, particularly in view of the current investigations, means a loss that cannot be estimated. There is so much the more reason for thankfulness, that he was allowed to see at least a great part of this work accomplished.”

It is important to understand the challenges that these scientists encountered in influencing the final decision process; their recommendations first had to pass through the necessary political filters before the conclusions could find their way into policy papers ready for public discussion and final legal decision-taking. As several of the discussions and misconceptions from that time are still relevant today, below we recall some of the key ingredients of this process.

Tinbergen and van Dantzig reasoned that absolute safety with respect to flood protection cannot be reached. As a direct consequence, statistical safety measures enter, such as "what is the level of risk with which the population is willing to live?" Typical questions then become "Do we want safety corresponding to a 1 in 100, 1 in 1000 or 1 in 10 000 years flood event, say, and what does this mean? How does one communicate these numbers to politicians and the broader public?" Surely, the dike height to be constructed must be primarily a function of the lives saved but also of the economic value of the protected land and infrastructure. Further, how does one put a monetary value on "lives lost" in case of a disastrous flooding, and last but not least what are the resulting technical-engineering constraints. To put the potential economic losses into perspective, the material loss of the 1953 flood stood at about 10% of GDP. The van Dantzig Report contains an explicit mathematical formula for a necessary increase $\Delta_{\text{height}}$ of the existing dike height (see van Dantzig, 1956, p. 283; combine (12) and (14)):

$$\Delta_{\text{height}} = \frac{1}{\alpha} \log\left(\frac{100 p_0 V \alpha}{(\delta' - \beta)k} \times \frac{1 - e^{-(\delta' - \beta)T}}{1 - e^{-\delta' T}}\right). \tag{1.1}$$

The exact analytic formula is less important in the present discussion. We mainly want to highlight the various input parameters. The crucial output variable $\Delta_{\text{height}}$ stands for the difference between the new dike height and the current, pre-flood one, expressed in meters. It depends on various parameters (the positive $p_0$, $V$, $\alpha$, $k$, $\delta'$, $\beta$, $T$). The constant $p_0$ denotes the probability that a high storm surge topples the current sea dike; it is determined through a parameter $\alpha$ which is estimated from daily high-tide observations. These parameters will become clear later in the book when we discuss extreme value theory. The crucial constant $V$ stands for the value of the "goods" lost as a consequence of a dike breach. We refer to the paper for a discussion on deriving $V$ on the basis of economic data.

The author also briefly discusses actuarial models for valuing "lives lost". The constant $k$ denotes the cost of heightening the dike by one meter. The time horizon $T$ is measured in centuries or fractions of a century. Over such long time horizons, the geological sinking of the land should be taken into account; here the constant $\beta$ enters. Finally, $\delta'$ corresponds to an appropriate discount factor, accounting for the change of the value of money over time. For more specific discussions we again refer to the paper. It is to be hoped that the above summary of the various parameters entering into van Dantzig's formula will convince you that the formula stays close to the initial task set, that of "determining the optimal height of the dikes, taking account of the cost of dike-building, of the material losses when a dike-break occurs, and of the frequency distribution of different sea levels". David van Dantzig stressed very clearly the many shortcomings of the formula and methodological shortcuts he had to take. Personally, we find its derivation a true gem of applied mathematics and recommend that you go over the paper's content in full detail. Our main aim in presenting the formula explicitly was to highlight the power of mathematics in contributing to the solution of such an important problem as determining the necessary heights of protective sea dikes.

In van Dantzig (1956) we find only one specific, though in van Dantzig's words somewhat pessimistic, dike height (p. 284), for Hoek van Holland, of 6.73 m. The word "pessimistic" here takes into account uncertainty bounds for the various constants included in the formula. He personally advocated, as a compromise, a height of about 6 m. It is worthwhile to quote the precise wording used in the paper: "The combination of these extreme values for all constants, however, is rather pessimistic. Several reasonable combinations of values lead to the conclusion that roughly 6.00 m may be considered as a reasonable estimate of a sufficiently safe height". In the end, the Delta Committee went for 5 m above NAP, which corresponded at the time to a heightening of the existing dike by 1.15 m. Needless to say, van Dantzig was not particularly happy with this decision.

More recently, several papers have been published improving on or criticizing (parts of) the van Dantzig formula. With hindsight, some of these more recent criticisms are justified. However, the methodological, data-oriented, statistical as well as economic approach that was present in van Dantzig's work was innovative and of the utmost importance. It served (still serves) as a guiding light for generations of risk managers.

Below we recall part of the resulting political discourse surrounding the Delta Report, as its implications for wider risk management are highly relevant. We quote part of the decision process from Kruizinga and Lewis (2018) as it perfectly reflects the difficulties one encounters when communication of risk and rare events to politicians and a broader public becomes important.

> [. . .] the Delta Committee agreed that the report addressed to the Minister of Transport, Public Works and Water Management needed to be massaged in order to help him sell the necessity of spending about 1.5 to 2 billion guilders (roughly between 8 and 11.5 billion euros in 2018) on the new integrated system of dikes and sea defenses. It was also agreed that the report would omit any mention of methodological uncertainty. Furthermore, the report would not go into details as to the risks of future storms, as these would need to be expressed in the form of statistical probabilities. It was feared that the public would be confused by statements such as 'statistically once every 125 000 years'. The Delta Committee feared the public would misinterpret this statement and think that The Netherlands would be safe for the next 125 millennia rather than there being a 0.0008% chance of a storm of a certain magnitude occurring every year.

Important takeaways from the above quote are the need for a clear political communication, the suggested (even ordered) omission of uncertainty, and the possible misinterpretation of the statistical meaning of return periods by the public. The 1 in 125 000 years event mentioned in the above quote refers to the large economic and social loss potential for the "Randstad" (the built-up area around major cities like Rotterdam, Amsterdam and The Hague) in the case of a serious flood. In its conclusion, the Delta Committee settled for a 1 in 10 000 years safety measure resulting in a 5 m above NAP dike height at Hoek van Holland. The "1 in 10 000 years" became the so-called Dutch National Standard. This standard only applies to the more exposed areas like Hoek van Holland and indeed different safety requirements hold for different coastal areas and river basins, ranging from 1 in 250 to 1 in 10 000. We will continue this important discussion after we have analyzed historical sea-level data for Hoek van Holland in Section 9.5.2.

As already stated above, the Delta Works are never finished. And indeed, Veerman and Stive (2008) contains the findings of the new Delta Committee. Its mandate from the government was "to come up with recommendations on how to protect the Dutch coast and the low-lying hinterland against the consequences of climate change. The issue is how The Netherlands can be made climate proof over the very long term: safe against flooding, while still remaining an attractive place to live, to reside and work, for recreation and investment." One of its 12 recommendations was that all diked areas must be improved by a factor 10, hence the standard safety measure would move from 1 in 10 000 to 1 in 100 000. For a somewhat differentiated view on this recommendation, see Kind (2014). It is clear that climate change enters the equations in a fundamental way; the (new) Delta Committee concludes 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. [. . .] These values present plausible upper limits based on the latest scientific insights.

This brings us to a very pivotal point in time. We started with a major flood catastrophe on January 31 to February 1, 1953, and discussed the way in which a country, in this case The Netherlands, faced the consequences and came up with a technical engineering solution in order to avoid such events in the future, and this with a (very) high degree of certainty. In the meantime, science has given us further knowledge on future climatological scenarios, which of course have a strong bearing on flood risk. Dutch society has to (and actually did) react to these threats and came up with protective recommendations for generations to come. The following quote from Veerman and Stive (2008) on the ever-increasing need for scientific advice is worth stating explicitly (we will come back to the work of the IPCC in Section 10.1):

> The Delta Committee sought scientific advice on a number of aspects, which form part of the present recommendations. In summary, these are the findings of a group of national and international experts, including those close to the IPCC (Intergovernmental Panel on Climate Change) and Dutch experts on flood protection and water management. This group of experts has supplemented the latest insights into climate scenarios, and come up with new estimates of extreme values.

We stress this statement as all too often scientific advice and expertise is frowned upon by (some) politicians worldwide, especially when it is related to climate change and its societal consequences. Besides possible reinforcements to the various existing dikes, most recently a further factor entered the discussion. As several of the moveable barriers are driven by IT systems, cyber risk becomes of great concern. In its 2019 Annual Report of the Delta Programme to the Dutch Parliament, the Delta Committee highlights this new type of risk. It strongly advises measures to be taken to make the computer systems of the various barriers sufficiently resilient against cyber attacks. Of course, the key question is whether in the end all the effort has paid off. In a way this question is unanswerable, especially as dike constructions are very long-term projects. What can be said is that, at the time of writing this book, The Netherlands have been safe behind their coastal defenses and that the various dikes have so far stood the test of time. An important question then naturally becomes: "What can other countries learn from the Dutch experience?" Of course on the engineering side a clear answer is available: "A lot!" Dutch engineers and firms are already exporting the technical knowledge obtained throughout the Delta Works to the rest of the world. Examples range from the building of levies in New Orleans to land reclamation in Singapore. However, as already stated above, one can never make a one-to-one translation from "what worked in The Netherlands" to "what would work in country X". This is perhaps less relevant for the technical engineering side, but it is surely true for the political socio-economic side. An excellent discussion on this, where X stands for the United States of America, is Iovenko (2018). From the latter paper we borrow the following statement: "The greatest lesson to be learned from the Dutch is perhaps less about engineering and more about mindset and culture." The author then continues by quoting from the book of Goodell (2017).

> It's easy just to talk about technological and engineering solutions, but a lot of the problems surrounding sea-level rise are legal and political. The Dutch have a legal and political system that is united around dealing with water issues; they've been doing it for a thousand years. Here in the US, it's not getting the right engineering ideas figuring out what technology or design ideas we're going to use. It's that our legal system and our political system are just not adapted to thinking about sea-level rise in any kind of holistic way.

At the end of this chapter, we would like to honor three scientists who contributed fundamentally to the success of the coastal protection in The Netherlands. Of course there are so many more names to be mentioned, but we chose Hendrik Antoon Lorentz, David van Dantzig and Jan Tinbergen; see Figure 1.7. They were able to step down from the pillars in their ivory tower, go beyond the typical academic thinking, and engage in truly interdisciplinary research. Their contributions have been fundamental towards making the Dutch population feel safe behind the dikes constructed. The world as a whole benefits from their original and courageous thinking.

**Figure 1.7** Hendrik Antoon Lorentz (1853–1928) (left); David van Dantzig (1900–1959) (center); Jan Tinbergen (1903–1994) (right). Source: Wikimedia Commons

## 1.4 Lessons Learned

Throughout the book, we will return to the 1953 flood several times, as it is indeed a blueprint for lessons to be learned when dealing with extreme risks. We have learned how a country, The Netherlands in this case, reacted politically as well as scientifically to an existential environmental threat. The time scale, and hence the planning of underlying dike constructions, may run into hundreds of years and as such needs full societal support over a much longer time period than is normally found on political agendas. A key component underlying the Delta project is interdisciplinarity. In the case of the very important Oosterscheldekering, already environmental considerations were actively taken into account. We also learned how difficult the communication of an imminent risk to the population was in pre-social-media times. For the first time we met the notion of a risk measure, a return period, and the difficulty science faces in communicating statistical uncertainty in its estimation. In Chapters 8 and 9 we will review the key techniques from probability and statistics needed to address these issues. In particular, in Section 9.5.2 we present a detailed analysis of sea-level data at Hoek van Holland. By now, the technology underlying the engineering of coastal defenses has become a Dutch export product *par excellence*. An interesting exercise consists of comparing and contrasting different dike constructions worldwide; as examples we would like to mention New Orleans (USA), Pulau Tekong (Singapore), the Thames Barrier (UK) and the MOSE project (Venice), the first of which we will briefly meet later in the book.