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What happened in 1953? The Big Flood in the Netherlands in retrospect

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During the weekend of Saturday 31 January to Sunday 1 February 1953, a storm tide raged across the northwest European shelf and flooded the low-lying coastal areas of the countries around the North Sea. The peak high waters occurred during the night and the storm surprised many people in their sleep. The resulting disaster in terms of loss of life and damage to infrastructure was enormous. In the Netherlands, 1836 people fell victim to the flood; in the UK and Belgium, the casualities were 307 and 22, respectively. The large number of fatalities in the Netherlands was related to the fact that much of the affected area is below sea-level.

This paper focuses on the case of the Netherlands. It discusses the history of land reclamation, and the fact that living in low-lying areas protected by dykes, often below sea-level, is an accepted fact of life in the Netherlands. The historical approach to dyke maintenance is then outlined, and the state of the dykes in the early twentieth century and after the war is discussed. The characteristics of the storm and the flood are discussed, along with people's experiences of the first hours and days following the flood. The impact of this human stress has often been lasting many survivors continue to live with daily memories of the flood. Attention is given to the large-scale rescue and relief efforts, the closure of the dykes during the following nine months and the concept of the Delta Plan, designed to prevent such a large-scale disaster ever happening again. Although the 1953 storm was indeed a low probability event leading to very high storm-induced water-levels, and occurred in combination with spring tide, several arguments are presented that explain why this flood turned into a disaster of such a large scale. Equally, the question is raised whether the disaster could have been prevented. The paper concludes by noting the importance of awareness and preparedness in order to prevent a future storm threat of this scale turning into a disaster of the scope of the Big Flood of 1953.

Keywords: storm surges; coastal flooding; human stress; storm surge barrier; hazard preparedness

1. Introduction

The present paper presents an overview of the events of the 1953 Big Flood and puts them into a historic context. It focuses on the situation of the Netherlands,

One contribution of 14 to a Theme 'The Big Flood: North Sea storm surge'.

which in several respects, differs from the British situation. Although the weather and the tidal and surge motion in the North Sea are largely shared by the two countries, the different geographical position, form of coastline and the physical geography of the Netherlands leads to a different flood threat. The key feature is even reflected in two of the names for the country: the Netherlands or the Low Countries. In many areas in the northern, western and particularly the southwestern parts of their country, the Dutch live below sea-level.

The paper considers the normalcy of living below sea-level and living with flood threats, and the safety and preparedness of the coastal areas for a threat from the sea. Next, the storm and the situation during the first hours of the flood are described along with the efforts to prevent and limit dyke breaches and inundation. Impressions are given of the rescue and relief efforts and the closure of the dykes for the nine months that followed. Some arguments are presented against the view that the disaster could have in fact been prevented. Several factors that contributed to the turning of a natural event into a disaster of such scope are considered. Finally, this paper stresses the importance of awareness and preparedness for preventing a future storm threat of this scale from becoming a disaster of the scope of the Big Flood of 1953.

At the time of the flood, the author was not yet four years old, living in the eastern part of the country, with a street level at 10.6 m above NAP (Dutch National Ordnance Level; roughly equal to long-term mean sea-level along the Dutch coast). The historical parts of this overview are not based on personal experience or in-depth research by the author. Rather, they are largely based on existing material such as the official government documents on the flood and the subsequent flood protection works (Deltacomissie 1961; Rijkswaterstaat & KNMI 1961), while the later monographs of Slager (1992) and Van der Ham (2003) have provided both factual material and eyewitness accounts for this paper.

2. Living below sea-level

The Netherlands is a low-lying delta-type region, where three large rivers, the Rhine, Meuse and Scheldt, discharge into the North Sea. A long line of natural dunes stretches along the coast at places intersected by the river inlets that are part of the delta. Without the present dykes and other flood protection measures, approximately half of the country would be vulnerable to flooding. Until approximately a millennium ago, land freely accreted and eroded because of the dynamic behaviour of the sea and the rivers (figure 1). The local population lived on the higher land or on artificial mounds, protected by a simple dyke.

From the thirteenth century onwards, natural accretion was furthered when the local population built small dykes to keep areas that dried at low water more permanently dry. Later, this was followed by more planned, larger scale reclamation by damming and draining, creating so-called 'polders'. (The Dutch word 'polder' refers to a low-lying area, often below sea-level, which is prevented from flooding by a dyke constructed around it, and which needs to be drained from upcoming groundwater.) Along the northern coasts of the Netherlands, but particularly in the southwest or delta area, this small-scale but continuous land reclamation has resulted, over many centuries, in a landscape in which the

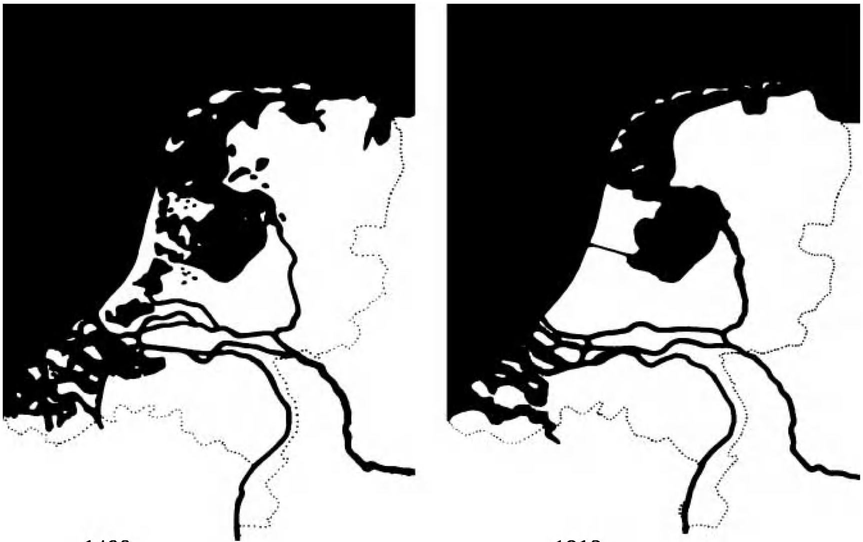

Figure 1. Physical development of the Netherlands: net result of natural sedimentation and erosion plus active coastal and inland land reclamation (based on Van Veen 1962).

original dykes are still visible. When these dykes no longer have a primary sea defence function, they are called 'sleeper dykes'.

On the islands of Walcheren and Schouwen, however, hardly any sleeper dykes exist, as these islands were largely already in existence in the thirteenth century (figure 2; Van Veen 1962). The local inhabitants shared the burden of maintaining the dykes and keeping their dammed polder dry. These structures of cooperation, called 'polder boards' or 'water boards', formed a vital and effective early form of local and democratic government, which exists to the present day.

3. The role of the polder or water boards

In the early twentieth century, this system of polder boards or water boards, in which the burden of dyke maintenance and draining is shared by all who directly benefit, still functioned as it had for many centuries. The principle was still that every polder board was responsible for its own dyke or dykes ('Elc sinen dyke'; Slager 1992). In the southwest, where stepwise reclamation had enlarged many of the originally small and vulnerable islands and joined them into larger, much better protected ones, there were now more than 200 polders with their own independent polder boards. Some consisted of only several dozen farmsteads and households. All kept their specific dyke in order. Steam (and later turbine-based) pumping stations had replaced the windmills used for drainage, although in many places, windmills could still help when needed.

In this delta area, the communities lived largely below the high-water mark and even below sea-level, protected by their own dykes, in their own polder and—in relative isolation—on their own island. Sometimes, floods were

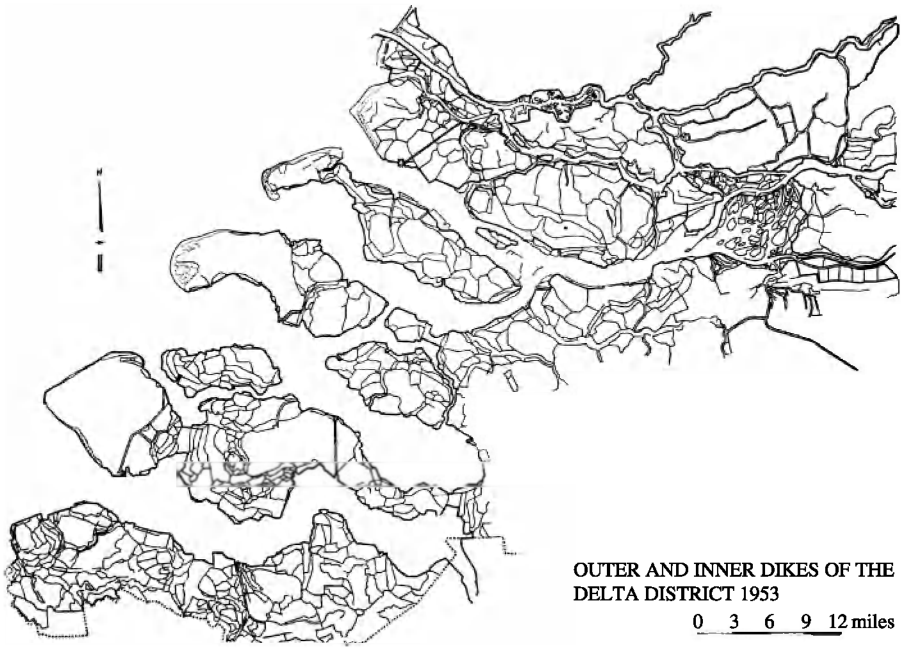

Figure 2. Outer and inner or sleeper dykes in the delta area, resulting from step-by-step land reclamation (source: Rijkswaterstaat, the Hague).

experienced (figure 3). This was accepted by the people as an act of nature, which can never be fully tamed, or it was seen as simply the consequence of some neglected and quickly repaired, local dyke stretch. Alternatively, for some, it was accepted as the will of God (Slager 1992). The people realized that absolute safety did not exist. However, they created a physical environment and a unique system of mutual cooperation in the form of polder boards that allowed them to live below sea-level and to live with the threat of the sea.

4. The state of the dykes in the early twentieth century

Until the middle of the twentieth century, a dyke was largely characterized by its height. Very little was known about the factors influencing its strength or failure mechanisms. Historical practice determined its construction, its height and its slope (Van Veen 1962; Slager 1992). The bulk material for its construction was generally clay or less cohesive sandy clay, which was put on a clay foundation with a subsoil of (sandy) clay, sometimes sand or even peat. The dyke height was simply the height of the highest recorded high water plus a safety level of approximately half a metre (Battjes & Gerritsen 2002). The landward side often was rather steep, with a ratio of 1 : 2, or even 1 : 1.5, while the seaward slope from the low water-line commonly had a ratio clearly steeper than the present maximum ratio of 1 : 3. The seaward face was generally covered with Vilvoordse break stone, or basalt, while the landward face often had a simple grass covering.

A recurring feature in the southwestern delta area was the so-called dyke-fall or flow slide in areas where the tidal channel came close to the toe of the dyke,

Figure 3. Flood marks in the delta area (from Van Veen 1962).

such as along the western Scheldt and along Noord Beveland. Usually occurring at extreme low water, the dyke collapsed by sliding on the seaward side. The mechanism behind this failure is related to the different ground-water pressures outside and inside the dyke, which may cause liquefaction of the loosely packed sand of the underwater slope, leading to a seaward sliding of the whole dyke. Between 1900 and 1940, dyke falls occurred some 140 times (Van Veen 1962). The main innovation in dyke construction was introduced in the early twentieth century, after the 1906 flood. Along many dyke sections, low concrete, so-called 'Muralt', walls were constructed along the dyke crest, to reduce wave overtopping (Van Veen 1962; Slager 1992).

The official provincial supervision of the state of the dykes largely existed only on paper. Recommendations for the centralization of the polder boards in the southwest made after the evaluation of the 1906 flood, in order to coordinate dyke maintenance and dyke improvements, were effectively resisted by the boards. Until after 1945, hardly any merging of polder boards took place, and there was no overall approach to dyke maintenance. Only in a few cases, the Rijkswaterstaat (the national public works organization) or the Provinciale Waterstaat (its counterpart at the provincial level) used its authority for effective supervision of dyke maintenance (e.g. on Goeree; Slager 1992).

War-related construction in the period between 1940 and 1945 also affected the state of the dykes. Military bunkers, and even whole complexes, were built into the dykes as part of the military defence system against an expected attack from the sea. Machine-gun units and manholes were dug, and piping was laid through the dyke (Slager 1992). Since the dykes were in now closed military areas, undermining by rabbits and moles increased. After the war, many of these weak spots were insufficiently repaired by filling up the holes. Of course, this has to be viewed in the context of the many priorities at the time in terms of repairing the infrastructural devastation that had occurred during the war.

In 1953, the weak spots mentioned above often proved to be the locations where the dyke first gave way. Most dykes started to collapse from the inside. The primary cause was wave overtopping, which led to penetration and subsequent saturation of the landward side with water. On steep slopes, this quickly led to sliding and collapse. The first visual impact of such a failure often was an along-crest crack at the landward side, often only some 10 cm wide. This absorbed the overtopping water, which seeped down and exited at the dyke toe. This erosion of the dyke base then led to sliding and overall collapse. Overall, the state of the dykes in 1953 left much to be desired—in respect to their height, their slopes, overall strength and the maintenance approach.

5. The 1953 flood

(a) *The storm track and surge heights in the southern North Sea*

In comparison with other major storms and floods in the Netherlands, such as those that occurred in 1894, 1906 and 1916, the depression of the 1953 storm field was not exceptionally deep, but its storm track was different and its propagation somewhat slower. From the Atlantic, it moved east to the north of Scotland after which it curved sharply southward to propagate into the German Bight and then proceeded in a southeasterly direction over land (figure 4).

This was a track much closer to the Netherlands than any of the preceding storm tracks on record. As a result, storm winds from the northwest were stronger and more sustained, leading to a higher and more sustained surge. Much insight into the detailed behaviour of the storm and the flood over sea and along the coast has been gained from modelling the 1953 storm surge with the Dutch continental shelf model or DCSM (see Gerritsen & Bijlsma 1988; De Ronde & Gerritsen 1989).

Figure 5 presents the maximum surge-height distribution (the wind-induced part of the water-level) in the southern North Sea during the storm. This occurred on 1 February 1953 at 03.00 GMT. Figure 6 presents both the total water-level and the storm-induced surge effect for Hoek van Holland and Vlissingen. The figure shows that the maximum surge occurred at the time of spring-tide high water. Because the time of the surge surge peak coincided with the time of spring-tide high water, the total water-level reached heights that, in many locations, exceeded those recorded ever before.

It is clear that all of the southern North Sea—the English east coast, Belgium, the Netherlands, and parts of the German coast—was affected by the storm surge.[1] Although this large-scale DCSM model does not permit detailed modelling of the flow in the delta inlets, nor the inundation process, it is clear that with the further resonance in the basin, the local water-level inside the inlets was even higher—much higher than many dykes could withstand.

During the night and over the following days, some 150 dyke breaches occurred in the sea dykes—the primary sea defences, later followed by more breaches in the inner or sleeper dykes (see figure 7). At the time, some 750 000 people lived in the

[1] The animation of the development of the modelled surge heights during the 1953 storm can be viewed at http://wldelft.nl/goto/surge1953.

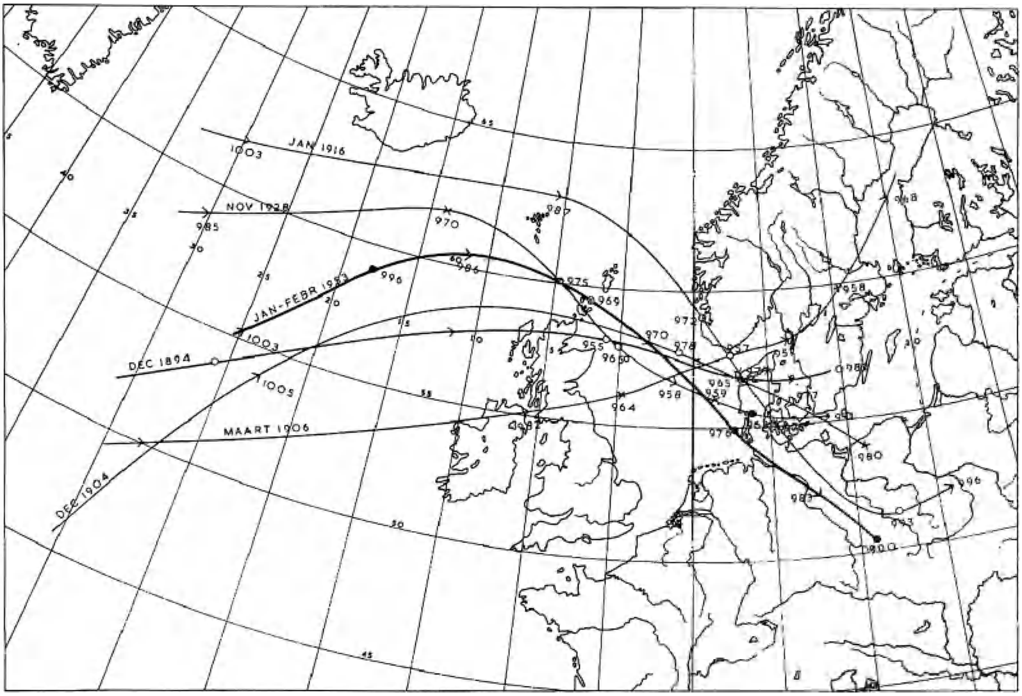

Figure 4. Storm track of the 1953 storm compared with other major storms (source: Rijkswaterstaat, the Hague).

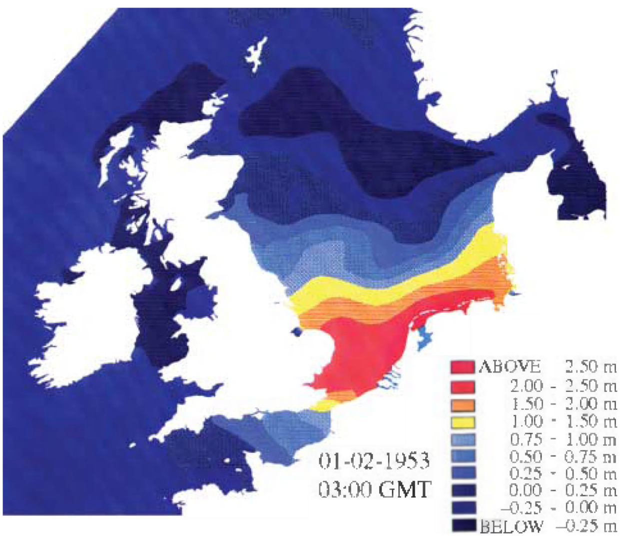

Figure 5. The distribution of the storm-induced water-level over the southern North Sea at the time of maximum surge, which coincided with spring-tide high water (from De Ronde & Gerritsen 1989).

affected areas, of which about 136 500 ha were inundated. As a result of the flood disaster, a total of 1836 casualties occurred, tens of thousands of livestock perished, and approximately 100 000 people were evacuated. The damage to buildings, dykes and other infrastructure was enormous.

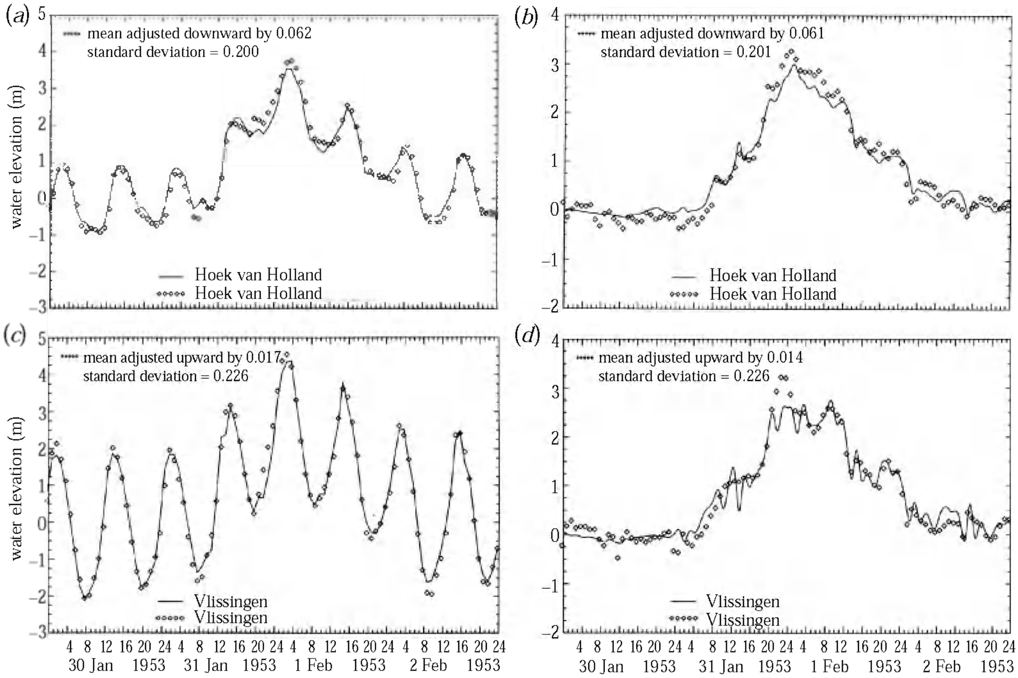

Figure 6. Observed model hindcast time-series of the total water-level and the storm induced parts for Hoek van Holland and Vlissingen for the 1953 storm (from De Ronde & Gerritsen 1989).

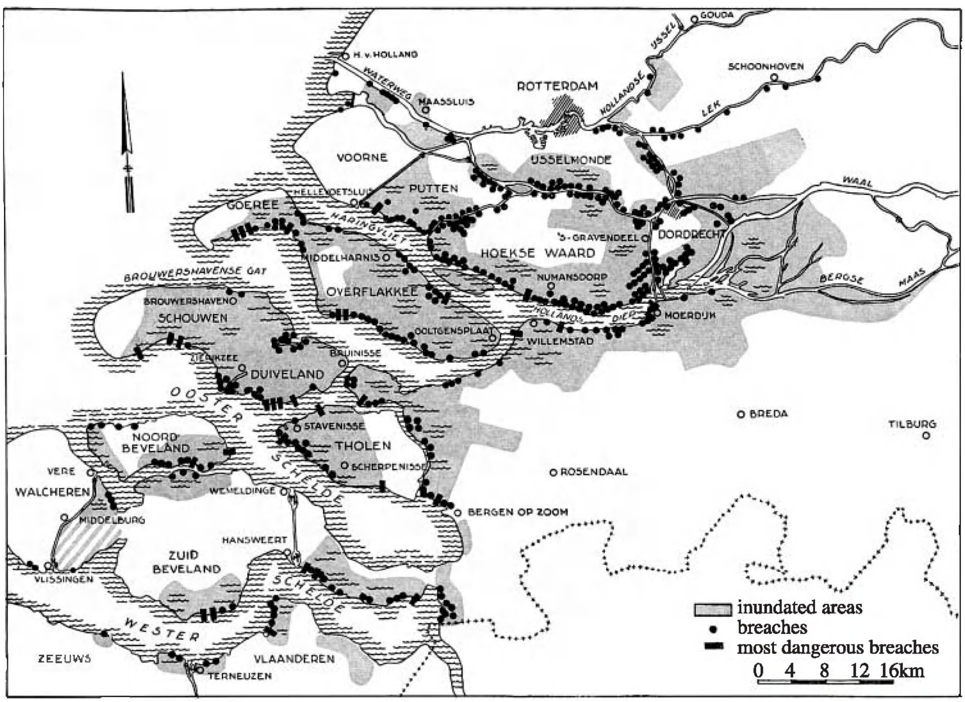

Figure 7. Extent of inundations during the 1953 storm (source: Rijkswaterstaat, the Hague).

(b) The storm surge warnings

The Netherlands' storm tide warning service (SVSD) was created in 1921 as part of the Royal Netherlands Meteorological Institute (KNMI). In case the weather forecast gave reason to expect a water-level significantly higher than the tabulated astronomic tide-levels, SVSD became operational. Its tasks were to formulate a warning in terms of 'considerable high water' or 'dangerous high water', for the relevant sections into which the delta area, the central coast and the Wadden area to the north had been divided. Warnings would be distributed by national radio as part of the regular weather information, and by telegrams.

On the evening of Friday 30 January, KNMI noted the development of stormy weather behind a depression south of Iceland, which created incredible wind speeds north of Scotland. At 11.00 on Saturday 31 January, the first telegram and message of the SVSD was sent out (Flameling 2003): 'Over the northern and western parts of the North Sea a strong gale rages between northwest and west. The storm field is extending further over the southern and eastern parts of the North Sea'. During the day, the situation worsened and the radio bulletins were adjusted accordingly. Around 18.00, the warning telegram and radio bulletin were extended: 'It is expected that the storm will continue all night and given this fact, this afternoon at 1730, the areas of Rotterdam, Willemstad and Bergen op Zoom have been warned for dangerous high water' (Slager 1992).

Dr K. R. Postma of KNMI, who was on duty that Saturday, recalls that such a warning telegram had not been issued in many years (Slager 1992). In the weather room that Saturday afternoon, the staff realized that the situation was very serious in terms of very or extremely dangerous high water, although such more quantified assessments were not forseen in the SVSD procedures. KNMI's responsibility was confined to sending the warning telegrams and submitting the radio weather bulletins, which were repeatedly broadcast on the radio as part of the weather bulletins. The latter stopped at midnight, since the radio broadcasts were stopped from midnight until early morning. In that respect, the night of 31 January–1 February was no different from any other.

KNMI sent the above telegrams to the authorities and organizations that had subscribed to that service. In 1953, there were 30 subscriptions. Among these were a number of directors and departments of Rijkswaterstaat in the Hague; three water boards: Delfland, Hoeksche Waard and Walcheren; two mayors: Willemstad and Ooltgensplaat and various others. There were no subscriptions, however, on the islands of Schouwen-Duiveland, Noord and Zuid-Beveland, Tholen, St Philipsland and Goeree-Overflakkee, all located in the delta area (Slager 1992). Of more than 200 water boards, only one (Walcheren) would be warned by telegram of an expected unusual high water, even though these were the organizations responsible for the dykes.

Although during the 1953 storm threat, official warnings of dangerous high water were issued by radio and telegram, these communications were largely ineffective given that the event took place during the weekend. When the high water peak occurred between 03.00 and 04.00, the radio had been off the air for hours and would remain so for several more. Private telephones were not yet widespread, and the islands were effectively isolated during the night, after the ferry boats had stopped. Moreover, all but a few people were in bed. As a result,

Figure 8. Breach at Ouderkerk aan de IJssel, upstream along the tidal reach of the river Hollandse IJssel, at the time of tidal low water (from Van Veen 1962).

the surprise attack of the flood occurred in much the same way, from village to village, polder to polder, island to island.

(c) Impressions of the immediate response during the first day

The night and the day of the storm are best characterized by chaos and on the spot improvisation (Slager 2003). In some places, one or two people who did not trust the situation, stayed up, alerted their neighbours and the mayor and, in the raging gale, mobilized men to try to save the dyke, woke up people and evacuated people in the low-lying polder to safer locations nearby. This was not as straightforward as it seems. The water board was responsible for the dyke, while the mayor had the responsibility of coordination in emergencies. Nothing, however, had been arranged for cases like the breaking of a dyke and flooding (figure 8). Moreover, there were no formal disaster plans in place (Slager 1992).

Based on the hundreds of eyewitness accounts (see Slager 1992) as well as official material, a picture emerges of confusion, disorder and chaos, with some positive exceptions. Exceptions included situations where, early in the night, a person assumed the role of leader and organized the activities. As Slager (1992) notes, this could be a mayor, somebody from the Dike Council or just some concerned 'non-official' inhabitant(s). Such was the case in the town of Scherpenisse, where early on the Sunday morning, the strongly Christian men assembled not to go to church but to save their dyke. Their work was successful, and there were no casualties. In Ooltgensplaat, the mayor heeded the telegrammed warning, and took the lead. Only two casualties resulted. In the neighbouring Oude Tonge, the mayor hesitated and started coordinating much too late. The casualty count in Oude Tonge alone was 305—more than in any other town (Slager 1992). That night, hesitation and indecisiveness often proved to be fatal. Equally serious were the cases in which wrong decisions were made, especially where motives other than safety played a role. One case was that of

Figure 9. The ship that closed the dyke breach and saved the central parts of Holland from flooding (from Slager 1992; photo: C. van Gennip).

farmer Sieling, who noted that at the time of low water, the water slightly flowed back through the still small breach in the dyke near Herkingen. He concluded that the breach should be enlarged by removing the clay toe of the dyke to let the water flow to sea more quickly than would be possible by using the pumping station. As a member of the Dike Council, he overruled the urgent pleas not to do so. His action to prevent salt water ruining his land eventually led to a 300 m wide tidal gap, washing out to a depth of 10–14 m. 2500 trucks with stone and rubble and 100 000 sandbags were needed to close this scornfully called 'Sieling Canal' 6 weeks later (Slager 2003). There were also cases of heroism, such as that of Nieuwerkerk aan de IJssel to the east of Rotterdam. Here, a noted weak spot in the dyke collapsed at approximately 05.00, threatening to flood the vast low-lying area behind. Parts of this polder area are over 6.5 m below sea-level, making it the lowest polder in the country. Mayor Vogelaar resolutely commandeered a nearby river freight ship and ordered skipper Evegroen to manoeuvre it into the dyke breach and sink it (figure 9).

Immediately consolidated with tarps and sandbags, the ship closed the breach and prevented the inundation of Central Holland, saving its 3 million inhabitants from the flood (Slager 2003).

(*d*) *The rescue and support from outside the stricken area*

On Sunday 1 February, the scope of the disaster gradually became clear to the outside world, and the regional and national authorities started to take stock of the situation and to set up larger-scale coordination (Slager 1992, 2003). From that day, hundreds of people from all ranks of society took the train to the area to help. Although much of that help was badly needed, it increased the already large logistical problems. For the isolated islands, which already had a complex communication system of ferries and roads along dykes, logistics quickly proved to be the main problem (figure 10). Rescue workers, equipment, food, fresh water and medication had to be brought in, while casualties, particularly

Figure 10. Rescuers arrive at a flooded farm on the island of Flakkee (from Anonymous 1953; photo: H. Jonker).

the elderly and children, had to be taken elsewhere. The Dutch army, with its amphibious vehicles, was brought in at an early stage to support the evacuation and to provide help in sandbagging the dykes. French and American military worked wonders by shuttling food and people by helicopter to and from the remote areas, in addition to providing local support using small boats and skiffs. After a few days it was decided to also evacuate the less affected areas, such as Zierikzee, largely for reasons of logistics (Slager 1992). People and cattle had to be evacuated given the shortage of available space and food. Cadavers had to be removed for fear of potential epidemics. At the same time, thousands were working on the dykes and on general clean-up activities. The human stress that the flood and its aftermath brought about should not be underestimated. The exposure to this stress was not limited to only the first days; it continued for many months; during the evacuation, the return, the cleaning up and the gradual building of a new life. For many of those who were affected, that stress continued for the rest of their lives (Slager 1992).

(e) *The closure of the dykes to stop the tide coming in twice a day*

The ground level of much of the inundated land in the Netherlands was below the level of tidal high water. An immediate concern (apart from rescue operations) was therefore the closure of the dyke breaches. This was an extremely urgent issue as, after the storm and the surge had disappeared, the tide would still come in and go out twice a day, threatening to further enlarge existing gaps by erosion. Obviously, the extent and complexity of the closures and the repair works were far beyond the technical and financial capabilities of the polder boards (Slager 1992).

(a) (b)

Figure 11. Hydraulic scale-model of the caisson closures at Hellevoetsluis (*a*) and Ouwerkerk (*b*) (source: WL|Delft Hydraulics, Delft).

The overall coordinating authorities, aware of the various conflicting decisions that had been taken at the local level, realized that overall safety could only be obtained by a well-coordinated approach. It was therefore determined by special government decree that the national government would fund the cost of the reconstruction and that the Rijkswaterstaat would be in charge of the closure works, with the polder boards providing assistance where needed (Van der Ham 2003). During the month of February, some 60 breaches in the primary sea defences were closed, some already by the first or second day after breaching.

(*f*) *The use of caissons and hydraulic scale-modelling*

The closure of the remaining 89 gaps proved to become increasingly complicated with time. Twice daily, flood and ebb tide rushed in and out, enlarging these tidal gaps and eroding the weak foundations, in several cases to well over 20 m. The experience with the closure of the four large dyke breaches after the inundation by the Allied forces of the island of Walcheren from 1945 to 1946 now proved to be very valuable. At the time, several $62\times19\times18$ m Phoenix caissons from the Normandy invasion had been used for the closures. To manoeuvre these unwieldy elements, detailed hydraulic scale-model tests in a specially built Walcheren physical scale-model at Delft Hydraulics had preceded the closures, to provide the optimal circumstances and closure approach.

For the closure of these remaining tidal gaps, hundreds of specially designed caissons of 11×7.5 m were constructed, which could be joined together to make larger units, while another seven of the mammoth Phoenix caissons were acquired for the most complex closures (Rijkswaterstaat & KNMI 1961). A number of closures were first simulated by dedicated hydraulic scale-model tests to define optimal closure techniques and circumstances (figure 11). The four largest and most complex tidal gaps were those near Kruiningen on Zuid-Beveland (closed 24 July), and the Schouwen-Duiveland locations Stevenssluis (closed 28 July), Schelphoek (closed 27–28 August) and Ouwerkerk. Of these, the Schelphoek closure, with its 520 m wide and 36 m deep gap, was recognized as the most complicated and was planned as the last closure. The Ouwerkerk closure on 24 August failed, however, and this last remaining closure could only be attempted again 2 months later on 6 November, when the gap was indeed

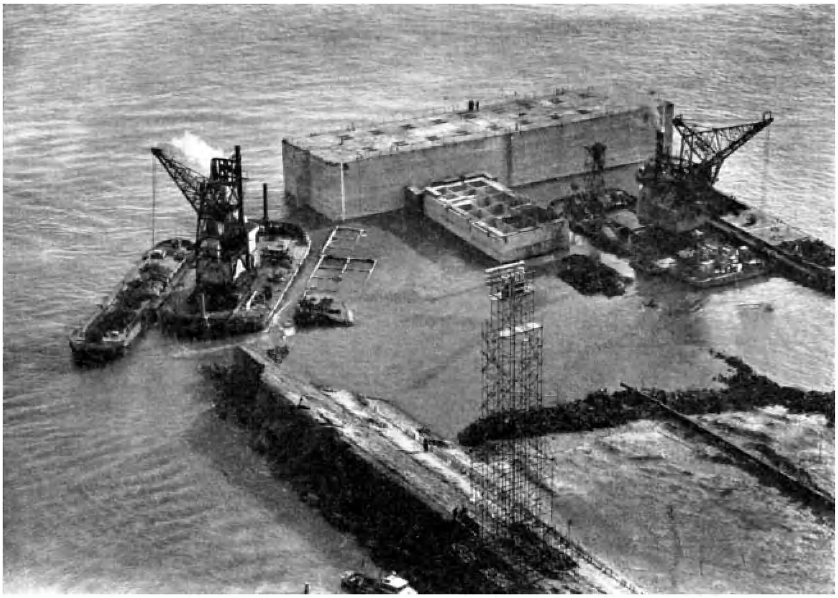

Figure 12. Preparations for the Ouwerkerk closure, 3 November 1953 (source: Rijkswaterstaat, the Hague).

successfully closed (figure 12). Overall, it took a total of 9 months before all gaps were closed, just before the onset of the winter storms of that year (Rijkswaterstaat & KNMI 1961).

With the closure of Ouwerkerk, the island of Schouwen-Duiveland was the last of the inundated areas to be pumped dry. It was officially declared dry on 31 December 1953, although it took many years before the land so drenched with salt returned the agricultural yield of the years before the flood.

6. The actions to prevent future floods

(a) *Establishment of the Delta Committee*

On 18 February 1953, only 17 days after the disaster took place, the Delta Committee was installed. Its task was 'to develop measures, in order that such a disaster could not happen again'. It was able to draw on a series of reports and plans produced by the study service of Rijkswaterstaat and the 1939 Flood Tide Committee on the safety of the delta. These materials and analyses, prepared in the two decades before 1953 by engineers and scientists of Rijkswaterstaat, had already highlighted the insufficient safety against floods of many parts of the delta area. However, the materials' status was largely that of specialist analyses and plans for scientists and senior staff. Owing to a combination of internal disagreements between the old and modern schools of civil engineering, the outbreak of the war in 1940 and the priority of rebuilding infrastructure after 1945, specific proposals and cost estimates to parliament did not eventuate (Lintsen 2003; Van der Ham 2003). The driving force behind many of these studies on the dangers of serious flooding in the delta and the plans for its

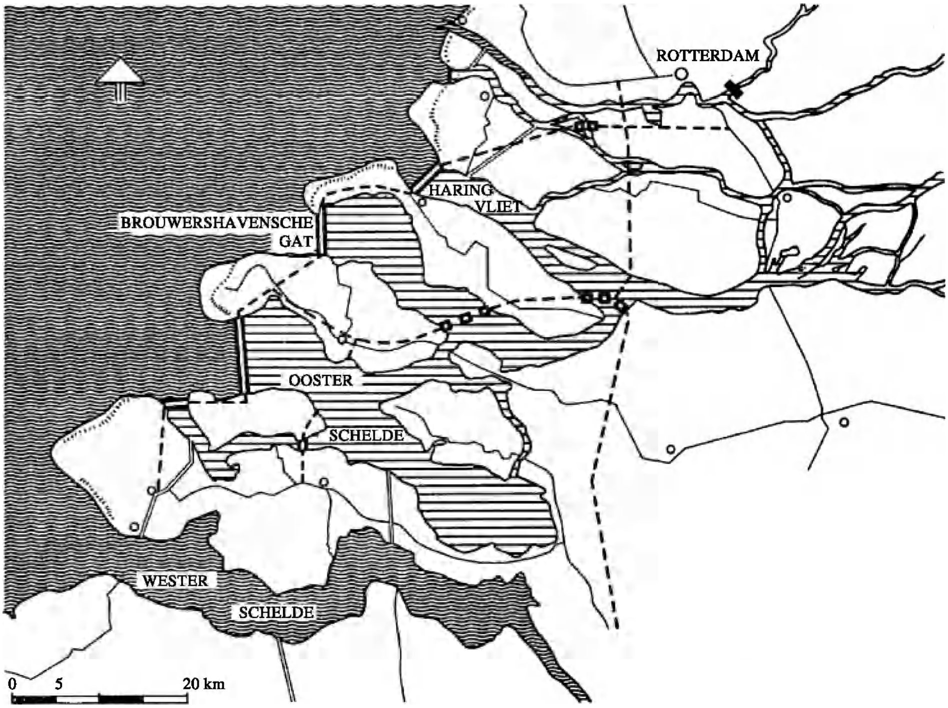

Figure 13. The original Delta Plan, as proposed by the Delta Committee (source: Rijkswaterstaat, the Hague).

mitigation was chief engineer Johan van Veen. He was the director of the Study Service and was the secretary, and later a full member, of the Storm Tide Committee. Just 2 days before the Big Flood occurred, on 29 January 1953, he had completed his last report on this issue, in which he focused on the closure of the three northern inlets, proposing to close these at half-length (Van der Ham 2003).

The 13 members of the Delta Committee comprised the most experienced Dutch civil engineers such as the internationally known specialists V. J. P. de Blocq van Kuffeler, who directed the closure of the Zuyderzee, P. Ph. Janssen, responsible for the Walcheren closures in 1945–1946 and J. Th. Thijsse, director of the Delft Hydraulics Laboratory. Another member was the economist and future Nobel Prize winner J. Tinbergen, while Van Veen served as its secretary. This combination of existing reports of study and the practical experience of its members allowed the Delta Committee to work efficiently and effectively.

(*b*) *The Delta Plan*

By May 1953, the Delta Committee had produced its advice on the closure of the most complicated tidal gap at Schelphoek, and its advice to build a storm surge barrier in the Hollandsche IJssel, just east of Rotterdam, to protect the low-lying central parts of the province of Holland. After 1 year, the Delta Committee submitted its main advice. This report dated 27 February 1954 was brief—it ran to just seven pages. The essence of the advice was not to heighten all the dykes but to realize the so-called Delta Plan (figure 13). The key part of this plan was the full closure of the three northern inlets by an almost direct connection of the natural dunes to create a closed coastline. This was largely in line with Van Veen's proposal of 29 January, although he proposed to construct the closure dams halfway the inlets (Van der Ham 2003). It was estimated that the works could be completed in 20–25 years. As a result, the southwest area of the Netherlands should be safe against flood threats with a return period of once in 10 000 years (Deltacommissie 1961; part 3). An interesting aspect is the cost-benefit analysis that was made to evaluate this Delta Plan against the option to heighten and strengthen existing dykes. Although the net cost of the Delta Plan was some 130 million guilders higher, indirect benefits not related to safety, such as land reclamation, traffic, connections, reduced salinity intrusion, recreation, and so on, tipped the scales in favour of the Delta Plan by well over 500 million guilders (Deltacommissie 1961; part 6).

A fourth interim report, dated 5 January 1955, dealt with the closures of Veerse Gat and Zandkreek to connect the islands of Walcheren, Noord-Beveland and Zuid-Beveland, which created a new inland lake. A fifth interim report, dated 18 October 1955, discussed in more detail the closure of the inlets and the order of the works.

The draft Delta Plan law for the full works was submitted to parliament on 17 November 1955. On 2 July 1956, 3 years and five months after the Big Flood, the work on the Delta Plan could officially be started.

Although officially part of the Delta Plan, the construction of the storm surge barrier across the Hollandsche IJssel had already started much earlier, on 18 January 1954. The barrier was designed as two parallel vertically-lifting steel walls of 81.2×11.5 m, dubbed 'Holland's safety latch' (Van der Ham 2003). With its official inauguration on 22 October 1958, the safety of the so narrowly escaped central parts of Holland was finally ensured and the first part of the Delta Plan was completed. The final report of the Delta Committee was published just 2 years later (Deltacommissie 1961).

In 1975, owing to pressure from fishing, oyster and mussel culture and much increased environmental awareness, the Netherlands' parliament approved the additional cost for changing the plans for full damming of the eastern Scheldt by a plan for a movable storm surge barrier. The sheer size of a barrier for the 8 km wide inlet of enormous tidal volume required novel engineering solutions in its design, foundation and hydraulic systems. In normal situations, an average tidal cycle forces some 950 million m^3 water in and out of the eastern Scheldt through its 62 massive steel gates, keeping the tidal nature and the environment of the basin largely intact (see figure 14). On 4 October 1986, Queen Beatrix inaugurated this major engineering complex. The inauguration of the barrier also marked the completion of the Delta Plan, more than 33 years after the Big Flood.

(c) *Organizational measures to enhance safety and preparedness*

A further issue that the Delta Committee addressed was the overall responsibility for maintaining safety against floods in the long term. On the committee's recommendation, Rijkswaterstaat was put in charge of the main sea defence line between the Western Scheldt and Hook of Holland. Furthermore, it was to implement the supervision on safety, dyke design and maintenance by the

Figure 14. The Eastern Scheldt storm surge barrier (source: Rijkswaterstaat, the Hague).

water boards (Van der Ham 2003). It was then that the long-resisted rationalization and merging of water boards finally got underway. It was perceived as an absolute necessity to give these organizational structures a size to effectively deal with their responsibilities, which more and more required advanced technological approaches and solutions.

On a national level, within the normally inactive SVSD, a 24 h, rotating operational duty was initiated with the authority to call up a crisis management team in case of emergency and to initiate a coordinated response. Disaster plans were created, with a clear definition of responsibilities and scenarios for action, and appropriate training schemes were designed.

The above section shows that the Big Flood had a much more far-reaching impact than the disaster and its immediate aftermath. It led to an integrated safety concept and major infrastructure works to ensure preparedness against flood threats to a level never envisaged before. In parallel organizational changes were introduced to ensure permanent preparedness to set in motion effective response scenarios, to mitigate potential damage in case of an actual flood threat.

7. Was there an element of bad luck involved?

Reflecting on the events of the Big Flood and the scope of the human tragedy and material damage, one may wonder whether the disaster was not simply an awful coincidence. Let us assume that the whole storm and flood occurred 2.5 days later; that is, a shift in time of all natural events by 60 h. The peak water-levels would not have occurred around 03.00 on 1 February but around 15.00 the following Tuesday on 3 February. This simple difference in time of occurrence might have led to a different evolution of events in various respects:

(i) Few (if any) people would have been surprised while sleeping.
(ii) Many people would have been at work or at school and it would therefore have been easier to contact and mobilize people.
(iii) The daylight would have made it much easier to assess the local situation at an early stage and organize protection activities and evacuation.
(iv) Telegrams would have been received and acted upon at an early stage.
(v) All local and national authorities would have been actively functioning, and communication between responsible authorities would have been easy using available office telephones.
(vi) Radio could have been used for dissemination of warnings and coordination of rescue.
(vii) The central coordination of large-scale response activities and rescue operations, mobilization of external materials would probably have started earlier.

There would also have been neutral or negative impacts, however. There would probably have been more victims at sea, since on 1 February, most of the fishing fleet was at home for the weekend. In addition, physical communication with the islands would still have been extremely difficult, as the ferries would not have been operating in a storm of such severity.

This simple thought experiment shows that the occurrence of the Big Flood during a weekend and over night most probably led to more casualties, and less timely and less effective action and coordination than would have been the case if it had happened during a weekday afternoon. If it had happened that way, then there would still have been a disaster—undoubtedly with human casualties and material damage—just not on the scale that occurred that weekend.

8. Could the disaster have been prevented?

The response to the Big Flood was one of nationwide help and assistance, of closing the dykes and rebuilding what had been damaged. At the time, the question of possible prevention, negligence or blame was not openly discussed (Lintsen 2003). It was a time of rebuilding the nation after the war, and the same attitude of looking towards the future was also applied to the flood disaster.

(a) *Perception of vulnerability to floods versus actual prevention*

The answer to the question of whether the 1953 disaster could have been prevented should be based first on an analysis of the perception of the quantitative vulnerability to such an extreme event. This should then be combined with a realistic estimate of the time necessary to make the step from perception and analysis of the nature and scope of the flood threat, via mitigation plans and cost estimates, to approval and implementation of measures to reduce

Figure 15. Dr Johan van Veen presenting the Delta Plan (source: Rijkswaterstaat, the Hague).

the risk to an acceptable level. The latter has been presented in more detail in Lintsen (2003), while much information about the perception and analysis is provided in Van der Ham (2003).

Analysis of the perception question shows that the insufficient state of the dykes was known and had been reported. The evaluation of the 1906 flood already mentioned the insufficient dyke safety and the need for urgent adjustment of responsibilities and centralization of dyke maintenance (Slager 1992). Its recommendations were successfully resisted by the polder boards, however, and were not enforced by the supervising national authorities, although concrete Muralt walls to prevent wave overtopping were introduced at various places. Allocating the necessary funds for heightening the dykes was often not a priority, as was noted in evaluation reports in the 1930s regarding the heightening and strengthening of the West-Brabant sea dykes that were known to be too low and too weak (Van der Ham 2003).

(*b*) *The role of Johan van Veen*

At the time, most comprehensive plans to address the analysed inadequate safety of the southwestern parts were put forward by the chief engineer and director of the Study Service of Rijkswaterstaat, Johan van Veen, one of a new generation of modern, research-minded engineers (figure 15). Since the 1920s, much insight had been gained in terms of the propagation of tides and surges in the delta area by his work and the work of J. P. Mazure, and on the probability of occurrence of surges by P. J. Wemelsfelder. Much of this insight was developed from the studies and measurement campaigns undertaken by the Study Service of Rijkswaterstaat, headed by Van Veen.

In many reports and presentations, Van Veen and his colleagues had shown that drastic measures were needed in the delta area, notably around Dordrecht and Rotterdam. As a result of his reports, the 1939 Storm Surge Committee was installed, which carried these studies further during and after the war. It developed both ambitious and more realistic plans to tackle the issues of safety, salinity intrusion and sedimentation all in one (Van der Ham 2003). One may thus conclude that these studies had proved that existing safety measures were insufficient. Indeed, large-scale plans for mitigation and improvement had been prepared. However, it is realistic to assume that it would have taken many years to create the consensus within the organizations in the field, and at the political level to implement such plans. One of the key issues is that after the war, the first priority of the country lay with repairing the damaged infrastructure and rebuilding the nation as a whole. Even if the plans for increasing safety against flood threats had been on the political agenda and had been approved in, say, 1946, it would have taken many more years to allocate the necessary funds and to realize their coordinated implementation. This suggests that the Big Flood disaster could not realistically have been prevented.

9. Awareness and preparedness in the twenty-first century

Will a flood disaster of this magnitude ever happen again? We simply cannot tell. A sobering fact in all the discussions about safety is that absolute safety against floods does not exist. In that respect, one only has to think of the various sea-level rise scenarios, and the uncertainties regarding the effects in this region caused by global warming. In the countries around the North Sea, people are forced to live with flood threats and uncertainty, and should be prepared to cope with those threats in a balanced way. We can arrange for a comprehensive monitoring system and for dedicated research to know what is going on and to better understand the atmospheric and ocean processes and the uncertainties involved, so as to be better prepared and not be taken by surprise should floods occur. Such thorough understanding of the natural processes and the existing state of the flood defences are essential elements for determining the further measures that should be taken to ensure continued adequate flood protection. This is necessary, as cost-benefit analysis will increasingly be applied to safety issues. What level of safety is economically defensible given the stochastic nature of a storm and the uncertainties about the potential impacts it may entail? Public investment in safety will simply have to compete with other priorities, and that is clearly different from the reaction to the 1953 flood. Preparedness and political support for public and private investments in safety can be achieved only through enhanced public awareness of the present and future flood risk and their potential consequences.

Clearly, in order to prevent a disaster of this scope, the key issues that should be addressed by the North Sea countries are:

(i) monitoring procedures for the state of the dyke and dune systems and regular evaluation of the adequacy of the overall flood defences;
(ii) an adequate monitoring system of weather and waters, and continuous interpretation of the data to assess what is happening;
(iii) effective operational capabilities to forecast winds, waves and water-levels and to disseminate these forecasts effectively;

(iv) in-depth research to increase the level of understanding of the physical processes and the uncertainties/probabilities associated with their forecasting; and
(v) permanent awareness and preparedness in terms of public information and well-trained response scenarios.

The main lessons of the Big Flood of 1953 are therefore not to forget, but to be aware and to be prepared.

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