Flood events in the southwestern Netherlands and coastal Belgium, 1400–1953

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Abstract This paper focuses on the causes and impacts of flood events between 1400 and 1953 in the estuaries of the rivers Meuse, Rhine and Schelde, and further south along the Belgian coast. Floods in this delta area have been caused by natural mechanisms. In particular, weather extremes such as storm surges interacting with tidal dynamics have been reshaping the estuaries for centuries. Therefore, the most important storm surges are briefly described and, by applying criteria to analyse their causes and using additional characteristics, they are furthermore compared amongst themselves. Because of the close interaction between man and nature in the delta area, several floods had purely human causes. These floods have been assessed by applying additional criteria. From the analysis of all the major floods discussed, it may be concluded that floods occurring during storm surges were most common, but floods during warfare had the greatest impact on the environment.

Key words Belgium; climate impact; damage assessment; floods; proxy data; storm surges; inundations during warfare; The Netherlands; weather extremes

Inondations dans le sud-ouest des Pays-Bas et en Belgique littorale, 1400–1953

Résumé Cet essai traite des causes et des impacts des inondations dans les estuaires du Rhin, de la Meuse, de l'Escaut et le long du littoral belge entre 1400 et 1953. Les inondations dans cette zone deltaïque ont été causées par des facteurs naturels. Ce sont en particulier les extrêmes météorologiques, comme les raz-de-marée associés à la dynamique des marées, qui ont remodelé les estuaires pour des siècles. C'est pourquoi nous décrirons brièvement les marées de tempête les plus importantes et en appliquant des critères pour en analyser les causes et grâce à des caractéristiques supplémentaires, elles ont pu être mutuellement comparées. En raison de l'étroite interaction entre l'homme et la nature dans le delta, certaines inondations ont été causées par l'homme. Ces inondations ont été évaluées en appliquant des critères supplémentaires. L'analyse des grandes inondations considérées ici montre que la plupart ont été causées par les grandes marées de tempêtes, mais que les inondations en période de guerre sont celles qui ont exercé la plus grande influence sur l'environnement.

Mots clefs Belgique; conséquences du climat; estimations des dommages; submersions; données analogues; raz-de-marée; marée de tempête; inondations en période de guerre; Pays-Bas; extrêmes météorologiques

INTRODUCTION

This paper looks into the number and nature of large-scale floods that occurred in the southwestern delta of The Netherlands and on the Belgian coast between 1400 and 1953. In particular, it addresses the question: to what extent have these flood events been caused by nature or by human intervention? The area dealt with is largely an archipelago with large inlets and low-lying lands on its banks that are protected by dikes and dunes which are very vulnerable to westerly and northwesterly gales. This makes it a perfect area to study the interaction between man and nature, because most floods also affected the hydrological character of the area.

First, the main features of the area are briefly discussed; then, an overview of the most important flood events in each century is presented, for which a range of natural and human characteristics is explained. Finally, the results are assessed by applying a range of criteria to explain the interactions between man and nature and to be able to distinguish which flood events had natural causes and which could be attributed to mainly human causes, or both.

KEY FEATURES OF THE STUDY AREA

General features

The southwestern part of The Netherlands, including Zeeland, the western part of Noord-Brabant and the adjacent Belgian coast, are part of the delta of the rivers Rhine, Meuse and Schelde. The area is located on the southeastern coast of the North Sea between 51°48′–50°N and 2°53′–4°50′E. In the past, several major tidal inlets or estuaries and many smaller branches dominated the landscape, while further south along the Belgian coast there were some smaller tidal inlets (Vos *et al.*, 1997; Baeteman, 2005). Therefore, the area has always had a very dynamic nature and the interaction between physical and manmade features has determined its development. But, as soon as large parts of the area became embanked, the human impact seems to have become the dominating feature in this process. However, this does not imply that physical processes became less dynamic, because on several occasions man seems to have lost control over the natural dynamics. Therefore, the process of increasing human impact on the study area cannot be considered as a gradual weakening of natural dynamics. Furthermore, the interaction between man and nature in the study area is very complex, because so many different manmade and physical features differed greatly from each other from place to place. Therefore, it needs to be stressed that the interactions between man and nature differ not only in time, but also in place, making it very complex to assess the impact of each and every factor in the development of the area between 1400 and 1953, and the part played by the floods.

Particular features

Tidal inlets have a dynamic nature: some erode and then become silted up, while others become silted up and then erosive forces tend to dominate the process. At the same time, tidal channels continually change shape and tend to migrate (Baeteman, 2005). To interfere with such a process in terms of embankments implies sufficient knowledge of these natural dynamics.

Being a lowland, the study area is most vulnerable to storms ranging from west to northwest (Jelgersma, 1992). For a long time the area was an archipelago with several major funnel-like inlets in which tidal amplitude increased to the east, especially in the estuary of the Westerschelde. On both its banks, salt marshes were reclaimed by the construction of dikes, but these were unable to withstand major storm surges. Although large-scale or general floods were rather rare, there are numerous cases of dikes being damaged at certain times (de Kraker, 2005a). Until the 17th century, there were also a few estuaries along the Belgian coast and numerous cases of erosion on parts of the coastal dunes (Augustyn, 1992).

The Zeeland area (see Fig. 1) consists of many small polders, the inhabitants of which each had to maintain their own dikes. Maintenance usually occurred twice a

Fig. 1 Christiaan sGrooten map of the Zeeland area, including the western part of Brabant and the Belgian coast, 1550 (courtesy of the Royal Library Albert I, Brussels, Belgium).

year and consisted of the replacement of vulnerable straw or reed cover. Consequently, there are many series of dike accounts, some of which originate from the 15th century. There are also many documents that deal with special cases of dike breach or flooding incidents. In the mouths of inlets and on the North Sea coast, lowlands were protected by dunes. In order to prevent the gradual migration of the dune to the east, dunes also needed annual maintenance. This was usually carried out by the authorities of small ports, such as Sluice, Oostende, Nieuwpoort, and Dunkirk. From about 1400, there are annual town accounts which provide details of maintenance of the dunes and several flood events (de Kraker, 2005b).

Flooding was not always a natural phenomenon. In particular during warfare, large areas were inundated in order to prevent the enemy side from taking territorial advantage. Military reports and accounts give information about the time, place, size and reason why such inundations happened. When storm surges and strategic flooding occurred within the same short period, it is hard to distinguish clearly between the natural and manmade aspects of such incidents.

There are more human features to be considered. As soon as the salt marshes were embanked by dikes, not only did the process of silting-up stop, but the polder levels slowly started to subside; this was strongly enhanced by quarrying of peat for fuel and by local salt production (Leenders, 1989, 2003). Improved drainage resulted in further subsidence.

Time frame

Looking at the development of the landscape in the study area, three stages can be distinguished:

– The first is the Late Medieval stage, during which most of the lowlands had already been heavily exploited by quarrying peat, while at some locations much land was flooded as well and even remained flooded for centuries.
– The second stage is characterized by many storm surges, which strongly suggests an increase in storminess in the course of the 16th century, coinciding with a large-scale strategic flooding that happened at the end of that century (de Kraker, 1999, 2005b). Half of the eastern part of central Zeeland was already flooded during storm surges and over three quarters of the lowland on the left bank of the Schelde-Westerschelde and nearby Bergen op Zoom were flooded as well (van Ham, 1975). On the Belgian coast, the area around Oostende suffered from strategic inundation too (de Leper, 1957).
– The third stage is the gradual re-embankment of flooded lowlands, a process which started during the middle of the 17th century and, with the exception of a few local setbacks, continued until the middle of the 20th century.

Data

The weather information or proxy data used for this paper comes directly from primary and contemporary written sources (see References). These kinds of sources are more reliable than, for instance, chronicles (Gottschalk, 1971, 1975, 1977), which are mostly of a much later date than the weather events described and may contain all kinds of transmission errors. Moreover, the primary written sources used in this paper, particularly the town and dike accounts, are homogeneous, contemporary and all come from the disaster area.

FLOOD EVENTS, 1400–1953

General

In the following overview, the data of one or two flooding incidents per century are presented. This number is representative, because, during the 18th–20th centuries, only two large-scale flood events occurred per century and, as far as those of the 17th or 16th century are concerned, they only differ in terms of causes and frequency.

If flooding and storm surges occurred at the same time, they are explained here in terms of meteorological preconditions, size and nature of damage and additional information. Although the other flood events may also be described in terms of size and nature of the damage, they predominantly need to be explained in a political context by looking at the details of warfare. The events are compared and discussed below in terms of their main characteristics.

15th century floods

The 15th century is characterized by at least four storm surges, of which only the first three are described here. In addition, a flood occurred during wartime between 1488 and 1494 (de Kraker, 1997, pp. 23–27), but, as the area covered with water was limited to just one region in the study area, it is not explained any further.

At the start of the 15th century, three successive St Elisabeth [19 November] floods occurred (1404, 1421 and 1424 – see Fig. 2). Primary written sources have recorded these floods in terms of "flooding" (1404) or "flooding of the sea" (1424) at Nieuwpoort (GSAB, CdC nos. 36709, 36727); and "big flood" (1404), "high flood" (1421) and "big flood" (1424) at Biervliet (GSAB, CdC nos. 32061, 32072, 32074). Further to the northeast, in the province of Noord-Brabant, these floods were similarly characterized as being "big floods". The 1404 and 1421 storm surges in particular, lasted for about 36 hours (Gottschalk, 1975; Buisman & van Engelen, 1996; Soens, 2005). The 1421 storm surge could have lasted even longer, because it started late on 18 November in southwest Flanders and moved north, still causing great damage in central Holland (Buisman & van Engelen, 1996). Although the 1424 storm surge seems to have been less damaging, this is hard to asses, because large areas that were flooded in 1421 had still not been recovered (Hendriks *et al.*, 2004). At all locations mentioned, large-scale flooding indeed occurred and, because floods occurred shortly after each other, there appears to have been little time to carry out all necessary repairs in a proper way. The three consecutive St Elisabeth floods resulted in the tidal impact reaching as far as the southeastern river area of Dordrecht, turning Biervliet into an island. If one compares the 1404 proportion of land to water to that of 1424, it becomes clear that the proportion of water had substantially increased. Consequently, the hydrology of parts of the archipelago was seriously affected in terms of more water pushing into the inlets and also further eastward.

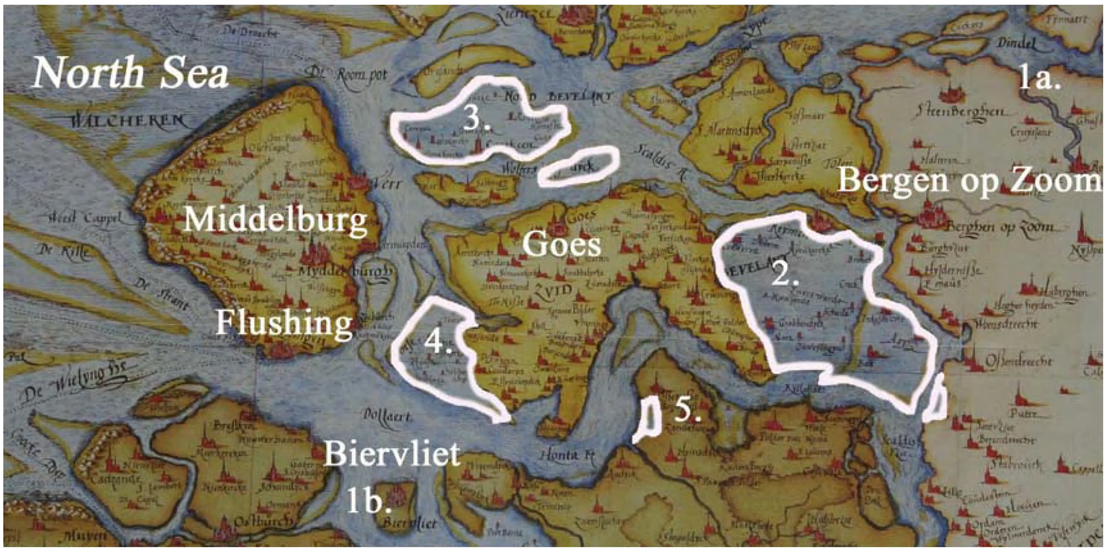

Fig. 2 Five of the major flooded areas of the 15th and 16th century. 1a. Area of Noord-Brabant flooded between 1404 and 1421; 1b. Biervliet, which became an island during the 1404 flood; 2. Eastern part of Zuid-Beveland washed away in 1530; 3. Noord-Beveland flooded in 1530; 4. Southwestern part of Zuid-Beveland flooded in 1530; and 5. Kerckepolder lost during the 1530–1532 floods.

16th century floods

The 16th century is characterized by at least eight storm surges. These seem to have occurred in pairs: the 1509 and 1511 storm surges were quite destructive on the left bank of the Westerschelde; the 1530 and 1532 storm surges were really devastating; then storm surges occurred in January and February 1552 and again in November 1570. The last 16th century storm surge, although it seems to have been a minor one, occurred in 1594.

The storm surge of 5 November 1530, which happened around the Full Moon (RLAIB, ms.), was very carefully recorded by contemporaries and has since been studied in detail as well (Dekker, 1971, 1988; Gottschalk, 1975; de Kraker, 1997, 1999).

Depending on the kinds of written sources, contemporaries spoke of this hazard in terms of "big tempest", "large-scale flooding" and "horrible flood". Those who actually witnessed the incident were more specific and emotional than the distant civil servants of the Brussels government. Moreover, church accounts immediately perceived these kinds of incidents as divine acts (Kempe, 2003; Rohr, 2003), while the responsible local water boards and town authorities most likely joined them in order to cover up the fact that they had been neglecting dike maintenance for many years. In spite of the fact that research of the 1530 floods has shown how contemporaries perceived "natural hazards", more information than just a few observations is needed in order to assess the impact of a storm surge.

The size of the natural hazard can be assessed in terms of number of flooded acres. Although no exact data are known, this must have easily surpassed fifty thousand acres. All along the Belgian coast, inlets had to cope with large-scale damage and flood events, such as at Nieuwpoort and Oostende (GSAB, CdC nos. 36829-36830, 37353, 27797), where water pushed into the cities. This also occurred at Biervliet (GSAB, CdC, no 6892), where even bridges were washed away. In the neighbouring polder areas, tens of thousands of acres flooded and in Zeeland the eastern part of Zuid-Beveland, including some twenty thousand acres and many villages, was lost for centuries (Dekker, 1988; Augustyn, 1992, pp. 622–636; de Kraker, 1997, pp. 204–207). Further east on the Brabant side, flooding also occurred, but, because large parts were still covered with large amounts of water since the 1400s, there are considerably fewer reports of large-scale damage. Only around Bergen op Zoom was there large-scale damage (van Ham, 1975).

The large-scale floods of 1530 affected the hydrology of both the Oosterschelde and Westerschelde profoundly. It caused the slow silting-up of the eastern branch near Bergen op Zoom and widened the Westerschelde (Dekker, 1971, 1988).

Another flood incident occurred in 1570. First, on 11 March, a severe gale hit the region. Although it did not cause flooding, the gale caused general damage to the dikes. Most of the damage was repaired by November, but in several places repairs were done in such haste that they were still fragile. So, when the big storm surge hit the region on 2 November 1570, it caused general flooding. Floods occurred in most of the polder regions of Flanders (de Kraker, 1997, pp. 103–129) and also in the lowlands west of Bergen op Zoom, on the right bank of the Oosterschelde, and parts of central Zeeland. The coastal towns of Nieuwpoort and Oostende (GSAB, CdC, nos 36868, 37393) were also partly flooded. Although repairs started immediately, these were hampered by a third storm in late November and severe frost during January 1571. The coastal ports authorities managed to carry out repairs, as did most of the polder boards on the Flemish side, but in central Zeeland and to the southwest of Bergen op Zoom, on the right bank of the Westerschelde, several areas had to be abandoned (Dekker, 1971; van Ham, 1975).

Again the flood event of 1570 shows how contemporaries perceived the event. Most local authorities refer to it as a tempest, a big flood, a high sea. When Oostende (GSAB, CdC, no. 37393) was also partly covered with water, local authorities had to beg for financial assistance from the Brussels government. On that occasion they referred to the flood event as the "horrible tempest and high seas that occurred on All Saints and All Souls 1570 of which there was no recollection at all and that caused very large damage" (ADN B no. 1625). In the 1570/71 town account, the event was only recorded as a "big flood".

Between 1583 and 1586 large-scale flooding occurred in the northern part of Flanders and in the lowlands of Bergen op Zoom (van Ham, 1975; de Kraker, 1997). These floods coincided with warfare in Flanders during the Eighty Years' War (1568–1648). As soon as the Spanish army started to recapture the northern part of Flanders, including the towns of Ghent and Bruges and, in 1585, Antwerp as well, the Dutch rebels tried to stop them by flooding the polders of northern Flanders and the lowlands of Bergen op Zoom. Having obtained information about the most vulnerable locations of dikes from local officials, they acted by systematically breaching dikes at the lowest locations. Because of the tidal impact, breaches deepened and widened and, consequently, the flooded area extended in size and somehow regained its natural flood plain.

17th century floods

In the afternoon of 27 March 1606, a severe storm surge hit the Flanders-Zeeland area (Gottschalk, 1975). Contemporaries also observed hailstones falling during the thunderstorm. Although damage seems to have been rather limited, most of the area was still flooded as a consequence of war; yet several parts were flooded again and many earthen strongholds were severely damaged (de Kraker, 1997).

Flooding occurred in 1673 on the occasion of the French armies marching into the lowlands of northern Flanders. On a limited scale, some polders were flooded near strategically important towns. Because the French did not threaten Bergen op Zoom, no inundation occurred there. Although it was only natural to carry out repairs after the departure of the French troops, again tidal impact had changed the character of polders and dikes, causing some to remain flooded for a long time.

The storm surge of 26 January 1682 happened two days after the Full Moon and lasted for two days (Hollestelle, 1996; Kool-Blokland, 2003). This storm surge happened at the same time that the rivers Rhine, Waal and Meuse showed peak discharges because of melting snow and extreme rainfall in Germany (Gottschalk, 1977). However, storm surges upstream in the estuaries seldom meet such peak discharges at the same time. The storm surge caused large-scale flooding in parts of coastal Flanders and its inlets. Even the fishing towns of Nieuwpoort and Oostende were partly damaged. The northern polder area of Flanders was also flooded, and so were parts of Zeeland. Even in the towns of Flushing and Middelburg, water partly destroyed stock kept in warehouses. At Antwerp, abundant water from the River Schelde ran into the lower part of the city, flooding its main church and many warehouses as well. The lowlands around Bergen op Zoom and further north were flooded too. In fact, flooding and large-scale damage can be traced as far north as the fishing village of Katwijk aan Zee. In fact, some 200 polders in the disaster area were affected very badly by the floods (Buisman & van Engelen, 2006). The destruction of Valkenisse on the right bank of the Westerschelde estuary had an impact on its hydrology; because of the flooding of this protruding obstacle, more water could push into the eastern part of the inlet.

18th century floods

Although the 18th century seems to have been a rather quiet period in terms of storm surges and floods, one major storm surge hit the area on 3 March 1715 causing large-scale flooding. The storm surge happened two days prior to the Full Moon (Kool-Blokland, 2003). The impact of this weather extreme cannot be properly assessed without looking at the broader time frame of 1714–1717. During that short period of time, the North Sea area was hit by several storms. On 26 February and 2 and 7 March 1714 storms also caused damage in the coastal area of Flanders and Zeeland. The 1715 storm surge, with a northwesterly wind direction, was the severest to hit this region during the 18th century. Table 1 shows how the storm was observed, even as far north as Bilderdam, near Amsterdam, by the officials of the large regional water board "Hoogheemraadschap Rijnland" (Buisman & van Engelen, 2006, pp. 323–325). The Christmas storm surge of 1717 particularly hit the northern part of The Netherlands and Germany (Jakubowski-Tiessen, 1992).

Although much of the flooded land in the Flanders–Zeeland area could be reclaimed in 1715, the particular protruding Polder van Namen on the left bank of the

Table 1 Wind direction recorded in Amsterdam, 1714–1715.

1714: Date	a.m.	Evening	1715: Date	a.m.	Evening
24 February	SSW		1 March	WSW	
25 February	SW		2 March	WSW	NW
26 February	SW	N	3 March	NW	
27 February	NNW		4 March	NNW	
28 February	NE		5 March	NNW	NW
1 March	SW		6 March	Variable	
2 March	W				
3 March	NNW				
4 March	SW				
5 March	WSW				
6 March	SW				
7 March	NNW				
8 March	NNE				

Source: Leiden, Hoogheemraadschap Rijnland, no. 975.

Westerschelde had to be abandoned. As this was situated right opposite the already flooded Valkenisse, this affected the hydrology of the Westerschelde again in terms of producing more room which allowed more water to push further eastward.

19th century floods

Although there were several very local floods in the study area during the 19th century, most of which were caused by erosion of banks or the abandonment of a secondary dike area (inlaag), only the January flood of 1808 resulted in major flooding.

During the early morning of 15 January 1808 a severe gale hit the Flanders–Zeeland area. The event occurred two days after the Full Moon (Kool-Blokland, 2003). Antwerp newspapers reported that the storm surges occurred at Full Moon and that sea level reached a maximum of over 1.10–1.38 m above the maximum level known at the time (Pauwels, 1993). The storm surge caused flooding at many locations. At Flushing, for instance, water inundated the town centre, killing over 30 people; even graves had been washed out. Also many ships were destroyed and sank. In the Dutch part of the left bank of the Westerschelde, about 40 polders were flooded and some 70 in the remaining part of Zeeland. If one widens the perspective to the entire Zeeland Delta, including parts of Noord-Brabant and the Belgian coast, the number of polders flooded could easily have reached over 130.

Because the disaster happened during the French occupation of The Netherlands and Belgium, this flooding anticipated far-reaching reforms that would affect water and coastal management during the 19th century.

20th century floods

During the 20th century, there were only two flooding incidents in the study area: the first occurred in 1906 and the second in 1953.

On 12 March 1906, a storm surge occurred. It lasted only a short time, but happened at Full Moon, which resulted in the highest level ever recorded in the Zeeland Delta. The storm surge only caused flooding at a local scale, yet 18 polders flooded, totalling 5411 acres. However, there were no casualties and it did not take long for people to carry out repairs.

On 1 February 1953, a large-scale flood occurred that was caused by the severest storm surge ever recorded by man in this southeastern part of the North Sea. Blowing from a northwesterly direction, a storm surge of Force 10–11 on the Beaufort scale was not only pounding the low-lying lands of the study area, but also affected the Thames estuary in England and the Dutch coastal region as far as north of Rotterdam. Because of its long duration (31 January and 1 February), three consecutive high spring tides pushed the sea to an unsurpassed maximum level in the eastern part of the inlets (Wemelsfelder, 1953). There were 1836 casualties, and, because some140 000 ha were flooded for a longer time and 4500 houses were destroyed, another 100 000 people had to be evacuated (Slager, 2003).

DISCUSSION OF DATA

General

Of the many flooding incidents that occurred between 1400 and 1953, only nine are presented which were clearly caused by natural forcing. However, if one looks more closely at the impact which incidents had in terms of flooded area and additional damage, there always seems to have been a combination of natural forcing and human impact. In order to distinguish between the natural and human aspects, the following criteria are of interest.

Criteria

In order to assess the natural forcing of flood events, we need to know the meteorological conditions at the time of the flooding, such as wind direction, the duration of the event and how soon after the first flooding similar meteorological conditions recurred. Wind direction is vital, because the area under study is especially vulnerable to storms and gales coming from the northwest, west and southwest. At the same time, we need to know how strong wind speeds were at that time. Because wind force is usually referred to as tempest, high flood, big flood or high seas, this kind of information is hardly conclusive to assess the impact of the event (de Kraker, 1999). Therefore, we also have to include the duration of the event. The longer a storm lasts, the higher the tides rise. If a severe storm (Beaufort Force 10) lasts for 24 or even 36 hours, there will be two, or even three, consecutive high tides, the last one of which will reach such a high level that water overflows the dikes and therefore causes flooding. Discussing high tides during storm surges nearly always refers to the astronomical tide or spring tide, which occurs at Full Moon and at New Moon. For instance, in the Westerschelde estuary, the average tidal amplitude at Flushing is 3.90 m, while at Terneuzen it increases to 4.30 m; during the spring tide of 30 March 2006, which occurred at New Moon, these figures were respectively 5.05 and 5.44 m. Therefore, information about Full and New Moon, even prior to 1700, needs to be included (Tables 2 and 3) as a separate criterion. Because there were many local marks on dikes and near sluices, contemporaries had a fair knowledge of the average level high seas could reach during severe gales. They also tended to compare one flooding incident to another by looking at these marks. Therefore we also have to take into account the distinctive heights of floods as a separate criterion.

Another criterion is the pace at which one flood followed another. Was the interval only one or two years or even a few months, or did next flooding incidents not occur for some decades? If storm surges occurred within a short period of time, the damaging impact was greater.

A final natural factor is the nature of the soil of the lowlands. Clay and peat are far more resistant to the erosive force of water, while sandy soils are less resistant. Because the lowlands of the Zeeland Delta have such a local diversity in soil composition, and so many changes happened during the period under study, this natural feature is not discussed any further here (Vos *et al.*, 1997; Baeteman, 2005).

Table 2 Natural and human criteria.

Natural	Human
a. Wind direction	a. Maintenance
b. Duration	b. Response
c. Astronomical constellation	c. Subsided levels
d. Repetition (pace)	d. Organisation (administrative-legislative)
e. Height of water levels	e. Political-military events
f. Nature of the event	f. Damage assessment
g. Soil composition	

Flooding incidents can only be fully understood by looking at the part played by local communities, or by taking the societal conditions of the period into consideration. The first human criterion is the upkeep of dikes, dunes and sluices. Dikes were built of clay and covered with thick sods. Nevertheless, dikes can be worn by rain and wind and are particularly vulnerable during the stormy winter. That is why, until about 1900, annual maintenance consisted of putting bundles of straw and reed on the seaward side of dikes in order to protect the sods from being washed away during high tides. Effective dike upkeep also meant being attentive after every storm by checking the reed and sod cover of the dike. Spending less money on annual maintenance, or being absent during storms, could cause immediate and serious problems and result in flooding during storm surges. Even dikes of inland polders had to be watched, because the flooding of one polder could easily lead to the flooding of another. In cases of long-term negligence of dike maintenance, polders could be voluntarily abandoned, leaving the neighbouring polders at risk. As far as the upkeep of dunes is concerned, the inland migration of sand and the wearing off of sand caused dangerous gaps, which needed to be prevented by also putting bundles of straw and reed at vulnerable locations.

Another vital criterion is speed. If danger lurks during heavy weather, officials need to be on the spot to be able to take immediate measures. The fast fixing of holes and having large amounts of straw and reed available nearby and a large labour force in case of breaches are vital for preventing large-scale flooding. Although common law or most dike regulations required the official's presence at times of need during certain periods, some lived at great distances from the dikes.

Next, the economic exploitation of polders had a negative impact on ground levels. That is why many older polders suffered from long-term subsidence of their ground levels. This was not only caused by a large-scale quarrying of local peat for fuel and by the salt industry that was practised throughout the area; clay and sand were also used for maintenance of dikes and roads. Moreover, local polder boards also constructed drainage in order to have the perfect conditions for growing crops. This drainage caused the gradual subsidence of local ground levels. In the oldest polders, ground levels had become dangerously below the mean sea level.

Another factor is the administration of polders. Most of the polders were only small territorial administrative units directed by local boards. Because of the basic idea: "those who are threatened by the sea protect themselves from the sea", responsibility for maintenance of every small polder lay with the owners. Therefore abandoning a polder was easier than struggling for years competing with neighbouring polders for financial assistance. Only in some cases was the government willing to give financial aid and later on this even became part of polder legislation. Therefore, only large-sized polders or those owned by wealthy landlords could survive through time. Because the administrative situation of polders and their sizes differed across the whole area, dangerous situations and even flooding incidents were dealt with in different ways.

Lowlands protected mainly by dikes and dunes are vulnerable to every sudden change, natural or human. One of the unexpected human impacts was warfare. Between 1400 and 1953 there were at least eight periods of warfare, most of which caused flooding. These so-called military inundations were part of military strategy. Armies could protect themselves behind a flooded area. Flooded areas also prevented armies from penetrating much further. An area was flooded well if water reached a level that was high enough to prevent heavy canons from being dragged through it, while at the same time the enemy was unable to use flat boats to cross it. During the 17th and 18th centuries, particular areas were even intended for military inundation as soon as enemy armies approached the area.

Basically, strategic flooding was carried out by carefully selecting the right locations to breach dikes to make sure water would penetrate into polders and remain there for as long as needed. At the same time, tidal amplitude very quickly changed parts of polders by its erosive force. If polders were selected that already had markedly subsided ground surface levels, strategic flooding immediately became a success.

There are two short periods that seem rather confusing, because both storm surges and military strategy caused flooding. These occurred between 1570 and 1586 and between 1673 and 1682. In both cases some areas remained flooded for many years, while warfare added to the size of the flooded area by the onset of strategic flooding. For example, in 1673, dikes were breached and soon afterward repaired, but breached again by the sudden re-approaching of armies. Then parts of the polders around Aardenburg were again repaired, but shortly afterwards the 1682 storm surge caused flooding for the third time.

Assessment

The criteria discussed above were applied to the flood events and the results, as far as they can be reconstructed, are summarized in Table 3.

Looking at the natural criteria, nearly all storm surges occurred while there was a strong wind blowing from the west, or which turned from a western to a more northerly direction. Because the North Sea in the study area only reaches dangerously high levels for one or two days after, or prior to, a Full Moon, the average flood caused by a storm surge nearly always coincided with the Full Moon. On the other hand, written sources seldom mentioned this coincidence, the exceptions being those for the storms of 1530, 1682, 1715, 1808, 1906 and 1953. However, if one looks a little closer at this time series, it becomes clear that contemporaries began to record these specific circumstances only as late as the 17th century. There is more information about the duration of storms. During storm surges that lasted more than one day, there were at least two or three consecutive high spring tides. In particular the 1404, 1421, 1530, 1682 and 1953 storms are of such a long duration. In all these cases, the flood events

Table 3 Flood events, 1400–1953.

Year	Natural features: A	B	C	D	E	F	Human features: G*	H*	I*	J*	K	Damage assessment Spatial	Short/long-term
1404	W	36	n.d.	None	n.d.	Storm surge	M	M	I.	M	Peace	General	Partly long-term
1421	W	36	n.d.	None	n.d.	Storm surge	A	A	I.	M	Peace	General	Partly long-term
1424	W	24	n.d.	3 y.	n.d.	Storm surge	I.	I.	I.	M	Peace	General	Partly long-term
1488					*n.d.*	*Strategic fl.*					*War*	*Local*	*Long-term*
1509			n.d.	None	Some	Storm surge	M	M	I.	M	Aid	General	Short-term
1511			n.d.	2 y.	Some	Storm surge	I.	I.	I.	M	Peace	General	Partly long-term
1530	W–N	36	FM	None	Some	Storm surge	M	M	I.	M	Aid	General	Partly long-term
1532			n.d.	2 y.	n.d.	Storm surge	I.	I.	I.	M	Peace	General	Partly long-term
1552			n.d.	None	n.d.	Storm surge	M	I.	I.	M	Peace	General	short-term
1552			n.d.	1 m.	n.d.	Storm surge						General	Short-term
1570	N, NW	24	n.d.	9 m.	Some	Storm surge	M	M	I.	M	Aid	General	[partly long-term
1583/6					*Some*	*Strategic fl.*					*War*	*Local*	*Long-term*
1600/4					*n.d.*	*Strategic fl.*					*War*	*Local*	*Short-term*
1606			n.d.	None	Some	Storm surge	M	I.	I.	M	"war"	General	Short-term
1672/3						*Strategic fl.*					*War*	*Local*	*Partly long-term*
1682	SW–NW	36	FM	None	Some	Storm surge	M	I.	I.		Peace	General	Partly long-term
1702/9					*n.d.*	*Strategic fl.*					*War*	*Local*	*Short-term*
1715	NW	24	FM	None	Some	Storm surge	M	M	I	M	Peace	General	Partly long-term
1747/9					*None*	*Strategic fl.*					*War*	*Local*	*Short-term*
1784/5					*None*	*Strategic fl.*					*War*	*Local*	*Short-term*
1808		24	FM	None	Some	Storm surge	M	I.	I.	I.	"war"	General	Short-term
1906	WSW		FM	None	Data	Storm surge					Peace	Local	Short-term
1943/4					*Data*	*Strategic fl*					*War*	*Local*	*Short-term*
1953	NW	36	FM	None	Data	Storm surge	M	I.	I.	I.	Aid	General	Short-term

Key:
A: wind direction.
B: duration (in hours).
C: astronomical constellation – FM: Full Moon.
D: repetition – pace of events in months (m.)/years (y.).
E: maximum height of water levels above National Ordnance Datum.
F: nature of flood.
G: degree of maintenance.
H: quality of response time.
I: subsidence of surface levels.
J: administration – legislation.
K: political situation: Aid – large-scale financial and material support given by the government; "war" – flooding occurring during war time, but not caused by warfare.
* M: sufficient; A: average; I: insufficient; in terms of ground surface levels, too low, and in terms of administration, too bad;
All entries in italics refer to flooding events caused by warfare.

were devastating in terms of size and damage caused. It was only since the middle of the 19th century, when systematic measurement of water levels began, that the connection between duration of a storm surge and maximum heights of spring high tide became clear. From then on it also became clear that the general sea level in the study area was slowly rising and that the top levels of dikes had to be raised accordingly.

Another interesting factor is the time between two major storm surges and flood events, and the repetitive character of such coincidences over the centuries. On the time scale of nearly six centuries, there are five such examples: 1421 and 1424, 1509 and 1511, 1530 and 1532, January and February 1552 and, finally, March and November 1570. It is not really possible to assess the impact of each second storm surge or flooding, because in none of these cases was the damage of the first flood event entirely repaired. It needs to be stated that the 16th century was a particular period of increasing storminess, which resulted in many flood events (de Kraker, 1999).

This takes us to the human impact of flooding. If one considers the quality or effect of dike maintenance, it is improper to make general statements. Dike maintenance was carried out by many different local authorities and polder boards. Some of these were financially in strong positions, while others were not. Some had to maintain dikes in dangerous locations, or had responsibility for very long stretches of dike and dunes; others had less of a problem because they had responsibility for an inland polder, or only had to maintain short stretches of dike or dune. Effective dike upkeep and a fast response to dangerous weather conditions nearly always coincide. Whilst monasteries during the 15th and 16th centuries found themselves in a worsening financial position, wealthy merchants and, in particular, the central government could easily subsidize the financial burden of dike maintenance (de Kraker, 1997). Economic power was also reflected in the different responses to flooding and the carrying out of adequate repairs. As far as the 1906 and 1953 floods are concerned, it needs to be noted that it is generally thought that dikes had not been maintained well enough, because the raising of top levels, which was badly needed, had not been carried out effectively. On the other hand, dikes were generally closely watched during the storms, but again not at all locations. A too slow response to the 1953 storm surge on the islet of Noord-Beveland resulted in its partial flooding (Slager, 2003). This storm surge finally taught the people of The Netherlands to have a "dike task force" available in times of need.

Looking at the local ground level of flooded areas, it would be too simple to state that only the lowest lying parts always remained under water. On the other hand, it is clear that areas where intensive peat quarrying had taken place were most at risk. The larger part of Zuid-Beveland and the town of Reimerswaal were located in such an area, which has remained flooded since 1530; however, at the same time, responsible local authorities took the "wrong" decisions (Dekker, 1988). In fact the largest sized floods were caused during warfare. In order to obtain the best success, the military used local authorities to advise them of the best locations to breach dikes to obtain large-scale coverage with water that could not be undone easily by the enemy. On the other hand, if such an area remained covered with large amounts of water for decades or centuries, its surface level became raised again by the new clay deposits resulting from each high tide. Taking into consideration the general rise in local sea level, which has been observed since the mid-19th century, the larger part of the Zeeland Delta has been in danger of flooding for a long time. Moreover, most of the old small market towns are located in the earliest embanked part of this region and are therefore located below the mean sea level. In particular, the former island of Walcheren is a kind of basin. The wartime flooding of 1944 clearly showed how water ran to the centre of this former island right to the provincial capital, Middelburg. The mention of large salt stocks that were kept in cellars at Middelburg being destroyed during the 1682 floods, is therefore by no means exaggerated by contemporary chroniclers (MLC, ms.).

The lack of sufficient dike maintenance and the continued recurrence of flooding at the same location often forced provincial or central government to give financial assistance, or even to reform the local or regional water authorities and polder management into administrative units. This finally happened after the 1570 storm surge on the left bank of the Westerschelde. Two large polder boards were set up in order to face the heavy financial burden of dike maintenance. Right after the 1715 storm surge, the provincial government at Middelburg implemented new regulations enabling owners of polders at risk to appeal for financial assistance to a wide range of neighbouring polders. During the French occupation of the study area, authorities also tried to implement this kind of legislation on the left bank of the Westerschelde. Although they failed, the kind of new regulations were generally implemented during the 19th century. Together with the creation of a new department, the scientific monitoring of storm surges, water levels and changes taking place in the inlets of the delta region on the Dutch side, coastal and water management were again reformed. In 1870 this was carried out by implementing new legislation to provide owners of polders at risk sufficient financial means to face the problems of dike maintenance. At that time, the monitoring of tidal inlets in terms of sounding and coring banks and putting large constructions of wicker at eroding locations in the inlets had become a standardized part of dike maintenance (de Kraker, 2005a). On the Belgian side, hardly any reforms were carried out in terms of setting up polder boards as small geographical and administrative units, as had become customary in The Netherlands.

Damage assessment is a last important criterion to compare the impact of floods. Damage can be assessed in terms of casualties, number of cattle drowned, buildings destroyed and number of acres covered with water. There are several reasons why it remains impossible to make a comparison of flood events in terms of particular damage assessment. First, there is no statistical information about damage caused by floods prior to 1682. Second, even as late as the 1808 floods, no hard information about the precise number of acres flooded is available. Third, information about the total number of acres flooded only makes sense if the proportion of land to water is precisely known, which is also not the case until as late as 1808. Finally, the comparative study of quantitative damage assessment of the floods between 1400 and 1953 still has to be carried out.

CONCLUSIONS

This paper has looked into the flood events that occurred in the estuaries of the rivers Rhine, Meuse and Schelde in the southwestern part of The Netherlands and coastal Belgium between 1400 and 1953. From the overview of such events presented, it is clear that there have been natural floods mainly caused during storm surges and those that were deliberately caused during war time. Comparing both kinds of flood events, the strategic floods of the Eighty Years' War (1568-1648) have had the longest-term and therefore the biggest impact on the development of the landscape. Generally, "natural" floods occurred during storm surges, which happened under similar natural conditions, such as a westerly or northwesterly wind that lasted for at least two or three consecutive spring high tides about the New or Full Moon, causing sea levels to reach maximum heights in the funnel-shaped inlets as far as over 100 km upstream. The occurrence of a second, or even third, storm surge shortly after the first one needs also to be considered as having a lasting negative impact on repairs going on at the time. In particular, during the first quarter of the 15th century and the entire 16th century, several storm surges followed one another within a few years or even months. In the broader historical framework of climate variability, the floods in the estuaries caused by storm surges must be seen as examples of weather extremes rather than triggers of climate change or some phase of the Little Ice Age. In spite of so many identical natural criteria that may cause flooding, the lasting impact of floods finally depends on human response in terms of (in)sufficient dike maintenance, carrying out fast repairs, local surface levels of polders, and the quality and size of polder management and administrative units. In fact, this means that floods can only be fully understood by studying them at a local level. The different impact of flood events was clearly shown during the 1953 storm surge and floods; many historical floods did not paint such a distinct picture. However, there is one very decisive factor: the involvement of higher authorities such as provincial and central government. Lastly, a challenge for future flood research is the quantitative comparison of flood events throughout the period 1400–1953.

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