Hydrol. Earth Syst. Sci. Discuss., 12, 6541–6573, 2015
www.hydrol-earth-syst-sci-discuss.net/12/6541/2015/
doi:10.5194/hessd-12-6541-2015

Hydrology and Earth System Sciences
Open Access
Discussions

At the risk of floodwaters: historical flood risk and its social impacts in the area of the Wash in eastern England (Cambridgeshire, Norfolk, Lincolnshire) Mid 17th century–end of the 19th century

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Received: 20 May 2015 – Accepted: 21 May 2015 – Published: 06 July 2015

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

The floods were classified according to a severity scale derived from the contents of the historical sources. It enables an evaluation of these events in spite of the lack of instrumental data for the major part of period. It shows that the chronology and the severity of the floods in this part of England were contradictory from one century to another one and that their origins, as their seasonality, underwent not insignificant changes. The paper then shows that local societies (urban and rural) did not passively accept these extreme climate events. It shows that the flood questioned directly challenged the socioeconomic balance of the populations and that they tried to face it in a pragmatic and sustainable way.

1 Introduction

Just like numerous countries of Europe, Great Britain offers a wide range of sources of archives dedicated historical floods. The interest of these documents was perfectly demonstrated these last years by the historians (Mc Ewen, 1987; Brazdil et al., 2005, 2012; Barriendos et al., 2006). Some get direct information as private diaries which describe an extreme event while others evoke the flood in a indirect way in the form of flood marks or still administrative reports drafted a posteriori. Yet, in spite of the frequent lack of instrumental data for 17th and 19th centuries, these archives can be used to estimate in a relative way at least the climatic aspects of these disasters in order to understand their impacts on societies.

The objective of this work is to be simultaneously research the frequency and intensity of the floods over the last four centuries in the east of England (Cambridgeshire, Norfolk, Lincolnshire) and in their economic, social and cultural consequences. To achieve this, the study mainly exploits local textual archives. Their exploitation results in the construction of a regional floods series from the 1660s to the present day. Thanks to the contents of the archives, these historical events are placed in their contexts in

terms of intensity and weather conditions. This preliminary stage aims at observing possible changes in the frequency and the seasonality of the floods and to consider if a particular climatic signal can be observed for the most recent period.

Finally, according to the chronology revealed by this historical reconstruction, the research considers the reactions of the local English societies confronted with the risk of flood. To achieve this, a multiple and interdisciplinary approach was adopted. It takes into account the nature of the damage recorded in the historical documentation, the impact of the floods on the evolution of local mortality and finally the strategies of resilience developed by the populations.

2 Study area and background

Eastern England is primarily rural, with land use being largely agricultural outside of the main settlements of Boston, King's Lynn, Wisbech, Ely and Cambridge. The topography of this area is flat and low lying with large areas of fenland where the landscape is dominated by drainage channels which are crucial to maintain the agricultural system (Fig. 1). Significant areas lie within the fluvial and/or tidal flood zone of the Wash estuary. And only a few settlements as Ely, Littleport are located on "islands" of high ground above the floodplain. In East Cambridgeshire district, the largest river is the River Great Ouse, a large upstream catchment dominated by the city of Cambridge which eventually flows into the Wash. The study area contains several important wetlands which are remnants of the original fenland landscape. They include the Ouse and Cam Washes which are nowdays very important storage areas. In South Cambridgeshire and Cambridge City the River Cam flows in a south to north direction through the centre of Cambridge. It is joined by several tributaries such as the River Rhee and the River Granta and then falls within the catchment of the Great Ouse (Cambridgeshire Strategic Flood Risk Assessment, 2010).

Medievalists historians have proved that the Fens and swamps of this part of eastern England were not simply useless lands before their drainage in the 17th century. In

Lincolnshire, 2/3 of the lands were already arable land at the end of the 13th century. In addition, the Fens also had at the end of the Middle Ages extensive sheeps flocks for the export of the wool via the port of Boston (Galloway, 2013).

Under the reign of King Charles I (1600–1649) the inhabitants agreed with the Earl of Bedford to drain the area by employing the Dutch engineer Cornelius Vermuyden who introduced Dutch land reclamation methods to England. In 1664, King Charles II (1630–1685) decided to constitute a corporation for governing the Level under the authority of the Company of the Conservators of the Great Level of the Fenns, later named the Bedford Level Corporation (Carter, 1753; Ash, 2007). More exactly, the Great Level was in charge of a territory of nearly 161 875 ha of peat and silt. At this point it is interesting to define the general characteristics of the hundreds of landowners who collectively constituted the Bedford Level Corporation. Some few of the adventure lands were institutional properties; for instance land was owned at different periods by such bodies as the March Charity School Trustees, the Parish of Over, the Wisbech and March Turnpike Trustees, the Bank of England and two Cambridge Colleges (Summers, 1971). Amongst the individuals prorietors a wide range of rural occupations were represented. Landownership was mostly agrarian and local in charactere but there were also some proprietors coming from the ranks of London traders and merchants originating from such towns as Cambridge, Wisbech and Peterborough. Apart a minority of gentry and aristocracy, the majority of landowners were farmers, graziers and associated professions (blacksmiths, watermen, grocers) and this vast majority had their permanent residence within, or adjacent to, the Bedford Level. From the beginning, the Corporation undertook the work of rodding, dredging, scouring and banking all rivers and drains under its care, a major sustained and expensive operation (Darby, 1983).

3 Material and methods

This research is based on the exploitation of primary sources consisting mainly of textual archives and which, consequently, raises a problem of reading because they use various paleographies over the centuries. These are varied and heterogeneous because they derive from different origins, such as the archives of the Beford Level Corporation, the municipal archives of the cities of Cambridge Norwich, Wisbech or From King Lynn and newspapers were deprived of the notables and the academics of Cambridge Colleges.

Kept the the Cambridgeshire Archives (Cambridge), the archives of Bedford Level Corporation are central because for more than 200 years, the Proceedings and Order Book of the Conservators of the Level recorded all the business to do with the management of Fens. The records of their meetings begin in 1663; that of their Ely meetings in 1665. Very soon, both sets of records are full of complaints from owners of flooded lands; and full, too, of references to the rebuilding of broken banks, to the opening of blocked sewers, and to the improvement of difficult navigation. The minutes of successive meetings form an eloquent narrative of the struggle to maintain the drained level.

The series S/B/SP of the archives of Cambridgeshire so contains 2314 petitions among which 260 concern problems of floods. Drafted by several landowners victims of the flood, the petition is often precise. Besides names and places of residence of the authors, they can indicate the date (day and/or month) of the event then they describe exactly the damage caused by the waters (Fig. 2):

Petition from Thomas Jenkinson, John Northon and John Wrangle, on behalf of land owners in Waldersey and Elm. On 12th December 1669 a flood from the High Country caused several breaches in the bank on the south side of Wisbech River and flooded their lands as far as March. The petitioners ask for the breaches and gulls in the bank to be repaired as soon as possible.

Cambridgeshire Archives, S/B/SP38

When the damages are important and expensive, petitions indicate the figures asked for by the victims and the favorable answer (or not) given by the persons in charge of the Bedford Level Corporation:

Petitioners report that since making an agreement with the Corporation in April 1717 they have repaired the bank of their lode with clunch, but that it was badly damaged by the wet summer of 1725 and the floods in Feb 1726. They are ready to continue with the repairs, and ask for £ 60 or £ 70 to be spent on them. A copy of the BLC agreement is attached.

Cambridgeshire Archives, S/B/SP315

With the prospect of a historical study of the floods of natural origin, these petitions have the advantage that they identify clearly the causes of the events, wheter caused by a misuse of hydraulic plants (gates, banks, sluices) or by the activities which take place (haling, boats so-called lighters) of Great Level there. On the other hand, they rarely specify the weather conditions (rain, snow, ice, storm) or maritime (tide) which provoked the flood.

The municipal archives kept in Norfolk Record Office and in Cambridgeshire Archives allow us to study the floods in an urban frame from the examples of the cities of Kings Lynn and Cambridge. In the first case, Hall or congregation (assembly) Rolls and books get regular information on the climatic extremes because the elected representatives watched to take measures (defense of dikes, taking care of victims) quickly when a flood threatened the city or its supply. For Cambridge, the Annals of Cambridge tell the history of the academic city under a document published in the 19th century. This paper uses essentially the volumes 3, 4 and 5 of the collection which cover the 17th, 18th and 19th centuries.

Their contents are supplemented by the private diaries written by Fellows (academics members of Colleges) of Cambridge (Gonville and Caius, King's, Magdalene, Queens, Saint John and Trinity Colleges) the location of which close to the river Cam is relevant for the historical study of the floods. For the latest period, the diaries of two bourgeois women give a precious perspective on the floods after the 1840s. Used in conjonction with the archives of the Bedford Level Corporation, these numerous city testimonies allow us to register the floods in the urban area on the geographical and social level. Indeed, they locate flooded sectors very exactly by mentioning the district, the steps or the height of water in the cloister of a College.

On the 10th of February there was a great flood, the waters being nearly a foot higher than the flood of October 1762. 'The water ran over the high walks at King's College, Clare Hall, Trinity College, and St. John's, and the road at the back of the colleges, was for some hours impassable. A person plied with a cart opposite Magadalen college, to carry passengers to the Great Bridge.

Annals of Cambridge, vol. 4, p. 453.

A major problem is the lack of instrumental data (flow, pluviometry, height of waters) in archives previous to 1850s in this part of England. It is thus very difficult to properly quantify reasonably the floods from written archives. To try to remedy this, since the 1990s European historians of the climate have used the measurement systems established by severity index to translate statistically textual data (Barriendos and Martin-Vide, 1998). Nevertheless, this estimation does not allow a precise hierarchy of the events, in that we cannot distinguish the very localised floods from the major events on the geographical, financial and social levels.

We thus propose another way to quantify flooding by taking into account the contents of archives and the documentation. The method addresses the problem by using 6 grades, of which one is a negative (Table A1). The first five grades (from 1 to 5) estimate the flood according to its geographical, social, material and economic impact.

The grade −1 corresponds to a flood for which it is impossible to know its exact date, its duration and its socioeconomic impact. This negative grade allows us to keep this type of event in the chronological series even if its severity cannot be estimated.

To complete the historical series of the floods later than the activity of Bedford Level Corporation, we used the historical data of the BHS Chronology of British Hydrological Events web site. This historical reference database is available on the server of the University of Dundee and it uses essentially secondhand information resulting from mainly descriptive published sources (Black and Law, 2004). Their contents have the advantage of being adaptable to the contents of the Cambridgeshire Archives and consequently, being suitable to complete the chronology of the floods up to the beginning of the 21st century.

4 Results and discussion

4.1 Fluctuations, severity and origins of the floods 1663–2006

With all these prior archive and online data, the result of the survey is as folows. A total of 51 flood events have been found for the period 1663–2006 (Fig. 3).

For the period 1663–1900, only 11 events are listed by BHS Chronology of British Hydrological Events out of a total of 38 floods. This analysis consequently underlines the benefit of exploiting the primary sources in historical archives to reconstruct long series of climatic extremes. There is no very clear single trend during all the period studied but strong and contradictory fluctuations do appear. So there are episodes in the course of which floods are numerous in the second half of the 17th century, in the 1660s, and especially during the years 1850–1890. This chronology is relatively well confirmed by other historical studies which evoke the influence of the little ice age which reaches a climax then (Le Roy Ladurie, 1967; Brazdil et al., 2005).

The later period between 1900 and 2010 achieves a moderate frequency of events. The secular fluctuations reveal that the centuries the most affected by hydrometeors

are the 18th and 19th centuries with respectively 12 and 20 floods. Whereas the 20th century has only 11 events.

On the other hand, the distribution of the floods by periods of 50 years and by index of severity refines the frequency and the intensity of the floods considerably while underlining the strong disparities between periods (Fig. 4). The second half of the 17th century, in spite of the quality of the archives of Bedford Level Corporation from 1663 records a peak of 6 floods at the beginning of the period. The number decreases between 1700 and 1750 with only 3 events. Whereas from the 1750s, the floods are more frequent and this trend persists till the end of the 19th century. In this respect, the period 1850–1899 seems particularly singular because it undergoes 13 floods against an average of 8 events for periods 1750–1799 and 1800–1849.

From the point of view of the intensity of these floods, the episodes with the most catastrophic flooding (index 4 and 5), derived from the valuation method based on the damage described by archives, are in the second halves of the 18th and 19th centuries as well as first half of the 20th century whereas the period after the Second World War suffers less frequent and at the same time less severe floods. As for the period of return, the average is around 7.5 years (Table A2). The most exposed centuries at the risk of flood are 17th, 18th centuries and especially 19th century. For both the first ones, the period of return is a little more than 8 years whereas it reaches only 5 years after 1800. On the other hand, the 20th century presents a flood risk only every 9 years approximately.

4.2 Causes and seasonality

Archives and published documentation evoke four major causes of floods, the influence of which fluctuates considerably between centuries (Fig. 5). Unsurprisingly, the rain is at the origin of the very great majority of the floods (approximately 75 % on average) in this part of England, irrespective of the century studied. More surprisingly, the snow is in second place but concerns only the last three centuries, even though the 17th century is generally considered by the historians as that of the climax of the little ice

age (Pfister, 1999; Parker, 2013). The majority of the periods of ice on the French river Seine occur in this century, in particular at the end, during the Maunder solar minimum (Garnier, 2010 and 2015). Most often, the meteorological scenario is the followin: after heavy snowfalls, a sudden warming up accompanied by rains causes the thaw of the covering of snow. The latter engenders then in its turn the overflowing of rivers, especially if a strong tide occurs at the same moment in the estuary of the Wash. About the flood of February 1795, the annals of Cambridge report:

"Subsequently to the setting in of the frost, there had been a heavy fall of snow, and the frost broke up with a heavy rain. The great floods have made many breaches in the banks of the Great Ouse (Fens) which they have no mean to repair."

Annals of Cambridge, vol. 4, p. 453

Geographical space opened on the estuary of the Wash and on the North Sea, the eastern England also undergoes a not insignificant influence of the sea. During the last four centuries, it is directly or indirectly at the origin of 16 % of the floods in the region. The local historical sources mention so jointly astronomical phenomena such as tides (15,5 %) and sea surges (7 %). If this maritime scenario is associated with a strong pluviometry upstream, the situation is systematically translated by generalized overflowing at the level of the entire regional river system.

In December 1663 (Fig. 2), a very high tide produced floods everywhere in eastern and southeast England. Besides the regions of Norfolk, Lincolnshire and Cambridgeshire, the estuary of the Thames estuary was totally submerged by waters which even reached Whitehall in London (Brook, 1928). The worst maritime flood in terms of damage and human losses was the disaster of January 1953. It affected all the North of Great Britain and other countries bordering the North Sea (Lamb, 1991).

Finally, the last meteorological cause of floods, the intense cold which freezes rivers and canals. When the thaw occurs, this ice breaks up and forms blockages which prevent the water flowing. This then causes the surrounding territories to flood. Contrary to

all expectations, these ice is consistently mentioned in the course of the 19th century, in 1814 (January), 1830 (January) and 1861 (February). The first date corresponds to a obvious cooling between 1809 and 1817 and the event is described in the petitions of Bedford Level Corporation:

"The petitioners report that the channel of the Hundred Foot River is obstructed by more than 10 feet of ice (around 3 m). They ask for it to be removed and ask for a payment for breaking up ice and removing obstruction during the recent floods"

Cambridgeshire Archives, S/B/SP1002

The freezing of 1830 is incorporated within the framework of a cool climatic sequence which is acompanied in Europe by severe winters and of bad harvests. The social climax will be the second French Revolution on 27, 28 and 29 July, known as the "Three Glorious Days" (Le Roy Ladurie, 2013)

The seasonal distribution of the floods shows strong disparities during the four centuries and provides rather contradictory climatic signals, in particular for the 20th century (Fig. 6). The winter counts for more than half floods (25 events) for which sources give the monthly date. Then, and in a decreasing order, the seasons the most affected by these climatic extremes are the autumn (9 events), the spring (7 events) and finally the summer with 5 floods.

Nevertheless, with the prospect of contemporary climate change, we observe a sizeable seasonal evolution between the 20th century and the beginning of the 21th century and the centuries which precede them. A clear trend emerges towards a greater frequency of floods during the spring, especially in May, and in autumn (in September mainly). Yet floods in May and September were unknown until 1900. On the other hand, the risk of eastern England undergoing a wintry flood decreases appreciably. This report realized from data history is moreover confirmed by various studies which talk about outbreaks of the flooding resulting from heavy rainfall in May and in autumn (Bayliss, 1994; Hannaford and Mars, 2008; Macdonald, 2012).

4.3 Socioeconomic impacts

4.3.1 Economical and material damage

Between 1663 and 1852, the Bedford Level Corporation regularly paid victims the cost of the repairs to infrastructures damaged by the floods. The chronology of these payments shows that the compensation was far from being systematic because only 14 floods out of 26 gave rise to financial compensation. On average, the amount of this compensation came to GBP 1425. The vast majority of these payments concern severe floods with an indications of severity of which are between 4 and 5 (Fig. 7). As a consequence, the victims could not hope help with a low intensity flood. They had to manage by themselves. Nevertheless, in spite of this restrictive compensation policy, the big financial crises of the company coincide closely with the highest expenses because of floods (Summers, 1971). So the financial crisis of the years 1753–1777 corresponds with three hydrometeors of which the one in 1756 cost the Bedford Level Corporation GBP 6000. The financial strain this put on the Corporation meant drainage works were frequently dangerously deficient in many parts of the Level. The waterways were difficult and dangerous, sometimes even unavigable. In the 1770s, a series of disasters in the North Level precipitated a crisis. Several breaches had occurred in the north bank in 1763 (GBP 190), 1764, 1767 (GBP 113) and 1770–1771.

Financial difficulties reappeared at the beginning of the 19th century after the expensive floods (GBP 3960) of 1809, 1820 and 1821. Naturally, the agricultural and river activities connected to the exploitation of the river system were also affected.

The petitions of the victims and the financial statements of Bedford Level Corporation indicate the types of technical damage caused by the floods and their social consequences. For the inhabitants, the floods have a very negative impact on their income. Besides the potential loss of their harvests, their equipment and their cattle, they immediately have to undertake expenditure to repair infrastructures. In one year after the flood of 1764, the taxpayers could not pay their taxes any more because their lands were still flooded. In these conditions, the debt of the local populations increases

strongly after every disaster and evictions multiply for those who cannot pay their taxes or their debts.

In April 1822, petition of certain Commissionners of the Lower Barrier Bank says:

"The petitioners report that they have spent more than £ 1600 repairing the Lower Barrier Bank, which was badly damaged by recent floods. They ask for financial assistance towards the cost of the repairs, as their funds are now totally diminished. The report also includes a detailed account of money expended on repairs to the Lower Barrier Bank."

Cambridgeshire Archives, S/B/SP1205

The damage caused to infrastructures worsens the precarious existence of the local populations. Bridges are often swept away or partially destroyed by floods. Their disappearance hinders the economic activity. After the destruction of the bridge which crosses Hundred Foot River to Sutton Gault in 1663, the farmers cannot reach their lands any more to cultivate them. As dramatic is the loss of the ferry boats. Some are taken by the current or sunk during the works undertaken as a matter of urgency to repair breaches in dikes. The flood also damages canals and sluices. In 1795, the majority of dikes are badly damaged by multiple breaches. As for sluices, they are often blocked by materials and vegetation carried along by the river. After the big floods of 1809, petitions mention the very worrisome situation of the North Barrier Bank which is strongly eroded and undermined.

It is common that navigation is completely blocked between upstream areas and the ports of Wisbech and King's Lynn. Finally, waters threaten the livestock directly as it was the case in February 1763 in Fens Holland. The flood submerged more than 22 000 acr (approximately 9000 ha) under 2 ft of water and drowned 3000 sheeps.

The city was no less affected by the floods. It was also very vulnerable because of its very exposed situation on the hydrographic plan. Bridges and roads were the first infrastructures damaged as shown by the flood of 1795 at Cambridge:

"On the 10th of February there was a great flood, the waters being nearly a foot higher than the flood of October 1762. 'The water ran over the high walks at King's College, Clare Hall, Trinity College, and St. John's, and the road at the back of the colleges, was for some hours impassable. A person plied with a cart opposite Magadalen college, to carry passengers to the Great Bridge. . . A flood higher by a foot that of October 10th, 1762, took place in February of this year. The doors of the house of Mr. Anderson, at Newnham, situated was forced and open by the violence of the waters, which stood seven feet deep in the house. The inhabitants of Newnham had no communication with any one until the following morning."

Annals of Cambridge, vol. 4, p. 453.

Besides infrastructures, the vulnerable sectors corresponded to the lowlying parts of the city close to the river where the inhabitants were frequently the first victims of the urban flood. In 1872, in Lincoln, help was sent to the populations of the low city totally flooded after heavy rainfall for several days (Wheeler, 1856). In the southwest of Cambridge, the inhabitants of the parish of Newnham were regularly threatened by the waters of Cam in 18th and 19th centuries. After the Cam river invaded gardens and houses, and cut roads, the village became an island in the middle of a temporary lake.

4.3.2 Demography: example of Ely

Beside the economic losses, the potential impact on health is also not insignificant. Potential physical impact on the individual are: mortality, injuries, diseases (e.g. diarrhoeal, vector-borne) and infection (Few et al., 2004). The first effect to consider when assessing the impact of a disaster on the population is the risk to life. However this risk is really low and usually related to coastal flooding and flash floods (e.g. North Sea floods of 1953; Xynthia 2010 France). On the other hand, the longterm effects of the floods in the past could be significant. Because of the scale of some historical events

and also but because of the living conditions and preexistent diseases, the long-term effects of floods were mainly related to poverty and bad health conditions.

To complete this demographic approach, the example of the city of Ely was chosen because it is situated at the heart of the wet region of the Fens. Up to the 17th century, it formed the so-called "isle of Ely", a territory affected by alternate sea-water and fresh-water incursions. In spite of the drainage undertaken later, the English writer Daniel Defoe still described the city and its swamps at the beginning of the 18th century as "the sink of no less than thirteen Counties" (Defoe, 1722). 52 years later, Church of England cleric John Wesley wrote of his approach to Ely and said that water covered the high road and people had to wade through to come to the town (Wesley, 1827).

Kept in the Cambridgeshire archives, the Holy Trinity parish registers of Ely record the baptisms, the marriages and deaths since the end of the 16th century. The comparison of the mortality and the floods shows that 15 floods (on a total of 38 events) precede an increase of the mortality between 1669 and 1878 (Fig. 8).

In rare cases, the mortality increases shortly after the flood. In others, the deaths increase later, because of the stagnant waters in the territory. However, it is difficult to establish a systematic link between mortality and flood because it is impossible to know the medical origin of the deaths in archives. Nevertheless, the historical documentation and the narratives of the travellers of the time explain that people mainly suffered from headaches, colds coughs and flu.

After the breaches of dikes and sluices on 15 November 1852, the region suffered a major flood (index 5 of severity) which was followed by an increase of the number of deaths during January and February 1853 then during the autumn of the same year (Fig. 9). This pattern of mortality is not consistent with the models defined for several decades by the English historical demographers. In England, the peaks of mortality generally occurred during spring while the summer and the autumn (especially in September) were characterized on the contrary by a low number of deaths (Wrigley and Schofield, 1989; Dobson, 1997).

As a consequence, the mortality postponed and concentrated in winter and in autumn, 1853 can probably by explained by the stagnant waters in the region for almost 9 months according to archives. At that time, the physicians and the Church of England clergy evoke many fevers which decimate families. Again, it is difficult to propose a definitive answer as for the role of the flood in this mortality. Nevertheless, it is possible that these "fevers" were connected to the presence of stagnant waters. Maybe it favored an epidemic of malaria, an endemic disease in this part of England in the 19th century.

4.3.3 Strategies of adaptation

Quite unexpectedly, the various actors exposed to the risk of flood developed strategies precociously to increase their resilience on the economic and social plans. The first strategy consisted in taking technical measures intended to prevent the most negative effects of a flood. In the case of the wetlands of Fens, it was especially a question of facilitating the flow of the water in canals and rivers. The petitioners requested regularly Commissioners of the Bedford Level Corporation so that preventative works are undertaken before the floods. Firstly, it was a question of cleaning out the stream beds by means of machines specially designed for that purpose. In 1818, the owners of Land in Stoke Ferry used a spade machine to scour the Stoke River at a cost of GBP 131.14 and asked for the financial assistance of the Corporation. The use of this machine represents a sizeable investment for the company which asks before its engineers to express their opinion before committing to its use. In 1820 for example, its engineers examined the state of chanels of the Ouse and the Lark and authorised use of spade machine for clearing the river Ouse.

These works costed GBP 500 and they were justified "for preventing flooding." The efforts also concerned the strengthening of the hydraulic defenses as embankments and cleaning of drains and canals partially or totally obstructed by vegetation and silt. The lodes were examined and repaired in anticipation of spring tides and wintry floods.

More unexpected is the collective will to create and to maintain a memory of the flood risk. Repeatedly, in archives, witnesses are capable of asserting that the current flood is higher or lower than a previous flood. It was the case for example at Cambridge during the great flood of February 1795 that was estimated then "nearly a foot higher than the flood of October 1762." The preservation in the memory of an event of 33 years earlier certainly implied the existence of material testimonies in the city. De facto, from the 18th century at least flood marks existed inside Colleges in the city. From the 19th century, new marks appeared. They were different from their predecessors because they were situated in busy streets. It was thus a question more of "democratizing" the knowledge of the risk thanks to very visible marks situated in particularly vulnerable districts. The flood marks of Fair Street are situated in a strategic street which faces the river Cam and the meadows of Midsummer Common (Fig. 10). Nowadays they are the record of the floods of 1821, 1861, 1878 and 1984 estimated as events of extreme severity (index from 4 to 5).

The desire to anticipate the rise in the water level better is also obvious in the Fens. There, it was a question of improving the alarm system through the installation of marks by the farmers along canals and sluices to better anticipate the overflowing of rivers. In a Memorial of July 1877, the landed proprietors and occupiers and inhabitants of towns in the Valley of the Ouse after the heavy loss of property and injury to health engendered by the flood of 1876 asked for the creation of a spike or other mark 2 ft below the level of the old mark done by the Bedford Level Corporation. This example extracted from archives demonstrate that there was a clear strategy of alert based on the observation of marks, being the object of regular improvements within the framework of a concerted management between the company and the farmers.

5 Conclusion

The paper clearly demonstrates the benefits of using primary historical data even when they are not instrumental data. Indeed, without these textual data, it would have been

impossible to reconstruct a relatively reliable series prior to 1850. The classification proposed in this work according to the damage described in the historical documentation is not perfect and includes important gaps. Nevertheless, it allowed the creation of a new and relatively homogeneous series between the most oldest and the most recent floods because it is based on comparable criteria of evaluation. Quite unexpectedly, it reveals a surprising chronology which does not show worsening of the floods in the 20th century in the comparison with the previous century which saw a peak of the phenomenon, particularly between 1850 and 1900. On the other hand, the study of the seasonality actually shows a contemporary climatic signal with regard to the previous centuries with a shift of the flood risk away from the winter months towards spring and the autumn.

On the socioeconomic level, the study confirms the impact which the floods had on the survival of very vulnerable societies. Far from being fatalistic, they tried to act on two fronts. The first involved engineering in the form of regular hydraulic works to better prevent floods. It was based on technical knowledge shared by the local populations and the authorities which implied a control and an important and sustained financial investment. The second strategy of resilience was based on the conservation and the transmission of the memory of the flood risk. It aimed at anticipating disaster by safeguarding properties and individuals as far as possible. For that purpose, it was necessary to have visual markers in strategic places. These markers allowed individuals as well as the authorities to estimate future flood risk by reference to the markers, and helped to define priorities for the management of the risk. More than a simple contribution to patrimonial vocation, this historical experience must be also regarded as useful feedback from the past to strengthen current warning and relief systems.

Acknowledgements. E. Garnier ackowledges financial and logistical support from Churchill College (Cambridge) and the French Embassy in London for the HEALTH project (Historical Extremes And heaLTH). He is very grateful for the support of the Cambridgeshire Archives and the University of Cambridge (Department of Geography). Finally, he thanks George Turner for proofreading his text and David Moncoulon (CCR reinsurance company) for his technical advice.

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Table A1. Method of assessment of the severity of historical floods before the instrumental period.

Category	Type of damage according with historical archives
5	Exceptional event because of its geographical scale (local, regional and national), financial and social (scarcity, riots, mortality)
4	Very big damage on a regional scale: hydraulic plants, bridges, farms, cattle, harvests, lines of communication
3	Damage important but limited to some localities or to a city: cost, scarcity, cattle drowned, human mortality
2	Little important and located damage: some villages, farmlands, wetlands, neighborhood of the river
1	Mentioned in sources, not much damage, local event
−1	Mentioned in sources, absence of further information

Table A2. Period of return of floods in eastern England 1663–2010.

Century	Return period	Yearly probability
17th	8.33	0.12
18th	8.33	0.12
19th	5	0.2
20th	9.09	0.11

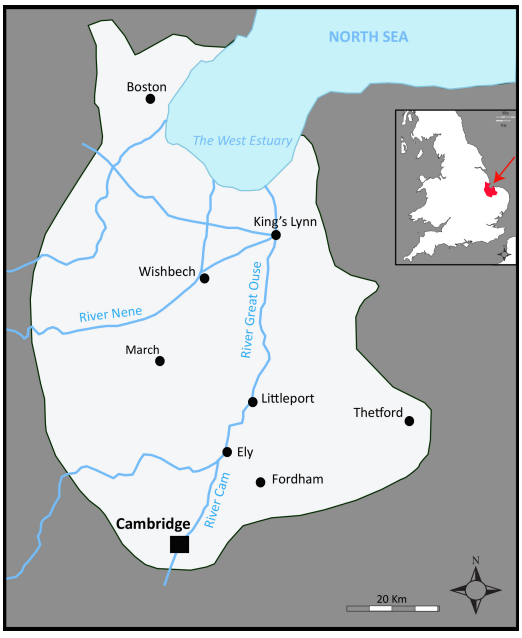

Figure 1. Study area for which historical reconstruction has been undertaken with cities and rivers mentionned in the text.

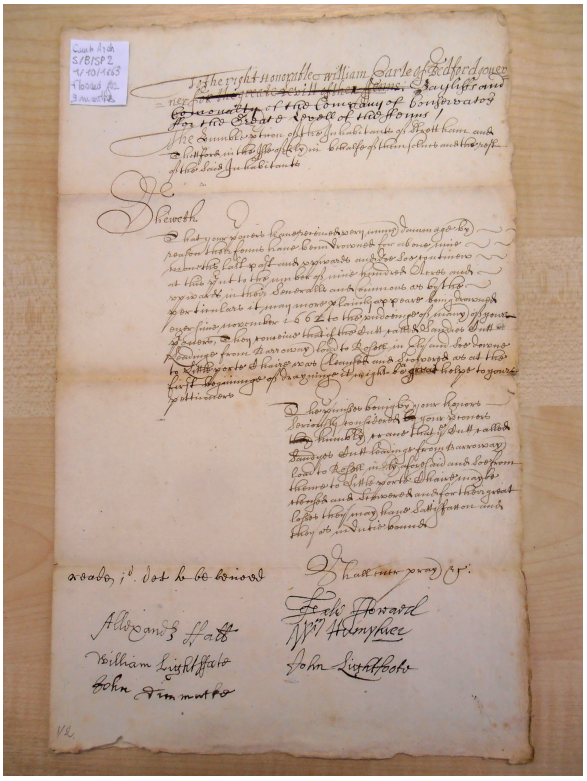

Figure 2. Example of petition of the Bedford Level Corporation after the flood of October 1663, because of a strong tide. Cambridgeshire Archives, S/B/SP2.

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |

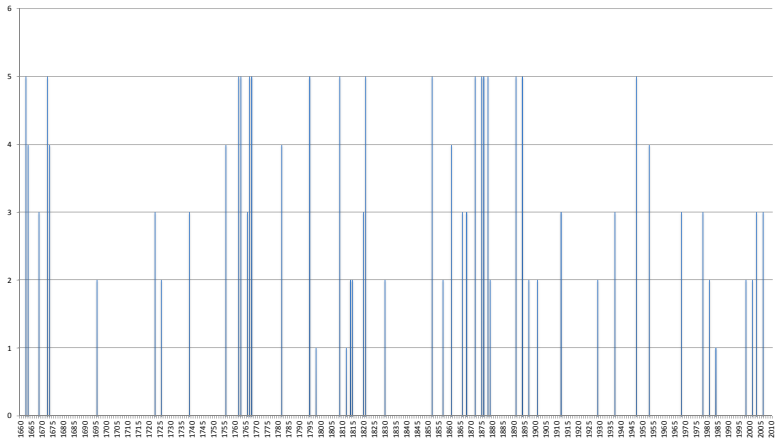

Figure 3. Chronology and severity of floods in eastern England between 1663 and 2006.

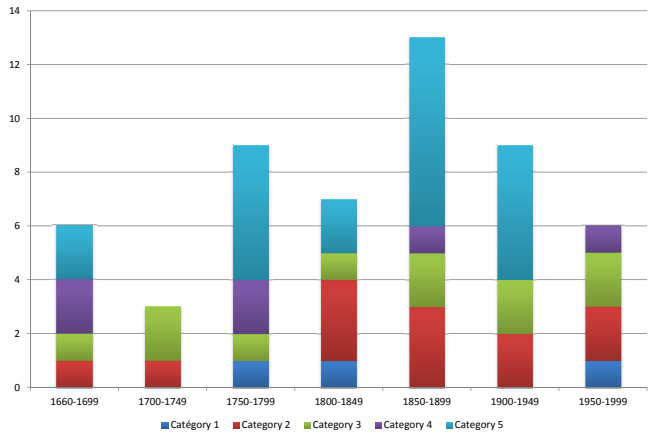

Figure 4. Distribution of floods by periods of 49 years and by category (from 1 to 5) in eastern England.

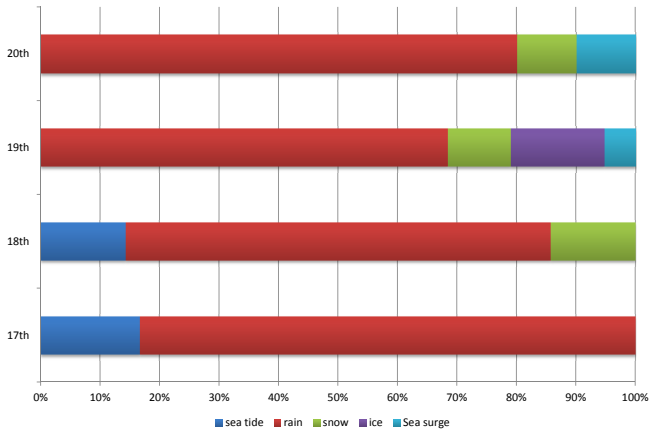

Figure 5. Natural causes of the floods in eastern England in the last four centuries.

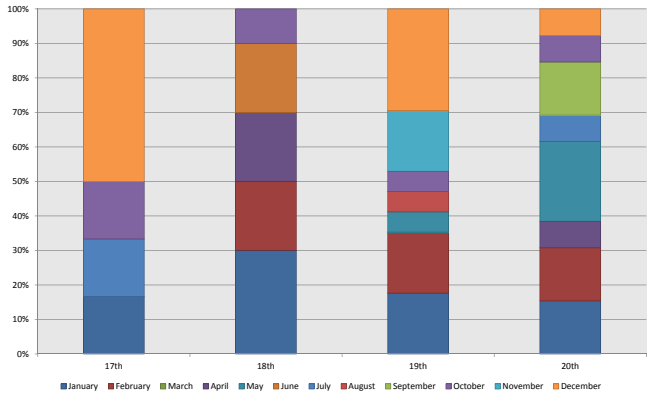

Figure 6. Monthly distribution of the floods in eastern England 17th–20th centuries.

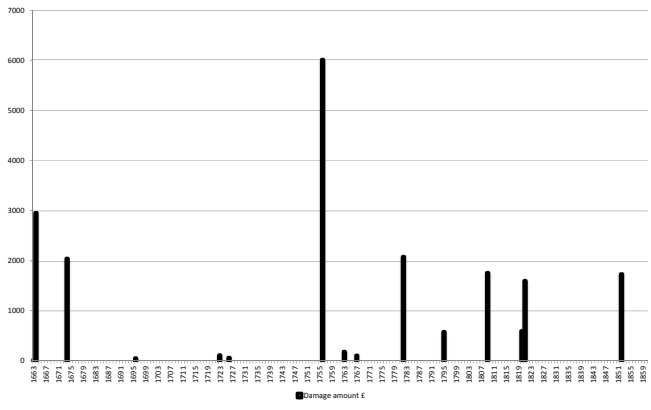

Figure 7. Amount (in GBP) of the flood damage paid by the Bedford Level Corporation 1663–1855.

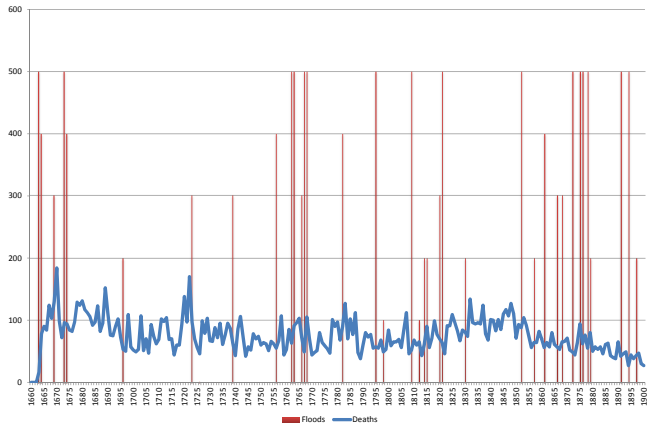

Figure 8. Comparison between the mortality of Holy Trinity parish of Ely (Fenlands, Cambidgeshire) and the floods 1669–1878.

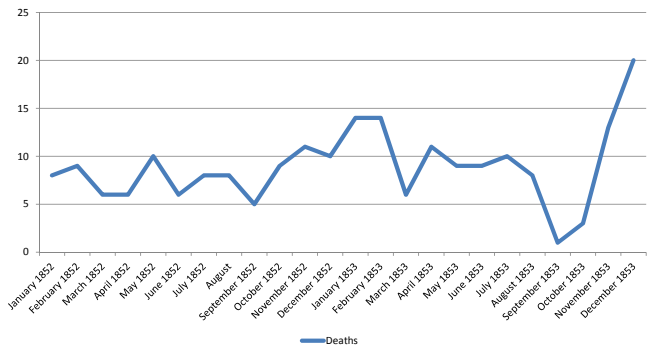

Figure 9. Flood and mortality at Ely (parish of Holy Trinity) in 1852.

Figure 10. Historical floods marks in Cambridge keeping the memory of the floods of 1821, 1861, 1878 and 1984.