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### Trends in reported flooding in the UK: 1884-2013

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## **Trends in reported flooding in the UK: 1884-2013**

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**Abstract:** A long term dataset of reported flooding based on reports from the UK Meteorological Office and the UK Centre for Ecology and Hydrology is described. This is possibly a unique dataset as the authors are unaware of any other 100+ year records of flood events and their consequences on a national scale. Flood events are classified by severity based upon qualitative descriptions. There is an increase in the number of reported flood events over time associated with an increased exposure to flooding as floodplain areas were developed. The data was de-trended for exposure, using population and dwelling house data. The adjusted record shows no trend in reported flooding over time, but there is significant decade to decade variability. This study opens a new approach considering flood occurrence over a long timescale using reported information (and thus likely effects on society) rather than just considering trends in extreme hydrological conditions.

**Keywords:** Flooding, Flood Risk, Detection, Flood Trends, UK

### **INTRODUCTION**

Flooding has always been a feature in the British Isles and a number of major flood events in the 20<sup>th</sup>/21<sup>st</sup> Century have caused significant damage and sometimes significant loss of life. They have also left an important legacy in how we manage flooding. The 1947, 1953, 1998/2000 and 2007 floods are examples, with the winter 2013/14 floods also likely to leave an important mark. Recently, the connection between flooding and climate change has been raised both in the UK (e.g. Wilby et al. 2008) and more widely (IPCC 2012, Jongman et al. 2012), and a linkage between climate change and flooding is often mentioned in the media. This raises questions about both historic trends and future prognosis of damaging floods. Growth in exposure to flooding is a major driver of flood risk (Evans et al 2004, Merz et al. 2010, IPCC 2012) and hence increasing flood Consequences may not be linked to just changes in hydrological regime. Detecting and understanding trends in flood Consequences and all the relevant drivers is important as this informs decision-makers how best to allocate scarce resources for flood management (Pielke Jr. 2000).

In this paper, we describe the historic trends in flooding in the UK by analysing a national dataset of >125 years of reported flood events. This data is based on reporting systems that describe damaging terrestrial and tidal floods. National population and housing data are also considered to scale reported flooding by exposure. These datasets provide an unusual and possibly unique opportunity to evaluate any changes in the occurrence of damaging floods.

Flooding is often analysed using the Source-Pathway-Receptor-Consequence (SPRC) Model (Thorne et al. 2007, FloodSite 2009, Narayan et al. 2014). Most historic studies focus on trends on flood Sources, be it high river flows, extreme sea-level events and coastal storms. (e.g. Robson et al. 1998, Haigh et al. 2010, Menéndez and Woodworth 2010, Marsh and Harvey 2012, Murphy et al. 2013, Wilby and Quinn, 2013). Anticipated climate change

suggests that in many areas of Europe, summers are likely to be drier, but winters may be wetter, with a potential for a greater frequency of fluvial winter floods (Hulme et al. 2002, IPCC 2007). Coastal areas are likely to be more vulnerable than inland areas due to changes in sea level, wave heights and accelerated erosion (Zsamboky et al. 2011). However, an analysis in trends in Consequences also needs to consider changes to the Pathways and Receptors. Changes in Pathways may include degradation of natural protection, but they also include the provision of new and upgraded flood defences and other improvements in flood management over time. It is recognised that many flood defences have improved substantially over the last 100 years as exemplified by London's flood defences, including the Thames Barrier. This has reduced flood Consequences over time. In contrast, the number of Receptors in the flood plain has increased significantly due to population growth and an increase in the number of buildings. This increases the potential Consequences of a flood event (Hooijer et al. 2004, Evans et al 2004).

Flood events have typically been evaluated using river flow data and the analysis of the frequency of peak flows (Robson et al. 1998, Robson 2002, Macdonald 2006, Petrow and Merz 2009, Delgado et al. 2010, Macdonald et al. 2010, Kjeldsen et al. 2012, Marsh and Harvey 2012). Long flow series are rare, with few records extending over 70 years (Macdonald and Black 2010). In the UK only the Thames and the Lee have flow records >100 years (CEH 2013). There is much more data available in the last 50 years. For example, Petrow and Merz (2009) evaluated flow data for 145 sites in Germany between 1951 and 2002. Some studies have supplemented the hydrometric flow data with historical sources such as flood marks and descriptions (Macdonald 2006), documentary records (Macdonald and Black 2010) or paleoflood hydrology such as geological records (Costa 1986). More local studies into the frequency and distribution of coastal flooding have used extreme sea level data combined with local records (newspaper reports) to judge when tidal floods have occurred and consider their Consequences (Ruocco et al. 2011).

Evaluations of trends in flood sources suggest there is variation spatially (IPCC 2007, 2013). Barredo (2009) assessed European flood losses in 31 countries between 1970 and 2006. The study shows no evidence of any trend in normalised flood losses. Delgado et al. (2010) found an increasing likelihood of extreme events in the Mekong river whilst the probability of an 'average flood' has decreased. Significant trends (both positive and negative) have been detected in a 'considerable fraction' of basins in Germany (Petrow and Merz 2009). There is high year-to-year climate led variation in the UK with no significant long term trends in flood frequency (Robson et al. 1998, Macdonald 2006, Marsh and Harvey 2012). There is evidence for a shorter term (40-50 year) trend in the UK (Robson 2002) and significant trends were found in the UK in recent decades (Kjeldsen et al. 2012). Hannaford and Marsh (2008) found significant positive trends in the frequency and magnitude of flood events in 'relatively undisturbed' catchments in the UK in the last four decades of the 20<sup>th</sup> century. However differing methodologies and the time scale of these studies make them difficult to compare with climate change scenarios which typically consider time scales of 30 to 100 years (Hulme et al. 2002, IPCC 2007, Ramsbottom et al. 2012).

Whilst historic sources can be used to extend records, these are not always consistent or reliable. Robson et al. (1998) state that long datasets are needed to identify trends, yet older data can be 'sketchy'. For instance in European studies it was found minor flood events were reported more widely in recent times (Barredo 2009). Journalistic evidence of flooding on the other hand may suffer from its ephemeral nature and potential lack of scientific rationale. It is clear that a trade-off exists between increasing the length of record with multiple data sources and maintaining consistency and quality of the record.

This paper develops and analyses a dataset of reported flood events covering the whole of the UK from 1884 to 2013, a period of 129 years. We are unaware of any other

records >100 years in the world that describe flood events for rivers and coasts on a national scale. The data record was used to explore trends in flooding over the 20<sup>th</sup> century. The effectiveness of the analysis framework used was evaluated to determine the ability to extract consistent knowledge in a changing social and physical world.

The reported datasets are described and critiqued, and limitations discussed. Validation of the dataset using independent flood impact data is then undertaken. The full time series is presented, and the data is de-trended for exposure and the implications of the findings are discussed.

## **METHODOLOGY**

### **Data sets used for the long term study of UK flood impacts**

Macdonald and Black (2010) state ‘the suitability and value of historical data in flood frequency analysis is determined by availability of records, their level of detail and their reliability’. There is a difference between a hydrological flood in terms of water level and a damaging flood which impacts society. In this study only floods which have been reported as having an impact on society are considered. These are listed in the UK Meteorological Office (henceforth Met Office) Monthly Weather Reports (Met Office 2012a) and UK Climate Summaries (Met Office 2012b) (© Crown Copyright). These records span the period 1884-present (Figure 1) and are probably one of the longest regular set of national reported flood consequences in the world.

The Met Office monthly weather summaries ended in 1993 and the UK Climate Summaries start in 2001. Hence, in this paper these reports are supplemented with the CEH (Centre for Ecology and Hydrology) monthly Hydrological Summaries (CEH 2012) for 1988-2012 (© NERC - Centre for Ecology & Hydrology). These consider flood events (with limited descriptions of impacts), and they overlap with the Met Office reports for 18 years, allowing comparison.

The Met Office monthly weather summaries report on the Meteorological ‘highlights’ for the UK each month (Figure 2). Where flood impacts occur as a result of Meteorological processes (such as rainfall, storm surges, high tides and gales) these are reported in the summaries as both terrestrial flooding (pluvial and fluvial) and tidal flooding.

This paper appraises the sources and methodology for producing a single unified record to provide an unbroken time series of reported flood events in the UK from 1884-2013.

### **Flood reporting terminology**

The monthly weather reports provided the following information about flood events:

- Place(s) affected
- Description
- Cause (flood type)

The terminology used was often only descriptive; flow values or tide levels were rarely reported. Phrases used included ‘Disastrous’, ‘Destructive’ or ‘Severe’ which are difficult to quantify but nevertheless are useful indicators of the perceived scale of the event. The distribution of words used to describe flood events in the reports is shown in Table 1. The terms ‘Widespread’ and ‘Severe’ and ‘Extensive’ have similar frequency of use in the two data sets, but CEH tends to use ‘Significant’ in place of a wider series of terms used by the Met Office.

### Consistency of reporting terminology through time

The consistency of terminology through time is an important consideration. The use of the five most commonly used terms in the datasets ('Severe', 'Widespread', 'Serious', 'Extensive' and 'Considerable' - see Table 1) was analysed. Figure 3 shows that the majority of terms ('Severe', 'Serious', 'Extensive' and 'Considerable') are used continuously through time in the Met datasets and may be good indicators of the scale of event. The use of the term 'Widespread' is much more sporadic; first being used in the 1920s and with heightened use in the 1960s and 1980s. However it is used more consistently toward the end of the record and so it may also be an indicator of scale. In the CEH dataset 'Serious' and 'Considerable' are used infrequently, however 'Widespread', 'Severe' and 'Extensive' are used continuously (the dataset starts in 1989 and so the 1980s data is only based upon one year and therefore is not comprehensive).

The evolution of use of the terms was explored for all of the datasets. The Weather Reports (Met-WR – Figure 4a, b) used a wide array of descriptive terms which evolved into a smaller number of terms in the Climate Summaries (Met-CS – figure 4d). The proportion of records using the terms 'Considerable' (6%), 'Severe' (9%) and 'Widespread' (9%) has remained relatively consistent through time. The use of 'Serious' is used continuously through the record (used to describe an average of 7% of flood events). The term 'Heavy' is seen at the start of the record only. 'Extensive' is used consistently through the Met-WR and also in the CEH-HS. 'Widespread' and 'Severe' appear throughout all the datasets.

### Validation of Descriptive Terms

The descriptive terms used were compared to the Dartmouth Flood Observatory records for the common period in the data (1985-2013). The Dartmouth flood observatory (DFO) uses news, governmental, instrumental, and remote sensing sources to compile a global database of large flood events (Brakenridge 2014). The dataset contains quantitative information such as number of fatalities, people displaced, estimated damages and area affected. These are used to assign a logarithmic flood magnitude score similar to the Richter scale for earthquakes. Events with a flood magnitude score of 7, 8 or 9 can be reached for truly large events (Kundzewicz et al 2013).

The flood events from the Met Office and CEH reports were compared to the DFO floods. Floods from each dataset were matched by consideration of start dates, places affected and flood type. 69% of the events in the Met record and 81% of the CEH events were reported in the DFO records. Flood events described in the Met and CEH reports that are not present in the DFO record were excluded from the validation exercise.

The magnitude of event from the DFO record was matched to the descriptive term used in the Met and CEH records. Where several descriptive terms were used for a single flood event, each term was considered separately.

In the Met data (Figure 5) the term 'Widespread' is used frequently to describe high magnitude flood events. 'Serious', 'Extensive' or 'Disastrous' also describe high magnitude events from the DFO record although the terms are used infrequently and therefore there is less certainty that the terms can be good indicators of scale. However they still offer insight into the scale of the events they describe. Floods described as 'Severe' or that offer an estimated recurrence interval (or give assertions as to when the last flood of that magnitude was, e.g. 'worst flooding seen in xx years') are associated with mid-interval floods and are more frequently used in the dataset. The term 'Devastation' correlates to a low magnitude event in the DFO (flood magnitude score 2.7) – however this refers to the locally significant event in Boscastle in 2004. This was a destructive event (Miller et al 2013) that required a major airborne rescue operation to rescue victims (HR Wallingford et al 2006). This is likely to have been underplayed in the global DFO dataset. Floods described in the Met reports as

'Localised' frequently correlated to intermediate to large floods from the DFO record. This highlights the limitation that locally significant events may be underplayed in the reports.

Some events described in the Met Office dataset which were considered to be 'Significant' on a UK scale have been missed in the global DFO data. For example the Met describes 'significant' flooding in Aberystwyth on June 9<sup>th</sup> 2012 with hundreds of people rescued, costly damages to infrastructure and described as not seen in over 50 years (e.g. BBC 2012). This event is not present in the DFO, perhaps due to more severe flooding in the USA and Thailand occurring on the same date.

The CEH data (Figure 6) uses 13 descriptive terms compared with the 8 used by the Met Office. These tend to have a lower average DFO magnitude than Met Office data. Floods described as 'Devastating', 'Substantial' or 'Protracted' are associated with the highest magnitude DFO floods, and are used infrequently within the CEH data. However the relationship is not strong because we are comparing reported issues of space, scale, rarity, duration and impact (DFO scoring system) with a single descriptive term that summarises a flood event (CEH and Met Office). These terms are more difficult to quantify than information such as maximum water levels or peak flows. Nevertheless Figures 5 and 6 shows that it is feasible to categorise these reports into classes, albeit not rank them in order of magnitude as for the DFO events. The comparison with the Dartmouth Flood Observatory dataset shows that descriptive terms used in the Met and CEH datasets can be related to an independent assessment of the magnitude of flood event.

### **Reported impacts**

Figure 7 shows the proportion of reports where flood impacts were described either qualitatively (e.g. descriptively) or quantitatively (more substantially, such as spatial extent of flooding or specific impacts). The number of reports including information on impacts in the Met Weather Reports (Met-WR) varies through time; the number of quantitative records increased over the first part of the 20<sup>th</sup> century, falling towards the middle of the century before rising into the 1980s and 1990s. Between 20-40% of early reports record qualitative information on impacts, this proportion falls into the middle and end of the 20th century (being mostly replaced by quantitative descriptions). 21% of the total records provide quantitative information on flood impacts with a further 8% providing qualitative descriptions. Only a small proportion (<10%) of Met Climate Summaries (Met-CS) provide information on flood impacts in the 2000s - however the limited data for the 2010s show almost half of the reports record quantitative information on flood impacts.

The CEH Hydrological Summaries provide limited quantitative information on flood impacts (only 10% of the total), with a further 10% of reports describing flood impacts qualitatively.

This assessment shows that the two datasets do not provide a comprehensive record on flood impacts; however we can still extract meaningful information from a significant proportion of reported floods.

### **Classification of flood event descriptors**

The DFO validated descriptive phrases and information on flood impacts used in the CEH and Met reports were used to classify floods into groups which indicate the impact of the flood event. Three flood impact classes were created; Class 1 for low magnitude events, Class 2 for intermediate magnitude events, and Class 3 for high magnitude events. Floods where 'Localised' is the only description given were assigned to Class 1 (low magnitude of impact) because the use of 'Localised' as a descriptor was considered to be uncertain and

inconsistent. Less than 10% of all floods described in the DFO dataset were 'Localised' so the effect of this assumption is minor.

The Met Office and CEH data were classified using Table 2. Concurrent reports from the Met Office and CEH were available between 1989-1993 and 2001-2012 (Figure 8). In this period 206 floods occur in the Met dataset and 204 in the CEH dataset. The CEH describes slightly more Class 2 (intermediate) floods and the Met describes slightly more Class 1 (smaller) and Class 3 (bigger) floods. The agreement between these data sets gives confidence in developing a consistent long term reported flood event record.

### Creating a Unified Record

In order to create an unbroken record of records from 1884-2013 the datasets were combined. A total of 785 reported flood events were identified in the combined dataset. For the period 2001-2013, the Met Climate Summaries are used as they describe impacts more comprehensively than in the CEH reports. For the period 1993-2000 the CEH hydrological summaries are used, and the Met Weather Reports are used to extend the record from 1993 back to 1884. The combined data set is shown in Figure 9.

Well known events such as the floods of 1947, 1953, 2001, 2007, 2012, etc. were readily identified. The causative mechanism (pluvial, fluvial) was rarely described and only 47 coastal flood events were identified from the records. The flood events were classified into 'Class 1' 'Class 2' and 'Class 3' floods using the definitions in Table 2. The annual totals of these events are shown in Figure 9.

There is an upward trend in reported flooding over time and flood events appear more frequently towards the end of the 20<sup>th</sup> century. The start of the record is 'flood poor' but the number of events rose sharply through the 1910s and the 1920s. The number of reported events is lower between 1930 and the mid-1960s. This is most noted for 1939 and 1945 when there were government restrictions on reporting due to the Second World War. Reported events increased noticeably in the 1960s with a peak in the early 1990s. 2012 was an exceptional year for floods in the UK, where annual rainfall was the second highest in over 100 years (Met Office 2013).

### Estimating changes in exposure (Receptors)

Over the 20<sup>th</sup> Century, the UK population grew from 38.2 million to 59.1 million and the number of dwelling houses grew from 7.7 million to 24.8 million (Figure 10). As a result there were more properties exposed to flooding and also more people to report flooding. A higher exposure to flooding will result in more reported flood events and larger potential consequential damages.

The reported flood events from the Met Office and CEH were normalised using the UK population and the number of dwellings. The population and dwelling counts were used as a proxy for exposure to flooding assuming that the percentage of the population in floodplains is proportional to total population. This is supported by data for the percentage of new households built on floodplains in England 1989-2010 (DCLG 2012) (Figure 10). The population and dwelling data were used to scale the aggregate yearly flood totals using:

$$FSP_i = (F_i / P_i) \quad (1)$$

$$FSD_i = (F_i / D_i) \quad (2)$$

Where:

$FSP_i$  is the flood count scaled for population in year  $i$

$FSD_i$  is the flood count scaled for dwellings in year  $i$

$F_i$  is the count of reported flood events in year  $i$

$P_i$  is the UK population in year  $i$

$D_i$  is the UK dwellings count in year  $i$ .

### **Estimating changes in defences (Pathways)**

There is no data available at a national scale that records changes in natural defences, artificial defences and other management. Natural defences are important and they may have declined, but data is poor (Jones et al. 2011). There have been significant upgrades to artificial defences, most notably following the 1947 Thames floods with a sustained effort to improve conveyance of rivers, and the 1953 North Sea storm surge which led to a major upgrade of flood defences on the East Coast, including the Thames Barrier and London's flood defences. Hence subsequent extreme sea level events on the East Coast had much lower impacts even if the hydraulic conditions were similar – compare the major Consequences of the 31 January/1 February 1953 event including more than 300 deaths (Steers 1953) with the 11 January 1978 event (Steers et al. 1979), and the recent 5/6 December 2013 event with similar or higher water levels and much smaller Consequences. As well as defences, flood warnings have improved substantially and are now routine components of flood risk management (Horsburgh et al. 2008). The implications of these trends are considered later.

### **TRENDS IN REPORTED FLOODING – NORMALISED FOR EXPOSURE**

Reported flood impacts are normalised for exposure using population and number of dwelling houses in the UK (Figures 11a, b). When scaled for exposure, the relative count of flood events shows a weaker trend and greater variability than the raw data shown in Figure 9. The normalised data suggests that there is no consistent trend in the number of floods per head of population during the 20<sup>th</sup> century. There is significant decadal variability in both the raw data and normalised counts. Wilby and Quinn (2013) identified three hydrologically flood rich episodes in river catchments since the 1870s as follows: 1908–1934, 1977–1988 and from 1998 onwards. The first period is visible in Figure 9, and the second and third periods are characterised by higher numbers of flood events (fluvial, pluvial and coastal) in the 1980's and post 1998. However the reports also indicate a peak in the early 1970's which differs from the Wilby and Quinn (2013) analysis. Figure 11b shows that flood counts normalised by number of dwellings have not increased during the 20<sup>th</sup> Century.

Clusters of 'Class 3' (high magnitude) flooding (as defined in Table 2) appear in the 1920s, 1960s and the 1990s. 'Class 2' (intermediate) flood events appear more uniformly through time. The number of 'Class 1' (low magnitude) events is highly variable. There is a fall in 'Class 1' floods between 1930 and 1960 but the frequency of 'Class 1' floods increases sharply after 1968. This may be associated with increased development on floodplains during the latter part of the 20<sup>th</sup> Century (Parker, 1995).

We cannot normalise for defences, but we note that the last peak of Wilby and Quinn (2013) is not apparent in Figure 9. While it is speculative, this may represent the effect of improved defences reducing impacts and therefore "reportable" flood events.

### **DISCUSSION**

Consequences are the combined results of high river flows, pluvial flooding and coastal flooding, the numbers of people and property exposed to flooding and the effects of flood defence construction and floodplain management policies. The increase in the total number of



reported flood events in the 20<sup>th</sup> century in the UK appears to be a function of the gradual increase in exposure due to urban expansion and population growth. However there is also greater capacity to report flood events. The number of reported 'Class 3' flooding events has remained static or decreased slightly over the 20<sup>th</sup> Century. This is despite the UK population almost doubling and the number of dwelling houses tripling over the same time period.

There is no clear underlying trend in flood reports present in the UK flood data when it is normalised for exposure. Pielke Jr. and Landsea (1998) studied damage caused by hurricanes in the USA. They also found that normalising damage reports to take account of exposure removed the upward trend of losses over time and only left a large decade to decade variation in losses. The lack of a systematic trend in the normalised UK total flood count mirrors these findings. It is also in agreement with studies of trends in river flows (Robson 2002). Land use change can affect the number of reported floods e.g. Kjeldsen (2010) and Kjeldsen et al. (2012) suggested that increased urbanisation has a pronounced effect on flood hydrology. In this work we used population and number of dwellings as a measure of exposure but not as a driver of increased hazard such as higher runoff. This demonstrates the complexity of separating hydrology from flood impacts

These observations do not preclude concern about future flood impacts, especially in coastal areas where sea-level rise is being observed and faster rises are expected (Haigh et al. 2011) and areas potentially exposed to higher rainfall intensities (Hulme et al. 2002, Stern 2006). However attributing periods of reduced flooding simply to the effects of improved management is difficult and must be done with care. Future flood risk may be very sensitive to changes in funding or management approaches and this has important implications for decision makers.

The reporting framework used by both the Met Office and by CEH has been shown to be an effective resource for a national scale study of reported flooding. The consistency of the data is a key asset with the length of record giving useful insights into flood trends at a national level. Care must be taken with the use of multiple data sources and variations in the terminology used to describe floods. The reporting framework has some limitations – it is descriptive and it rarely provides the opportunity for classification of flooding by mechanism (fluvial, pluvial, coastal etc.). It may also be biased towards urban areas where reporting of flooding is more likely. Further, the data is likely to under-represent localised events which may have had implications for national policy. However, despite these drawbacks the dataset opens the possibility of considering flood occurrence over a long timescale using reported information (and thus likely effects on society) rather than just changes in extreme hydrological events.

As a tool for reviewing the change in flood impacts through time supplementary data is needed (such as local newspaper reports, post-hoc academic or professional reviews) as key events are typically mentioned, but underplayed in the data (e.g. the North Sea surge of 1953 which was condensed to 'unprecedented coastal damage and floods' – see figure 2). Additional data can be gathered for individual flood events, for example, the Environment Agency report on the costs of the summer 2007 flood events (Chatterton 2010), Met Office reviews of the 2005 and 2008 flooding (Met Office 2011, Met Office 2012c) and an appraisal of the 1947 fluvial event (RMS 2007).

The dataset presented here serves as a 'catalogue' of national level flood events in the UK over the last 125 years. A further study linking date of occurrence from this record with rainfall/river flow data could make assessment of flooding 'type' possible. The study could be complemented or extended further in time by using ancillary data sources such as The Chronology of British Hydrological Events (Black and Law 2004). Analysis of the recurrence interval of events within the record could provide further validation. However care must be taken due to the quality of reported impacts and the limitations of qualitative data sources as

discussed in this paper. This work highlights the need to maintain the reporting framework of flood events in order to provide continued information on long term trends such as the effects of climate change and sea level rise.

## CONCLUSIONS

This paper has developed a 100+ year national dataset of 785 notable flood events in the UK. It is an unusual if not unique dataset. The data indicates an increase in reported flood events during the 20<sup>th</sup>/21<sup>st</sup> Century and significant variation from decade to decade. However, normalising the data by population and number of dwellings removes any long term temporal trend and leaves a strong decadal variability. The effects of increasing and improving defences is unclear. It also shows the importance of drivers of flood events and losses, and the continuing benefits of monitoring changes in climate, exposure and impacts. Descriptive datasets of reported flooding can complement existing hydrological analysis, especially for combined descriptive/quantitative datasets such as the CEH Hydrological Summary of the UK.

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Table 1 Number of times terminology used within the Met Office and CEH flood

|        | Severe | Widespread | Serious | Extensive | Considerable | Significant | Disastrous | Destructive | Notable | Major | Substantial | Heavy | Protracted | Devastation | Great | Unprecedented |
|--------|--------|------------|---------|-----------|--------------|-------------|------------|-------------|---------|-------|-------------|-------|------------|-------------|-------|---------------|
| Met-WR | 50     | 52         | 51      | 38        | 44           | 0           | 12         | 9           | 0       | 0     | 0           | 5     | 0          | 0           | 4     | 3             |
| Met_CS | 7      | 10         | 3       | 0         | 1            | 3           | 0          | 0           | 0       | 1     | 0           | 0     | 0          | 1           | 0     | 0             |
| CEH-HS | 48     | 23         | 2       | 14        | 1            | 26          | 0          | 0           | 8       | 5     | 5           | 0     | 5          | 3           | 0     | 1             |
| Total  | 105    | 85         | 56      | 52        | 46           | 29          | 12         | 9           | 8       | 6     | 5           | 5     | 5          | 4           | 4     | 4             |

Table 2 Classification of flood events according to estimated severity of event

| Classification | Description  |
|----------------|--|
| Class 3        | The most significant or damaging flooding as estimated from the reported record. For the Met record these are floods described as 'Widespread', 'Serious', 'Extensive' or 'Disastrous'. In the CEH record these are floods described as 'Devastating', 'Substantial' or 'Protracted'. Where quantifiable impacts are reported a flood event involving loss of life, >1000 people evacuated or severe structural damages (such as hundreds of homes flooded, >£100 million in material damages) |
| Class 2        | Floods events described in the Met reports as 'Severe' or 'Worst in xx' and in the CEH as 'Widespread', 'Serious', 'Severe', 'Considerable', 'Extensive', 'Significant', 'Disastrous', 'Worst in xx', 'Major' or 'Notable'. Quantified impacts less severe than class 3 such as a handful (or unspecified number) of buildings destroyed, >£1 million material damages, some evacuations, substantial loss of livestock)   |
| Class 1        | Floods events either not described or with perceived low magnitude impacts: such as 'Localised'.   |

Figure 1 Lengths of the datasets used within this study

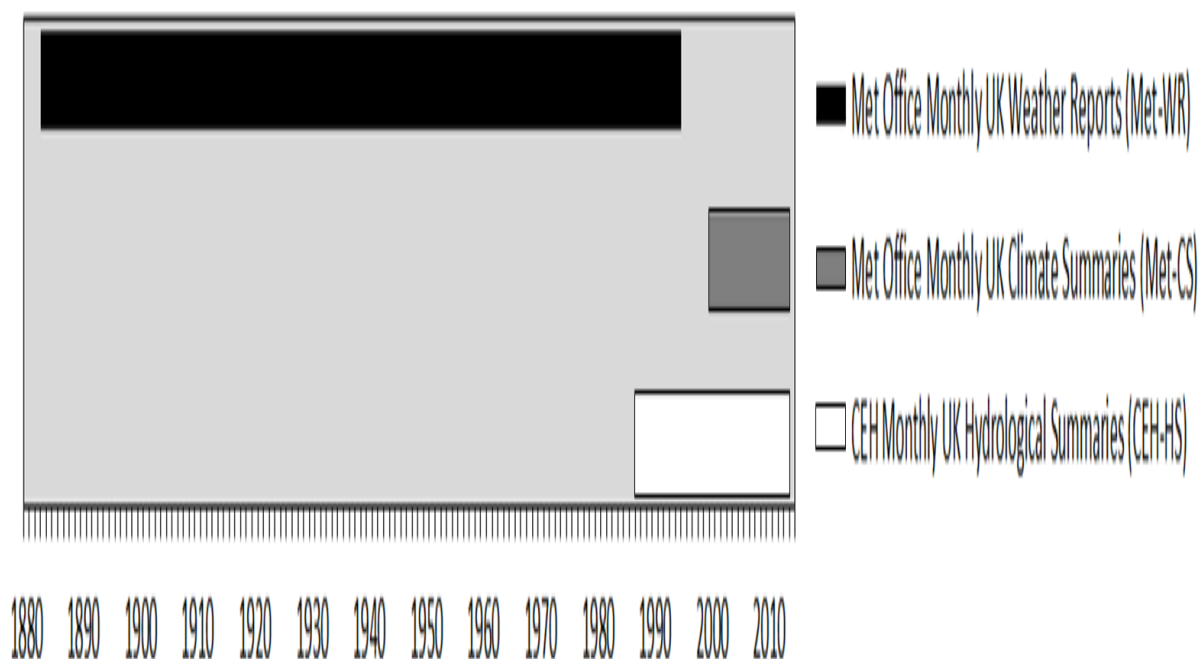


Figure 2 Extract from the January 1953 Monthly Weather Report. This includes the extreme coastal flood event that caused over 2000 deaths in NW Europe. (Source: Met Office Monthly Weather Reports © Crown Copyright)

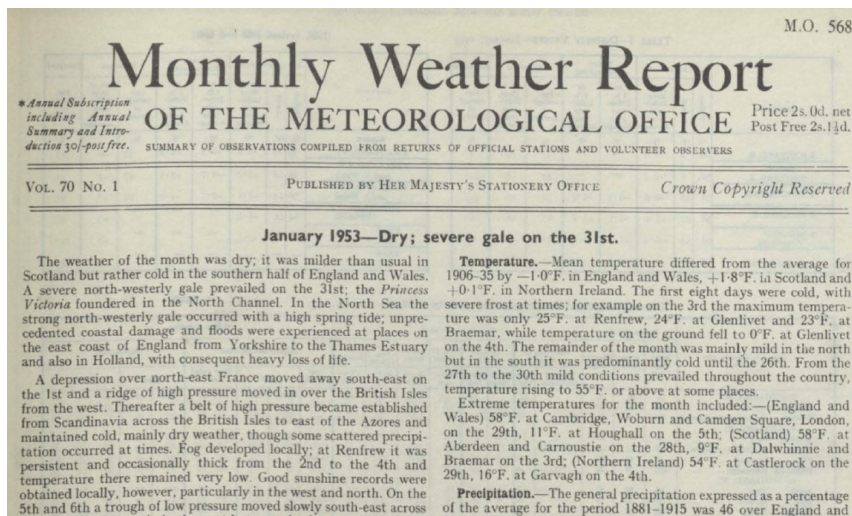


Figure 3 Frequency of commonly used terms over time in the Met Monthly Weather Reports (1884-1993) and Climate Summaries (2001-2013) (above) and CEH Hydrological Summaries (1988-2013) (below)

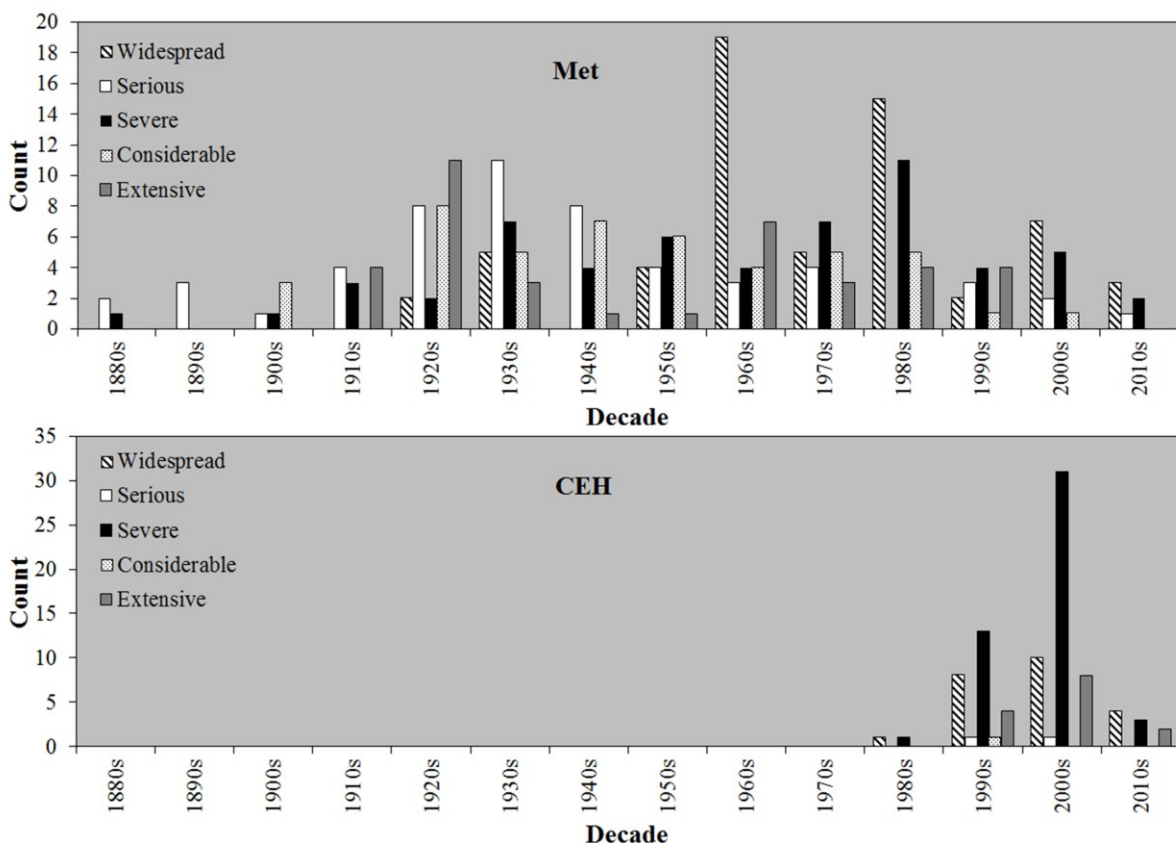




Figure 4 Descriptive terms in the Met Office Monthly Weather Reports (Met-WR) and Climate Summaries (Met-CS) and the CEH Hydrological Summaries (CEH-HS)

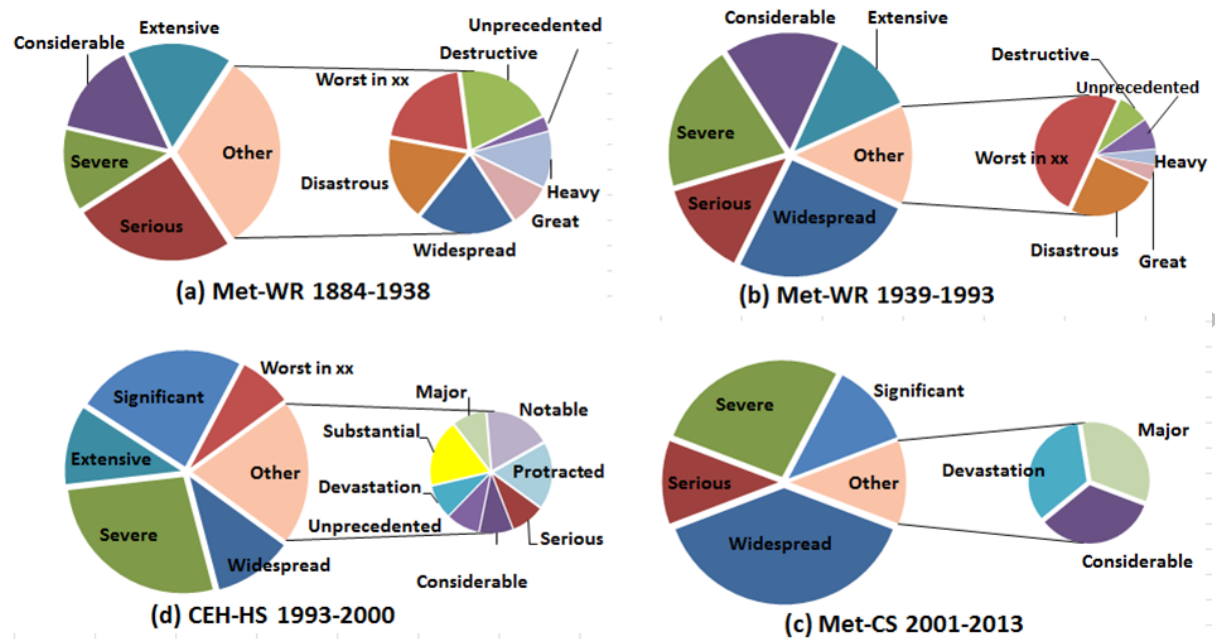


Figure 5 DFO Magnitude of descriptive terms used in the Met reports (star shows average magnitude, points show the spread)

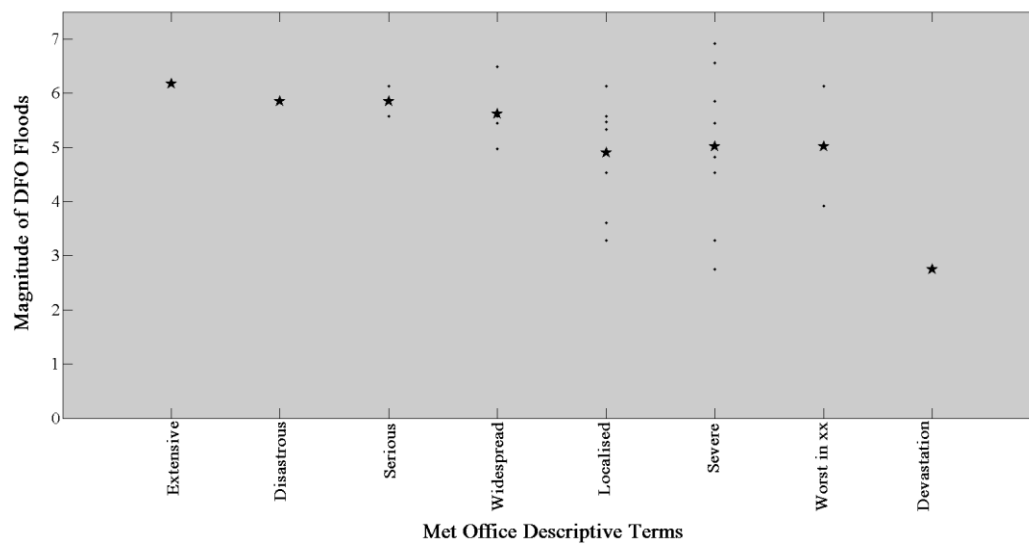




Figure 6 DFO Magnitude of descriptive terms used in the CEH reports (star shows average magnitude, points show the spread)

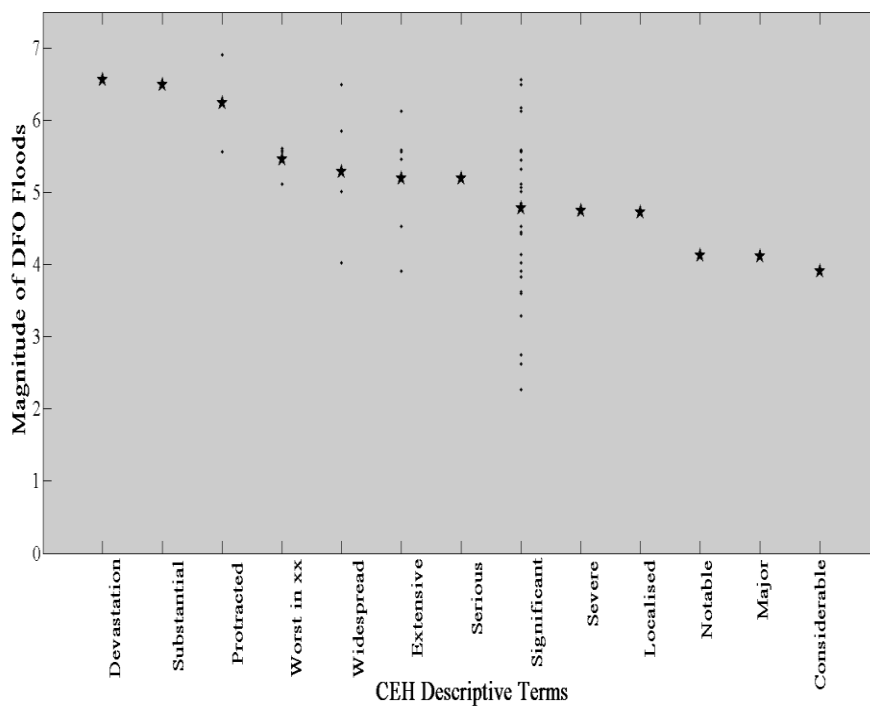


Figure 7 Percentage of flood records that described flood impacts (qualitative or quantitative)

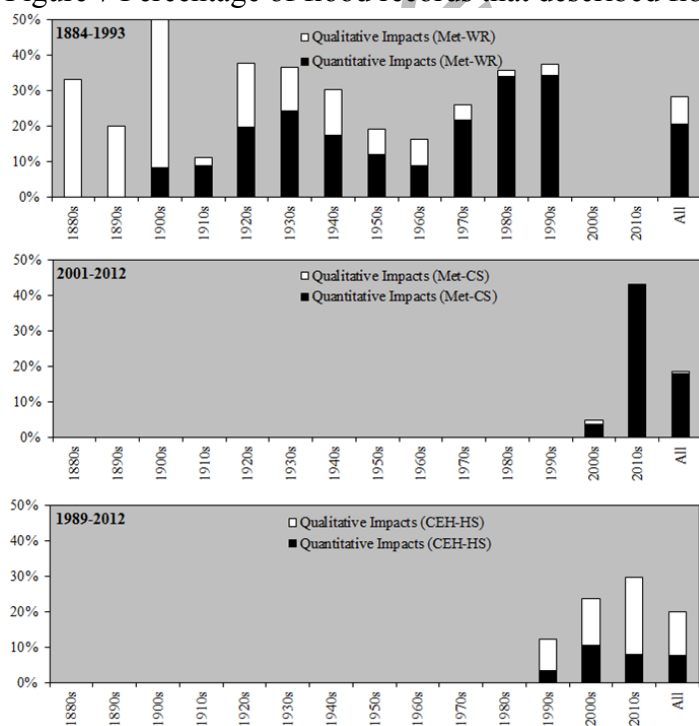


Figure 8 Comparison of reported flooding between Met Office and CEH data

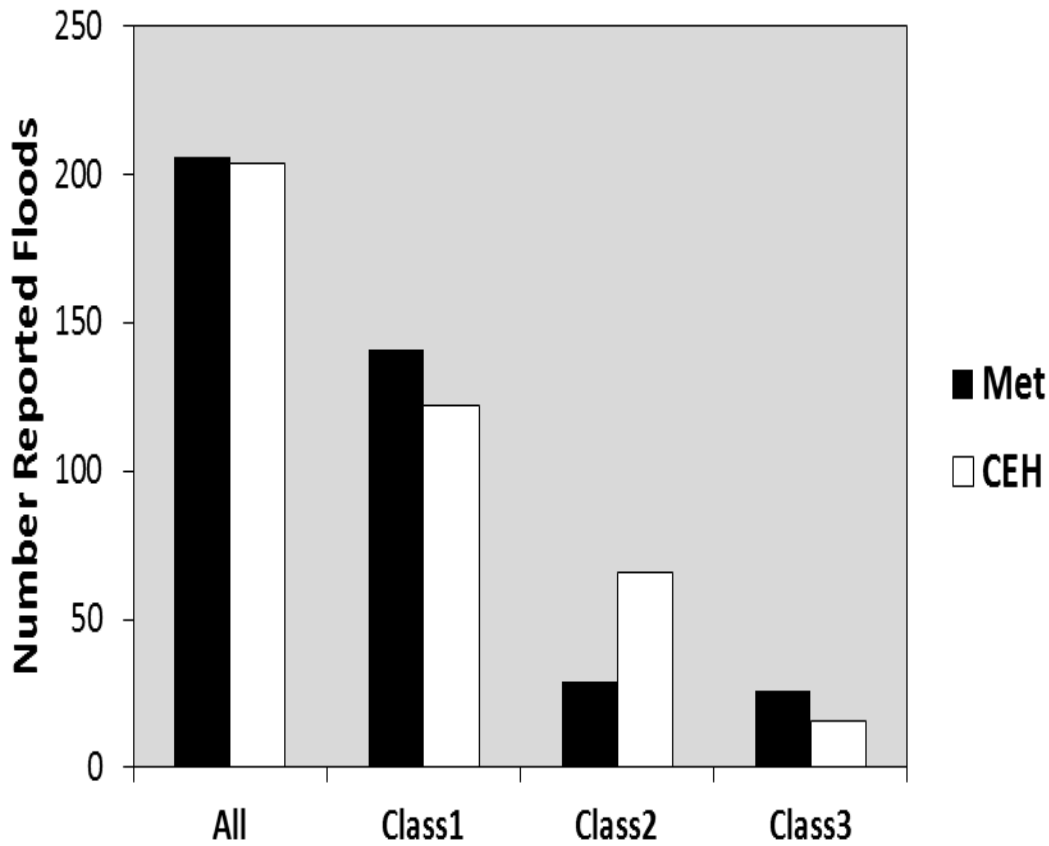


Figure 9 Instances of reported flooding in the UK each year 1884-2013 using combined Met Office/CEH data

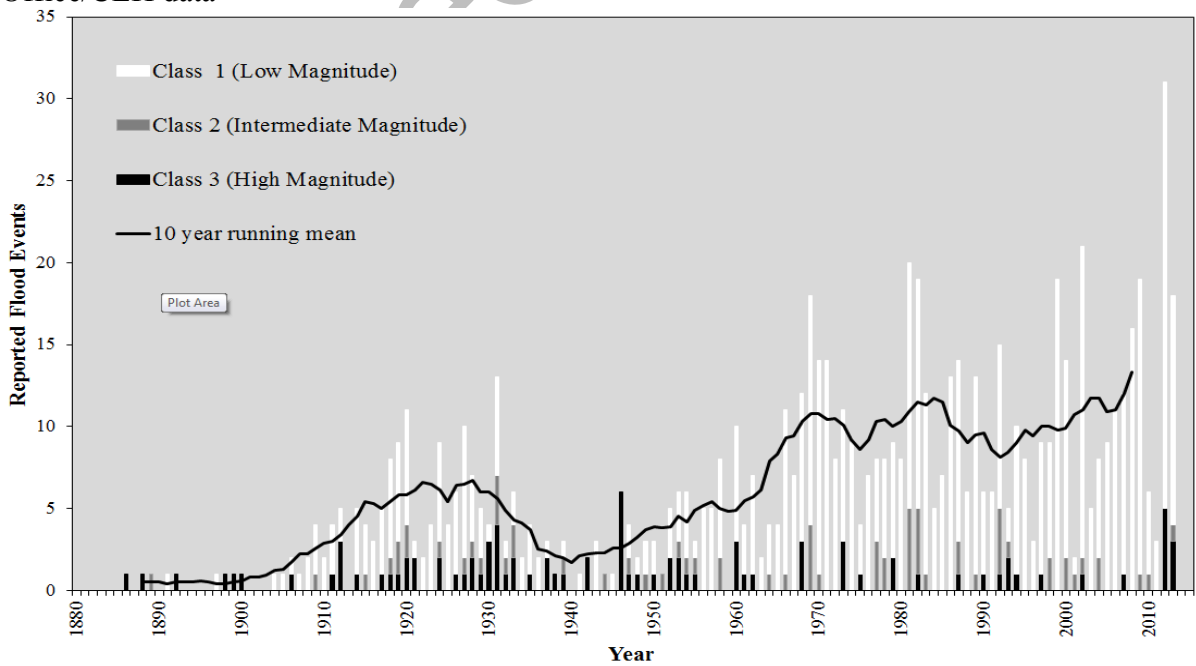


Figure 10 UK population counts (NISRA 2012, NRS 2012, ONS 2012a, 2012b), dwelling counts (DCLG 2013) and the proportion of new homes built in areas of flood risk (DCLG 2012)

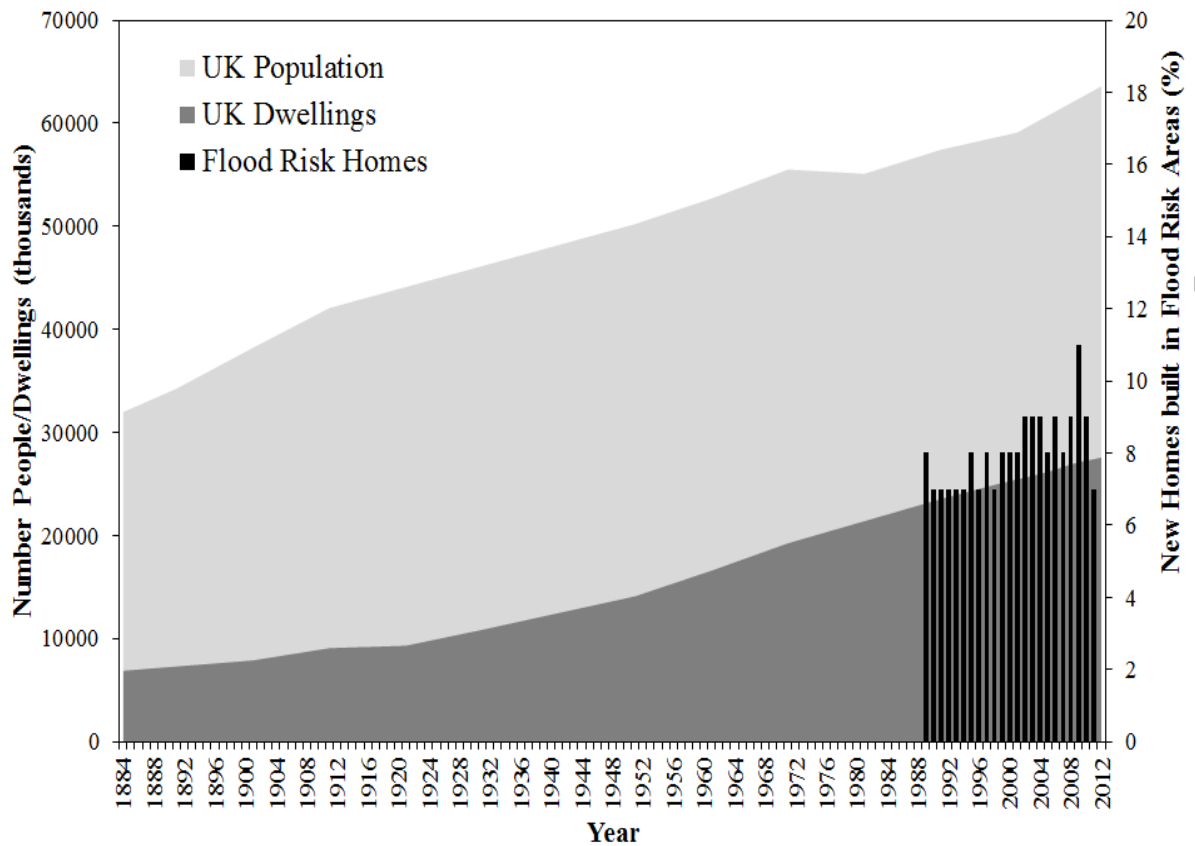
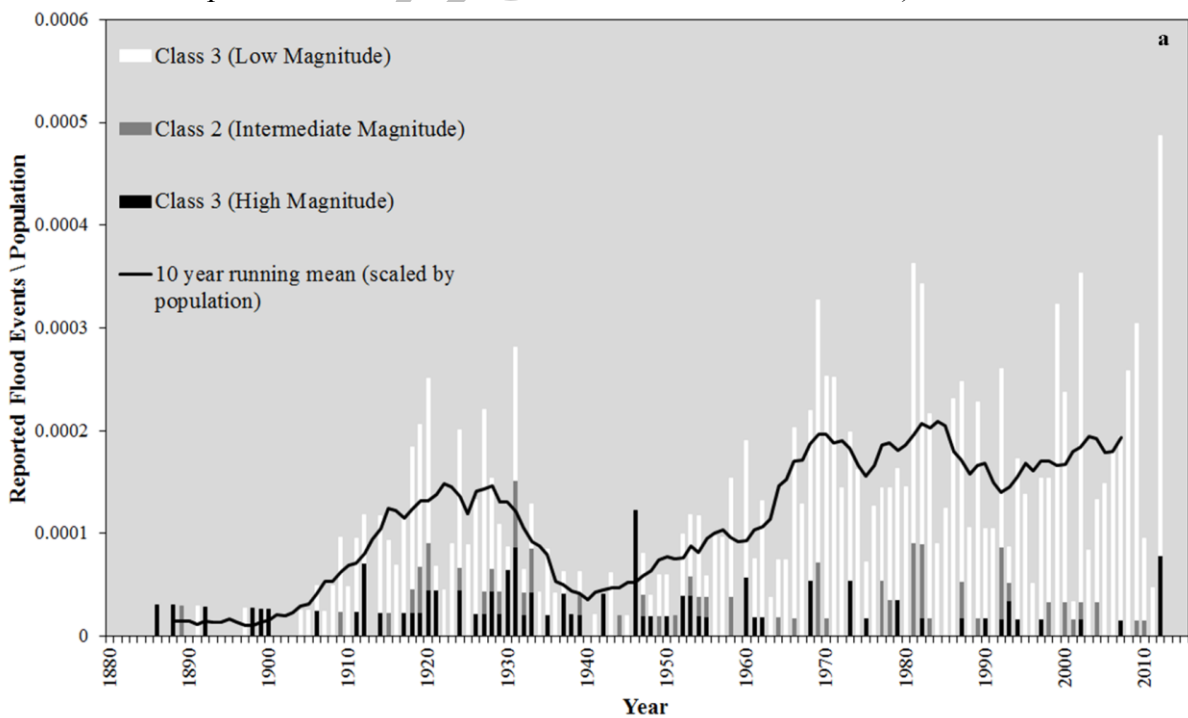
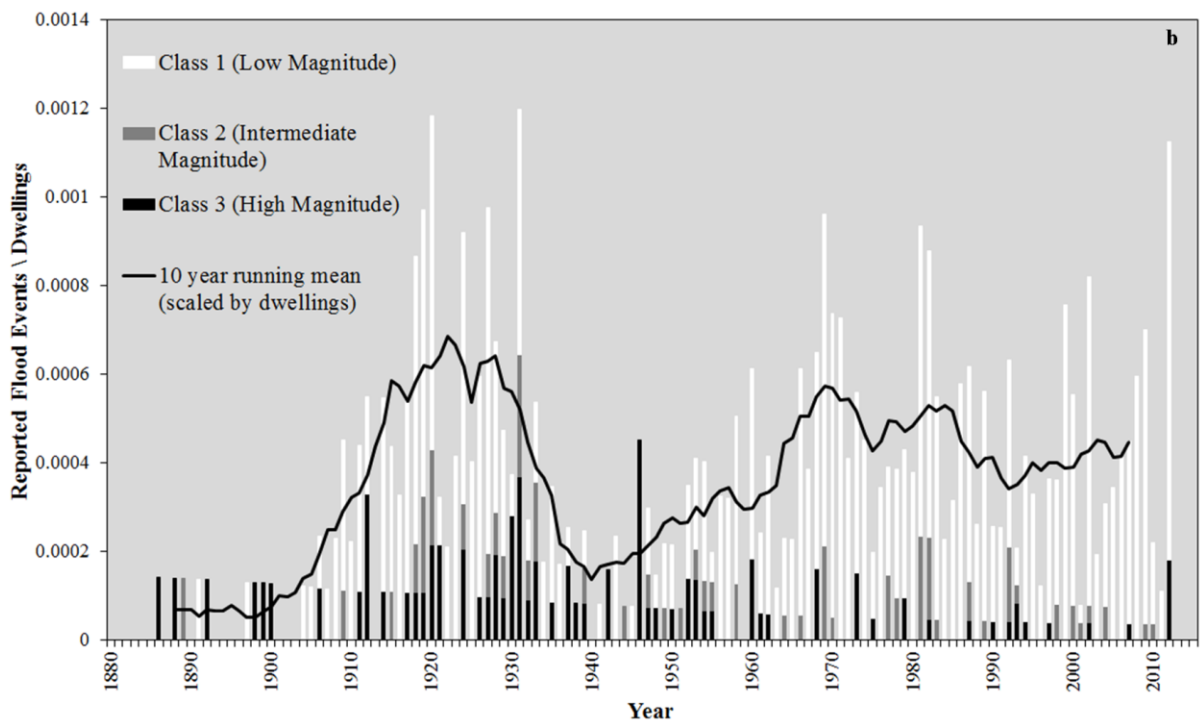


Figure 11 UK Flooding normalised by (a) population and by (b) number of dwellings (note: normalised data plotted to 2012 due to lack of 2013 normalisation data)





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