A digital archive of extreme rainfalls in the British Isles from 1866 to 1968 based on *British Rainfall*

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The 2007 UK summer floods have once again prompted the question whether extreme events are becoming more frequent as a feature of climate change. The flood events were widely reported in the media with unquantified references to the heaviest-ever rainfall and the wettest summer on record. The monitoring data now show that the period May, June and July was the wettest on record (Marsh and Hannaford, 2008), but the individual daily totals are not unusual compared with historical extreme rainfall records. It is often the case that extreme meteorological and hydrological events are quickly forgotten by the general public and when events do occur, they are often described as the worst in living memory. A new digital archive has been compiled as part of a current, government-funded research project through the Natural Environment Research Council (NERC) Flood Risk from Extreme Events (FREE) programme. This article describes the original paper archive from which the digital data has been sourced and the types of data extracted; it also provides a preliminary analysis of some of the features of the data.

British Rainfall

The new digital archive has been compiled from the annual publication, *British Rainfall*, which ran from 1860 to 1991. *British Rainfall* was started by George J. Symons in 1860 under the title *Symons's British Rainfall*. This publication contained information on the spatial and temporal distribution of rainfall in the British Isles as recorded by a network of observers. This network started at around 100 observers in the first few years and had grown to over 6000 by 1991. The volume was published by the British Rainfall Organization up to 1919 when it was transferred to the Director of the Meteorological Office (Pedgley, 2002). Issues from 1969 to 1991 were given the name *Rainfall* and the specific year (e.g., *Rainfall 1979*).

For the years 1866 to 1968, the publication also contained a section on extreme rainfall events under the heading *Heavy Falls on Rainfall Days* or *Heavy Falls in 24 Hours*. Within this section, all observed 24-hour rainfall depths that exceeded a certain threshold were listed. This threshold was set at 2.5 inches (63.5 mm) or 7.5% of the annual total at the specific gauge up to 1961. For the editions from 1961 to 1968, the threshold was set at 50 mm or 4% of the annual total. In addition to the depth observations, descriptive text from the observers was included in the chapter which provided a range of information, such as an overview of the synoptic meteorology, a description of the characteristics and intensity of the rainfall, whether thunder was heard, and accounts of resulting flooding and damage. This chapter provided researchers and practitioners within the fields of meteorology, climatology and hydrology a single, easily accessible resource for extreme rainfall events in the British Isles. For the most significant and interesting events, isohyetal maps, estimates of rainfall over specific areas, and photographs were included. The new digital archive has been compiled from all of this information with files generated for each year. All depth observations have been input into tables giving the date, the location of the rain gauge, the county or division, the rainfall depth in inches and millimetres (for all years up to 1961) or just millimetres for 1961–1968, and the depth as a percentage of the annual total (as shown in Table 1). The text and tables giving additional information (such as duration, estimated areas of rainfall) have been typed and all the maps and photographs have been scanned as image files. Examples of this information are presented below as text extracts, sample observations of rainfall amounts (Table 1), an isohyetal map (Figure 1) and a photograph of flood damage following extreme rainfall (Figure 2). Particularly extreme rainfall events were dealt with in special sections, such as The Great Rain Storm of 25/26 August 1912 (Mill, 1913), The Great Rain Storm of 28 June 1917 (Mill and Salter, 1918), and 1968 (Bleasdale, 1974). An extract of the last of these events is included below together with an event from 1923, to illustrate the more technical and precise meteorological observations of the later issues. As the information present in *British Rainfall* covers any rainfall event exceeding the threshold values, however,

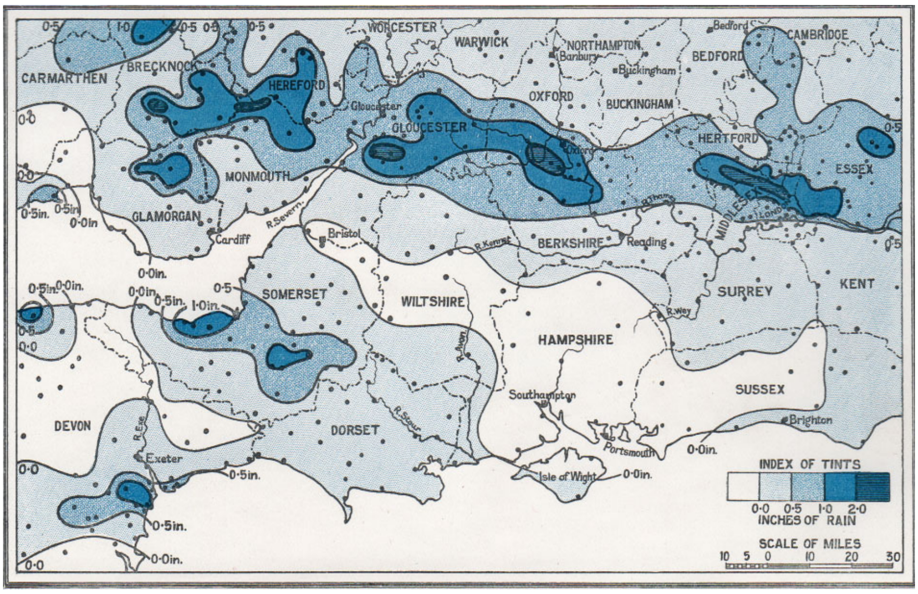

Figure 1. An isohyetal map from British Rainfall, *for 22 July 1907 (Mill, 1908).*

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Table 1

An example of extreme rainfall depth observation from British Rainfall, 1953 *(Meteorological Office, 1955). The value in inches is as listed in the publication; the value in mm has been calculated for the digital archive. Percentage is of annual average rainfall at that station.*

Date	County	Gauge Name	Rainfall (inches)	Rainfall (mm)	%
28/03/1953	Yorkshire	Dunford Bridge (Stoneygate)	2.62	66.55	5.8
28/03/1953	Yorkshire	Great Hey	3.26	82.80	5.5
28/03/1953	Yorkshire	Hey Springs	3.04	77.22	5.9
28/03/1953	Yorkshire	Holmbridge (Yateholme)	3.02	76.71	5.7
28/03/1953	Yorkshire	Holmbridge (Ramden)	2.94	74.68	6.0
28/03/1953	Glamorgan	Rhondda (Lluest Wen Reservoir)	2.62	66.55	2.9
28/03/1953	Brecknockshire	Ystradfellte Reservoir	2.71	68.83	3.8
28/03/1953	Brecknockshire	Cardiff W.W. (Beacons Reservoir)	3.20	81.28	4.6
28/03/1953	Brecknockshire	Cardiff W.W. (Storey Arms Field)	2.97	75.44	4.2
28/03/1953	Brecknockshire	Taf Fechan (Neuadd Reservoir)	2.84	72.14	4.2
28/03/1953	Montgomeryshire	Llangurig (Manod)	4.22	107.19	5.6
28/03/1953	Montgomeryshire	Hafren Nurseries	3.00	76.20	5.7
28/03/1953	Montgomeryshire	Clywedog (Aber Biga)	3.00	76.20	5.8
28/03/1953	Montgomeryshire	Gam (Abercannon Farm)	4.23	107.44	7.1
28/03/1953	Montgomeryshire	Twrch (Dol y Gaseg)	3.45	87.63	5.7
28/03/1953	Montgomeryshire	Lake Vyrnwy	2.90	73.66	5.5
28/03/1953	Montgomeryshire	Lake Vyrnwy (Experimental Station)	2.97	75.44	5.4
28/03/1953	Montgomeryshire	Lake Vyrnwy (Bank Cynon Isaf)	2.70	68.58	5.2
28/03/1953	Merionethshire	Aberangell (Gwynynd)	3.00	76.20	4.7
29/03/1953	Glamorgan	Rhondda W.W. (Lyn Fawr Reservoir)	2.66	67.56	3.1
29/03/1953	Glamorgan	Rhondda (Castell Nos Reservoir)	2.72	69.09	3.3
29/03/1953	Glamorgan	Rhondda (Lluest Wen Filter)	2.60	66.04	3.1
29/03/1953	Glamorgan	Rhondda (Lluest Wen Reservoir)	2.89	73.41	3.2
29/03/1953	Brecknockshire	Cardiff W.W. (Storey Arms Field)	2.82	71.63	4.0

the descriptions are not confined to these well-known storms but many other events such as those illustrated from 1900, 1907, 1923 and 1953.

An extract of descriptive text from *British Rainfall 1923* (Meteorological Office – Air Ministry, 1924):

> *July*
>
> *The heavy falls of July were all associated with a series of thunderstorms which occurred in the middle of the month. In discussing them we shall make use of articles by Mr. M. A. Giblett and Mr. Spencer Russell in the Meteorological Magazine of August, 1923.*
>
> *The weather at the beginning of July was cool, but a warm spell commenced on Thursday, July 5th, with the simultaneous filling up of a deep depression near Iceland and the growth of an anti-cyclone over the Continent. By the next day a south-easterly current was flowing over the whole kingdom, carrying warm air to the extreme west and north-west coasts. This condition was, however, only transitory. It was followed by the development of a depression west of Ireland and the gradual spreading of south-westerly winds back again over the British Isles. Thus there were two streams of air, a hot, dry one from the Continent, a cooler and damper one from the Atlantic, uniting to flow from south to north over the British Isles. The boundary between two such streams is likely to fluctuate and to be marked by instability.*
>
> *The first outburst of thunderstorms occurred early on July 7th along the west coast from Stornoway to the Channel Islands, heavy rain falling before 9 a.m. was credited to the 6th at many places in Devonshire. During the day the line of storms pushed eastward and reached Lancashire and Yorkshire. The same evening there was a severe storm at Nottingham. On the 8th the current from the Atlantic covered the whole of England, and the area of atmospheric instability was found in Scotland, severe storms occurring in the north-eastern counties, the worst being on the north of the Grampians near Carrbridge.*

> *An extract of text from the special article from British Rainfall, 1968 (Bleasdale, 1974): In the early hours of 14/9/68 a rather shallow but deepening depression was centred near the mouth of the English Channel, with the occlusion of a frontal system swinging round it and beginning to cross France. The centre had moved slightly south-west by 18 GMT and thereafter moved south over the Bay of Biscay, and after 12 GMT on 15/9/68 eastwards over France. The main front crossed France rather quickly, and whilst it produced rain the totals were not exceptionally large. But after becoming aligned west-east across southern England the front had become almost stationary by 18 GMT, 14/9/68, and remained so until 06 GMT or later, 15/9/68. Thereafter it rotated slowly to a south-west to north-east alignment, crossing the Thames estuary, but not London. The largest accumulations of rain extended from Hampshire through Sussex and Kent, more or less along the line of the front whilst stationary, and into Essex when it was taking up the new alignment. (The front later crossed London, in the early hours of 16/9/68, with much reduced activity.)*

Every effort was made to ensure that the observations entered in *British Rainfall* were of good quality. There was a detailed correspondence between the Editor and observers to ensure the standard procedures for

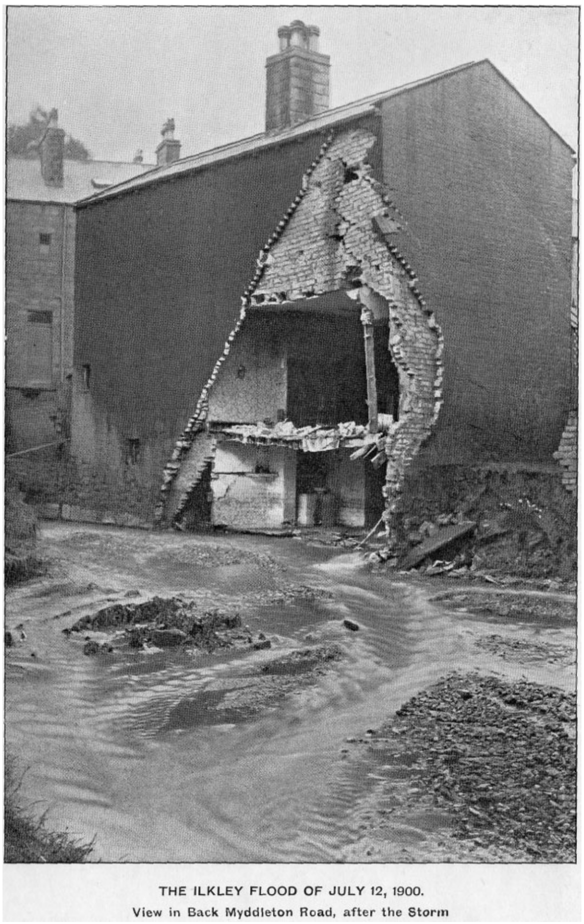

Figure 2. Photograph of flood damage from British Rainfall, 1900 *(Sowerby Wallis, and Mill, 1901).*

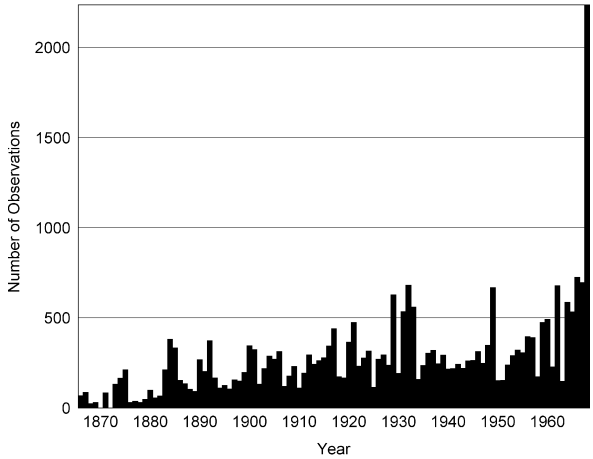

Figure 3. Numbers of extreme 24-hour rainfall observations per year from British Rainfall 1866–1968, *defined as amounts above 63.5 mm or 7.5% of the annual total up to 1960, and 50 mm and 4% of the annual total thereafter.*

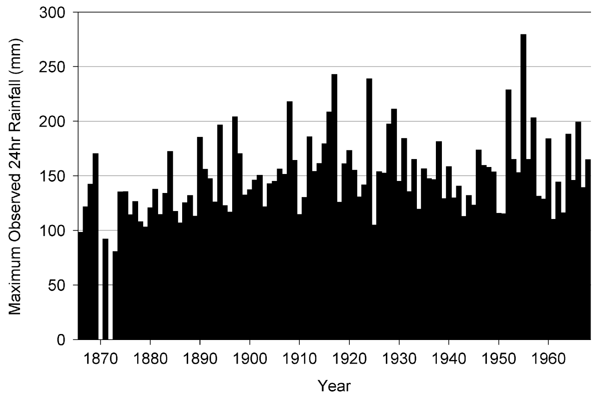

Figure 4. Maximum annual 24-hour rainfall listed in British Rainfall. *The zero values for 1870 and 1872 were because no rainfall observations were listed in these issues.*

measuring and entering rainfall observations were followed. Any unlikely depth observations were compared with observations from nearby gauges and if these could not be supported then averages from the surrounding gauges were taken. Also instances where gauges overflowed were noted in the publication. A statement concerning the quality of the observations was often included in the text as shown in the following extract from *British Rainfall 1884* (Symons, 1885):

> *Nor does a shadow of suspicion rest upon the record; the gauge is a good one, the observations have always been carefully made, and the above Figures are thoroughly supported by the surrounding stations.*

Data analysis

A preliminary data analysis of the rainfall depth data has been undertaken to look at the magnitude, ranges and frequency of the observations, and the seasonal and spatial distributions. These are summarized in the following sections.

Numbers of events

Over the period 1866–1968 a total of 28 223 extreme rainfall observations were entered. The average number per year was 280, with the maximum number of entries, 2237, in 1968 and the minimum number being 24 in both 1868 and 1878. In the years 1870 and 1872 no depth observations were listed. The numbers of observations are plotted over the study period in Figure 3, bearing in mind that for the years 1961–1968 the threshold was reduced to 50 mm and 4% of the annual total. This, therefore, significantly increased the number of observations listed. Even with the adjusted value, 1968 was still an exceptional year for extreme rainfall observations with 1652, as the next highest year was 1932 with 681 observations (Table 2). It is uncertain whether the high number of observations in 1968 is in part a result of more rain gauges. The exact number of gauges used in *British Rainfall* was given in the introduction until 1958, but only an approximation of 'around 6000' gauges was stated for the remaining 10 years of the series. The 1968 entries include three notable events in March, July and September with maximum observations of 164.3 mm at Glen Etive on 26 March, 143.5 mm at Chew Stoke Pumping Station on 10 July, and 129.5 mm at Bromley on 15 September. It is also interesting that 1968 was the last year of the 'Heavy Rainfall on Rainfall Days' section; perhaps the documentation of the 2000-plus observations was too much for the Met Office to contemplate continuing the section for future years!

Magnitude of observed rainfalls

In terms of the magnitude and ranges of the extreme rainfall over the study period, the highest annual maximum observed 24-hour depth was 279.4 mm (at Martinstown,

Table 2

The top ten years in terms of number of extreme rainfall observations listed in British Rainfall *using the original threshold of 63.5mm or 7.5% of the annual total.*

Year	Observations
1968	1652
1932	681
1949	667
1929	627
1933	560
1931	534
1960	492
1921	474
1959	474
1917	438

Table 3

British Rainfall *observations of over 200 mm in 24 hours.*

Date	Depth (mm)	Depth (in)	Location	County (pre-1974)
18/07/1955	279.4	11.0	Martinstown (The Chantry)	Dorset
28/06/1917	242.8	9.6	Bruton (Sexey's School)	Somerset
18/07/1955	241.3	9.5	Upwey (Friar Waddon)	Dorset
18/08/1924	238.8	9.4	Cannington (Brymore)	Somerset
15/08/1952	228.6	9.0	Longstone Barrow	Devonshire
18/07/1955	228.6	9.0	Upwey (Higher Well)	Dorset
22/11/1908	217.9	8.6	Snowdon (Llyn Llydaw Copper Mill)	Caernarvonshire
28/06/1917	215.4	8.5	Bruton (King's School)	Somerset
28/06/1917	213.1	8.4	Aisholt (Timberscombe)	Somerset
11/11/1929	211.1	8.3	Rhondda (Lluest Wen Res.)	Glamorgan
18/07/1955	211.1	8.3	Upwey (Elwell)	Dorset
11/10/1916	208.3	8.2	Loch Quoich (Kinlochquoich)	Invernesshire
12/11/1897	204.0	8.0	Seathwaite	Cumberland
08/06/1957	203.2	8.0	Camelford (Roughtor View)	Cornwall
28/06/1917	200.7	7.9	Bruton (Pitcombe Vicarage)	Somerset
18/07/1955	200.7	7.9	Wynford House	Dorset

18 July 1955) and lowest annual maximum observed 24-hour depth for any year was 80.5 mm in 1873. The full series of annual maxima is plotted in Figure 4; no depth observations were listed for the years 1870 and 1872, hence the zero value in the figure. The mean maximum depth per year was 149.8 mm and only three years over the whole study period had maxima of less than 100 mm (1866, 1871 and 1873). This gives a probability that somewhere over the British Isles will experience a 24-hour fall of 100 mm or more in any calendar year as 0.97 (assuming the events are independent). Over the study period, 1714 observations of 100 mm or over were listed, 129 observations of 150 mm or over and 16 observations of 200 mm or over (these 16 observations are listed in Table 3). Nine of the observations over 200 mm are from just two events: 18 July 1955 and 28 June 1917. Only two further measurements in excess of 200 mm in 24 hours have been observed in the UK in the years since 1968. These were 238 mm at Sloy Main Adit, near Loch Lomond, 17 January 1974 and 200.4 mm at Otterham, Cornwall 16 August 2004 according to data compiled by Burt (2005). The latter of these led to the Boscastle flood.

Seasonal distribution

The distribution of all observations on a monthly basis (Figure 5) shows a much greater frequency in the latter half of the year (July to December), with a maximum in July (16.6%) and the minimum in April (1.6%). This pattern is more or less replicated for all observations of 100 mm and above, although the maximum number of observations is found in November. For all observations of 150 mm and above, the pattern is different with a peak in the frequency of observations in the summer months as expected but then a second peak in November and December (Figure 6). An earlier study by Hand *et al.* (2004) classified different types of extreme rainfall and reasons as to why they occurred during different times of the year. Events during the summer months were due to the effect of the warmer atmosphere being able to hold more moisture and the warmer ocean fuelling the development of weather systems which bring precipitation. A lack of

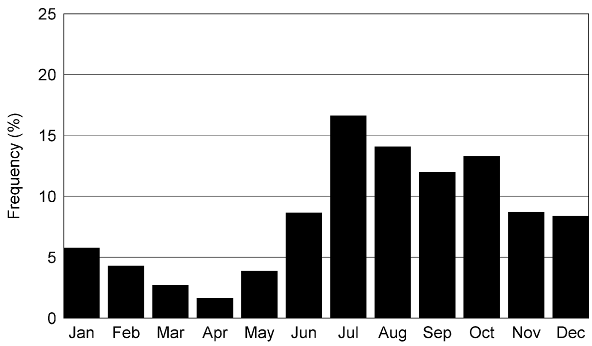

Figure 5. The seasonal distribution of all extreme rainfall observations

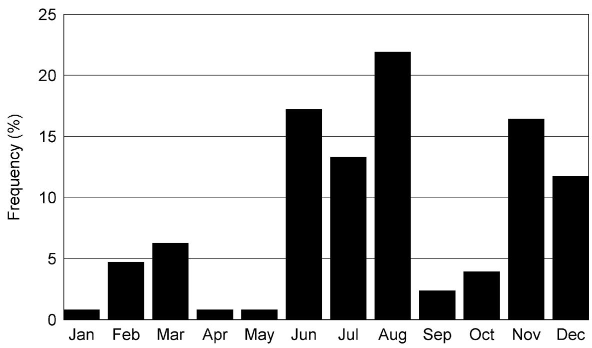

Figure 6. The seasonal distribution of daily observations of 150 mm and above.

Figure 7. A map of British Rainfall *divisions.*

events between January and April was attributed to low sea-surface temperatures. The autumn and winter events, associated with vigorous frontal passages, are likely to be more extreme in November and December due to the greater temperature difference between air masses causing greater uplift and more rain.

Spatial distribution

A full spatial distribution of all events was not possible as the exact locations of rain gauges (i.e., grid references) were not given. Instead the gauges were listed by division (up to 1923) and then by county. Grid references were only given from 1957 onwards. An attempt was made to use the divisions defined in early editions of *British Rainfall* (Figure 7) since these were combinations of counties but they were disproportionate in terms of area and numbers of observers. Division I, for example, covered the London area and Division XI covered the whole of Wales. The percentage of total observations in each division is shown in Figure 8. Certainly some of the more well-known wetter areas, as defined by the Met Office (2008), are shown to have high proportions of observations in this plot such as Division V (south-west England) and Division XI (Wales), but other wetter areas, such as divisions in western Scotland (XV, XVII), have a small proportion of observations largely due to the low number of gauges and record years. For example, in 1899, out of 3528 gauges only 446 were in Scotland.

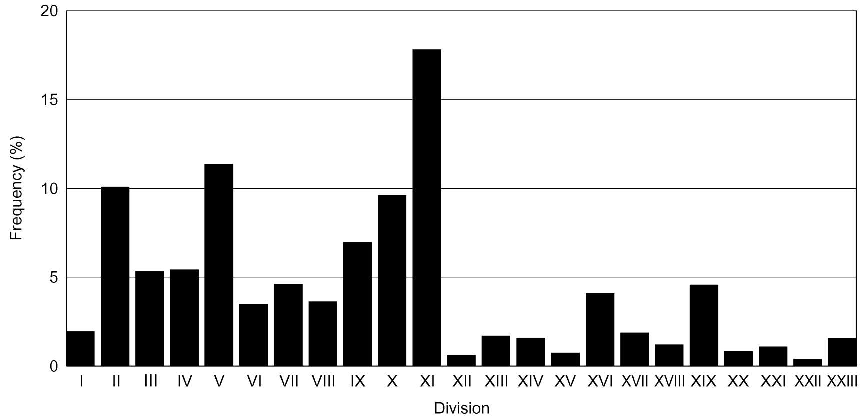

Figure 8. The percentage of all observations occurring within each division (Figure 7).

Applications

There is a wide range of research applications of this digital archive in the fields of meteorology, climatology and hydrology. Indeed, on completion, the data will be made freely available for research purposes in the UK through the British Atmospheric Data Centre. Within the framework of the current project, the data has been used to produce a classification of types of rainfall events which affect the UK, based largely on considering the areas affected and the magnitudes of different events where isohyetal maps are available, supported by information listed in the descriptive text. The observed rainfall depths from the archive are being used as input to test a series of data-based mechanistic mathematical models to produce forecasts for extreme rainfalls (Little *et al.*, 2008). In addition, a GIS-based interface is being developed for the Thames Region of the Environment Agency. This would enable a user to identify the locations of rain gauges on a map screen and then download the listed depth observations from the archive for any selected gauge. Such historical information on extreme rainfall is regarded as more useful for public dissemination than simply quoting the design rainfalls (e.g., 1 in 100 years) for a particular location.

The study would also greatly benefit from having data from 1969 onwards included in the archive and it is a pity that the 'Heavy Rainfall on Rainfall Days' chapter was discontinued. With such information it would be possible to consider trends in UK extreme rainfall up to the present day, a feature that is particularly relevant in relation to climate change projections which state the frequency of extreme rainfall will increase in a warmer climate (Semenov and Bengtsson, 2002). Extending the archive to the present day would, however, require considerable effort. Although the Met Office holds digital rainfall records over this period, the other information, namely the written descriptions from observers and isohyetal maps, would have to be obtained from a number of sources (e.g., the Environment Agency, Scottish Environmental Protection Agency, CEH Wallingford). It is hoped that such work will be undertaken in the future.

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