

The exceptional rainfall of 20 July 2007

John Prior and Mark Beswick

*National Climate Information Centre,
Met Office, Exeter*

On 20 July 2007, many places in central southern England and the south Midlands had their wettest day on record. This resulted from up to 18 hours of rainfall, often heavy, over an area stretching from the Thames Valley north-westwards across the Cotswolds and Severn Valley to mid-Wales. The highest totals were recorded in Gloucestershire, Worcestershire, Oxfordshire and adjacent counties. Localized flooding soon affected thousands of homes and businesses and caused severe road and rail transport disruption across a wide area. Many rivers subsequently burst their banks, including the lower Severn, the upper Thames and their tributaries. The flooding was exacerbated by

the preceding unsettled weather, with over twice the average rainfall across the south and west Midlands in May and June.

The location of places mentioned in this article are shown in Figure 1.

Meteorological context

The rainfall resulted from a very warm, moist air mass over southern England and the Midlands, associated with an occluded front and area of low pressure that were slowly moving northwards. Embedded convective elements led to significant spatial variability. Figure 2 shows the surface synoptic analysis at 1200 UTC on the 20th. The synoptic situation and the forecasts that were issued are discussed by Grahame and Davies (2008).

Temporal distribution

Maps of rainfall intensity derived from the weather radar network are given in Figure 3.

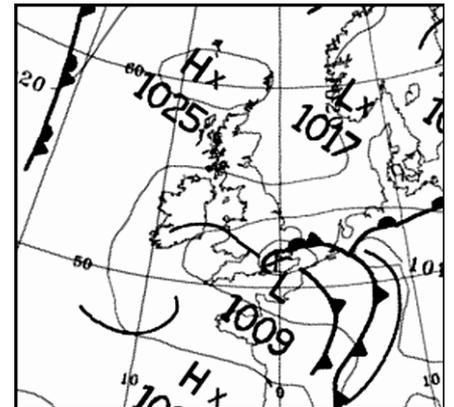


Figure 2. Synoptic surface analysis for 20 July 2007 at 1200 UTC.

These illustrate how the rain spread north-westwards during the morning of the 20th before dying out around midnight. Unfortunately, radar beam attenuation during the day resulted in the rainfall being

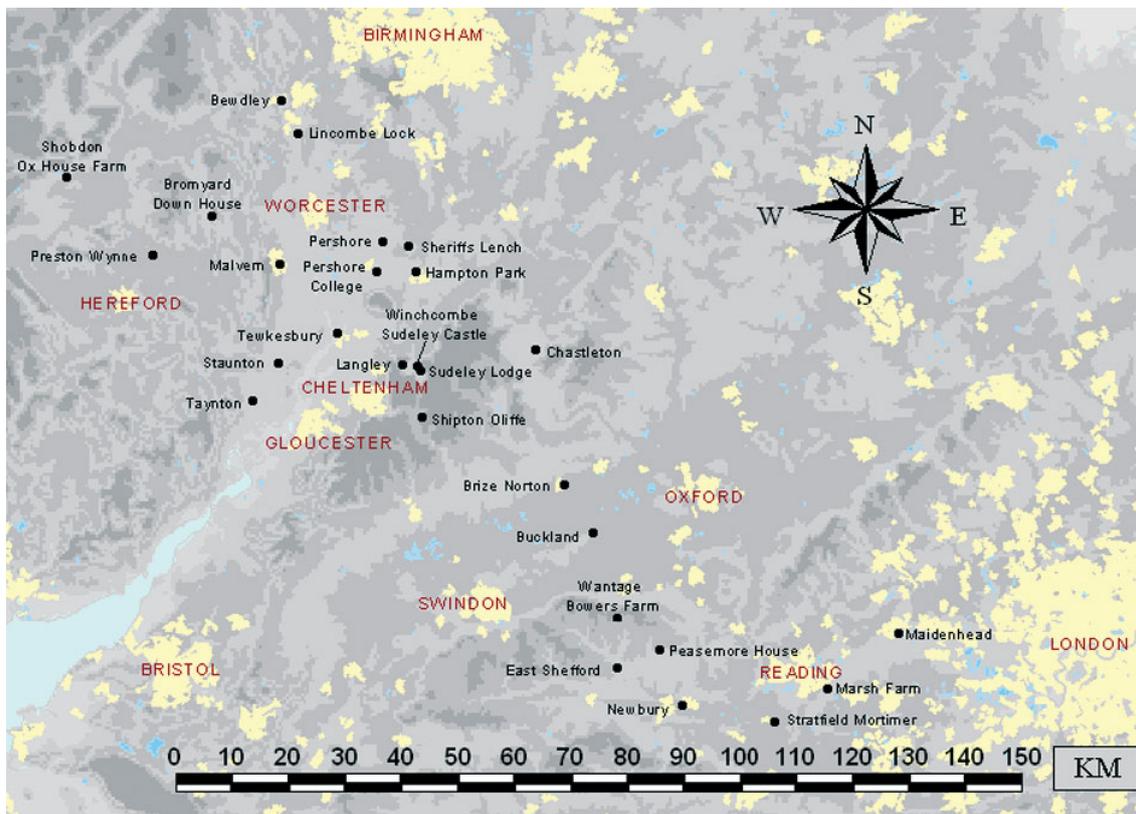


Figure 1. Locations of places mentioned in the text.

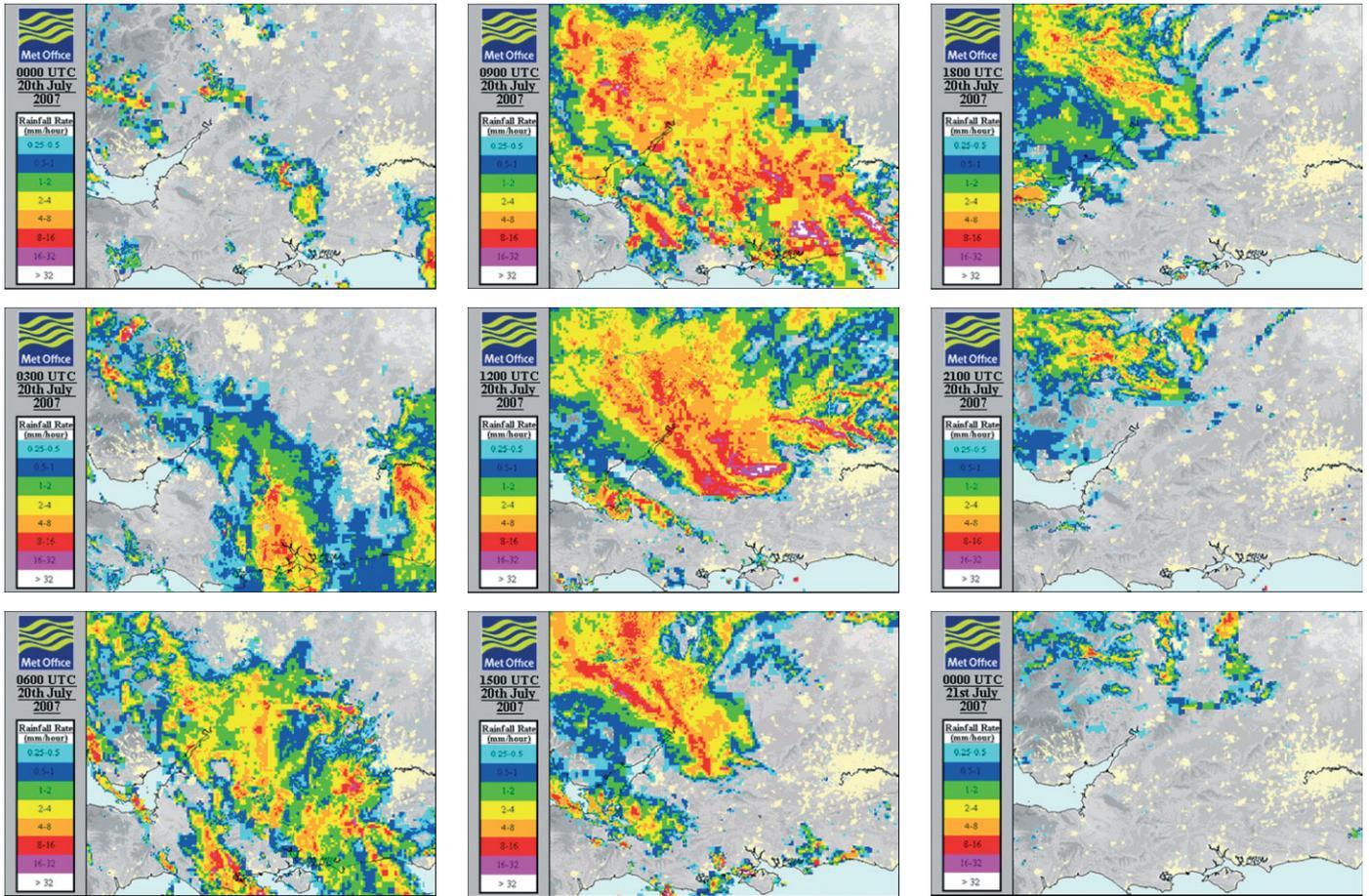


Figure 3. Rainfall intensities derived from the weather radar network, for every 3 hours from 0000 UTC on 20 July 2007 to 0000 UTC on 21 July 2007.

under-estimated in some areas, for example over parts of the Cotswolds, so the intensities shown are only a guide.

To complement the rainfall intensity sequence, Figures 4 and 5 show the hourly rainfall distribution at Pershore College (Worcestershire) and Brize Norton (Oxfordshire) on 20 July. These histograms illustrate the persistence and intensity of the rain. At Pershore, there were 15 hours of heavy rain ($>=4$ mm/h) including 5 hours with over 10 mm. At Brize Norton, the rainfall was heavy for 8 consecutive hours (from 0700 UTC) and exceeded 10 mm for 7 of those. One-minute rainfall data are available for Brize Norton and these have been analysed in terms of durations from 5 minutes upwards. The results for 15-minute totals are presented in Figure 6, and the peak rainfalls for various durations are summarized in Table 1.

Higher peak rainfalls were recorded at sites further south-east during the morning of the 20th. Burt (2008) summarizes the rainfall at Stratfield Mortimer near Reading (Berkshire), where the falls were the highest in 20 years of records for durations from 35 minutes to 48 hours. Over 5 minutes the peak intensity here averaged 69 mm/h at 1100 UTC. Even heavier rainfall was recorded at gauges operated by Thames Water Utilities in east Berkshire and an example for Marsh Farm Pumping Station (PS) on the south-eastern edge of Reading is given in

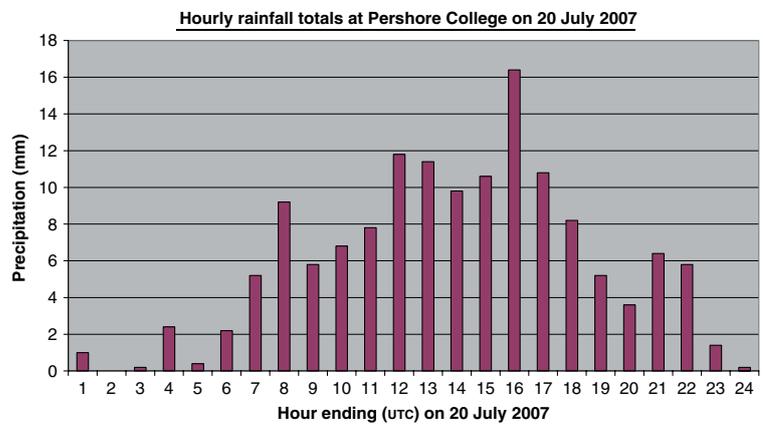


Figure 4. Hourly rainfalls at Pershore College (Worcestershire) on 20 July 2007.

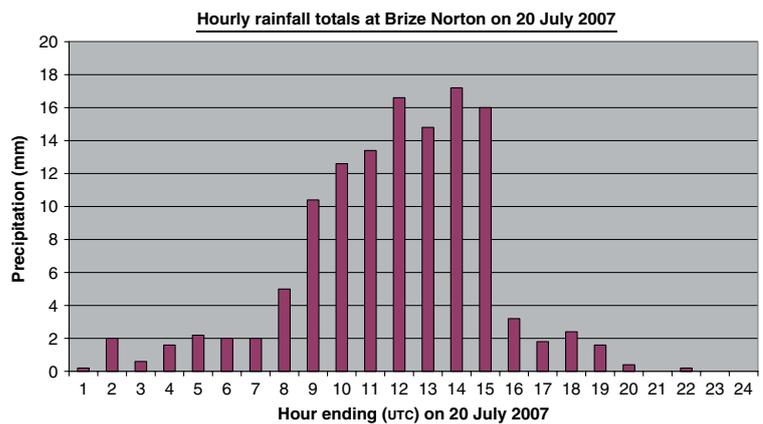


Figure 5. Hourly rainfalls at Brize Norton (Oxfordshire) on 20 July 2007.

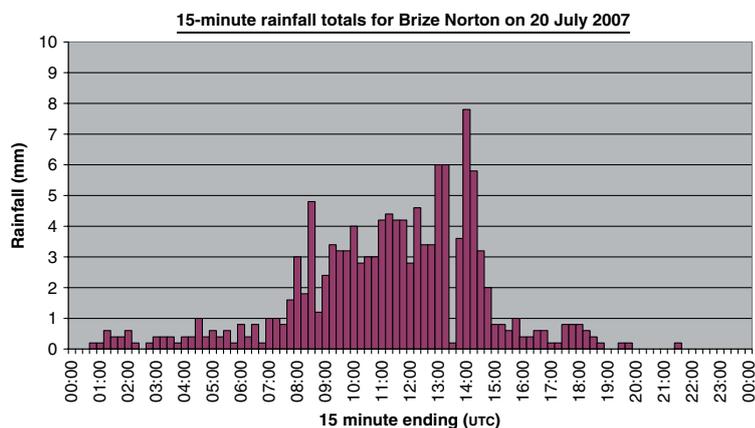


Figure 6. 15-minute rainfalls (mm) at Brize Norton (Oxfordshire) on 20 July 2007.

| Period | Rainfall (mm) | Time started (UTC) | Return period (years) |
|------------|---------------|--------------------|-----------------------|
| 5 minutes | 3.2 | 0820 | <1 ^a |
| 15 minutes | 8.4 | 1340 | 1 ^a |
| 30 minutes | 15.0 | 1340 | 5 ^a |
| 1 hour | 21.2 | 1335 | 10 ^b |
| 2 hours | 37.0 | 1210 | 35 ^b |
| 3 hours | 52.6 | 1113 | 95 ^b |
| 4 hours | 67.0 | 1031 | 190 ^b |

^a Estimated using the *Flood Studies Report*, 1975.
^b Estimated using the *Flood Estimation Handbook*, 1999.

| Period | Rainfall (mm) | Time started (UTC) | Return period (years) |
|------------|-------------------|--------------------|-----------------------|
| 5 minutes | 11.2 ^c | 1100 ^c | 100 ^a |
| 15 minutes | 20.0 ^c | 1054 ^c | 90 ^a |
| 30 minutes | 24.6 | 1052 | 65 ^a |
| 1 hour | 28.8 | 1010 | 10 ^b |
| 2 hours | 46.4 | 0922 | 40 ^b |
| 3 hours | 62.4 | 0810 | 90 ^b |
| 4 hours | 73.3 | 0738 | 150 ^b |

^a Estimated using the *Flood Studies Report*, 1975.
^b Estimated using the *Flood Estimation Handbook*, 1999.
^c Estimated from 2-minute totals.

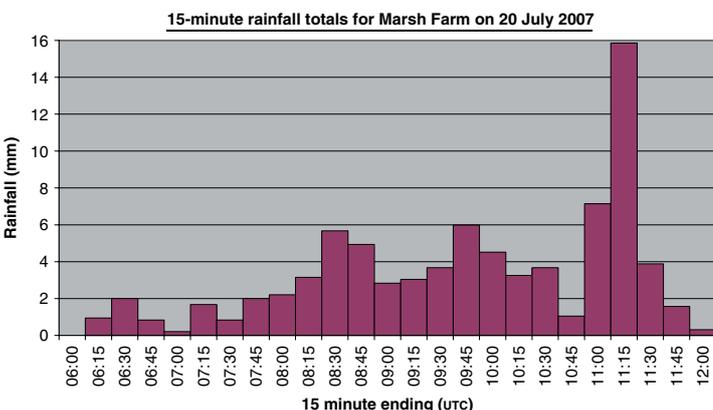


Figure 7. Estimated 15-minute rainfalls (mm) at Marsh Farm PS, near Reading on 20 July 2007.

Figure 7. Although this gauge is not registered with the Met Office, the total of 84.2 mm for this event agrees well with neighbouring registered gauges. The 15-minute totals shown have been estimated from 2-minute data and the peak falls for various durations are shown in Table 2. The peak 2-minute rainfall intensity recorded at this site and several others just east of Reading approached or exceeded 100 mm/h close to 1100 UTC on the 20th.

The average frequency of occurrence of these falls may be estimated using the methods of the *Flood Estimation Handbook* (Institute of Hydrology, 1999) for durations of 1 hour or longer and the *Flood Studies Report* (Natural Environment Research Council, 1975) for shorter durations. At Brize Norton, the peak rainfalls for durations up to 1 hour had return periods less than 10 years and only for durations over 3 hours did they exceed 100 years (Table 1). This typifies places in the south Midlands where it was the prolonged nature of the heavy rainfall that was noteworthy. It appears that the event was more notable for shorter durations further east, as illustrated by the peak rainfalls for Marsh Farm PS near Reading (Table 2) and a fall of 51 mm recorded between 0630 and 0733 UTC at a Climatological Observers Link site in the western part of Maidenhead (Berkshire).

Spatial distribution

Daily measurements of rainfall are made at 0900 UTC. This rainfall event lasted for most of the 20th and therefore fell over two 'rainfall days', the 19th (24-hour period ending at 0900 UTC/20th) and the 20th (24-hour period ending 0900 UTC/21st). The rainfall accumulation for these two days is mapped in Figure 8.

The defining characteristic was the large area affected by the exceptional rainfall, with about 20% of England and Wales (28 250 km²) recording over 50 mm and about 3800 km² over 100 mm. These areas have been calculated from an analysis of daily 5 km

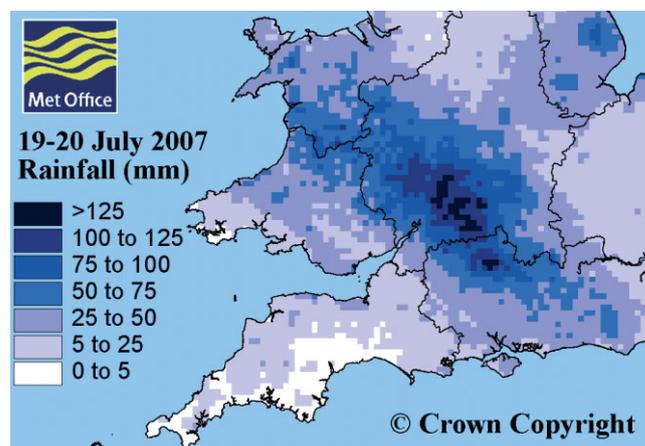


Figure 8. Rainfall (mm) on 19/20 July 2007.

Table 3*A selection of the wettest rainfall stations on 19/20 July 2007.*

| Station | National Grid Ref. | 19 July 2007 rainfall (mm) | 20 July 2007 rainfall (mm) | 19/20 July 2007 rainfall (mm) |
|--|--------------------|----------------------------|----------------------------|-------------------------------|
| Sudeley Lodge (Gloucestershire) | SP(42)/039270 | 16.1 | 147.0 | 163.1 |
| Pershore College (Worcestershire) | SO(32)/960447 | 36.6 | 120.8 | 157.4 |
| Chastleton (Warwickshire) | SP(42)/241307 | 24.7 | 115.4 | 140.1 |
| Langley (Gloucestershire) | SP(42)/002281 | 24.4 | 115.2 | 139.6 |
| Winchcombe, Sudeley Castle (Gloucestershire) | SP(42)/033277 | 30.4 | 107.7 | 138.1 |
| East Shefford (Berkshire) | SU(41)/386738 | 25.9 | 110.6 | 136.5 |
| Tewkesbury (Gloucestershire) | SO(32)/891337 | 13.7 | 119.0 | 132.7 |
| Pershore (Worcestershire) | SO(32)/973500 | 24.8 | 107.8 | 132.6 |
| Brize Norton (Oxfordshire) | SP(42)/292067 | 27.6 ^a | 100.2 ^a | 127.8 |
| Sheriffs Lench (Worcestershire) | SP(42)/018491 | 29.6 | 97.2 | 126.8 |
| Wantage, Bowers Farm (Berkshire) | SU(41)/385828 | 19.4 | 106.2 | 125.6 |

a: These are values from the principal (recording) rain gauge which are in good agreement with those from a co-located manual check gauge (27.2 mm on the 19th and 102.8 mm on the 20th, giving a 2-day total of 130.0 mm).

Table 4*A selection of long period stations that set new daily rainfall records on 20 July 2007.*

| Station | National Grid Ref. | Rainfall 20 July 2007 (mm) | Previous highest daily rainfall (mm) and date | Earliest year of record |
|-----------------------------------|--------------------|----------------------------|---|-------------------------|
| Sudeley Lodge (Gloucestershire) | SP(42)/039270 | 147.0 | 64.5 4 June 1985 | 1977 |
| Pershore College (Worcestershire) | SO(32)/960447 | 120.8 | 67.5 24 Sept 1976 | 1957 |
| Tewkesbury (Gloucestershire) | SO(32)/891337 | 119.0 | 70.6 10 July 1968 | 1961 |
| East Shefford (Berkshire) | SU(41)/386738 | 110.6 | 51.3 10 July 1968 | 1964 |
| Shipton Oliffe (Gloucestershire) | SP(42)/040186 | 107.5 | 69.3 24 June 2007 | 1974 |
| Peasemore House (Berkshire) | SU(41)/461770 | 104.1 | 71.7 22 September 1992 | 1961 |
| Brize Norton (Oxfordshire) | SP(42)/292067 | 100.2 | 70.9 10 July 1968 | 1968 |

Table 5*New county daily rainfall records set on 20 July 2007, for any month.*

| County | Station | Rainfall 20 July 2007 (mm) | Previous highest daily rainfall |
|-----------------|------------------|----------------------------|--|
| Berkshire | East Shefford | 110.6 | Maidenhead 107.7 mm 12 July 1901 |
| Gloucestershire | Sudeley Lodge | 147.0 | Winchcombe, Sudeley Castle 122.0 mm 10 July 1968 |
| Worcestershire | Pershore College | 120.8 | Bewdley 101.3 mm 31 May 1924 |

gridded rainfalls. The wettest area stretched from the Thames Valley to the Welsh border, where over 75 mm fell in a broad swathe.

A selection of the wettest stations, i.e. those with two-day totals over 125.0 mm, is shown in Table 3. The return periods of all

the 20 July and 19/20 July totals shown in Table 3 are in excess of 200 years.

At many places, the daily total for the 20th either exceeded or came close to the previous highest daily fall on record – examples of sites with long records that set new records

are given in Table 4. Interestingly, for the gauge at Shipton Oliffe, near Cheltenham in Gloucestershire, the previous record was set as recently as 24 June 2007, when 69.3 mm fell during an event that affected parts of the Midlands but mainly Northern England.

Webb (1987) lists the highest daily falls by county from 1860 to 1985. In order to extend this analysis and assess the wettest counties on 20 July, daily rainfall records from 1986 to 2007 were analysed. The totals on 20 July 2007 set new records for Berkshire, Gloucestershire and Worcestershire (Table 5).

It is unusual for daily rainfall amounts over 100 mm to occur widely over central - southern England and the south Midlands. Most such falls there are caused by convective rainfall, which tends to be localized. The national archive of digitized daily rainfalls from 1961 (> 3000 gauges) was examined to identify any similarly widespread heavy rainfall events affecting the area shown in Figure 1. One-day and two-day events were considered, in terms of the areas recording falls of over 50 mm and over 100 mm. Candidates include 24/25 September 1976 when 32 175 km² centred on the west Midlands and east Wales collected over 50 mm, with isolated falls exceeding 100 mm. A further example is 16/17 August 1977 with an area of some 19 350 km² stretching from London across the south Midlands to South Wales receiving over 50 mm, again with a small area over 100 mm. However, the event affecting the south Midlands in the last 46 years that appears most comparable to 20 July 2007 was that of 10 July 1968 when over 50 mm fell across an area about 100 km wide stretching from east Devon to Lincolnshire and the Wash (32 525 km²), including 1450 km² with over 100 mm (Meteorological Office, 1974; Salter, 1968, 1969). This remains the wettest day on record at Winchcombe, Sudeley Castle with 122.0 mm.

Table 6

Estimated areas of England and Wales with rainfall exceeding 50 mm and 100 mm during events that affected the south Midlands.

| Date | Area > 50 mm (km ²) | Area > 100 mm (km ²) |
|-----------------|---------------------------------|----------------------------------|
| 31 May 1924 | 22500 a, b | 1700 a, b |
| 10 July 1968 | 32525 c | 1450 c, d |
| 24/25 Sept 1976 | 32175 c | 750 c |
| 16/17 Aug 1977 | 19350 c | 150 c |
| 19/20 July 2007 | 28250 c | 3800 c, e |

^a includes separate areas of ~ 6500 km² >50 mm and ~ 800 km² >100 mm over north-east England.
^b estimated from map in British Rainfall 1924. (Meteorological Office, 1925.)
^c calculated using 5km daily rainfall grids, available for 1961 onwards.
^d 2250 km² was stated in British Rainfall 1968. (Meteorological Office, 1974.)
^e update to area of 3500 km² quoted by Marsh and Hannaford, 2007.

Before 1961, a further similar event was that of 31 May 1924, with over 50 mm falling in an area some 80 km wide from the Cotswolds to Merseyside (16000 km²) including approximately 900 km² with over 100 mm (Meteorological Office, 1925). This remains the wettest day at Malvern, Worcestershire (96.9 mm) since records began there in 1900 and at Lincombe Lock, Worcestershire (91.4 mm) where the record started in 1921.

The areas of England and Wales affected by these events are summarized in Table 6, for comparison with the 19/20 July 2007 event.

Impacts

The prolonged, widespread, heavy rainfall resulted in thousands of homes and businesses being flooded, the worst-affected counties being Gloucestershire, Worcestershire, Oxfordshire and Berkshire. Two types of flooding occurred. Initially, there was localized pluvial flooding as drainage ditches and, particularly, drains and sewers in urban areas were overwhelmed. Extreme

flows quickly followed in responsive streams and small rivers. Subsequently, as these fed into major rivers, floodplain inundations were widespread and protracted, lasting several days. Severe flooding occurred along the lower Severn and the upper Thames. On the Severn between Worcester and Gloucester conditions were comparable to those of March 1947, the most extensive flood episode in England and Wales in the twentieth century. On the Thames at Eynsham, near Oxford, the peak river level (which occurred on 24 July) was second only to that of the flood of 1903. A more complete hydrological appraisal is given by Marsh and Hannaford (2007) and Marsh (2008). Throughout, many road and rail routes were severely disrupted. For example, flooding on the M5 motorway in Gloucestershire and Worcestershire left 10 000 vehicles stranded overnight on 20/21 July.

In addition to the flooding of property and transport routes, some of the critical infrastructure was adversely affected. On the 22nd, the Mythe water treatment works

near Tewkesbury was flooded and had to be shut down, leaving 350 000 people across Gloucestershire without a water supply for up to 17 days. Electricity supplies were also threatened, as substations became vulnerable to flood water. The deployment of a temporary barrier at the Walham substation near Gloucester (visible in the front cover photograph) prevented the loss of supplies to 500 000 properties but the Castle Meads substation at Gloucester had to be shut down, leaving 42 000 without power (Cabinet Office, 2007).

The impact of the flooding was long lasting for many households. For example, some eight months afterwards (in late March 2008), it was reported that 465 homes were still uninhabitable in Tewkesbury, with a further 176 affected in Gloucester (BBC News, 2008). This was due partly to the length of time properties took to dry out and partly to a shortage of skilled labour to carry out repairs.

Monthly totals

The rainfall on the 20th contributed to some weather stations having their wettest July on record, in particular stations in Gloucestershire, Worcestershire and Herefordshire, and examples of those with long records are provided in Table 7. For Pershore College, Worcestershire, July 2007 was also the wettest calendar month in its 50-year record.

Monthly areal rainfall series are available for 1914 onwards for the UK, its constituent countries, regions and historic counties (pre-1974 re-organization) based upon 5 km grid point rainfalls calculated using the methods of Perry and Hollis (2005). The values for July 2007 for England and Wales, the Midlands and several English counties set new records for July, as shown in Table 8.

Table 7

Examples of stations for which July 2007 was the wettest July on record.

| Station | National Grid Ref. | July 2007 rainfall (mm) | % of 1961-1990 July average | Previous highest July rainfall (mm) and year | First year of record |
|--|--------------------|-------------------------|-----------------------------|--|----------------------|
| Tewkesbury (Gloucestershire) | SO(32)/891337 | 240.7 | 531 | 115.4 - 1968 | 1961 |
| Pershore College (Worcestershire) | SO(32)/960447 | 252.4 | 513 | 130.0 - 1957 | 1957 |
| Hampton Park (Worcestershire) | SP(42)/029447 | 245.0 | 507 | 123.9 - 1988 | 1961 |
| Buckland (Oxfordshire) | SU(41)/343982 | 203.5 | 477 | 137.0 - 2006 | 1964 |
| Newbury (Berkshire) | SU(41)/501672 | 200.8 | 476 | 88.4 - 1988 | 1971 |
| Shobdon, Ox House Farm (Herefordshire) | SO(32)/409616 | 194.7 | 475 | 113.5 - 1988 | 1971 |
| Staunton (Gloucestershire) | SO(32)/786283 | 216.2 | 472 | 99.1 - 1988 | 1977 |
| Bromyard, Down House (Herefordshire) | SO(32)/671545 | 220.5 | 446 | 137.7 - 1968 | 1961 |
| East Shefford (Berkshire) | SU(41)/386738 | 199.4 | 428 | 104.2 - 1992 | 1964 |
| Peasemore House (Berkshire) | SU(41)/461770 | 187.5 | 427 | 107.9 - 1966 | 1961 |
| Malvern (Worcestershire) | SO(32)/790461 | 194.6 | 410 | 141.0 - 1915 | 1900 |
| Taynton (Gloucestershire) | SO(32)/742216 | 179.4 | 385 | 153.2 - 1968 | 1961 |
| Sudeley Lodge (Gloucestershire) | SP(42)/039270 | 283.5 | 384 | 129.5 - 1978 | 1977 |
| Brize Norton (Oxfordshire) | SP(42)/292067 | 177.8 | 383 | 114.6 - 1988 | 1968 |
| Preston Wynne (Herefordshire) | SO(32)/564476 | 173.2 | 367 | 129.1 - 1968 | 1952 |
| Lincombe Lock (Worcestershire) | SO(32)/820693 | 177.3 | 363 | 126.8 - 1936 | 1921 |

| Table 8 | | | |
|--|-------------------------|--------------------------------------|---|
| Rainfall values for areas experiencing the wettest July in 2007, using series from 1914. | | | |
| Area | July 2007 rainfall (mm) | % of 1961–1990 average July rainfall | Previous wettest July in series from 1914 |
| England and Wales | 136 | 218 | 135 mm / 1936 |
| Midlands | 145 | 256 | 136 mm / 1915 |
| Berkshire | 148 | 320 | 129 mm / 1920 |
| Gloucestershire | 182 | 335 | 143 mm / 1936 |
| Herefordshire | 182 | 375 | 141 mm / 1936 |
| Oxfordshire | 144 | 292 | 117 mm / 1920 |
| Shropshire | 162 | 298 | 159 mm / 1939 |
| Warwickshire | 157 | 303 | 144 mm / 1915 |
| Worcestershire | 191 a | 379 | 161 mm / 1915 |

^a highest for any calendar month.

Summary

The weather situation on 20 July 2007 produced record-breaking rainfalls across much of central southern England and the south Midlands, both on a daily timescale and for the month of July. Intense rainfall occurred over eastern parts of the Thames Valley in the morning, whereas further north-west the rainfall was somewhat less intense but much more prolonged. It lasted up to 18 hours over the south-west Midlands, where the highest totals were recorded. The resulting flooding was initially localized as drains, streams and small rivers were overwhelmed but as these fed into major rivers, floodplain inundations became widespread and protracted. The impacts of this flooding on property and infrastructure were severe, widespread and, in some cases, very long-lasting.

Acknowledgements

The authors acknowledge, with thanks, the co-operation of the Environment Agency, other organizations and private individuals in providing rainfall data that enables noteworthy events such as this to be studied. In particular, we are grateful to Thames Water Utilities Ltd for permission to reproduce the rainfall data from their gauge at Marsh Farm PS and to Roger Brugge for details of rainfall recorded at his site in Maidenhead. Useful liaison with Terry Marsh at the Centre for Ecology and Hydrology is also gratefully acknowledged.

There is also a historic monthly rainfall series for England and Wales from 1766, based upon selected station data (Wigley *et al.*, 1984). In this series, the July 2007 total of 139.4 mm is ranked fourteenth wettest for July. All the wetter months were between 1767 and 1888, with the wettest being July 1828 (182.6 mm).

In order to provide the complete national context, Figure 9 presents the July 2007 rainfall, showing that in excess of 150 mm fell over most of Wales, the western half of England and parts of the Scottish Highlands. This represents over twice the normal July rainfall

over large areas of England and Wales, over three times in most of the south Midlands and south-east Wales and over four times locally in the south Midlands (Figure 10).

For the south Midlands, the rainfall of 20 July was the culmination of a period of frequent wet days that began in mid-June, with some days in May also being wet. This sequence is illustrated by the daily areal rainfalls for Worcestershire from May to July 2007 (Figure 11). The preceding rainfall led to the wet ground conditions and hence contributed to the severity of the flooding on the 20th and subsequent days.

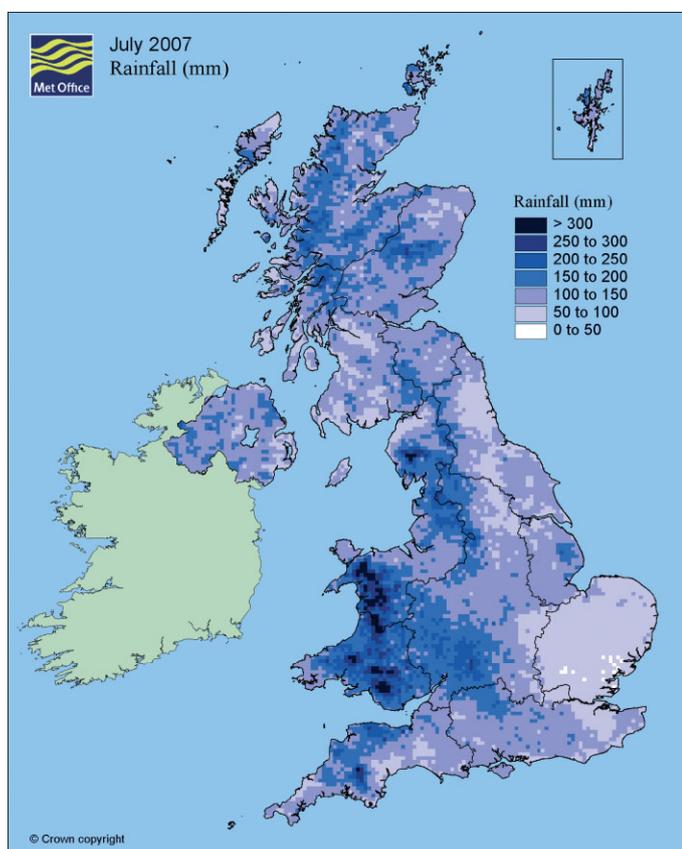


Figure 9. Rainfall totals (mm) in July 2007.

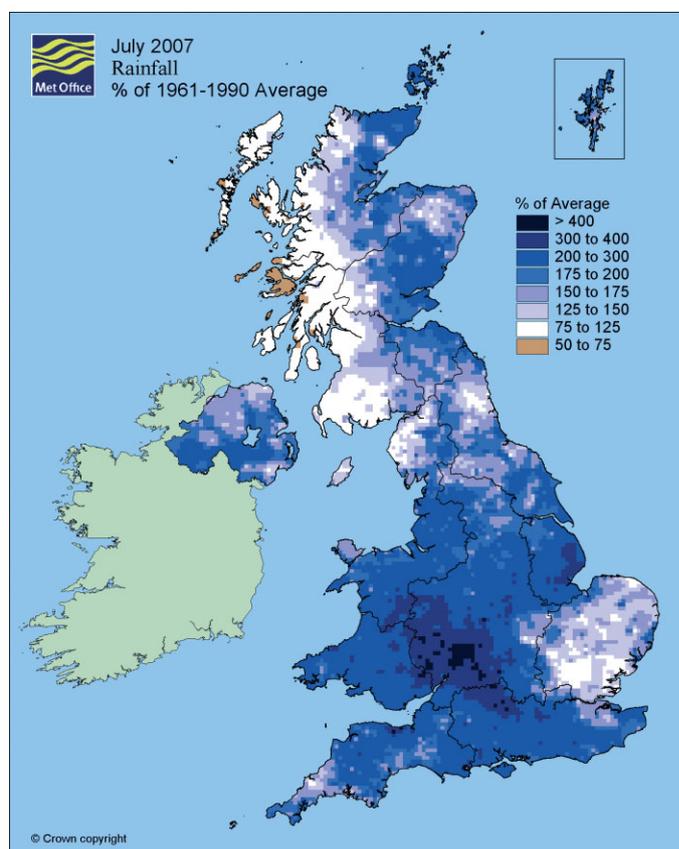


Figure 10. Rainfall in July 2007 expressed as % of the July 1961–1990 average.

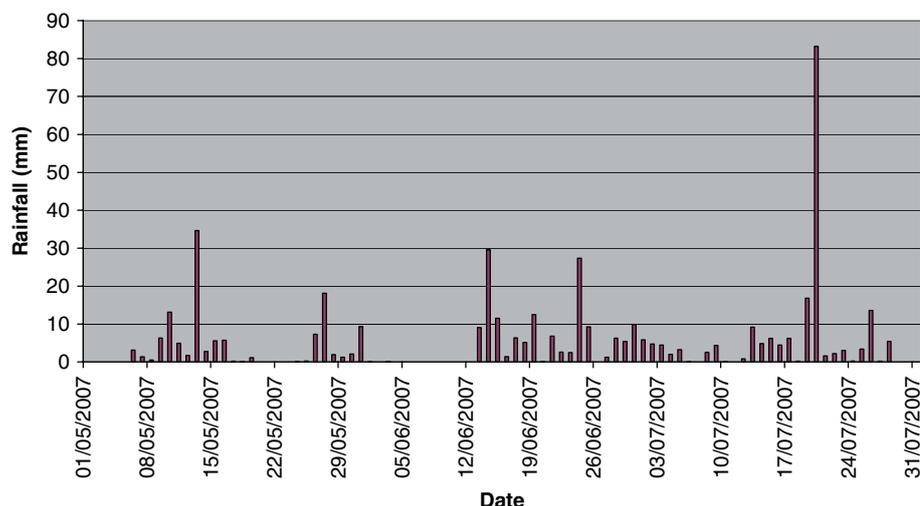


Figure 11. Daily areal rainfall (mm) for Worcestershire for May to July 2007.

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Correspondence to: John Prior, National Climate Information Centre, Met Office, FitzRoy Road, Exeter, EX1 3PB

Email: ncic@metoffice.gov.uk

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From the Archives – the weather of 40 years ago

Continuing the flooding theme of this month's issue, mid-September 1968 brought one of the most remarkable flooding events in recent UK history. A slow-moving occluded front over south-east England became the focal point for a series of thunderstorms, later developing into more widespread frontal rain: 48-hour rainfall totals for 14 to 16 September exceeded 200 mm around Tilbury in Essex and surpassed 100 mm from Hampshire to north Kent as well as locally in East Anglia.

The event was analysed in *Weather* by Mervyn Jackson (January 1977 issue) who compiled hourly rainfall maps from recording rain gauge data, this being before the days of operational rainfall radar. It is fortunate that it occurred over the part of the UK having the greatest density of recording gauges; the unfortunate corollary of this was that it hit a relatively densely populated area.

Sporadic thundery rainfall on the evening of the 14th gave hourly totals of more than 25 mm in places. More continuous thundery rain developed after midnight, spreading west-south-west from east London; over 100 mm fell between Maidstone and Reigate. As this became less intense on the 15th a separate thunderstorm formed over the Thames Estuary, possibly encouraged by sea-surface warmth. Later, another band of more persistent rain developed over East Anglia and extended towards the Chilterns.

Severe flooding occurred widely in Surrey, north-west Kent and south-east London. The Wey flooded Guildford and the Medway cut a swathe through Tonbridge (see Ogley, Currie & Davison's *'The Kent Weather Book'* and Davison & Currie's *'The Surrey Weather Book'*, both published by Frosted Earth). The seriousness of the situation was illustrated by an 'AA' temporary road-sign pictured in many accounts of the flood:

'East and West Molesey – Closed'

The Surrey town of Molesey lies at the confluence of the Mole and the Thames. The Mole catchment bore the brunt of the rain; Molesey became inundated with water, closing most roads and leading to the evacuation of residents. After these floods, major flood-prevention works were carried out on the Mole and the Medway to reduce the risk of future flooding on this scale.

1968 was a notable year for intense rainfalls, as noted by Bob Prichard in a retrospect of the year's weather (*Weather*: December 1992) and it was perhaps fortunate that *British Rainfall* survived until that year in its traditional format, including a chronology of severe rainfall events.

Julian Mayes, Editor,
West Molesey,
Surrey