The 2019/2020 floods in the UK: a hydrological appraisal

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Introduction

After an extended dry period, lasting for well over two years in some parts of the United Kingdom, early 2019 saw concerns over potential drought conditions (Turner et al., 2021). In the event, the summer and autumn of 2019, as well as the winter that followed were exceptionally wet across much of the country, and saw a remarkable succession of damaging flood events. Exceptional flooding occurred during the summer in parts of north Wales and central and northern England, most notably at Wainfleet (Lincolnshire) in June, and was dramatically prevented at Whaley Bridge (Derbyshire) in July/August. Large areas of central and northern England saw further exceptional river flow responses in November, with severe flooding in parts of South Yorkshire. The late winter then saw a series of intense storms that triggered a remarkably widespread and protracted flood episode across many major river systems of central Britain, causing severe impacts across northern England and on both sides of the English/Welsh border.

The successive, large rainfall events of early 2020, which have been attributed to atmospheric rivers, affected the UK and wider northern Europe (Lavers et al., 2020). Each of the resulting flood events would have been noteworthy in its own right, with those of November and early 2020 amongst the most severe in recent years. However, the clustering of such a run of major floods – in some cases, with multiple flood events in the same catchment in a short space of time – has further fuelled long-standing debates around changing flood risk in a warming world. Certainly, these floods underline the continuing vulnerability of the UK to flooding, coming soon after other nationally significant flooding episodes in the 2010s (e.g. in 2013/2014, Muchan et al., 2015; and 2015/2016, Barker et al., 2016). This calls for a rigorous appraisal of the severity of the 2019/2020 floods.

Here, we report on the flood events that occurred between June 2019 and February 2020, considering the hydrological characteristics of the events, and the combination of magnitude, duration and extent of the high flows that resulted in their impacts. Magnitudes are expressed as peak flows (the highest in the 15min time series during an event) and their annual maxima (AMAX, during UK water years starting on 1 October), combined with duration by considering daily mean and monthly mean flows. We place the river flows in historical context, asking how the floods compare with previous episodes and whether they are part of an emerging trend. A companion paper to this study analyses the winter flooding from a meteorological perspective (Davies et al., 2021).

July/August 2019

There was further unsettled weather during July, with convective rainfall and strong winds mid-month causing surface water flooding and transport impacts across northern and western Britain. Unsettled weather returned on the 24th/25th causing surface water flooding, travel disruption on flooded roads and railways, and loss of power to around 20,000 properties in Scotland and northern England.

Most notably, on 30 July, persistent rainfall across the Peak District and Yorkshire Dales produced remarkable rainfall totals with 95mm at Old Spital Farm (58mm of which fell in 45min) and 102mm at Arkle Town (82mm in 90min). There were swift increases in river flows in northern Britain as a result – the Mersey recorded its highest July daily mean flow (in a series from 1976) on the 31st (breaking its record set just three days earlier). On the Goyt, the peak flow on 31 July was the second highest in the 50-year record, with a return period estimate of 20 to 45 years (using the Flood Estimation Handbook rainfall frequency model, FEH13; UK Centre for Ecology and Hydrology, 2021). A widely used alternative expression of this return period, addressing the common misinterpretation that a given interval should be expected between flows of this magnitude, is that it has an annual exceedance probability (AEP) of between 2.2 and 5.0% (e.g. Villarini et al., 2009; Darwish et al., 2020). Further historical context for

1Details of flow data types are available on the National River Flow Archive website: https://nrlf.coe.sc.uk/about-data

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Table 1

Peak flow records established between June 2019 and February 2020 for selected rivers in the UK, those in bold are ranked 1 for magnitude in their respective period of record.

| River   | Station   | AMAX record start | Peak flow (m^3/s) | Date       | Rank in AMAX record | Return period range (years) | Annual exceedance probability (%) | Historical AMAX1 flow | Historical AMAX1 date |
|---------|-----------|-------------------|-------------------|------------|----------------------|---------------------------|---------------------------------|----------------------|----------------------|
| July 2019 | Goyt     | Marple Bridge     | 1969/1970         | 101.5      | 31 July 2019         | 2                         | 20–45                           | 2.2–5                | 131.1                | 16 July 1973         |
| November 2019 | Don     | Doncaster         | 1958/1959         | 338.9      | 8 November 2019      | 1                         | 110–460                        | 0.2–0.9              | 338.3                | 26 June 2007         |
|          | Rother   | Whittington       | 1960/1961         | 99.5       | 8 November 2019      | 2                         | 45–130                         | 0.8–2.2              | 125.7                | 25 June 2007         |
|          | Derwent  | Chatsworth        | 1975/1976         | 230.2      | 8 November 2019      | 1                         | 60–240                         | 0.4–1.7              | 197.3                | 25 June 2007         |
| February 2020 | Wear    | Witton Park       | 1974/1975         | 322        | 9 February 2020      | 2                         | 15–40                          | 2.5–6.7              | 353.2                | 31 January 1995      |
|          | Aire     | Armley            | 1960/1961         | 240        | 9 February 2020      | 2                         | 30–75                          | 1.3–3.3              | 344.4                | 27 December 2015     |
|          | Calder   | Elland            | 1970/1971         | 272.1      | 9 February 2020      | 2                         | 35–100                         | 1–2.9                | 337.6                | 26 December 2015     |
|          | Ribble   | Samlesbury        | 1960/1961         | 1111.6     | 9 February 2020      | 2                         | 35–895                         | 1.1–2.9              | 1112.8               | 26 December 2015     |
|          | Irwell   | Bury Ground       | 1973/1974         | 267.3      | 9 February 2020      | 2                         | 90–420                         | 0.2–1.1              | 283.6                | 26 December 2015     |
|          | Roch     | Blackford Bridge  | 1948/1949         | 143.8      | 9 February 2020      | 2                         | 55–140                         | 0.7–1.8              | 192.2                | 26 December 2015     |
|          | Elwy     | Pont-y-Gwyddel    | 1974/1975         | 220        | 9 February 2020      | 1                         | 30–65                          | 1.5–3.3              | 263.4                | 27 July 2007         |
|          | Teme     | Tenbury           | 1958/1957         | 231        | 16 February 2020     | 2                         | 120–550                        | 0.2–0.8              | 87.8                 | 28 October 1998      |
| Lugg     | Byton    | 1966/1967         | 103.4             | 16 February 2020 | 1              | 120–550                 | 0.2–0.8              | 87.8                 | 28 October 1998      |
|          | Usk      | Chainbridge       | 1957/1958         | 718        | 16 February 2020     | 2                         | 819.6                          | 27 December 1979     |
|          | Cynon    | Abercynon         | 1961/1962         | 211        | 16 February 2020     | 1                         | 181.7                          | 27 December 1979     |
|          | Taff     | Pontypidd         | 1967/1968         | 805        | 16 February 2020     | 1                         | 612.3                          | 27 December 1979     |
|          | Ebbw     | Rhiwerin          | 1957/1958         | 198        | 16 February 2020     | 1                         | 190                            | 16 October 1967      |
|          | Ogmore   | Bridgend          | 1960/1961         | 180        | 16 February 2020     | 1                         | 178.8                          | 24 October 1998      |
| Neath    | Resolven | 1978/1979         | 529                | 16 February 2020 | 1              | 461                        | 23 October 1998      |
| Wye      | Belmont  | 1908/1909         | 688.8             | 17 February 2020 | 1        | 160–550                | 0.6–2               | 607.7                | 28 October 1998      |
| Severn   | Bewdley  | 1923/1924         | 534.7             | 26 February 2020 | 5             | 30–55                   | 1.8–3.3             | 604.2                | 21 March 1947        |

Gauging stations presented are those for which data were available to February 2020, with long historical period of record, rank 1 or 2 AMAX events in 2018/2019 or 2019/2020 and large catchment area, prioritised in that order. Data for the Severn are included due to long record length. Return periods are calculated using FEH methodology and presented for catchments in England only.

Historical records have been taken from Version 9 of the National River Flow Archive Peak Flow Dataset (NRFA, 2020) with data ending September 2019 (for stations with new records in June–August 2019, data ending September 2018).

this, and other notable peak flows referenced in this paper are shown in Table 1, with the locations of the gauging stations at which they were measured shown in Figure 1. The exceptional flow volumes in the Goyt catchment caused damage to Toddbrook Reservoir in the Peak District, leading to the evacuation of over 1500 residents from Whaley Bridge on 1 August. A major emergency response ensued to reinforce the spillway and reduce levels over the following week before residents could return. Repairs to the drained reservoir continued through the winter, with completion of the restoration expected in 2023.

November 2019

The remainder of the summer and autumn was predominantly unsettled and many parts of central and northern England received more than twice the average rainfall for this period. For the Severn-Trent region, it was the wettest June–October on record (in a series from 1910). The wet conditions in early autumn saturated the soils in these areas, reducing their capacity to store rainfall and increasing the susceptibility to flooding at the start of November. On the 7th, an occluded front stalled across north Wales and central England bringing persistent heavy rainfall. Daily rainfall totals equalled or exceeded the rainfall expected for the whole of November in some locations; 24-hour rainfall totals of 78mm near Doncaster and 82mm in Sheffield have equalled or exceeded the rainfall expected on record (in a series from 1975). The event was also exceptional on the Don (Figure 2(a)). Although flows in Sheffield were not as high as those recorded in 2007, further downstream in Doncaster and Rotherham (after the confluence with the Rother catchment) new peak flow records were established. There was extensive fluvial flooding in central and northern England with 1100 properties inundated, and the Doncaster area worst affected (260 and 220 properties were flooded in Bentley and Fishlake, respectively). However, flooding was alleviated by a network of defences which generally performed well, protecting over 22,000 properties.

Travel by road was disrupted with many major routes impassable and some rail lines blocked by flooding or landslides, particularly around Sheffield, Derby and Nottingham. Three schools in Derbyshire were shut as a...
result of flooding and a woman’s body was recovered from the Derwent in Darley Dale. The conditions caused considerable damage in the agricultural sector and a Farming Recovery Fund provided grants to cover repair costs. The Association of British Insurers (ABI) estimated insurance payouts to homes and businesses hit by flooding in counties of Yorkshire and the Midlands would reach £110 million (House of Commons Library, 2020).

With the exceptional flows recorded in central England, monthly mean flows were the highest on record for November in the Don catchment (Figure 3(a)), in fact, over four times the long-term average. New records were also set on the Lud, Witham, Warwickshire Avon and Kenwyn (Figure 3(a)). Conversely, records at the other end of the hydrological regime were established in the same month in northwest Scotland on the Ewe and Carron where November rainfall was, by contrast, exceptionally low (Figure 3(a)).

February 2020

There were further, albeit less dramatic, high flows for parts of the UK in both December and January, but the severe wet weather returned with renewed intensity during February (Davies et al., 2021). The first of three named storms, Ciara, brought sharp increases in river flows across the country on 8th/9th, most notably in southern Scotland and northern England where the peak flow on the Ribble was comparable with the record established in December 2015 (Table 1). Heavy rain and flooding caused disruption to road and rail transport, and there were widespread agricultural impacts with farmland flooded and rural roads impassable. While thousands of properties were successfully protected from flooding in the southwest and northern parts of England, in the worst affected area to the north of Manchester, more than 500 were inundated by rivers draining to the south (the Irwell), the east (the Calder, a tributary of the Aire) and the west (the Ribble).

A week later, with flows still receding in large catchments, widespread heavy rain from storm Dennis (15th/16th) interrupted the recovery, both in hydrological and human terms. A second peak in river flows, exceeding the first in Wales and the Midlands, saw new peak flow records set on the Lugg, Wye,
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Cynon and Taff amongst others, with the probability (AEP) of these flows being exceeded in any given year on the Lugg or the Wye less than 2% (Table 1 and Figures 2(b) and (c)). While over 25,000 properties were successfully protected, the high flows saw more than 1,500 properties flooded across English counties, a further 800 in Rhondda Cynon Taf, and unfortunately another fatality, on the Teme in Worcestershire. These weather extremes again caused widespread travel disruption, with major incidents declared in Herefordshire and south Wales. Such was the extent of rivers affected, that on 16 February more than 600 Flood Alerts and Warnings were in force on rivers in England (the most simultaneously since the introduction of the scheme in 2006).

Further unnamed low pressure systems brought substantial rainfall accumulations (180mm of rain at Honister Pass, Cumbria, on the 19th and 110mm at Littondale, North Yorkshire, on 21st/22nd) and kept flows high, particularly in western parts of the UK and the north of England. There was little respite towards the end of the month, as storm Jorge (28th/29th) delivered further rainfall onto fully saturated soils. The resulting runoff compounded and prolonged the exceptionally high flows in larger catchments such as the Severn and the Aire as the flood peaks travelled downstream.

With river flow recessions repeatedly interrupted, it is unsurprising that February saw numerous new monthly flow maxima established, many on rivers with flow series of 60 years or more (Figure 3(b)). The widespread locations of these rivers in Scotland (Clyde), Northern Ireland (Mourne), England (Leven, Lune, Don and many others) and Wales (Conwy, Dee, Tawe), illustrates the national footprint of the persistently high flows. Indeed, the combined average monthly outflow from the UK as a whole had previously been exceeded only in February 1990 and in December 2015.

Overall, February’s dramatic weather resulted in the flooding of more than 4,200 properties across England and Wales, and the protection of over 120,000 more by permanent or deployed measures. Between 1 February and 1 March, 38 landslides were reported in Great Britain, triggered by rainfall (BGS, 2020). The February storms caused devastating impacts across the country and the ABI reported 82,000 claims for flood and wind damage, with anticipated payouts expected to total £214 million and £149 million, respectively.

Historical context and trends

How do the floods of 2019/2020 compare with previous episodes?

After a protracted period of rainfall deficiency spanning multiple dry winters (Turner et al., 2021), successive periods of wet weather from June 2019 to February 2020 dramatically altered the water resources situation of the UK and resulted in a series of disruptive and damaging flood events.

The flooding in summer 2019 resulted from intense convective rainfall and was generally localised in its spatial footprint. While locally extreme, similar events are not uncommon during the summertime in the UK (especially during hot spells). The physical basis for an increasing likelihood and/or magnitude of intense rainfall events under anthropogenic warming is well founded, but the extent to which these events corroborate this association is subject to further exploration (Kendon et al., 2014; Kendon et al., 2018). One noteworthy feature of the events of summer 2019 was the repetition with which a similar area of northern, central and eastern England was impacted on each occasion. Persistent rainfall through the second half of 2019 reduced soil moisture deficits, bringing catchments closer to saturation and establishing the
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In contrast, the flooding of November 2019 and February 2020 was predominantly fluvial in nature, again not uncommon during the winter half-year (October–March) in the UK. While each event had a slightly different spatial footprint (e.g. south Wales impacted in February 2020 but not November 2019), it was notable that a swathe of northern and central England was impacted on both occasions. In some catchments, peak river flows in November 2019 and February 2020 comprised two of the five highest flows on record; for the Dearne and Doe Lea in North Yorkshire, they were two of the top three flows in records exceeding 50 years. To have two such flows from independent events within a few months of one another is remarkable.

In terms of flow magnitude, the events of 2019/2020 were amongst the top 10 highest peak flows ever recorded across a broad swathe of Wales and northern and central England. Northern England has been particularly frequently impacted by major flooding over the last two decades (Figure 4), making the fact that peak flows in some catchments in 2019/2020 are AMAX1 (a new record, eclipsing the memorable events of 2007, 2012 and 2015/2016) all the more remarkable. In a historical context, the flooding in mid and south Wales was even more exceptional; according to provisional data, a substantial majority of catchments recorded their highest peak flows in series of at least 50 years in length. In contrast with northern England which has experienced a number of notable flood events in recent years, it is clear that for south Wales, the February 2020 event was by some margin the most significant of any episode of at least the last 20 years (Figure 4).

In addition, the spatial footprint of very high flows across northern England, parts of central England and much of mid and south Wales was notable (Figure 4). It should also be noted that the provisional nature of data availability for this initial assessment likely underestimates the spatial extent of top 10 peak flows; a more comprehensive assessment will follow once all peak flow data for 2019/2020 have been validated and made available. Nevertheless, on 16 February 2020, outflows from England and Wales established a new maximum in a series from 1961 (Figure 5(a)), eclipsing the daily outflows in all other major events of the last 60 years. High values in the outflows series are not achievable without concurrent high flows across many of the largest catchments. Although concurrent events across multiple basins have received more attention in recent years (e.g. De Luca et al., 2017), flooding is typically considered to be a relatively localised phenomenon. Nevertheless, a number of flood events of the last 20 years have had similarly vast footprints, at times remarkably similar to that of 2019/2020 (Figure 4).

The total number of properties flooded during the June 2019 to February 2020 period was around 6000. This number is comparable with some of the other major flood events of the last decade, including 7000 in winter 2013/2014 (Muchan et al., 2015) and 8000 in 2012 (Parry et al., 2013), although falling short of the more than 16000 in winter 2015/2016 (Barker et al., 2016). While consistent comparisons between events are challenging due to the nuances of event hydroclimatic characteristics and populations impacted, it is clear that the prevalence of flooding in large catchments enhanced forecasting potential, allowing deployable flood defences to mitigate more significant property flooding in communities across the UK. Nevertheless, this is of limited comfort to those residents and businesses impacted in 2019/2020 for which there will have been a considerable physical and emotional recovery.

The duration of the flooding in February 2020 was perhaps its most remarkable characteristic of all. High flows triggered by named storm events were maintained by
The 2019/2020 floods in the UK further rainfall in between, and the swift succession of three major storms yielding very protracted floodplain inundations that were slow to drain away due to continued high flows. Compounding this was the occurrence of flooding in the large catchments of northern and central England (Yorkshire Ouse, Aire, Trent), and across the English/Welsh border (Severn, Wye, Teme). While the slowly responding nature of such catchments provided forewarning to authorities of the flooding that was to follow, they also receded slowly due to the sheer volume of water on floodplains. The extent of inundation of the Severn and Ouse washlands was such that flood impacts continued for some time after the flood peak. At Bewdley on the Severn (Figure 2(d)), flows exceeded 220 cumecs from 11 February to 4 March (inclusive; this is the longest duration (23 consecutive days) above this threshold in the long series from 1921). To provide some context for this amount of water, a sustained flow of 220 cumecs is the equivalent to the volume of more than 100 London double-decker buses passing through Bewdley every minute for 23 days. Moreover, for around half of those days, daily flows were almost double 220 cumecs, peaking at 526 cumecs. While relatively rare, similar long duration flooding has also been observed in recent years in other large catchments of the UK, such as the Thames in winter 2013/2014 (Huntingford et al., 2014; Muchan et al., 2015).

To what extent are recent floods part of an emerging trend? The 2019/2020 period was not the first time in recent years that a cluster of flood events has been observed. The record for the highest 24-hour rain gauge total in the UK was reportedly broken twice in six years (2009 and 2015) in locations only a matter of miles apart in the Lake District and, notwithstanding the omission of the 2009 record in subsequent analysis of reliably recorded data, both events triggered devastating flooding of downstream communities in Cumbria (Stewart et al., 2012; Parry et al., 2013; Burt, 2016). Towns in the Yorkshire Dales were flooded in November 2019 just prior to the scheduled completion of flood defences funded as a result of the previous severe flood episode in winter 2015/2016. Major flood events in 2007, 2009, 2012, 2013/2014, 2015/2016 and 2019/2020 have led to the suggestion that flooding is becoming worse.

Capitalising on the wealth of hydrological data in the UK, undertaking trend analysis on annual maximum (AMAX) flows can inform understanding of patterns in the variability of river flows over the historical record. A more comprehensive assessment of UK hydrological trends can be found in Hannaford et al. (2021), but herein the addition of 2019/2020 data for selected catchments provides a truly current perspective. Trends were analysed over two fixed periods, 1987–2019 and 1967–2019, with water years starting on 1 October, and pragmatic tolerances of up to two years on start dates to maximise sample size. Of the 35 catchments with sufficient record lengths to provide robust trend assessments (at least 1969-present) which also recorded one of their highest three AMAX on record, the vast majority (33 catchments, 94%) demonstrated a positive trend (12 of which were statistically significant at the 10% level). While any trend assessment is sensitive to the record length, as well as the start and end dates over which analysis is undertaken (Griffin et al., 2019), 28 of the 35 catchments also exhibited positive trends over a shorter timeframe (1987-present). Figure 6 illustrates these findings for two catchments that were particularly impacted by flooding in 2019/2020. The cluster of high flows over the last two decades is apparent for the Don (Figure 6(a)), and less so for the Teme (Figure 6(b)) but positive trends were identified over both timeframes in both catchments.

These analyses and others (e.g. Harrigan et al., 2018) highlight increasing trends in peak flow magnitude in many catchments of northern and western Britain. Moreover, although not yet subject to formal trend detection, the recent clustering of large spatial footprint and/or long duration flood events over the last two decades (Figure 4) is further underlined by patterns in the outflows series. In a record from 1961, nine of the ten highest monthly outflows from Great Britain have occurred since 2000 (Figure 5(b)).

While such findings are consistent with what is expected to occur under climate change in the UK (e.g. Watts et al., 2015), and despite the increasing number of studies partially attributing major flood episodes to climate change, the extent to which this can be differentiated from natural variability for any given event remains a complex question. Regardless of the drivers, it is apparent that we are living through a time of hydrological volatility not previously experienced in living memory.

The events of 2019/2020 are the latest in a sequence of notable flood events over the last two decades which, taken together, comprise a flood-rich period of the UK's hydroclimatological record. The tendency for positive trends in AMAX series in parts of the UK has been established herein and elsewhere, but this is just one aspect of high flow trends. The recurrence of long duration and/or large spatial footprint flood events in recent times (often impacting the same locations) is perhaps an early indication of the influence of climate change on flood hydrology in the UK. However, with a few exceptions, present and future changes in frequency, duration and spatial extent have not been thoroughly assessed. Any suggestion of simultaneous increases in these characteristics (alongside magnitude) would imply profound impacts on our society and ability.
to manage and mitigate extreme floods in future.

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