The winter 2023/2024 floods in the UK: a hydrological appraisal

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Introduction

During 2023/2024, England and Wales both saw their wettest winter half-years (October–March), and the UK registered its second wettest winter half-year, all in series from 1890. Additionally, 2023/2024 saw the wettest winter half-year in the combined England & Wales precipitation series from 1767 (Alexander and Jones, 2000), making it the wettest winter half-year in more than 250 years. The associated storm season (September 2023–August 2024) saw 12 UK Met Office named storms and an additional storm named by the Danish Meteorological Institute. The prevalence of sustained above-average rainfall and record storminess caused a number of rivers to register record peak flows, leading to flooding with widespread, and sometimes very severe, impacts on transport and infrastructure, properties and agriculture, among others.

This paper describes the evolution of the flooding throughout the winter half-year of 2023/2024, the hydrology of the event, and the impacts. It also explores whether there is a trend towards increased winter half-year flows in the UK, including those seen in this event. A companion paper uses a 'storyline' approach to explore how this event could have evolved differently and attributes the event to long-term climate change (Chan *et al.*, 2025). This forms part of a series of appraisals of notable hydrological events in the UK (e.g. Barker *et al.*, 2016, 2024; Sefton *et al.*, 2021; Turner *et al.*, 2021), which serve as comprehensive records of UK hydrological extremes.

Data and information used to describe the characteristics of the flooding were sourced from the National Hydrological Monitoring Programme (NHMP),[1] which contains provisional data supplied by UK Measuring Authorities. The data analysed here consists of a set of 107 National River Flow Archive (NRFA)[2] gauging stations which are routinely collated by the NHMP, as well as the NRFA Peak Flows Dataset[3] and NRFA daily mean flows for the UK Benchmark Network of near-natural catchments (Harrigan *et al.*, 2018a). The gauging stations shown in Figure 1a are a subset of 77 of the 107 NHMP stations. These 77 stations are a representative selection of UK rivers and drain catchments corresponding to approximately 35% of the total UK land area.

[1] https://nrfa.ceh.ac.uk/nhmp.
[2] https://nrfa.ceh.ac.uk/.
[3] https://nrfa.ceh.ac.uk/data/peak-flow-dataset.

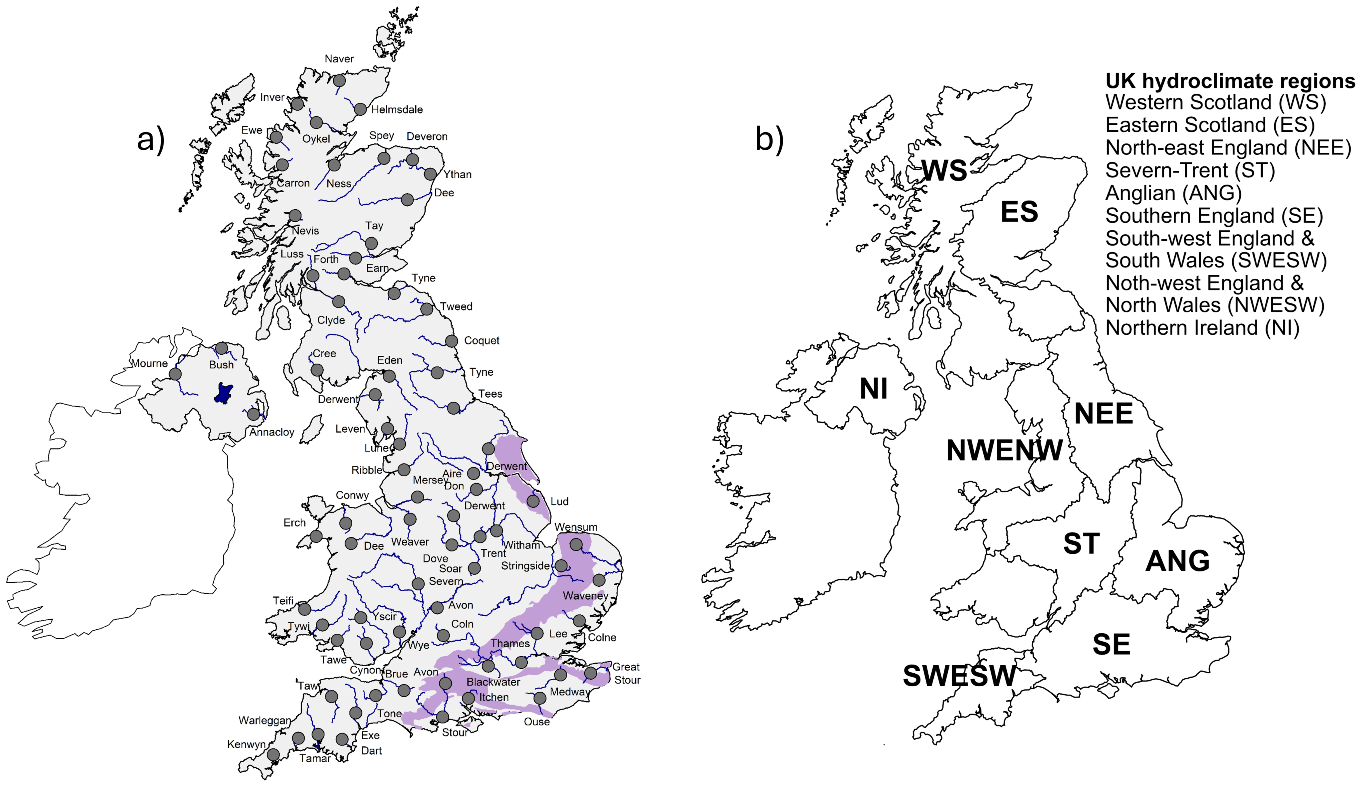

Figure 1. Location maps showing (a) gauging stations used in the National Hydrological Monitoring Programme, with chalk aquifers highlighted, (b) hydroclimate regions of the UK (Harrigan et al.*, 2018b).*

RMetS Royal Meteorological Society

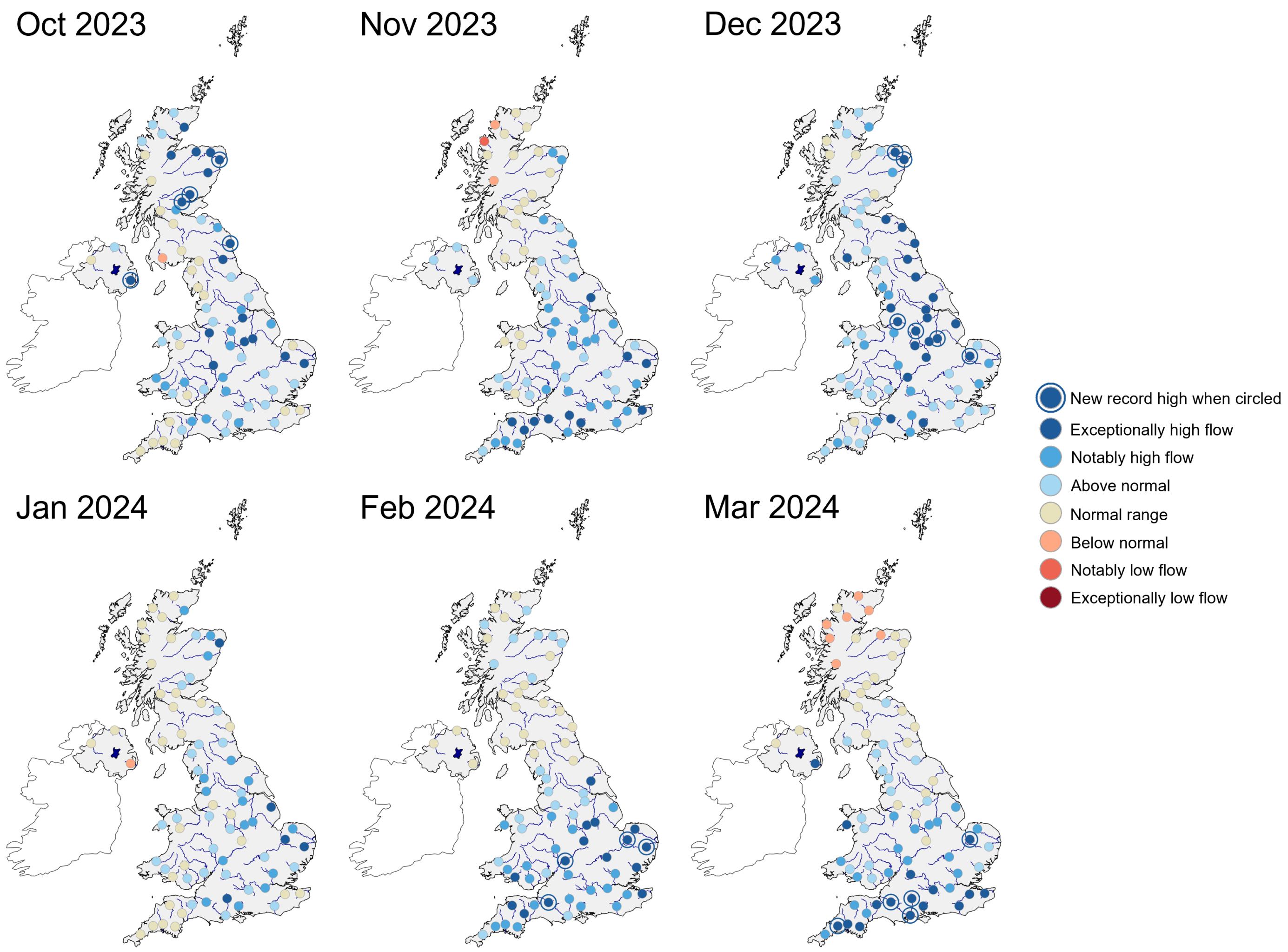

Figure 2. Maps of ranked monthly mean river flows for each month in the winter half-year of 2023/2024 (October to March). New records for the respective calendar month are circled. Equivalent monthly and seasonal rainfall maps are available online from the UK Met Office (https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-actual-and-anomaly-maps).

Rainfall series quoted throughout are derived from the HadUK-Grid dataset which contains monthly data from 1836, although the series is only presented from 1890 due to reduced station coverage in earlier years (Hollis *et al*., 2019; Kendon *et al*., 2025). Note that rainfall statistics presented are based on provisional data available at the time of reporting and these values may change.

Chronology of the winter half-year

The latter half of summer 2023 was notably wet, with the UK experiencing 170% of average rainfall for July, and 130% of average for July–August, placing it in stark contrast to the record-breaking dry summer experienced the year before and a relatively dry start to 2023 itself (Barker *et al*., 2024). This wet end to the summer heralded the beginning of a much more prolonged wet period across the entirety of the UK.

September started largely dry and warm, with occasional thundery showers, resulting in recessions in flows for many catchments. However, a series of Atlantic low-pressure systems and associated rainfall in the latter half of the month led to sustained high flows for many catchments. These high flows were further reinforced by the first named storm of the season, *Agnes*, which brought heavy rain across western areas of the UK on the 27th/28th.

A succession of Atlantic frontal systems at the start of October brought notable rainfall totals and flooding to parts of Scotland following the wettest 2-day period on record for Scotland (64.1mm on the 6th/7th). In mid-October, Storm *Babet* tracked slowly northwards across the UK, bringing persistent heavy rain from the 18th to 21st, particularly across eastern areas of England and Scotland. The Met Office issued two red severe weather warnings for rain across eastern Scotland, only the sixth and seventh red rain warnings issued since the National Severe Weather Warnings Service began in 2011.[4] River flows rose throughout October for much of the UK and five NHMP catchments in northeastern Great Britain and southeast Northern Ireland registered their highest October mean flows on record (the Annacloy, Ythan, Tay, Earn and Coquet, circled in Figure 2). The impact of the prolonged wet weather was beginning to register in groundwater levels, with many boreholes across England recording notably high to exceptionally high levels by month-end (Hannaford *et al*., 2023).

At the start of November, Storm *Ciarán* brought heavy rainfall to southern areas of the UK from the 1st/2nd; however, this storm was most notable for high wind speeds, and it set a new minimum atmospheric pressure record for November in England and Wales. Storm *Debi* brought further heavy rain for Northern Ireland and northwest England on the 13th. Despite the drier end to the month, and associated recessions, November mean flows across the UK were largely above normal, and in the south of England nine catchments registered notably high flows (e.g. the Stringside, Itchen and Exe).

The final month of 2023 initially saw a continuation of the cold and wintry conditions that began in November. As December pro-

[4]Weather warnings are issued by the UK Met Office using an impact matrix based on the likelihood and severity of forecasted impacts; for more information see: https://weather.metoffice.gov.uk/guides/warnings.

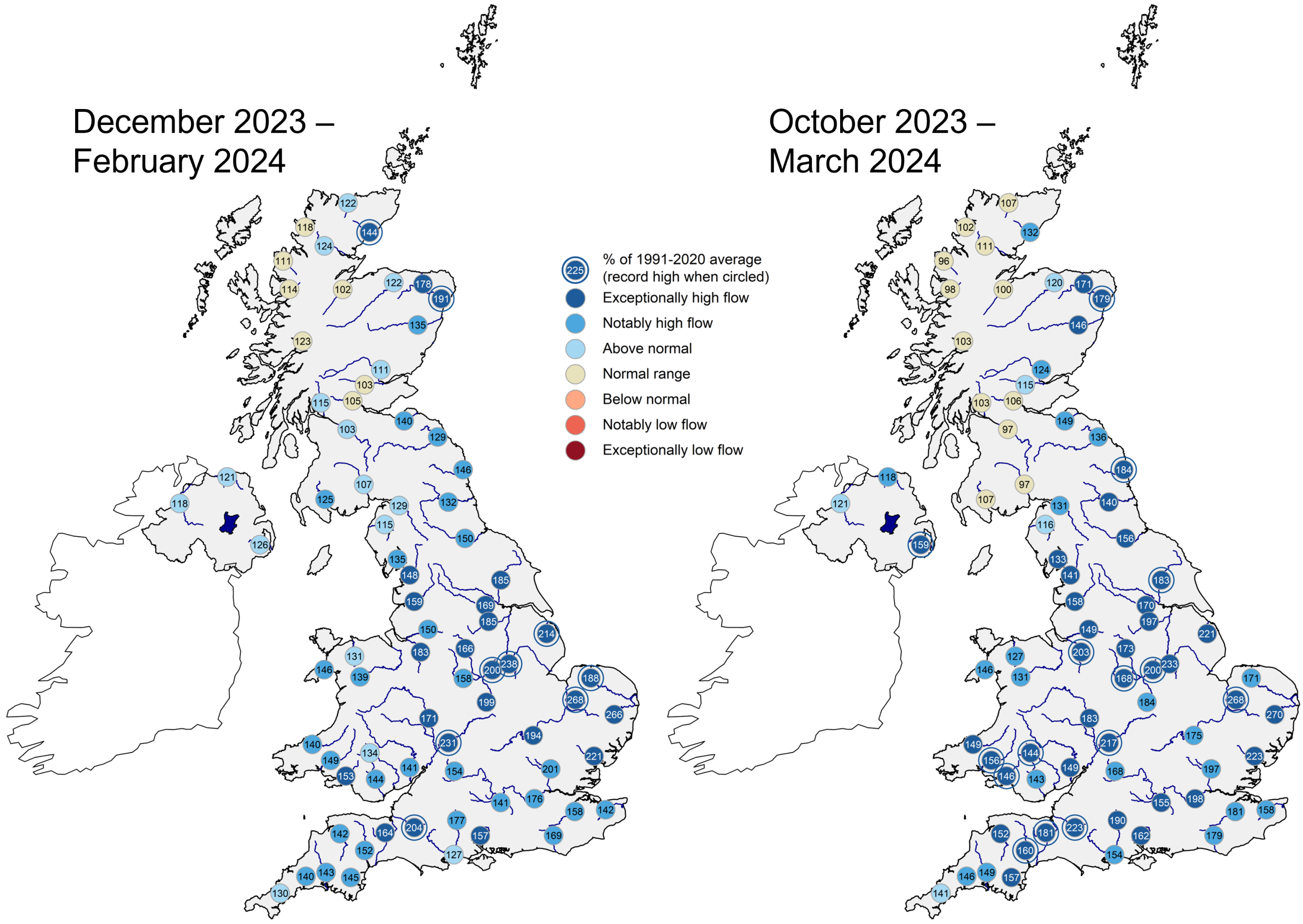

Figure 3. Maps of mean river flows for the meteorological winter (December to February, left) and winter half-year (October to March, right) of 2023/2024, showing river flows as a percentage of 1991–2020 long-term average (numbers in the circles), and flow rankings relative to the period of record for each catchment (colours of the circles). New records for the period in question are circled. See high-quality digital version for flow percentages.

gressed, a succession of storms brought wet and windy weather to the UK, starting with Storms *Elin* and *Fergus* on the 9th and 10th, respectively. The wet conditions of autumn so far had saturated soils and raised groundwater levels, leading to an increased risk of both surface and groundwater flooding. Unsettled conditions continued with Storm *Pia* (named by the Danish Meteorological Institute) on the 21st, bringing more wind and rain to northern areas. Storm *Gerrit* further exacerbated the wet conditions with heavy rain in Wales, northwest England and Scotland on the 27th/28th. The series of flow peaks caused by the storms meant that rivers across the UK registered notably to exceptionally high monthly mean flows, and six catchments registered new record December mean flows including the Ythan, Mersey, Derwent (Derbyshire) and Witham (all in records exceeding 40 years, Figure 2).

Rainfall for January 2024 was near average for the UK as a whole, although this masks both spatial and temporal variability. Parts of northern England, northern Wales and eastern Scotland experienced wetter than usual conditions while elsewhere rainfall was less than average. Storm *Henk* (2nd January) brought notable rainfall at the start of the month which, in combination with the exceptionally wet December and associated high flows, led to some notable flow peaks, particularly in southern and central England. The Thames at Kingston recorded the third highest January peak flow since 1976, behind 2014 and 2003, and new record January peak flows were registered on the Warwickshire Avon and the Nottinghamshire Trent in records from 1938 and 1959, respectively. This exceptional start was followed by a dry and calm period mid-month leading to recessions in responsive catchments, before a sequence of three named storms brought more rain towards the end of the month, resulting in a sharp rise in flows across the country. Storms *Isha* and *Jocelyn* brought heavy rain to northern areas of the UK from the 21st/22nd and 23rd/24th, respectively. Additional rain came from Storm *Ingunn* (named by the Norwegian Meteorological Institute) on the 31st, becoming the eighth named storm to impact the UK in just two months, though this storm tracked north of the UK with the worst of the impacts being felt in Norway. More than half of the stations registered above normal January mean flows, as the modest rain that did fall was over catchments that were already saturated.

February 2024 was a very wet month for central and southern areas of the UK. Nationally, the UK received 145% of average February rainfall. Notably, large areas around The Wash and East Anglia received more than three times the average. In contrast to the incredibly wet month for the south, much of Scotland, Northern Ireland and northern England received average rainfall. Monthly river flows strongly reflected this pattern, with rivers across northern England, Scotland and Northern Ireland registering flows in the normal range or above, while flows for the rest of the UK were notably high to exceptionally high, including four catchments that registered their highest February flows on record (including the Stringside, Warwickshire Avon and Brue in records from at least 1966; Figure 2).

Atlantic low-pressure systems continued to bring wet conditions to most of the UK throughout March, with southern and central England particularly affected. This helped to sustain the notably high to exceptionally high river flows across southern

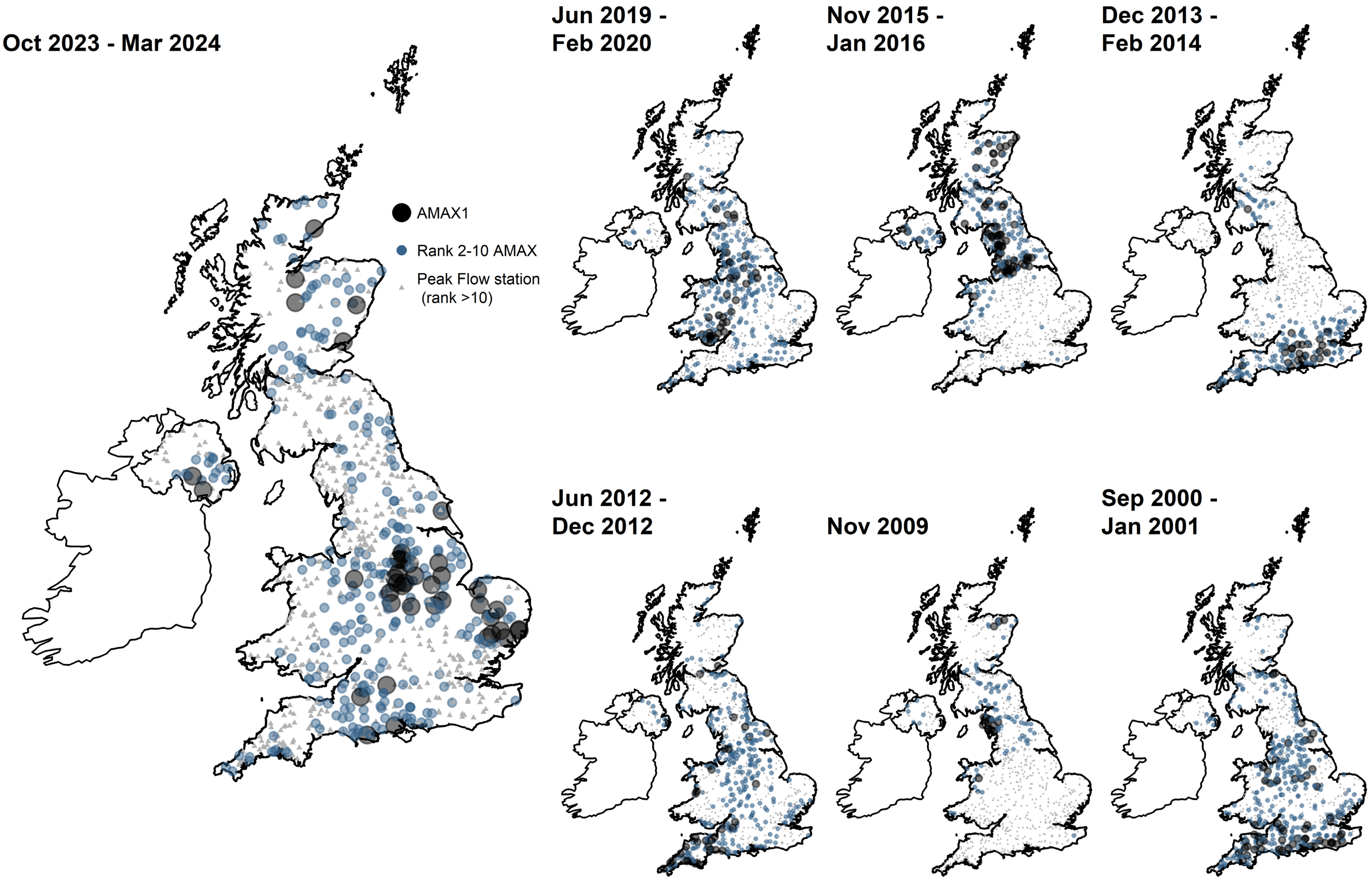

Figure 4. Maps of Annual Maxima (AMAX) flow rankings, showing stations within the NRFA Peak Flow Dataset where the AMAX was the highest observed in the AMAX series (transparent black circles, AMAX1), ranked between second and tenth highest in the series (blue circles), and ranked outside the top 10 (grey triangles) for the winter half year of 2023/2024 alongside a set of notable flood events for comparison.

areas, leading to new March flow records for four rivers in the southwest of England, including the Brue and Kenwyn in records from 1965 and 1969, respectively (Figure 2). All catchments shown on the map across southern England and southern Wales experienced flows exceeding 150% of the March average, with 12 catchments registering flows exceeding 200% of the March average.

The summer of 2024 broadly saw a return to more normal conditions for rivers, except for some slow-responding, groundwater-dominated catchments in southern England (e.g. stations on or near the chalk aquifers in Figure 1a) where flows remained high following the wet winter, ending the summer with above normal flows.

Severity of the flooding

The flooding during the winter of 2023/2024 was notable for both the extent and duration of high flows. Many areas of the UK experienced prolonged periods of exceptionally high flows in the six-month period between October 2023 and March 2024, owing to the compounding effect of a wet summer and the frequency of named storms and associated rainfall events throughout the winter half-year. Large parts of eastern Britain recorded over twice the average rainfall for October, and again in December. This was repeated for central and southern England in February and March, with large areas seeing more than twice the average rainfall in each of these months. The coincidence of exceptional rainfall led to the record-breaking flows seen in Figure 2.

Rainfall anomalies over the winter half-year (October to March) were generally high. Nationally, the UK experienced 126% of average rainfall for this period, the second highest in a record from 1890, only behind the winter of 2013/2014, which also saw a succession of severe storms and widespread flooding (Muchan *et al*., 2015). There was a small geographical gradient in rainfall for the 2023/2024 winter half-year, with northwestern areas generally being slightly drier than southeastern areas. England experienced 149% of the average winter half-year rainfall; Northern Ireland, Wales and Scotland also saw above-average rainfall for the same period. Rainfall for the meteorological winter (December–February) tells a similar story, with the UK receiving 130% of average, and for this shorter period, all regions of the UK saw above-average rainfall totals.

River flows across the UK reflect the pattern in rainfall, with many rivers recording new mean flow records across the meteorological winter (Figure 3). The Ythan, Trent, Stringside, Warwickshire Avon and Brue were among the rivers that saw new mean flow records for the December to February period. Above-average river flows were registered widely across the UK over the three months, with the exception of western Scotland, which registered flows in the normal range. The winter half-year also saw a number of rivers recording record high mean flows, including those listed previously, with the addition of rivers in south Wales (e.g. the Tywi and the Tawe), northwest England (e.g. the Weaver) and Northern Ireland (e.g. the Annacloy). Figure 3 shows the widespread nature of exceptionally high flows throughout the winter. The highest concentration of exceptionally high flows was seen across central England.

Figure 4 shows stations from the NRFA Peak Flow Dataset that recorded annual maxima (AMAX[5]) flows between October 2023 and March 2024 ranking within the top 10 on record. It also shows other notable UK flood events for comparison. The events shown are indicative of notable recent flood events but are not exhaustive, and other recent periods could also be considered (e.g. the floods of summer 2007, Marsh and Hannaford, 2007). AMAX values

[5] https://nrfa.ceh.ac.uk/data/about-data/peak-flow-data/data-types/annual-maximum.

Table 1

Rivers with HIFs ranking in the ten highest for each station and calendar month between October 2023 and March 2024.

Station	River	Start of period of record	Catchment area (km²)	HIF rank Oct	Nov	Dec	Jan	Feb	Mar
205004	Lagan	Aug-1972	492	**1**	**1**	5	–	–	7
205011	Annacloy	Nov-1973	187	**1**	**1**	**2**	–	–	**3**
27041	Derwent	Sep-1973	1568	**3**	**3**	**2**	5	4	–
27009	Ouse	Sep-1969	3315	4	6	6	9	–	–
27021	Don	Jul-1959	1256	**1**	6	4	**2**	6	–
28060	Dover Beck	Mar-1972	69	**1**	4	**2**	**1**	**2**	4
28009	Trent	Oct-1959	7486	**2**	6	6	**2**	9	–
33029	Stringside	Jul-1965	99	**1**	**3**	**3**	**1**	**1**	9
28082	Soar	Aug-1971	184	5	–	5	**2**	**3**	–
39001	Thames	Jan-1883	9948	9	9	–	**3**	10	4
43005	Avon	Feb-1965	324	–	6	–	**2**	4	**1**
52010	Brue	Oct-1965	135	**2**	6	4	**1**	**1**	**1**
42010	Itchen	Oct-1959	360	**3**	**3**	4	6	–	5
42003	Lymington	Oct-1960	99	**1**	**2**	**2**	**1**	**3**	7

HIFs within the top three are highlighted in bold. Stations are ordered from north to south.

in the top 10 were recorded across the UK, in contrast to the more localised high-ranking peak flows of 2009, 2013/2014 and 2015/2016. The number of peak flow stations registering new records in the 2023/2024 event (44 stations out of a total of 734) is comparable to the number seen for the 2019/2020 event (43), but fewer than those in 2015/2016 and 2000/2001 (74 and 61, respectively).

The duration and severity of high flows were analysed further by looking at consecutive months with high-ranking highest instantaneous flows (HIFs). These are the maximum flows recorded each month by gauging stations measuring flow every 15 min. For each gauge, HIFs were ranked against those recorded in the same calendar month, and stations with consecutive months of high-ranking HIFs during the winter half-year were collated (Table 1). For each month from October 2023 to February 2024, the Stringside and Lymington registered HIFs within the top three, and the Yorkshire Derwent registered HIFs in the top five (all in records exceeding 50 years). In each of the three months from January to March 2024, the Brue in southwest England recorded its highest ranking HIF in a record from 1964.

High flows can also be assessed through the analysis of *n*-day flows. These were calculated by averaging the flows over a period of *n* days, finding the maximum for each water year, and ranking the years (excluding overlapping periods); longer *n*-day periods capture longer durations of high flows. Table 2 shows the 23 stations where 2023/2024 maxima ranked in the top five for 14-, 30-, 60- and 90-day periods. Flows for the Whiteadder Water and Stringside ranked as the highest on record for all of the chosen *n*-day periods, both in records exceeding 50 years. The Ythan, Bervie, Coquet, Annacloy, Mersey, Wensum and Brue also registered flows ranking in the top two for all *n*-day periods. Table 2 also highlights the extremity of the duration of high flows, with 13 of the 23 stations registering their highest 90-day maxima on record in 2023/2024, in contrast to only six stations registering their highest 14-day maxima, and seven stations for both the 30- and 60-day periods. Also notable are the records on larger rivers such as the Trent and the Severn, both stations with large catchments (>6800km²) that registered new record high 90-day flows over the winter of 2023/2024, further emphasising the duration and extent of the wet weather. Most catchments where the winter half-year of 2023/2024 recorded the second highest flows were behind 2013/2014, 2015/2016 or 2019/2020, three recent winters that were notable for severe storms that led to widespread flooding (Muchan *et al*., 2015; Barker *et al*., 2016; Sefton *et al*., 2021). In the case of the Don, the highest ranked event for the 14-day period occurred in the winter of 2015/2016 where the value was approximately 23% higher (111.40m^{3}s^{-1}) than the 2023/2024 half year which ranked second. In contrast, 2023/2024 was the highest 90-day flow for the Don, with a value approximately 7% higher than 2019/2020, further emphasising that the importance of this event was in its long duration, rather than the shorter, higher extremes of prior events.

Outflows are quantified as the sum of the flow of all rivers draining the corresponding region (see Marsh *et al*., 2015 for more information). Mean outflows are then found by averaging these values over the specified time period. Mean combined outflows from the English Lowlands, England and England & Wales for the meteorological winter all ranked the second highest in records from 1961. Outflows for the winter half-year were the highest on record for the UK in a series from 1980, and the highest on record for Great Britain and England & Wales, both in series from 1961 (Great Britain shown in Figure 5). Daily outflows for the UK were above average for almost the entire period, with only a few short-lived drops below the mean. The outflows hydrograph from July 2023–June 2024 (Figure 6a) illustrates the consistently high nature of river flows across the UK throughout the winter, although individual peaks of the UK outflows fall short of being record breaking in magnitude. The hydrograph of monthly outflows from the UK (Figure 6b) shows the effect of averaging flows over longer time periods and further emphasises the persistently high flows. Although the detail of the daily outflows is lost, it provides a clearer indication of long-term deviations from average which can be challenging using the daily outflow series. During the winter half-year, outflows from the UK for all months were above the long-term mean (1991–2020) but only October 2023 outflows exceeded the previous record for that month.

Impacts

A chronological breakdown of the flood impacts is presented throughout this section, detailing the spatial footprint and the affected sectors. The impacts of the flooding during the winter 2023/2024 period were spatially widespread, at times affecting large areas of the country concurrently, as well as more localised impacts. The flooding affected multiple sectors, including infrastructure, travel and agriculture, and was also the cause of multiple related fatalities and emergency responses.

The first storm of the season, *Agnes* in late September, impacted Northern Ireland and some parts of Cumbria and southwest Scotland, with disruption to road, air and ferry travel. Heavy rainfall at the start of October caused landslips, which led to disruption and closures on key roads, with one incident on the A83 and A815 in Scotland requiring an HM Coastguard helicopter to airlift ten people to safety (BBC News, 2023b). Scottish farmers reported the loss of several million pounds' worth of veg-

Table 2

Rivers where the n-day periods for the 2023/2024 winter half-year were in the top 5 years for all the non-overlapping periods analysed.

					14-day			30-day			60-day			90-day		
Station ID	River	Start of period of record	Catchment area (km^2)	Mean flow (m^{3}s^{-1})	2023/2024 14-day flow (m^{3}s^{-1})	2023/2024 rank	Year of max	2023/2024 30-day flow (m^{3}s^{-1})	2023/2024 rank	Year of Max	2023/2024 60-day flow (m^{3}s^{-1})	2023/2024 rank	Year of max	2023/2024 90-day flow (m^{3}s^{-1})	2023/2024 rank	Year of max
2001	Helmsdale	Jun-74	551	13.15	61.25	2	2006/2007	**44.73**	**1**	**2023/2024**	36.16	3	2006/2007	32.60	3	2006/2007
10003	Ythan	May-83	523	8.13	48.45	2	2015/2016	**38.98**	**1**	**2023/2024**	29.86	2	2002/2003	**29.19**	**1**	**2023/2024**
11002	Don (Scotland)	Jul-69	787	14.42	90.50	2	2015/2016	65.03	3	2015/2016	48.80	2	2002/2003	**49.33**	**1**	**2023/2024**
13001	Bervie	Sep-79	123	2.22	19.84	2	2022/2023	**14.87**	**1**	**2023/2024**	**11.40**	**1**	**2023/2024**	**11.44**	**1**	**2023/2024**
21022	Whiteadder Water	Sep-69	503	6.70	**52.13**	**1**	**2023/2024**	**37.93**	**1**	**2023/2024**	**33.15**	**1**	**2023/2024**	**27.29**	**1**	**2023/2024**
22001	Coquet	Oct-63	570	8.75	78.03	2	2015/2016	51.88	2	2015/2016	40.91	2	2015/2016	33.79	2	2015/2016
205011	Annacloy	Nov-73	187	3.60	**29.98**	**1**	**2023/2024**	19.01	2	2002/2003	**15.46**	**1**	**2023/2024**	12.77	2	2002/2003
71001	Ribble	May-66	1145	7.51	175.06	4	2015/2016	138.46	4	2015/2016	106.89	5	2015/2016	93.63	4	2015/2016
27021	Don (Yorkshire)	Jul-59	1256	16.51	101.19	3	2019/2020	75.13	4	2019/2020	60.99	3	2019/2020	**59.13**	**1**	**2023/2024**
69007	Mersey (Ashton)	May-76	660	13.99	68.24	4	2020/2021	51.89	3	2020/2021	40.22	3	2000/2001	36.83	2	2000/2001
29003	Lud	Jul-68	55	0.45	1.75	4	2019/2020	1.54	4	2019/2020	1.38	3	2019/2020	1.38	2	2019/2020
28043	Derwent	Nov-68	335	6.44	44.41	4	1968/1969	34.10	3	1968/1969	24.94	3	1968/1969	23.53	2	1968/1969
28060	Dover Beck	Mar-72	69	0.18	**1.79**	**1**	**2023/2024**	**1.58**	**1**	**2023/2024**	**1.15**	**1**	**2023/2024**	**1.12**	**1**	**2023/2024**
30001	Witham	May-59	298	1.90	11.88	2	1976/1977	9.95	3	1976/1977	8.17	3	2020/1921	**7.70**	**1**	**2023/2024**
28009	Trent	Oct-58	7486	85.88	456.51	3	2000/2001	376.64	3	1976/1977	283.21	4	2000/2001	**278.15**	**1**	**2023/2024**
34011	Wensum	May-66	162	0.86	3.67	2	1976/1977	3.11	2	1976/1977	**2.65**	**1**	**2023/2024**	**2.43**	**1**	**2023/2024**
33029	Stringside	Jul-65	99	0.51	**3.02**	**1**	**2023/2024**	**2.59**	**1**	**2023/2024**	**2.14**	**1**	**2023/2024**	**2.14**	**1**	**2023/2024**
33034	Little Ouse	Apr-68	689	3.69	16.81	4	2000/2001	14.65	3	2000/2001	11.89	5	2000/2001	11.58	4	2000/2001
54002	Avon (Warwickshire)	Dec-36	2210	15.94	118.99	3	1946/1947	**85.93**	**1**	**2023/2024**	70.29	3	2013/2014	65.26	2	2012/2013
54032	Severn	Oct-70	6850	88.34	425.57	4	2013/2014	363.63	3	2013/2014	303.55	4	2013/2014	**302.45**	**1**	**2023/2024**
52010	Brue	Oct-64	135	1.95	**12.27**	**1**	**2023/2024**	9.97	2	2013/2014	8.06	2	2013/2014	**7.78**	**1**	**2023/2024**
42003	Lymington	Oct-69	99	1.14	**11.00**	**1**	**2023/2024**	7.29	2	2013/2014	5.89	3	2013/2014	5.07	4	1960/1961

The ranks are relative to all water years for each station. Stations are ordered from north to south. Rank 1 *n*-day maxima in 2023/2024 are highlighted in bold.

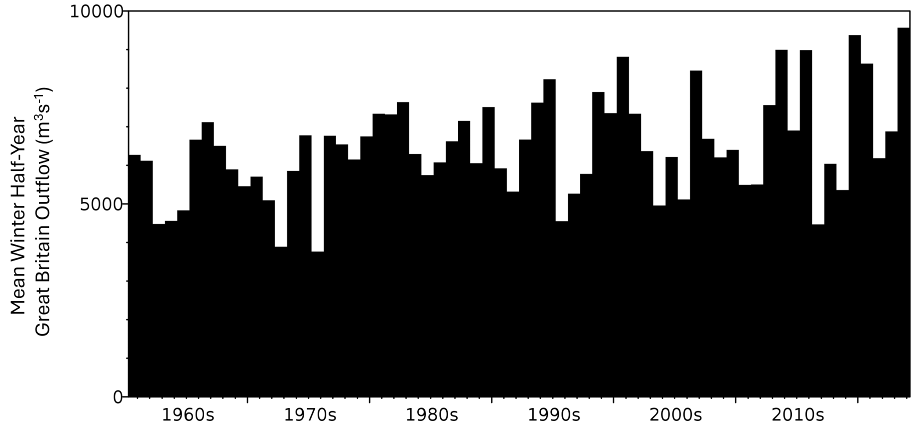

Figure 5. Mean winter half-year outflows from Great Britain from 1960/1961 to 2023/2024.

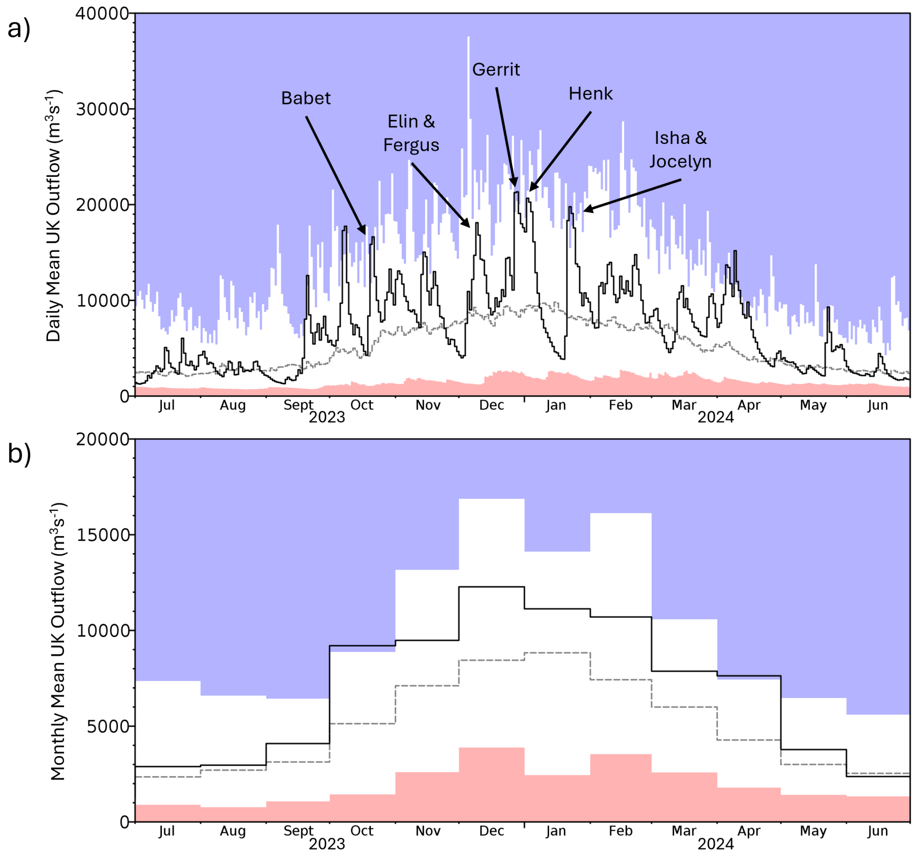

Figure 6. Daily mean (a) and monthly mean (b) outflows from the UK for July 2023 to June 2024 (solid black lines) compared to the long-term mean (grey dashed line, averaged over 1991–2020) and the maxima and minima on record (blue and red shaded areas, respectively, both from 1980–2022). Notable storm event peaks are highlighted in the daily mean outflows hydrograph.

etable crops due to the resulting flooding (BBC News, 2023c).

Storm *Babet* (18th October) was responsible for at least seven fatalities and prompted emergency responses in many areas: residents close to the River South Esk in Scotland were urged to evacuate by HM Coastguard (HM Coastguard, 2024); people were rescued from their homes near Wrexham; and properties were also evacuated in Angus, Nottinghamshire and South Yorkshire. A reported 2146 properties were flooded during Storm *Babet*, over 1000 of which were located across Yorkshire, East Midlands and Humber, and the Environment Agency estimated that nearly 100 000 properties were protected from flooding (Environment Agency, 2023; Turner, 2024). There was widespread travel disruption due to the storm, with many rail services across Scotland and eastern England cancelled or disrupted (Kendon, 2023). Furthermore, the heavy rain across southeast Northern Ireland led to the flooding of more than 600 properties in late October and early November (Department for Infrastructure, 2024). Travel in Northern Ireland was disrupted as roads were inundated, and parts of the A2 Antrim coast road were closed due to a landside (BBC News, 2023a).

Storm *Ciarán* (1st/2nd November) mainly affected those in the Channel Islands with strong winds, although it also caused motorway and rail disruption due to localised flooding in East Anglia and southwest England. Continuing unsettled weather led to flooding in southern England, including groundwater flooding in Dorset (Met Office, 2023). Storm *Debi* (13th November) brought strong winds and heavy rain to Northern Ireland, north Wales and northwest England. *Debi*'s severe impacts were mainly associated with strong winds, rather than particularly notable rainfall totals. The combined impacts of Storms *Babet*, *Ciarán* and *Debi* are estimated to have cost insurers £560 million (ABI, 2023).

The remainder of November passed with minimal impacts, before Storms *Elin* and *Fergus* arrived in quick succession on the 9th and 10th of December. The duo's main impacts were felt in the Republic of Ireland, but they also caused localised flooding in the UK due to the wet antecedent conditions. Rail networks were disrupted in Yorkshire and Cornwall due to heavy flooding (BBC News, 2023d), and flooded roads were reported in south London. Further heavy rain in mid-December affected several major roads in Scotland (Met Office, 2024a).

The calendar year ended with a period of unsettled weather as Storms *Pia* and *Gerrit* passed over the UK. Storm *Pia* (21st December) caused widespread road, rail and flight travel disruption and power outages due to strong winds. Storm *Gerrit* (27th/28th December) followed with further power supply issues, rail disruption due to flooding and landslips in Scotland, and road closures in Scotland, Northern Ireland, Yorkshire and south Wales (Kendon, 2024a; Met Office, 2024a).

2024 started with heavy rainfall associated with Storm *Henk* (2nd January), which was particularly impactful for regions that had already experienced a wet autumn and early winter – thousands of acres of farmland were left submerged by floodwaters, with many other fields too wet for planting (BBC News, 2024b). The impacts from Storm *Henk* were largely concentrated in the East Midlands, where Nottingham County Council declared a major incident along the River Trent with the flooding of over 100 properties (BBC News, 2024c). Hundreds of people were told to evacuate properties along the River Nene, and more than 70 properties were flooded in Lincolnshire (BBC News, 2024a). Further properties were flooded in York when the River Ouse overtopped; properties were evacuated in Gloucester, and a canal burst its banks in east London (BBC News, 2024c; Met Office, 2024c). An estimated 2000 properties were flooded across Britain due to Storm *Henk* (Environment Agency, 2024).

Storm *Isha* (21st /22nd January) caused widespread impacts in relation to the strong winds – including two fatalities in Northern Ireland and Scotland – while flood impacts were limited to parts of Cumbria and north Wales (Kendon, 2024b). Storm *Jocelyn* (23rd/24th January) followed with heavy rain and further strong winds, causing power supply issues in England and Scotland. Although Storm *Jocelyn* was not expected to be as severe as Storm *Isha*, the quick succession led to further impacts and delayed recovery (BBC News, 2024d).

Heavy rainfall caused rail and road closures in northern and western Scotland over the first five days of February (Met Office, 2024b). The 6th–8th saw flooding in southern England causing further rail line closures and disruption, followed by road closures due to flooding in Essex, Cambridgeshire and Peterborough on the 9th. Widespread rainfall for southern UK mid-month brought further flooding and associated impacts; roads were closed in Suffolk and Essex whilst floodwaters disrupted rail services in the East Midlands, West Midlands and western England (Met Office, 2024b; BBC News, 2024e).

The persistently wet conditions throughout the winter half-year in the UK impacted multiple sectors and caused particular issues for agriculture, for example one farmer in Staffordshire was forced to write off £15 000 worth of crops (BBC News, 2024f). The extended period of wetness from October to March, with the rapid succession of storms, rainfall and associated flooding events, compounded impacts and in some cases limited communities from fully recovering before the next event.

Is this event part of a trend?

Recent years have seen other notable national scale flood events in the winter half-year (e.g. 2015/2016 and 2019/2020; Barker *et al*., 2016; Sefton *et al*., 2021). Here, an up-to-date trend analysis on winter half-year mean river flows provides context on past river flow variability. Observed trends for a wide set of NRFA stations with less than 10% of missing data between 1965 and 2024 were analysed over the fixed period 1965–2024. Trends were compared with stations in the UK Benchmark Network (UKBN2), consisting of near-natural catchments that are relatively free from human influences (Harrigan *et al*., 2018a). The significance of the trends is estimated using the Mann-Kendall trend test at a 5% significance level, following standard trend analysis methodologies for the UK. The same methodology has been used to assess whether recent UK floods and droughts are part of a robust trend (e.g. details in Hannaford *et al*., 2021; Harrigan *et al*., 2018a). The analysis of winter half-year mean river flows quantifies changes in long-term flows but does not provide direct evidence for changes in flood impacts.

Figure 7 shows a tendency for increasing winter half-year mean river flows across the UK. Positive trends were found for most of these catchments (90%), with statistically significant positive trends for 33% of catchments, particularly in northern and western areas. This includes most catchments in West and East Scotland (75% and 70%, respectively) and more than half of the catchments in the northwest England and north Wales regions (see Figure 1b for a map of the hydroclimate regions). Negative trends are seen for some catchments in England (9% of all catchments) and are mostly concentrated within the Severn Trent, south-east (England) and Anglian regions. River flow trends are highly sensitive to human influences such as abstractions or land use change. In near-natural UKBN2 catchments (Figure 7b), positive trends dominate with statistically significant increases in the north and west and in parts of Wales. Trends at UKBN2 sites in England show both increases and decreases, including some stronger reductions at sites in the Anglian region but none are statistically significant.

Long river flow records are required to fully appraise the changing nature of flood risk. Multi-temporal analysis placing short-term fixed period trends in wider historical context often shows that trends are highly sensitive to the period of analysis (Hannaford *et al*., 2021). However, most UK gauging stations were installed in the 1960s/1970s (Dixon *et al*., 2013), precluding the assessment of trends over longer timescales. Daily river flow reconstructions using a catchment hydrological model driven by high-resolution precipitation and potential evapotranspiration input for 303 UK catchments are available for the 1891–2015 period (Smith *et al*., 2019; available from Smith *et al*., 2018). While model-based reconstructions are limited by input uncertainties (e.g. lower rain gauge network density before the 1960s; Hollis *et al*., 2019),

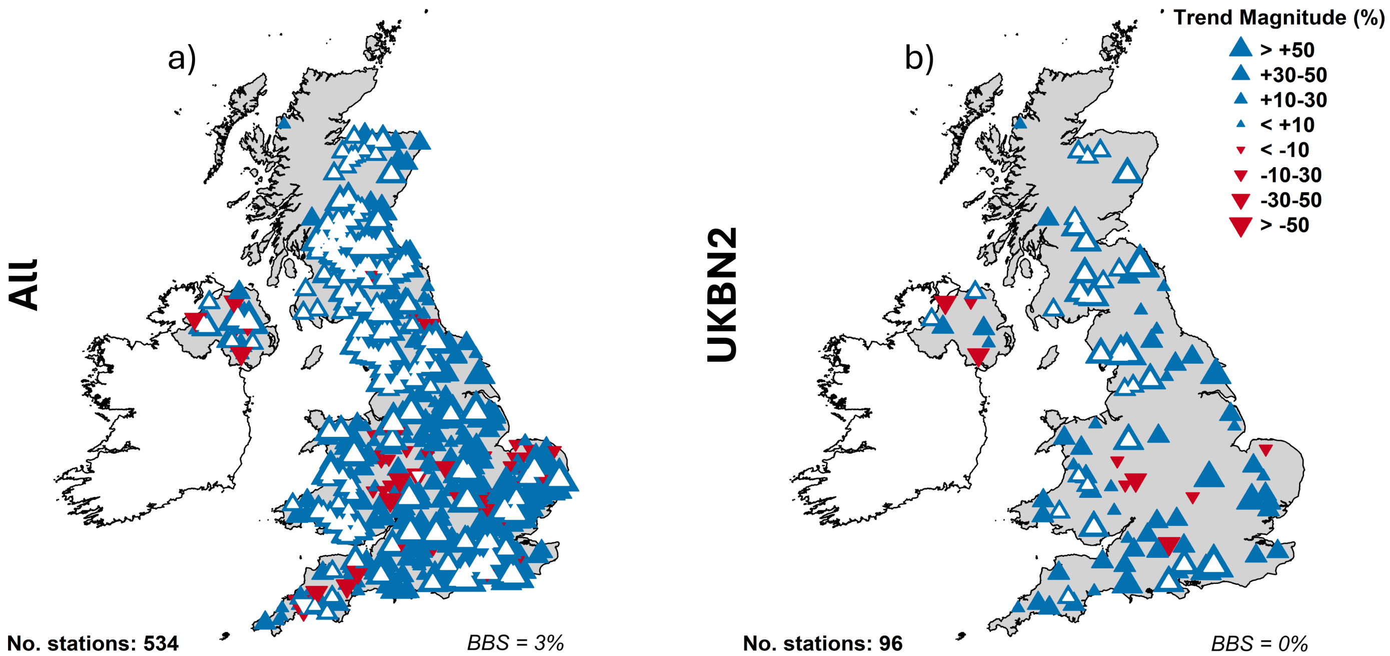

Figure 7. Trend analysis of winter half-year mean river flows for the period 1965–2024 for (a) all 534 NRFA catchments with available data over this period and (b) near-natural catchments in the UK Benchmark Network (UKBN2). Trend magnitude is shown using the size of the symbols, and expressed as percentage change. White triangles denote statistically significant trends at a 5% significance level.

and hydrological model uncertainties, they are the only currently available estimate of long-term river flow variability at the national scale. Smith *et al*. (2019) showed that model performance was generally good over the observational period, with reconstructions reliably capturing the timing and magnitude of observed hydrological extremes (as detailed in Smith *et al*., 2019). However, model performance was poorer in groundwater-dominated catchments and those heavily influenced by artificial water management (e.g. dams and reservoirs). Formal trend analyses using the reconstructions were previously applied to hydrological droughts (Hannaford *et al*., 2025), but similar analyses for high flows have not been carried out. Figure 8 shows multi-temporal trends in winter half-year river flows across successive overlapping periods of at least 30 years between 1891 and 2015 for six example catchments across Great Britain using these reconstructed series, following established multi-temporal hydrological trend visualisation style for the UK (e.g. Hannaford *et al*., 2021). For catchments in the north/west (e.g. Cree, Allan Water and Ellen) and Wales (e.g. Cynon), statistically significant increases in winter half-year river flows are found when analyses start from the early 20th century and end in 2015. Earlier end periods (e.g. in the 1960s and 1970s) show strong reductions, suggesting past flood-poor or flood-rich decades (Figure 8). For catchments in the south and east (e.g. Lambourn and Lud), negative trends in winter half-year flows are found when starting from the early 20th century, but statistically significant trends are rare, although there is a positive trend in recent decades starting from the 1960s.

In summary, the 2023/2024 event is part of a large-scale pattern of increasing winter half-year river flows across large parts of the UK, with particularly strong statistically significant trends found in near-natural catchments with limited artificial influences in northern and western areas. Formal probabilistic climate change attribution of the high rainfall and storminess over the winter half-year confirm that an anthropogenic climate change component is apparent (Clarke *et al*., 2024; Kew *et al*., 2024). This is consistent with Chan *et al*. (2025), who

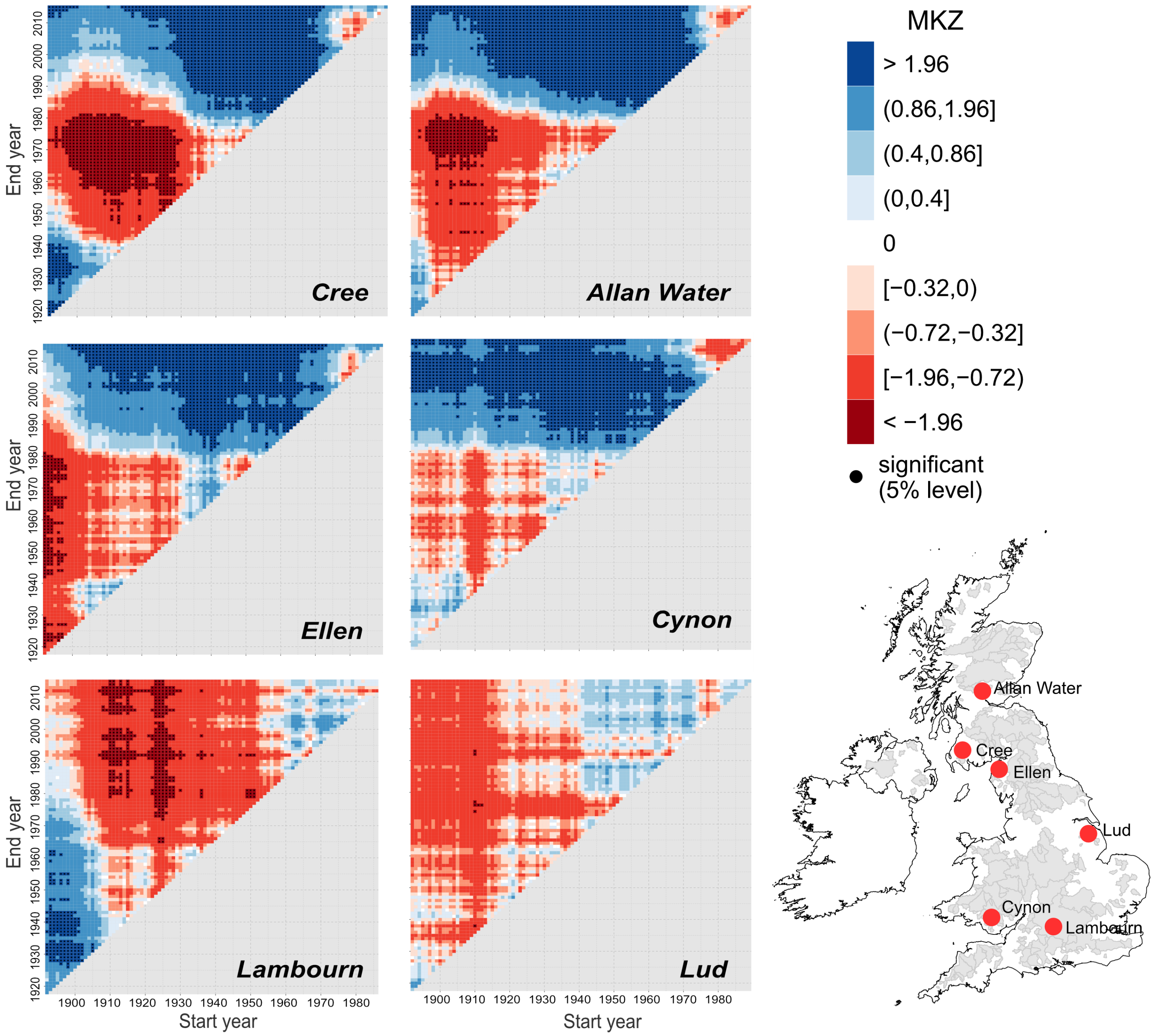

Figure 8. Multi-temporal trend analysis applied to time series of winter half-year mean river flows for six example long reconstructed records for all overlapping periods of at least 30 years between 1891 and 2015. The x-axis denotes the start year and the y-axis the end year, with each grid cell showing the MKZ trend statistic calculated over the given combination of start and end years. The colour scale indicates the values of the Mann-Kendell trend test Z statistic (blue = positive, red = negative), with cells with dots denoting statistically significant trends corresponding to the extremes of the colour scale. The inset map shows the approximate location of the outlets of the six case study catchments.

further found that events driven by similar atmospheric circulation patterns to the winter half-year 2023/2024 have become warmer and wetter with higher river flows across the British and Irish Isles.

Concluding remarks

The winter half-year of 2023/2024 was notable for the long-term and widespread nature of high river flows, and this was compounded by the preceding wet summer, placing it in contrast to other recent notable events, such as 2015/2016, which was characterised by higher but shorter-lived peaks in river flows (Barker *et al*., 2016). A succession of named storms and additional heavy rainfall events was responsible for the pattern seen in river flows, with little time between low-pressure systems for rivers to recede, leading to exceptionally high monthly mean flows for consecutive months. The compound effects of these storms led to the persistent inundation of flood plains and impacted agriculture and resulted in the flooding of many properties.

There is an increasing trend in mean winter half-year river flows across the UK over the past few decades, with positive trends being found for many catchments, especially in northern and western areas, where trends are statistically significant and spatially coherent. Trends continue to be present when taking a subset of catchments that are near-natural. This indicates, at the broad national scale, that patterns are indicative of a climate-driven trend, rather than land or water management, although further work is needed to fully discern the role of climate and catchment drivers at finer regional and catchment scales.

This is consistent with climate projections showing further increases in the severity of high flows into the future as a result of climate change (Kay *et al*., 2021; Lane and Kay, 2021). Improving understanding of the current risk of plausible worst-case extreme rainfall and floods (e.g. Thompson *et al*., 2017) and the changing nature of flood events with large spatial footprints (e.g. Griffin *et al*., 2024) and long durations remains crucial for informing management of future flood risk and response.

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Data availability statement

The data used in this study are all available from the sources highlighted in the introduction and corresponding URLs highlighted in the footnotes. Additionally, data can be supplied by the corresponding author upon request. Observed river flow trends across UK catchments can be explored through an interactive data portal (https://connect-apps.ceh.ac.uk/river-flow-trends-explorer/).

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