The winter storms of 2013/2014 in the UK: hydrological responses and impacts

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Introduction

Throughout the winter of 2013/2014, a succession of vigorous low pressure systems crossed the UK. This resulted in the wettest winter on record for the UK (since records began in 1910), by a considerable margin, and the stormiest for the UK and Ireland (Matthews *et al*., 2014). The persistent heavy rainfall, combined with strong winds, high tides and storm surge conditions, severely impacted many parts of the country. The winter was distinctive for the occurrence of multiple types of flooding. Pluvial, fluvial, groundwater and coastal flooding all affected the UK, sometimes simultaneously, although the relative importance of these sources of flooding varied geographically and over the course of the winter. The winter was also notable for the exceptional duration of flooding and the high profile that the severe weather impacts commanded. From late December until late February, flooding was at the forefront of the media spotlight and received a high level of public and political attention.

This paper outlines the hydrological aspects of the 2013/2014 winter flooding in the UK, as well as the impacts. The episode is considered in a long-term historical context and wider issues raised by the flood events are discussed briefly. Companion papers focus on the meteorological characteristics (Kendon and McCarthy, 2015) and coastal dimensions (Sibley *et al*., 2015) of the winter storms. Taken together, these papers provide a comprehensive overview of the winter weather patterns and their impacts on the UK.

The National Hydrological Monitoring Programme (NHMP) forms the source of much of the material discussed in this paper. The NHMP collates data for 104 index river flow gauging stations and 37 index groundwater boreholes in the UK, and produces monthly Hydrological Summaries (http://www.ceh.ac.uk/data/nrfa/nhmp/monthly_hs.html). The data submitted to the NHMP are provisional, and therefore any records mentioned in this paper may be subject to change. In addition, this paper refers to total outflows for Great Britain and its constituent countries (as featured routinely in the monthly summaries), calculated using a method described in Marsh and Dixon (2012).

River flows

At the end of November 2013, flows in most rivers across the UK were declining and runoff rates fell well below the seasonal average by month-end. Flows continued to recede in early December, with some rivers in England and Wales approaching their period-of-record minimum for the time of year. These recessions, however, were interrupted by sharp river flow responses, triggered by the onset of the storms in mid-December. As a result of intense rainfall on the 23rd, the wettest day of the month, new December daily flow maxima were registered at five index stations as a severe flood episode unfolded in parts of southeast England. Flows on the Medway (Figure 1(a)) were the highest on record (from 1957), exemplifying the rapid response of many rivers draining impermeable catchments. The unprecedented December rainfall recorded in Scotland (Kendon and McCarthy, 2015) resulted in high spate conditions across much of the country. Despite a high prevalence of fluvial and tidal flood warnings, impacts were relatively localised (e.g. evacuations in Dumfries and Galloway as the Nith recorded its highest December flow in a series from 1957). In contrast, parts of the Midlands, Yorkshire and East Anglia were substantially drier during December. Correspondingly, some rivers in these regions experienced below average flows for the time of year, with the Lud in Lincolnshire recording only a third of the average December flow.

During the last week of December, as larger rivers responded to the persistent heavy rainfall, floodplain inundations became widespread and overall outflows from Great Britain approached their previous maximum for the time of year. With further rain falling on already saturated ground, flooding continued into the New Year. Several index rivers across southern England established new January runoff maxima, with remarkable increases in flows in many groundwater-fed rivers across the Chalk outcrop (e.g. Figure 1(b)). Substantial increases in river flow were also witnessed away from southern England – many rivers in central and eastern England recorded above average flows every day in January, and the Trent recorded twice the monthly average flow. Conversely, after the wettest December on record in Scotland, some rivers in the far northwest (e.g. Naver, Ewe and Carron) recorded below average flows on most days in January. Elsewhere, by late January, the exceptional accumulated rainfall totals resulted in extensive inundation of floodplains and other low-lying areas. The Somerset Levels and Moors were particularly badly affected as floodwaters inundated an estimated 6500ha of land, with drainage hampered by high tides.

By February, there had been little respite in the storms since mid-December. Several major storms early in the month brought further increases in river flow, and floodplain inundations remained widespread. The risk of flooding extended across much of the UK, and for England and Wales flood warnings totalled around 500 (embracing the severe warning, warning, and alert categories) early in the month. Flows continued to rise in the UK's larger rivers (e.g. Figure 1(c,d)): the Thames peak was the highest since November 1974, leading to major flooding in some middle and lower reaches, and flows on the Severn (at Bewdley) exceeded those recorded in the summer floods of 2007. Northern Ireland recorded twice the average February rainfall (Kendon and McCarthy, 2015) and new monthly flow records were established on five of the seven index rivers. Average flows for February were the highest on record for 18 index catchments across central and southern England, including several groundwater-fed rivers as a result of the volume of aquifer recharge.

With nearly twice the average rainfall, February concluded the wettest winter on record for the UK (Kendon and McCarthy,

RMetS Royal Meteorological Society

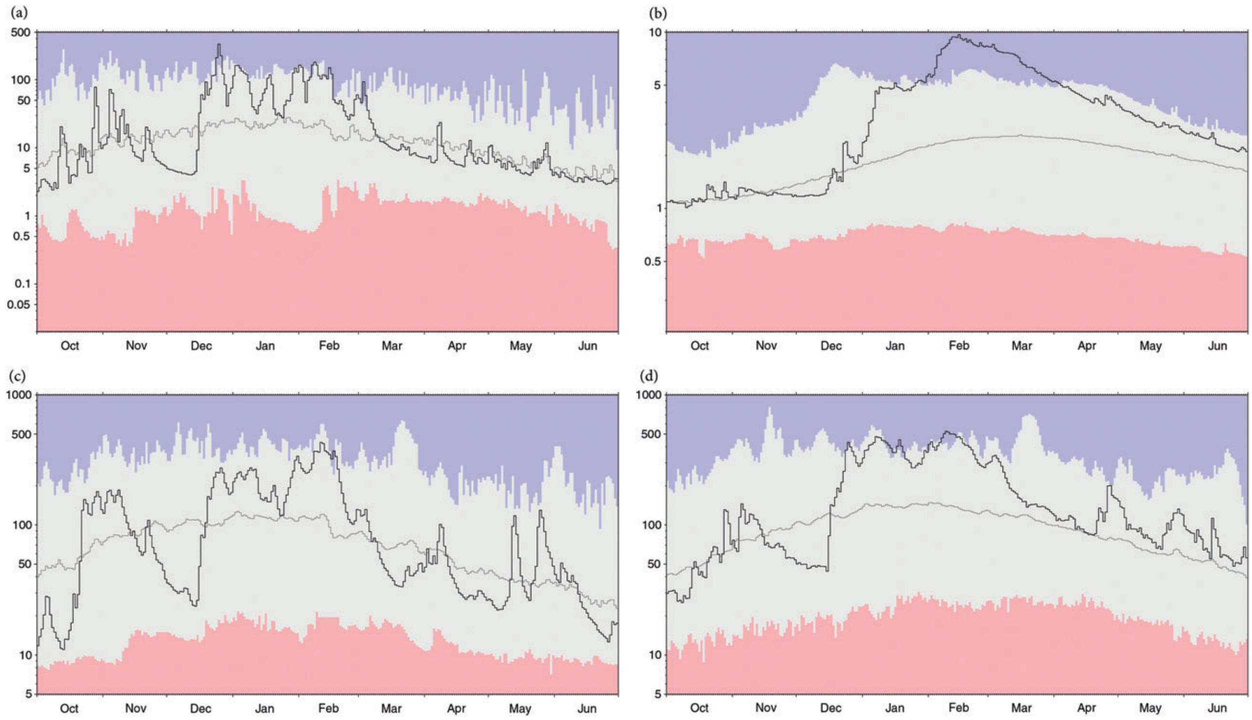

Figure 1. Daily river flows (m^{3}s^{-1}) for the period October 2013 to June 2014. The long-term average is shown by the grey line. The blue and red envelopes show the highest and lowest flows on record respectively. Flows on the y-axis are logarithmic. (a) Medway at Teston/East Farleigh, (b) Lambourn at Shaw, (c) Severn at Bewdley, (d) Thames at Kingston.

2015). Correspondingly, a substantial majority of index rivers, both in responsive and slowly responding catchments, eclipsed their previous winter runoff records (Figure 2). For Great Britain as a whole, the previous average winter runoff was exceeded by a considerable margin (Figure 3). Despite this sustained runoff, few significant peak flow records were attained during the winter of 2013/2014[1] and new period-of-record maximum flows were registered at only a handful of index stations. In some responsive catchments in southeast England, the December peak flows were notable. New period-of-record maximum flows were established for the Medway in Kent and Mole in Surrey, although in the latter case the Kinnersley Manor record begins in 1972 and the 1968 flood was greater at other stations in this catchment. In permeable catchments across southern England, new maxima were registered in February, for example on the Coln, Itchen and Lambourn. The winter was more notable for the duration of high flows and floodplain inundation, demonstrated by flow patterns on the Thames, where at Kingston flows exceeded 250m^{3}s^{-1} for 76 consecutive days[2] (Figure 1(d)), more than twice as many as any previous period in the record from 1883.

[1]It should be noted that this is based on the 104 index catchments. More records may have been established across the wider gauging station network.

[2]The threshold of 250m^{3}s^{-1} corresponds to the flow at which spilling would have occurred in the Kingston reach before the channel reprofiling that took place as a result of the 1947 flood.

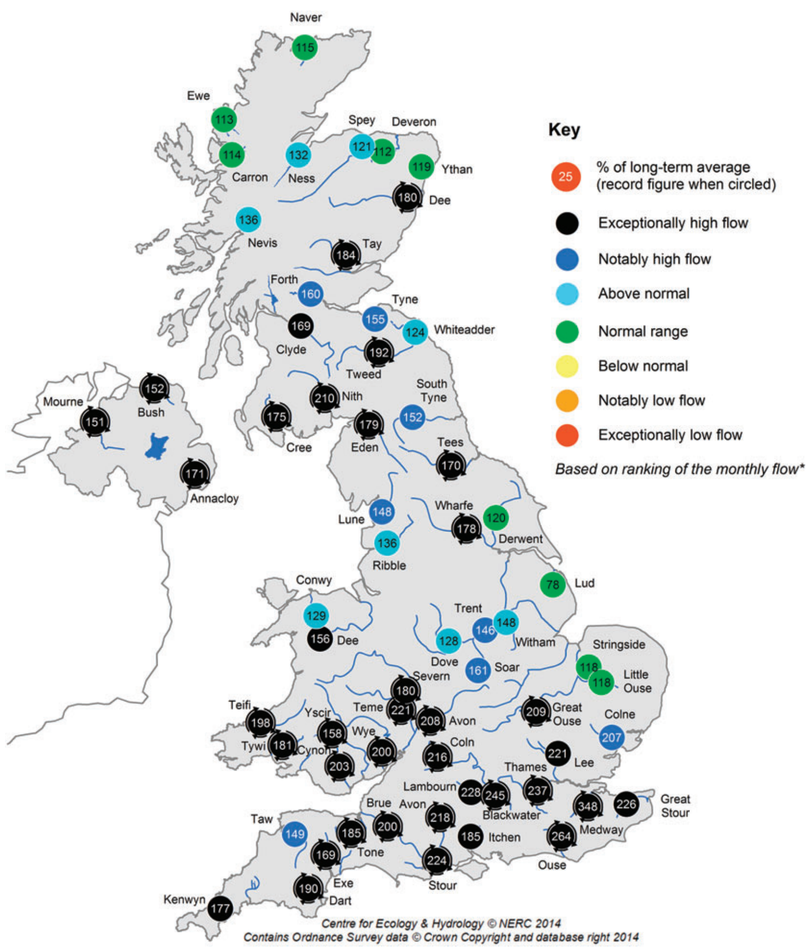

*Figure 2. River-flow accumulation map for December 2013 to February 2014. Flows are expressed as a percentage of long-term average flows. Note: new period-of-record maxima are circled with arrows. *Comparisons based on percentage flows alone can be misleading. A given percentage flow can represent extreme drought conditions in permeable catchments where flow patterns are relatively stable but be well within the normal range in impermeable catchments where the natural variation in flows is much greater.*

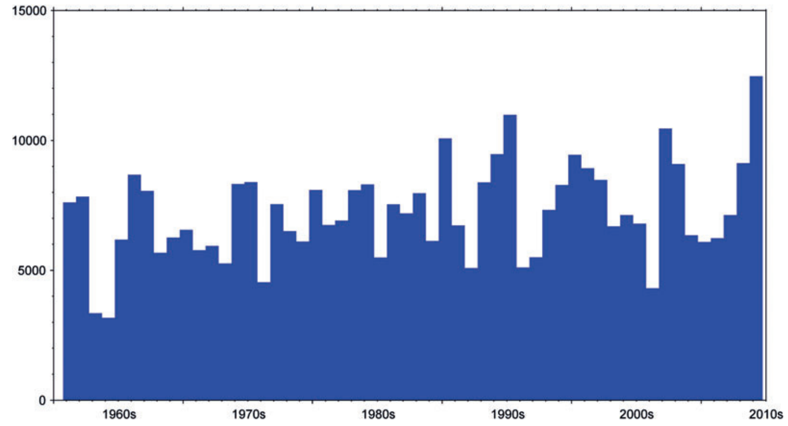

Figure 3. Average winter outflows (m^3s^{-1}) for Great Britain 1961–2013.

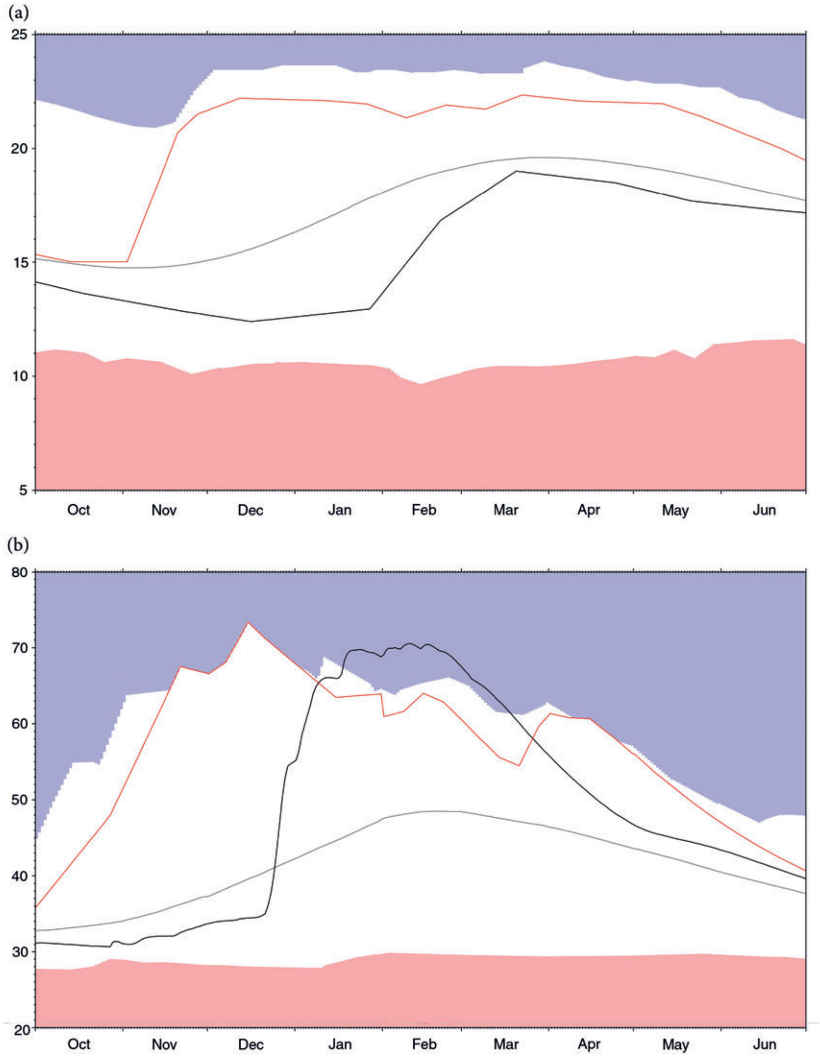

Figure 4. Groundwater levels (m above Ordnance Datum) in two Chalk boreholes for the period October 2013 to June 2014 (black) and October 2000 to June 2001 (red). (a) Dalton Holme (Humberside), (b) Compton House (West Sussex). The long-term average is shown by the grey line. The blue and red envelopes show the highest and lowest levels on record respectively.

The last major storm occurred in mid-February, and the following dry spell allowed river levels to recede. In the second week of March, outflows from Great Britain fell below average for the first time since the onset of the storms in mid-December, bringing an end to the immediate risk of flooding in many areas. A continuation of seasonally exceptional flows in many spring-fed streams across southern England, however, meant that some flood alerts on rivers draining Chalk catchments were to remain in place until the early summer.

Groundwater

At the end of November 2013, groundwater levels across the country were generally in the normal range, with levels still declining in some boreholes in Yorkshire and parts of the Chilterns. A month later, however, steep recoveries had been triggered in southern England. Rises of over 25m were recorded in the Chalk index wells at West Woodyates Manor (Dorset) and Chilgrove House (West Sussex) during December, and some groundwater flood alerts were issued on Boxing Day. In contrast, levels remained low or close to the seasonal average in the slower responding Chalk in eastern England. This contrast continued into January, where levels in the Chalk of East Anglia, Lincolnshire and Yorkshire remained in the normal range or slightly below average (e.g. Figure 4(a)), while six index boreholes in the southern Chalk recorded new monthly maxima (Figure 5). The Chilgrove House borehole overflowed (one of around six similar artesian episodes in a record dating back to 1836), and Tilshead (Wiltshire) was also artesian in January and February. Groundwater also emerged above the ground in bournes, e.g. South Winterbourne (Dorset), Aldbourne (Berkshire), Caterham (Surrey) and Nailbourne (Kent).

In February, levels fell at all six of the Chalk index boreholes that registered new maxima in the previous month. However, three of these (plus an additional borehole in Kent) again recorded monthly maxima in February. After two months of contrasting behaviour, levels in the slower responding eastern Chalk began to rise steeply in February, although they still remained at or near average. Further north, where the rainfall had not been exceptional, levels also started to rise, although due to the notably low starting point at Dalton Holme (East Yorkshire), levels were below average throughout the winter and remained so until July 2014 (Figure 4(a)). Into the spring, levels fell by more than 20m from February to April at West Woodyates Manor, Compton House and Chilgrove House (Figure 4(b)). In contrast, water levels peaked from mid-March onwards in the Chilterns, and remained exceptionally high in the North Downs. By the end of April, levels in the Chalk were consistently falling from Dorset to Kent, and had mainly returned to within the normal range. Although the falling levels meant that by the end of April most of the flood alerts had been removed, areas of Buckinghamshire, the Berkshire–Oxfordshire border and Hampshire were still affected by groundwater flooding. Here, groundwater flood alerts remained in place until late May or early June; however with much of the water still to drain away, sewers continued to surcharge, with a few basements still being pumped and some minor roads remaining submerged in mid-July.

Although the majority of high groundwater levels during the winter of 2013/2014 were recorded in the Chalk, other aquifers in

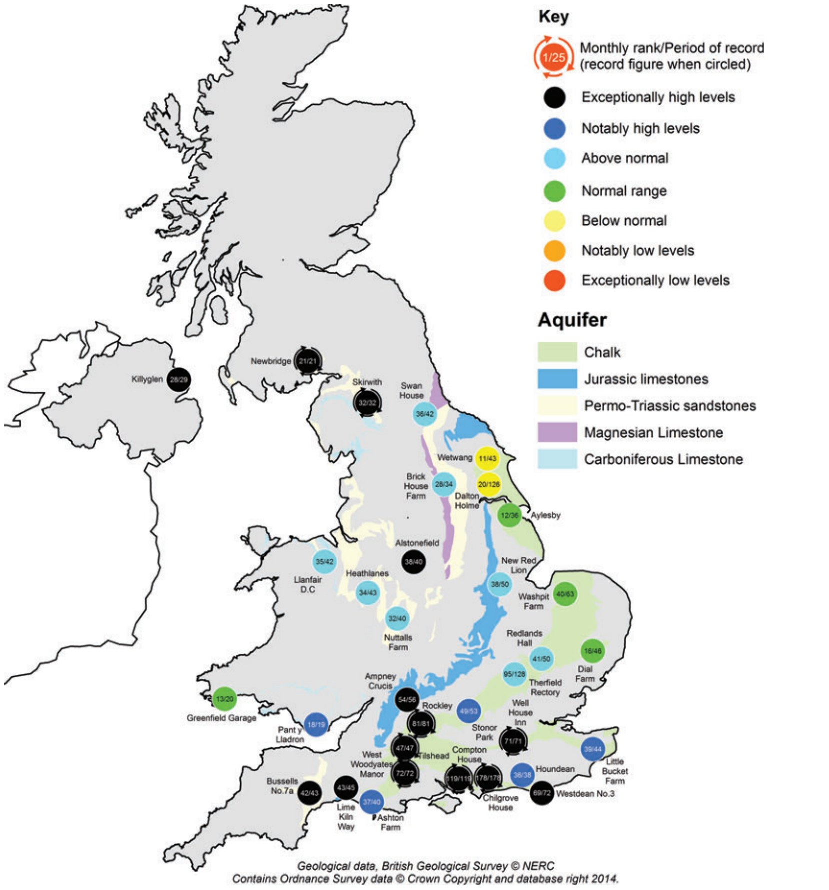

Figure 5. Rank of groundwater levels at the end of January 2014 (current rank/number of years of record). Note: new period-of-record maxima are circled with arrows.

the UK also experienced periods of notably high water levels. In the Permo-Triassic sandstones, levels became exceptionally high in December/January in southwest and northwest England and were still high at the end of August 2014. Record monthly maxima were established in the northwest at Skirwith (Cumbria) for 8 consecutive months (January–August 2014) and Newbridge (Dumfries and Galloway) for 6 (January–June 2014). No groundwater flooding was reported however, due to the high storage coefficient of the aquifer and hence small overall rises in water level – Nuttalls Farm (West Midlands) rose by only 1.1m between the end of January and the end of June, but for the last four of these months, levels were exceptionally high. New monthly maximum levels were recorded in the Upper Greensand at Lime Kiln Way (Somerset) for a sustained period (February–September 2014) and in the Lower Greensand, between Haslemere and Godalming (Surrey), groundwater flood alerts were issued on 9 January and remained in force until 12 March; however little flooding occurred.

Some flooding occurred from the Jurassic (Great Oolite) limestones of the Cotswolds (e.g. Barnsley, Gloucestershire and Blenheim Park, Oxfordshire) and exceptional levels were recorded in January in the Ampney Crucis borehole (Gloucestershire). However, any groundwater flooding was of short duration and affected only a small number of properties. In the responsive Carboniferous limestone, levels at Alstonefield (Peak District) were exceptional in January in response to the persistent rainfall. Levels in the Magnesian Limestone of northeast England remained high throughout 2013, a legacy of the exceptional 2012 rainfall and therefore the 2013/2014 winter recharge started from a high baseline. As a result, levels were above average for the time of year throughout the winter at Swan House (Durham), reaching exceptionally high levels in June and July 2014.

Impacts and responses

A defining characteristic of the winter was the spatial extent and persistence of floodplain inundations, rather than the magnitude of peak river levels. Accordingly, this shaped the nature of the flood impacts. In total, more than 7000 properties were flooded during the winter (Environment Agency, 2014), comparable with the 2012 floods (Parry *et al*., 2013) but significantly less than the 55 000 impacted properties during the summer 2007 floods (Marsh and Hannaford, 2008). Comparisons of flood events based on impacts are made problematic by a number of factors, including the role of flood defences, but broadly the 2013/2014 floods were not outside the range of recent nationally significant flood events in terms of properties flooded. However, the prolonged nature of the flooding ensured that its wider impacts were substantial.

A particular focus of flood impacts throughout the winter was the Somerset Levels and Moors, where a major incident[3] was declared on the 25 January following several weeks of inundation. The prolonged flooding isolated some communities for 4–6 weeks, flooded 150–200 homes (according to the Environment Agency) and prompted a major emergency response, including efforts to pump away the floodwater. By early February, pumps were removing 1.5 million tonnes of flood water (the equivalent of 600 Olympic-sized swimming pools) per day; the largest pumping operation the UK has ever witnessed. There was much media and political debate around the topic of channel maintenance, and in the aftermath of the flooding, a programme to dredge 8km of the Parrett and Tone began (Environment Agency, 2014).

Southeast England was another key focal area of the winter floods. Properties in Surrey, Sussex, Kent and Dorset bore the brunt of flooding around Christmas and New Year. In early February, the focus of the flooding switched to the lower Thames, culminating in widespread transport disruption in the Thames Valley and significant flooding of properties in areas such as Datchet and Wraysbury. Elsewhere in central and southern England, although flood warnings were widespread and major efforts were required to manage rising river levels, flooding had relatively limited impacts, notwithstanding the major transport disruption.

Staff from risk management authorities, the Environment Agency, emergency services and the military were involved in round-the-clock efforts to defend against rising floodwaters and provide aid and assistance to those affected. With the prolonged flooding occurring alongside other impacts of the severe storms (e.g. widespread power shortages and destruction along coastlines), the situation became regarded as a major crisis, requiring strategic coordination at the highest level (including regular meetings of COBRA, the emergencies and civil contingencies committee). Funds were provided for emergency flood mitigation as well as long-term recovery and prevention; £130 million was reallocated from existing budgets, with another £140 million announced in the 2014 Budget (EFRA Committee, 2014).

[3] A major incident is declared where the situation could not be dealt with by the local council and could threaten lives, disrupt the community or damage property. The local authority can organise emergency evacuations, set up rest centres and mobilise voluntary organisations. http://www.bbc.co.uk/news/uk-england-somerset-25876309

Flooding was minimised by a network of defences that performed well, alongside temporary flood defences installed widely across the UK (e.g. along the Itchen, Thames and Severn). It was estimated that 1.3 million properties were protected through the winter, although this figure includes coastal areas protected from the early December storm surge (Environment Agency, 2014). It was often agricultural land that bore the brunt of fluvial flooding, as the prolonged inundation inhibited access to land, destroyed winter crops and necessitated evacuations of livestock. Nearly 50 000ha of farmland were inundated in a single week in February, most significantly across the Somerset Levels and Moors, extensive tracts of the Thames and Severn floodplains and in the southern counties of England (EFRA Committee, 2014). Although the full financial cost of the winter floods to agriculture has yet to be calculated, farmers have sought support from the Royal Agricultural Benevolent Institute and other charities to cope with the costs and stress associated with the flooding (RABI, 2014).

The protracted nature of the fluvial flooding, alongside wider impacts from the storms, led to particularly severe impacts on the transport network. The flooding immediately before Christmas caused major problems across much of the country during one of the busiest periods of the year. In early January, major roads were closed in almost every county of southeast England and South Wales. Railway infrastructure was similarly affected, with numerous delays and cancellations. Southwest England was completely cut off from the rest of the UK rail network. Train services from London to Exeter were disrupted by inundation north of Exeter and across the Somerset Levels and Moors (on the Paddington line) and landslips at Crewkerne (on the Waterloo line). Furthermore, the Exeter–Plymouth line, which provides the only rail line into Cornwall, was washed away by coastal erosion in Dawlish (Sibley *et al*., 2015).

The impacts of fluvial flooding throughout the winter of 2013/2014 were further exacerbated in some areas by high groundwater levels. In the Thames valley (e.g. Oxford and the Thames below Maidenhead), the river terrace deposits were saturated by late January, with high water levels preventing drainage back into the river and resulting in flooding that lasted much longer than that from the river alone. In Egham, for example, flooding from the river gravels started before, and continued for a few weeks after, the fluvial flooding. Groundwater flooding alone also had very protracted impacts on many rural communities (e.g. West Ilsley in Berkshire, and Hambledon in Hampshire) and some urban areas (e.g. in parts of Brighton, Basingstoke and Coulsdon in south London). The duration of the flooding was a major factor – some evacuated residents were unable to return home for many months. The high levels also surcharged sewers (e.g. in the Pang and Lambourn Chalk valleys in Berkshire and the Jurassic limestones in Cirencester), and locally resulted in floodwaters becoming contaminated (e.g. at Buckskin in Basingstoke). The high groundwater levels also brought historic plumes of solvent to the surface (e.g. at Harwell in Oxfordshire) and mobilised banned pesticide chemicals that had remained in the unsaturated zone for years.

The wet winter also produced an increase in the incidence of sinkholes, such as the one in Ripon (Yorkshire), the first in this area for 7 years, and 21 others reported across England in February. These occur where voids (natural solution features in soluble rocks such as carbonate or gypsum or anthropogenic features e.g. due to mining) present at depth are covered by material that is subsequently washed away by the increase in rainfall and infiltration. The intense heavy rainfall also caused landslides, on both natural unmodified slopes and anthropogenic structures such as railway embankments, with 138 reported in Great Britain between December 2013 and February 2014 (Figure 6).

Historical perspective

The 2013/2014 winter floods came only a year after the last major flood event of national significance. Frequent and widespread severe flooding was seen in 2012, which was all the more remarkable because it followed the protracted 2010–2012 drought (Parry *et al.,* 2013). Damaging flooding occurred through the summer, but winter half-year flooding was also severe, particularly in November and December. In common with winter 2013/2014, the autumn/winter of 2012 was notable for the persistence of high flows and the spatial extent of floodplain inundation, rather than flood magnitude. In terms of England and Wales outflows, winter 2012/2013 was more severe over shorter durations (e.g. 10 days; Table 1). Exceptional winter groundwater levels were also observed in 2012/2013 across the major aquifer outcrops, with new maxima recorded in several Chalk boreholes in the winter and Permo-Triassic boreholes from winter through to the following summer.

In terms of duration and extent of high flows and groundwater levels, the only close modern parallel is 2000/2001 (Marsh and Dale, 2002). This was a winter half-year associated with widespread and protracted fluvial flooding as well as unprecedented groundwater flooding. The period of high runoff across England and Wales was more protracted in 2000/2001 (Table 1), with exceptional fluvial flooding beginning in early October and groundwater flooding persisting, in a few areas, well into the following summer. The winter months of 2013/2014 were much wetter, however, and over the December–February timeframe outflows from Great Britain were considerably higher (Figure 3). Furthermore, winter 2013/2014 saw a greater frequency of severe storms concentrated into a shorter time period and within that period flows remained elevated, particularly in major rivers, permeable catchments and low-lying settings. However, several fluvial flood events in autumn 2000 were more severe and destructive river flooding was more widespread, with maximum peak-flow records established from Sussex to Yorkshire (Marsh and Dale, 2002).

To put the 2013/2014 fluvial floods in a much longer-term context, Figure 7(a) shows the water year (October–September) maximum flow record for the Thames, the longest continuous flow series on the UK National River Flow Archive and a focal area for the winter floods. Although the winter 2013/2014 maximum flow was the highest since 1974, and higher than the winter flooding of 2003, there were eight larger events in the past, with 1947 and 1894 being substantially higher. Many of these earlier events were associated with different flood-generation mechanisms, such as snowmelt

Table 1

Ranked England and Wales outflows (m^3s^{-1}) averaged over a range of n-day periods (records since 1961). The date shown is the end date of the n-day period. Flows during the winter of 2013/2014 are shown in bold.

10-day		*30-day*		*60-day*		*120-day*	
08/11/2000	11442	27/11/2000	8178	**18/02/2014**	**7897**	19/02/2001	6051
31/12/2012	11055	**23/02/2014**	**8173**	26/12/2000	7794	**12/04/2014**	**5565**
16/02/2014	**10302**	21/02/1990	8029	24/02/1995	6539	11/03/1995	5267
23/01/2008	9705	19/02/1995	7286	17/01/2013	6240	24/02/2013	5044
08/02/1990	9410	04/01/2013	7259	05/02/1994	6141	15/03/2007	5009

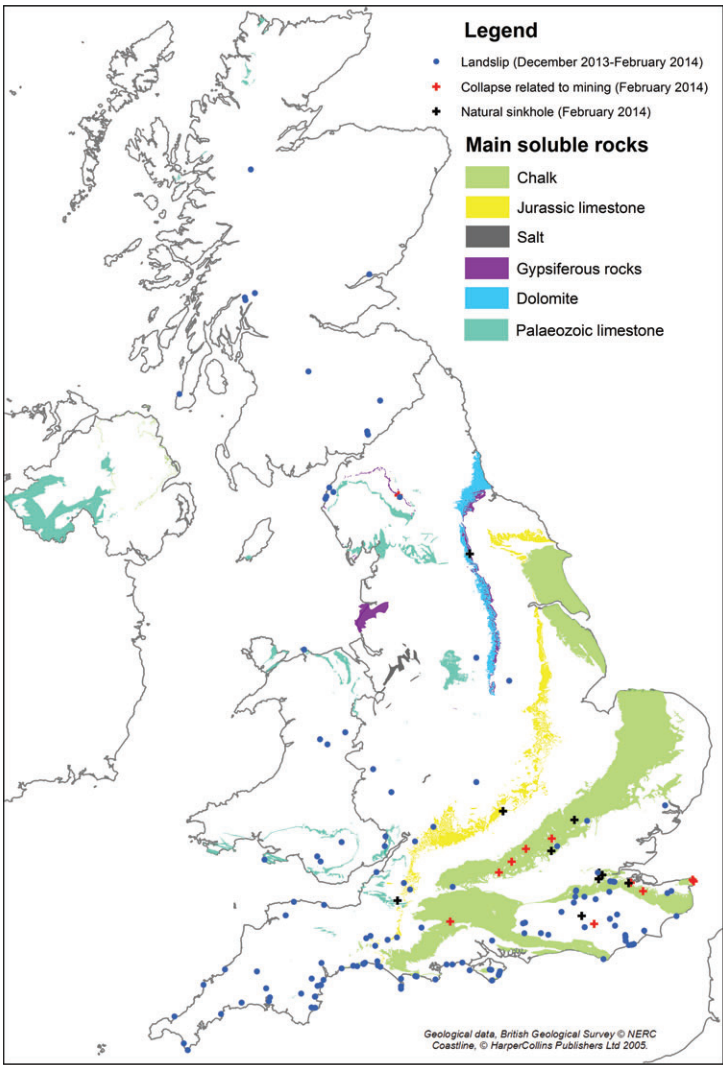

Figure 6. Reported locations of sinkholes and landslips during the winter of 2013/2014 displayed against the main soluble rock units (National Landslide Database of Great Britain (Foster et al., 2012)).

flooding and frozen ground. The plot also shows that, in general, there is no evidence of a trend towards increasing flood magnitude; in fact levels have decreased (Marsh and Harvey, 2012). In other major rivers with long records in lowland England (e.g. the Warwickshire Avon and Trent), the peak flows of 2013/2014 do not rank among the top ten events on record, and were significantly less severe than other flood peaks such as 1998, 2000, 2007 and 2012.

In terms of groundwater, compared with 2000/2001, annual maximum levels for 2013/2014 were generally not as high (Figure 4) and groundwater flooding was less extensive. In the Berkshire Downs, Basingstoke and Maidenhead, however, higher levels occurred in 2013/2014, causing groundwater flooding to emerge in areas not affected in 2000/2001, and hence outside areas where flood alert systems exist (e.g. Newbury). At Compton House, one of the longest groundwater level records in the UK, the peak water level was the second highest since records began in 1894, but 2.8m lower than in 2000/2001 (Figure 7(b)). Furthermore, all five of the highest levels recorded have been since 1990, with the next three highest being in 1993/1994, 2012/2013, and 1994/1995. At Chilgrove House (where the record goes back to 1836), however, the only date definitely with artesian flow recorded before January 1994 was December 1852. This indicates such exceptional high water levels have occurred in the past, but more than 100 years previously.

In other aquifers, where the period-of-record is significantly shorter, new record levels in the Upper Greensand (Lime Kiln Way, record from 1969) were recorded for 8 consecutive months in 2013/2014. In the Permo-Triassic sandstones of southwest and northwest England and southwest Scotland, levels started above average due to the 2012/2013 rainfall, but remained exceptionally high for more than 6 months at Bussells, Skirwith and Newbridge (records from 1971, 1978 and 1993 respectively). In both aquifers, the exceptionally high levels persisted for a longer duration in 2013/2014 than in 2000/2001, although comparison is complicated by levels being estimated for some months in the earlier period due to foot-and-mouth restrictions.

Discussion

The 2013/2014 winter was a period of severe storms that has few modern parallels (Matthews *et al*., 2014; Kendon and McCarthy, 2015). The associated flood response was remarkable – high flows and groundwater levels were protracted, spatially extensive and associated with a range of severe impacts. Although the winter was exceptional in terms of the total rainfall and runoff response, the fluvial flooding events were generally not outstanding in terms of peak-flow magnitude (with a few notable exceptions in the Thames catchment and groundwater-dominated rivers in southern England), and groundwater flooding was widespread but not as severe as in 2000/2001.

A defining aspect of the winter was the occurrence of multiple types of flooding. The combination of coastal, pluvial, fluvial and groundwater flooding in winter is not unusual, but its extent, frequency and severity through the winter of 2013/2014 was extraordinary. The simultaneous occurrence of multiple types of flooding and other weather hazards presented a major challenge for the emergency services. The interactions between different flood generating mechanisms were also important – fluvial flooding in the lower reaches of major rivers was made worse by tide-locking (i.e. where fluvial flows are prevented from entering an estuary by high tides). Additionally, groundwater flooding from the river terrace deposits in major river valleys compounded the problem. The same weather patterns that lead to heavy rainfall and high winds can also lead to storm surges, and previous work has elaborated on the interdependence of these factors (e.g. Svensson and Jones, 2004). The winter 2013/2014 raises important questions about the joint occurrence of multiple types of flooding in future.

Winter 2013/2014 certainly eclipsed all other recent flood events in terms of the media and political spotlight. As with other recent floods, it occurred in an age of social media and 24h news coverage. Although the floods caused very severe impacts in some areas, the worst damage was relatively localised. The emotive imagery (e.g. of the Somerset Levels and Moors), however, heightened perceptions of the scale of the flooding, particularly alongside scenes of devastation resulting from high winds and coastal flooding. The events occurred against a backdrop of intense political debate around flood defence spending as part of a wider discourse surrounding public sector austerity measures. As would be expected, not all of the coverage was

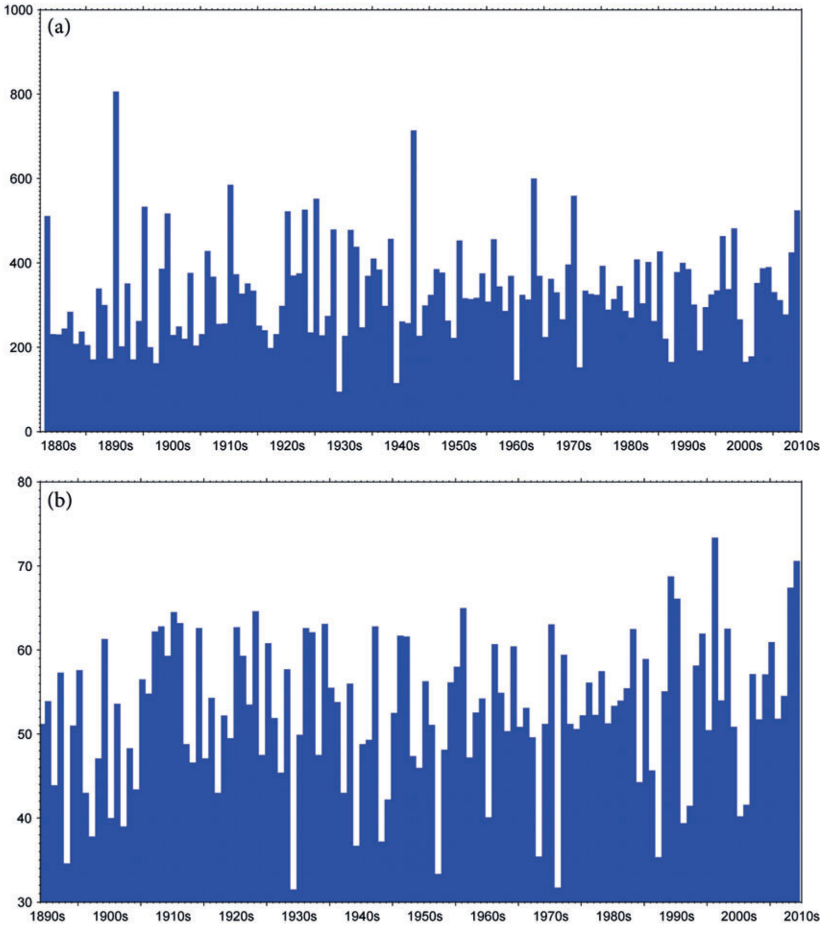

Figure 7. (a) Water-year maximum naturalised flows (m^3s^{-1}) on the Thames at Kingston. (b) Water-year maximum levels (m above Ordnance Datum) at Compton House (West Sussex).

proportionate or balanced, but in general contributed to an important debate around flood risk issues, including river catchment and coastal management strategies.

As with other extreme weather events of the recent past, climate change was, unsurprisingly, a key focus of public debate. The degree to which the hydrological volatility of the early years of the twenty-first century is attributable to climate change is a focus of ongoing scientific investigations. Currently it is not possible to say conclusively, but detection and attribution studies are underway (Huntingford *et al*., 2014). Even without a categorical answer, the events of winter 2013/2014 are certainly consistent with expectations of wetter winters in future, and heightened coastal-flood risk due to rising sea levels. The consequences of protracted spells of heavy rainfall are clear from winter 2013/2014, and previous events such as 2012 and 2000/2001. Even if flood maxima do not increase substantially, changes in duration or frequency of heavy winter rainfall events could have major impacts on transport infrastructure and would increase the risk of groundwater flooding.

Generally, the early part of the twenty-first century has seen major variability and unusual seasonal patterns – most associated with persistent perturbations in the strength and location of the Jet Stream, which may be influenced by a wide range of potential climatic drivers. There is a pressing scientific need to understand the relative contributions of these drivers in influencing hydrological extremes (Huntingford *et al*., 2014).

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