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A systematic assessment of drought termination in the United Kingdom

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Abstract

Drought termination can be associated with dramatic transitions from drought to storms and flooding, and this is certainly true for recent events in the United Kingdom (UK). Attention devoted to these newsworthy and memorable events may be at the expense of drought terminations that proceed gradually and pose a different set of challenges for water resource managers. This paper defines drought termination as a phase of drought in its own right and makes the case for a more systematic approach to its identification and characterisation, applying an objective approach to detect drought terminations in observed river flow records for 52 catchments. The resulting archive of 459 drought terminations provides an unprecedented historical perspective on drought termination in the UK. Nationally- and regionally-coherent drought termination events are identifiable, although drought termination characteristics vary both between and within major episodes. Contrasting drought termination events in 1995–1998 and 2009–2012 are described in greater depth. The dataset is also used to assess potential linkages between metrics of drought termination characteristics and catchment properties. The duration of drought termination is moderately negatively correlated with elevation and catchment average rainfall, suggesting that wetter catchments in upland areas of the UK tend to experience shorter drought terminations. More urbanised catchments have a tendency for gradual drought terminations, contrary to perceptions of flashy hydrological response in these areas, although this may also be related to the type of catchments typical of lowland England. Potential linkages are found between both the duration and rate of drought termination and the duration of the preceding drought development phase, which may have important implications for water resources management during a drought. The dataset helps to place individual events within a long-term context. The drought termination phase in 2009–2012 was, at the time, regarded as exceptional in terms of magnitude and spatial footprint but the Thames river flow record reveals comparable events before 1930. Hence, the approach adopted and the chronologies of drought termination enable objective intercomparison of events. The dataset may

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in due course provide a basis for better understanding the drivers, long-term trends in occurrence and characteristics, and impacts of historical and contemporary drought termination events.

1 Introduction

5 Drought termination, generally defined as the end of a drought, has often been associated with violent weather conditions and flooding, including in Colorado (Lavers and Villarini, 2013), Pakistan (Webster et al., 2011), China (Lam et al., 2012) and Australia (Leblanc et al., 2009). The UK also experienced notable drought terminations in August–September 1976 (Doornkamp et al., 1980) and in April–July 2012 (Parry et al., 2013). Notwithstanding these examples, drought termination events have been relatively neglected by drought research. Studies which address this phenomenon have focused on extreme transitions at the end of a drought (e.g. Yang et al., 2012; Ning et al., 2013). Such events are more newsworthy and damaging, but there has been a lack of attention devoted to assessing the full range of drought termination types and characteristics. Whilst abrupt drought terminations may result in destructive impacts, gradual drought terminations may be problematic for water resource managers who must reconcile public relations with continued water restrictions during wet weather.

15 Some studies systematically identify and characterise droughts themselves (e.g. Hisdal et al., 2001; Pfister et al., 2006; Marsh et al., 2007; Fleig et al., 2011; Li et al., 2013), but these have generally not considered the drought termination phase. A limited historical perspective can be gained from studies of drought termination on an event basis, including those based on hydrometeorological (e.g. Kienzle, 2006; Marengo et al., 2008), remotely sensed (e.g. Wang et al., 2013; Chew and Small, 2014) or experimental catchment data (e.g. Miller et al., 1997; Lange and Haensler, 2012). Even considering several events is too limited a sample to generalise (e.g. Eltahir and Yeh, 1999; Shukla et al., 2011) or move beyond qualitative descriptions (e.g. Parry et al., 2013). A

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systematic assessment of drought termination would enable a more robust analysis of its spatial and temporal variability.

Studies that systematically identify drought termination in the historical record (e.g. Mo, 2011; Kam et al., 2013; Maxwell et al., 2013; Patterson et al., 2013) have typically considered drought termination to be an instantaneous point in time. The exceptions to this are two studies which attempt to characterise a period of drought termination. Bonsal et al. (2011) sub-divided drought into six phases including drought termination (referred to as “recovery”), and Nkemdirim and Weber (1999) expressed the drought termination rate (referred to as “rate of recovery”) using Palmer Drought Severity Index units over time.

Some preliminary steps have been taken to identify and characterise the spatial signature of a single drought termination for 15 catchments in the UK (Parry et al., 2016), and to apply the same assessment technique in a temporal analysis of drought terminations in a single catchment for the period 1883–2013 (Parry et al., 2015). By combining these spatial and temporal approaches, the aim of this study is to derive chronologies of drought termination metrics for 52 UK catchments. These data are then used to explore the link between drought termination metrics and catchment properties, and to assess the historical variability of drought termination. In due course, it is hoped that a better understanding of the physical processes driving drought termination will lead to improved water resources management and forecasting during these problematic episodes.

2 Data

Fifty-two catchments (Fig. 1; Table A1) were selected to maximise the spatio-temporal coverage of the dataset, both providing a representative coverage in the UK (accounting for more than 40 % of the gauged area) whilst capturing some of the longest river flow records. Nearly half (21 of 52) of the catchments are classified as near-natural, and these are predominantly located in northern and western areas of the UK. To the

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The start of a drought development phase (t_{sd} ; Fig. 2) is the first month of D consecutive months (pre-defined by the user) for which Z_{anom_t} is negative. R months within the D -month duration are permitted to be above average, to account for minor wet phases during drought development. Once a drought has been initiated, the end of the drought termination phase (t_{et} ; Fig. 2) is the last month of T consecutive months for which Z_{anom_t} is greater than Z_{LTA_m} . The recovery threshold (RT; Fig. 2) is Z_{anom_t} at t_{et} .

The end of the drought development phase (t_{ed} ; Fig. 2) is the month with the largest negative Z_{anom_t} value (defining the drought magnitude; DM, Fig. 2) between t_{sd} and t_{et} . The start of the drought termination phase (t_{st} ; Fig. 2) is the next month after t_{ed} .

The conceptual diagram in Fig. 2 illustrates the temporal stages of drought and some of the associated drought termination metrics. The drought termination duration (DTD; Fig. 2) is the number of months between t_{st} and t_{et} . The drought termination rate (DTR; Fig. 2) is the difference between the drought magnitude and the recovery threshold, divided by the drought termination duration. The drought termination seasonality is a code relating to the seasons through which drought termination occurs. For example, if the start of drought termination is in autumn and the end of drought termination is in the next winter, the drought termination seasonality would be “Aut-Win”.

In this study, the parameters are specified as $D = 10$, $R = 1$ and $T = 2$ (Fig. 2). The drought initiation parameters (D and R) relate to persistent below average river flows for at least ten months to identify multi-season droughts, with an allowance for one month of above average flows. The drought cessation parameter (T ; two consecutive months of above average river flows) has been chosen to avoid identifying intermittent high flows as the t_{et} . These values were applied to all of the study catchments.

To assess potential relationships with drought termination characteristics, Spearman correlations (Spearman, 1944) were calculated. This method was selected because testing has not been performed to assess whether the values of drought termination characteristics are normally distributed. Correlation analysis was performed on the whole dataset of 52 catchments, and on a smaller subset of catchments for which at least ten drought termination events were identified. This provided a more robust sam-

drought terminations tend to occur over longer time periods in the south. However, it is important to note the wide range of variability in drought termination characteristics exhibited within individual catchments. Two events are singled out for more detailed analysis: 1995–1998, the most nationally coherent event in the post-1970 period; and 2009–2012, reported as unprecedented in the historical record (Parry et al., 2013).

4.2 Event analysis: 1995–1998

Drought in 1995–1998 affected all but one of the study catchments (Fig. 4; left), offering the best opportunity to analyse the spatial variability of drought termination within an individual episode. The overall duration of drought was generally longer (almost three years) further south and east in the UK. There were two distinct patterns of drought termination. In the north and west, the drought termination phase began within six months of the start of drought development and long drought termination phases (three or more seasons) followed in 13 catchments. In contrast, drought termination started almost two years later in 25 catchments, mainly in the south and east. The transition to drought termination was spatially coherent across North and Central Wales, Midlands, South-west UK and Southern England.

Drought termination durations were generally longer (by six to nine months) for catchments in Southern England, Thames and Anglian regions (Fig. 4; top right). Conventionally referred to as the 1995–1997 drought in the literature, it was the second half of 1998 before catchments in parts of lowland England (e.g. the Warwickshire Avon, Colne, Thames, Itchen and Dorset Avon) had completed the drought termination phase. The drought termination rate displayed a west–east divide in 1995–1998, particularly apparent for Wales and southern, central and eastern England (Fig. 4; middle right). Whilst much of Wales and south-west England exhibited drought termination rates of 16–32 % month⁻¹, this decreased to less than 8 % month⁻¹ across large areas of south-eastern England. Further north, the pattern was more mixed. Three-season drought terminations (Fig. 4; bottom right) started in the autumn in Scotland and in the

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England and north Wales experienced drought terminations through the summer half-year. Drought terminations through the winter months were not very common for the 2009–2012 event, restricted to the Warwickshire Avon (Midlands) and smaller catchments in the Anglian and Southern England regions.

4.4 Drought termination and catchment properties

The analysis above offers a qualitative assessment of the impact of catchment type on drought termination characteristics. Longer drought termination durations occurred in groundwater influenced catchments of southern and eastern England (e.g. the String-side in Anglian and the Itchen and Dorset Avon in Southern England) in both 1995–1998 and 2009–2012. However, the synchronicity of the end of drought termination in spring 2012 (Fig. 5; left), when compared to the incoherent end of drought termination in 1995–1998 (Fig. 4; left), suggests that catchment properties are less influential during abrupt drought terminations than during gradual events.

Spearman correlations between drought termination characteristics (duration and rate) and five catchment properties (catchment area, median elevation, SAAR6190, BFI and urban extent) and two drought characteristics (drought magnitude and duration of drought development) were calculated from the complete catalogue of events. Correlations were assessed for individual events ($n = 459$) as well as for catchment averaged values ($n = 52$) (Table 1). Stronger correlations are found between catchment average drought termination characteristics and catchment properties than when drought termination events are considered individually. Correlations between characteristics of drought development and drought termination exhibit the opposite pattern. Three of these correlations weaken when using catchment averages, although one (drought magnitude and drought termination rate) strengthens. More of the correlations are statistically significant at the 95 % confidence level when using the individual event dataset ($n = 459$), particularly for correlations with drought termination rate, although correlations are weaker.

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The strongest correlation ($r_s = -0.48$; $p = 0.000407$) was found for catchment average drought termination duration and median elevation, suggesting that upland catchments tend to experience shorter drought terminations. Although slightly weaker, correlations with SAAR6190 ($r_s = -0.40$; $p = 0.00366$) show a similar pattern, possibly explained by notable autocorrelation between elevation and rainfall ($r_s = 0.71$; $p = 2.03 \times 10^{-8}$). Drought termination rate and urban extent are negatively correlated ($r_s = -0.43$; $p = 0.00172$). Correlations between the BFI and drought termination rate are relatively weak.

Spearman correlations were also derived for a subset of the study catchments (not shown), with 17 out of the 52 meeting the criteria of at least ten identified drought termination events. A stronger (though not statistically significant) link was found between catchment average drought termination rate and BFI ($r_s = -0.36$; $p = 0.156$). This implies that lower BFI (i.e. more responsive) catchments tend to have faster drought termination rates (i.e. more abrupt). For this subset of catchments, relationships between drought termination duration and both elevation and rainfall remained the strongest, but the linkages between urban extent and both drought termination duration and drought termination rate were comparable.

For correlations between drought termination characteristics and those of the preceding drought development phase, although relatively weak the strongest relationships were detected for drought development duration with both drought termination duration ($r_s = -0.30$; $p = 1.07 \times 10^{-10}$) and drought termination rate ($r_s = 0.28$; $p = 7.35 \times 10^{-10}$). This suggests that prolonged drought development phases tend to be followed by shorter and more abrupt drought terminations. Relationships with catchment average drought development characteristics are not statistically significant, but assessments with the larger individual event dataset found that most linkages (e.g. drought magnitude and drought termination duration, drought development duration and drought termination rate) are significant at the 95 % level.

5 Discussion

This study has systematically defined drought terminations in the historical river flow record for the UK for the first time. The approach has identified 459 drought events across 52 study catchments, providing a comprehensive dataset for further analysis of the historical variability of drought termination. Two aspects were explored: a preliminary assessment of linkages between drought termination characteristics and catchment properties, including features of the preceding drought development phase (informed by the correlation analysis above); and a re-appraisal of drought termination characteristics in 2009–2012 within a hydrological context.

5.1 Drought termination characteristics and catchment properties

The spatio-temporal variability in drought termination within individual events (Figs. 3–5) is partly related to catchment properties that modulate the rainfall inputs. This reflects other studies that found hydrological drought termination to be more spatially variable than drought development, owing to the heterogeneity of catchment characteristics (e.g. Nkemdirim and Weber, 1999; Bell et al., 2013; DeChant and Moradkhani, 2015).

Some of the strongest correlations were found between drought termination duration and both elevation and catchment average rainfall (SAAR6190). This is likely to be because catchments in wetter upland areas of the UK are typically impermeable and responsive to rainfall, translating to shorter drought terminations. The correlations between urban extent and both drought termination duration and drought termination rate imply that drought terminations tend to be longer and more gradual in catchments with larger urban areas. This contradicts the expectation that typically impermeable urban areas may exhibit more abrupt drought terminations. The more urbanised catchments of the UK are generally in the south-east with more permeable geology and it may be that lower responsiveness to rainfall negates the impact of the urban extent. Note also that the urban extent data are based on satellite imagery from 1998–2000 and there-

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fore do not reflect the changing proportion of a catchment as built area through the 20th century. Further analysis will be required to assess the impact of increasing urbanisation on trends in drought termination characteristics within the study catchments.

The BFI is widely regarded as a proxy for groundwater influence in the UK. However, water storage in lakes and seasonal snowpacks can also be locally important, with BFI values of 0.43–0.60 for the Spey, Deveron, Scottish Dee and Naver in northern Scotland despite negligible groundwater influence. Whilst these impermeable catchments typically respond rapidly to rainfall, catchments with similar BFI values in areas of groundwater influence further south are less responsive. Elevation is a better indicator of the spatial variability of geology in the UK than BFI, which may explain why correlations between drought termination characteristics and elevation are stronger than those with BFI. By excluding catchments in Scotland that exhibit mismatches between BFI and responsiveness (through the use of the subset of 17 catchments with at least ten events), the correlation analysis found a stronger association between drought termination rate and BFI. This linkage, as well as the qualitative observation of longer drought terminations in groundwater influenced catchments, is consistent with previous studies that report longer duration drought termination in subsurface storage (Thomas et al., 2014) and groundwater levels (e.g. Eltahir and Yeh, 1999).

The stronger relationships identified in the larger dataset between drought development and drought termination characteristics suggest that catchment averaging both metrics before correlation may smooth out unique pairs of characteristics, resulting in information loss and obscuring any detectable signal. Weak negative (although statistically significant) correlation was found between drought magnitude and drought termination duration, contrary to a pattern observed for two multi-year droughts in the US (Nkemdirim and Weber, 1999). The most important linkages identified between drought development and drought termination characteristics were for drought development duration with both drought termination duration and drought termination rate. This suggests that there may be critical thresholds of drought development duration, beyond which complete drought termination is unlikely except in the most extreme scenarios

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tions occurred entirely in spring or in summer. Five of these nine relate to the 2009–2012 event (the Severn, Trent, Derwent and Witham in spring, and the Colne in summer). With the exception of the Severn, the drought termination in 2009–2012 is the only single season event in the historical record for each catchment. Drought terminations across both spring and summer are similarly uncommon. Of the 13 events (out of 459) with spring-summer drought termination seasonality, five occurred in 2009–2012 (the Yscir, Exe, Thames, Itchen and Sydling Water). Of the remaining eight events, no other drought termination is represented by more than two catchments. For the Thames, the only previous example of a drought termination entirely within the spring and summer was in 1888. Other studies have also found that it is difficult to terminate multi-season droughts in two seasons or less (Karl et al., 1987).

Rather than simply the wettest season, it is the season with the greatest potential for large positive rainfall anomalies that are most likely to facilitate drought termination (Karl et al., 1987; Mo, 2011). In the UK, these two factors are coincident, so the winter provides the greatest likelihood for drought termination (Van Loon et al., 2014). The larger evaporative demand in summer reduces the effectiveness of all but the most extreme rainfall, explaining the skewed distribution of drought terminations towards the winter half-year. Of the 459 drought terminations, single season events were more common in autumn (eight) and winter (eight) than in spring (six) and particularly summer (three).

At regional scales, variation in drought termination seasonality is likely to be determined by catchment properties, such as storage causing lagged responses. For catchments in Scotland, the influence of snow may also influence drought termination. Where seasonal snowpacks exist, winter drought terminations may be delayed until the snowmelt season (Van Loon et al., 2014). However, the large variability of drought termination characteristics and the moderate to weak correlations with catchment properties imply that a range of physical processes exist. At national or continental scales, variability in drought termination seasonality is likely to be influenced by larger scale drivers such as El Niño and La Niña events in the Pacific (e.g. Tomasella et al., 2011;

Marengo and Espinoza, 2015), switches in Atlantic temperatures (Wilby, 2001; Folland et al., 2015), or tropical cyclones (e.g. Patterson et al., 2013).

6 Conclusions

For the first time, drought terminations have been systematically identified in the UK. This analysis detected 459 events in 52 catchments covering a range of geographical settings, and provides chronologies of both drought development and drought termination phases. This information gives a new perspective to the historical variability of drought termination in the UK that is potentially useful for water resource managers and researchers in a range of fields including ecology, geomorphology and water quality. It is hoped that characterising 459 drought termination events will underpin trend analyses and provide the basis for the development of a drought termination typology.

Although the identification procedure applied consistent rules, the parameter values set to define a drought and its phases influence the chronologies. The parameters were chosen to maximise the detection of multi-season events. Drought termination phases following shorter drought developments driven by summer heatwaves, for example, would not be well represented by the parameter settings used in this study. In addition, events in the more hydrologically responsive north and west of the UK might be less well represented because droughts in these wetter regions are typically shorter than multi-season in duration. However, the spatial variability in the number of identified droughts is consistent with the levels of service offered by regional water companies, with drought-induced water restrictions expected more frequently in the south-east of the UK than in the north.

The use of a monthly time step in this study may also restrict the approach. Drought termination can occur rapidly, within a few days, particularly in hydroclimatic settings in which the end of a drought is often triggered by tropical cyclone activity. In such locations, the application of the approach used in this study may obscure accurate

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Table 1. Spearman correlations for relationships between drought termination characteristics and both catchment properties and drought development characteristics. Correlations are presented for individual events (rows for which $n = 459$) and for catchment mean drought characteristics (rows for which $n = 52$). Values indicated with an asterisk (*) are statistically significant at the 95 % confidence level. Drought termination characteristics denoted as follows: DTD = drought termination duration; DTR = drought termination rate. Drought development characteristics are denoted as follows: DDD = drought development duration; DM = drought magnitude. Catchment properties are denoted as follows: SAAR6190 = Standard-period Average Annual Rainfall for 1961–1990; BFI = Base Flow Index.

	n	Catchment properties					Drought development characteristics	
		Area	Median elevation	SAAR6190	BFI	Urban extent	DDD	DM
DTD	459	-0.03	-0.15*	-0.12*	0.04	0.14*	-0.30*	-0.19*
DTD	52	-0.23	-0.48*	-0.40*	0.13	0.40*	0.03	-0.06
DTR	459	0.02	0.12*	0.12*	-0.18*	-0.15*	0.28*	-0.04
DTR	52	0.11	0.22	0.12	-0.12	-0.43*	0.01	-0.19

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Table 2. Study catchments which established new period of record maximum drought termination rates in 2009–2012.

Catchment	Drought termination rate (% month ⁻¹)	Rank (out of total number)	Drought termination rate (% month ⁻¹) for rank 2	Year of drought termination ranking 2nd by drought termination rate
Severn	90.6	1/16	26.5	1997
Derwent	62.3	1/7	42.6	1976
Trent	56.3	1/11	28.0	1959/1960
Warwickshire Avon	49.6	1/20	33.7	1963
Thames	38.1	1/35	37.2	1929/1930
Teme	33.6	1/8	29.6	1975/1976
Sydling Water	30.8	1/10	25.5	1974
Itchen	21.1	1/9	12.5	1963
Carron	18.2	1/3	11.9	2001

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Table A1. Gauging station metadata for the 52 study catchments.

Region	Catchment	Record length (years)	Area (km ²)	Median elevation (m)	SAAR6190 (mm)	BFI	Urban extent (%)
W Scotland	Naver	37	477	187	1384	0.43	0.0
W Scotland	Carron	35	138	342	2620	0.26	0.0
W Scotland	Nevis	32	69	518	2912	0.27	0.1
W Scotland	Clyde	51	1903	252	1129	0.46	3.0
W Scotland	Ayr	38	574	212	1214	0.30	0.6
W Scotland	Cree	51	368	212	1760	0.28	0.2
W Scotland	Nith	37	477	288	1460	0.39	0.2
E Scotland	Findhorn	56	782	408	1064	0.40	0.0
E Scotland	Spey	62	2861	420	1120	0.60	0.1
E Scotland	Deveron	54	955	209	928	0.57	0.2
E Scotland	Scottish Dee	85	1370	508	1109	0.53	0.1
E Scotland	Tay	62	4587	395	1425	0.65	0.2
E Scotland	Forth	33	1036	180	1752	0.41	0.0
E Scotland	Whiteadder Water	45	503	230	813	0.51	0.2
E Scotland	Tweed	52	4390	255	955	0.52	0.3
N Ireland	Mourne	32	1844	153	1288	0.39	0.3
N Ireland	Faughan	38	273	173	1219	0.47	0.4
N Ireland	Lagan	42	492	95	916	0.43	3.2
NW England	Eden	47	2287	210	1183	0.49	0.8
NW England	Kent	46	209	205	1732	0.41	1.8
NW England	Ribble	54	1145	198	1353	0.34	3.7
NE England	South Tyne	52	751	333	1148	0.34	0.2
NE England	Tees	58	818	370	1141	0.34	0.4
NE England	Ure	56	915	264	1118	0.39	0.8
NE England	Derwent	41	1586	102	765	0.70	0.8
N&C Wales	Conwy	50	345	328	2055	0.28	0.1
N&C Wales	Welsh Dee	77	1013	347	1369	0.54	0.4
N&C Wales	Severn	93	4325	127	913	0.53	2.0
N&C Wales	Teme	44	1480	191	818	0.55	0.7
N&C Wales	Wye	78	4010	199	1011	0.54	0.7

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Table A1. Continued.

Region	Catchment	Record length (years)	Area (km ²)	Median elevation (m)	SAAR6190 (mm)	BFI	Urban extent (%)
Midlands	Trent	56	7486	118	761	0.64	10.5
Midlands	Warwickshire Avon	78	2210	96	654	0.51	4.9
SW UK	Tywi	56	1090	220	1534	0.47	0.2
SW UK	Yscir	42	63	361	1299	0.46	0.0
SW UK	Tone	53	202	120	966	0.60	1.6
SW UK	Torridge	54	663	146	1186	0.38	0.4
SW UK	Exe	58	601	235	1248	0.50	0.6
SW UK	Dart	56	248	347	1765	0.52	0.7
SW UK	Warleggan	45	25	232	1442	0.70	0.2
SW UK	Sydling Water	45	12	190	1032	0.88	0.5
Anglian	Lud	46	55	89	699	0.90	2.2
Anglian	Witham	55	298	91	614	0.69	3.5
Anglian	Bedford Ouse	81	1460	101	636	0.53	3.5
Anglian	Stringside	49	99	20	629	0.84	0.7
Anglian	Wensum	45	398	57	684	0.75	1.3
Anglian	Colne	55	238	68	566	0.52	2.2
S England	Thames	131	9948	100	706	0.63	6.6
S England	Great Stour	50	345	75	747	0.70	3.2
S England	Bull	36	41	58	820	0.37	0.9
S England	Itchen	56	360	107	833	0.96	2.9
S England	Dorset Avon	49	324	129	745	0.91	1.3
S England	Stour	41	1073	83	861	0.64	2.0

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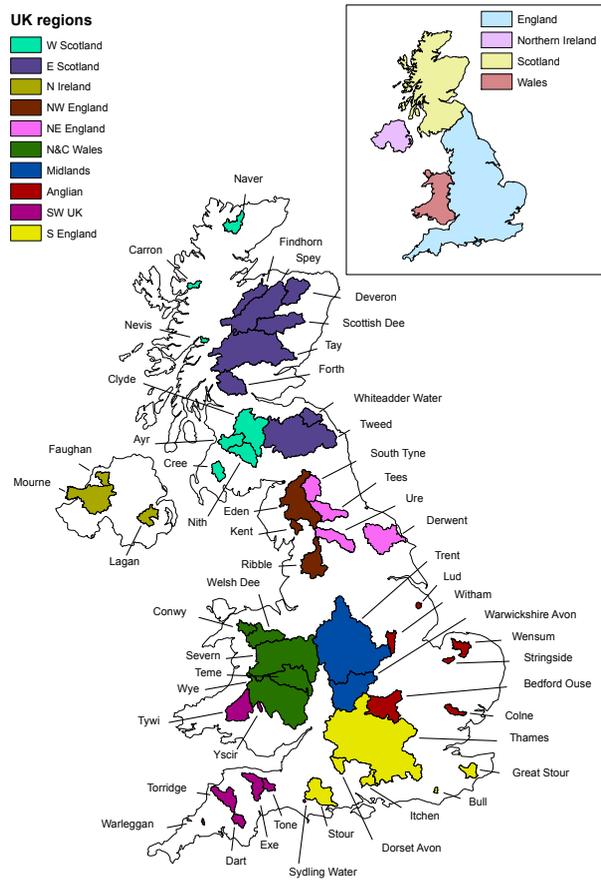


Figure 1. Location of the 52 study catchments in the UK, colour-coded by their region. Inset: the constituent countries of the UK.

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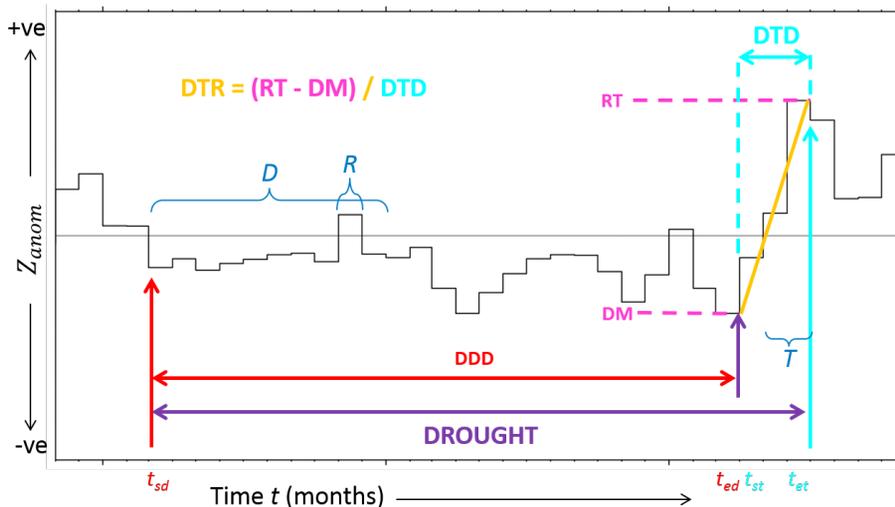


Figure 2. Conceptual diagram of drought termination definition and metrics. The three parameters are as follows: D is the number of months of below average flows required for the drought development phase to begin; R is the number of months of intermittent above average flows permitted within D ; and T is the number of months of above average flows required for the end of the drought termination phase. t_{sd} is the start of drought development, t_{ed} is the end of drought development, t_{st} is the start of drought termination, and t_{et} is the end of drought termination. The grey horizontal line represents an anomaly of zero, below which flows are below average and above which flows are above average.

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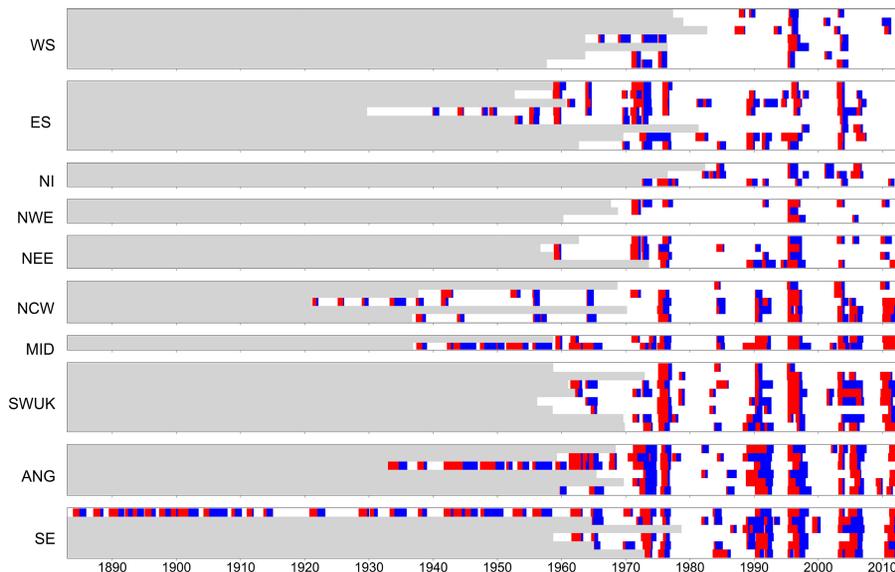


Figure 3. Period of record chronologies of drought termination for all 52 study catchments. Red bars indicate drought development, blue bars indicate drought termination, white bars indicate no drought development or drought termination, and grey bars signify periods before gauged river flow records began. Regions are denoted as follows: WS = Western Scotland; ES = Eastern Scotland; NI = Northern Ireland; NWE = North-west England; NEE = North-east England; NCW = North and Central Wales; MID = Midlands; SWUK = South-west United Kingdom; ANG = Anglian; SE = Southern England.

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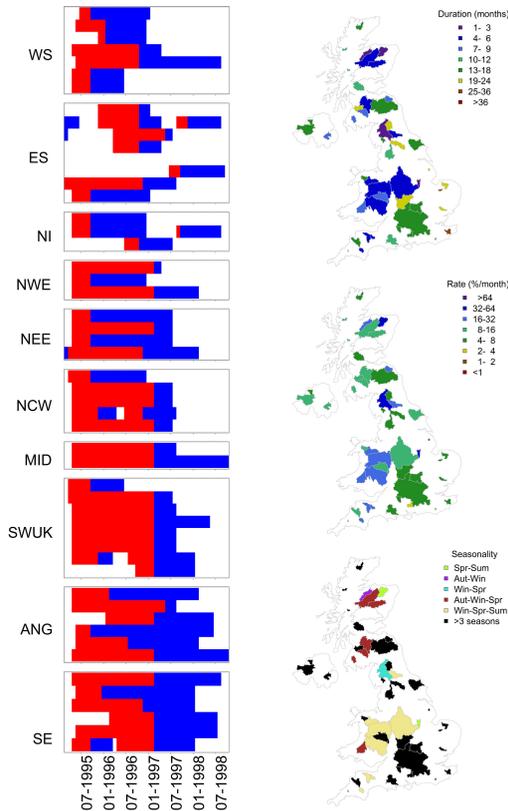


Figure 4. The 1995–1998 drought termination: chronologies of drought development and drought termination (left); drought termination duration (top right); drought termination rate (middle right); drought termination seasonality (bottom right). Regions are denoted as follows: WS = Western Scotland; ES = Eastern Scotland; NI = Northern Ireland; NWE = North-west England; NEE = North-east England; NCW = North and Central Wales; MID = Midlands; SWUK = South-west UK; ANG = Anglian; SE = Southern England.

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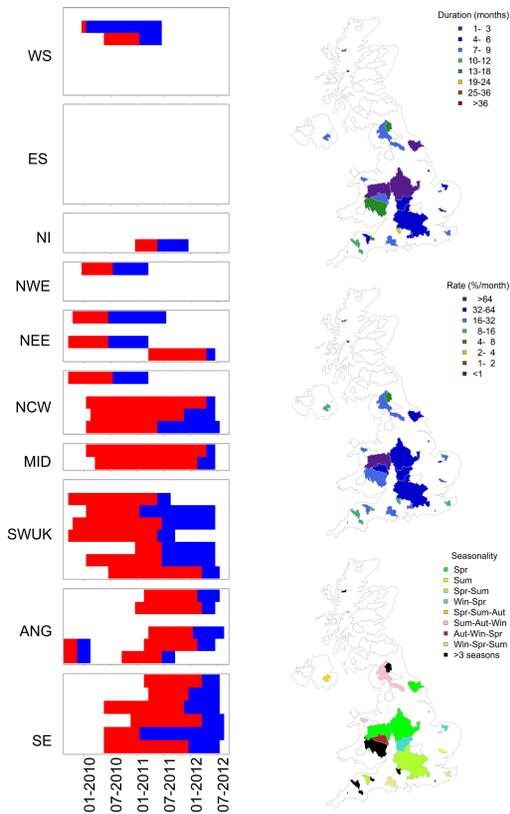


Figure 5. The 2009–2012 drought termination: chronologies of drought development and drought termination (left); drought termination duration (top right); drought termination rate (middle right); drought termination seasonality (bottom right). Regions are denoted as follows: WS = Western Scotland; ES = Eastern Scotland; NI = Northern Ireland; NWE = North-west England; NEE = North-east England; NCW = North and Central Wales; MID = Midlands; SWUK = South-west UK; ANG = Anglian; SE = Southern England.

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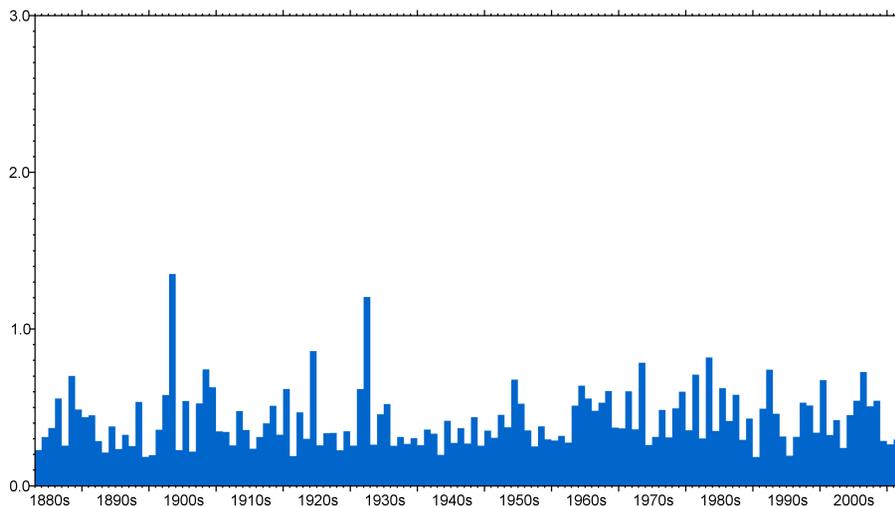


Figure 6. Ratio between average naturalised river flows for May–July and the preceding January–March for the Thames at Kingston (from Marsh et al., 2013).