Covering letter: Author response to Editor Decision

Dear Lena

Thank you for accepting our responses to the reviewers and considering the next revision of our manuscript.

We have made a number of revisions to the original manuscript (see marked up version at the end of this document), reflecting what we proposed to do in the response to reviewers (see below). We have taken your comments on board regarding a limited sensitivity analysis, and now include a new figure (Fig. 3) and a new section (section 3.2) of the manuscript. We think that this strengthens the paper and hope that this addresses the request made by the reviewers, who we thank for their considered suggestions and valuable feedback.

I look forward to continuing through the review process towards publication. Please let me know if we can provide any further information or modifications.

Best wishes,

Simon Parry

Author Comment in response to review by Anonymous Referee #1

General Comments

The reviewer raises important points on the novelty of the approach and the overgeneralisation of results which we have addressed below. We hope that our responses are acceptable, and we thank the reviewer for their constructive and complimentary review which has improved the manuscript.

Specific Comments

Page 4 Lines 3–10:

Whilst some of the studies cited conduct analysis at the monthly time step (as we do here), and some use the PDSI which accounts for the water balance over recent months, these studies do refer to a day (e.g. Kam *et al*. 2013) or month (e.g. Patterson *et al*. 2013) in which drought termination occurs. Where SPI3 (e.g. Kam *et al*. 2013) or a three-month termination criterion (e.g. Patterson *et al*. 2013) are used, any implied 'termination duration' is 'hard coded' to be three months. This does not give an appreciation of the variability in the duration of drought termination, and in both studies the day or month of drought termination (as an instantaneous point in time) is further analysed (e.g. for the season in which that point in time occurs). Our study differs from these because drought termination is a defined period of a drought event with its own start and end and a duration in between these points. The drought termination rate is the magnitude of change in river flow anomalies over time during this period and the seasonality is the seasons through which the period occurs. Our approach could complement existing threshold-based methods by subdividing an identified period of drought into drought development and drought termination phases based on the minimum value of the index used (e.g. PDSI). We have updated the text at the end of the Introduction to clarify the differences between our approach and those of other studies.

Page6, Lines 18–23:

We thank the reviewer for their comments on this important aspect of our approach. The decisions on the parameter values are probably the most important factor in the number and characteristics of the identified drought termination events. For a previous application (not published), we conducted a very preliminary sensitivity analysis which demonstrated the impact of varying the parameter values. For this application, we tested a smaller number of combinations of parameter values (informed by that previous sensitivity analysis) and found that values of 10, 1 and 2 for *D*, *R* and *T* (respectively) identify droughts (and terminations) that are well documented in the literature (e.g. Marsh *et al*. 2007 and Parry *et al*. 2013, both cited in the manuscript). These values also capture the spatial variability in drought risk in the UK (lower in the north and west, higher in the south and east). The reviewer is correct that there are instances in the chronologies of drought termination presented in the manuscript when a drought termination period is immediately followed by the next drought development phase (when two months are above average followed by nine out of the next ten months below average) which would be classified as the same event if *T*=3. However, the same issue would arise if *T*=2,3,4,…. The subjective decisions we have made here are not different to those of many studies in the literature on threshold-based drought indices which may make arbitrary choices on the threshold quantile and *n*-month accumulation periods. We agree with the reviewer that a comprehensive sensitivity analysis is required, but it is a complex question that we believe is worthy of a study in its own right. This paper aims to be a proof of concept that the approach is useful in systematically identifying and characterising drought terminations in the historical record. We have strengthened the text in the discussion to explain our future plans to more comprehensively address the question of parameter selection.

Page 6 Line 27:

We have tested for normality in each of the series used in correlation analysis through the Shapiro-Wilk test and quantile-quantile (Q-Q) plots. The majority of the series are not normally distributed so the use of Spearman correlations is justified. We have modified the manuscript to better justify our use of the Spearman approach.

Page 4 Line 23:

We have restructured the first sentence to emphasise the selection criteria and de-emphasise the importance of the number of catchments which satisfy these criteria.

Page 10 section 4.4:

The sentence relates specifically to the 1995-1998 and 2009-2012 events, drawing on the analyses provided in sections 4.2 and 4.3. This statement also holds true for some other events; for example, the top 5 drought termination durations for the 1973 event are the Bedford Ouse, Wensum, Lud, Stringside and Colne (see Figure 3), all of which are in Anglian region and have moderate to high BFI values (0.52-0.90), indicative of groundwater influence in the catchments. However, we agree with the reviewer that the link between larger groundwater influence in catchments and longer drought termination durations does not apply for all identified drought termination events. We have extended the sentence to acknowledge that this does not apply to all events.

Similarly, on Page 12 Lines 11–16:

We accept that the spatio-temporal distribution of rainfall will impact the spatio-temporal variability of drought termination in river flows. Two of the most important factors in the characteristics of drought termination in a given catchment are the amount and timing of rainfall and the modulating effect of the catchment characteristics. We only claim on page 12, lines 11-16 that characteristics are *partly* (i.e. not wholly) attributable to catchment characteristics, but we agree that the link to rainfall could be made more explicitly. We have modified the manuscript accordingly.

Technical Corrections

Abstract, Line 1:

We have removed "storms and" from the first line of the Abstract.

Page 15 Lines 3:

We have replaced the numbers with percentages, as well as the reference to "five catchments" later in the same sentence (for consistency).

Author Comment in response to review by Dr. van Lanen (Referee #2)

General Comments

We thank the reviewer for their very comprehensive review and positive conclusion. The comments provided by the reviewer are constructive in their nature and have helped to considerably improve the manuscript. We have responded below to each of the points in turn, providing the clarifications requested and making the changes necessary. We hope that the reviewer finds our responses acceptable so that we can revise and improve the manuscript accordingly.

Major Comments

1) We thank the reviewer for their thoughts on the methodological approach applied in this study. Using the drought magnitude (DM) to subdivide a drought into drought development and drought termination is a core element of our approach. The decision that the DM should be the maximum negative anomaly (rather than the absolute lowest flow) was taken to objectively compare droughts and drought terminations that occur in different seasons. We agree wholeheartedly that the decisions on the parameter values are probably the most important factor in the number and characteristics of the identified drought termination events. This was demonstrated by a very preliminary sensitivity analysis as part of a previous application (not published). Following this test case, we realised that this is a complex topic and worthy of a more comprehensive analysis that we believe is beyond the scope of this already relatively long paper. For this application, we tested a number of different combinations of parameter values (informed by that previous sensitivity analysis) and decided upon 10, 1 and 2 for *D*, *R* and *T* (respectively) because they identify droughts (and terminations) that are well known and which appear in the literature (e.g. Marsh *et al*. 2007 and Parry *et al*. 2013, both cited in the manuscript). As we suggest in the manuscript, these parameters identify multi-year to multi-season droughts well and capture the spatial variability in drought risk (lower in the north and west, higher in the south and east of the UK). Our study is one of many in the literature that must make subjective decisions on parameter values related to threshold-based drought indices, such as the threshold quantile and any *n*-month accumulation period. One of the main aims of this paper is a proof of concept to demonstrate the utility of the approach in systematically identifying and characterising drought termination in the historical record. The

next stage will be to undertake a robust assessment of the sensitivity of the results to parameter values to provide advice to users. This is now included in the discussion.

2) We recognise that many drought studies apply a lower threshold than the average monthly flow such as Q70, Q80, Q90 or Q95. We have not applied any of these lower thresholds but it can be assumed that the durations of drought overall (and therefore both drought development and drought termination phases) would decrease. A lower threshold is likely to sub-divide long duration events into a number of shorter more extreme episodes each of which would have a drought termination phase. It is difficult to envisage a well constrained drought (e.g. 2010-12) containing *n* Q80-derived droughts, for example, each with their own termination. In order to focus on the multi-season to multi-year events (pg. 6, line 20) which cause water supply problems, a duration-based approach using a higher threshold is required. The question of the most appropriate threshold will also be subject to a sensitivity analysis, but is outside the scope of this paper as a proof of concept. We acknowledge that the suitability of a given threshold differs depending on individual perceptions or applications and have added text in the discussion to provide this caveat.

3) We agree with the reviewer that deficit volume based approaches are certainly important for some studies on the recovery from drought, such as to replenish stores within the catchment (e.g. reservoirs or aquifers). However, river flows are naturally integrative and the focus of this study is on river flow dynamics rather than recovering a volume of water in a river that was 'lost' during drought development. We have included text in the discussion section to reflect these different approaches.

4) One of the main overall aims of the study is "assessing the full range of drought termination types and characteristics" (pg.3, lines 14-15). The two brief case study events (1995-98 and 2009-12; sections 4.2 and 4.3) were chosen to provide a contrast between a more gradual event (1995-98) and a more abrupt event (2009-12). We recognise that the focus on 2009-12 in sections 5.2 and 5.3 may shift the focus towards abrupt events, but this was only to put the most recent event in its historical context (we could have performed the same analysis of historical context on the more gradual 1995-98, for example). We identified three comparably abrupt events to 2009-12 for the Thames catchment, but we do not say that these are the only abrupt events (4/35) for this catchment. The 2009-12 event was an extreme drought termination event; it is likely that smaller values of DTR also caused substantial problems for water managers.

5) We agree with the reviewer and have decided to remove this sentence from the manuscript.

6) We accept that the correlations presented in the manuscript are relatively weak and cannot yet be the basis of water management decisions. We have removed the suggested sentence and caveated a corresponding part of the conclusion (pg. 18, lines 20-23).

7) Whilst the approach used in the manuscript could be applied to groundwater level data, we stand by our view that this would be beyond the scope of the study which was to demonstrate that the concept can be used to systematically analyse hydrological drought termination. Future work will provide a similar systematic assessment of drought termination in long groundwater level records and show comparisons with those derived from river flows to better understand the complex concept of the propagation of drought termination. The reviewer is correct that drought termination in river flows may not correspond to drought termination in the associated groundwater level records, but this does not necessarily imply that river flow terminations have been incorrectly identified. There are also important differences between drought terminations identified in river flow and groundwater level records even within the same catchment; boreholes provide an understanding of a very localised part of a heterogeneous aquifer whereas river flow records integrate over a larger area. This question of the propagation of drought termination through the hydrological cycle is a key question that our approach could address but we feel is a large enough topic for a study in its own right.

8) We have moved the paragraphs mentioned in the reviewer comments into the discussion section.

9) It is true that the termination is traditionally an instantaneous point in time. However, we feel that 'recovery' is also a loaded term that may create confusion amongst readers. Recovery is frequently used in ecological studies to refer to the resilience of ecosystems and can relate to a period of up to five years or more over which plants and animals return following a drought disturbance. In hydrology, recovery might imply the longer-term cumulative water deficit method which our approach does not use (see response to point 3 above).

Minor comments

Pg. 2, lines 1 - 2: By removing the specific reference to recent events in the UK and combining the first two sentences of the abstract, we have reduced the emphasis on abrupt terminations and strengthened the recognition that there are a wide range of possible scenarios for drought termination.

Pg. 2, lines 21 - 24: We have removed the element of the sentence that implies potential use for water resources management (given the lack of strong relationships) and we have been more specific about the direction of correlations.

Pg. 3, lines 1 - 3: We have reduced the length of this sentence.

Pg. 3, lines 1 - 14: We have removed references to violent weather and flooding, and restructured the first paragraph to better reflect the range of possible scenarios of drought termination.

Pg. 3, lines 20 - 26: We have made reference to these two papers in terms of their consideration of the end of a drought.

Pg. 4, line 6: Following our response to point 9 above, we hope to maintain the terminology that is used consistently throughout the manuscript: drought termination as a phase of drought. We have modified the sentence explaining Bonsal *et al*. (2011) and Nkemdirim & Weber (1999) to better explain that these two studies also apply the concept of drought termination as a phase.

Pg. 4, line 20: We have rephrased this sentence so that representativeness is not concluded from having coverage of ~40% of the gauged area.

Pg. 5, lines 26 - 27 and pg. 6, lines 1 - 3: We have added text into the anthropogenic influences paragraph of the discussion to recognise the north-west / south-east bias.

Pg. 5, line 22: We have now included text that recognises the shorter records and explains the calculation when this applies. We have included statistics on data availability for those shorter records that intends to reassure the reader that the LTA values are derived from large enough sample sizes of data.

Pg. 6, line 6: We agree with the reviewer that the use of the term 'threshold' is confusing to readers. We have renamed this as the 'termination magnitude' (or TM) and have revised Fig. 2 accordingly.

Pg. 6, line 12: The DTR provides an indication of the slope of a line from the DM to the RT (now TM). We agree that the RT (TM) is an arbitrary point and we could use instead the average over the two months of $>Z_{LTAm}$, for example. We believe that the DTR is potentially useful to water managers. For two events of the same duration, a higher DTR indicates a more rapid transition from drought to potential flooding. The research presented in this manuscript focuses on the identification of events and their characterisation (including their DTR). Water managers may use the information provided by the historical chronologies to better understand how different types of catchments respond to different scenarios, and could tailor decisions or actions accordingly.

Pg. 7- 11, Chapter 4: We have updated references to "central" England to now read "the Midlands" because these terms essentially refer to the same geographic region.

Pg. 7, lines 9- 10: On reflection we agree with the comments of the reviewer so we have removed this event.

Pg. 7, line 11: The use of both "2003-04" and "2004-07" is deliberate in order to differentiate between two different events. For many catchments in south-eastern England, the events are identified separately. The 2003 event was not as severe in the UK as in Europe, and the 2004-07 event was much more problematic than the 2003 event in south-eastern England. Hopefully now that "2003-04" has been removed (see response above) any confusion can be avoided.

Pg. 7, line 16: On reflection we agree with the comments of the reviewer so we have removed this event.

Pg. 7, lines 22- 23: We agree with the comments of the reviewer and have added Anglian into this statement.

Pg. 7, line 25 and pg. 8, line 4: We agree that this reads as a contradiction so we have removed the first statement and clarified the second statement.

Pg. 8, line 7: We propose to retain the current text because we prefer the reader to consider the widespread nature of drought rather than being pre-occupied with why a specific catchment was the exception.

Pg. 8, line 9: The reviewer is correct that we mean a three-year overall drought duration in the south and east, so we have clarified the text accordingly.

Pg. 8, lines 14- 16: We have specified the exceptions to this statement.

Pg. 8, line 18 and pg. 9, line 10: We have removed the two references to Thames region.

Pg. 8, line 19: We have added two example references from the literature.

Pg. 8, lines 26- 27 and pg. 9, lines 1- 2: We have added text to acknowledge the prevalence of >3-season drought terminations.

Pg. 9, lines 10- 11: We agree with the reviewer that there is inconsistency and we have modified both paragraphs for clarity.

Pg. 9, lines 24- 25: We agree with the comments of the reviewer and have made this modification.

Pg. 10, lines 16- 17: We have made this modification.

Pg. 10, lines 24- 26: We have removed this sentence.

Pg. 11, lines 9- 10: We have indicated in Table A1 the catchments which are included in the subset, and have referred to Table A1 on pg.11, lines 9-10.

Pg. 12, line 5: We have made this modification.

Pg. 12- 16. Discussion: We have added a new section into the discussion which evaluates the chronologies of drought termination relative to the wider literature on the spatio-temporal distribution of drought (and drought termination) in the UK.

Pg. 13, line 23- 24: Even though the DM is an instantaneous value, one would think a larger DM is more likely to lead to longer drought termination duration (DTD), as found by Nkemdirim & Weber (1999), rather than shorter. For responsive catchments, it may be that DTD is insensitive to DM because the rainfall input dominates the trajectory of drought termination.

Pg. 14, line 10: We have made this modification.

Pg. 14, lines 20- 23: We have removed Fig. 6 and now refer to Marsh *et al*. (2013).

Pg. 16, lines 5- 7: We have added a reference to Fig. 5 bottom right.

Pg. 16, lines 27- 30 and pg. 17, lines 1- 2: We have modified the text in order to retain some of the different synoptic drivers that have been shown to be influential on drought termination, but to clarify that further work is required to assess whether these factors are important in the historical chronology of drought termination for the UK.

Pg. 17, lines 12- 22: We have moved this section into the discussion.

Pg. 17, lines 23- 26, pg. 18, lines 1- 2: We have moved this section into the discussion.

Pg. 18, lines 3- 10: We have moved this section into the discussion.

Pg. 19, lines 2- 4: We have removed the reference to hydrometeorological variables but maintained groundwater and merged it with the following sentence on water quality and ecology.

Pg. 24, caption: There is no duplication in explaining the definition of DTD, DTR, DDD and DM between the captions of Table 1 and Fig. 2. The terms DTD, DTR, DDD and DM are not used in the caption of Fig. 2.

Pg. 25, Table 2: We have revised the table headings in Table 2 as suggested by the reviewer.

Pg. 28, Fig. 1: We have added acronyms and description of regions from the caption of Fig. 3 to the caption of Fig. 1 (and removed them from the caption of Fig. 3 to avoid duplication). We have added acronyms to the legend in the top left. We have removed the colours from the inset map and now use lines to label constituent countries.

Pg. 29, Fig. 2: We have removed the '+ve' and '-ve' directions for Z_{anom}.

Pg. 29, caption Fig. 2: We have added the word "consecutive" into the caption of Fig. 2.

Pg. 30, Fig. 3: We have modified the caption of Fig. 3 to indicate that a decade can be subdivided into 120 monthly time steps as well as information on the total number of time steps along the *x*-axis. We have deleted the acronyms denoting the regions from the caption of Fig. 3, moving them instead to the caption (and legend) of Fig. 1.

Pg. 31, Fig. 4 and pg. 32, Fig. 5: We have modified the duration legend accordingly.

Pg. 31 and pg. 32, captions Fig. 4 and 5: We have deleted the acronyms and descriptions of regions from the captions of Fig. 4 and Fig. 5 and added them into the caption of Fig. 1.

Pg. 33, Fig. 6: We have removed Fig. 6.

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)~~. Greater ~~A~~attention ~~devoted~~ may be given to these newsworthy and memorable events ~~may be at the expense of~~but drought terminations that proceed gradually ~~and~~ also pose ~~a different set of~~ challenges for water resource managers. This paper defines drought termination as a distinctive phase of the event ~~drought~~. Using observed river flow records for 52 UK catchments, ~~in its own right and makes the case for~~ a more systematic and objective approach ~~to its identification and characterisation, applying an objective approach to~~ for detecting drought terminations ~~in observed river flow records for 52 catchments~~ is demonstrated. The resulting ~~archive~~ inventory of 459 drought terminations provides an unprecedented historical perspective on ~~drought termination~~this phenomenon in the UK. Nationally- and regionally-coherent drought termination events are identifiable, although ~~drought termination~~their characteristics vary both between and within major episodes. Contrasting drought termination events in 1995-98 and 2009-12 are ~~described~~ examined in greater depth. The data~~set is~~ are 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 (r_s=-0.48) and catchment average rainfall (r_s=-0.40), suggesting that wetter catchments in upland areas of the UK tend to experience shorter drought terminations. More urbanised catchments ~~have a~~ tend~~ency for~~ to have gradual drought terminations ~~,~~ (contrary to ~~perceptions~~ expectations of

flashy hydrological response in ~~these~~ such areas)~~,~~ although this may also ~~be related to~~reflect the type of catchments typical of lowland England. ~~Potential linkages~~Significant correlations are found between the duration of the drought development phase and both the duration (r_s=-0.30) and rate (r_s=0.28) of drought termination~~ and the duration of the preceding drought development phase, which may have important implications for water resources management during a drought~~. This suggests that prolonged drought development phases tend to be followed by shorter and more abrupt drought terminations. The ~~dataset~~ inventory helps to place individual events within a long-term context. The drought termination phase in 2009-12 was, at the time, regarded as exceptional in terms of magnitude and spatial footprint but the Thames river flow record ~~reveals~~ identifies several comparable events before 1930. ~~Hence, the approach adopted and the chronologies of drought termination enable objective intercomparison of events.~~ The ~~dataset~~ chronology could, ~~may~~ in due course, provide a basis for ~~better understanding~~exploring the complex drivers, long-term ~~trends in occurrence and characteristics~~variability~~,~~ and impacts of ~~historical and contemporary~~ drought termination events.

1 Introduction

Drought termination, generally defined as the end point of a drought, ~~has often been associated with violent weather conditions and flooding, including in Colorado (Lavers & 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~~ has been neglected in research literature relative to drought onset. 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 more destructive and newsworthy impacts (e.g. Webster et al. 2011; Lavers & Villarini 2013; Parry et al. 2013), gradual drought terminations ~~may be~~are problematic for water resource managers who must reconcile public relations with continued water restrictions during wet weather.

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 & Small 2014) or experimental catchment data (e.g. Miller et al. 1997; Lange & Hansler 2012). Even considering several events (e.g. Eltahir & Yeh 1999; Shukla et al. 2011) is too limited a sample to generalise, ~~(e.g. Eltahir & Yeh 1999; Shukla et al. 2011)~~ or move beyond qualitative descriptions (e.g. Parry et al. 2013). A systematic assessment of drought termination would enable a more robust analysis of their spatial and temporal variability. Moreover, the importance of the end of a drought has already been recognised as a criterion in a hydrological drought typology and a basis for differentiating drought types (Van Loon & Van Lanen 2012; Van Loon et al. 2015).

Studies that systematically identify ~~drought termination~~the ends of droughts 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.~~ There are two notable exceptions. Bonsal et al. (2011) sub-divided drought into six ~~phases~~stages, one of which is the concept of ~~including~~ drought termination as a phase considered herein ~~(referred to as 'recovery')~~, and Nkemdirim & Weber (1999) expressed the concept of a rate of drought termination ~~rate (referred to as 'rate of recovery')~~ using Palmer Drought Severity Index units over time.

~~Some p~~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. in ~~review~~press), 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). The approach adopted in these studies differs from others (e.g. Kam et al. 2013; Patterson et al. 2013) by considering drought termination to be a period of a drought event with its own start, end and duration between these points.

~~–~~By combining these spatial (Parry et al. in press) and temporal approaches (Parry et al. 2015), the aim of this study is to derive chronologies of drought termination ~~metrics~~ for 52 UK catchments. These data are ~~then~~ subsequently used to assess the historical variability of drought termination and to explore the link between drought termination metrics and catchment properties~~, and to assess the historical variability of drought termination~~. ~~In due course, i~~It is ~~hoped~~ anticipated that a better understanding of the physical processes driving drought termination will lead to improved water resources management and forecasting during these problematic episodes in the future.

2 Data

Catchments were selected on the basis of their area and record length, favouring larger catchments with longer records in order to maximise the spatial and temporal coverage of the chronologies. This selection was supplemented by additional catchments to improve representation of the diversity of hydrogeological conditions in the UK. The resulting ~~Fifty-two~~52 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~~ing~~ for more than 40% of the gauged area of the UK~~)~~ 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 south and east and for the larger catchments, flows may be affected by anthropogenic influences (such as abstractions and return flows)~~,~~ which ~~have been shown to~~can mask changes associated with drought termination (Ning et al. 2013). A naturalised river flow ~~time~~ series is used for the Thames; no other naturalised series are available for the study catchments. River flow data were obtained from the UK National River Flow Archive (NRFA). Start dates range between January 1883 and June 1982, but all series extend to September 2013. Time series of monthly mean river flows ~~data~~ were derived for each catchment for every month in which at least 90% of the daily data were available. Metadata on catchment area, median elevation, Standard-period Average Annual Rainfall for 1961-90 (hereafter SAAR6190; Spackman 1993), Base Flow Index (hereafter BFI; Gustard et al. 1992), and urban extent (Marsh & Hannaford 2008) were also obtained for each catchment from the NRFA (Table A1).

3 Methodology

3.1 Defining drought termination

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Drought termination is defined here as a phase of a drought, rather than an instantaneous point in time. The threshold level method (Zelenhasić & Salvai 1987) has been applied on a monthly time step, and drought events are sub-divided at the point of the maximum negative flow anomaly (Bravar & Kavvas 1991) into two phases: drought development and drought termination (Fig. 2). Drought termination is characterised by its duration (e.g. Bonsal et al. 2011), rate of change (e.g. Correia et al. 1987; Nkemdirim & Weber 1999), and seasonality (e.g. Mo 2011).

For each catchment, monthly mean flow data were converted into a percentage anomaly of the monthly long-term average (LTA), calculated from a 1971-2000 reference period (Eq. 1).

$$Z_{anom} = 100\left(Z_{obs} / Z_{LTA_m} - 1\right) \quad (1)$$

where t is the time step index, m is the month of the time step, Z_{anom} is the percentage anomaly at t, Z_{obs} is the observed value at t, and Z_{LTA_m} is the LTA at m. Where river flow records commence after 1971 (13 of the 52 catchments; Table A1), the monthly LTA is an average of all available monthly mean flows within the 1971-2000 timeframe. Of these 13 catchments, only five sets of monthly LTAs are derived from less than 24 years of available data and all catchments have at least 19 years in the 1971-2000 period.

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

The end of the drought development phase (t_{ed}; Fig. 2) is the month with the largest negative Z_{anom} 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 two phasesstages 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 thresholdtermination magnitude, 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'. Because seasonality is assessed on the entire drought termination period rather than its beginning or end, when drought termination durations span four or more seasons they are considered not to have a seasonality.

3.2 Parameter selection

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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 ET point. These values were applied to all of the study catchments.At the outset, expert judgement was used to select parameters which identified well known hydrological droughts in the historical record (for example, those outlined in Marsh et al. 2007). This study on a drought chronology for the UK identified an average of two events per decade over the last 50 years. Experimentation with different parameter sets suggested that a moderately high value for *D* is required to ensure a focus on multi-season and multi-year droughts. The value of *R* must balance between identifying unrealistically large numbers of events or none at all. Combining these findings with prior expert knowledge on drought occurrence in the UK, the following parameters were identified as appropriate for the aims of this study: *D*=10; *R*=1; *T*=2.

Once the parameters had been selected, response surfaces were used to provide quantitative support for this decision. At first glance across a range of catchment sizes, characteristics and hydroclimatic settings, the parameters above generally satisfy the approximate events per decade criteria outlined above. Two contrasting catchments were selected to illustrate typical patterns of sensitivity in the response surfaces. The Scottish Dee (Eastern Scotland; Fig. 3, left) is a relatively wet upland catchment with impermeable geology and a flashy hydrological response, whilst the Itchen (Southern England; Fig. 3, right) is a relatively dry lowland catchment with permeable geology and a buffered hydrological response. The combination of parameters above is indicated by bold boxes on the response surfaces in Fig. 3.

The response surfaces illustrated how the numbers of drought events identified varied with parameter selection. Fewer events were identified with increasing *D* (moving from left to right in Fig. 3, top left and top right) due to stricter criteria for drought initiation. Conversely, increasing *R* (for a given *D* and *T*, moving from bottom to top in Fig. 3, top left and top right) detected more events because this relaxed the initiation criteria (ratio between *D* and *R*) to allow more intermittent months above the average flow threshold. As *T* increased (for a given *D* and *R*, moving from bottom to top in Fig. 3, top left and top right), the number of identified events decreased as the threshold for completion of drought termination became more stringent. These patterns were consistent across a range of catchment sizes, characteristics and hydroclimatic settings.

Although the number of identified events was the primary verification provided by the response surfaces, variations in the average characteristics of the resulting events were also explored. For total drought duration (TDD), increasing *T* for the Scottish Dee (moving from bottom to top in Fig. 3, middle left) caused identified droughts to lengthen considerably and resulted in merging of previously distinct events into unrealistically long periods (e.g. exceeding 120 months, or 10 years). The Itchen did not exhibit this behaviour (Fig. 3, middle right) suggesting that individual drought events were typically separated by long spells (greater than six months) with above threshold flows such that merging was less likely. This was consistent with the lower variability of river flows in groundwater influenced catchments like the Itchen. Similar contrasts between the two catchments were also apparent for drought termination rate (DTR; Fig. 3, bottom left and bottom right), in part because duration is a component of the DTR calculation. Higher values of *T* caused more merging of events in responsive catchments such as the Scottish Dee, increasing TDD (and DTD) and thereby reducing DTR.

In general, drought termination metrics showed greater sensitivity to parameter values in more responsive catchments (less responsive catchments were insensitive). Severe initiation criteria (high *D* and low *R*) and larger values of *T* are not appropriate for responsive catchments because these combinations are physically implausible, resulting in the merging of events into unrealistic durations with corresponding effects on derived drought termination metrics.

These key findings of the sensitivity analysis verified the initial decision on parameter selection. Values of *D*=10, *R*=1 and *T*=2 do not over- or under-represent drought occurrence for catchments of different size, geology or average rainfall, whilst primarily identifying severe multi-year and multi-season events that form the focus of this study. For these reasons the same parameter values were applied to all 52 catchments in this study, and enabled a comparison of drought termination characteristics across catchments without the influence of variations in parameter selection.

3.3 Correlation analysis

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~~To assess p~~Potential relationships between~~with~~ drought termination characteristics and catchment properties were explored through a correlation analysis. Since the majority of drought termination characteristics are not normally distributed, and to limit the influence of outliers, the Spearman rank correlation~~s~~ test (Spearman 1944) ~~were calculated~~was applied to the inventory of drought development and drought termination characteristics and catchment metadata. ~~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~~using all 52 catchments, ~~and~~ as well as on a ~~smaller~~ subset of catchments ~~for which~~with at least ~~ten~~ 10 drought terminations events ~~were identified~~. ~~This provided a more robust sample size for deriving catchment average values of drought termination characteristics, which may smooth out inter-event variability and result in stronger correlations.~~ By omitting catchments with only a few identified events, a subset of catchments is retained for which catchment average drought termination characteristics are more robust against the potential variability exhibited by individual atypical events.

4 Results

4.1 Spatio-temporal variability of drought termination

Drought termination chronologies for all 52 catchments, approximately ordered from the north-west (top) to the south-east (bottom) of the UK, are presented in Fig. ~~3~~4. This allows visual inspection of the spatial coherence of drought events over a common data period beginning in the early 1970s. ~~Figure 3 shows that~~ At a national ~~-~~scale, droughts have been relatively infrequent, occurring only in 1975-77 and~~,~~ 1995-98~~, and possibly 2003-04~~. Regional droughts affected southern and eastern areas in 1988-93, 2004-07 and 2009-12. Drought-poor periods are also evident, the longest of which was the decade following the 1975-77 event~~,~~ during which there were few ~~widespread or~~ prolonged droughts at either regional or national scales.

Prior to 1970, a lack of river flow data before gauged records commenced (particularly in northern and western areas of the UK; Table A1) limits the assessment of the spatial coherence of drought phases, but events in 1962-64 and~~,~~ 1959 ~~and 1943-45~~ are identifiable in longer records in South-west UK, Anglian, Southern England and the Midlands. Persistent drought conditions (with intermittent drought terminations) within the 1890-1910 'Long Drought' (Marsh et al. 2007) are observed in the Thames river flow record from 1883.

Drought terminations show considerable spatio-temporal variability. For example, the 1988-93 event had a notably uneven temporal evolution, with the transition to drought termination occurring early in the drought followed by a long drought termination phase for catchments in South-west UK and Anglian, whereas shorter drought terminations were apparent in the rest of the country. ~~Conversely, the drought termination in 1995-98 was relatively coherent at a regional scale.~~ Fewer droughts have occurred in northern and western areas of the UK than in southern and eastern areas, while 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 drought termination events are singled out for more detailed analysis: 1995-98, the most ~~nationally coherent~~widespread event ~~in the post-~~since the 1970s~~-period~~; and 2009-12, reported as unprecedented in the historical record (Parry et al. 2013).

4.2 Event analysis: 1995-98

Drought in 1995-98 affected all but one of the study catchments (Fig. ~~4~~5; left), offering the best opportunity to analyse the spatial variability of drought termination within ~~an individual episode~~ a single, severe event. The overall duration of drought was ~~generally longer (almost~~up to three years~~) further~~ in the south and east in the UK but generally shorter in the north. 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 generally spatially coherent across North & Central Wales, Midlands, South-west UK and Southern England, with the exceptions of the Conwy (NCW), Tywi (SWUK) and Great Stour (SE).

Drought termination durations were generally longer (by six to nine months) for catchments in Southern England~~, Thames~~ and Anglian regions (Fig. ~~4~~5; top right). Conventionally referred to as the 1995-97 drought in the literature (e.g. Marsh et al. 2013; Spraggs et al. 2015), 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 1995-98, particularly apparent for Wales, ~~and~~ southern~~, central~~ and eastern England, and the Midlands (Fig. 5~~4~~; middle right). Whilst much of Wales and south-west England exhibited drought termination rates of 16-32% per ~~/~~month, this decreased to less than 8%~~/~~ per month across large areas of south-eastern England. Further north, the pattern was more mixed. Two-season drought terminations (Fig. 5; bottom right) generally were confined to the far northern parts of Scotland and England. Three-season drought terminations ~~(Fig. 4; bottom right)~~ started in the autumn in Scotland ~~-~~and in the winter in Wales, ~~and central and~~ south-western England and the Midlands.~~ Two-season drought terminations generally were confined to the far northern parts of Scotland and England.~~ Long drought terminations (more than eight months across four or more seasons) in many catchments in Western Scotland, Northern Ireland, North-west England, North-east England, Anglian and Southern England prevented an assessment of drought termination seasonality.

4.3 Event analysis: 2009-12

In contrast to the 1995-98 event the 2009-12 drought was regional, primarily affecting ~~Wales and southern, central and eastern England~~ North & Central Wales, South-west UK, Anglian, Southern England and the Midlands. The temporal sequencing of drought termination was also more regionally variable than in 1995-98. Drought terminations began much sooner (early summer 2010) in North-west England, and had ended whilst drought continued to develop further south (Fig. ~~5~~6; left). Droughts terminations started in South-west UK up to a year before those in ~~central and eastern England~~Anglian and the Midlands. In ~~the Midlands, Thames,~~ Anglian, ~~and~~ Southern England ~~regions~~and the Midlands, drought termination began in winter 2011/12 or spring 2012 and ended in late spring or early summer 2012. The end of the drought termination phase was much more spatially coherent in 2009-12 than in 1995-98.

Drought termination durations in 2009-12 were generally six months or less (Fig. ~~5~~6; top right), much shorter than those for 1995-98. There was a gradient in drought termination duration from north-east to south-west across the affected catchments. The shortest durations (1-3 months) occurred across southern~~, central~~ and eastern England and the Midlands, but lasted longer (10-18 months) for catchments in the south-west of England and Wales. The highest drought termination rates (more than 32% per ~~/~~month) occurred in the largest catchments, whilst ~~the~~ lowe~~st~~rst values (less than 16% per ~~/~~month) were restricted to smaller catchments in Northern Ireland, North-east England and the ~~coastal counties of southern~~far south of England (Fig. ~~5~~6; middle right). Drought termination rates in 2009-12 showed a similar gradient to drought termination duration. There was more uniformity in drought termination rate across the drought-affected area for 2009-12 than in 1995-98, and drought terminations ~~rates~~ were generally more abrupt in 2009-12.

There was ~~a larger degree of~~greater seasonality for the 2009-12 drought (Fig. ~~5~~6; bottom right) than for the 1995-98 event because drought terminations were generally shorter and started at different times. Catchments in southern~~, central~~ and eastern England, the Midlands and north Wales experienced drought terminations ~~through the summer half-year~~in spring and/or summer. Drought terminations ~~through~~ in the winter months were ~~not very~~un~~-~~common for the 2009-12 event.~~,~~ Winter drought terminations were restricted to the Warwickshire Avon (Midlands) and smaller catchments in the Anglian and Southern England regions.

4.4 Drought termination and catchment properties

The above 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 Stringside in Anglian and the Itchen and Dorset Avon in Southern England) ~~in~~ during both 1995-98 and 2009-12, although this link does not apply for all identified drought termination events in the historical record. However, the synchronicity of the end of drought termination in spring 2012 (Fig. ~~5~~6; left), when compared to the incoherent end of drought termination in 1995-98 (Fig. ~~4~~5; left), suggests that catchment properties are less influential during abrupt drought terminations than during gradual events.

Spearman correlations between drought ~~termination~~ characteristics (magnitude, termination duration and termination 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~~inventory of events. Correlations were assessed for individual drought 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.~~

The strongest correlation (r_s=-0.48; *p*~~=0.000407~~<0.001) was found ~~for~~ between catchment average drought termination duration and median elevation, suggesting that upland catchments tend to experience shorter drought terminations. ~~Although slightly weaker,~~ Similarcorrelations ~~with~~ are found between SAAR6190 (r_s=-0.40; *p*=~~0.00366~~0.004) ~~show a similar pattern~~and drought termination duration, ~~possibly explained by notable autocorrelation~~most likely due to the strong association between elevation and rainfall (r_s=0.71; *p*~~=2.03x10^{-8}~~<0.001). Drought termination rate and urban extent are negatively correlated (r_s=-0.43; *p*=~~0.00172~~0.002). This association may be influenced by a groundwater signal that is generally stronger in the more urbanised south and east of the UK, although ~~. C~~correlations between the BFI and drought termination rate are ~~relatively~~ weak (r_s=-0.12; *p*=0.412).

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~~ 10 identified drought termination events (Table A1). A ~~stronger (though not~~ statistically insignificant~~)~~ ~~link~~ correlation was found between catchment average drought termination rate and BFI (r_s=-0.36; *p*=0.156). ~~This implies that~~ This is consistent with the expectation of faster drought termination rates (i.e. more abrupt drought endings) in 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 (r_s=0.49; *p*=0.049) and drought termination rate (r_s=-0.47; *p*=0.057) were comparable.

For correlations between the properties of the ~~drought termination characteristics and those of the preceding~~ drought development phase and drought termination characteristics, ~~although relatively weak the strongest~~significant relationships were detected for drought development duration with both drought termination duration (r_s=-0.30; *p*~~=1.07x10^{-10}~~<0.001) and drought termination rate (r_s=0.28; *p*~~=7.35x10^{-10}~~<0.001). This ~~suggests~~ implies that ~~prolonged~~ sustained periods of drought development ~~phases~~ tend to be ~~followed~~ succeeded 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~~ associations (e.g. between drought magnitude and drought termination duration, or between drought development duration and drought termination rate) are significant ~~at the 95% level~~(p<0.05).

5 Discussion

This study has systematically ~~defined~~ discretised drought terminations in ~~the~~ historical river flow records for the UK for the first time. The ~~approach~~ detection method ~~has~~ identified 459 drought events across 52 study catchments, providing a comprehensive ~~dataset~~ inventory for further analysis of the historical variability of drought termination. Two aspects ~~were~~ are explored here: 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 2009-12 within a broader hydrological context. In addition, this section also corroborates the inventory of drought events and their terminations against existing work in the research literature, and considers the influence of the data and methodology on the results.

5.1 Drought termination characteristics and catchment properties

Whilst the amount and timing of rainfall affects the corresponding characteristics of drought termination, ~~The~~ spatio-temporal variability in drought termination within individual events (Fig. ~~3~~4; Fig. ~~4~~5; Fig. ~~5~~6) is also partly ~~related to~~determined by catchment properties ~~that modulate the rainfall inputs~~. This ~~reflects other~~supports the findings of earlier studies that ~~found~~ show hydrological drought termination to be more spatially variable than drought development, owing to the heterogeneity of catchment characteristics (e.g. Nkemdirim & Weber 1999; Bell et al. 2013; DeChant & 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, therefore, do not reflect the changing proportion of a catchment as built area ~~through the 20th century~~outside of this short period. Further ~~analysis will~~research could be ~~required~~ undertaken to assess the impact of increasing ~~urbanisation~~ urbanised area on ~~trends~~ changes in drought termination characteristics within ~~the~~ certain study catchments under increasing development pressure (e.g. the Great Stour in Southern England).

The BFI is widely regarded as a proxy for groundwater influence in the UK. However, water storage in lakes and seasonal ~~snowpacks~~ snow cover 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~~soil moisture ~~(Thomas et al. 2014)~~ and groundwater levels (e.g. Eltahir & Yeh 1999; Thomas et al. 2014).

~~The s~~Stronger relationships identified in the larger dataset between drought development and drought termination characteristics suggest that catchment averaging ~~both~~ of metrics ~~before~~ prior to correlation analysis may smooth out unique ~~pairs of characteristics~~associations, resulting in information loss and obscuring ~~any detectable~~some signals. ~~Weak~~ A weak negative (~~although~~ but statistically significant) correlation was found between drought magnitude and drought termination duration, contrary to ~~a~~ the pattern ~~observed~~ reported for two multi-year droughts in the US (Nkemdirim & Weber 1999). The most important linkages identified between drought development and drought termination characteristics were for between drought development duration with and 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 (short duration and/or high rate of drought termination). Although these correlations are only moderate and require further analysis, there may be important implications for the management of water resources beyond any possible critical time threshold within a drought.

5.2 Validating the chronologies of drought termination

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The rarity of national scale droughts over the instrumental period (i.e. 1970s onwards) – limited to events in the mid-1970s and mid/late 1990s – corroborates previous work on regional drought in Europe (Hannaford et al. 2011). The locus of the 1988-93 drought in the south-east of the UK confirms the chronology of Marsh et al. (2007). Time series of regional drought (Hannaford et al. 2011) identify a number of minor periods of river flow deficiency in the decade following the 1975-77 event but such episodes were not prolonged or severe enough to be detected in this study. However, the 1962-64 drought was identifiable here despite the limited spatial coverage of river flow data. This event has been cited as an important multi-year drought at both UK and European scales (Parry et al. 2012). Similarly, Marsh et al. (2007) identify both the 1959 event and 1890-1910 'Long Drought' when cataloguing major droughts in the UK. Whilst the use of standardised indicators (e.g. Hannaford et al. 2011) identifies the same amount of time under deficit conditions in each region, it is clear that streamflow deficiencies are fewer but more prolonged in southern and eastern areas of the UK, confirming the results presented herein.

5.25.3 Drought termination rate for 2009-12 in a historical context

The rate of drought termination in 2009-12 was particularly abrupt, – more so than any other event identified in the post-1970 common data period. Almost a third (nine out of 31) of the drought-affected catchments in 2009-12 registered new maxima for drought termination rate (Table 2). For the Severn, the drought termination in 2009-12 was almost four times more abrupt than any other event since records began in 1929. , andThis ranked ranks amongst the top five most abrupt drought terminations for *any* event in *any* of the 52 study catchments (*n*=459) although lagging substantially behind the most abrupt drought termination in this same dataset: the Whiteadder Water (Eastern Scotland) in 2004-07, which was a third larger than the second ranked event. Drought magnitudes in 2009-12 were not exceptional but it was the differences between drought magnitudes and ~~recovery thresholds~~termination magnitudes over such short drought termination durations ~~in 2009-12~~ that were particularly ~~influential~~ noteworthy in establishing new maximum drought termination rates. This suggests that exceptional rainfall totals accumulated over short durations (assessed as greater than a 100-year return period; Bell et al. 2013) ~~was a~~were more important ~~factor~~ than the severity of the preceding drought.

Research conducted in the immediate aftermath of the 2009-12 event suggested that the drought termination was unprecedented in the historical record (Parry et al. 2013; Marsh et al. 2013). However, the assessment of the rarity of such abrupt transitions was based on ratios between average river flows over arbitrarily defined periods (May-July and the preceding December-March; Marsh et al. 2007~~Fig. 6~~). The more systematic approach adopted here allows an objective re-appraisal of the historical context across all timeframes. Although the drought termination event in 2009-12 remains the most abrupt on record for the Thames (Table 2), there were three other comparably abrupt drought terminations between 1883 and 1930. This suggests that the rarity of the 2009-12 drought termination may have been overstated ~~in previous work~~ (in the specific case of the Thames).

~~Although difficult to assess consistently prior to 1970 due to limitations in data availability, t~~The drought termination phases in 2009-12 and 2004-07 were the most abrupt on record for ~~nine~~ 17% and ~~eight~~ 15% of the 52 catchments, respectively; no other event registered new maxima in more than ~~five~~ 10% of catchments, although this is difficult to assess consistently prior to 1970 due to limitations in data availability. These recent severe multi-year droughts featured consecutive dry winters (Wilby et al. ~~in press~~2015), ~~perhaps suggesting~~supporting the view that long droughts result in more abrupt drought termination phases. ~~They are also the most recent of the identified events~~However, ~~although~~ the ~~suggestion~~ possibility that drought termination rates ~~have~~ are ~~become~~ becoming more abrupt ~~requires~~ warrants further exploration. ~~The characteristics of the 2009-12 drought termination are consistent with studies that describe drought termination as abrupt (e.g. Dettinger 2013), and more rapid than drought development (e.g. Mo 2011).~~

~~However, t~~The wide ~~range of~~variation in drought termination rates both *between* and *within* catchments suggests that different drought termination mechanisms are ~~plausible~~at work.

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Drought termination ~~is~~ reflects a complex interplay of the specific hydroclimatic conditions ~~and~~ with local catchment properties, even for groundwater influenced permeable catchments (in which the rainfall signal is substantially modulated by ~~catchment properties~~geology). Groundwater drought termination has been observed to be much slower than drought development in the western US (Bravar & Kavvas 1991). Whether this applies to individual events in groundwater influenced catchments in this study would depend on the extent to which deficits have propagated to groundwater. The artificial depletion of groundwater aquifers in Southern England may also have impacted drought termination characteristics in some catchments (e.g. the Itchen). The approach adopted in this study could be ~~applied~~ extended to groundwater level records ~~where they exist within the catchments, although this is beyond the scope of this analysis~~as a further line of research. Similar variability in drought terminations was ~~also found~~reported by Bonsal et al. (2011), and was attributed by Kam et al. (2013) to differences in rainfall intensity determined by the ~~type of~~ synoptic ~~drivers~~ conditions (e.g. tropical cyclones).

~~5.3~~5.4 Drought termination seasonality for 2009-12 in a historical context

The drought termination in 2009-12 occurred through the spring and early summer, an unusual but not unprecedented ~~occurrence~~event. Only nine of the 459 drought terminations occurred entirely in spring or in summer. Five of these nine relate to the 2009-12 event (the Severn, Trent, Derwent and Witham in spring, and the Colne in summer). With the exception of the Severn, the drought termination in 2009-12 is the only single season event in the historical record for each catchment. Drought terminations across both spring and summer are similarly ~~uncommon~~rare. Of the 13 events (out of 459) with spring-summer drought termination seasonality, five occurred in 2009-12 (the Yscir, Exe, Thames, Itchen and Sydling Water; Fig. 6, bottom right). 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~~unlikely that multi-season droughts will terminate 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~~ is most likely to facilitate drought termination (Karl et al. 1987; Mo 2011). In the UK, these two factors ~~are coincident~~conincide~~,~~ ~~so the~~hence 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~~tendency for drought terminations ~~towards~~ in 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~~are involved. 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 & Espinoza 2015), switches in Atlantic temperatures (Wilby 2001; Folland et al. 2015)~~, or~~ and tropical cyclones (e.g. Kam et al. 2013; Patterson et al. 2013) have been shown to be a factor in drought termination events. Further research is required to assess the extent to which changes in these and other synoptic drivers might be influencing the seasonality of drought terminations in the UK. For instance, Matthews et al. (2015) report relatively low frequencies of summer cyclones in the period 1961-90 but a marked resurgence in counts since the 1990s.

5.5 Impact of methodology and data on results

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Although the detection procedure utilised herein applied consistent rules, the parameter values used to define a drought and its phases can influence the resulting chronology. This is illustrated by the sensitivity analysis (Fig. 3) and has been reported by other studies (e.g. Patterson et al. 2013). Drought termination phases following shorter drought developments, for example driven by summer heatwaves, would not be well represented by the parameter settings used in this study. This is because the parameters which determine the initiation of drought development (*D* and *R*) require below average river flows for at least nine of ten consecutive months, a timeframe which is too prolonged to adequately characterise typical single season drought events. 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 set by regional water companies, with drought-induced water restrictions expected more frequently in the south-east of the UK than in the north. Nevertheless, there is a need to more comprehensively assess the sensitivity of derived chronologies of drought termination to the choice of detection parameters.

The monthly time step used in this study may also be limiting. Drought termination can occur rapidly, perhaps within a few days in some instances of intense cyclonic activity. Under these circumstances, monthly data may obscure accurate definitions of the end of drought termination or underestimate the drought termination rate. In addition, the use of a monthly average flow threshold is higher than those sometimes applied in threshold-based studies. This may overestimate the overall duration of drought as well as the drought development and drought termination phases.

The approach utilised in this study focuses on the dynamics of river flows, which can increase substantially over relatively short timescales and replenish water supplies rapidly. However, it is acknowledged that deficit volume approaches (in which the accumulated volume of water 'lost' during drought development is recovered) may be important for studies which focus on the overall water balance.

The potential influence of abstractions from surface and groundwater sources during drought development may artificially extend the duration of the drought termination phase. The catchments used in this study include some of the largest in the UK in order to maximise spatial coverage, and few of these could be described as near-natural. Abstractions to meet higher water demand during drought development, particularly during heatwave conditions, combine with lower natural recharge. Drought-terminating rainfall must account for this 'anthropogenic deficit' in addition to the natural hydrological deficit. There is a regional bias in the anthropogenic influence on river flows, with more impacted catchments in the south and east of the UK and more near-natural catchments in the north and west. Whilst this spatial pattern also reflects the number of droughts identified, the selection of parameters that favour major multi-season droughts is probably more influential. The use of monthly mean river flows may also dilute the impact of artificial influences on individual days.

6 Conclusions

For the first time, drought terminations have been systematically identified in the UK. This ~~analysis~~ study 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~~ provides a new perspective ~~to~~ on 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 further research into any emerging trends ~~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 definitions of the end of drought termination or underestimate the drought termination rate.~~

~~The potential influence of abstractions from surface and groundwater sources during drought development may artificially increase the duration of the drought termination phase. The study catchments include some of the largest in the UK in order to maximise spatial coverage, and few of these could be described as near-natural. Abstractions to meet higher demand during drought development, particularly during heatwave conditions, are superimposed upon restricted recharge. Drought-terminating rainfall must account for this 'anthropogenic deficit' in addition to the natural river flow deficiencies.~~

Investigations into the link between drought termination characteristics and catchment properties or drought development characteristics would ~~benefit from~~be strengthened by a larger sample of events. ~~This is illustrated by the s~~Stronger correlations were found for catchment average drought termination metrics when using the subset of catchments with at least ten identified events, although this subset is biased towards catchments with longer records predominantly in southern and eastern areas of the UK. The BFI is not an adequate ~~metric~~ predictor of the responsiveness of a catchment. Further exploration of potential linkages between drought termination characteristics and catchment properties should seek to use variables which are more closely related to river flow responsiveness than BFI (e.g. a flashiness index; Baker et al. 2007). The use of ~~P~~potential associations between drought termination characteristics and those of the preceding drought development phase ~~may be useful for~~by water resource managers ~~in plotting near real-time drought termination trajectories based on the evolution of drought~~is constrained by weak to moderate correlations and requires further research before useful conclusions can be drawn. Ideally, coupled land-atmosphere model experiments would be performed to explore possible links between drought duration or magnitude and terminating rainfall mechanisms.

The identification and characterisation of 459 drought terminations has provided a comprehensive historical context within which to place the notable 2009-12 event. This illustrates the variability of drought termination characteristics in the UK, re-assessing the conclusion (based on a subset of newsworthy examples) that droughts tend to terminate abruptly. The long-term context could be improved further through the use of river flow reconstructions (e.g. Jones and Lister 1998; Jones et al. 2006) to 'fill in the grey space' in Fig. ~~3~~4, which represents the best historical perspective provided by available observed data. ~~Similarly comprehensive chronologies of drought termination in groundwater level records and other hydrometeorological variables have not yet been produced.~~ The method used in this study has the flexibility to produce similarly comprehensive chronologies of drought termination in groundwater level records, water quality metrics or ~~be applied to these and other metrics (e.g. water quality and~~ ecological indices~~)~~, to trace the propagation of drought termination throughout the river system and hydrological cycle. Drought termination in river flows and groundwater levels may not synchronise even within the same catchment due to lagged response times. Hence, even when a drought terminates abruptly with severe river flooding, (contrary to public expectations) water restrictions may not be removed until groundwater levels respond. The complexities associated with this propagation of drought termination require further research.

Appendix A

Table A1. ~~Gauging station m~~Metadata for the 52 study catchments. The subset of 17 catchments referred to in sections 4.4 and 5.1 is indicated with asterisks (*).

Region	Catchment	Record length (years)	Area (km²)	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
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

Author contribution

S. Parry devised the approach, ~~and~~ selected the catchments and coordinated the writing of the paper. R. L. Wilby provided input on the structure and content of the paper and the impetus for the correlation analysis. C. Prudhomme and P. J. Wood provided feedback on the different paper structures and content~~s proposed~~. All authors contributed to the manuscript writing and commented on the analyses. ~~S. Parry wrote the manuscript with constructive comments from R. L. Wilby, C. Prudhomme and P. J. Wood.~~

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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 a~~Asterisks (*) ~~are~~denote statistical~~ly~~ significance~~t~~ at the 95% confidence level. Drought termination characteristics are ~~denoted~~ defined as ~~follows~~: DTD = drought termination duration; DTR = drought termination rate. Drought development characteristics are ~~denoted~~ defined as ~~follows~~: DDD = drought development duration; DM = drought magnitude. Catchment properties are denoted as ~~follows~~: SAAR6190 = Standard-period Average Annual Rainfall for 1961-90; BFI = Base Flow Index.

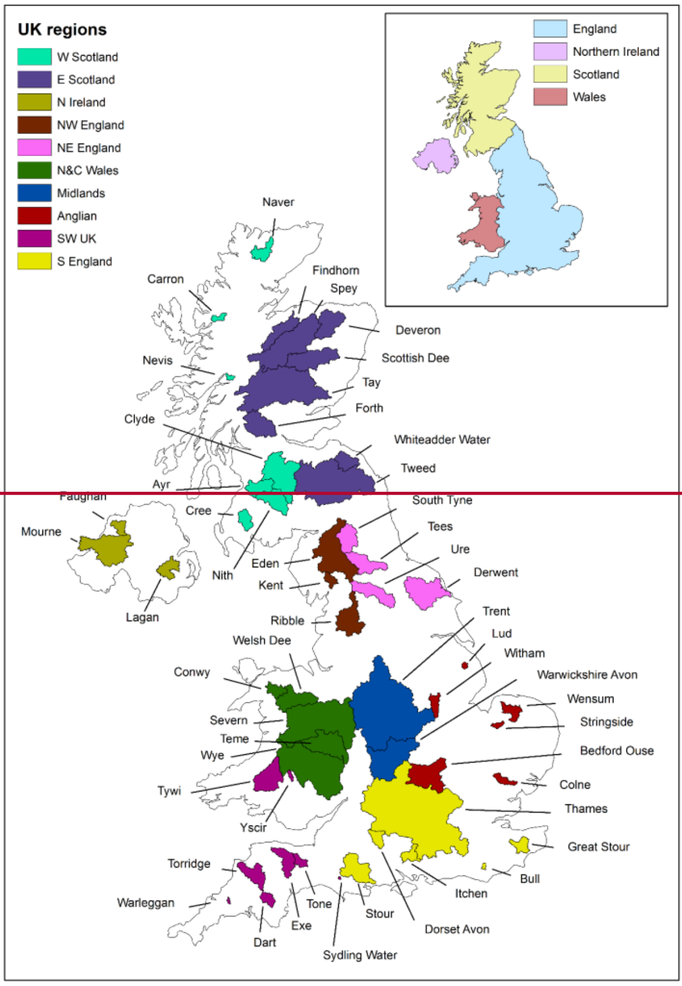
		Catchment properties					Drought development characteristics	
	n	Area	Median elevation	SAAR 6190	BFI	Urban extent	DDD	DM
DTD	459	-0.03	-0.15*	-0.12*	0.04	0.14*	-0.30*	-0.19*
DTD	52	-0.23	-0.48*	-0.40*	0.13	0.40*	0.03	-0.06
DTR	459	0.02	0.12*	0.12*	-0.18*	-0.15*	0.28*	-0.04
DTR	52	0.11	0.22	0.12	-0.12	-0.43*	0.01	-0.19

Table 2. Study cCatchments for which established new period of record maximumthe drought termination rates in during the 2009-12 event was the largest of any previous event in the historical record.

Catchment	Drought termination rate (%/month)	Rank (out of total number)	Drought termination rate (%/month) 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	1959/60
Warwickshire Avon	49.6	1/20	33.7	1963
Thames	38.1	1/35	37.2	1929/30
Teme	33.6	1/8	29.6	1975/76
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

Catchment	Number of drought events	Drought termination rate (% per month)		Year of drought termination ranking 2nd by drought termination rate
		2009-12	Rank 2	
Severn	16	90.6	26.5	1997
Derwent	7	62.3	42.6	1976
Trent	11	56.3	28.0	1959/60
Warwickshire Avon	20	49.6	33.7	1963
Thames	35	38.1	37.2	1929/30
Teme	8	33.6	29.6	1975/76
Sydling Water	10	30.8	25.5	1974

Itchen	9	21.1	12.5	1963
Carron	3	18.2	11.9	2001


UK regions
W Scotland
E Scotland
N Ireland
NW England
NE England
N&C Wales
Midlands
Anglian
SW UK
S England
England
Northern Ireland
Scotland
Wales
Naver
Carron
Findhorn
Spey
Deveron
Scottish Dee
Nevis
Tay
Forth
Clyde
Whiteadder Water
Tweed
Ayr
Faughan
Cree
South Tyne
Mourne
Tees
Ure
Nith
Eden
Derwent
Kent
Lagan
Trent
Ribble
Welsh Dee
Lud
Witham
Conwy
Warwickshire Avon
Wensum
Severn
Stringside
Teme
Wye
Bedford Ouse
Tywi
Colne
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Dorset Avon
Dart
Sydling Water

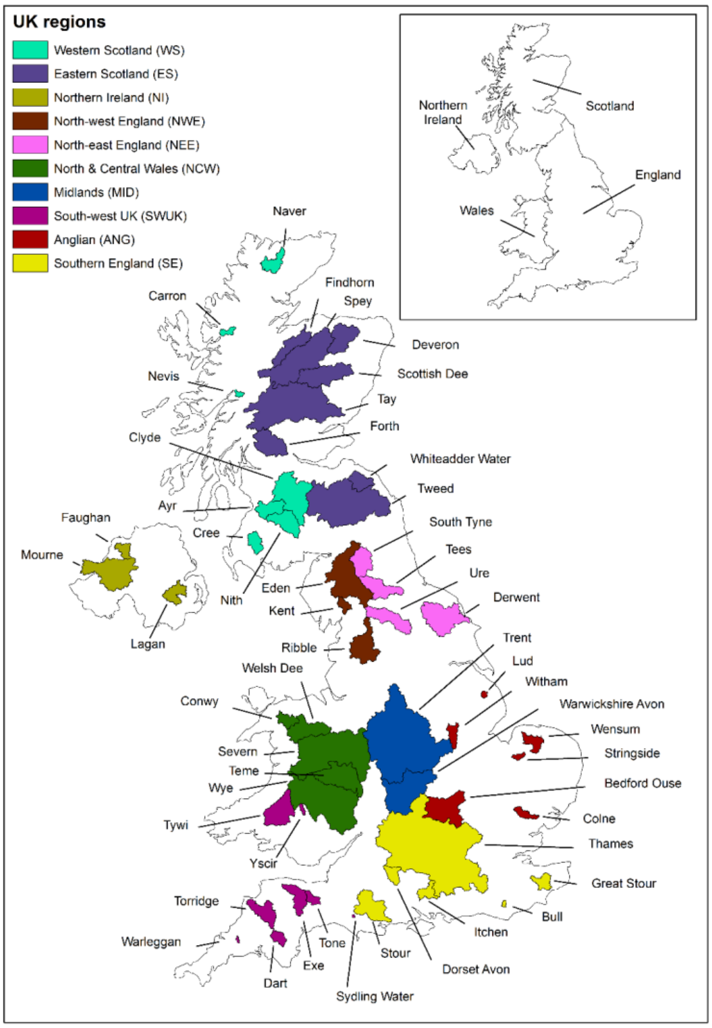
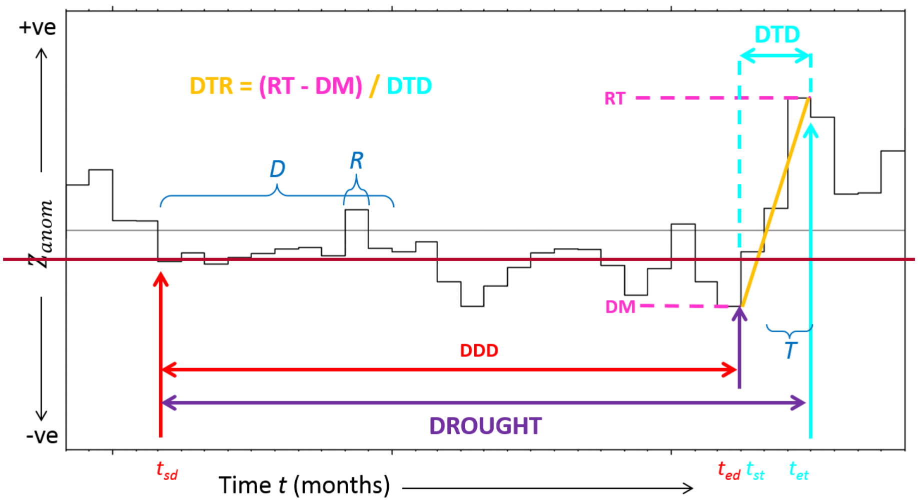


Figure 1. Locations of the 52 study catchments in the UK, colour-coded by their region. The regions are abbreviated in Fig. 4, Fig. 5 and Fig. 6 as follows: Western Scotland = WS; Eastern Scotland = ES; Northern Ireland = NI; North-west England = NWE; North-east England = NEE; North & Central Wales = NCW; Midlands = MID; South-west UK = SWUK; Anglian = ANG; Southern England = SE. Inset: the constituent countries of the UK.



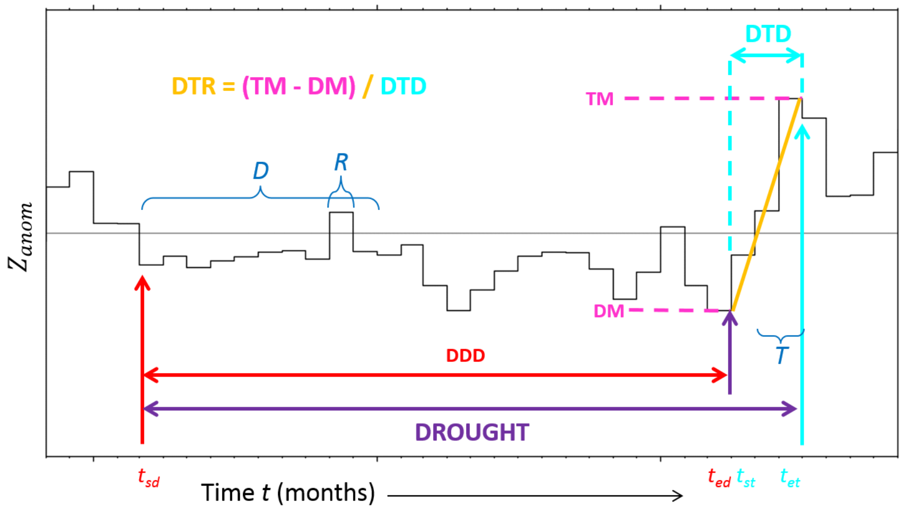


Figure 2. A ~~C~~conceptualisation ~~diagram~~ of drought termination definition and metrics. The three parameters are as follows: *D* is the number of months of below average flows required for the drought development phase to begin; *R* is the number of months of intermittent above average flows permitted within *D*; and *T* is the number of consecutive months of above average

flows required for the end of the drought termination phase. t_{sd} is the time of start of drought development, t_{ed} is the time of end of drought development, t_{st} is the time of start of drought termination, and t_{et} is the time of 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.

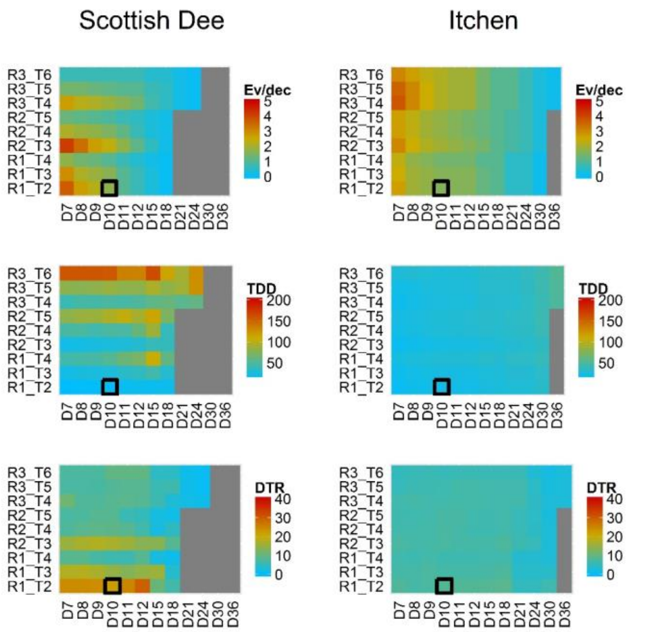


Figure 3. Demonstrations of the sensitivity of drought termination metrics to parameter selection for the Scottish Dee and Itchen catchments. *D*, *R* and *T* are the three parameters of the methodology. The metrics are: 'Ev/dec' = number of events per decade; TDD = total drought duration (drought development duration and drought termination duration taken together); DTR = drought termination rate. The bold box on each response surface shows the combination of parameters used to derive the drought termination chronologies in this study.

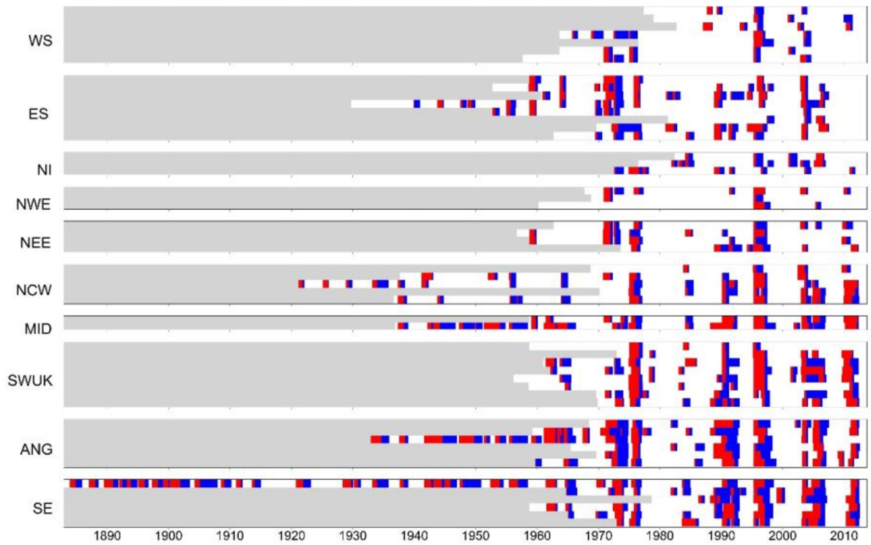


Figure ~~3~~4. ~~Period of record~~A ~~chronologies~~ chronology of drought termination for all 52 study catchments. Red bars indicate drought development, blue bars indicate drought termination, white bars indicate no drought development or drought termination, and grey bars signify periods before gauged river flow records began. On the *x*-axis, a decade (e.g. 1990-2000) is comprised of 120 monthly time steps and there are 1569 monthly time steps along the entire *x*-axis (January 1883 to September 2013, inclusive).~~Regions are denoted as follows: WS = Western Scotland; ES = Eastern Scotland; NI = Northern Ireland; NWE = North-west England; NEE = North-east England; NCW = North & Central Wales; MID = Midlands; SWUK = South-west United Kingdom; ANG = Anglian; SE = Southern England.~~

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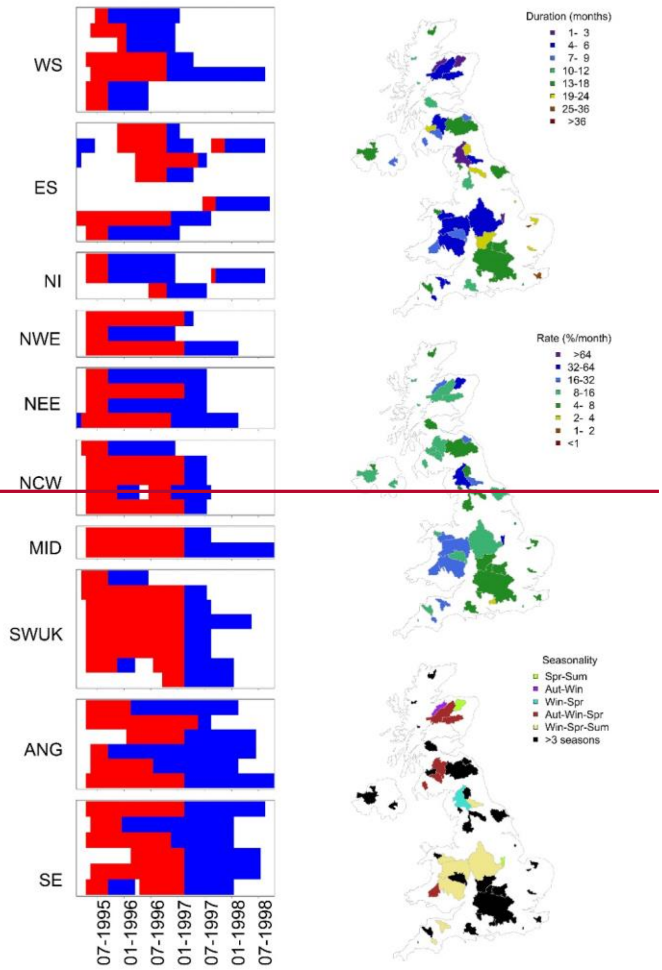

WS
ES
NI
NWE
NEE
NCW
MID
SWUK
ANG
SE
07-1995
01-1996
07-1996
01-1997
07-1997
01-1998
07-1998
Duration (months)
1- 3
4- 6
7- 9
10-12
13-18
19-24
25-36
>36
Rate (%/month)
>64
32-64
16-32
8-16
4- 8
2- 4
1- 2
<1
Seasonality
Spr-Sum
Aut-Win
Win-Spr
Aut-Win-Spr
Win-Spr-Sum
>3 seasons

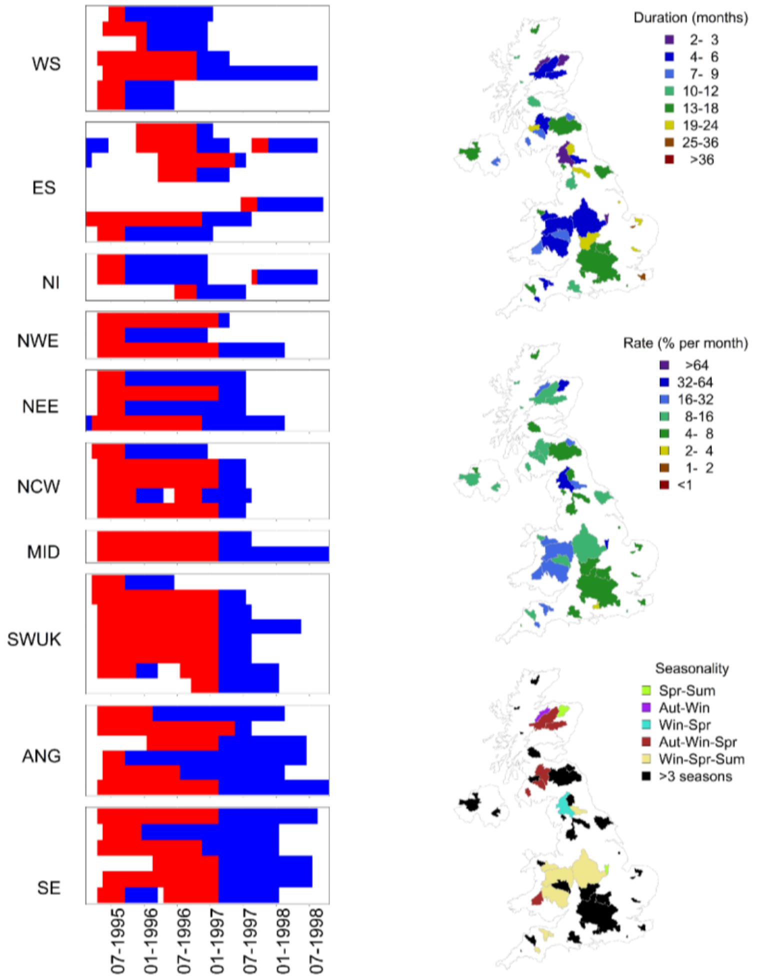
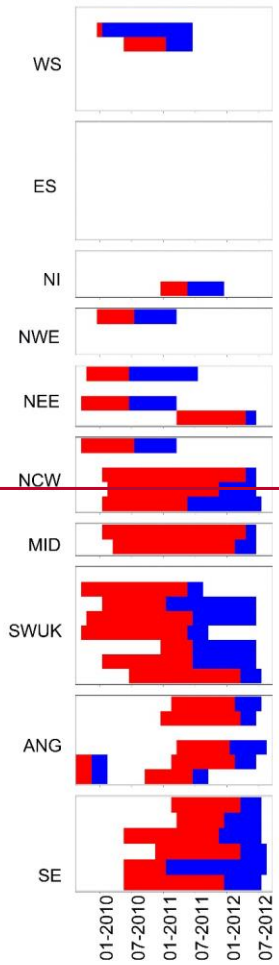
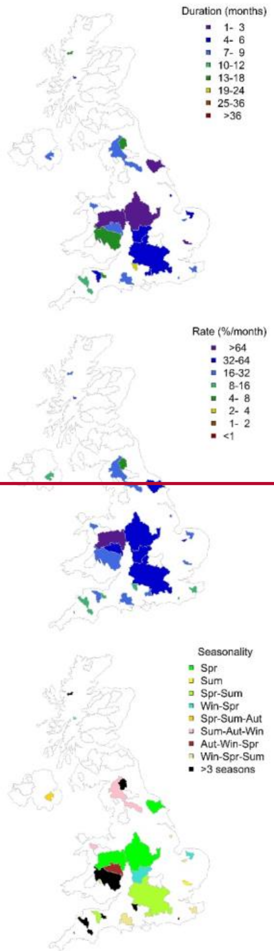


Figure 45. The 1995-98 drought termination: Chronologies of drought development and drought termination (left); Drought termination duration (top right); Drought termination rate (middle right); Drought termination seasonality (bottom right). Regions are denoted as follows: WS = Western Scotland; ES = Eastern Scotland; NI = Northern Ireland; NWE = North-west England; NEE = North-east England; NCW = North & Central Wales; MID = Midlands; SWUK = South-west United Kingdom; ANG = Anglian; SE = Southern England.


WS
ES
NI
NWE
NEE
NCW
MID
SWUK
ANG
SE
01-2010
07-2010
01-2011
07-2011
01-2012
07-2012


Duration (months)
1- 3
4- 6
7- 9
10-12
13-18
19-24
25-36
>36
Rate (%/month)
>64
32-64
16-32
8-16
4- 8
2- 4
1- 2
<1
Seasonality
Spr
Sum
Spr-Sum
Win-Spr
Spr-Sum-Aut
Sum-Aut-Win
Aut-Win-Spr
Win-Spr-Sum
>3 seasons

1

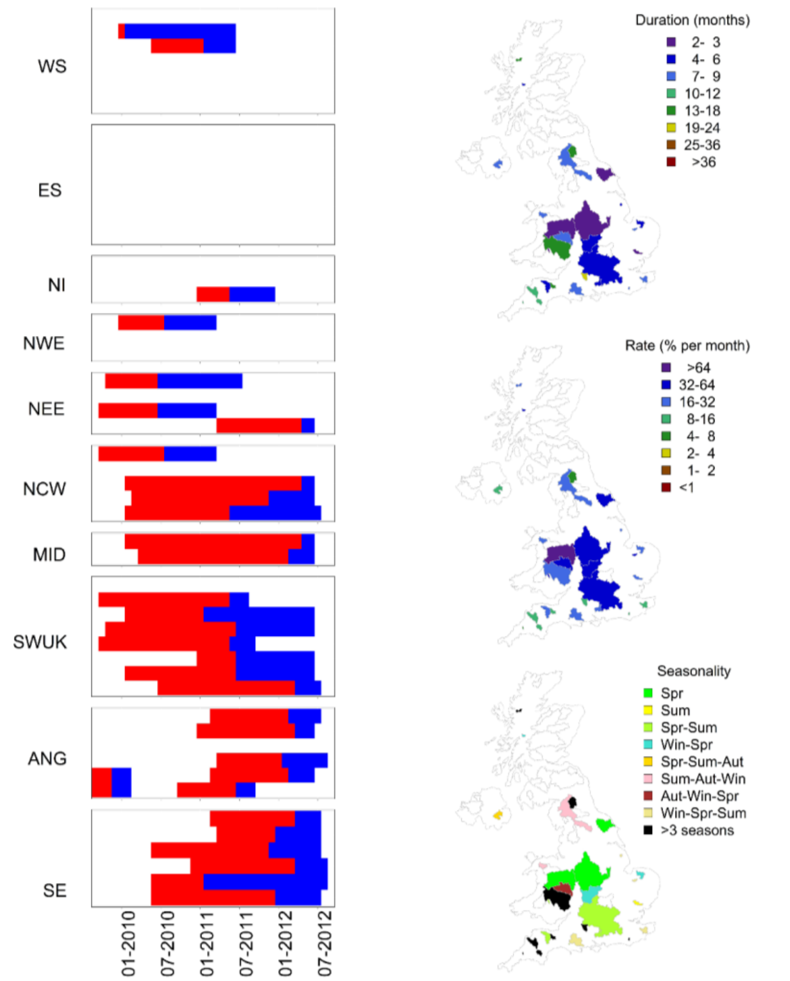
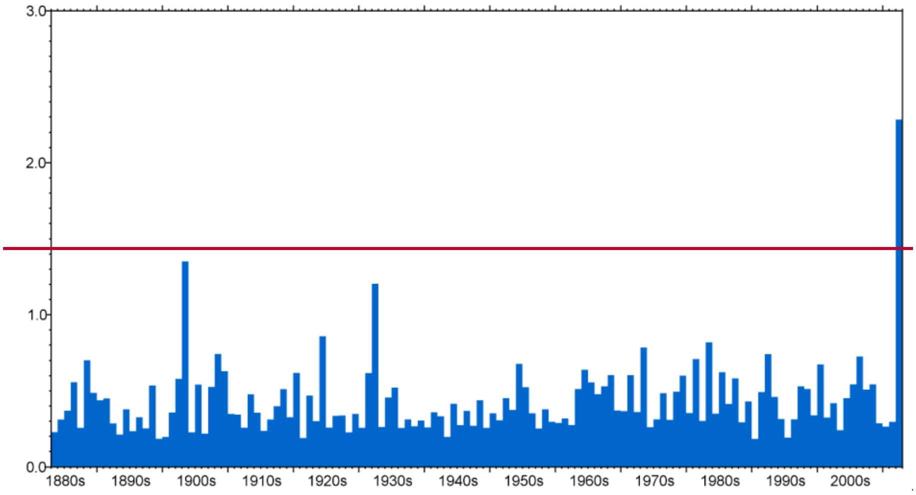


Figure ~~5~~6. The 2009-12 drought termination: Chronologies of drought development and drought termination (left); Drought termination duration (top right); Drought termination rate (middle right); Drought termination seasonality (bottom right).~~ Regions are denoted as follows: WS = Western Scotland; ES = Eastern Scotland; NI = Northern Ireland; NWE = North-west England; NEE = North-east England; NCW = North & Central Wales; MID = Midlands; SWUK = South-west United Kingdom; ANG = Anglian; SE = Southern England.~~



~~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].~~