UK Hydrological Review 1999

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Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

1999

UK HYDROLOGICAL REVIEW

This Hydrological Review, which also provides an overview of water resources status throughout 1999, is a reformatted version of the original commentary released as a web report in 2000. Some of the data featured in this report, particularly the more extreme flows, may have been subsequently revised.

The annual Hydrological Reviews are components in the National Hydrological Monitoring Programme (NHMP) which was instigated in 1988 and is undertaken jointly by the Centre for Ecology & Hydrology (CEH) and the British Geological Survey (BGS) – both are component bodies of the Natural Environment Research Council (NERC). The National River Flow Archive (maintained by CEH) and the National Groundwater Level Archive (maintained by BGS) provide the historical perspective within which to examine contemporary hydrological conditions.

A primary source of information for this review is the series of monthly UK Hydrological Summaries (for further details please visit: http://www.ceh.ac.uk/data/nrfa/nhmp/nhmp.html). The river flow and groundwater level data featured in the Hydrological Summaries – and utilised by many NHMP activities – have been provided by the Environment Agency (EA), Natural Resources Wales - Cyfoeth Naturiol Cymru, the Scottish Environment Protection Agency (SEPA) and their precursor organisations. For Northern Ireland, the hydrological data were sourced from the Rivers Agency and the Northern Ireland Environment Agency. The great majority of the reservoir level information has been provided by the Water Service Companies, the EA, Scottish Water and Northern Ireland Water (formerly Water Service). The generality of meteorological data, including the modelled assessments of evaporation and soil moisture deficits featured in the report, has been provided by the Met Office. To allow better spatial differentiation the monthly rainfall data for Britain are presented for the regional divisions of the precursor organisations of the EA and SEPA. The Met Office monthly rainfall series are Crown Copyright and may not be passed on to, or published by, any unauthorised person or organisation. The provision of the basic data, which provides the foundation both of this report and the wider activities of the NHMP, is gratefully acknowledged.

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For further information about the National Hydrological Monitoring Programme please visit: http://www.ceh.ac.uk/data/nrfa/nhmp/nhmp.html

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Hydrological Review of 1999

1999 Summary

1999 was another exceptionally warm year - provisionally the warmest in the Central England Temperature series which begins in 1659. The mild conditions reflected the predominance of westerly airflows and the associated regular passage of rain-bearing frontal systems resulted in above average rainfall for all regions - but not all localities - in the UK. Countrywide, the provisional rainfall total was 110% of the 1961-90 average but a few, mostly eastern, catchments registered less than 90%.

With the exception of June, all months in 1999 were warmer than average. The high temperatures, and above average wind speeds in many areas, encouraged high evaporative demands. Annual potential evaporation totals were considerably above average but mostly well below the corresponding totals for 1990 and 1995 (when summer temperatures were very high). With soil moisture deficits generally more modest than have characterised many recent summers, transpiration losses were significantly constrained for only a limited period in most areas. As a consequence, actual evaporation losses were close to the highest on record in parts of southern Britain, and unprecedented in some catchments.

Notwithstanding the high evaporative demands, water resources remained healthy throughout the year. Reservoir replenishment fell below the seasonal average for short periods in the late spring and early autumn but overall reservoir stocks for England and Wales remained well above the average in all months of 1999. Figure 1 provides an index of overall reservoir stocks for England and Wales covering the last five years; the recovery since the drought years of 1995 and 1996 is clearly evident. Annual average stocks in 1998 and 1999 both rank amongst the three highest since national compilation of statistics began in 1988. Entering 2000 stocks in most major reservoirs were approaching capacity and the resources outlook was very good.

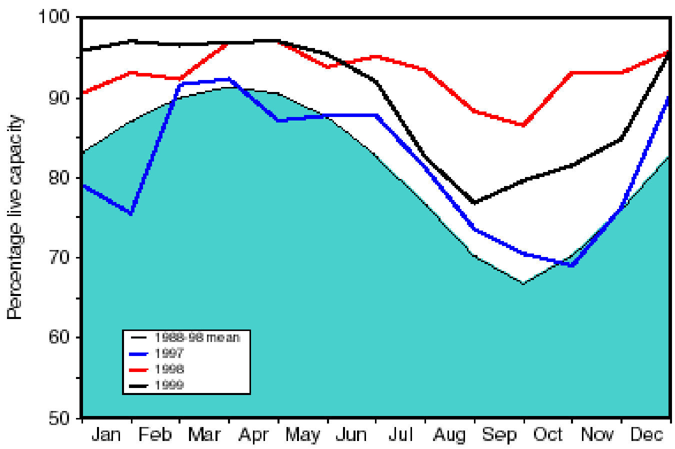


Figure 1 *Index of overall reservoir stocks for England and Wales 1995-99.*

Data sources: Water Service Companies and Environment Agency.

Compared to the extreme Easter 1998 event, flooding during 1999 was modest in magnitude. However, notable spates were common and floodplain inundations were a feature of many catchments, especially early and late in the year; runoff was exceptionally high in January and December. This, together with widespread low flows in July and early August, contributed to an exaggeration in the normal seasonality of river flow patterns across most of the UK; a recurring characteristic of the recent past. In addition, the north-west/south-east runoff gradient across the UK was accentuated in 1999. Overall runoff was above average in England and Wales (see Figure 2), and in Northern Ireland, and notably high in Scotland (Figure 3) where runoff over the 1990s is some 15% greater than the preceding average. Below average annual runoff totals were generally confined to the English Lowlands, especially in impermeable catchments in the South-East.

Most major aquifers are located in the drier regions of the country and 1999 rainfall totals (as a percentage of the 1961-90 average) for most outcrop areas

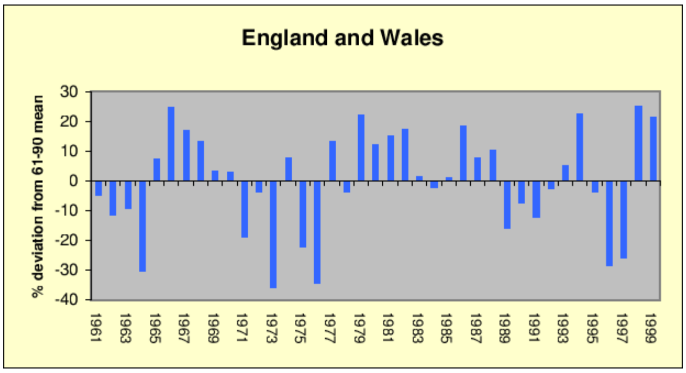


Figure 2 *Index of total runoff from England and Wales 1961-99.*

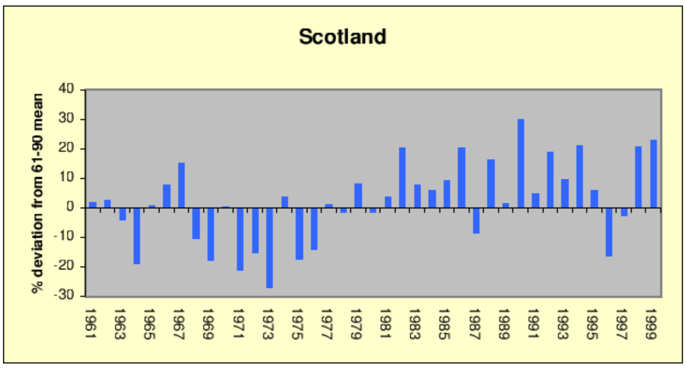


Figure 3 *Index of total runoff from Scotland 1961-99.*

were generally lower than in the west and north of the UK, but still mostly around the average. Healthy recharge over the 1998/99 winter helped to ensure that, notwithstanding high evaporative demands, groundwater levels remained well within the normal range throughout the year. Above average late spring and early summer infiltration helped moderate groundwater level recessions and, generally, 1999 minimum levels were well above those reported for the drought years of the early to mid-1990s. In the east particularly, the seasonal recovery was uneven in the autumn but heavy recharge in December ensured that levels were above average in early 2000 across most major aquifers. A broad distinction could, however, be drawn between the more westerly outcrops where levels tended to be appreciably above average, and the drier eastern regions where levels in 1999 were mostly a little below. In a few eastern areas – where annual recharge is typically modest - recoveries are still not complete following the extremely depressed levels registered at the end of the 1995-97 drought.

Hydrological conditions in 1999, as for the 1990s as a whole, exhibited some broad consistency with currently favoured climate change scenarios, for example - the high temperatures and increased seasonal flow contrasts. Runoff and recharge rates over the last decade have been towards the extreme range captured by the UK hydrometric networks. But the shortness of most records, the large range of natural variability, and the increasingly pervasive impact of man, dictate caution in extrapolating from recent tendencies to any long term trends. It is important that the UK capitalises on its hydrometric monitoring networks and strengthens it capability to identify and interpret trends - particularly the ability to distinguish between climate driven influences and those more directly attributable to man.

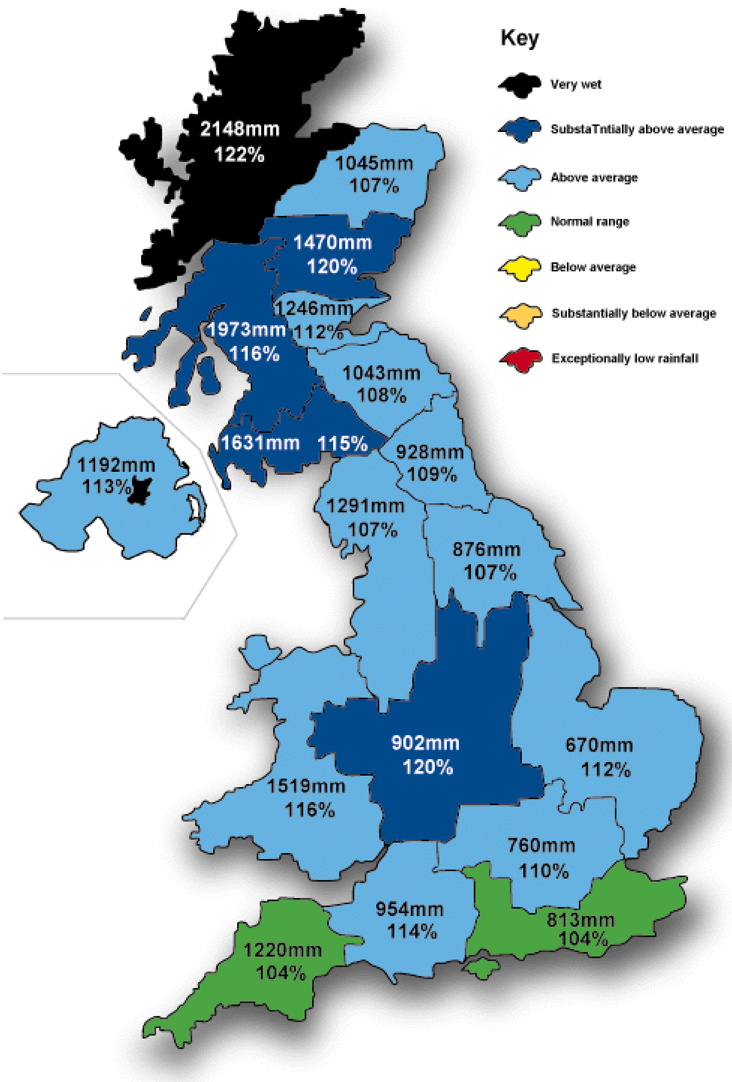
Rainfall

UK rainfall in 1999 was well distributed throughout the year with few protracted dry periods - although parts of southern England recorded significant rainfall deficiencies over the February to July timespan. In most regions January and December were the wettest months - the latter exceptionally so across much of northern Britain and Northern Ireland. For the UK as a whole, only July registered substantially below average rainfall and the provisional annual rainfall total ranks as the twelfth wettest in the twentieth century - but 1998, 1994 and 1992 were all significantly wetter. Scotland was also drier than 1998 but the provisional 1999 total still ranks in the highest six in a series from 1869. Northern Ireland registered its second successive notably wet year – the combined 1998-99 rainfall total is the highest two-year accumulation since 1923-24. Rainfall for England and Wales in 1999 was much less exceptional; the annual total was considerably below that for 1998 but still appreciably above the 1961-90 annual average.

Provisional regional annual rainfall totals for 1999 and corresponding percentages of the 1961-90 average are given on Figure 4. The regional totals exceeded the average throughout the UK, generally by a much more substantial margin in the north than the south. Precipitation totals throughout much of the Highland Region in Scotland were more than 20% above average adding to a cluster of notably wet years since the early 1980s. By contrast, regional rainfall totals were only modestly above average in parts of southern England and a few localities (e.g. in Hampshire) recorded below average annual totals.

The late autumn and early winter in 1998 were wet in most regions and the unsettled conditions continued in 1999. January was mostly wet and mild; the seasonally high temperatures increased the avalanche in northern mountains where significant snow accumulated over the early winter. February was also mild but relatively dry away from northern Britain where gales were common and precipitation was again well above average. In such areas, winter (December-February) rainfall totals were outstanding; for much of the Scottish Highlands it was the fifth exceptionally wet winter in the last 10 years. Rain-shadow effects contributed to modestly below average winter rainfall in north-east England and the northerly track of most low pressure systems is reflected in the near average totals for parts of southern England. Well above average rainfall over the winter half-year (October-March, see Figure 5) underpinned a healthy water resources outlook for the summer of 1999.

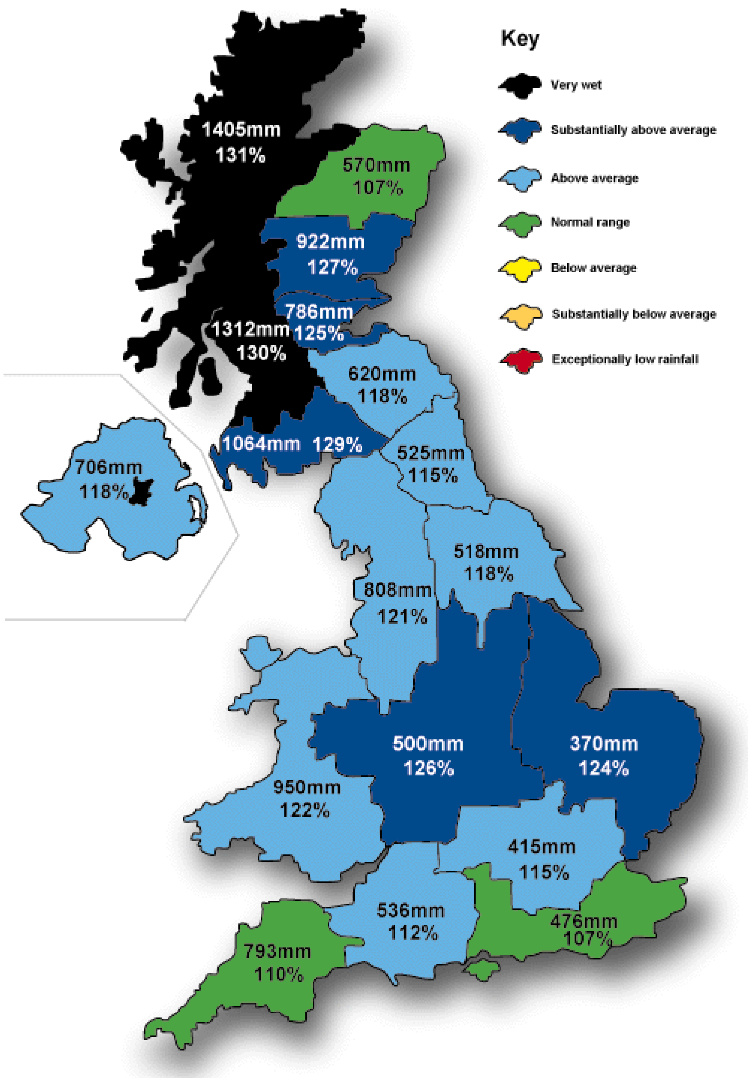
Well distributed rainfall in April usefully extended the aquifer replenishment season in the English lowlands and helped to ensure that accumulated totals over the November-April period (when the great majority of most recharge occurs) were above average. This reinforced a recent tendency for an increasing proportion of the annual rainfall (in Scotland particularly) to fall in the winter and early spring (see Figures 6 and 7); the plot for England and Wales – which extends over 334 years - demonstrates the how unusual the recent rainfall patterns have been. May was also wet with frequent thunderstorms – and correspondingly large spatial variations in rainfall totals. The spring (March-May) of 1999 was generally mild and unsettled but with a clear exaggeration in the north-west/south-east rainfall gradient across the country. A few southern catchments (e.g. in Essex and Hampshire) registered well below average spring rainfall with significant deficiencies having developed since the end of January;



The rainfall figures are provisional for all regions; revised figures will be posted subsequently.

Figure 4 *Annual rainfall (provisional) for 1999 in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.



The rainfall figures are provisional for all regions; revised figures will be posted subsequently.

Figure 5 *October 1998-March 1999 (winter half-year) rainfall (provisional) in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.

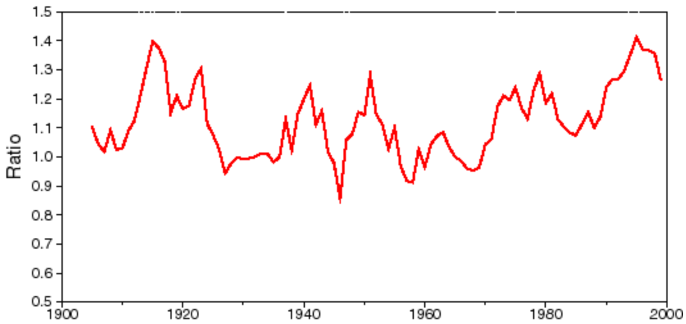


Figure 6 *Ratio of winter half-year (November-April) to summer half-year (May-October) rainfall for the UK.*

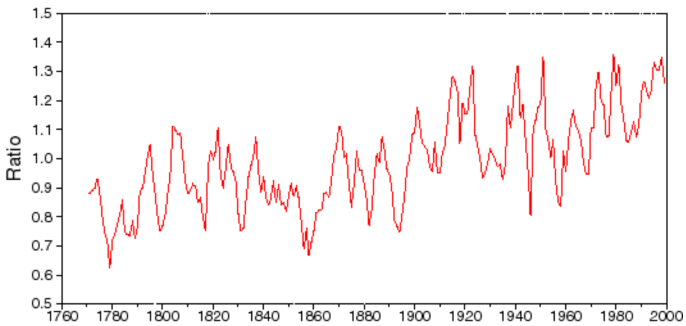


Figure 7 *Ratio of winter half-year (November-April) to summer half-year (May-October) rainfall for England and Wales.*

rainfall for the Roding catchment (Essex) was its 3rd lowest for the February-May period in at least 50 years.

The summer was notably unsettled but with a prolonged warm and dry spell extending through much of July for most of England and Wales - although the high humidity triggered some damaging but very localised thunderstorms. Many areas remained exceptionally dry throughout July; Havant (Hants) recorded its driest month since 1934, and its lowest Feb-July rainfall total for 24 years. In southern England, August provided a dramatic contrast – the wettest in 50 years in some areas, whilst Scotland recorded a relatively dry August, in the east particularly.

Indian summer conditions in early-September gave way to very unsettled weather which continued through early October. As a consequence, the seasonal recovery in river flows and groundwater recharge began early in many areas. Recoveries stalled somewhat in the late autumn but were given fresh impetus in December. For the UK as a whole, December was (provisionally) the fifth wettest this century and the wettest individual month since December 1993. Damaging gales, blizzards and widespread flooding produced a boisterous end to the century especially in northern and western Britain. Scotland reported its second wettest December in a series from 1869 and the Northern Ireland rainfall total was outstanding – ranking, provisionally, amongst the three wettest months of the twentieth century.

Evaporation and Soil Moisture Deficits

1999 added another exceptionally warm year to those of the recent past; five of the warmest six in the Central England Temperature series - which runs from 1659 - now cluster in the post-1988 period. Apart from June, monthly mean temperatures were typically 1.5-2.0°Celsius above average throughout 1999. Correspondingly evaporative demands were high across most of the UK. Actual evaporation (AE) totals based on the Met. Office Rainfall and Evaporation Calculation System (MORECS - see below) were the highest on record (the series begins in 1961) in a substantial proportion of southern Britain.

Provisional potential evaporation (PE) totals – assuming a grass cover - for 1999 are shown on Figure 8. The annual PE losses were broadly similar to those of the preceding three years. They were, however, substantially below those of 1995 when annual totals exceeded 700 across large parts of southern and eastern Britain. This difference is largely explained by the exceptionally high temperatures in 1995 during the spring and summer - when the major proportion of the annual evaporative losses occur. Although more modest, the1999 totals exceeded the 1961-90 average throughout the country with much of eastern England registering 115% or more. As a consequence, PE totals exceeded the 1999 rainfall totals in a few localities (e.g. adjacent to the Thames Estuary).

With the exception of a few East Anglian catchments, actual evaporation losses remained close to the corresponding PE totals throughout much of 1999. This was especially noteworthy in the South-East where dry soil conditions in the summer normally inhibit transpiration and produce a significant annual shortfall of AE relative to the PE totals. In parts of Kent, this shortfall is typically around 40-80mm; in 1999 it was less than 10mm. Only during July and early August was transpiration significantly moderated, and then only in southern Britain. Generally, AE totals approached PE totals more closely than has characterised much of the 1990s. AE losses in most of Scotland exceeded 470mm whilst losses across a substantial proportion of England exceeded 600mm (Figure 9); in most years this threshold is reached for few, if any, catchments. Whilst AE losses in much of Scotland were a little below average, they exceeded the average by 20% throughout much of the English Lowlands and were the highest in the MORECS series for many areas. The outstanding AE losses in southern Britain during 1999 directly reflect the very limited periods for which substantial soil moisture deficits (smds) were maintained.

The growth and decay of soil moisture deficits for six representative MORECS squares is shown in Figure 10. Soils in western Scotland generally remained close to saturation except in high summer and smds rarely constrained evaporation for more than a few weeks. In the English lowlands, deficits began to build in the spring but the normal steep increase in May failed to materialise and further sustained rainfall in June and, again, in August/September allowed only a limited period for very dry soil conditions to develop. Generally, maximum soil moisture deficits - typically registered in late July and early August in 1999 - were substantially below the maxima calculated for the early and mid-1990s. Nonetheless, MORECS soil moisture deficits (for a grass cover) for the end of July (Figure 11) exceeded the average throughout much of southern Britain; by contrast Scottish soils were relatively wet for the time of year. In most regions soil moisture deficits declined to very modest levels in October - by month-end soils were close to saturation throughout most of the UK. Exceptions could be found in a few eastern areas (e.g. parts of Cambridgeshire, Lincolnshire and the lower Trent basin) where, locally, marginal deficiencies were carried through until year-end.

Consistent with the notably high temperatures recorded throughout the 1990s, evaporative demands over the last decade have been well above average. In southern parts of the UK, annual average PE totals during the 1990s exceed the previous average, typically by around 15%. However, the implications of these exceptional evaporative demands in a water resources context have to take account also of the more modest trend in AE losses in most regions. One consequence of the cluster of very dry summers over the last decade has been very large annual shortfalls of AE relative to PE in the eastern lowlands (see Figure 10). 1999 did not follow this pattern but does serve to emphasise the need for a more complete understanding of the complex interplay between rainfall, evaporation and soil moisture conditions in order to better assess the impact of higher temperatures on runoff and recharge rates throughout the UK.

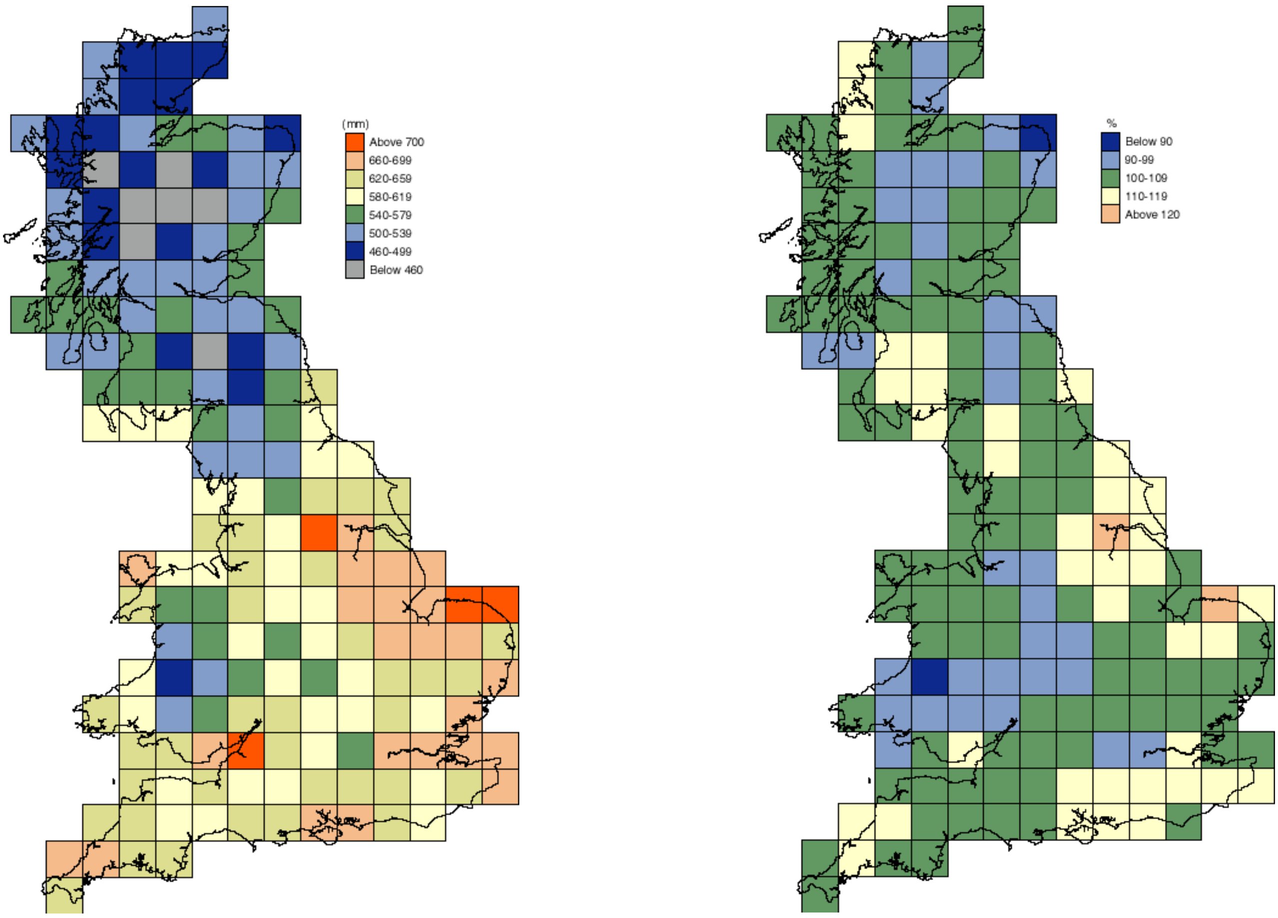


Figure 8 *Potential evaporation totals for 1999 in mm and as a percentage of the 1961-90 average.*
Note: the PE totals assume a grass cover.

Data source: MORECS.

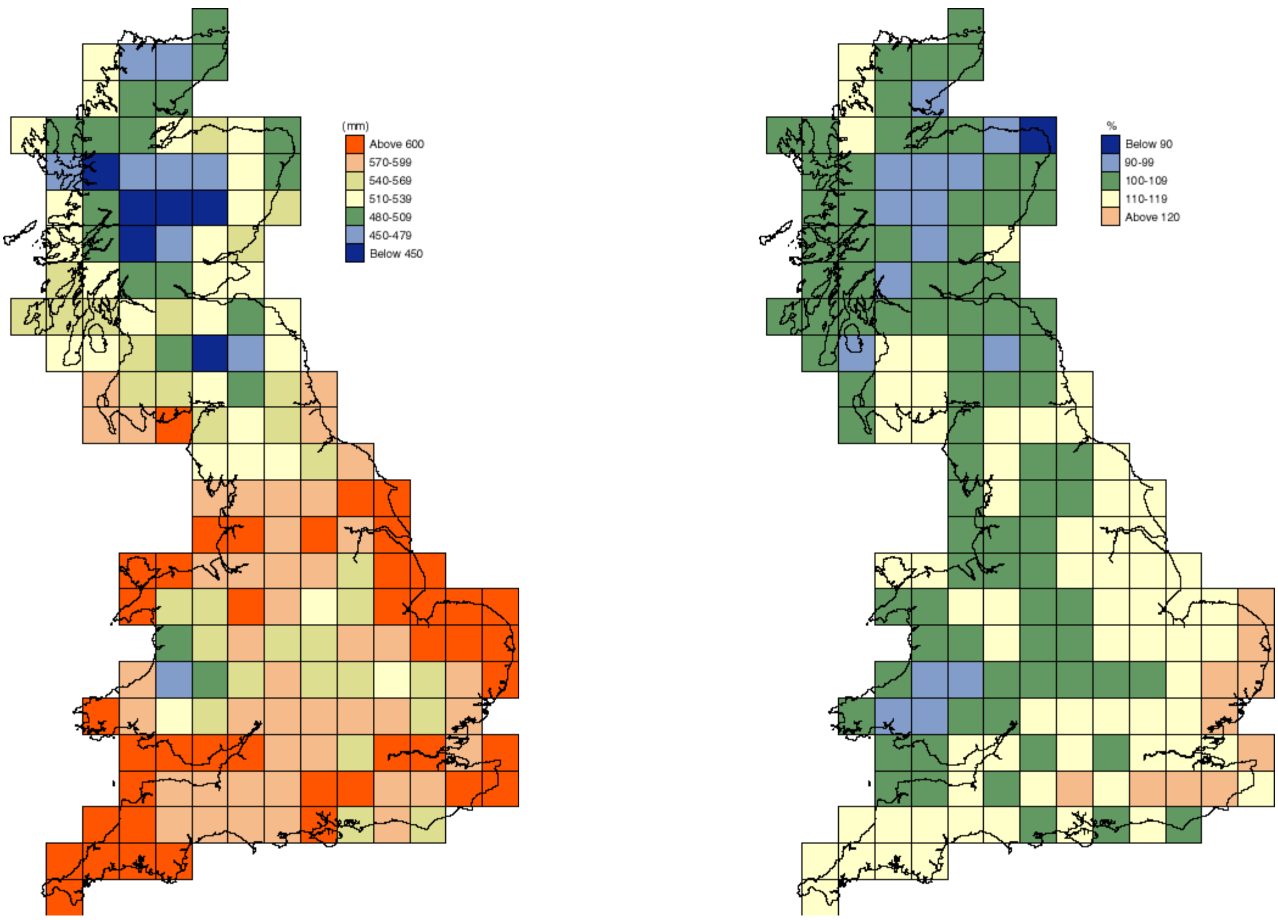


Figure 9 *Actual evaporation totals for 1999 in mm and as a percentage of the 1961-90 average.*
Note: the AE totals assume a grass cover.

Data source: MORECS.

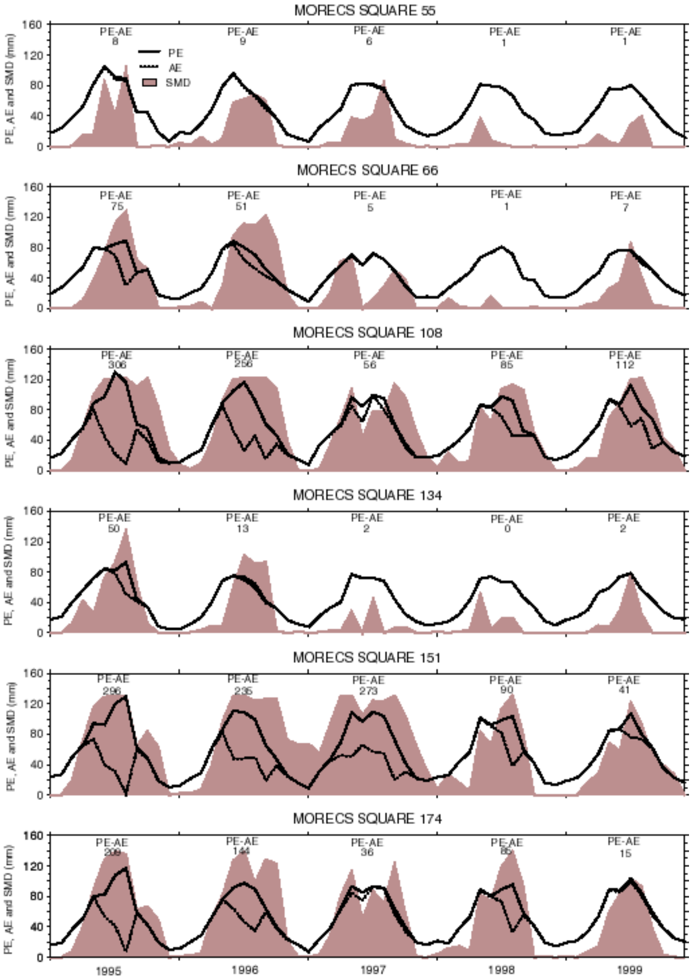


Figure 10a *The variation in potential evaporation, actual evaporation and soil moisture deficits for six MORECS squares.*

Data source: MORECS.

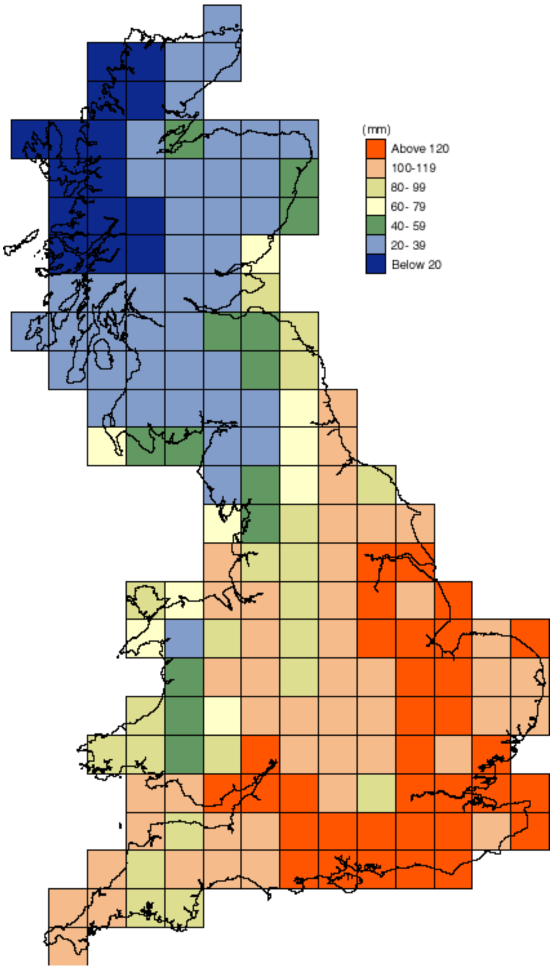


Figure 11 *Soil Moisture Deficits at the end of July 1999.*
Note: the PE totals assume a grass cover.
Data source: MORECS.

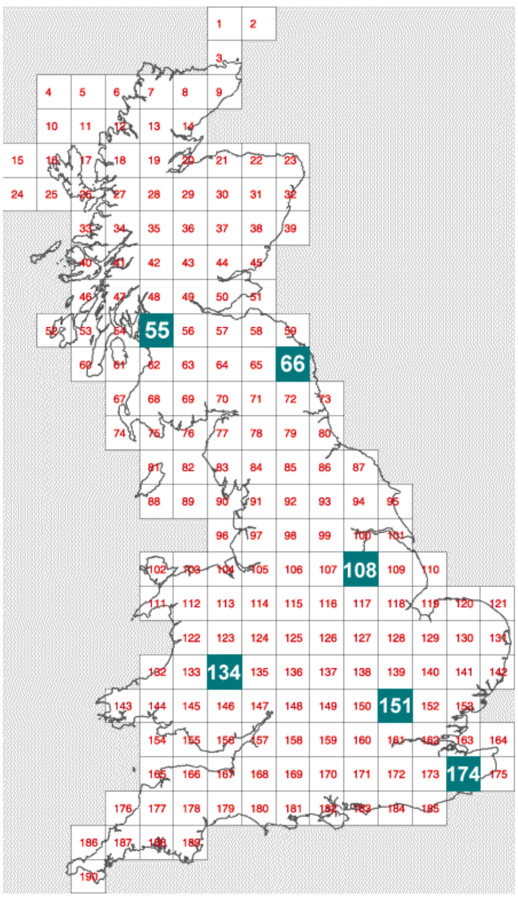
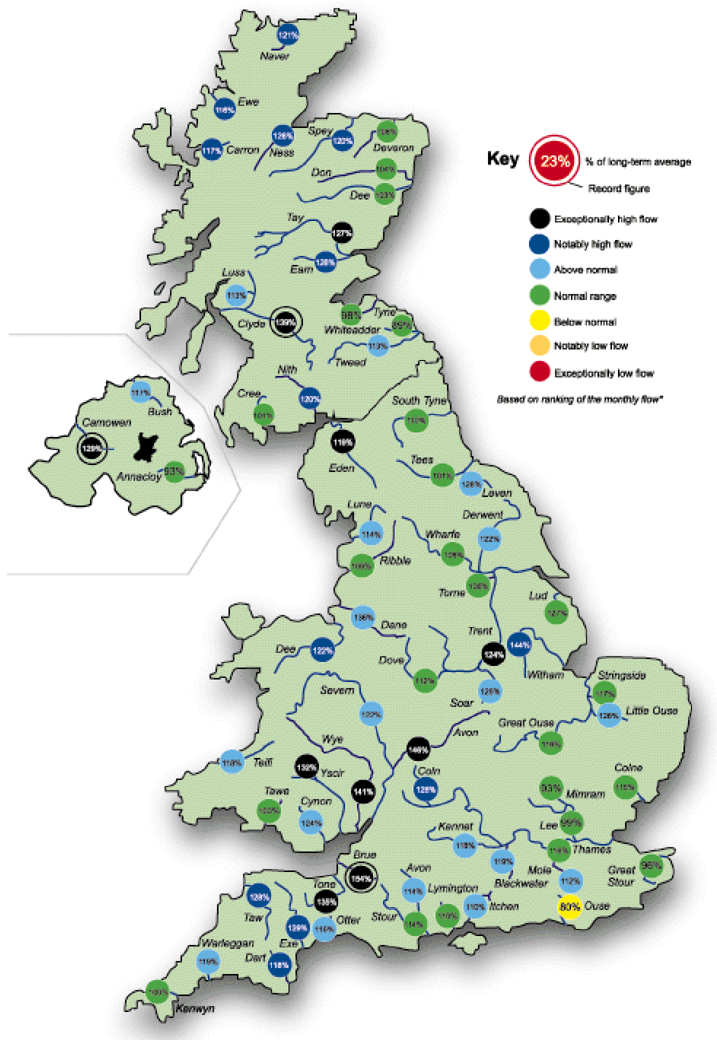


Figure 10b *MORECS Location Map: the location of the 40km squares and their associated reference numbers.*

River Flows

A year of generally high runoff, frequent spates in the more maritime catchments and enhanced seasonal contrasts in many eastern and southern rivers - partly a consequence of sustained high flows in January and December. In broad terms, the runoff pattern across the UK is indicative of a strengthening of the normal north-west to south-east runoff gradient - see Figure 12. Annual runoff totals for a number of rivers in Scotland (e.g. the Clyde) and Northern Ireland (e.g. the Camowen) were the highest on record. Corresponding totals for some rivers in south-eastern England were significantly below average - particularly for those draining largely impermeable catchments; many spring-fed rivers in the English lowlands benefited from the lagged response to high rates of aquifer recharge late in 1998.

Monthly flow patterns during 1999 (and the four preceding years) for 20 representative gauging stations throughout the UK are shown in Figure 13. The monthly mean flows are illustrated together with the monthly maximum and minimum for the pre-1995 period (the shaded envelopes) and the long term mean monthly flows (the dashed trace). The flows for the River Thames at Kingston have been adjusted to take account of the



* Comparisons based on percentage flows alone can be misleading. A given percentage flow can represent extreme drought conditions in permeable catchments where flow patterns are relatively stable but be well within the normal range in impermeable catchments where the natural variation in flows is much greater. Note: the period of record on which these percentages are based varies from station to station.

Figure 12 *1999 runoff totals as a percentage of the preceding average.*

major upstream abstractions for London's public water supply. Apart from January and December, monthly runoff rates - at the regional scale - generally remained well within the normal range throughout 1999. There was no single event to compare with the extreme April 1998 floods in the Midlands but floodplain inundations were common. During the winter - and also in the summer when localised thunderstorms overwhelmed local drainage networks - flooding caused severe transport disruption. Minimum flows during 1999 in impermeable catchments mostly occurred in July or early August; the minima for eastern spring-fed rivers generally occurred much later. With few exceptions minimum daily mean flows in 1999 were substantially above the depressed flow rates registered during the droughts of the 1990s.

The year began with most catchments near saturation and vulnerable to further rainfall. Spate conditions were common in January and around 15% of gauging stations established new maximum January mean flows. Floodplain inundations were common but, aided by the rapid passage of most frontal systems (restricting rainfall totals for individual storms), exceptional floods were avoided in the great majority of catchments. A significant exception was the severe flooding across northern Britain around the 6th. Healthy flows were maintained during February in rivers sustained primarily from groundwater outflows - the Mimram (Hertfordshire) recorded its highest monthly mean flow of the year - but steep recessions characterised most rivers draining impermeable catchments before spate conditions returned close to month-end. Winter (December-February) runoff totals within the normal range across the greater part of the UK.

In March exceptional runoff from the North York Moors triggered a major flood event on the River Derwent and, throughout the UK, March runoff totals were mostly above average. The normal seasonal decline in river flows was little evident in April with notably high flows in many catchments. In May, thunderstorms contributed to further, local reversals of an already very uneven seasonal decline but many eastern catchments were reporting below average late spring flows. In England June (and the summer generally) was notable for a series of urban flood events triggered by thunderstorms whilst in Scotland a series of, mostly minor, spates contributed to runoff rates more typical of April.

July was a month of sustained recessions in the majority of southern catchments - annual minimum daily mean flows in impermeable catchments were generally registered over the four weeks from mid-month. In northern Britain early July recessions were also steep but flows then recovered briskly and most annual minima on major rivers in Scotland occurred in August or early September. Throughout the UK most annual minima were well within the normal range. In southern England locally high urban runoff rates (following thunderstorms) coexisted with below average flows in rural catchments. Summer (June-August) runoff totals were mostly above average; exceptions included a number of rivers in the South-East where the Great Stour – registered its 8th successive year with below average June-August flows.

Following notably low flows in some impermeable lowland catchments early in September, seasonal recoveries gained rapid momentum and moderate flooding characterised many areas over the latter half of the month. New September runoff maxima were recorded in the west (e.g. the Yscir). Notable storm rainfall totals produced widespread but modest flooding in early October but, in northern Britain (Northern Ireland also) monthly runoff totals were well below average. Following another wet interlude in early November, spate conditions were common – with severe flooding in parts of Cumbria - but the seasonal recoveries again stalled in mid-month. This, together with a declining groundwater contribution to river flow in some eastern catchments produced some modest autumn runoff rates (e.g. the Medway in Kent).

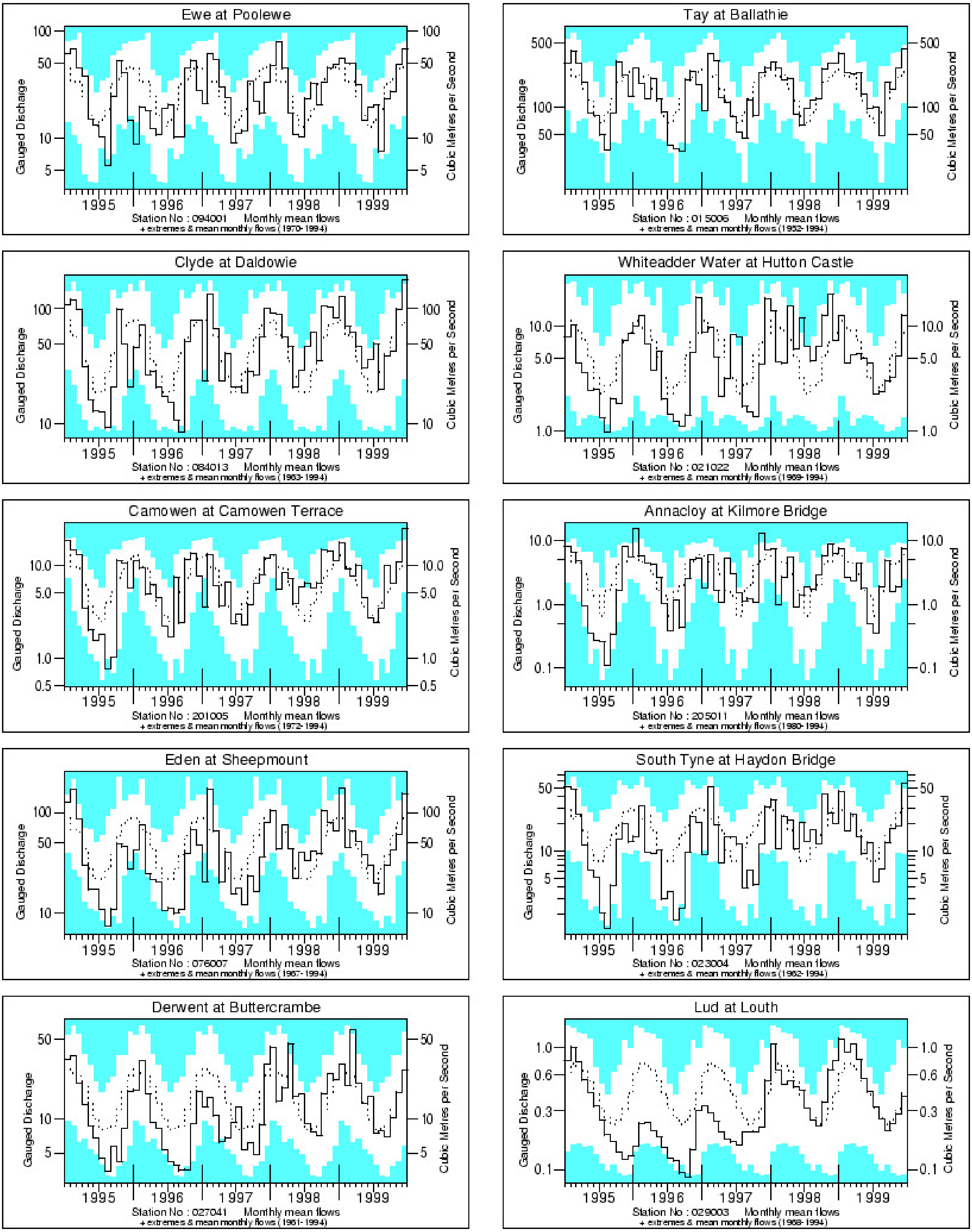


Figure 13 *River flow hydrographs 1995-1999.*

Data sources: Environment Agency/Scottish Environment Protection Agency/Rivers Agency.

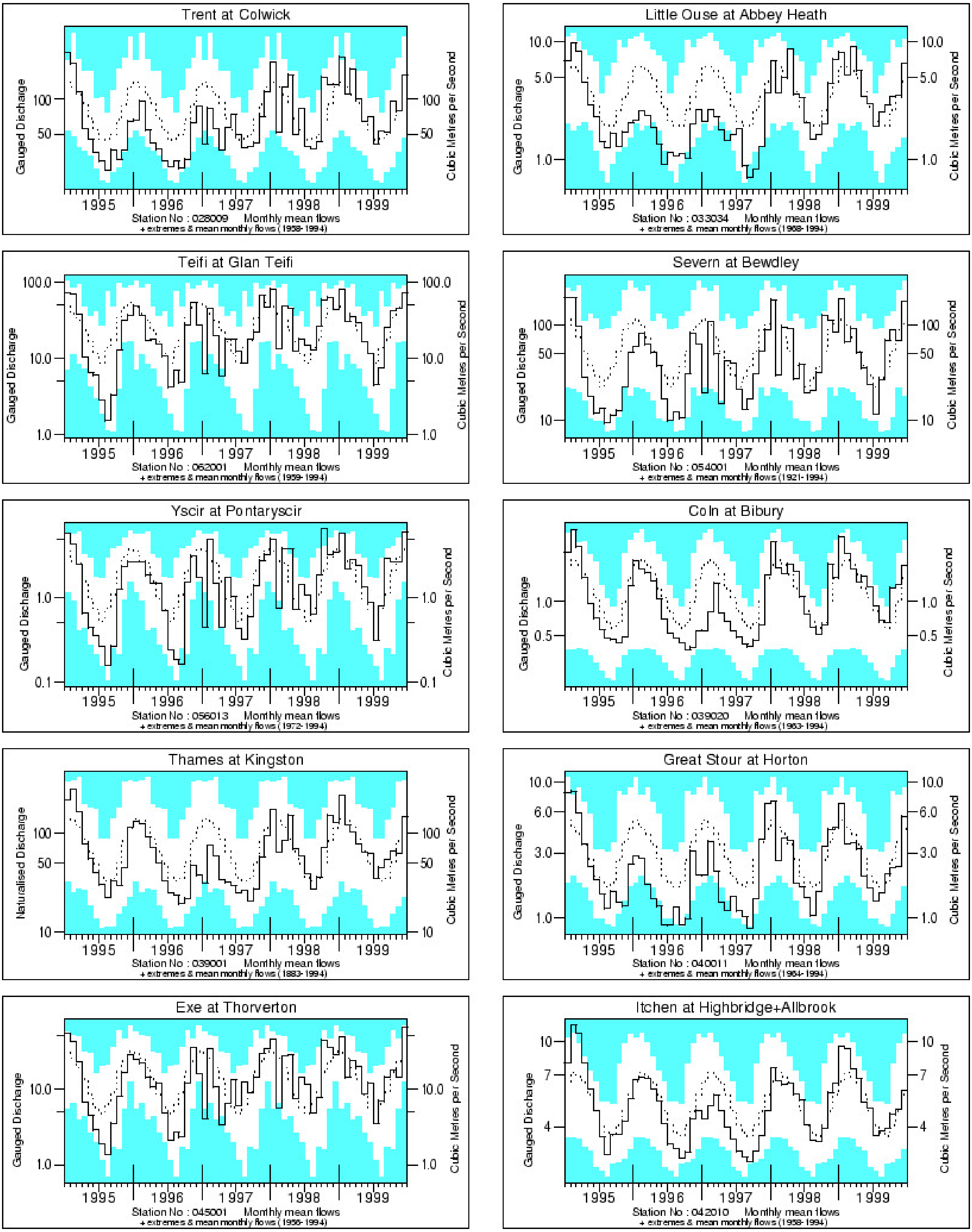


Figure 13 *(Contd.)*

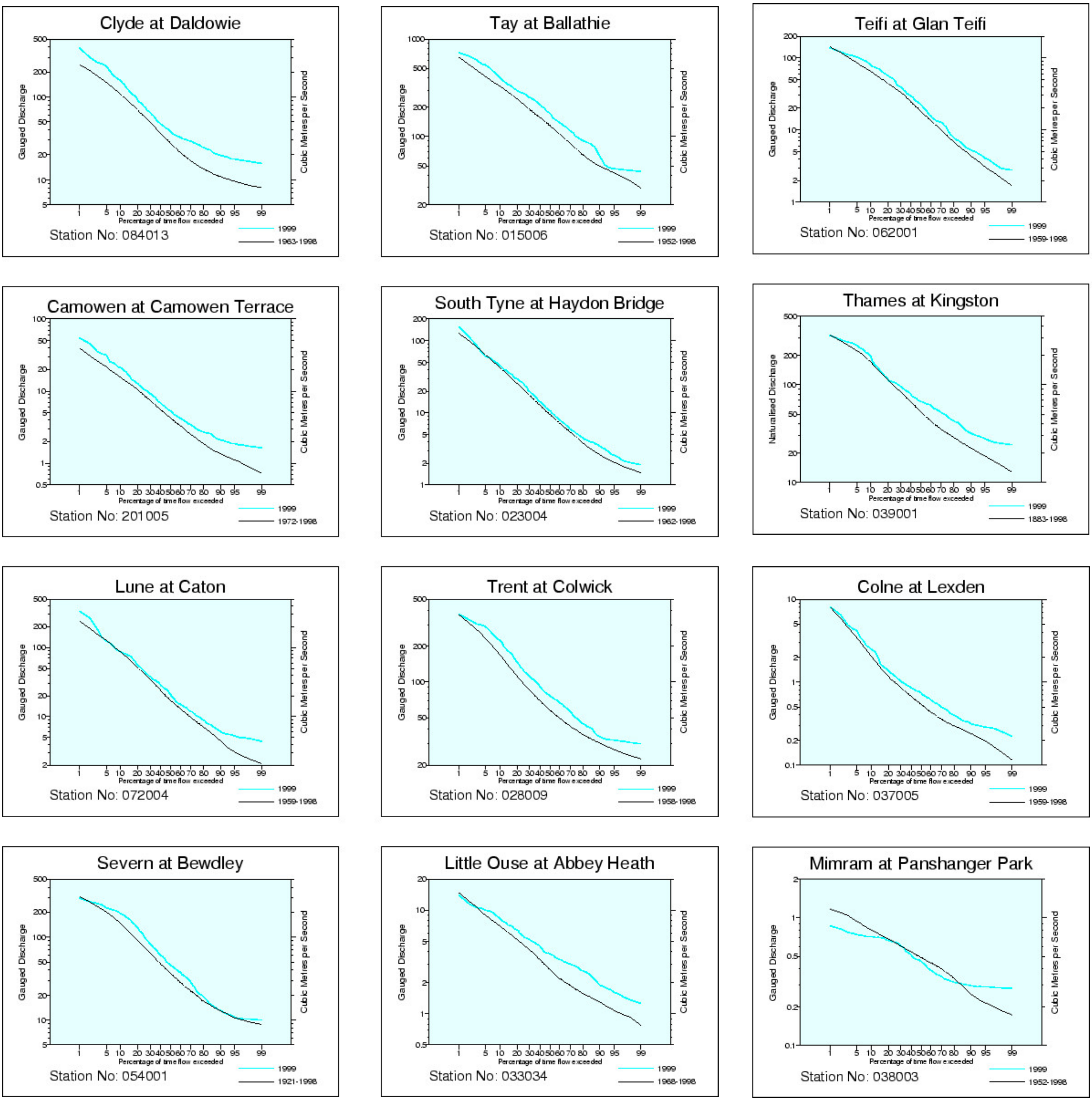


Figure 14 *Flow duration curves for 1999 (blue trace) and the preceding record*

Data sources: Environment Agency/Scottish Environment Protection Agency/Rivers Agency.

The passage of several vigorous low pressure systems in late November heralded a period of sustained high runoff and, in December, rivers which exceeded bankfull (often on several occasions) showed a very wide geographical distribution. Entering 2000, the flood risk was high across much of the UK.

Figure 14 shows flow duration curves for 12 representative gauging stations; such curves allow the proportion of time that river flows fall below any given threshold to be identified. Generally, flows exceeded 95% of the time (a commonly-used index of low flows) in 1999 were well above the period of record average - typically by a factor of two. 1999 flows in most index rivers were above the corresponding percentiles throughout the flow range; some exceptions at the very highest flows can be identified for rivers in England and Wales. In a UK context, the Mimram appears anomalous but the exceptionally flat duration curve for 1999 reflects both the modest flows early in the year (when runoff rates were still recovering from the 1995-97 drought) and the above average flows maintained through most of the summer and autumn; such behaviour was typical of many spring-fed lowland rivers in England.

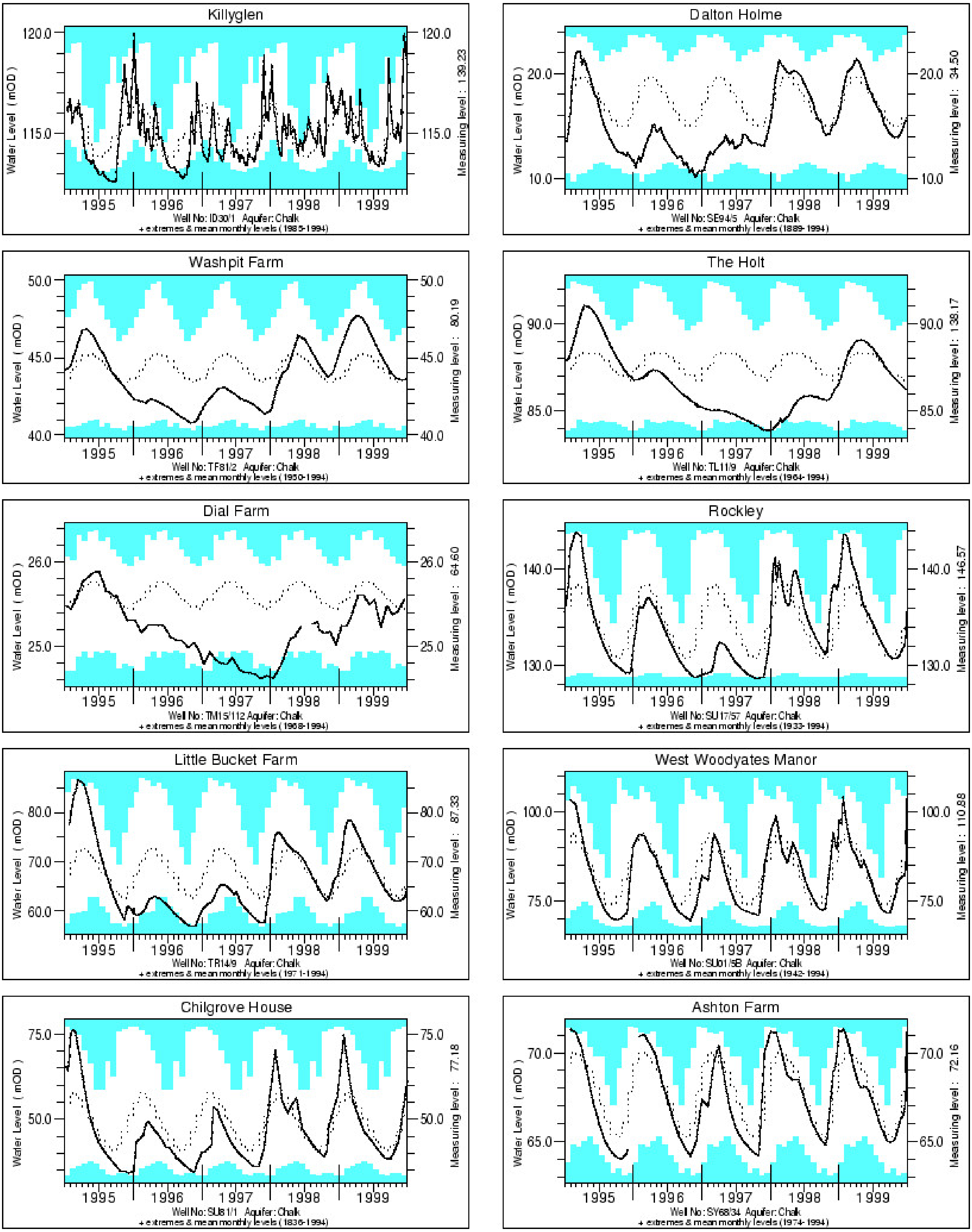


Figure 15 *Groundwater levels for selected observation sites 1995-1999.*

Data sources: Environment Agency/Scottish Environment Protection Agency/Rivers Agency.

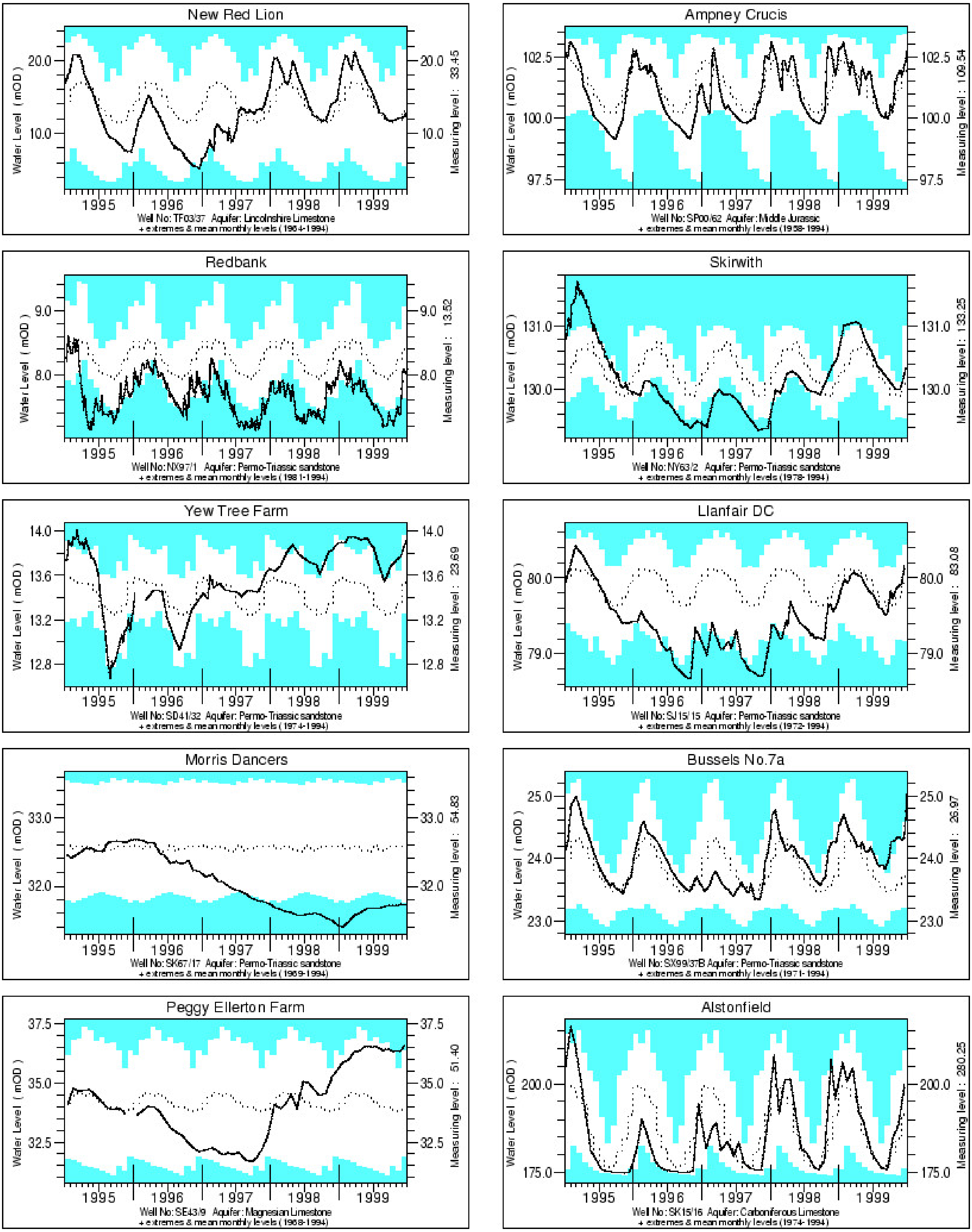


Figure 15 *(Contd.)*

Groundwater

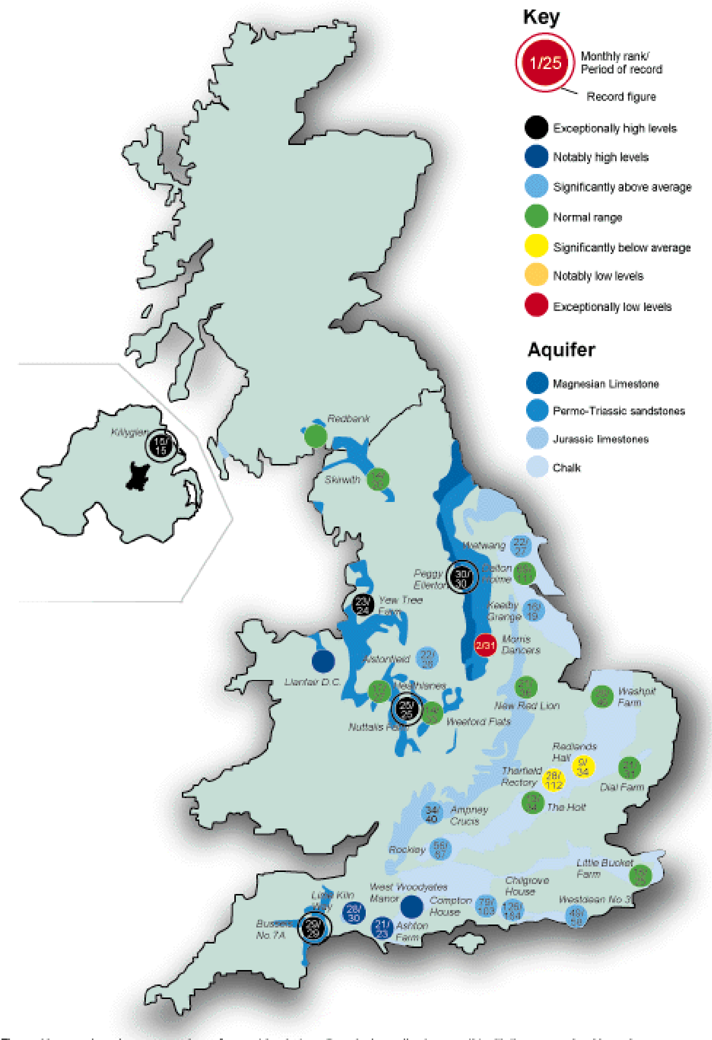
Overall and regional groundwater resources have displayed wide variability over the last decade. Protracted periods of depressed groundwater levels - punctuated by episodes of very heavy recharge - characterised the early and mid-1990s. Abundant rainfall in the autumn of 1997, and over the ensuing winter, sustained a general recovery which was reinforced by substantial infiltration in most aquifer areas during the autumn of 1998. Entering 1999, groundwater levels in most index wells and boreholes were within the normal winter range and rising. January produced around twice the monthly average recharge in many lowland areas, generating further brisk rises in levels. Saturated ground conditions and modest evaporative demands allowed further, more limited, groundwater level increases in February and March despite the below average rainfall to many outcrop areas.

The variation in groundwater levels in 1999 - and the four preceding years - is shown in Figure 15 which illustrates groundwater hydrographs for 20 representative boreholes; the monthly levels are shown together with the corresponding long term maximum and minimum monthly levels (the shaded envelopes) and the pre-1995 monthly mean. The hydrographs demonstrate that, except in the most western and northern aquifers, recharge rates declined rapidly in May as evaporation losses accelerated, exceeding the rainfall throughout most of the lowlands - but groundwater level recoveries continued in some deeper and slower responding units. This is particularly evident in the eastern Chalk much of the Permo-Triassic sandstone outcrops in the Midlands.

Sustained rainfall in June produced a little late - and rare - infiltration in parts of the Chalk and extended the recharge season in other aquifers. This helped moderate the summer recession and although recharge in July and August was, as usual, minimal, late summer and autumn levels were generally around average and well above the drought minima registered earlier in the decade.

As evaporation rates declined in the autumn seasonal recoveries in most western and northern index wells and boreholes gathered momentum, in October particularly. As usual, the persistence of soil moisture deficits - albeit modest ones - in the east delayed the seasonal recoveries, in the Chalk especially until later in the year (and beyond in a few aquifer units). However, most groundwater levels were rising briskly at year-end. December levels are shown in Figure 16 for a network of representative wells and boreholes. Levels in most exceeded the seasonal average but the response of individual units to rainfall can be very different. An extreme example of slow response is represented by the Morris Dancers well near Nottingham in the Sherwood Sandstones where only at the end of 1999 had levels recovered above period-of-record minima recorded following the 1995-97 drought.

The great majority of wells and boreholes for which data are held on the National Groundwater Level Archive were selected, so far as was practicable, to represent natural variations in water-table behaviour - avoiding the worst effects of local or regional groundwater pumping. In London, and to a lesser extent in other major conurbations, groundwater abstractions have declined over many years (since the mid-1950s in the case of London) and in response groundwater levels have maintained a steady increase. Levels in the Trafalgar Square borehole, which penetrates the confined



The rankings are based on a comparison of current levels (usually a single reading in a month) with the average level in each corresponding month on record. They need to be interpreted with caution especially when groundwater levels are changing rapidly or when comparing wells with very different periods of record. Rankings omitted where they are considered misleading.

Figure 16 *Groundwater levels at the end of December 1999.*

Chalk aquifer, are rising at around 1.2 metres a year (Figure 17). They now stand at a similar level to those last recorded a century ago; over the 1820-1950 period heavy abstractions led to a fall of around 70 metres. The continuing rise has caused geotechnical problems (e.g. flooding of tunnels and deep foundations) and will require careful management in the future.

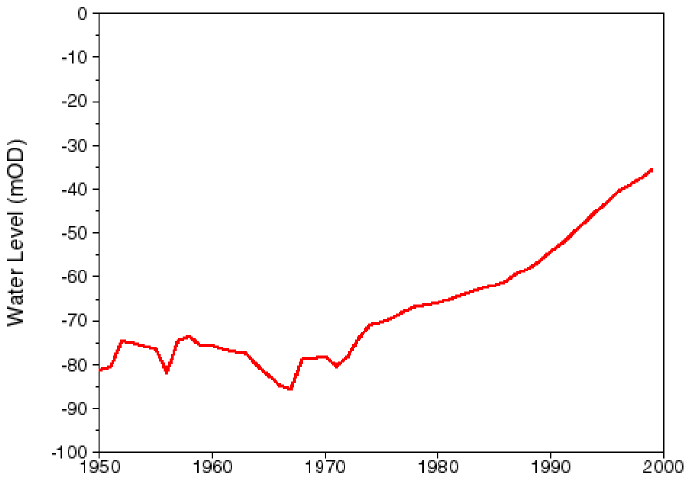


Figure 17 *Annual mean groundwater levels for the Trafalgar Square borehole (from 1950).*

Location Map

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