# UK Hydrological Review 2005

## 2nd Edition

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

# 2005

# UK HYDROLOGICAL REVIEW

This Hydrological Review, which also provides an overview of water resources status throughout 2005, is a reformatted version of the original commentary released as a web report in 2006. 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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# CONTENTS

# UK Hydrological Review of 2005

## 2005 Summary

### General

For the UK as whole, rainfall in 2005 was close to the long term average but its spatial distribution testified to a very notable exaggeration in the normal north-west/south-east rainfall gradient across the country. Whilst Scotland and parts of Northern England experienced a generally wet year, much of southern Britain saw an intensification in the drought conditions which began in the autumn of 2004. The associated water resources and environmental stress demonstrated the UK's continuing vulnerability to sustained periods of low rainfall - particularly when the deficiencies are disproportionately concentrated in the winter and spring. It is over these periods, when evaporative demands are modest, that replenishment of surface and groundwater resources is normally concentrated. In broad terms, the drought achieved its greatest severity in those parts of the country where rainfall is most limited and high population densities generate the highest water demand. Careful water management was therefore essential to reconcile the competing demands on dwindling water resources. Hosepipe bans were introduced in the early summer and low flow augmentation schemes were widely activated across southern Britain. A wet October provided a valuable respite but the very meagre late-autumn and early winter rainfall across much of the English Lowlands (for the second successive year) fuelled concern about the water resources outlook for 2006, particularly in relation to groundwater.

### Rainfall

2005 was a year of volatile weather conditions, with a marked contrast between the synoptic patterns influencing northern Britain and those which predominated across the rest of the country. Most rain-bearing frontal systems followed tracks relatively remote from the English Lowlands resulting in above average annual rainfall for most of Scotland. Parts of the Highlands registered over 130% of average and some of the Inner Hebrides (e.g. Skye) were exceptionally wet also. Overall, Scotland was appreciably drier than in 2004 but 2005 still added to a cluster of wet years since the mid-1980s. Most of southern Britain was characterised by sustained periods of below average rainfall - but punctuated by summer thunderstorms in many areas. The 2005 England & Wales rainfall total was 91% of the 1961- 90 average but regional, and more local, variations were exceptionally large. A few, mostly north-eastern localities, registered over 120% of average but much of the South East reported notably low annual totals; locally, rainfall deficiencies exceeded 35%, e.g. in a few parts of London and north Kent. For much of the South East it was the 2$^{nd}$ driest year since 1933. Notable annual rainfall deficiencies also extended across large parts of the South West, east Midlands and the southern Pennines. For Northern Ireland, the 2005 rainfall total was very close to average but the western hills were relatively wet whilst parts of Antrim and Down recorded less than 80%.

The late autumn and early winter of 2004 was notably dry across most of southern Britain - the combined November/December rainfall for England & Wales was the 3$^{rd}$ lowest since 1953. This dry spell initiated drought conditions across much of eastern and southern England. These intensified through 2005 as some parts of the English Lowlands registered 11 successive months (up to October) with below average rainfall. By the end of September, rainfall deficiencies exceeded 25% over wide areas; the Southern and Thames regions recorded, respectively, their 2$^{nd}$ and 3$^{rd}$ lowest November-September rainfall since 1933/34. In the drought-affected regions, above average rainfall in October heralded a dry end to the year and accumulated rainfall deficiencies for the 14 months to the end of December 2005 were between 15-25% over much of southern Britain. In the same timeframe, rainfall across northern Scotland was well above average. This marked regional contrast established a template for the intensification of drought conditions in 2006.

### Temperature and evaporation

2005 was another warm year: mean temperatures in 2005 were 0.8-1.2°C above average across the UK. Although unremarkable in the context of the recent past, the 2005 potential evaporation (PE) total for Great Britain still ranks 7$^{th}$ highest in the 45-yr MORECS[1] series with PE losses 5-15% above average across much of the country. Throughout a significant proportion of the English Lowlands, modelled PE losses for 2005 exceeded the corresponding annual rainfall totals. More significant from a water resources perspective were the notably high actual evaporation (AE) losses which exceeded the average over around 90% of the country; anomalies exceeded 15% in many, mostly low-lying, areas. Dry soil conditions inhibited transpiration losses during the summer for a more limited period than during most recent drought episodes but soil moisture deficits increased briskly across much of the drought-affected region in late September. This was an important factor in delaying the onset of the seasonal recovery in river flows and aquifer recharge across much of eastern and southern England.

### Reservoir stocks

The last 15 years have witnessed large variations in overall reservoir stocks for the UK. Figure 1 provides an index of overall stocks for England & Wales - based on a representative network of major reservoirs. Stocks remained very healthy throughout the 1998-2002 period but declined steeply during the latter stages of the 2003 drought, thereafter recovering to near normal levels during 2004. In 2005, stocks in most Scottish reservoirs began the year close to capacity and, due largely to substantial replenishment in the early autumn of 2004, overall stocks for England & Wales were also appreciably above the 1988-2004 average at the beginning of the year. Boosted by substantial replenishment in most regions during April, overall stocks then remained well within the normal range throughout the year, falling below 70% of capacity in September (see Figure 2). Very healthy reservoir inflows in October helped ensure that, at the national scale, stocks ended 2005 modestly above average. Regionally however, reservoir stocks displayed very substantial departures from the seasonal average throughout 2005 - a direct result of the drought in southern Britain.

Stocks in many southern reservoirs remained well below average throughout 2005 with a number of important impoundments falling well short of capacity in the spring (when most reservoirs are normally full). In the South West, Roadford and Colliford Reservoirs were only around 75% full and, in Sussex, Ardingly Reservoir failed to reach capacity in the late spring for

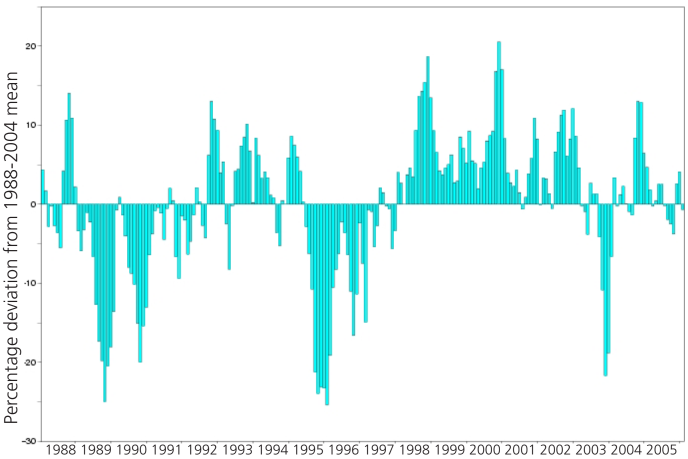



***Figure 1*** *A guide to England and Wales reservoir stocks 1988-2005.*

Data sources: Water Services Companies and the Environment Agency.

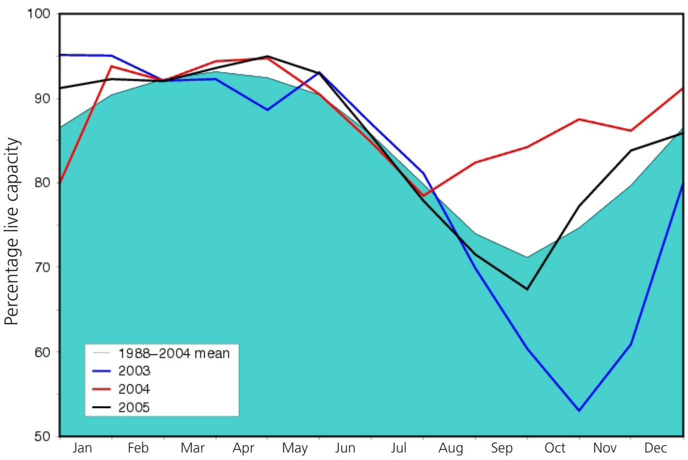



***Figure 2*** *Variation in overall reservoir stocks for England and Wales.*

Data sources: Water Services Companies and the Environment Agency.

the first time in a series from 1988. A surge in water demand during heat-wave conditions in June triggered the introduction of hosepipe bans in the South East. Subsequently, with algal blooms an exacerbating factor in some areas, more widespread restrictions on water use were introduced. By September, a number of southern reservoirs including Bewl, Colliford and Stithians had fallen to around 50% of capacity. At Weir Wood reservoir (Sussex) stocks continued to decline and by October were at their the lowest (for the month) since the reservoir's construction in 1953. Stocks were also seasonally very low in several other reservoirs in southern England at year-end. By contrast, overall stocks in the major pumped storage impoundments which service London's water needs had closely approached the early winter average.

## River flows

Despite the persistent drought conditions in southern England, totals outflows from the UK for 2005 were only around 7% below average. This reflects the balance between above average runoff for Scotland and considerable runoff deficiencies for Northern Ireland (for the 3rd successive year) and England & Wales which recorded its 4th lowest annual runoff since 1976. Figure 3 shows time series of annual runoff anomalies at the national scale, the assessments are based on representative networks of gauging stations monitoring outflows from major river basins. The estimates for the first few years of each plot are less reliable due to the relatively sparse monitoring network (prior to 1981 there were too few operational gauging stations to monitor total outflows from Northern Ireland with any precision).

Apart from a major flood event in north-west England in early January when the River Eden registered the 2nd highest daily mean flow for England & Wales on the National River Flow Archive, there were few extreme flood events in 2005. The lack of spate conditions throughout the English Lowlands was especially notable. For the River Thames, the maximum daily gauged flow in 2005 at Kingston was lower than for any other year apart from 1973 in the 123-year daily flow series. The dearth of high flows is reflected in the depressed annual runoff totals across southern Britain where a significant number of new annual minimum runoff totals were established, in Sussex and Kent especially. Despite the many notable accumulated runoff deficiencies in 2005, annual minima flows in individual rivers were unremarkable except in some, mostly spring-fed, rivers and streams in the English Lowlands. In the worst affected catchments the contraction in the stream network and associated loss of aquatic habitat was exceptional by the autumn.

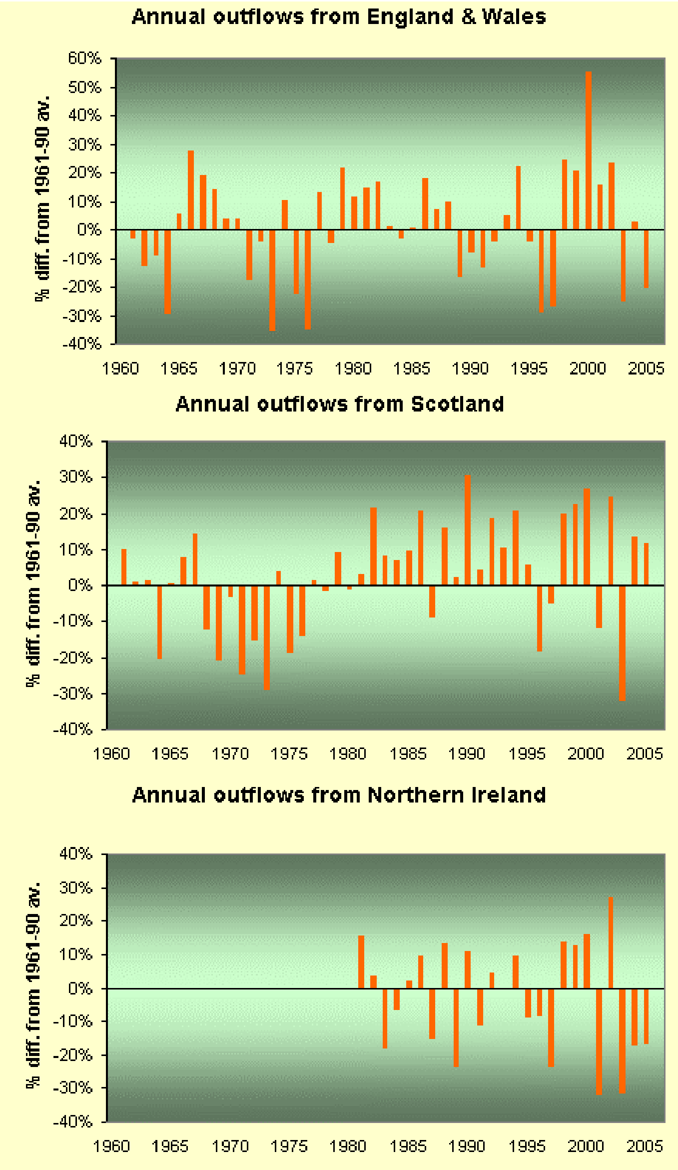



***Figure 3*** *Index of total runoff 1961-2005.*

## Groundwater

The spatial and temporal distribution of rainfall in 2005 was generally very unfavourable for groundwater recharge. Annual rainfall totals were less than 80% of average across most major aquifer outcrop areas and, importantly, a large proportion of the deficiency was associated with the winter and early spring, when groundwater replenishment is normally most abundant. As a result of the 3rd driest November-April period since 1953/54 (for England & Wales), replenishment over the 2004/05 recharge season was less than half of the long term average over wide areas. Correspondingly, the spring maxima in groundwater levels were appreciably below average in most outcrop areas of the major aquifers, and barely discernible in a parts of the Chalk (e.g. the Chilterns) and the Permo-Triassic sandstones (e.g. the in the East Midlands). By the late summer, protracted recessions in groundwater levels left water-tables well below the seasonal average across much of the country, but the degree of groundwater level depression varied markedly, even within individual outcrop areas. This reflects differences in both rainfall patterns and aquifer properties; generally, the combined impact on water-tables was most evident in those aquifers which are the most important in water supply terms. Sustained October rainfall helped initiate the 2005 seasonal recoveries in many western and northern aquifers and groundwater levels were mostly in the normal range by year-end. By contrast, in much of eastern, central and southern England, the early autumn rainfall was insufficient to overcome soil moisture deficiencies. Groundwater level recessions therefore continued and the very limited November and December rainfall served, in some areas, only to moderate the rate of decline in groundwater levels. The failure of the seasonal recoveries to gain any momentum by year-end foreshadowed continuing water resources and environmental stress in 2006.

# The year in context

This section places the hydrological conditions experienced in 2005 in the context of the recent past, and within a broader historical perspective.

2005 continued a sequence of years, beginning in the late-1980s, which taken together exhibit a greater degree of hydrological volatility than is captured in the previous records for most river flow and groundwater level monitoring stations. On the basis of climatological data and more limited hydrometric evidence, comparably volatile episodes with extended periods of depressed runoff and recharge rates can be identified in the historical record (e.g. the 1850s, 1890-1910, and the 1940s). There are, however, no close modern parallels to the very notable departures from the normal seasonal patterns in river flows and rates of aquifer recharge experienced over the last 15-20 years. An enduring feature of hydrological conditions across the UK is the large contrasts often experienced between northern and southern Britain - these differences have achieved an extreme expression in a number of recent years.

## The recent past

Following extended drought conditions in 1988-92, which were punctuated by the exceptionally wet winter of 1989/90, a wet interlude heralded a second protracted drought (1995-97) which impacted most severely on southern Britain - groundwater resources in particular. The drought terminated in the autumn of 1997 to be followed by the wettest five-year sequence on record for the UK. England & Wales registered its highest 5-year rainfall total in a series from 1766[2]. Severe flooding occurred in April 1998 (across the Midlands), throughout most of southern Britain in 2000/01, and again in early 2003. Existing maximum recorded flows were widely eclipsed - mostly by modest margins - and groundwater levels, responding to unprecedented rates of aquifer recharge (especially in the winter of 2000/01), exceeded previous maxima for extended periods in many southern outcrop areas. With most rain-bearing frontal systems following more southerly tracks than normal a further drought episode developed in northern Britain and Northern Ireland during 2001. More intense drought conditions extended across much of the UK during the exceptionally hot spring and summer of 2003. Sustained rainfall during the late autumn had a moderating effect but very limited replenishment of groundwater resources in the late winter and early spring of 2004 heralded the recent winter drought episodes which impacted most severely on parts of eastern, central and southern England in 2005 (and 2006).

Considering the last 15 years as a whole rainfall for Scotland has been around 9% higher (4% higher for Northern Ireland) than the preceding average with winters contributing most to the additional rainfall. Notwithstanding the recent drought periods, rainfall for England & Wales over the 1991-2005 period is very close to the preceding average. Figure 4 allows the rainfall during the recent past to be compared with rainfall variability since 1914. The outstanding wetness of the 1998-2002 period in southern Britain, together with the notable dryness of much of the 1970s, has served to exaggerate the apparent increasing trend in rainfall over the last 30- 40 years. This is particularly true of Scotland where the wetness of the last 20 years has seen an extension in the range of recorded variation in annual rainfall totals. A modest contributory factor to the increase in rainfall may be the decreasing proportion of snowfall in the overall precipitation totals (the underestimation of snowfall is normally greater than that for rainfall). The erratic increase in rainfall since the mid-1970s was not maintained over the 2003-05 period, underlining the dangers of extrapolation of time series characterized by protracted perturbations about a relatively stable long term mean.

A more extended historical perspective is provided by the 232-year England & Wales rainfall series[2]. It exhibits no overall trend but long term tendencies to increasing winter and decreasing summer rainfall may be identified. The last 35-years in particular has seen a clearer partitioning between winter half-year (November-April) and summer half-year (May-October) rainfall across much of the UK. For most of the 20th century England & Wales, winter half- year (November-April) rainfall exceeded those for the summer half-year. By contrast, prior to the 1st World War summers were very often wetter than winters and clusters of dry winters were common, in the 1850s and 1890-1905 period particularly[3]. Any repetition of similar rainfall patterns across southern Britain would represent a considerable water resource challenge given modern levels of water demand.

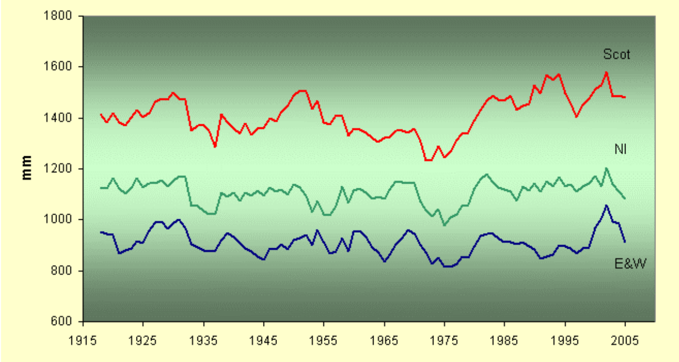



***Figure 4*** *National rainfall series 1914-2005 (5 year running annual means).*

Data source: UK Met Office.

A compelling climatological feature of the recent past has been the persistence of seasonally high temperatures, especially over the last 10 years. 1996 is the only year since 1988 that the annual mean Central England Temperature (CET)[4] has failed to exceed the average for the preceding record. Nine of the ten warmest years in the 337-year CET series cluster in the post-1988 period and the average CET for the last ten years is around 1.0°C greater than for a century ago. The recent very appreciable warming is evident in Figure 5 which illustrates winter (December-February) and summer (June-August) temperature and rainfall anomalies (relative to the 1845-1974 average) for England & Wales. The red diamonds show the plotting positions for the most recent 30-years; a high proportion, including the winter and summer half-years for 2004/05, have registered positive temperature anomalies. The last 30 years is notable for the above average frequency of mild, wet winters and hot, dry summers. However, the dryness of the 2004/05 winter and the limited summer rainfall deficiency underline the inherent variability of the British climate.

The warm conditions have contributed to significant increases in evaporative demands over the last 40 years. Figure 6 shows the 5-year running mean annual potential (PE) and actual (AE) evaporation losses for England & Wales and for Scotland (based on MORECS[1] data. PE losses for England & Wales have increased erratically but recent annual totals have been around 30mm greater than those that characterized the 1960s. AE losses exhibit a broadly similar trend although in the drier regions of England little overall increase can be detected. This is largely due to the warmer (and, often, drier) summers with correspondingly very dry soil conditions - inhibiting transpiration rates and, thereby, moderating overall AE losses. As a consequence, changing evaporative demands have had only a limited impact on the water balances of most catchments. In Scotland the generally higher rainfall implies that transpiration rates are normally restricted for only very short periods away from sheltered areas along the eastern seaboard. Correspondingly, countrywide annual AE losses closely approach PE totals in most years. Actual evaporation losses have increased by

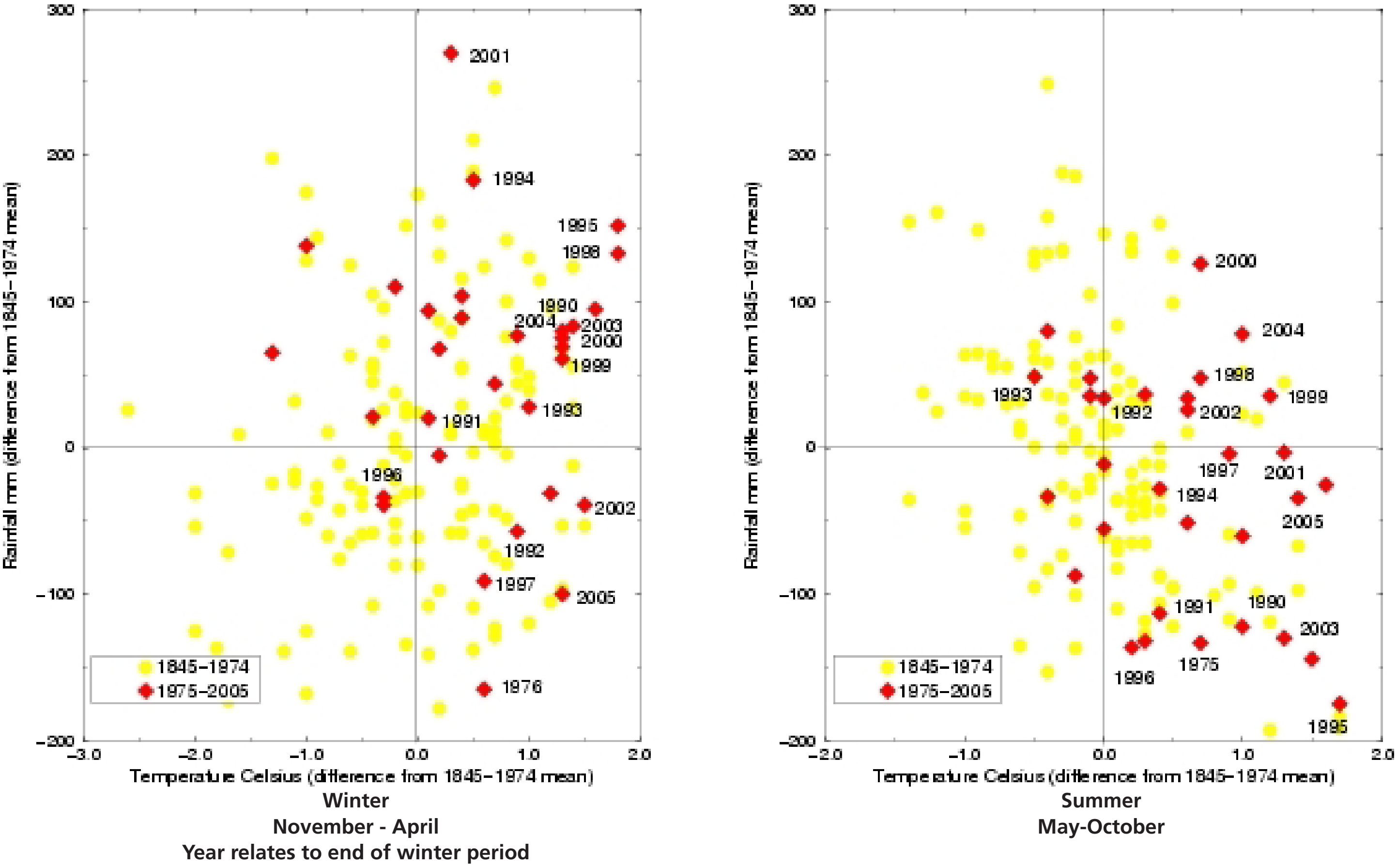



*Figure 5* *England and Wales rainfall and temperature anomalies 1845-2005.*

Data sources: Central England Temperature series/Hadley Centre

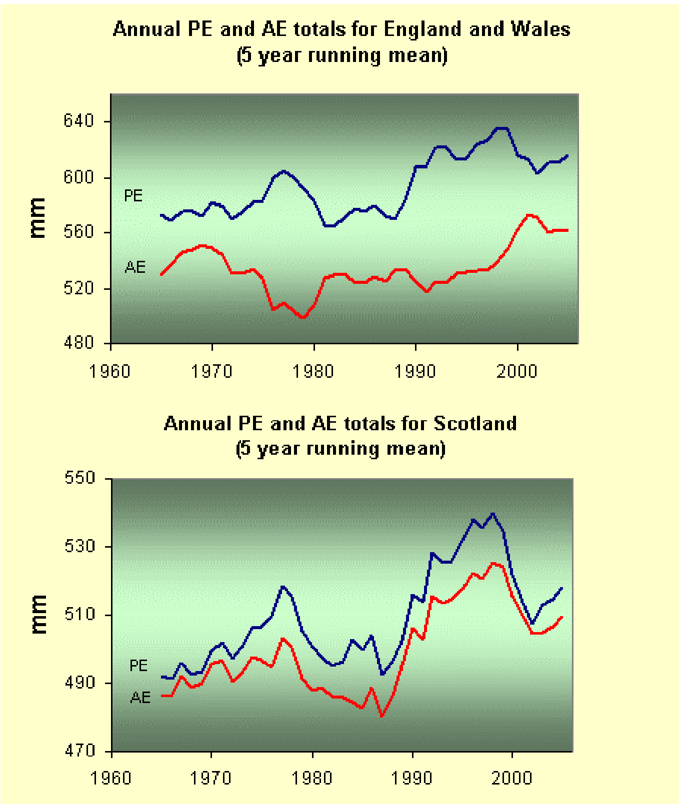



*Figure 6* *Annual potential evaporation and actual evaporation totals 1961-2005.*

Data source: MORECS.

a similar margin to those for England & Wales since the 1960s but the impact on water balances in most catchments has been more than counterbalanced by increases in annual precipitation totals over the same timespan.

River flows, reservoirs stocks and groundwater resources are sustained and replenished not by rainfall directly but by that proportion which remains after allowing for evaporative demands. Runoff therefore provides the best index of the health of water resources. Figure 6 provides evidence of substantially greater runoff from Scotland over the post-1980 period with a notable range of annual variation over the last decade and a downturn over the 2003-05 period. The latter is more prominent in Northern Ireland where the 2003-05 runoff is considerably lower than that for any three-year accumulation in a series from 1981. For England & Wales, notwithstanding the enhanced evaporative demands, total runoff over the five years beginning in 1998 was unprecedented over the post-1960 period (and, very probably, throughout the instrumented era - which stretches back into the 18th century). Subsequently, the dry winters have contributed to much more modest overall runoff and aquifer recharge, especially in southern Britain where an exceptional contrast may be recognized between groundwater resources in early 2003 and at the end of 2005 when depressed levels in parts of the Chalk and Permo-Triassic sandstones (of the Midlands) resulted in very low flows in many spring-fed streams and rivers.

Water resources and environmental stress, as well as impacts on the community, are influenced more by the frequency and magnitude of extreme events than changes in mean runoff or average groundwater levels. Over the last 40 years, statistically significant increases in runoff and flood magnitude have been identified over various timespans for some rivers (mostly in northern Britain) and examples of both positive and negative trends in low flows can readily be found[5]. However, given the natural range of hydrological variability and the pervasive impact of artificial influences (e.g. abstractions, river regulation, inter-basin transfers and flood alleviation measures) on extreme flows, any attribution to climatic change can be only tentative. Of particular significance in the UK is the fact that the great majority of river flow and groundwater level data has been collected over the post-1960 period. In relative terms, the early part of this period (up to the late-1970s) can be broadly characterised as quiescent - with below average runoff and a low frequency of major flood events across much of the country. By contrast, the recent past has been much more volatile. Correspondingly, trend analyses embracing datasets covering the last 30-40 years will inevitably detect significant trends. In assessing their implications it is important to recognize how sensitive trend recognition is to the timeframe over which the analysis is undertaken; even modest changes in the timeframe used can produce considerable differences in both the sign and magnitude of any apparent trend. When analyses are confined to the limited number of flow records which extend over 80 or more years, few compelling examples of long term trends can be discerned[5,6].

# Rainfall

## The year in brief

For its size, the UK exhibits very large regional rainfall differences even in an average year. This inherent spatial variability was considerably enhanced in 2005. In parts of the western Highlands of Scotland annual precipitation totals exceeded 5000mm whilst some localities in the South East recorded an order of magnitude less - rainfall totals falling below 450mm in a few areas adjacent to the Thames estuary (Figure 7). Relative to the 1961-90 average, this represents about a 20% shortfall and 2005 rainfall totals were more than 15% below average across much of the English Lowlands. Figure 8 serves to underline the north-south contrast in rainfall anomalies for 2005. For much of the South East and the east Midlands, 2005 was the 2nd driest year since 1933; by contrast, rainfall was close to, or above, average throughout almost all of Scotland with the most notable anomalies north-west of the Great Glen.

Table 1 gives monthly and half-yearly national and regional rainfall totals (in mm and as a percentage of the 1961-90 average) for 2005. The general pattern of rainfall through most of 2005 was established during the December 2004-February 2005 period (see Figure 9), for which Scotland reported its 7th highest winter rainfall since 1920. Rainfall over England & Wales however was the lowest for 30 years (although the winters of 1991/92 and 1996/97 produced similar totals) with deficiencies exceeding 40% in parts of the South and the Midlands. Catchments in the South East were especially dry and the regional focus of the drought was reinforced through the spring of 2005. In the drought-affected regions, summer (June-August) rainfall totals were generally well above drought minima (e.g. those of 1990, 1995 and 2003) but did little to moderate the increasing hydrological stress.

In a water resources context, the November 2004-September 2005 period provides a better insight to the severity of drought conditions experienced in 2005 (see Figure 10). Within this 11-month timeframe England & Wales registered its 3rd driest such sequence since 1976, with parts of the South East reporting their 3rd driest November- September period since 1944. October was wet throughout the UK and, by a substantial margin, the wettest month of the year across most of the country. However, anticyclonic weather patterns - and modest rainfall totals - again predominated in southern Britain during November and December. This second successive relatively dry late autumn and early winter ensured the continuation of severe drought conditions into 2006 - and a very fragile water resources outlook in parts of southern England and the Midlands

## Rainfall - through the year

Spatial contrasts in rainfall anomalies were particularly marked during the winter of 2004/05. Following a dry December in 2004, large parts of England recorded less than half the average rainfall in January whilst Scotland registered its 5th wettest January in a series from 1914. In the first fortnight, appreciable precipitation was recorded on almost every day, resulting in some extreme rainfall accumulations e.g. 341mm at Strathyre (north of Callander) by the 10th January (the estimated return period exceeds 50 years). Exceptional precipitation totals were also recorded in the Lake District and North Wales.

Generally mild conditions through the late winter meant that rainfall constituted much the greater part of the precipitation even in northern Britain but substantial

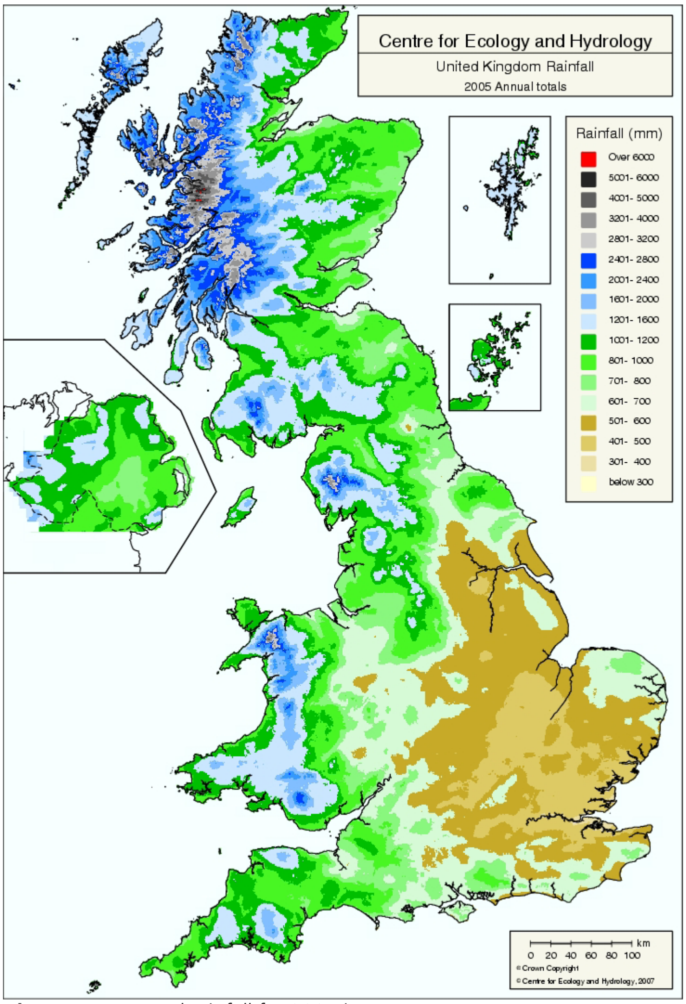



***Figure 7*** *Annual rainfall for 2005 in mm.*

Data source: UK Met Office.

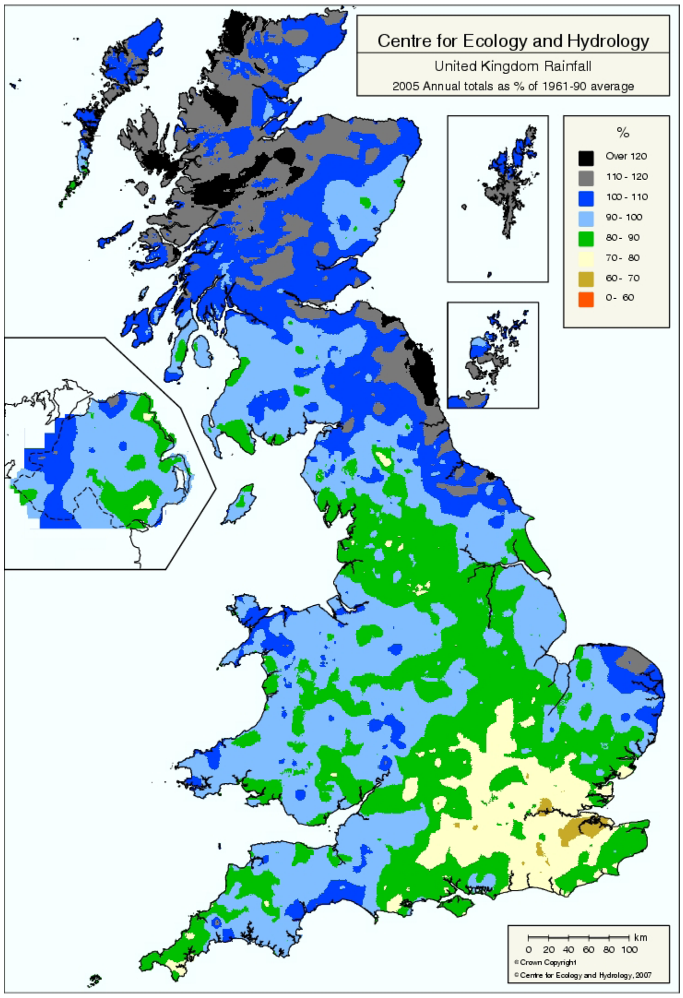



***Figure 8*** *Annual rainfall for 2005 as a percentage of the 1961-90 average.*

Data source: UK Met Office.

snowfall was experienced in northern England and the Scottish Borders during January and February. Snowstorms were less common but more widely distributed in March when, early in the month, drifting snow contributed to severe transport disruption and some school closures, as far south as Kent and Sussex. Such wintry interludes aside, the drought continued to intensify with some catchments in the South East reporting March rainfall totals below 50% of average; in London a number of raingauges registered monthly totals of 15mm or less.

By the end of March, accumulated rainfall deficiencies from the beginning of November 2004 exceeded 40% of the 1961-90 average in parts of southern England. For England & Wales, the November-March period was the driest since 1975/76 and in parts of the South East the 5-month total was the 2nd lowest in over 60 years, firmly establishing the regional dimension of the 2005 drought. Although April provided some respite in much of the drought-affected regions, dry conditions resumed in May - contributing to a remarkable sequence of months with below average rainfall in some parts of the English Lowlands. Parts of the Thames Valley recorded negative monthly rainfall anomalies for 11 successive months beginning in November 2004. In this timeframe, most southern catchments registered only two or three months with above average rainfall. By the early summer, rainfall deficiencies were outstanding for many catchments in eastern and southern England over the post-1975/76 period.

In southern Britain particularly, the summer was characterized by extended dry periods punctuated by intense convective storms. Some very notable events were reported e.g. 69.4mm in 3 hours at Hawnby (North Yorkshire), which included just over 50mm in one 30-minute period (estimated return period exceeds 300 years). Radar estimates indicate storm totals of up to 125mm in 3 hours at Sutton Bank. Notwithstanding the dry start, summer (June-August) rainfall totals were within the normal range in almost all regions and, in England, most of the drought-affected areas reported only moderate negative anomalies. However, Northern Ireland registered its 2nd lowest summer rainfall since 1984. July was unusual in the context of 2005 as a whole: warm and dry conditions typified most of northern Britain with above-average rainfall across much of England & Wales. The July rainfall was very useful agriculturally but dry soil conditions ensured that it had little impact on water resources (apart from modestly reducing water demand).

***Table 1*** *2005 Rainfall in mm and as a % of the 1961-90 average.*

Data source: UK Met Office.

| 2005 | | J | F | M | A | M | J | J | A | S | O | N | D | Year | Oct-Mar 2004/05 | Apr-Sep 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| United Kingdom | mm | 127 | 70 | 73 | 91 | 73 | 72 | 59 | 85 | 93 | 142 | 116 | 81 | 1083 | 622 | 473 |
| | % | 113 | 89 | 79 | 135 | 102 | 101 | 81 | 94 | 92 | 127 | 102 | 70 | 98 | 100 | 100 |
| England and Wales | mm | 68 | 50 | 52 | 74 | 48 | 57 | 66 | 60 | 68 | 122 | 90 | 69 | 823 | 440 | 373 |
| | % | 75 | 78 | 71 | 124 | 75 | 89 | 106 | 78 | 87 | 141 | 98 | 72 | 91 | 88 | 92 |
| Scotland | mm | 240 | 110 | 113 | 122 | 115 | 104 | 49 | 134 | 140 | 184 | 173 | 98 | 1582 | 980 | 664 |
| | % | 155 | 104 | 88 | 151 | 134 | 121 | 51 | 115 | 97 | 115 | 110 | 63 | 108 | 114 | 109 |
| Northern Ireland | mm | 136 | 60 | 76 | 92 | 103 | 55 | 46 | 91 | 89 | 130 | 83 | 112 | 1071 | 573 | 475 |
| | % | 117 | 74 | 84 | 138 | 141 | 76 | 64 | 95 | 89 | 113 | 77 | 102 | 98 | 93 | 99 |
| North West | mm | 136 | 68 | 58 | 105 | 78 | 65 | 53 | 87 | 103 | 164 | 129 | 79 | 1126 | 641 | 491 |
| | % | 114 | 86 | 60 | 147 | 103 | 79 | 62 | 79 | 88 | 128 | 103 | 63 | 93 | 95 | 91 |
| Northumbrian | mm | 97 | 71 | 66 | 104 | 53 | 48 | 83 | 54 | 74 | 123 | 94 | 56 | 924 | 480 | 417 |
| | % | 115 | 119 | 93 | 181 | 85 | 78 | 125 | 66 | 100 | 161 | 108 | 68 | 107 | 104 | 103 |
| Severn Trent | mm | 39 | 47 | 50 | 59 | 36 | 60 | 66 | 54 | 60 | 105 | 70 | 57 | 702 | 344 | 334 |
| | % | 54 | 85 | 82 | 105 | 60 | 100 | 119 | 78 | 93 | 159 | 98 | 73 | 91 | 85 | 98 |
| Yorkshire | mm | 69 | 63 | 42 | 87 | 41 | 51 | 77 | 60 | 67 | 92 | 80 | 50 | 779 | 388 | 35 |
| | % | 87 | 108 | 62 | 146 | 68 | 83 | 125 | 80 | 95 | 124 | 97 | 61 | 93 | 87 | 101 |
| Anglian | mm | 27 | 42 | 30 | 39 | 39 | 48 | 56 | 61 | 61 | 62 | 39 | 32 | 537 | 261 | 264 |
| | % | 53 | 113 | 64 | 85 | 81 | 92 | 112 | 110 | 122 | 121 | 66 | 58 | 89 | 87 | 80 |
| Thames | mm | 29 | 24 | 47 | 49 | 30 | 39 | 47 | 49 | 50 | 80 | 49 | 56 | 550 | 306 | 277 |
| | % | 44 | 53 | 83 | 97 | 53 | 72 | 93 | 83 | 84 | 125 | 74 | 79 | 79 | 83 | 82 |
| Southern | mm | 41 | 26 | 51 | 48 | 34 | 29 | 68 | 60 | 37 | 104 | 54 | 68 | 621 | 341 | 328 |
| | % | 50 | 49 | 80 | 91 | 63 | 54 | 141 | 103 | 54 | 129 | 63 | 83 | 79 | 76 | 90 |
| Wessex | mm | 56 | 27 | 59 | 67 | 48 | 69 | 58 | 46 | 40 | 123 | 81 | 95 | 769 | 404 | 442 |
| | % | 63 | 42 | 83 | 126 | 78 | 119 | 109 | 68 | 55 | 151 | 95 | 100 | 90 | 83 | 95 |
| South West | mm | 98 | 50 | 59 | 104 | 63 | 83 | 72 | 45 | 75 | 178 | 141 | 114 | 1083 | 576 | 493 |
| | % | 71 | 49 | 59 | 149 | 86 | 118 | 102 | 52 | 80 | 152 | 110 | 81 | 91 | 79 | 89 |
| Welsh | mm | 115 | 73 | 74 | 110 | 61 | 72 | 86 | 67 | 97 | 213 | 176 | 110 | 1256 | 725 | 493 |
| | % | 80 | 73 | 68 | 134 | 72 | 88 | 106 | 63 | 82 | 153 | 122 | 70 | 93 | 91 | 89 |
| Highland | mm | 337 | 146 | 153 | 136 | 126 | 120 | 61 | 185 | 197 | 173 | 244 | 114 | 1993 | 1310 | 825 |
| | % | 186 | 116 | 97 | 145 | 134 | 121 | 57 | 143 | 117 | 90 | 124 | 59 | 115 | 125 | 119 |
| North East | mm | 129 | 95 | 69 | 80 | 90 | 84 | 39 | 88 | 42 | 145 | 153 | 82 | 1098 | 630 | 424 |
| | % | 125 | 138 | 84 | 118 | 123 | 122 | 51 | 97 | 46 | 141 | 147 | 84 | 107 | 113 | 90 |
| Tay | mm | 215 | 90 | 90 | 136 | 109 | 92 | 30 | 91 | 89 | 194 | 147 | 81 | 1365 | 803 | 548 |
| | % | 147 | 90 | 80 | 199 | 126 | 121 | 36 | 92 | 73 | 143 | 116 | 60 | 106 | 106 | 103 |
| Forth | mm | 192 | 87 | 95 | 99 | 108 | 93 | 35 | 79 | 93 | 178 | 106 | 70 | 1235 | 745 | 508 |
| | % | 162 | 106 | 96 | 160 | 142 | 129 | 45 | 81 | 83 | 149 | 91 | 62 | 108 | 115 | 102 |
| Clyde | mm | 269 | 113 | 126 | 135 | 139 | 129 | 45 | 166 | 172 | 210 | 156 | 118 | 1777 | 1124 | 786 |
| | % | 143 | 91 | 83 | 151 | 145 | 133 | 39 | 117 | 94 | 107 | 85 | 64 | 101 | 109 | 109 |
| Tweed | mm | 132 | 70 | 75 | 97 | 77 | 67 | 55 | 57 | 64 | 196 | 96 | 61 | 1046 | 583 | 417 |
| | % | 130 | 100 | 92 | 160 | 105 | 99 | 73 | 63 | 69 | 199 | 100 | 62 | 104 | 107 | 91 |
| Solway | mm | 197 | 79 | 79 | 132 | 134 | 77 | 37 | 84 | 116 | 242 | 132 | 89 | 1398 | 804 | 580 |
| | % | 129 | 78 | 67 | 166 | 153 | 90 | 41 | 69 | 81 | 154 | 90 | 59 | 97 | 97 | 95 |
| Western Isles; Orkney and Shetland | mm | 181 | 96 | 109 | 107 | 78 | 99 | 75 | 148 | 194 | 143 | 155 | 101 | 1487 | 850 | 701 |
| | % | 125 | 97 | 92 | 137 | 113 | 137 | 87 | 148 | 141 | 93 | 102 | 68 | 109 | 104 | 129 |

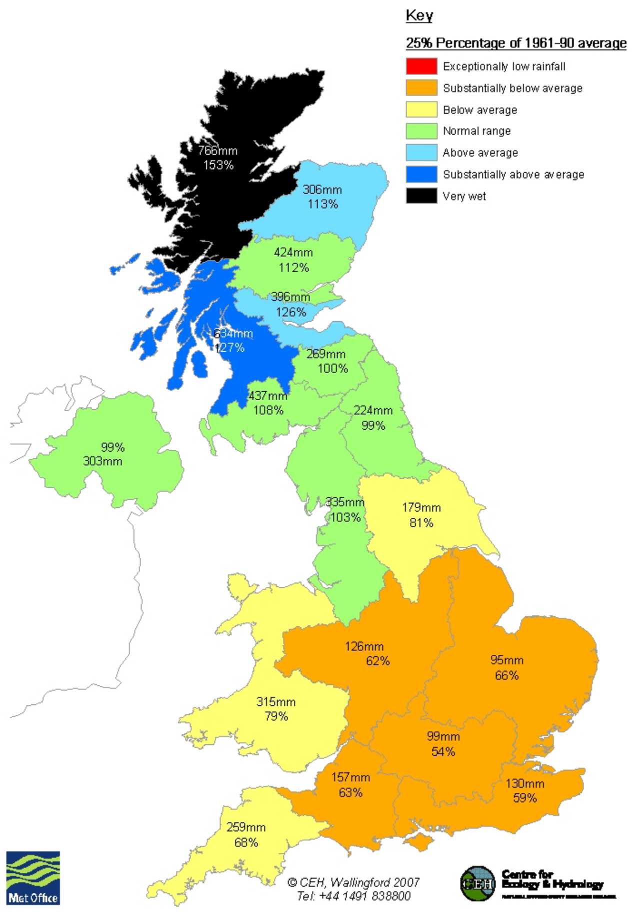



**Figure 9** *December 2004 - February 2005 rainfall in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.

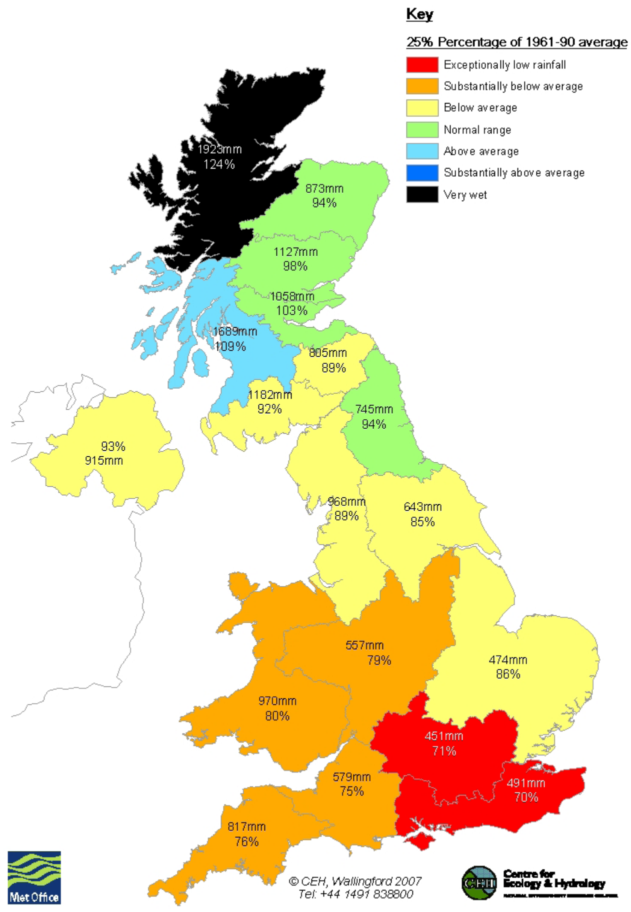



**Figure 10** *November 2004 - September 2005 rainfall in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.

Rainfall in August was spatially very variable with localized flash flooding and many lightning strikes with associated power loss (e.g. in North Tyneside and parts of Northern Ireland), whilst other areas (e.g. the South West), were notably dry. An unsettled late-September heralded generally wet conditions in October when successive pulses of frontal rainfall in the north and west and, especially in the Scottish Borders, triggered high spate conditions in many rivers. Nearly all the UK experienced above average rainfall but the impact on accumulated rainfall deficits was modest.

November saw significant snowfall in Cornwall and Wales which led to widespread transport disruption but, generally, weather conditions reverted to a familiar 2005 pattern with northern Scotland very wet whilst much of eastern and southern England reporting well below average rainfall. Autumn (September-November) regional rainfall totals were mostly well within the normal range but deficiencies of 15-25% typified much of the South East, further strengthening the drought's regional focus. Drought conditions intensified again in December when, despite significant snowfall towards the end of the month (e.g. in Yorkshire and Kent), all regions reported below average precipitation. In Northern Ireland, rainfall was only marginally below average but Great Britain registered its 4$^{th}$ driest December since 1975. The dry end to 2005 heralded the continuation of severe drought conditions into the following year.

See http://www.ceh.ac.uk/data/nrfa/ for a more detailed commentary on rainfall patterns in individual months of 2005.

## Evaporation and Soil Moisture Deficits

### Background

On average, over 40% of UK rainfall is accounted for by evaporative losses - but the proportion varies greatly from region to region, reaching around 80% in the driest parts of the English Lowlands. Evaporation may occur directly from open water surfaces, from the soil or as transpiration from plants. Potential evaporation (PE) is the maximum evaporation which would occur from a continuous vegetative cover amply supplied with moisture. Temperatures, particularly during the late spring and summer, are the primary influences on evaporative demands, but windspeed, sunshine hours, humidity and patterns of land use are all contributory factors. Evaporation losses exhibit a strong seasonal cycle, peaking normally in June or July; typically, only

10-20% of the annual PE loss occurs during the October-March period.

Given normal rainfall, the increasing temperatures and accelerating evaporative demands through the spring lead to a progressive drying of the soil profile and the creation of what is termed a Soil Moisture Deficit (SMD). Eventually, the ability of transpiration to proceed at the potential rate is reduced as a result of the drying soil conditions, the associated reduced capability of plants to take up water, and the measures plants take to restrict transpiration under such conditions. Thus in the absence of favourable soil moisture conditions actual evaporation (AE) rates will fall below the corresponding PE rates, appreciably so during dry summers. When plant activity and evaporation rates slacken in the autumn, rainfall wets-up the soil profile once more - allowing runoff rates to increase and infiltration to groundwater to recommence. Knowledge of the soil moisture status and evaporation rates are essential for understanding water resource variability.

The following commentary on evaporation patterns and soil moisture deficits during 2005 relies, in large part, on monthly figures derived by the Met Office Rainfall and Evaporation Calculation System (MORECS)[1].

## Temperatures and evaporation losses in 2005

The annual mean temperature for 2005 ranks 14th warmest in the 337-year Central England Series. Most years in the last decade have higher mean temperatures but 2005 was another warm year - annual mean temperatures in all regions of the UK were 1-2°C above the 1961-90 average. January and October were especially mild. Spring and summer temperatures were moderately above average apart from East Anglia, western Scotland and some extreme western coastal areas which experienced relatively cool temperatures for the time of year. Sunshine hours also exceeded the average, typically by 5-10% across most the UK (Northern Ireland was an exception).

In most areas, warm conditions in the first half of September and the exceptionally mild October, especially in the South, ensured that evaporative demands remained high well into the autumn. Correspondingly, 2005 PE totals were above average throughout most of the country, albeit unremarkable in the context of the preceding 15 years. MORECS PE totals (for a grass cover) ranged from a little above 400mm in the Scottish Highlands to around 700mm in some areas adjacent to the Bristol Channel (Figure 11). Typically, 2005 PE totals were 5-15% above the 1961-90 average (Figure 11). Actual evaporation losses also exceeded the average across most of Great Britain, with anomalies rising to 20% in many coastal areas, especially in the east (Figure 12). As usual, annual AE losses closely approached PE totals in most of western and northern Britain but briskly increasing early summer soil moisture deficits, especially in eastern England, helped ensure that actual evaporation rates in the June-September period fell considerably short of the potential rate. As a consequence, the annual shortfall of AE relative to PE in the English Lowlands was approximately double that of 2004; but relatively modest compared to the shortfall in 2003 when much of the spring-autumn period was notably arid.

## Soil moisture deficits

The development and decay of soil moisture deficits (SMDs) over the 2001-2005 period is illustrated in Figure 13 for six representative MORECS squares; the SMD values relate to the end of each month and assume a grass cover. The plots confirm the expected drying and wetting cycle through 2005 but some significant departures from the normal pattern can be identified. Notably wet conditions during April (across most of the country) delayed the onset of significant SMDs but, generally, soils dried out rapidly through May and June especially during the heat-wave conditions in mid-month. SMDs increased briskly in much of Scotland during July but declined considerably in parts of the English Lowlands - a response to substantial rainfall over the latter half of the month. Unsettled weather in August again moderated the growth of SMDs but an exceptional warm September, with below average rainfall across most of Great Britain, contributed to seasonally very dry soil conditions at month end. Away from the wettest catchments, deficits were 20-60mm above average over wide areas, and exceptional in eastern Scotland and parts of southern England (Figure 14).

The rate at which the SMDs were eliminated during the following months was of particular hydrological significance given the intensity of the drought in the early autumn. In most of northern Britain, deficits declined rapidly through the autumn and most catchments were close to saturation by late October. Soils in southern and eastern England remained much drier, albeit with large regional, and more local, variations in soil moisture conditions. In some of the more easterly drought stricken areas, appreciable SMDs were maintained to the end of the year (e.g. in Essex). These residual deficits contributed to the fragile water resources outlook in early 2006.

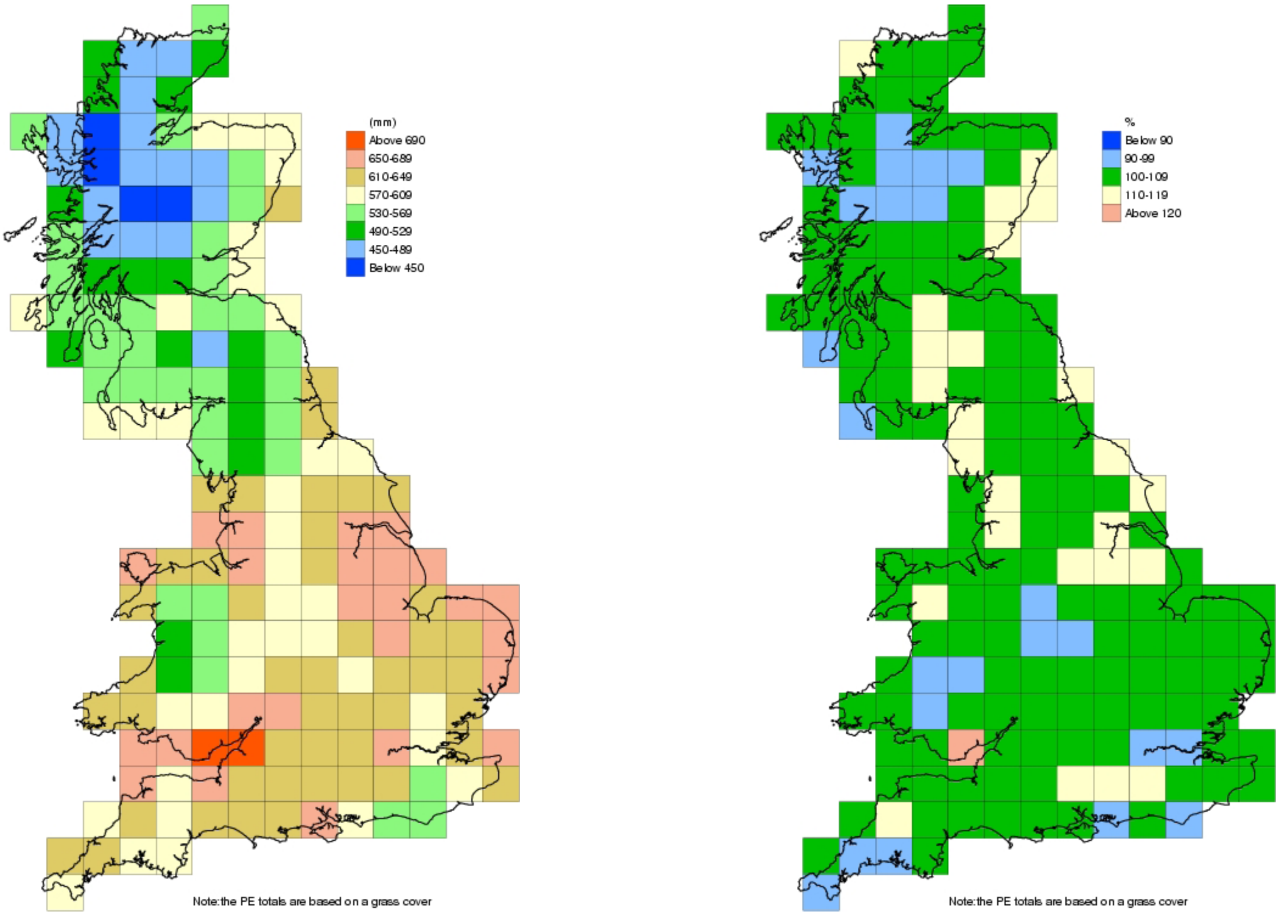



***Figure 11*** *Potential evaporation totals for 2005 in mm and as a percentage of the 1961-90 average.*

Data source: MORECS.

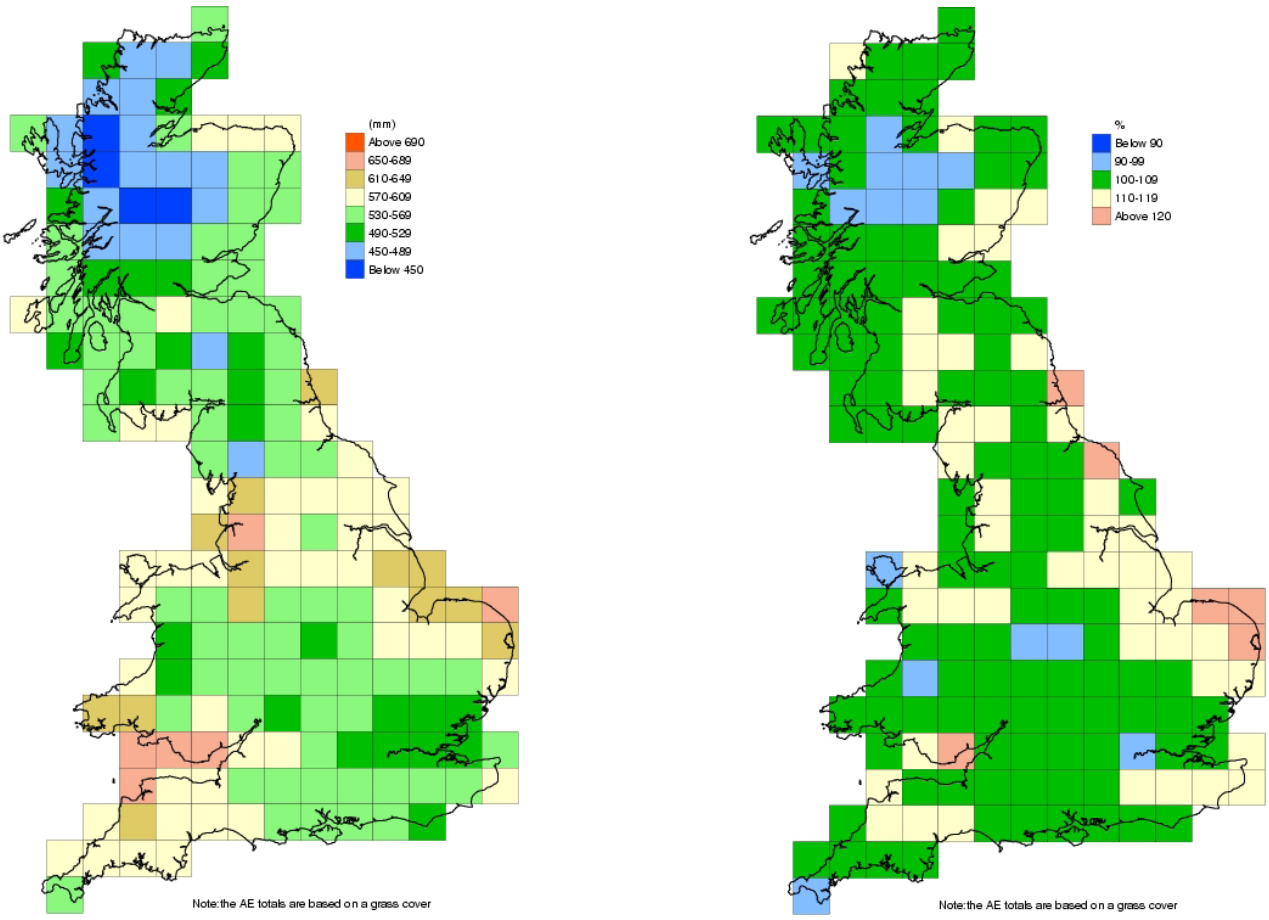



***Figure 12*** *Actual evaporation totals for 2005 in mm and as a percentage of the 1961-90 average.*

Data source: MORECS.

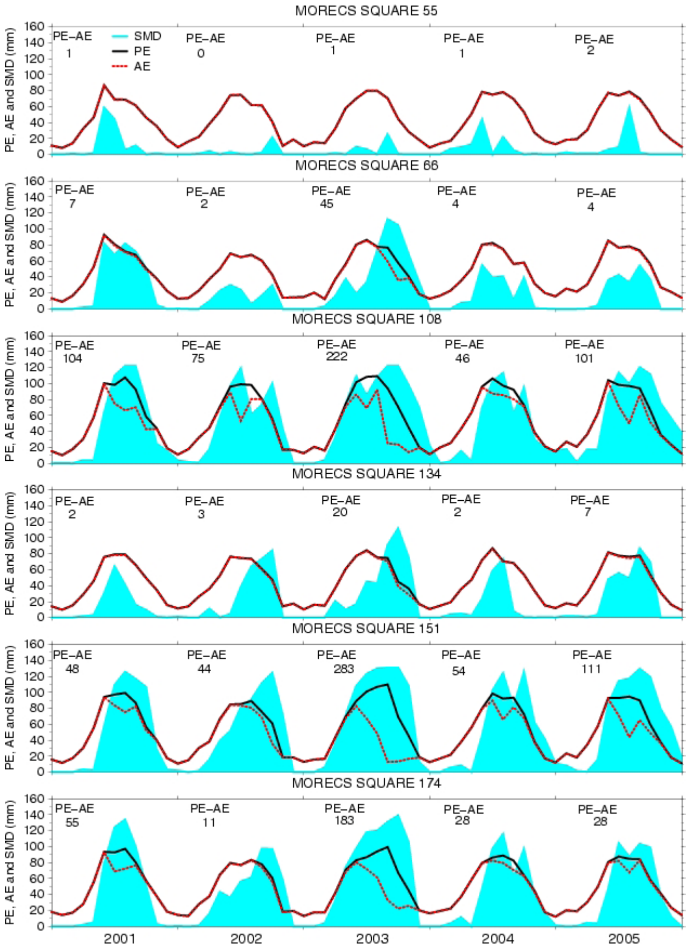



***Figure 13a*** *Monthly variation in potential evaporation, actual evaporation and soil moisture deficits for six MORECS squares 2001-2005.*

Data source: MORECS.

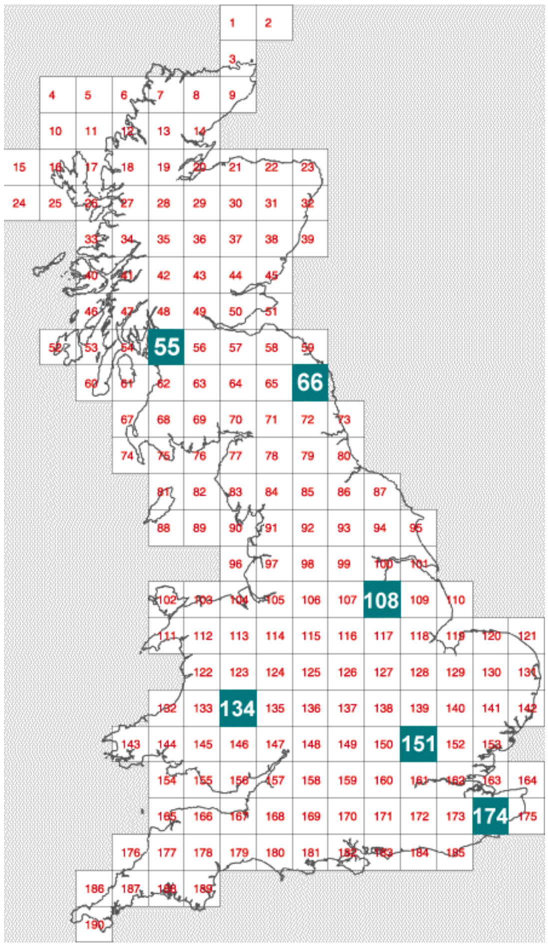


***Figure 13b*** *MORECS Location Map: the location of the 40km squares and their associated reference numbers.*

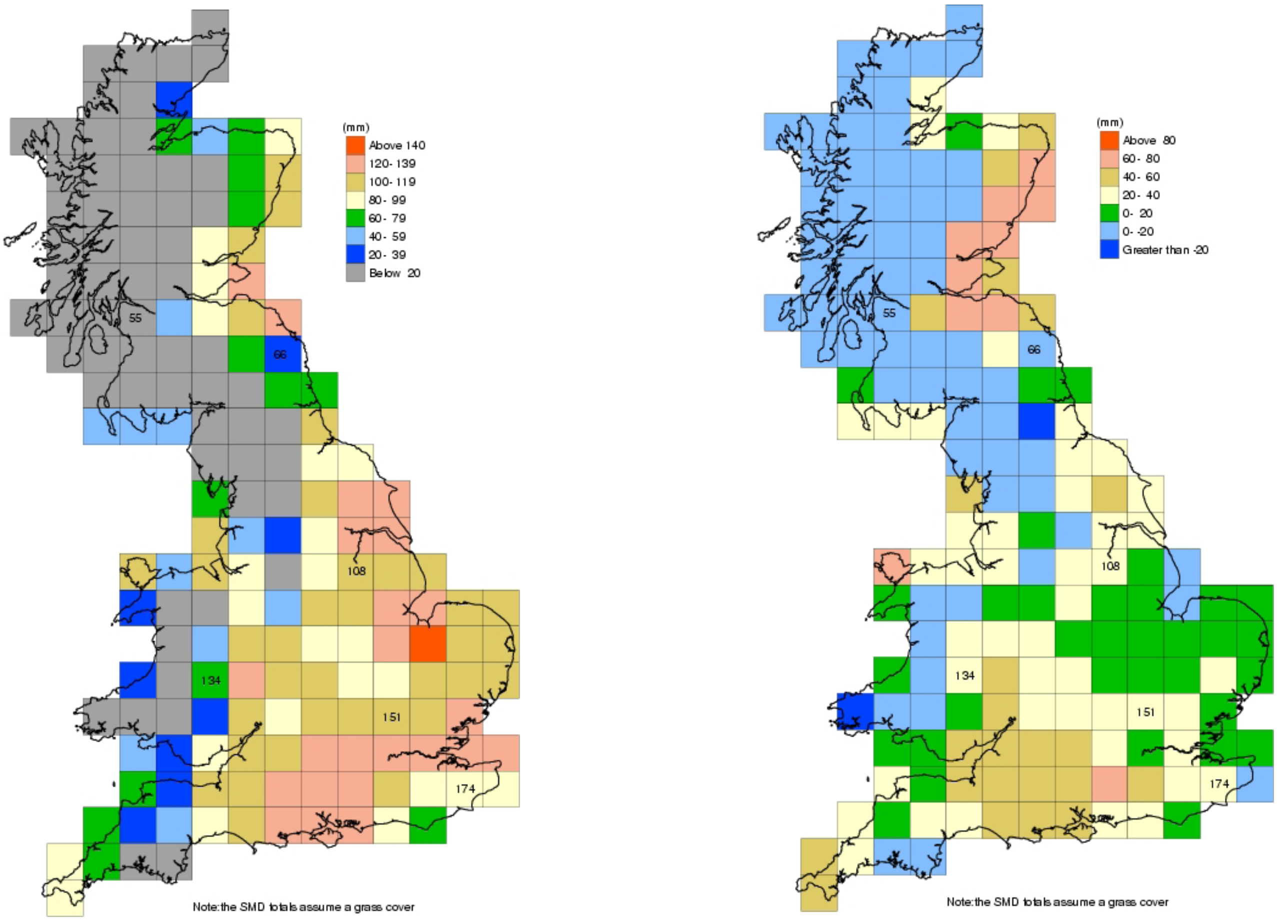



***Figure 14*** *Soil Moisture Deficits at the end of September 2005 in mm and as the anomaly from the 1961-90 average.*

Data source: MORECS.

# River Flows

## The year in brief

Runoff patterns during 2005 were characterised by wide spatial contrasts associated with the exaggeration in the normal north-west to south-east rainfall gradient across the country and the influence of catchment geology on the river flow response to the developing rainfall deficiencies. Their combined impact on annual runoff totals is shown in Figure 15. Regional, and more local, differences in accumulated runoff over the year were exceptionally large. Whilst in northern Scotland, annual runoff totals were generally well above average, most catchments in southern Britain registered totals below 75%. Deficiencies were most notable in the South East where many rivers remained below the monthly average throughout the year. Annual runoff totals fell below 50% in much of Sussex and Kent: the Sussex Ouse and Medway (Kent) were among a number of rivers eclipsing previous annual runoff minima (in records of around 45 years). Runoff deficiencies for the November 2004-December 2005 period were even more notable; new 14-month minima were recorded for a substantial minority of rivers across southern England - from Cornwall to Kent (see Figure 16).

Figure 17 shows 2001-2005 hydrographs representing the total outflows from Great Britain, England and Wales, Scotland, and Northern Ireland - the hydrographs are based on flows for a network of large rivers which, taken together, provide a convincing guide to runoff patterns at the national scale. The hydrograph for Northern Ireland reflects, in part, the controlled flow releases from Lough Neagh into the Lower Bann - these constitute more than a third of the total outflows from Northern Ireland. The daily outflows are shown as a bold trace and a red infill is used to emphasise periods of below average flow; the use of a logarithmic scale also gives greater prominence to low flow episodes. The long term daily maximum and minimum flows are also shown - represented by the blue and pink envelopes. In 2005, at the national scale, notably high outflows were confined to early January and the late autumn with seasonally low flows characterising the June-September period, and December. The rarity of high outflows is a notable feature of the 2005 hydrograph for England & Wales which registered its 4th lowest annual runoff in the last 30 years.

A spatially more detailed breakdown of flow patterns in 2005 is provided by Figure 18 which shows annual hydrographs for 20 index rivers across the UK. The long term daily maximum and minimum flow envelopes are also shown. The very limited incursions of the 2005 hydrograph into these envelopes confirms the rarity of exceptional daily flows throughout the year. Examples of outstanding high flows are largely restricted to parts of north western Britain ( the Lake District especially)

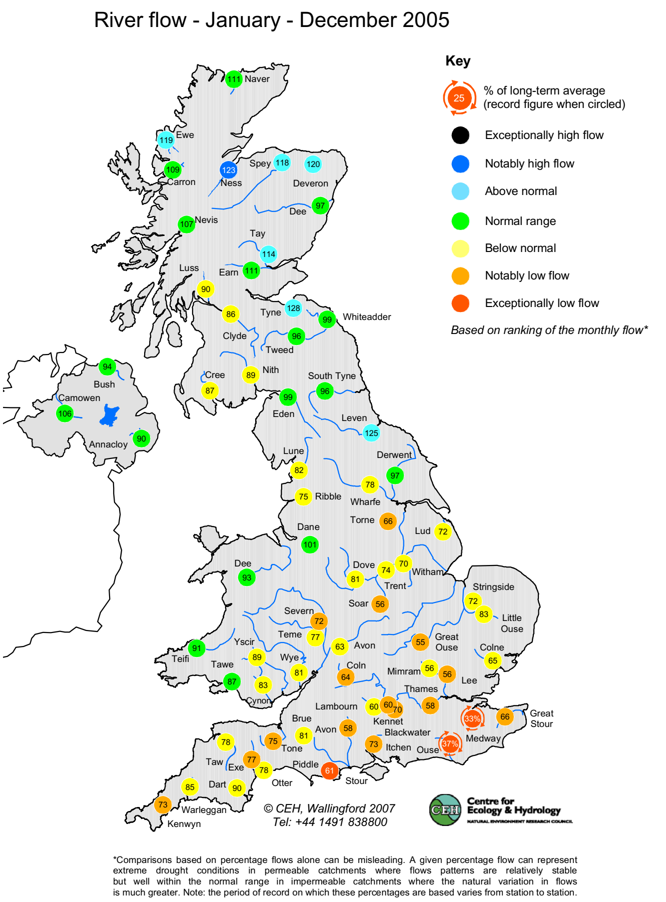



***Figure 15*** *2005 runoff totals as a percentage of the previous average.*

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

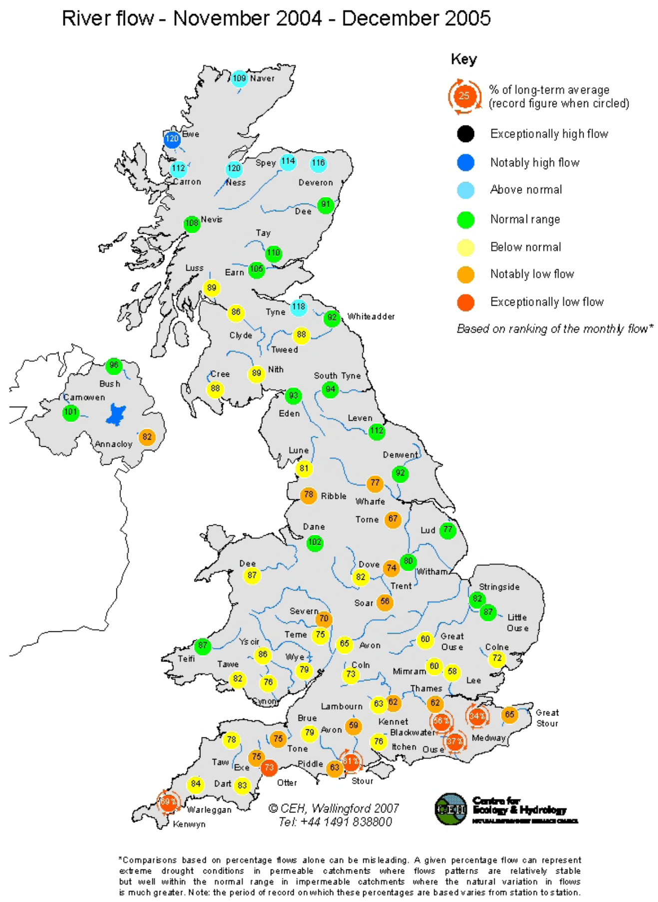



***Figure 16*** *November 2004 - December 2005 runoff totals as a percentage of the preceding average.*

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

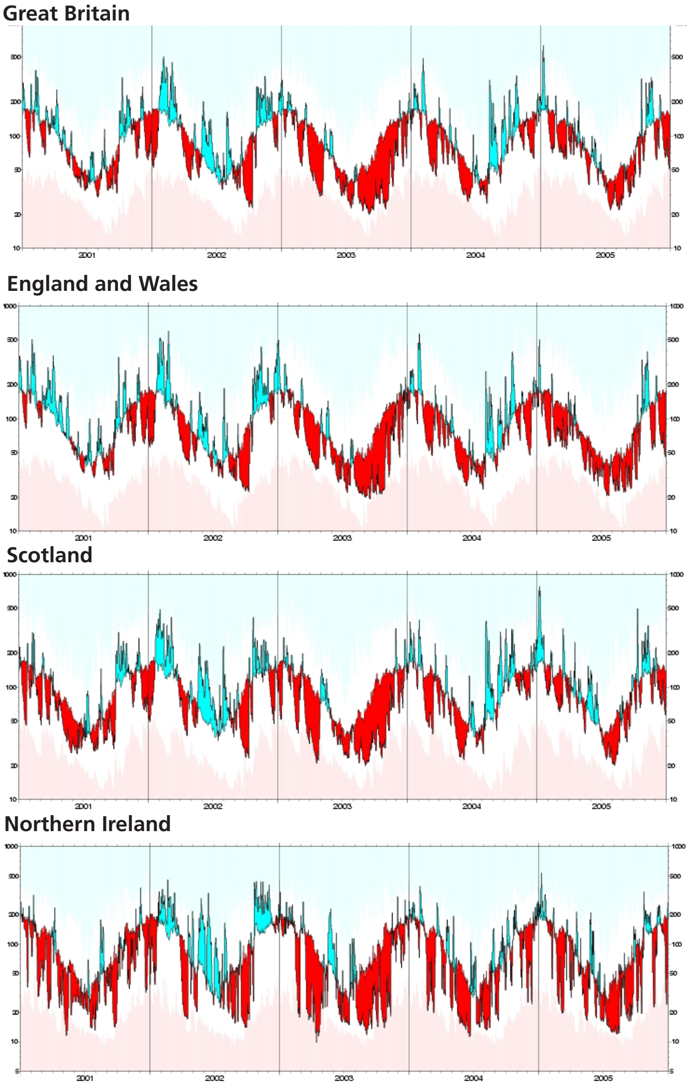



***Figure 17*** *A guide to total daily outflows (in cumecs) 2001-2005.*

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

early in January and in south western Britain (Wales especially) in early November. Notably low late summer/early autumn flows also characterised many spring-fed southern rivers but the hydrograph for the River Mole serves to illustrate how, in responsive catchments, intense summer storms provided valuable surface runoff to alleviate the protracted recessions.

In rivers draining permeable catchments, the summer storms had far less impact and the very meagre replenishment to groundwater over the 2004/05 winter resulted in monthly flows for many rivers spring-fed rivers remaining below average throughout 2005. The River Itchen is included in this category and its September runoff total was the lowest in a 48-year record (see Figure 19). In Sussex, the ephemeral River Lavant flowed for only 7 days in 2005 (it remained dry throughout 1973 and 1989) and high level spring failures led to a progressive contraction in the stream network, and a considerable loss of aquatic habitat. Aside from a few rivers draining permeable catchments, daily minimum flows in 2005 were not exceptionally low, generally exceeding the minima recorded in a number of recent drought episodes (notably 1976 and 1995).

Flow duration curves provide a means of comparing the regime for a particular year with that for the previous record. They allow the proportion of time that river flows are above, or below, any given threshold to be identified. The 2005 duration curve for Scotland exhibits little systematic departure from the 1961-2004 curve (Figure 20). For both England & Wales and Northern Ireland however flows for each percentile below the 98th are appreciably below the corresponding period-of-record figure. A substantially greater measure of disparity is evident for a number of individual rivers (see Figure 21). The lack of spates together with a reasonably healthy baseflow contribution through the summer explains the exceptionally stable regime for the River Stringside in Norfolk. In Hertfordshire, where drought conditions were much more severe, the impact on the 2005 flow regime for the River Mimram is very much more evident.

## River flows - through the year

The north-south disparity in runoff rates was particularly marked in January. While flows were below normal in the south, sustained heavy rainfall in Scotland and northern England on already wet catchments caused river levels to rise rapidly with widespread floodplain inundation. In Scotland, more than 70 Severe Flood Warnings were issued. The River Teith reached its highest level in 49 years; Loch Lomond its 2nd highest in a 27-year series and the Tay (at Caputh) recorded its 4th highest flow since 1948. Severe flooding in Carlisle on the 8th January necessitated the evacuation of several thousand people as the River Eden exceeded its previous highest flow in a 38-year record. Notable flood events also occurred on the South Tyne, in the Conway valley, and in Northern Ireland where the flooding was more localised. Flows then declined steeply into mid February. Meanwhile, in southern England, the winter drought intensified and accumulated runoff deficiencies continued to grow. February runoff for the Thames was the 3rd lowest since 1944; in Sussex, the Ouse registered its lowest February runoff in at least 40 years. In Northern Ireland the accumulated runoff since November 2004 for the River Annacloy ranks 2nd lowest in a 25-year record. February flows in many spring-fed streams (e.g. the Lambourn) were more typical of the late summer.

River flows remained depressed in March over wide areas but were interrupted by spates in mid month, most notably in northern Britain. Accumulated runoff deficiencies increased across much of southern Britain and March outflows from Northern Ireland were very moderate. The River Mimram is typical of many spring-fed southern catchments where the lack of a normal winter recovery is shown by the exceptional stability in flow rates through the winter and spring (as aquifer recharge struggled to match outflows). April flow patterns across most of northern Britain and Northern Ireland were typical for the time of year

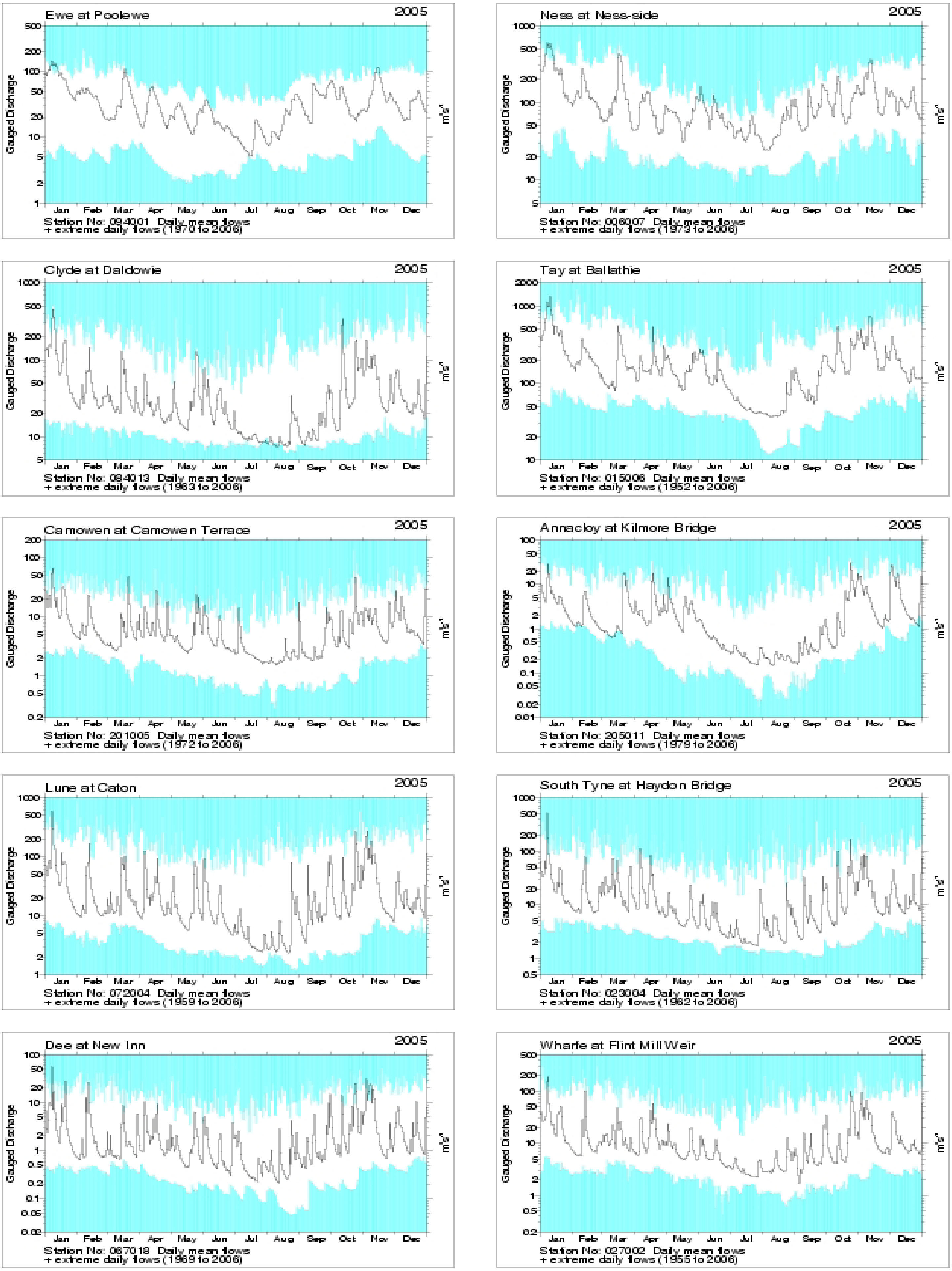



***Figure 18*** *Daily flow hydrographs for 2005 for a selection of index stations.*

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

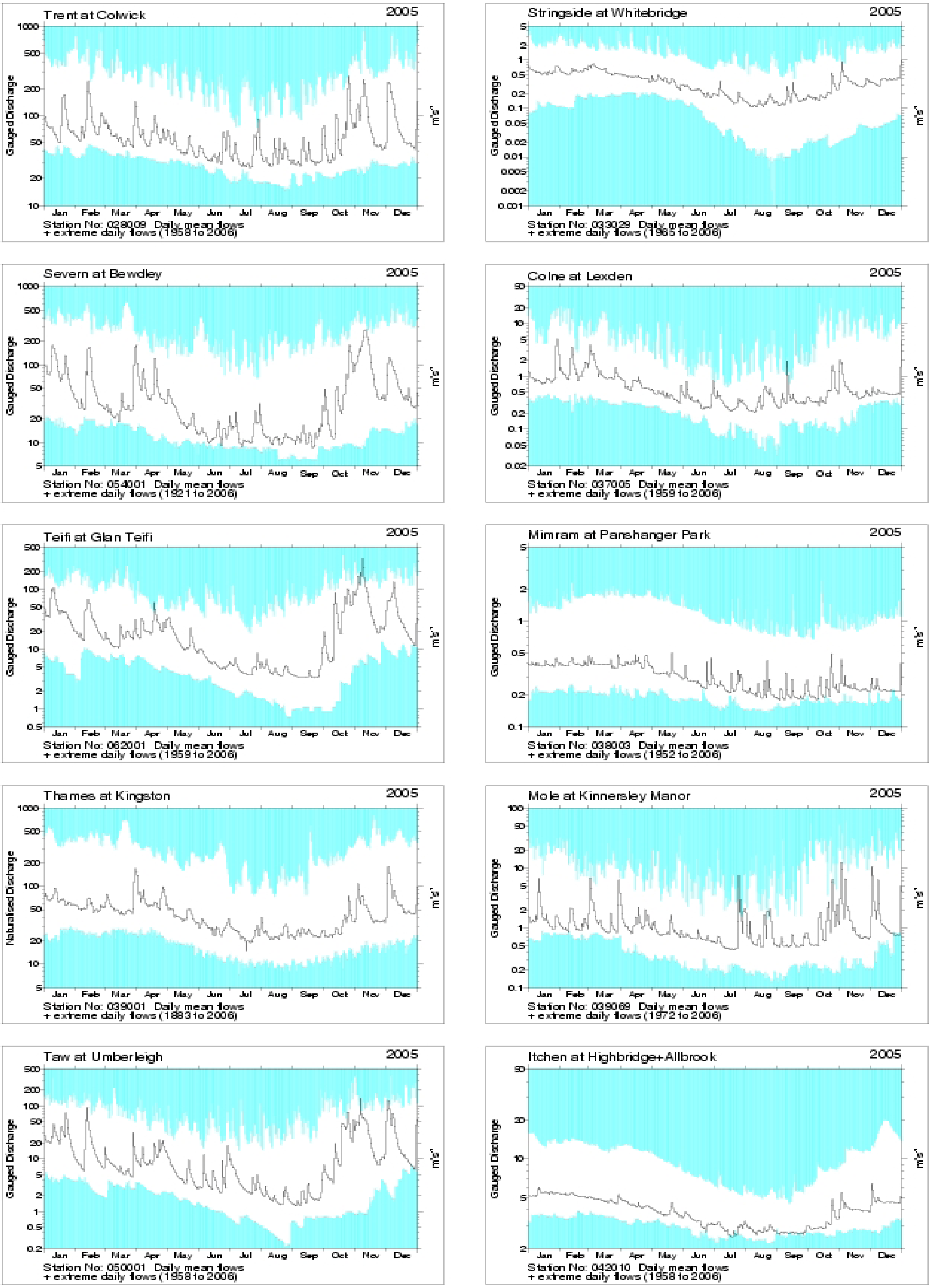
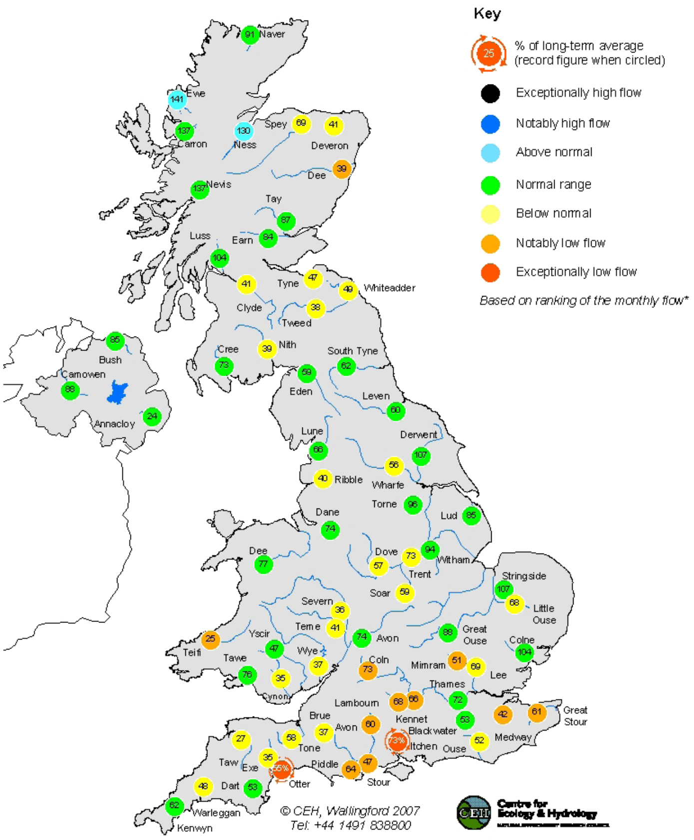



***Figure 18*** *(Contd.)*




*Comparisons based on percentage flows alone can be misleading. A given percentage flow can represent extreme drought conditions in permeable catchments where flows patterns are relatively stable but 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 19** *September 2005 runoff totals as a percentage of the preceding average.*

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

with significant spates in a few catchments (e.g. the River Leven, Cleveland and Vyrnwy in north Wales). In the south, flow recession continued apart from short spates arising from thunderstorms. Several rivers draining to the English Channel - including the Exe and Wallington (Hants), both with records of around 50 years, reported their second lowest November-April runoff. For the River Ouse (Sussex) and the Mole the accumulated runoff was the lowest on record, eclipsing the exceptional 1975/76 minima. A dry May led to a further intensification of the drought in southern Britain but in Scotland runoff over the November-April period was considerably above average in most catchments; the Spey registered its 3rd highest runoff in this timeframe in a 53-year record.

June saw high flows across much of northern Britain, with thunderstorms causing remarkable runoff rates in parts of North Yorkshire - monumental flows were reported for the River Rye and the Cod Beck; at Boltby Reservoir, flows over the dam spillway were close to design capacity. Some localised urban flooding also occurred in the North East (e.g. in Newcastle). By contrast, across most of southern, eastern and central England, drought severity increased. Flow recessions continued into July triggering the activation of additional low flow augmentation schemes (e.g. in Dorset). Despite some flow recoveries over the final week, recessions were especially steep in Scotland

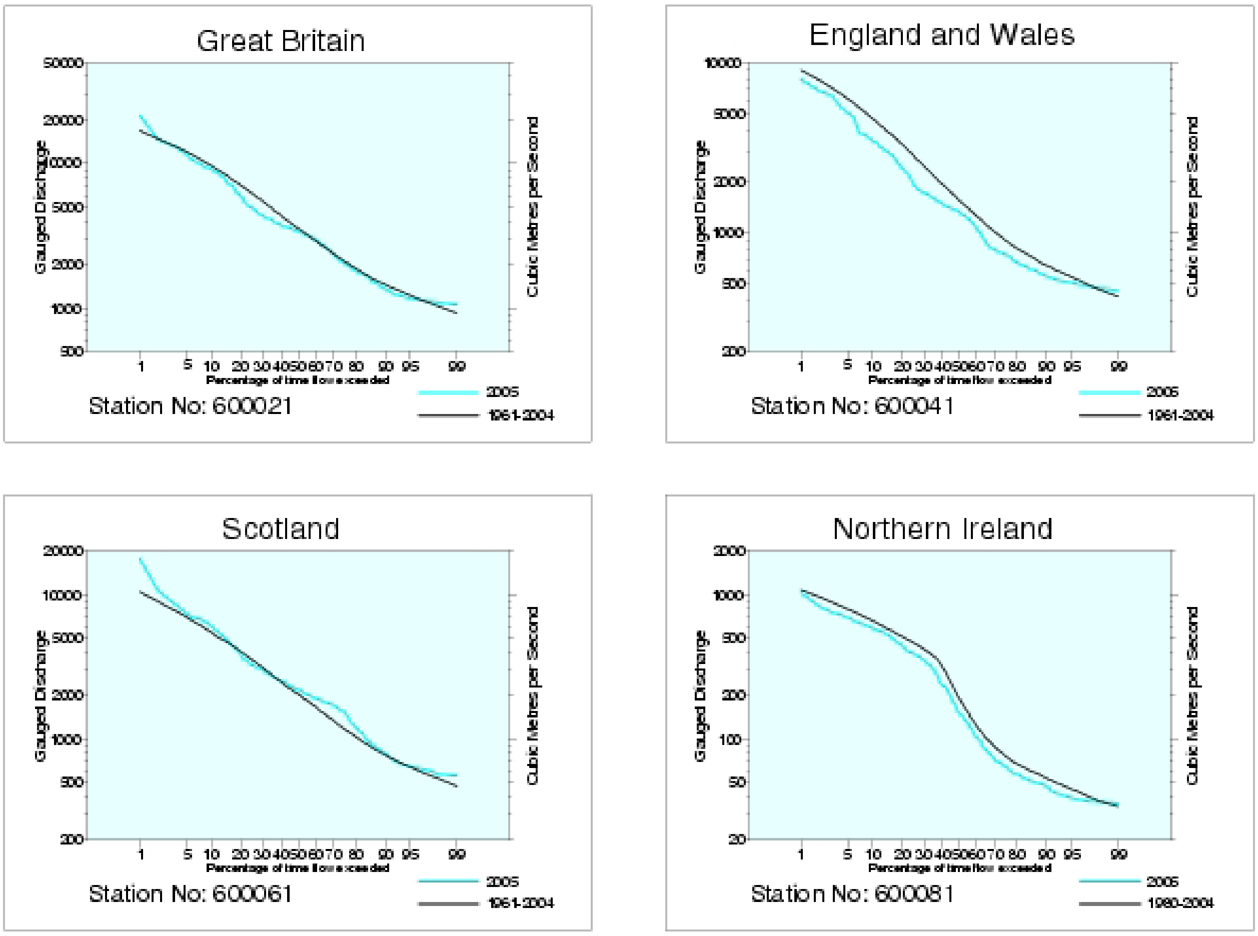



**Figure 20** *Indicative flow duration curves for 2005 national outflows (blue trace) and the preceding record.*

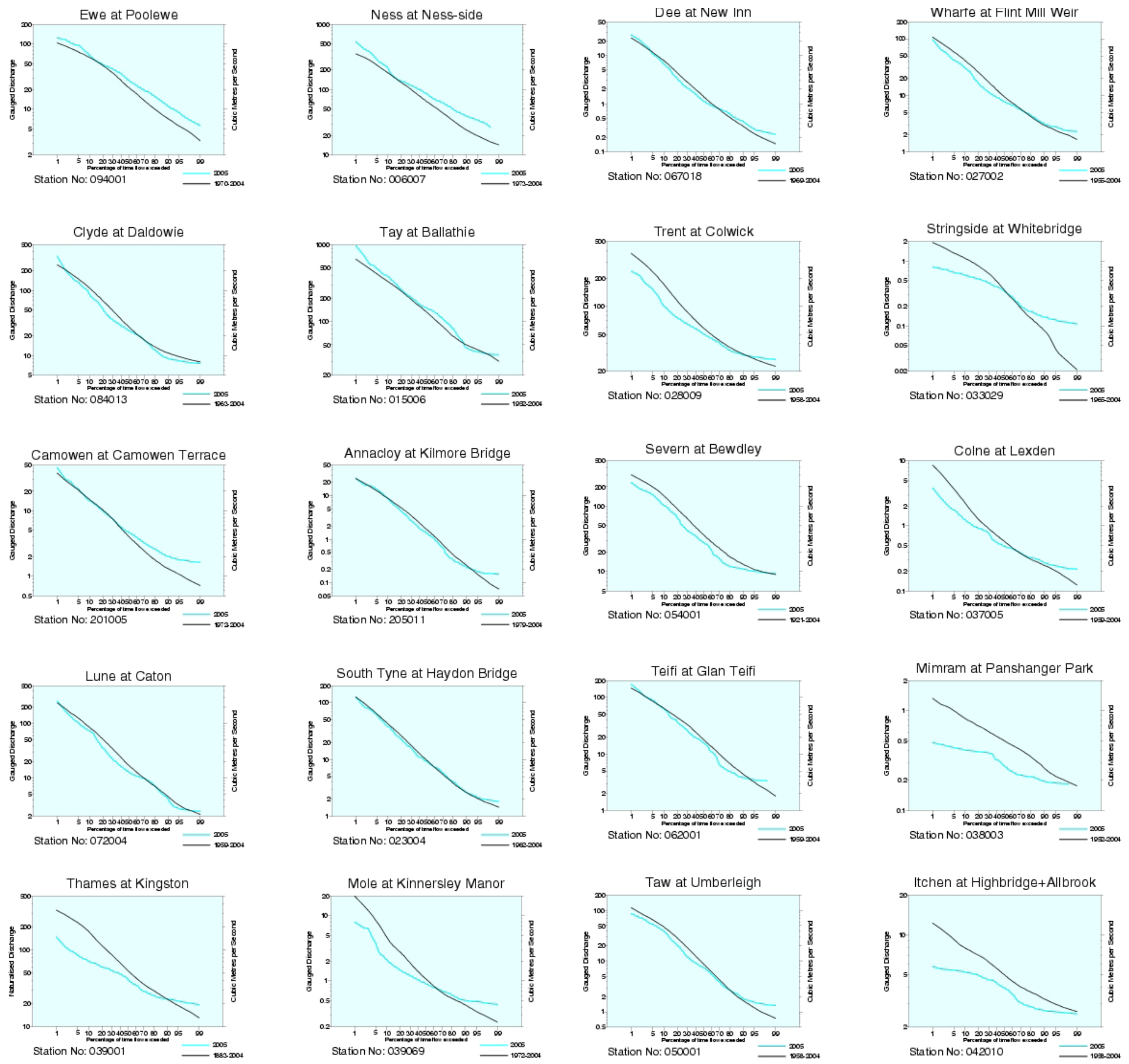



***Figure 21*** *Flow duration curves for 2005 (blue trace) and the preceding record*

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

where the rivers Luss and Clyde registered new late-July minimum flows. In August, convective activity led to further flash flooding from Tyneside to Dorset although these had little impact on runoff totals at the basin scale.

Newsworthy urban flooding (e.g. in parts of west London on the 9th/10th) was a regular feature during September and a few fluvial spates were reported (e.g. in Yorkshire and western Scotland). Generally however, recessions continued and were particularly protracted in the most drought-affected areas. Away from western Scotland, almost all index rivers registered well below average runoff. Monthly runoff totals continued to decline; the Test and Itchen both reported their lowest September flows in records of 48 years. The warm conditions encouraged algal blooms (e.g. on the Itchen and Medway) and fish rescues were triggered by the shrinkage of ponds and wetlands. In Northern Ireland, outflows from Lough Neagh were the lowest in a 25-year series.

October saw rapid recoveries in most responsive catchments with significant flooding in many areas. On the 11th, the Teviot (at Hawick), exceeded its previous maximum flow (established in January 2005) in a 42-year record; around 200 properties were flooded. In Wales, Haverfordwest was flooded as the Western

Cleddau recorded its highest level in 40-year record. More localised flooding was also common as rainfall intensities exceeded urban drainage capacities (e.g. in Carlisle) or soil infiltration capacities (surface runoff inundated vulnerable settlements near St Austell in Cornwall). Traffic disruption was severe and Flood Warnings were widespread, continuing into November. Some notable spates also occurred in impermeable lowland catchments (e.g. on the Wey in Surrey). However, depressed flow rates continued in many spring-fed rivers; following 29 consecutive months with below average monthly flows, the Lambourn closely approached its early October minima (in a record from 1962).

Further notable spates occurred in western and northern catchments in November with locally severe flooding and landslides in Wales. On the Severn, demountable flood barriers were employed at Bewdley and Worcester. More generally, storm debris and leaf-fall contributed to local drainage problems. From mid-month, recessions were particularly steep, aided by frozen upland catchments, and by month end, flows were approaching early winter minima (e.g. in the Forth) in many responsive catchments. Such impermeable catchments aside, November runoff totals were mostly within the normal range.

December began with very healthy flows in most rivers draining impermeable catchments and flood alerts were common. Steep river flow recessions then became established and daily flows were approaching late-December minima by the final week in many responsive catchments (from the Aberdeenshire Dee to the Mole in Surrey). Minor runoff recoveries were a feature of the final few days (snowmelt was a contributory factor in many areas) but December runoff totals were depressed over wide areas.

See http://www.ceh.ac.uk/data/nrfa/ for a more detailed commentary on runoff patterns in individual months of 2005.

# Groundwater

## Background

Most major aquifer outcrop areas are in the drier parts of the UK - predominately the English Lowlands where groundwater is the principal source of public water supply. In water resources terms the Chalk, which outcrops in eastern and southern England, is the major aquifer; the Permo-Triassic sandstones are regionally important - in the Midlands and North-West especially. Limestone aquifers are also regionally significant and a number of minor aquifers (e.g. the Norfolk Crag) are of local water supply importance.

Away from the more westerly aquifer outcrop areas, groundwater replenishment (or recharge) in a typical year ranges from 500mm to less than 100mm in the most easterly outcrops. Recharge is normally concentrated in the November-April period when evaporation losses are modest. Evaporation losses, which exhibit limited year- on-year variability, result in a non-linear relationship between rainfall and aquifer recharge; a 20% reduction in annual rainfall can result in a reduction of 50% or more in groundwater replenishment for the drier, eastern outcrop areas. Consequently recharge variations tend to be much greater than those for rainfall. This volatility has been well illustrated over the last decade. Depressed groundwater levels in the 1995-97 period contrast with remarkably healthy groundwater resources (and sustained groundwater flooding) during the winter and spring of 2000/01. The generally high groundwater levels over the first three years of the 21st century and particularly, the abundant groundwater resources early in 2003 helped limit the impact of the drought conditions during the ensuing summer.

## The year in brief

Aquifer recharge patterns and groundwater level variations in 2005 exhibited the normal seasonal contrasts in most western and northern aquifer outcrop areas. By contrast, the major aquifers in the English Lowlands showed muted seasonal variations and, in most areas, a substantial decline in groundwater resources between the beginning and end of the year. The spatial and temporal distribution of the 2005 rainfall was unhelpful from a groundwater resources perspective. Many outcrop areas of the major aquifers recorded annual rainfall totals of less than 85% and the greater part of the deficiency was associated with the winter and early spring months when the bulk of groundwater recharge normally occurs. January and February rainfall totaled less than 50% of average in large parts of the South East and both November and December were also relatively dry. Local variations in seasonal rainfall totals were unusually large; this is reflected in substantial sub-regional variations in the health of groundwater resources during much of 2005.

2005 began with groundwater resources in the normal range, albeit mostly below average seasonal levels, in most limestone aquifer units but in parts of the Permo-Triassic sandstones and, particularly, the Chalk the groundwater resources outlook was relatively fragile. To the north and west of London, January groundwater levels in the Chalk (e.g. at Stonor in the Chilterns) were typically at their lowest for eight years, although substantially above early winter drought minima (e.g. those for 1991, 1992 and 1997). Healthy recharge early in 2005 was required if a belated seasonal recovery in groundwater levels was to take place. In the event, most late-winter and early spring low pressure systems followed tracks remote from the major aquifer outcrop areas. Correspondingly, the 2004/05 recharge season was limited in length and the overall volume of recharge was modest; commonly less than half the long term average.

Rainfall deficiencies continued to build into the early spring - only in 1975/6 has the November-March period been appreciably drier in the last 60 years - triggering an early onset of seasonal recessions in 2005. This is confirmed by Figure 22 which shows groundwater level hydrographs for a selection of index wells and boreholes across the UK. The broken line indicates the long term monthly average and the upper and lower shaded envelopes delineate the highest and lowest monthly levels on record. A 5-year period is featured because groundwater levels in many areas reflect recharge over a number of winter/spring periods. For some index wells, the featured hydrographs embrace a remarkable range of groundwater levels. At Stonor, groundwater levels in the spring of 2001 were well above previous maxima in a series from 1965 but by the autumn of 2005 they were approaching long term minima. Broadly similar behaviour is exhibited by the more responsive Little Bucket borehole in the Kent Chalk and, in the Permo-Triassic sandstones of Devon (Bussells No. 7).

Very slow responding aquifer units apart, most index wells and boreholes reported their lowest 2005 levels in the autumn. In September groundwater levels were well below average throughout most of the country with especially depressed levels in parts of the South Downs where natural base levels were closely approached; elsewhere, levels were appreciably above drought minima (see Figure 23). A similar pattern is evident in December (Figure 24) except that seasonal recoveries, in southern England especially, had returned groundwater levels to within the normal range - but still mostly below average. At year-end, concern regarding the water resources outlook focused on those groundwater units, mostly in the South-East and the Midlands where notably low levels were still being recorded. In such areas widespread spring failures had caused a substantial contraction in the river network with an associated loss of aquatic habitat.

## The impact of long term water usage on groundwater levels

The majority of observation wells and boreholes for which data are held on the National Groundwater Level Archive monitor the natural variation in levels. However, in parts of the UK groundwater levels have been influenced, sometimes over very long periods, by pumping for water supply or other purposes. As a consequence, some local or regional water-tables have become substantially depressed. For instance, contemporary levels at a number of boreholes in the Permo-Triassic sandstones of the Midlands are indicative of a significant regional decline. In contrast, rising groundwater levels have been reported from a number of conurbations; leakage from water mains is considered a significant factor in some cases. The implications of rising groundwater levels extend beyond the potential improvement in water resources that the rise represents. Groundwater quality may be adversely affected as levels approach the surface and a number of geotechnical problems may result, for instance the flooding of tunnels and foundations.

Artificial influence on groundwater levels have been particularly pervasive in London where increasing groundwater abstraction through the nineteenth and the first half of the twentieth centuries led to a 70-metre decline in groundwater levels in the Trafalgar Square borehole. Since the 1950s, a much reduced abstraction rate has resulted in a recovery of around 40 metres with levels rising by 1-2 metres a year through the early 1990s (see Figure 25) The potential disruption and damage (e.g. to the stability of buildings) which would result from a continuation of this rise, stimulated the development of a strategy to control rising groundwaters below London. Implementation of this strategy has resulted in a modest decline in levels at Trafalgar Square over the post-2000 period.

## Groundwater levels - through the year

After a notably dry end to 2004, January rainfall totals in 2005 were below 50% of average across many aquifer outcrop areas. Although snowmelt contributed significantly to above average groundwater replenishment in some eastern areas in February, a dry early spring (and above average evaporative demands) generated insufficient recharge to produce seasonal water-table peaks within the normal range in much of the drought affected region.

Soil moisture deficits increased briskly in early March signaling an early onset to the 2005 recessions across much of the English Lowlands. Importantly however, the large spatial variations in winter and early spring recharge ensured that, even within a single aquifer, the drought's impact would be relatively patchy as the summer recessions developed. A modest pulse of recharge over the second half of April was useful in moderating the rate of decline in water-tables but Chilgrove (in the South Downs) still recorded its lowest April level since 1976; generally groundwater levels were significantly healthier to the north.

Limited May and early June rainfall, together with above average evaporative demands, effectively terminated the 2004/05 recharge season. With recessions now well established June groundwater levels were exceptionally depressed in parts of the South Downs and notably low (mostly in the lowest quartile for the month) across southern England and the Midlands. However, in many eastern outcrops of the Chalk, - from the Yorkshire Wolds to Suffolk - groundwater

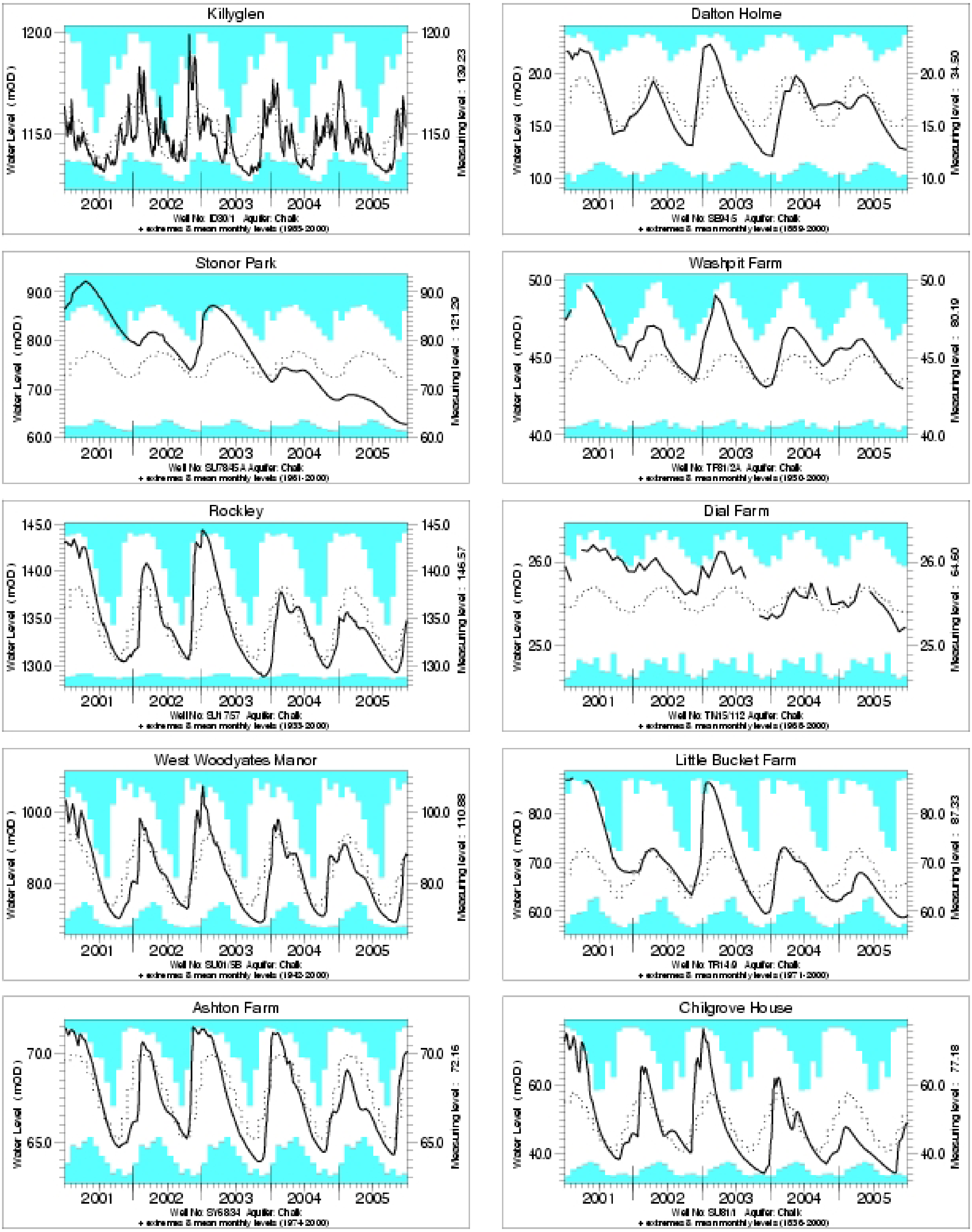



*Figure 22* *Groundwater level hydrographs 2001-2005.*

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

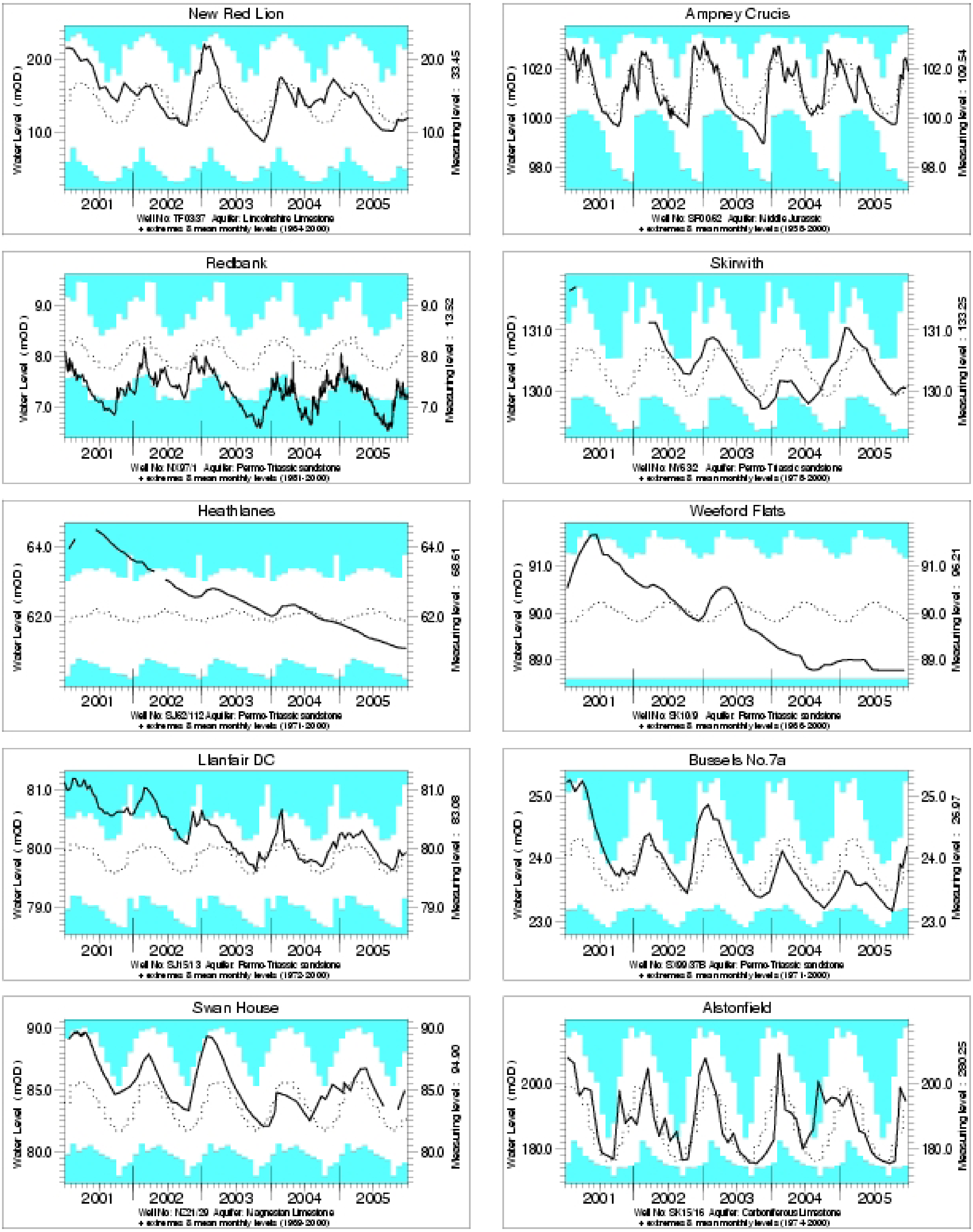



***Figure 22*** *(Contd.)*

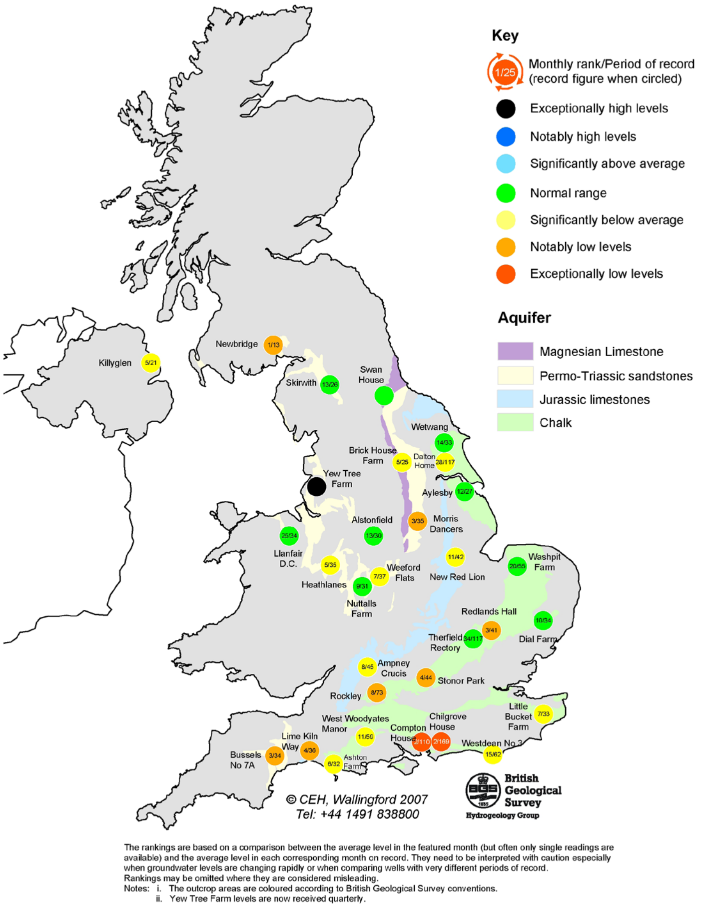



**Figure 23** *September 2005 groundwater levels.*

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

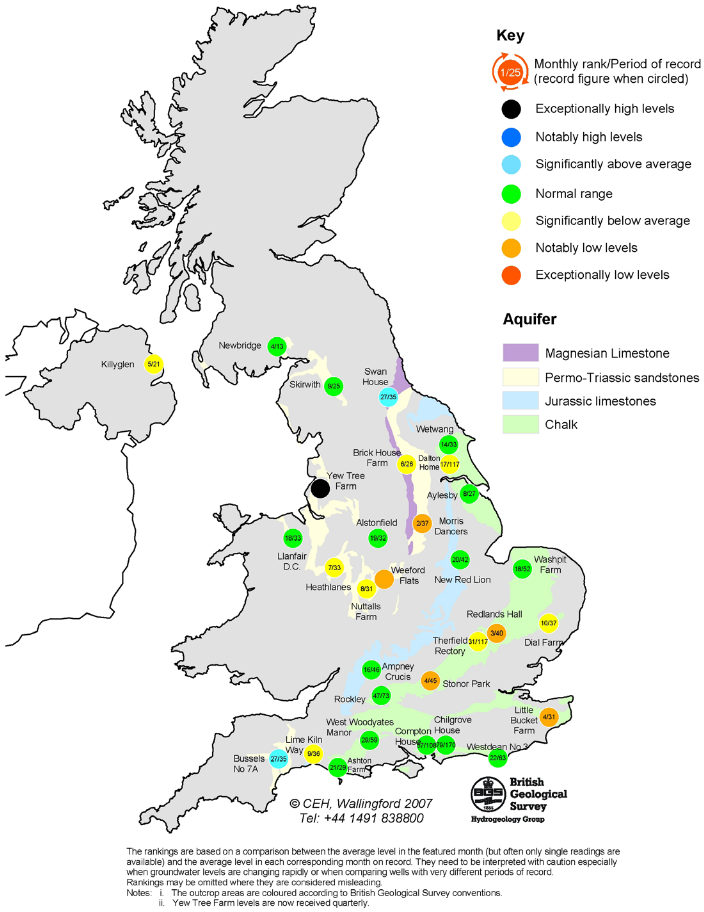



**Figure 24** *December 2005 groundwater levels.*

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

levels remained within the normal range. July rainfall totals were above average across most aquifer outcrop areas but the dry soil conditions allowed only minimal groundwater replenishment. In Sussex, the recessions at Chilgrove and Compton confirmed the notable local severity of the drought - in the last 100 years, only in 1934 and 1976 have groundwater levels followed a lower recession. Elsewhere the degree of water-table depression was less exceptional but by late September the regional character of the drought had been reinforced.

A notably wet October generated brisk groundwater level recoveries in northern aquifers, e.g. in the Permo-Triassic sandstones outcrops in Dumfries and Galloway and in the Chalk of Northern Ireland. Generally however, the seasonally dry soils provided limited opportunity for infiltration and seasonal recessions continued. In the Permo-Triassic sandstones of Devon, Bussels reported its lowest October level on record and water-tables were very depressed across most

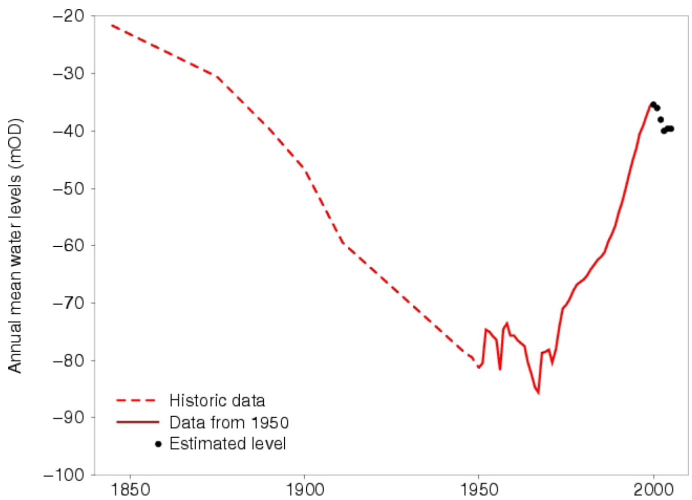



**Figure 25** *Annual mean groundwater levels for the Trafalgar Square borehole.*

Data source: Environment Agency

of southern England - and well below average in a broad zone through central southern England and the Midlands. With a few exceptions (including Compton) however, levels remained above the minima reported in 1976 and during the groundwater droughts of the early and mid-1990s.

Heavy November rainfall in the west and north strengthened the seasonal recoveries in most limestone outcrops and the more westerly of the Permo-Triassic sandstones and Chalk outcrops (e.g. Rockley). Rainfall total were much more modest to the east and recessions continued in the eastern Chalk and in the slow responding sandstones of the Midlands. With soil moisture deficits eliminated across almost all aquifer outcrops, December provided an opportunity for substantial recharge. In the event, rainfall was less than 80% of average across much of the English Lowlands and the failure of the late autumn and early winter rainfall for the 2nd successive year ensured that groundwater drought conditions would extend well into 2006.

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# Location Map

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