# The UK drought of 2003
## an overview

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Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

# THE UK DROUGHT OF 2003 - AN OVERVIEW

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## Introduction

Throughout much of the UK the five-year period beginning in 1998 was notable for the health of water resources and for a cluster of major flood events[1,2]. Heavy rainfall in November and December 2002 heralded further widespread flooding in southern England and, by early 2003, most reservoirs were close to capacity. Groundwater resources were also well above the seasonal average throughout all major aquifers.

Synoptic patterns changed decisively in mid February 2003 heralding extended spells of dry and warm weather which, by the late summer, had established widespread drought conditions for the first time since the mid-1990s. The 2003 drought - which achieved a more extreme expression across large parts of Europe[3,4] - was an episodic event across much of the UK, being interrupted by a damp late spring and early summer in most regions. Nonetheless, the UK registered its driest February-October period since 1921 (Table 1); only during the most intense phases of the 1959 and 1976 droughts have comparable, or lower, nine-month rainfall totals been registered in the last 75 years. The drought period was also exceptionally warm with very high evaporative demands and notably dry soil conditions, in the early autumn particularly. However, unlike much of Europe, the drought's impact across the UK was relatively modest. This paper examines the development of the drought in a hydrological framework, assesses its magnitude and considers the reasons for the UK's resilience to drought stress during 2003.

Locations of many of the monitoring sites referred to in the text are given on the Location Map.

***Table 1*** *Minimum February - October rainfall totals for the UK.*

| Rank | Year | Rainfall (mm) | % of 61-90 Av. |
|---|---|---|---|
| 1 | 1921 | 520 | 68.7 |
| 2 | 2003 | 546 | 72.1 |
| 3 | 1959 | 557 | 73.6 |
| 4 | 1975 | 572 | 75.6 |
| 5 | 1955 | 576 | 76.1 |
| 6 | 1929 | 598 | 79.0 |
| 7 | 1972 | 605 | 79.9 |
| 8 | 1911 | 606 | 80.1 |
| 9 | 1919 | 620 | 81.9 |
| 10 | 1971 | 622 | 82.2 |

## What is a Drought?

Most of us have a good intuitive understanding of what constitutes a drought but objective quantification and comparison of drought severities is hampered by variations in their extent, duration and intensity. Although each drought episode has unique characteristics, some broad categories can be identified: meteorological droughts, defined essentially on the basis of rainfall deficiency, hydrological droughts where accumulated shortfalls in runoff or aquifer recharge are of primary importance, and agricultural droughts where the availability of soil water through the growing season is the critical factor. Each of these categories could be recognised during 2003 - combining in the autumn to generate widespread severe drought conditions which triggered concern regarding the outlook for 2004, in relation to water resources especially.

## Rainfall

Drought conditions during 2003 were most evident over the spring-autumn period but the initial development of significant rainfall deficiencies showed considerable regional variations. Across much of southern Britain the October-December 2002 period was notably wet (Figure 1), contributing to the wettest 5-year sequence for England and Wales in a series from 1766. Over this period many Atlantic frontal systems favoured a southerly track across the British Isles. Correspondingly, northern Scotland experienced several relatively dry episodes. One which began in the summer of 2002 and intensified through Scotland's second driest winter since 1964, continued until late in 2003. Longer term (>12 months) rainfall deficiencies over this period closely approached the highest on record in many north-western catchments which are, on average, amongst the wettest in the UK. The notably different rainfall patterns which characterised northern and southern regions of the UK over the latter part of 2002 are reflected in the plots of monthly rainfall anomalies given on Figure 2 - which also emphasises the episodic nature of the ensuing drought.

Notwithstanding the contrasting antecedent rainfall patterns, drought conditions became established over most of the country during the late winter and early spring or 2003, a crucial period in relation to the water resources outlook for the summer. The February-April 2003 rainfall total for the UK as a whole was the lowest since 1956 with particularly arid conditions characterising the English Lowlands; in some areas (e.g. parts of Oxfordshire), less than 3mm of rainfall was recorded over the 45 days beginning on the 9$^{th}$ March[5]. Entering May, rainfall deficiencies with return periods greater than 30 years had developed across a large part

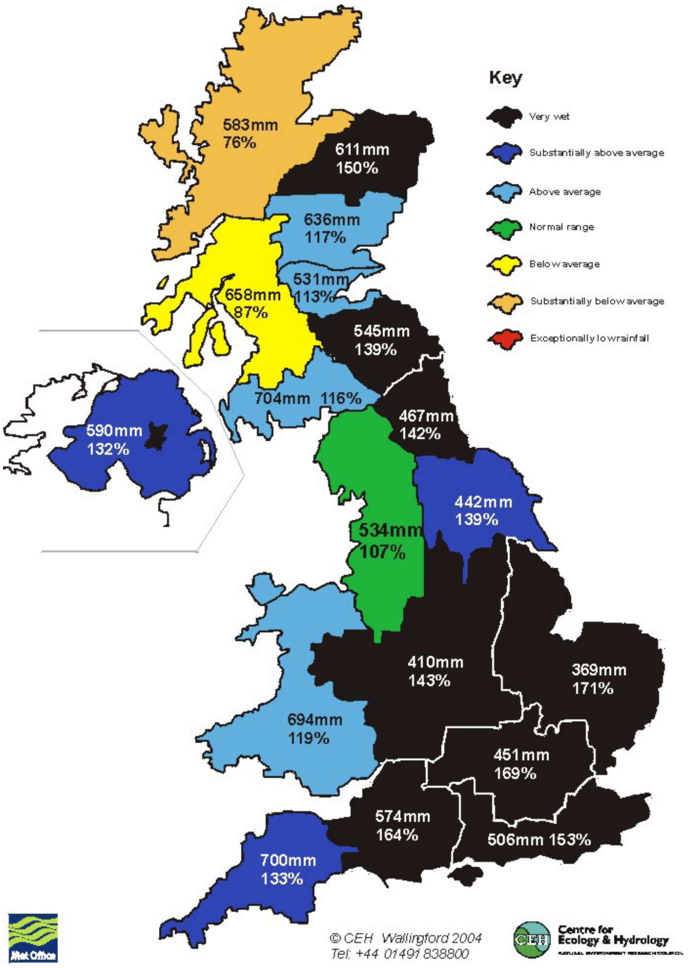



***Figure 1*** *October 2002 - January 2003 regional rainfall totals in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.

of eastern Britain[5]. The drought moderated over the late-spring to early-summer when rainfall was near-average in most regions; a circumstance particularly welcomed by the farming community. However with evaporation rates accelerating, the rainfall was too late to significantly benefit river flows and groundwater resources. The onset of heat-wave conditions in late July signalled the beginning of a third, particularly arid, phase of the drought which lasted until October. Rainfall over the August-October period was less than 50% of average in most regions (Figure 3) and the 3rd lowest for the UK as a whole in a series from 1900.

The severity of drought conditions throughout the whole of the UK is confirmed by the magnitude of the rainfall deficiencies during its terminal phase. In a few eastern areas, October was the ninth successive month to register below average rainfall and most regional deficiencies for the February-October period were around 25-40% of average. Such rainfall deficiencies correspond to return periods exceeding 50 years in much of eastern and southern Britain (see Figure 4). England and Wales registered its second lowest February-October rainfall in 83 years; as remarkably, Scotland reported its driest 9-month sequence (for any start month) since the 1955 drought. In this

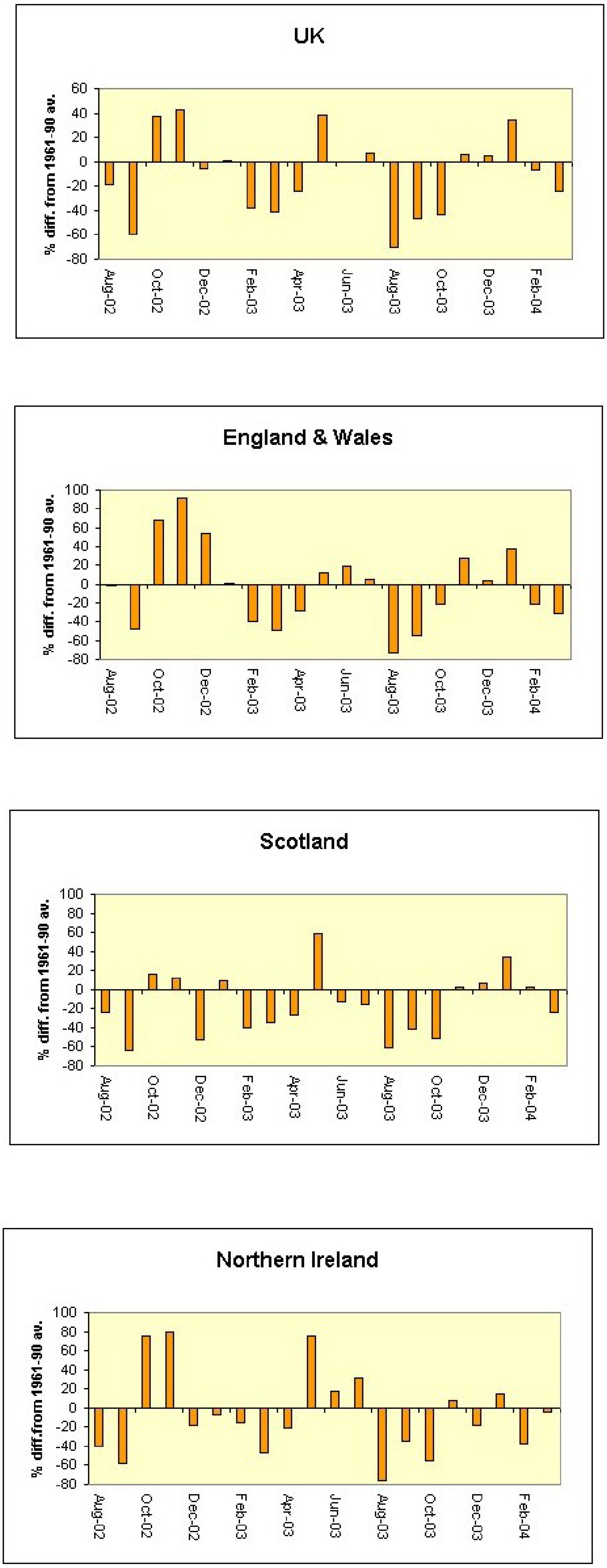



***Figure 2*** *Monthly rainfall anomalies August 2002 - March 2004.*

Data sources: UK Met Office and Hadley Centre.

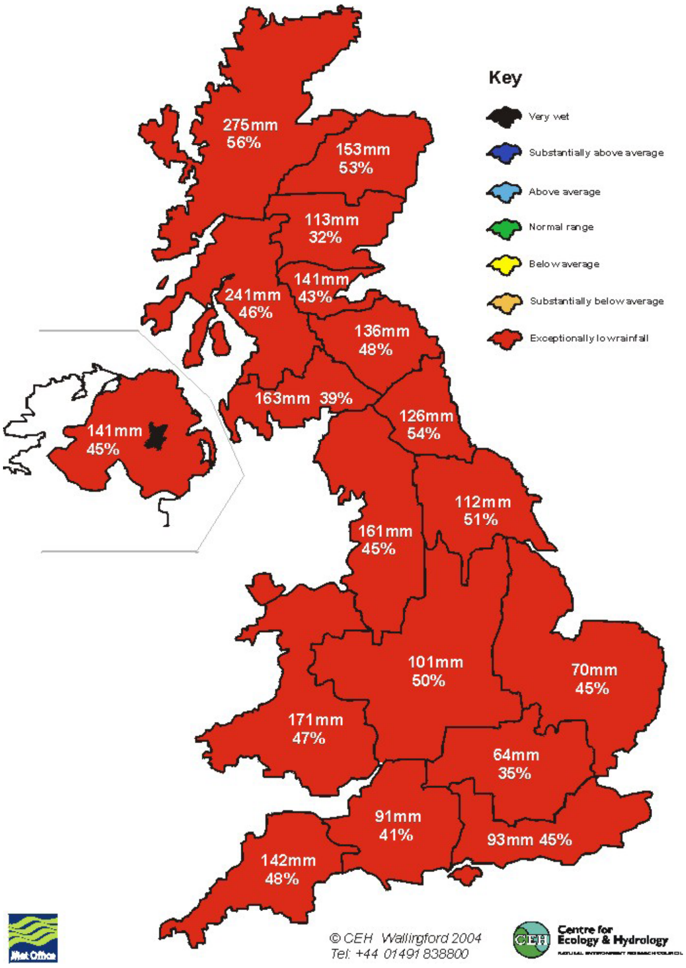



***Figure 3*** *August - October 2003 regional rainfall totals in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.

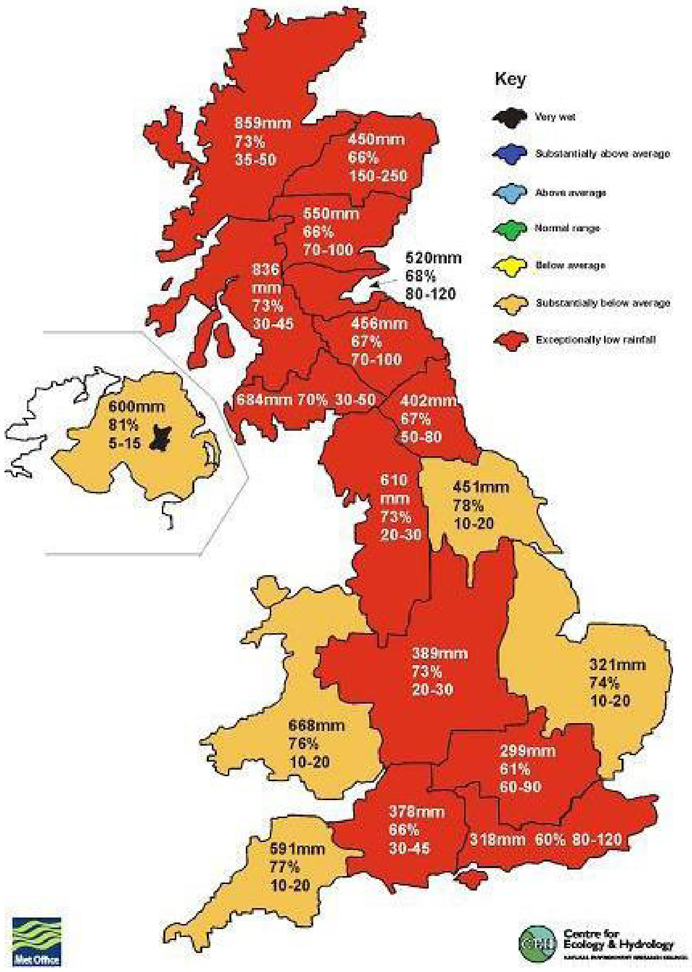



***Figure 4*** *February - October 2003 regional rainfall totals in mm and as a percentage of the 1961-90 average; with estimates of corresponding return periods (years).*

Data source: UK Met Office.

timeframe, regional rainfall deficiencies displayed an unusual measure of spatial coherence across the UK but local variations in drought intensity were appreciable - especially in those areas where convective rainfall constituted a substantial proportion of the summer precipitation. Localities missing the more severe thunderstorms registered exceptionally low accumulated rainfall totals; provisional data relating to west London (based on data for the Kew Observatory and West Molesey) suggest that the February-October accumulation was the second lowest in a series from 1697.

Across most of southern Britain, the drought broke in the last week of October, a few areas in central southern England reported more rain over the six days ending on November 2nd than in the previous 12 weeks[5]. In parts of northern Britain however, the drought intensified through November; this was of particular water resources significance in the Lake District. A sequence of Atlantic frontal systems then brought substantial pulses of rain at regular intervals through the early winter. November to January is, on average, the wettest period of the year and evaporation losses normally constitute <15% of the rainfall. Thus, although most regions registered only modest positive rainfall anomalies over the three months in 2003/04, they served to greatly diminish the drought's intensity - but without banishing entirely concern for the water resources outlook.

# Temperatures, Evaporation and Soil Moisture

Reservoirs, rivers and aquifers are sustained not by rainfall directly but by that proportion which remains after evaporative demands have been met. On average over 40% of UK rainfall is lost to evaporation, the proportion increasing to >80% in the driest parts of eastern England. Evaporation losses reflect windspeed and humidity as well as temperatures but exceptionally warm conditions during the summer half-year often exacerbate drought conditions. It should be noted that high temperatures are not a necessary component of drought in the UK - dry winters in particular can be the precursor of significant water resources stress even when followed by above average summer rainfall (as occurred in 1992 for instance). However, high temperatures were certainly an influential factor in 2003. Record temperatures were registered in the late summer heat-wave and, for the February- September period as a whole, the mean Central England Temperature[6] closely matched 1997 as the warmest since 1868.

For England and Wales, evaporative demands during 2003 were more typical of western France. Potential evaporation (PE) losses exceeded the average in all months except October and, based on MORECS[7] data, the February-September PE total ranks 4th highest in the 1961-2003 series (Table 2). Over the year as a whole PE losses exceeded rainfall across almost a third of the country. In the driest regions of Britain such circumstances are common, but the margin of exceedance in 2003 was exceptional, the highest on record in some areas (e.g. parts of East Anglia and in the lower Severn basin). In contrast, actual evaporation (AE) losses were marginally below average for England and Wales over the drought period, reflecting the constrained transpiration rates associated with the extremely dry soils during the summer months (see below). Open water evaporation losses were however unconstrained - pan evaporation figures commonly exceeded 4mm a day at Wallingford and totals for 2003 indicated losses of around 15% above the 1961-90 average at Chaldon Hill in Somerset[8]. This contributed to the seasonal decline in reservoir stocks but impacted most severely on shallow water bodies (including wetlands) - many of which were greatly diminished by the late summer.

**Table 2** *February - October Potential (PE) and Actual Evaporation (AE) Losses (MORECS) for England and Wales.*

| Rank | Year | PE (mm) | PE as % of 61-90 Av. | AE (mm) | AE as % of 61-90 Av. | Rank |
|---|---|---|---|---|---|---|
| 1 | 1995 | 638 | 119.6 | 452 | 94.6 | 38 |
| 2 | 1990 | 626 | 117.4 | 444 | 93.1 | 42 |
| 3 | 1989 | 612 | 114.6 | 461 | 96.7 | 35 |
| 4 | 2003 | 603 | 113.0 | 474 | 99.3 | 30 |
| 5 | 1976 | 593 | 111.2 | 371 | 77.7 | 43 |
| 6 | 1997 | 581 | 108.9 | 523 | 109.6 | 3 |
| 7 | 1996 | 572 | 107.2 | 454 | 95.1 | 37 |
| 8 | 1975 | 565 | 105.9 | 449 | 94.2 | 40 |
| 9 | 1992 | 563 | 105.6 | 522 | 109.4 | 4 |
| 10 | 1994 | 563 | 105.5 | 488 | 102.2 | 18 |

The increasing evaporative demands through the spring led to the normal progressive drying of the soil profile and the creation of soil moisture deficits (SMDs). The development and decline of SMDs during 2003 is shown on Figure 5 for the Centre for Ecology and Hydrology Wallingford's Met. Station; the profiles for several other recent drought years are featured together with the average trace. Deficits developed briskly in April 2003, and more erratically thereafter, but remained well above average through the summer - causing problems for the agricultural community in particular. Although late-summer deficits remained considerably below the outstandingly dry conditions recorded in the summer of 1976, they increased further in September and, for a brief interlude during October, were the highest on record. At this time, deficits were exceptionally high, relative to the early autumn average, across most of the UK (see Figure 6). In much of eastern England they were the equivalent of around three months effective rainfall (rainfall-actual evaporation). Consequently, the seasonal upturn in rates of runoff and aquifer recharge

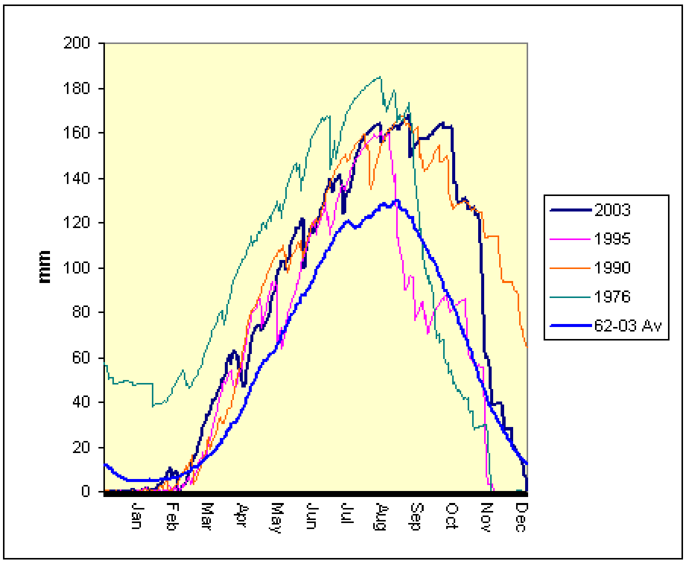



**Figure 5** *Soil moisture deficits at the Centre for Ecology and Hydrology, Wallingford.*

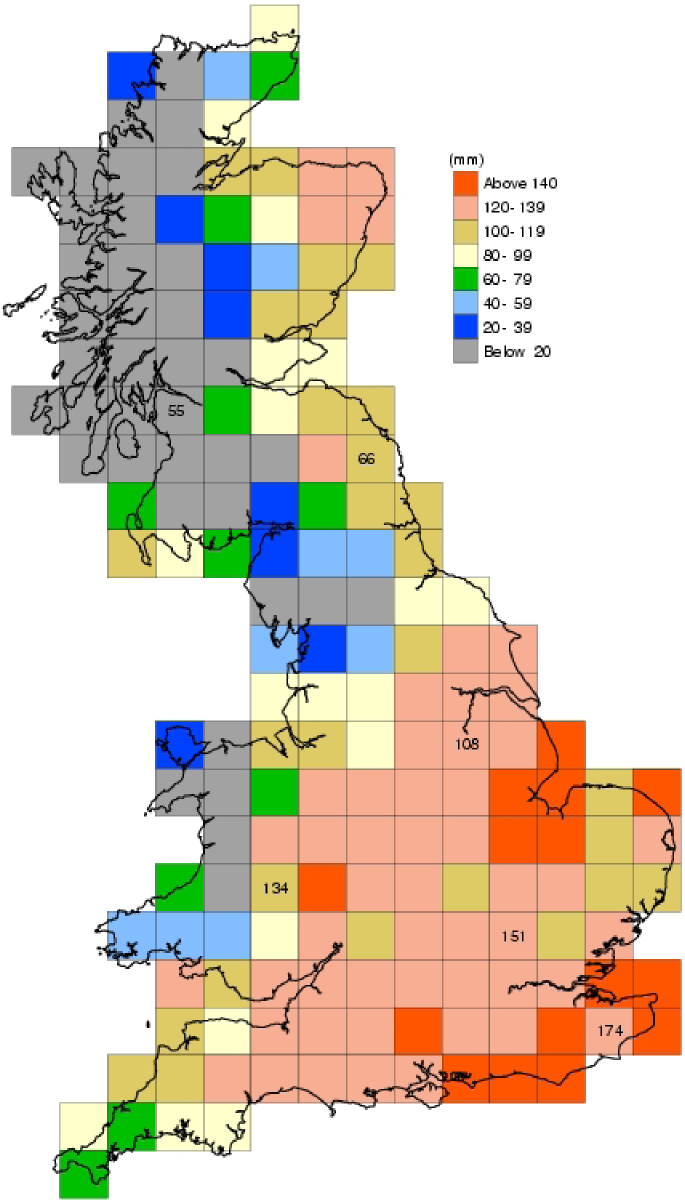



*Figure 6* *Soil moisture deficits in mm at the end of September 2003.*

Data source: MORECS.

was expected to be substantially delayed. Figure 5 shows that, in the event, the decline in SMDs was very steep - a feature of a number of recent years - with soil moisture conditions returning to normal in most areas by late November. This allowed infiltration to re-commence and reservoir replenishment to gain momentum at a critical time.

## An Aridity Index for England and Wales

By combining rainfall and temperature anomalies a simple aridity index can be developed which, for England and Wales, allows the conditions experienced in 2003 to be considered in a very lengthy historical perspective. Figure 7 shows an aridity index (AI) based on the England and Wales rainfall series[9] and the Central England Temperature (CET) series[6] for the 1766-2003 period. The rainfall and temperature anomalies for the April-Sept periods were standardised by their respective standard deviations and combined - with twice the weight apportioned to the rainfall anomalies. Figure 7 features the index value for each summer period together with the 5-year running mean. The AI usefully identifies a number of major arid episodes during the 20th century - including those in 1921,1933, 1947, 1959, 1976, 1995 and 2003 which ranks fourth highest in the 238-year series. These contrast with the frequency of notably cool, wet summers experienced during the nineteenth century. Overall, the trend in the aridity index is very significant reflecting a long term decline in summer rainfall and increase in temperatures. However, the trend is relatively weak, the year- on-year variability in the index scores is large, some apparent longer term perturbations are evident and, despite the recent clustering of high AI episodes, only a very modest positive trend is evident over the last 100 years.

The use of April-September as the accounting period for the aridity index provides an exaggerated impression of the relative severity of the 2003 drought. The summer half-year embraced much the greater part of its overall duration whilst other drought episodes (with similar AI scores on Figure 7) extended over substantially longer periods; correspondingly, drought impacts were greater. For instance, in water resources terms the 1933/34 and 1995/97 droughts were much more severe than 2003 and the May 1975-August 1976 period - the driest 16-month sequence on record for England and Wales - still stands as the benchmark drought across most of the UK, and large parts of western Europe also[10,11].

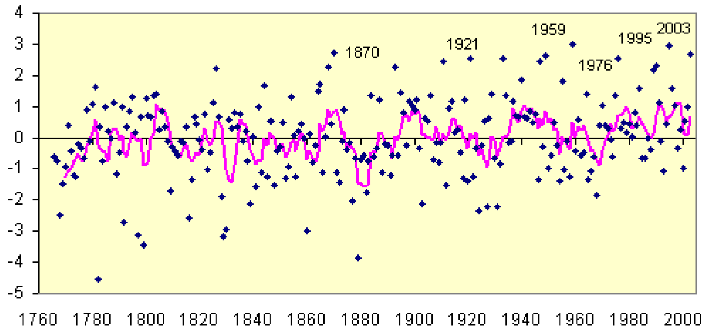



*Figure 7* *An aridity index for England and Wales, 1766-2003.*

# River Flows

Floodplain inundations were common across southern Britain during the first week of 2003[12] when a number of rivers recorded unprecedented flow rates. An example is shown on Figure 8 - the flow on January 2nd for the River Kennet at Marlborough (Wiltshire) substantially exceeded all previous daily maxima (defined by the blue envelope) in a series from 1972. Throughout early January many southern catchments were very vulnerable to further rainfall but the ensuing dry spell rapidly moderated the flood risk. Subsequently, a more protracted dry interlude beginning in February and continuing into the early spring, signalled an extremely early start to the seasonal recession in river flows. By April, flows were close to seasonal minima over wide areas and rivers registering new monthly minimum flows showed a wide distribution, in Scotland especially (see Figure 9). With evaporation rates accelerating, the above-average late spring rainfall was too late, in most regions of the UK, to generate other than modest spates. Some further short-lived flow recoveries occurred in July when localised urban flooding was common but, thereafter, the recessions extended well into the autumn. By mid-October, river flows were less than a quarter of the monthly average over wide areas and the river network had shrunk substantially.

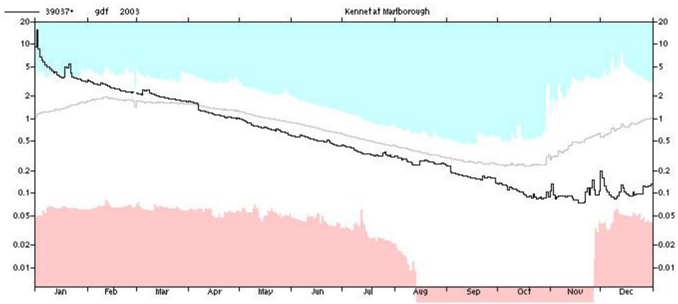
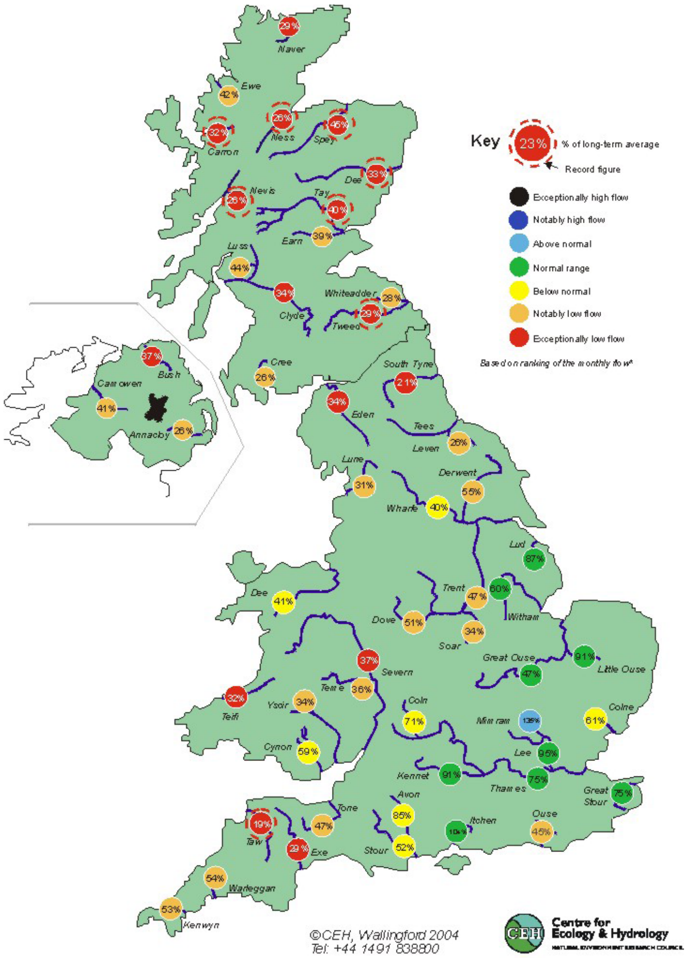



***Figure 8*** *2003 daily flow hydrograph for the River Kennet at Marlborough.*

During the 2003 drought, new daily minimum recorded flows were registered in only a few rivers - including the Findhorn in August and Tweed in mid-September (see Figure 10) - and annual minimum flows were generally well above those of other recent droughts, 1976 and 1995 in particular. The drought's severity is more clearly demonstrated by catchment runoff accumulations over periods of up to 10 months. Many February-April runoff minima were eclipsed in western and northern catchments (e.g. for the rivers Luss and Nevis). More notably, most index rivers in the National Hydrological Monitoring Programme registered new minima runoff totals for the three and five-month periods ending in October. Longer term deficiencies were also exceptional, particularly in north-east Scotland where the rivers Dee and Spey reported their lowest 9-month runoff totals in records of 74 and 52 years respectively.




*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 9*** *April 2003 runoff totals as a percentage of the previous average.*

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

Whilst rainfall deficiencies over the full compass of the drought showed considerable regional coherence, the influence of catchment geology made for significant spatial contrasts in runoff deficiencies and associated drought stress; this was particularly true across the English Lowlands. Summer and early autumn river flows were depressed in rivers draining impermeable catchments whilst rivers sustained principally from groundwater - which have much more stable flow regimes - benefited from the lagged response to the heavy aquifer replenishment in the late autumn and early winter of 2002/03. As an illustration, October

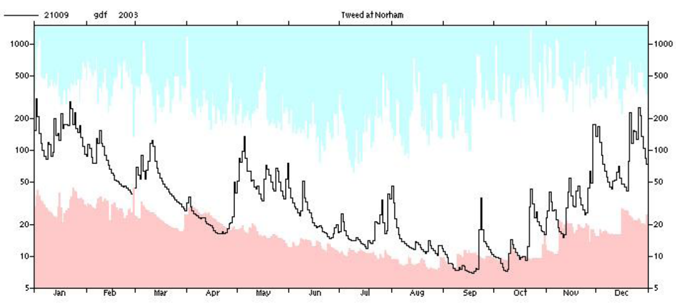



***Figure 10*** *2003 daily flow hydrograph for the River Tweed at Norham.*

Data source: Scottish Environment Protection Agency.

flows for the River Ock, which drains a largely impermeable catchment in Oxfordshire, were the lowest since 1964 whilst those for the neighbouring Lambourn, which drains a catchment of a very similar size, but in the Chalk of the Berkshire Downs, maintained near-average flows throughout most of the summer and autumn (see Figure 11).

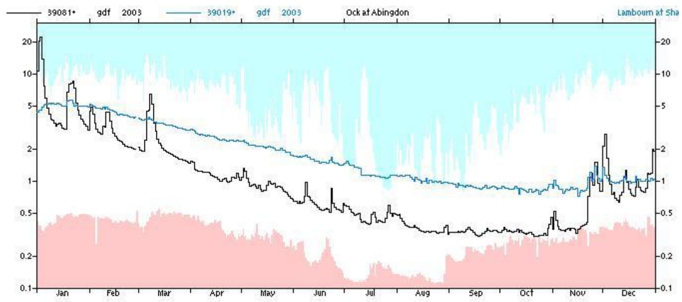



***Figure 11*** *2003 daily flow hydrographs for the Rivers Ock and Lambourne.*
Data source: Environment Agency.

A convincing impression of the temporal variation in the drought's severity at the national scale is given by Figure 12 which shows daily outflows for Great Britain based on a network of representative catchments. The long-term daily mean flow and the daily maximum and minimum envelopes are also featured; the red shading emphasises the periods of below average flow. In 2003, long term (1961-2002) daily minimum outflows were superseded in the early spring and closely approached in mid-autumn. More significantly, total outflows over the March-October period were less than 60% of average. This is a remarkable deficiency at the countrywide scale - the largest for any seven-month sequence in the 42-year record, eclipsing the February-September 1976 figure by an appreciable margin (see Table 3). This scale of deficiency is reflected in the steep decline in reservoir stocks (see below).

Unlike a number of recent drought episodes (including 1976, 1984 and 1995) which have witnessed notable flow recoveries in the early autumn, the very limited September rainfall and exceptionally dry soil conditions in 2003 resulted in a further intensification of the drought. The continuation of flows below the 95% exceedance threshold - extending to a record 88 days

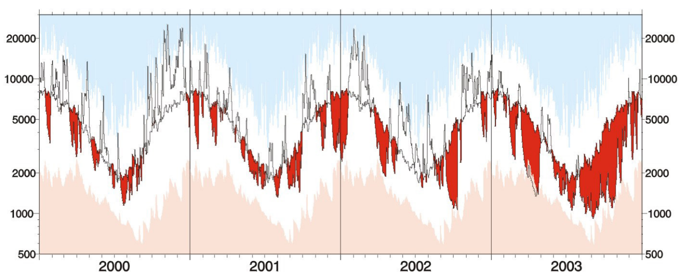



***Figure 12*** *A guide to daily outflows (in cumecs) from Great Britain.*

***Table 3*** *Minimum 7-month runoff totals for Great Britain.*

*Note: the return periods are based on tables provided by the Met Office (Tabony, 1977) and relate to the specified period of months only (return periods may be up to an order of magnitude less if n-month periods beginning in any month are considered. The tables reflect rainfall patterns over the 1911-70 period and assume a stable climate.*

*Non-overlapping periods only.*

*lta = long term average.*

| Rank | Period | Runoff (mm) | % of lta |
|---|---|---|---|
| 1 | Apr-Oct 2003 | 150 | 58.9 |
| 2 | Mar-Sep 1976 | 168 | 62.3 |
| 3 | Mar-Sep 1996 | 175 | 64.9 |
| 4 | Apr-Oct 1984 | 180 | 67.0 |
| 5 | May-Nov 1975 | 184 | 67.0 |
| 6 | May-Nov 1989 | 187 | 68.0 |

on the Aberdeenshire Dee - increased the stress on the aquatic environment at a time when the water supply outlook was also a matter of concern. Fortunately, the rapid decline in SMDs allowed runoff recoveries to gain momentum in November and flows in many rivers to returned to the normal range in December and January.

## Reservoir Stocks

Following the droughts of the mid-1990s, reservoir stocks across the UK generally remained at seasonally high levels and in January 2003 were the 2nd highest, for the month, on record (1988-2003) for England and Wales as a whole[5]. Almost all regions of the UK were well placed to withstand a summer drought - the size and integrated management of many reservoir groups allow them to accommodate even exceptional two-season rainfall deficiencies. Crucially however, the unusually early onset of the seasonal decline stocks in 2003, and the steep falls in the late summer and early autumn (when water demand increased in the hot weather) left overall stocks below 20% for some smaller reservoirs (e.g. Clatworthy and Ardingly). By late October overall stocks for England and Wales were only a little above 50% of capacity; their lowest since the autumn of 1995 (Figure 13). In Scotland, most reservoirs were also at seasonally depressed levels; Loch Katrine having fallen to 40% of capacity, its lowest in a 10-year series. Across the UK, some small impoundments and many agricultural reservoirs held minimal stocks by the third week of October and were very vulnerable to a continuation of drought conditions into the winter.

In the context of the preceding five years, overall reservoir stocks declined to notably low levels in 2003 but the

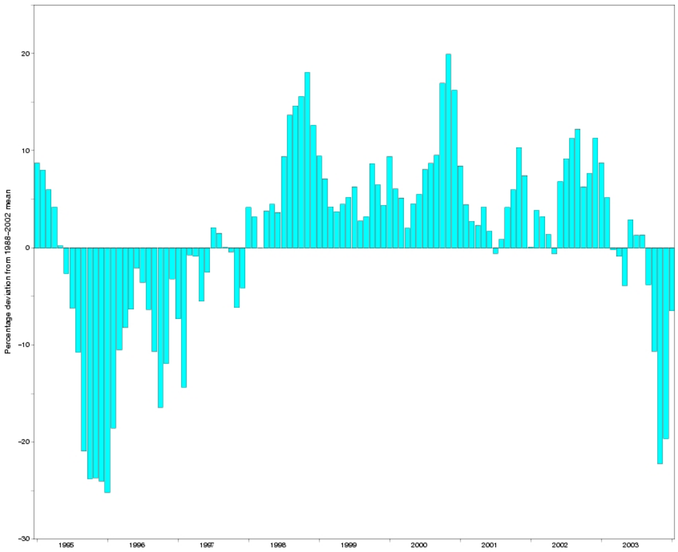



*Figure 13* *A guide to England and Wales reservoir stocks 1995-2003.*

Data sources: Water Services Companies and the Environment Agency.

degree of depletion is less remarkable by comparison with the more sustained droughts in the early and mid-1990s[13]. Nonetheless, the decline in surface water resources, especially its rapidity in the late summer, triggered calls from some water companies and the environment agencies for customers to moderate water demand (e.g. by reduced garden watering). With a further deterioration in the water resources outlook likely, additional mitigation measures were introduced in the autumn. The Environment Agency granted drought permits to allow, for example, additional river abstraction to augment stocks at Ardingly reservoir and (in December) to reduce compensation flow releases from several Welsh reservoirs[14]. Nonetheless, the sustained late-autumn rainfall was particularly welcome - allowing catchments to wet-up and initiate natural replenishment to generate recoveries in reservoirs stocks, and permitting increased abstraction rates from rivers to replenish pumped storage impoundments (which are common in the English Lowlands). The recovery of reservoir stocks was delayed in some areas (e.g. the Lake District) but, in December, stocks for England and Wales registered their largest single-month rise on record, to stand moderately above average entering 2004 (Figure 13). Recoveries were less dramatic in Scotland and Northern Ireland where early 2004 reservoir stocks were substantially below the seasonal average.

## Groundwater

Groundwater provides about 30% of the public water supply in England and Wales and is the principal supply source in large parts of southern and eastern England. Over wide areas it is also an important component of river discharge - sustaining flows during the summer and autumn when surface runoff is minimal. Total groundwater storage is many times that in surface reservoirs and provides a buffer which greatly reduces the UK's vulnerability to drought conditions. 2003 provided an excellent demonstration of groundwater's role in moderating drought impact in relation to both water supply and the health of the aquatic environment.

Groundwater levels in most aquifer outcrop areas exhibit a distinct seasonal cycle with peaks in the late winter/early spring and minima late in the year. This is a direct consequence of the aquifer recharge patterns - the great majority of groundwater replenishment occurring during the November-April period. However, groundwater level hydrographs also reflect aquifer replenishment over a number of years and in 2003 the influence of very healthy recharge over the 1998-2002 period - with unprecedented replenishment during the winter of 2000/01[2] - could still be detected, particularly in the slower responding aquifers. Thus, levels in some Permo-Triassic sandstones outcrops (e.g. in Lancashire) remained well above average throughout the drought whilst in most limestone aquifers, which are generally much more responsive to contemporary infiltration patterns, groundwater levels declined steeply from February 2003. The recessions continued well into the autumn when levels in parts of the Jurassic limestone of the Cotswolds were the lowest on record for October (Figure 14).

The Chalk is the UK's most important aquifer but its response to the developing drought conditions in 2003 showed wide variations across the extensive outcrop

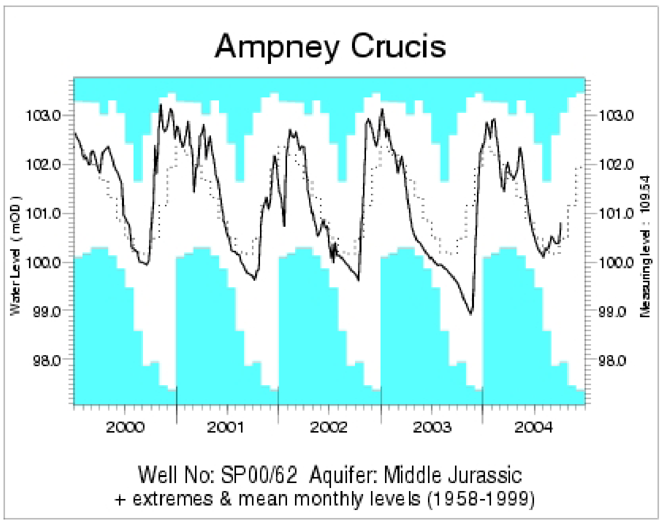



*Figure 14* *Groundwater level hydrograph for Ampney Crucis, 1999-2004.*

Data source: Environment Agency.

areas. This is illustrated in Figure 15 which shows four-year groundwater level hydrographs for boreholes in the South Downs (Chilgrove) and Chilterns (Stonor). In the former, the highly fissured Chalk promotes a rapid response to rainfall and groundwater levels fell rapidly over the March-May period when recharge was less than 30% of average across much of the outcrop[15]. By late-September, levels had declined by around 40 metres from their January peak and, in the neighbouring Compton well, levels were briefly at their lowest in series from 1893. By contrast, levels in the much slower responding Chalk of the Chilterns exhibit a more subdued recession and the notably high levels attained in early 2003 ensured that, even by year-end, levels had not fallen appreciably below the long term average.

Such aquifer units apart, groundwater levels were well below average in the autumn of 2003, exceptionally so in the southern Chalk (see Figure 16). Many shallow wells were dry and, over wide areas, the seasonal recovery needed to be generated from an exceptionally low base. With soils still notably dry, the late autumn rainfall triggered little recharge and, with a much truncated winter recharge season in prospect, there was an increasing likelihood that - as happened in 1996 - well below average groundwater levels would extend the drought into the following year in some areas. Fortunately, infiltration rates in January 2004 were twice the average across much of the worst affected aquifer units and groundwater levels rose briskly in the late winter. Nonetheless, most recessions began at below average levels.

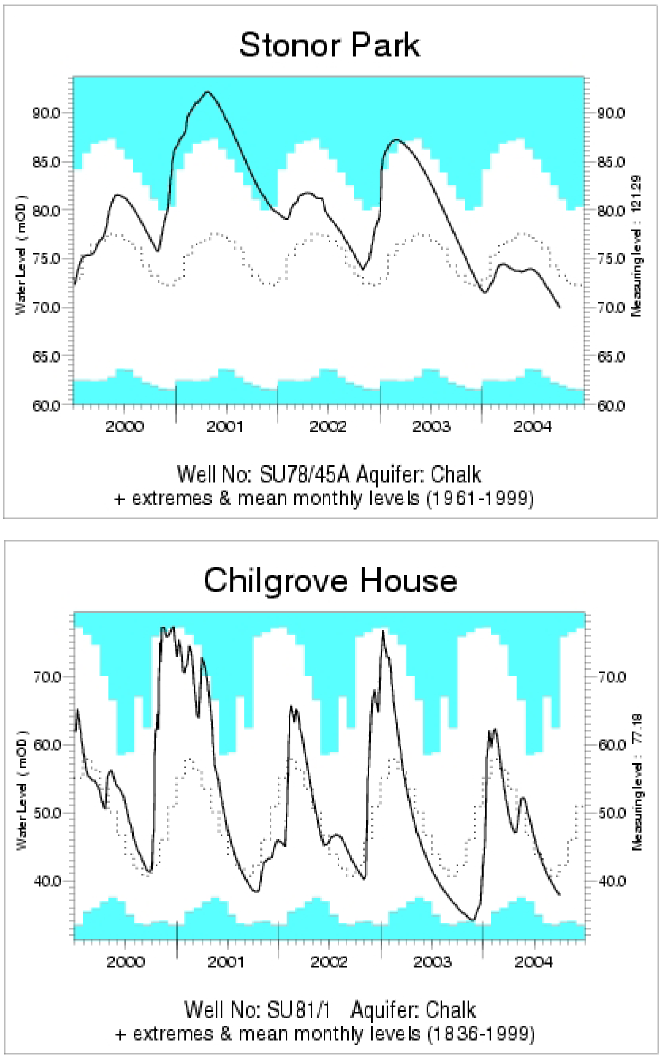
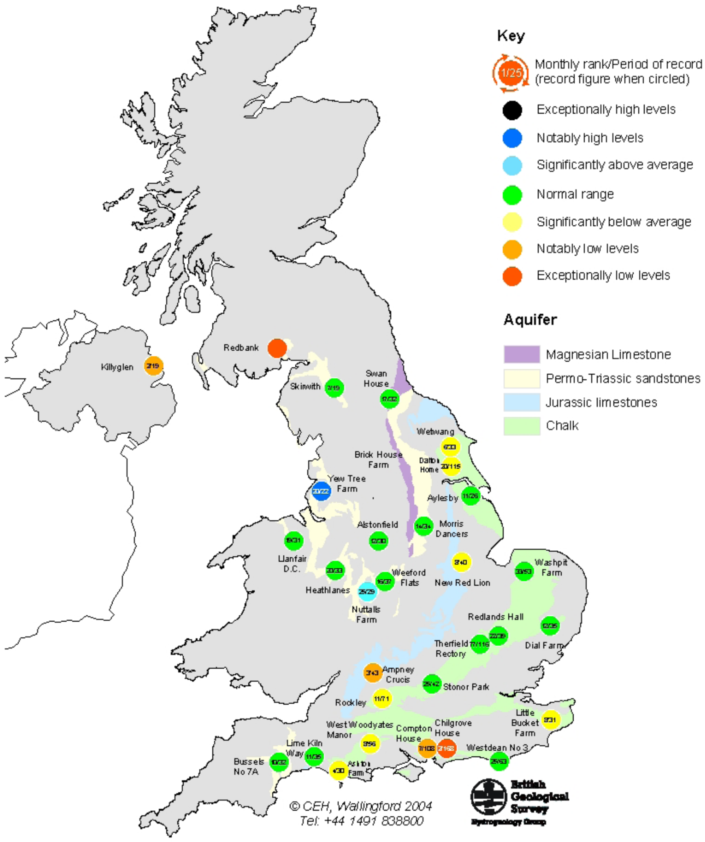



***Figure 15*** *Groundwater level hydrographs for Stonor Park and Chilgrove, 2000-2004.*

Data source: Environment Agency.




The rankings are based on a comparison between the average level in the featured month (but often only single readings are available) and 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 may be omitted where they are considered misleading.
Notes: i. The outcrop areas are coloured according to British Geological Survey conventions.
ii. Yew Tree Farm levels are now received quarterly.

***Figure 16*** *The ranking of October 2003 groundwater levels for a selection of observational wells and boreholes.*

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

## Impacts and Discussion

Over time, communities - and water resource management strategies - adapt to the threat of drought. At the individual level, coping mechanisms in the UK are less well developed than a century ago when almost the entire populace had a firmer grasp of the rhythm of the seasons - and an expectation that a dry summer could create difficulties for agriculture and water supply. On the other hand, the contemporary legislative framework, institutional arrangements and a holistic approach to water management[14] provide the foundation for much more sophisticated and flexible drought mitigation strategies. This mitigation capability served the UK well in 2003. Several other beneficial factors were, however, also influential - principally the excellent status of water resources at the beginning of the year, the very timely wet episode in the winter of 2003/04 and the relatively even intensity of the drought across the UK.

Perceptions of drought severity often vary substantially, the holiday maker typically taking a more sanguine view than the farmer or water resources manager. But a common manifestation of drought stress, one with particular public resonance, is the imposition of hose-pipe bans or restrictions on the non-essential use of water. None were needed in 2003. This reflects the increased regional and local integration of water resources (often involving both surface water and groundwater sources) which provides greater scope for responding to potential supply shortfalls. Operationally, the activation of stand-by sources, the granting of drought permits[14] to allow, for instance, additional abstraction to supplement dwindling reservoir stocks and publicity campaigns to moderate water demand also played a significant role in some of the worst afflicted areas. A continuation of the drought into the winter of 2003/04 would have caused significant water resources stress (in southern England especially) and operational problems for the water companies. However, seen in retrospect, it is a measure of the UK's resilience to within-year drought episodes that the elimination of less than half of the overall rainfall deficiencies (built-up by October) secured a generally healthy water resources outlook for 2004.

Although serious water resources stress was avoided in 2003 some local supply difficulties occurred (e.g. in the Hebrides) and spray irrigation restrictions were widely applied. In addition, a range of other drought-related problems were encountered. Leaving aside the threat to health caused by the summer heat-wave, these included, increased leakage rates as a consequence of soil shrinkage, fish fatalities and stress on other aquatic fauna (associated with low flows, high water temperatures and limited dissolved oxygen concentrations, e.g. on the Aberdeenshire Dee where fish kills were reported in August); the drying up of village ponds (raising questions regarding their sustainability in a warmer world), general water quality deterioration caused by low dilution and/or abundance of blue-green algae[14] and an increased risk of heath and forest fires. Hitherto less familiar impacts resulted from the remarkably dry autumn soils conditions - raising beet crops in the Midlands was particularly difficult and some autumn sown crops failed to establish (e.g. oilseed rape). More widely, temporary restrictions on the use of sports fields were imposed in September in response to the increased risk of injury due to the hardness of the ground.

The diversity of impacts emphasises the need for the sustainable use of water throughout the UK - balancing the often competing needs for water supply, agriculture, the environment and recreation. Achieving such a balance in 2003 would have been more challenging if the drought had been bracketed by dry winters - particularly in the South East where a combination of low rainfall, high population and projected demand increases make for a particular vulnerability. Whilst currently favoured climate change scenarios[16] suggest an increasing frequency of hot dry summers, wetter winters may provide a counterbalancing influence at least in relation to water resources vulnerability. It would be interesting though to speculate how readily demand patterns in a warmer world would be accommodated given a repeat of the low winter rainfall which was a feature of the 1850s or the 1888-1903 period across much of western Europe[11].

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# Location Map

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