The 2004–2006 drought in southern Britain

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This article documents the 2004–2006 drought in a hydrological framework with particular reference to its impact on water resources. The drought reached its maximum intensity in the late summer of 2006 and it is impossible to assess fully the impact of the heat of July 2006 without considering the arid conditions over southern Britain at the time.

Droughts are multi-faceted in both their character and range of impacts. Indexing drought severity is far from straightforward, reflecting the difficulties in quantifying a phenomenon which varies in its extent, duration and intensity both regionally and locally. Rainfall deficiencies are an obvious starting point but the unusual temporal distribution of rainfall throughout most of the 2004–2006 period means that, used alone, they provide a very incomplete index of drought intensity. Correspondingly, in this appraisal river flow and groundwater level variations are the preferred indices of the water resources stress experienced during much of 2004–2006.

Overture to the 2004–2006 drought

The drought conditions experienced over the 2004–2006 period were, in part, a legacy of the exceptionally dry and warm spring, summer and early autumn of 2003. England and Wales registered its second-lowest February–October rainfall in 83 years; as remarkably, Scotland reported its driest nine-month sequence (for any start month) since the 1955 drought. By July, severe drought conditions extended across much of Western and Central Europe but the UK was subject to relatively minor water resources and environmental stress (Marsh, 2004). The 2003 drought underlined the resilience of the UK's water supply capabilities to even major within-year rainfall deficiencies when the preceding winter has been sufficiently wet to leave surface and groundwater resources in a healthy state.

However, the very dry soil conditions during the autumn of 2003 delayed the onset of the seasonal recovery in runoff and, particularly, aquifer recharge rates throughout much of the English Lowlands. The continuing groundwater level recessions in parts of the Chalk (the primary source of water supply in much of eastern and southern England) left early winter levels at their lowest since 1997 in some areas. Consequently, the spring groundwater level recessions in 2004 began at below-average levels and, subsequently, the failure of the normal seasonal recovery to gain any momentum through the autumn signalled the onset of sustained drought conditions, in the South-East especially.

Overview of the drought

Taken together, 2005 and 2006 constitute the warmest two-year sequence in the 347-year Central England Temperature series (Manley, 1974). The summer periods included several notably arid episodes (e.g. June 2006) but the water resources and environmental impacts of the 2004–2006 drought largely reflected the lack of rainfall over two successive winter/spring periods. Drought conditions developed through the late autumn of 2004 across much of the English Lowlands and lasted, in most areas, until the early winter of 2006/2007. Whilst the elevated temperatures in 2004–2006 are consistent with a continuing warming trend, successive notably dry winters are unusual in the context of the last 30 years. Prior to the First World War however, clusters of dry winters were substantially more common with November–April rainfall totals in the English Lowlands often less than the corresponding summer half-year totals (Marsh *et al*., 2007a).

The 2004–2006 drought had a strong regional focus and was generally most severe in the driest parts of the UK where groundwater is the major source of water supply and a combination of high population density, intensive agriculture and commercial activity generates the highest water demand. Careful management was necessary to reconcile the needs of a wide range of water users with the requirements of the aquatic environment.

Rainfall

From the late autumn of 2004, persistent anticyclonic conditions across southern Britain resulted in most rain-bearing low-pressure systems following tracks remote from the English Lowlands. This resulted in a notable exaggeration in the normal north-west/south-east rainfall gradient across the UK. Parts of north-west Scotland were very wet whilst large rainfall deficiencies became established across much of eastern, central and southern England.

Figure 1 illustrates 2003–2006 monthly rainfall anomalies for England and Wales and for the Thames Basin. Across most of England and Wales, the winter and early spring periods of 2004/2005 and 2005/2006 were dry but the most persistent drought conditions extended across large parts of southern Britain. For the Thames Basin, October 2005 was the only month to report above average rainfall in an 18-month sequence.

Considering the drought-affected region as a whole, rainfall deficiencies were most severe over the 21 months ending in July 2006. In this timeframe England and Wales reported its third-lowest rainfall since 1932–1934 with the most exceptional regional deficiencies in the Thames and Southern regions (see Table 1). Figure 2 illustrates the 21-month rainfall deficiencies on a 5 km^2 grid across southern Britain. Maximum deficiencies exceeded 25% – mostly in the South-East but notable drought conditions also extended into parts of the Midlands and the South-West, Cornwall especially. Figure 2 also testifies to the very substantial local variations in drought intensity, due in part to the convective nature of much of the summer and early autumn rainfall.

In most drought-affected regions, rainfall over the May–October periods in both years was within the normal range, and close to the average across much of the South-East

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where a relatively dry summer in 2005 was balanced by above-average rainfall in the following year. Temporal variations in summer rainfall did, however, impact on the drought's severity in 2006. After a damp late spring, the drought re-intensified through June and July which, taken together, were the second driest in the last 23 years for England and Wales. Correspondingly, soil moisture deficits increased steeply and the area subject to drought stress extended.

Of primary significance from a water resources perspective was the disproportionate concentration of the overall rainfall deficiency in the winter and spring, when modest evaporation losses allow the bulk of reservoir replenishment and aquifer recharge to take place. Most of southern Britain reported two-year winter rainfall deficiencies of >25% and for the Thames Basin it was, marginally, the driest combination of November–April periods since the Long Drought of 1890–1910 (Marsh *et al.*, 2007a).

River flows

Throughout 2004–2006, river flow patterns in the drought-affected regions were notable for an exceptional lack of spates and outstanding long-term runoff deficiencies. Return periods for annual 30-day minimum flows for some groundwater-fed rivers in southern England exceeded 10 years but in most of the drought-affected basins annual minimum flows remained significantly above those registered during other recent drought years.

In runoff terms the drought's duration varied appreciably across southern Britain but, broadly, flows remained seasonally depressed from the late autumn of 2004 to the autumn of 2006 – later in many slow-responding spring-fed rivers in the English Lowlands. Of particular hydrological interest over this period was the virtual absence of high flow events. For the Thames at Kingston, no daily flow exceeded 200m^{3}s^{-1} during the 29 months to October 2006, the longest such sequence for over 100 years.

Figure 3 illustrates monthly river flows for the Lambourn (a permeable catchment in the Berkshire Downs) and the Great Stour (a largely impermeable catchment in Kent). The plots allow the development and decay of the drought to be tracked in more detail. Monthly flows are overlain on colour-coded bands (see Key in Figure 4) which signify the degree of departure from the normal range; monthly flows which extend into the grey (high) and orange (low) envelopes have return periods in excess of 20 years.

In responsive southern rivers like the Great Stour flows were, typically, more seasonally depressed in 2005 than in 2006 when short-lived spates in the late summer helped to maintain runoff rates above

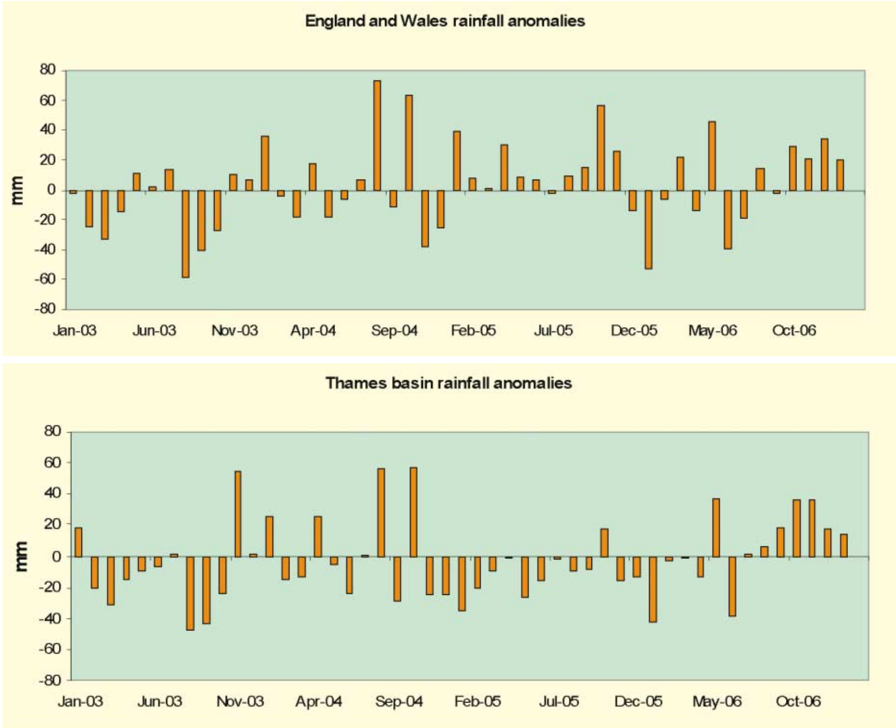

Figure 1. 2003–2006 monthly rainfall anomalies for England and Wales and for the Thames Basin (relative to the 1961–1990 average). Source: Met Office.

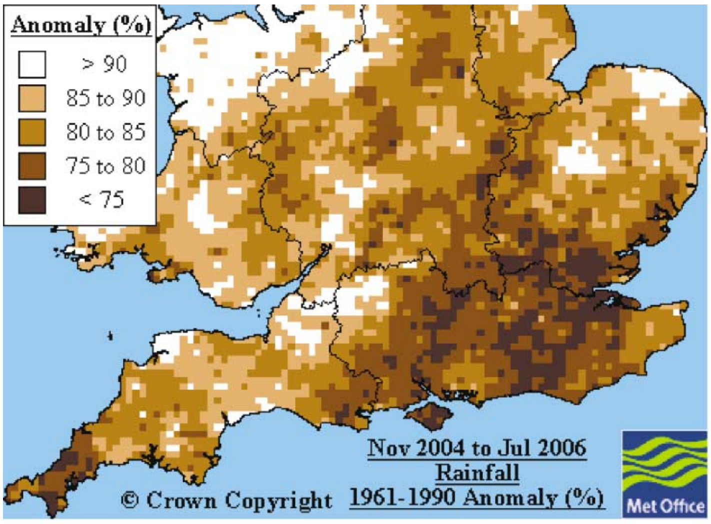

Figure 2. November 2004–July 2006 rainfall anomalies. Source: Met Office.

Table 1

Minimum 21-month rainfall totals (ending in July).

	England and Wales			Thames Region			Southern Region		
Rank	*Total (mm)*	*% of lta**	*End yr*	*Total (mm)*	*% of lta**	*End yr*	*Total (mm)*	*% of lta**	*End yr*
1	1187	76.6	1934	868	71.5	1934	985	72.4	1934
2	1220	78.9	1976	922	76.0	1922	990	72.8	1922
3	1318	85.0	1922	944	77.8	1976	1050	77.2	2006
4	1332	85.9	1997	949	78.2	2006	1063	78.1	1944
5	1355	87.4	2006	956	78.8	1944	1094	80.4	1949
6	1355	87.4	1944	995	82.0	1997	1095	80.5	1973

Data source: Met Office areal rainfall series (beginning in 1914).
* *lta* – long term average

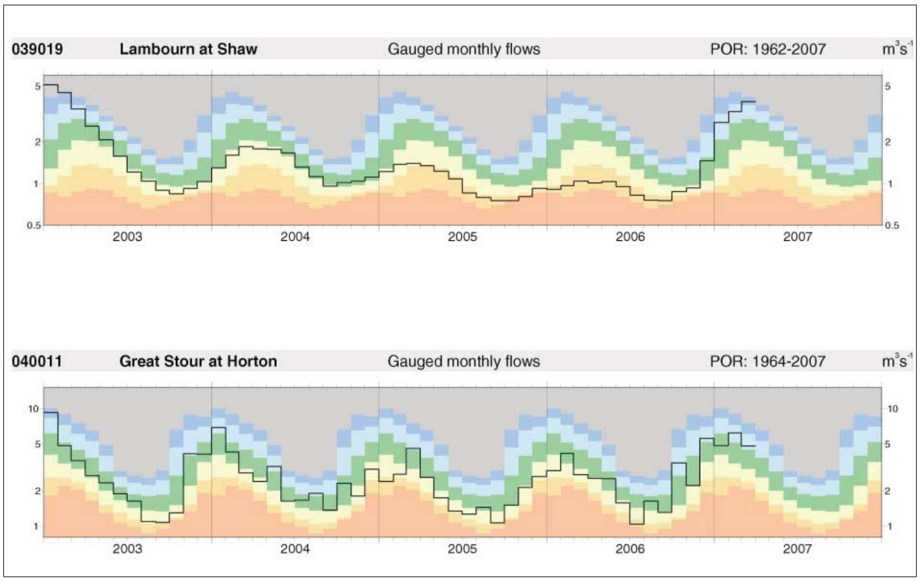

Figure 3. Monthly river flow hydrographs 2003–2007 for the Lambourn (Berkshire) and the Great Stour (Kent).

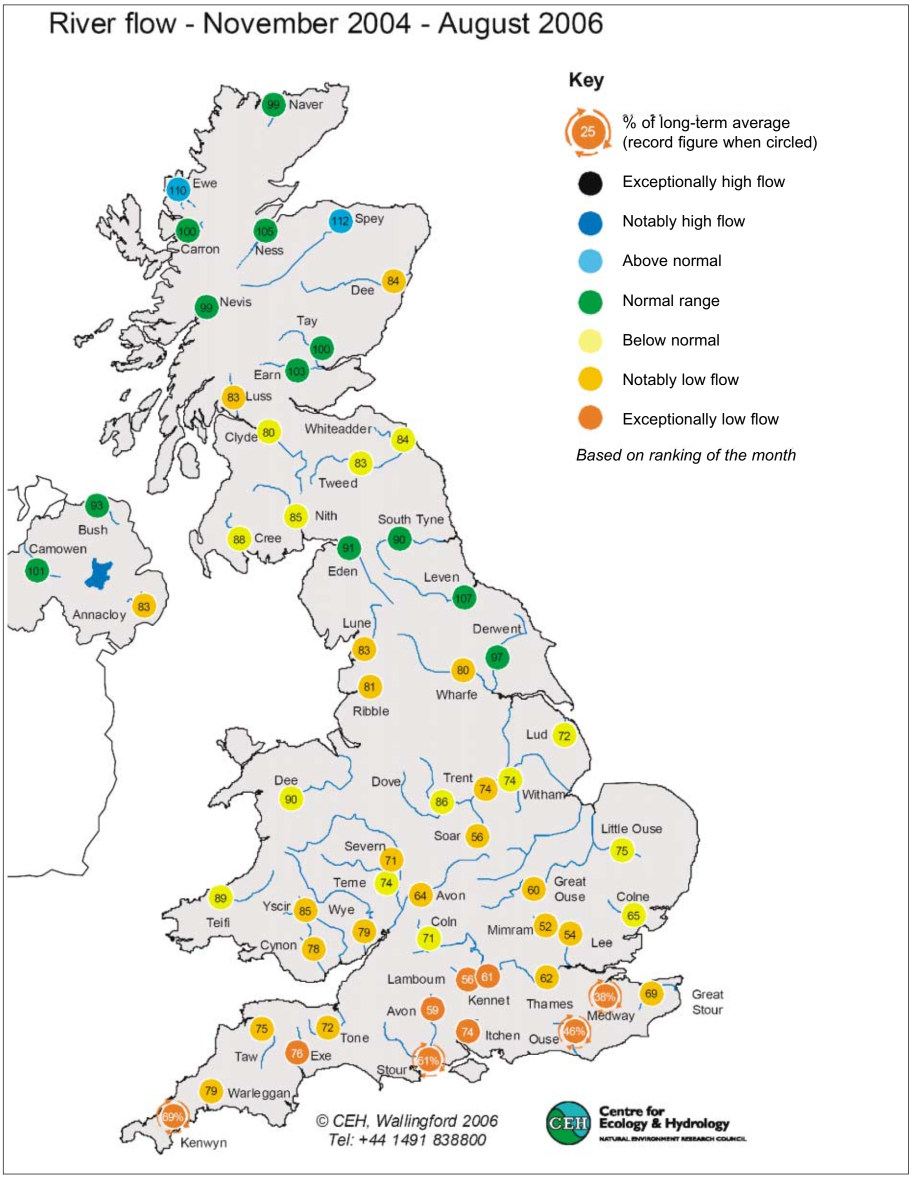

Figure 4. River flows for the 22 months ending in August 2006 as a percentage of the long-term average.

drought minima. The drought's impact was generally more evident in spring-fed streams and rivers where monthly flows remained below average for very extended periods – over three and a half years in the Lambourn – and closely approached long-term minima in the final stages of the drought. For the spring-fed Mimram (Hertfordshire), the mean September flow in 2006 was the lowest in a series from 1953 (Centre for Ecology and Hydrology, 2006).

In relation to water resources stress, the long-term runoff deficiencies were of more direct relevance. Over the November 2004–August 2006 timespan, runoff was below average across almost all of England and Wales but the largest deficiencies – exceeding 30% – were mostly confined to central and southern England (see Figure 4). New minimum 22-month runoff totals (for periods beginning in November) were established from Cornwall to Kent. A significant minority of these minima represented the lowest runoff for any 22-month period. Some, including those for the Medway (Kent) and the Sussex Ouse, eclipsed previous minima by a considerable margin. For the Thames, the November 2004–September 2006 runoff was the lowest since 1947–1949. Elsewhere, the 20–22 month minima were, typically, a little greater than those registered during the protracted droughts of the early and mid-1990s.

Depressed groundwater levels (see below) and the associated widespread failure of springs contributed to a major contraction in the lowland stream network over the 2004–2006 period. The lack of spates and drying up of headwater tributaries represented a particular risk to migratory fish that require sufficient flow to trigger upstream movement and to reach their spawning grounds. Limited inflows (from surface or groundwater) and exceptional evaporation demands led to many ponds drying up and fish rescues were needed as water levels became critically low. Low oxygen levels were an exacerbating factor in some water bodies but oxygen concentrations remained relatively healthy in most spring-fed streams. Flows recorded across southern England in the summer of 2006 suggest that (temporary) habitat loss was broadly similar to 1992 and 1997; and much less than in 1976 (Marsh *et al.*, 2007b).

Reservoir stocks

Over the 1998–2002 period, reservoir stocks across England and Wales remained very healthy but declined steeply through the intense spring and summer drought of 2003. Stocks generally recovered in 2004 and, despite the drought conditions over the succeeding two years, they remained mostly well within the normal range at the

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national scale – a reflection of the drought's very moderate impact across much of the country.

The limited depletion at the national scale masks the degree of water resources stress evident in parts of southern Britain where the impact of the developing drought on reservoir stocks was much more evident. Figure 5 shows 2004, 2005 and 2006 monthly reservoir stocks for Bewl Water (on the Kent/Sussex border) and Colliford (Cornwall). For the former, stocks remained reasonably healthy until the summer of 2005. Thereafter, the absence of any appreciable seasonal recovery left stocks at their lowest on record entering 2006. Aided by a wet late spring and Drought Permits allowing additional pumping from the River Medway, stocks at Bewl Reservoir recovered briskly. Summer stocks were considerably higher than in 2005; a situation replicated throughout much of the drought-affected region but there were important exceptions. In parts of the South-West stocks remained seasonally depressed, particularly in Cornwall where Stithians and Colliford reservoirs declined to below 50% of capacity in the late summer. Even at the end of 2006, Colliford remained only marginally above half full – a reflection of both the long-term rainfall deficiency (since 2001) and the reservoir's small catchment area relative to its capacity, implying that the post-drought recovery could extend over several years.

Depleted water resources triggered the introduction of a range of drought mitigation measures (e.g. publicity campaigns to moderate demand, local water transfers, reductions in compensation flows and temporary switching of depleted reservoirs to non-consumptive mode). Sutton and East Surrey Water introduced a hosepipe ban in the late spring of 2005, heralding a series of successful applications for Drought Orders concentrated in the South-East. A year later, with groundwater resources also seasonally depressed over wide areas, water use restrictions affected over 13 million consumers in total. However, aided by a wet May and reduced water demands, stocks in the major-pumped storage reservoirs which service London's needs held up well in 2006.

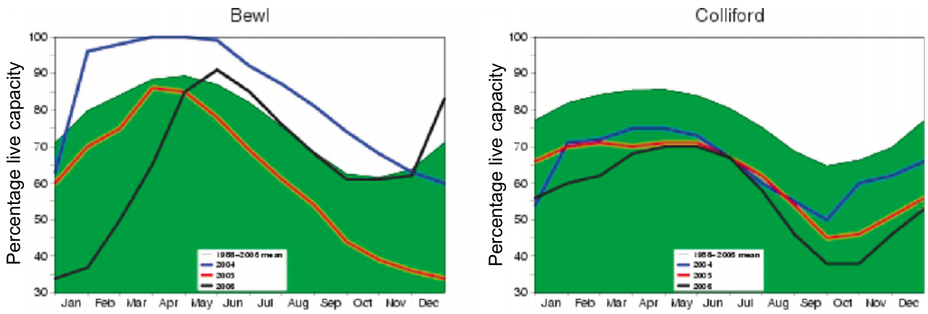

Figure 5. Variations in monthly stocks for Bewl Water (East Sussex/Kent) and Colliford (Cornwall) reservoirs.

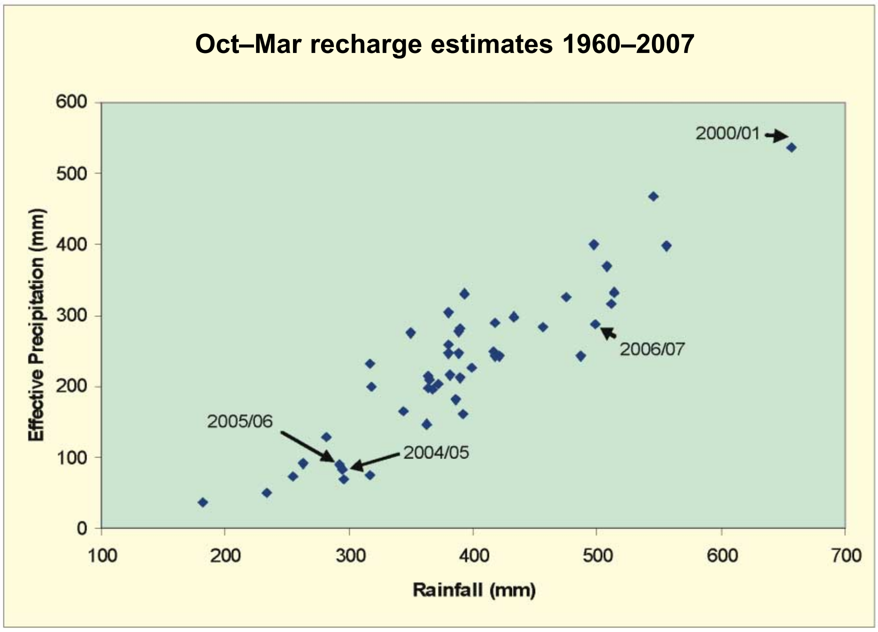

Figure 6. October–March rainfall and Effective Precipitation for the west Chilterns.

Groundwater resources

The drought achieved its most extreme expression in relation to groundwater resources in parts of the English Lowlands. From the autumn of 2003 to the autumn of 2006 the spatial and temporal distribution of rainfall was very unhelpful from a groundwater perspective. Winter and spring rainfall was well below average across most major aquifer outcrops and seasonally dry soil conditions (a consequence of above average evaporative demands as well as limited rainfall) served to restrict the length of the recharge seasons.

The 2004–2006 period provides a very clear demonstration of the sensitivity of aquifer recharge to rainfall over the winter and spring periods, and the consequent vulnerability of groundwater resources to clusters of dry winters. Figure 6 plots the relationship between October–March rainfall and Effective Precipitation[1] (a measure of aquifer recharge) totals for the western Chilterns. Winter half-year rainfall totals of less than 250 mm are seen to generate very meagre recharge and, broadly, a 30% deficiency in rainfall translates into a recharge deficiency of around 60%. In both 2004/2005 and 2005/2006 estimated Effective Precipitation totals for the October–March periods were below 35% of average.

The effect of this paucity of recharge is illustrated in Figure 7 which features 1997–2007 groundwater level hydrographs for index wells in the Chalk and the Permo-Triassic sandstones – the two most important aquifers from a water supply perspective. For the Chilterns (represented by the Stonor borehole), the residual benefit of exceptionally high groundwater levels in early 2003 was still evident in 2004 but the weakness of the subsequent seasonal recoveries left levels approaching long-term minima by the early autumn of 2006. As in other Chalk outcrops, the degree of water-table depression would have been more severe without a seasonally late pulse of recharge in April and May which moderated groundwater level recessions (and briefly reversed them in a few areas). A broadly similar recharge pattern is evident in the slow-responding Permo-Triassic sandstones of the Midlands where groundwater levels reflect recharge patterns over a number of years. At Heathlanes (Shropshire), barely an inflection in the recession can be recognized over the 2004–2006 period and, by the autumn of 2006, groundwater levels had fallen below all but the minima recorded in the final phase of the 1995–1997 drought.

[1] Effective Precipitation accounts for the proportion of rainfall absorbed by the soils. Data kindly supplied by the Environment Agency, Thames Region.

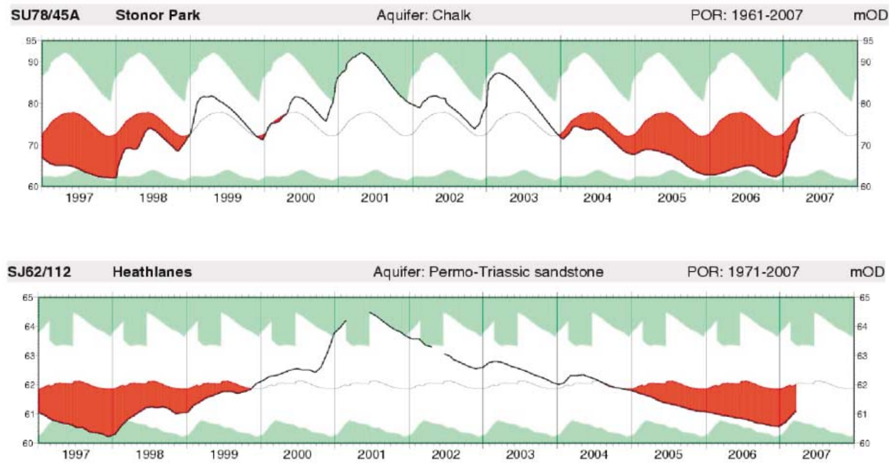

Figure 7. Groundwater level hydrographs for Stonor Park (Chiltern Hills, Buckinghamshire) and Heathlanes (Shropshire).

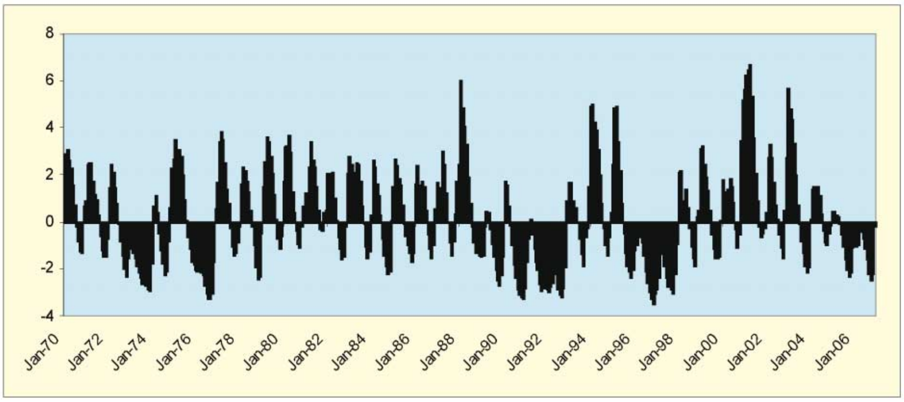

Figure 8. An index of total storage in the Chalk aquifer, 1970–2006.

The wells featured in Figure 7 are located in outcrops where the drought achieved its greatest severity. Away from these aquifer units, the depletion of groundwater resources was generally much more moderate. Levels in most limestone aquifers remained within the normal range and the drought's impact on minor aquifers (e.g. in Norfolk) was limited. Even within the Chalk aquifer, the degree of resource depletion varied substantially with relatively healthy resources in the more northerly outcrops.

Figure 8 is based on monthly groundwater level anomalies for seven index wells and boreholes across the Chalk aquifer, extending from Dorset to the Yorkshire Wolds. This simple index allows the drought's impact on overall storage in the Chalk to be considered in the context of groundwater resource variability over the 1970–2007 period. The limited spatial extent of the most severely depressed water tables in 2004–2006 is confirmed by the lesser magnitude of the resource depletion relative to the protracted groundwater droughts of the early and mid-1990s. Limited evidence suggests that these latter droughts may have been the most severe, in groundwater terms, for more than 80 years (Bryant *et al*., 1994; Marsh *et al*., 1994).

The terminal phase of the 2004–2006 drought

Drought termination can be a protracted process in the UK with wet interludes, particularly during the summer half-year, providing a temporary respite but having little immediate impact on water resources (aside from a reduction in water demand). On the other hand, some recent droughts (e.g. 1976, 1984, 1995) have ended dramatically as prolonged sequences of vigorous low-pressure systems brought heavy rainfall extending over a number of months.

In 2006, convective storms in the late summer helped, locally, to moderate soil moisture deficits but a more general amelioration of the drought awaited the onset of persistent cyclonic conditions during an exceptionally mild autumn and early winter. But rainfall patterns were again very spatially variable; some areas reported only average rainfall over the August–December period (e.g. the Isle of Wight) and, for a few catchments, overall rainfall deficiencies actually increased, for example in Cornwall (Centre for Ecology and Hydrology, 2007).

Soil moisture deficits generally declined rapidly through October 2006 allowing runoff and recharge rates to recover smartly across much of the English Lowlands. River flows increased briskly through November in many impermeable catchments – most reporting above average flows by month-end. With most gathering grounds close to saturation, gravity-fed reservoirs reported healthy replenishment from mid-October. Seasonal water-table recoveries in most western and northern aquifers also gathered momentum, heralding the most productive recharge episode for the Chalk in the last four years. In the West Chilterns, recharge over the 2006/2007 winter half-year was around 50% greater than the combined totals for 2004/2005 and 2005/2006 (see Figure 5).

A high frequency of active frontal systems continued through the winter which for the October–March period was the wettest on record for the UK as a whole (in a series from 1914). By the turn of the year the focus of hydrological stress had switched decisively to the risk of flooding and the water resources outlook in early March was very healthy. However, the abrupt switch back to very dry (and warm) conditions in early March across most of Britain provided another example of how quickly a change in weather type can affect hydrological conditions. The lack of rainfall continued through April – much of eastern Britain registered less than 10% of the monthly average – contributing to exceptionally dry soil conditions and a steep decline in river flows; by early May seasonal minimum flows were being approached in many eastern rivers.

Concluding remarks

England and Wales are now considerably more resilient to drought stress than in the nineteenth century when droughts posed a real threat to lives and livelihoods. This resilience is built upon improvements in water management and more effective institutional, regulatory and legislative structures. Their benefits were well demonstrated in 2005 and 2006 but our continuing water resource vulnerability to successive notably dry winters was also clearly evident. With temperatures, water demand and the expectations of stakeholders increasing (e.g. in relation to moderating drought impacts on the aquatic environment), the 2004–2006 drought has demonstrated the need for improved understanding of medium-term climatic variability; ultimately to allow greater predictive skill in identifying circumstances when clusters of dry winters may be expected to occur.

Note

Up-to-date assessments of hydrological variability and water resources status across the UK are available via the Centre for Ecology and Hydrology's 'Water Watch' website: http://www.ceh.ac.uk/data/nrfa/water_watch.html

Acknowledgements

This report is adapted from a more comprehensive review of the drought posted on the National River Flow Archive website: http://www.nwl.ac.uk/ih/nrfa/water_watch/dr2004_06/index.html

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Stratus and stratocumulus over Ben Lomond, viewed from Balloch, Loch Lomond, Scotland, 16 August 2004. (© George D. Anderson.)