National Hydrological Monitoring Programme

2006

UK HYDROLOGICAL REVIEW

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
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This hydrological review, which also provides an overview of water resources status throughout 2006, was undertaken as part of the National Hydrological Monitoring Programme (NHMP). The NHMP was set up in 1988 to document hydrological and water resources variability across the UK. It is a collaborative programme between the Centre for Ecology and Hydrology, which maintains the National River Flow Archive, and the British Geological Survey which maintains the National Groundwater Level Archive. Both organisations are component bodies of the Natural Environment Research Council.

This report has been compiled with the active cooperation of the principal measuring authorities in the UK: the Environment Agency[a] (EA), Scottish Environment Protection Agency (SEPA) and, in Northern Ireland, the Rivers Agency (RA). These organisations provided the great majority of the required river flow and groundwater level data. The Met Office provided almost all of the rainfall and climatological information featured in the report and the reservoir stocks information derive from the Water Service Companies, Scottish Water and Northern Ireland Water. Groundwater level data for Northern Ireland was provided by the Northern Ireland Environment Agency. The provision of the basic data which provides the foundation both of this report and the wider activities of the NHMP is gratefully acknowledged.

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/water_watch.html). Financial support for the production of the Hydrological Summaries is provided by: the Department of the Environment, Food and Rural Affairs (Defra), EA, SEPA, RA and the Office of Water Services (OFWAT).

Authors

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Cover photo: Latchmore Lake, Gerrards Cross (Bucks) in August 2006

[a] Including the Environment Agency Wales which is both an Assembly Public Body (obtaining a proportion of its funding and direction from the Welsh Assembly) and part of the corporate Environment Agency for England and Wales.

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2006 Summary

Monthly and seasonal variations in rainfall throughout 2006 were unusually large but, for the UK as a whole, the annual total was appreciably above average. Relatively few notable flood events were reported and, in hydrological terms, the most significant feature of the year was the continuation of drought conditions across southern Britain. Over the 21-month period beginning in November 2004, England & Wales registered its 6th lowest rainfall total (in this timeframe) in a series from 1914 (see Table 1) with deficiencies exceeding 20% in parts of southern and central England. The overall rainfall deficiency was disproportionately concentrated in the winter periods – when the bulk of reservoir replenishment and aquifer recharge normally takes place.

The 2004-06 drought had a strong regional focus and was generally most severe in the South-East – one of the driest part of the country, where groundwater is a major source of water supply and a combination of high population density, intensive agriculture and commercial activity generates the highest water demand. By early summer 2006, water-use restrictions were affecting around 13 million consumers and river flows were depressed across much of the UK, particularly in permeable catchments. Careful water resources and river management was therefore necessary to reconcile the needs of a wide range of water users with the requirements of the aquatic environment[b].

Table 1 Minimum 21-month England & Wales rainfall totals (starting in Nov.) Data source: Met Office

Rank	Timespan	% of lta	mm
1	1932 - 1934	76.3	1187
2	1974 - 1976	78.5	1220
3	1920 - 1922	84.8	1318
4	1995 - 1997	85.7	1332
5	1933 - 1935	85.7	1332
6	2004 - 2006	87.1	1355
7	1942 - 1944	87.1	1355
8	1988 - 1990	87.6	1362
9	1963 - 1965	87.9	1366
10	1990 - 1992	87.9	1367

Locally, convective summer storms helped to moderate the drought's intensity but a more general amelioration awaited the onset of persistent cyclonic conditions during an exceptionally mild autumn and early winter. In some areas, most significantly in the South West, rainfall deficiencies continued to increase through September but an exceptionally wet end to the year – the October-December period was the 2nd wettest at the national scale since 1954 – resulted in the UK's 2006 runoff total being very close to the long-term annual average. More importantly, the sustained wet episode ensured that the outlook for water resources entering 2007 was very much healthier than 12 months previously. However, the spatially very variable rainfall patterns, and the need to satisfy soil moisture deficits before aquifer recharge could re-commence, resulted in groundwater levels remaining seasonally low at year-end in a few slow-responding aquifer units in central and southern England[c].

Overview of the recent past

This section places the hydrological conditions of 2006 in the context of the recent past and within a broader historical perspective.

Following extended drought conditions in 1988-92, which were punctuated by the exceptionally wet winter of 1989/90, an extended 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, heralding the wettest five-year sequence on record for the UK; England & Wales registered its highest five-year rainfall total in a series from 1766[1]. Severe flooding occurred in April 1998 (across the Midlands), throughout most of southern Britain during the autumn and winter of 2000/01, and again in early 2003. Maximum recorded river 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.

In northern Britain and Northern Ireland, with most rain-bearing frontal systems following more southerly tracks than normal, 2001 witnessed the development of a further drought episode. 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 clear moderating effect but very limited replenishment of groundwater resources in the late winter and early spring of 2004 signalled the onset of a further sustained drought episode. The drought intensified through the following two winters and impacted most severely on parts of eastern, central and southern England in both 2005 and 2006. By contrast, annual rainfall totals for these two years were notably high across much of Scotland.

[b] A more detailed account of the 2004-06 drought may be found at: http://www.nwl.ac.uk/ih/nrfa/water_watch/dr2004_06/index.html

[c] The Location Map (page 17) gives the locations of many of the rivers, reservoirs and aquifer outcrop areas mentioned in this Hydrological Review.

Rainfall

Annual rainfall

The UK rainfall total for 2006 was around 7% above the 1961-90 average and the great majority of regional[d] totals also exceeded the average (see Table 2). The spatial pattern of 2006 annual rainfall totals exhibit a typical north-west to south-east gradient (Figure 1). Whilst precipitation totals reached around 6000 mm in the western Highlands of Scotland, totals were an order of magnitude lower in the driest parts of south-east Britain. Even here however, annual rainfall totals were generally close to, or above, average and significant rainfall deficiencies were largely confined to Cornwall, the Isle of Wight and sheltered parts of north-eastern Britain (see Figure 2). By contrast, parts of Scotland (including a large part of the central lowlands around Glasgow), and scattered localities throughout England & Wales, registered 2006 rainfall totals exceeding 120% of the 1961-90 average.

The year in brief

Table 2 also gives monthly and half-yearly national and regional rainfall totals for 2006 (in mm and as a percentage of the 1961-90 average). In hydrological terms, temporal variations in rainfall were of greater significance than its spatial distribution. Nationally, January and June were notably dry whilst well above average rainfall characterised March, May and the October-December period. Very low rainfall early in the year contributed to the driest winter (December-February) for the UK since 1963/64; most regions registering less than 70% of the 1961-90 winter average with especially meagre rainfall across parts of the Midlands (see Figure 3). The dry winter served to intensify protracted drought conditions across much of the country.

The drought eased through an unsettled spring, particularly during May which was the wettest since 1986 at the national scale. However, a further notably dry episode in June-July, the driest in a series from 1914 for the Northumbrian Region, signalled a re-intensification of the drought. In rainfall deficiency terms the drought achieved its maximum severity around mid-summer. Figure 4 shows rainfall deficiencies over

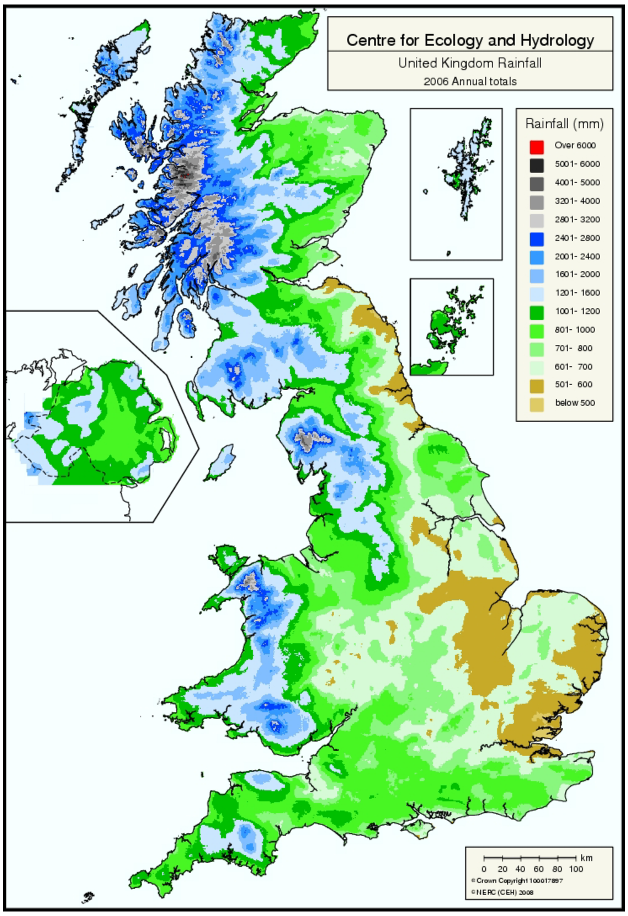

Figure 1   2006 annual rainfall totals in mm
Data source: Met Office

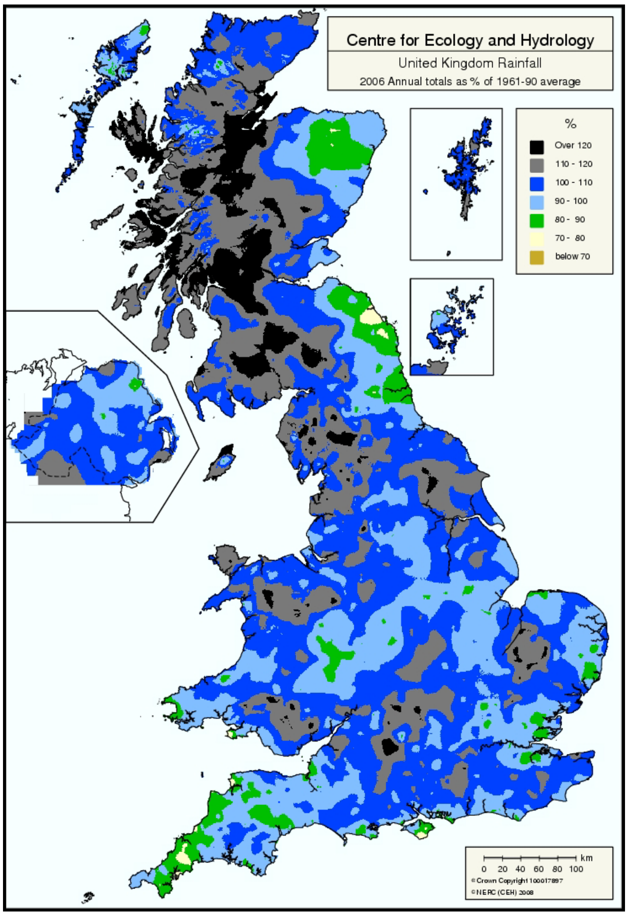

Figure 2 2006 rainfall totals as a % of the 1961-90 average
Data source: Met Office

[d] To allow better spatial differentiation, the rainfall data for Britain are presented for the regional divisions of the precursor organisations to the Environment Agency and Scottish Environment Protection Agency.

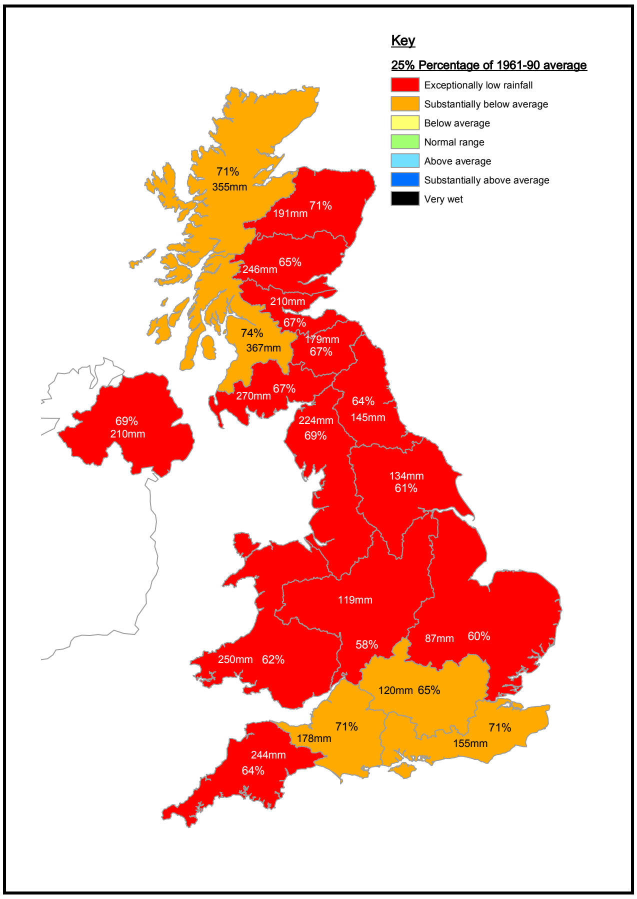

Figure 3 *2005-06 December-February rainfall in mm and as a % of the 1961-90 average*
Data source: Met Office

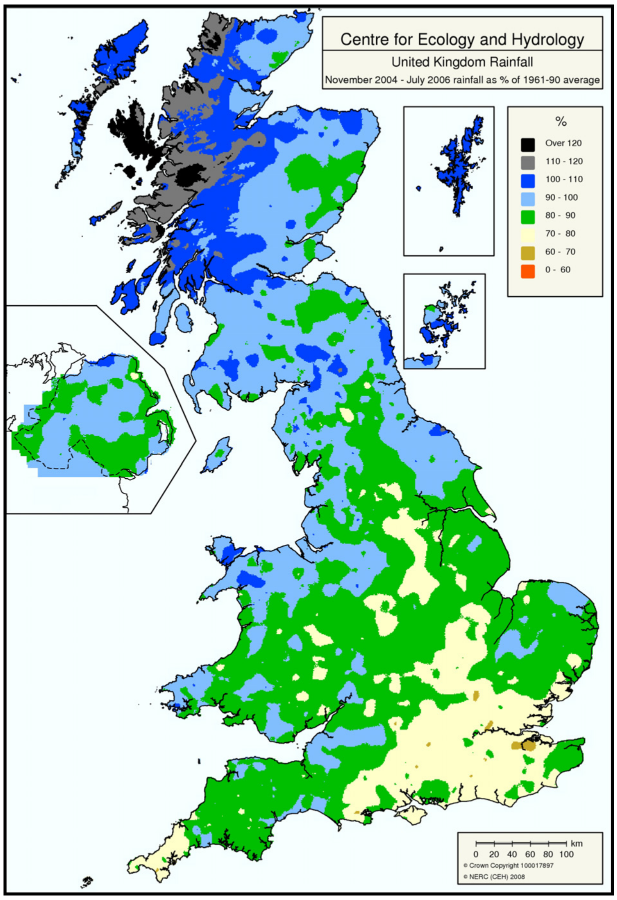

Figure 4 *November 2004 –July 2006 rainfall as a % of the 1961-90 average*
Data source: Met Office

the November 2004 – July 2006 period; the deficiencies were most exceptional in the South East (and Cornwall) where such moderate 21-month rainfall accumulations would be expected, on average, less than once in 20 years (for the particular timeframe examined). A wet August was therefore very welcome in water resources terms and the early autumn saw a further decline in rainfall deficiencies in most areas. Correspondingly, summer half-year (April-September) rainfall totals were within the normal range in most regions but, importantly, well below average in the South-West which had become the focus of regional drought concern following the 2nd lowest summer half-year rainfall since 1990; Cornwall was especially dry through the summer and early autumn.

A decisive change in synoptic patterns during September heralded a sustained sequence of Atlantic frontal systems that brought significant pulses of frontal rainfall throughout the last three months of 2006. All regions of the country reported considerably above average rainfall in the October-December timeframe; countrywide, only 2000 has been wetter since 1954 and medium-term rainfall deficiencies were greatly moderated by year-end.

Table 2   2006 rainfall in mm and as a % of the 1961-90 average   Data source: Met Office

2006		J	F	M	A	M	J	J	A	S	O	N	D	Y	Oct05-Mar06	Apr06-Sep06
United Kingdom	mm	60	65	110	68	112	42	53	92	102	143	154	173	1175	575	470
	%	53%	83%	120%	101%	157%	59%	73%	102%	102%	128%	135%	149%	107%	92%	99%
England & Wales	mm	35	56	94	46	110	26	43	90	75	118	110	130	932	465	389
	%	39%	87%	128%	77%	173%	40%	69%	118%	96%	136%	120%	136%	103%	93%	96%
Scotland	mm	109	85	137	108	117	75	70	97	149	196	241	262	1646	787	616
	%	70%	81%	107%	134%	136%	87%	74%	83%	104%	123%	153%	168%	112%	91%	101%
Northern Ireland	mm	51	47	142	73	114	36	68	91	136	125	130	139	1153	565	518
	%	44%	58%	157%	109%	156%	50%	95%	96%	136%	109%	122%	127%	105%	91%	108%
North West	mm	73	72	152	78	119	44	47	123	108	160	151	218	1344	667	519
	%	61%	91%	158%	110%	158%	53%	54%	112%	92%	125%	120%	173%	110%	99%	96%
Northumbria	mm	35	54	104	38	94	26	21	99	77	99	74	118	839	464	355
	%	42%	91%	145%	65%	150%	42%	31%	119%	104%	129%	85%	144%	97%	101%	87%
Severn Trent	mm	21	42	72	43	105	17	47	85	71	96	78	101	779	365	370
	%	29%	76%	118%	77%	176%	29%	86%	124%	110%	146%	109%	128%	101%	91%	101%
Yorkshire	mm	30	54	109	50	111	18	36	122	80	92	78	112	892	415	417
	%	38%	92%	160%	84%	184%	29%	58%	161%	114%	124%	95%	135%	107%	93%	107%
Anglian	mm	17	38	40	35	83	16	38	102	59	67	64	54	614	228	333
	%	33%	101%	86%	74%	172%	32%	76%	184%	117%	131%	111%	97%	102%	76%	110%
Thames	mm	21	42	55	36	93	16	51	64	78	99	98	87	740	304	339
	%	32%	91%	97%	71%	165%	29%	102%	109%	130%	154%	149%	122%	106%	82%	102%
Southern	mm	25	63	58	44	95	22	28	69	63	124	85	110	786	367	321
	%	30%	116%	91%	83%	175%	40%	58%	119%	91%	154%	100%	133%	100%	82%	95%
Wessex	mm	24	59	74	27	107	32	58	51	66	125	126	118	868	456	343
	%	27%	89%	105%	51%	174%	56%	109%	76%	91%	154%	148%	124%	102%	94%	93%
South West	mm	46	84	123	35	120	43	50	51	70	164	170	151	1108	688	370
	%	33%	82%	123%	50%	164%	62%	70%	59%	75%	140%	133%	107%	93%	95%	80%
Wales	mm	63	77	164	63	159	34	49	99	82	181	191	243	1404	803	486
	%	44%	76%	151%	77%	189%	42%	60%	93%	69%	130%	133%	155%	104%	101%	88%
Highland	mm	134	105	139	173	135	90	82	109	153	261	286	338	2007	915	743
	%	74%	83%	88%	185%	144%	91%	77%	84%	91%	136%	145%	175%	115%	87%	107%
North East	mm	44	65	108	45	78	47	48	89	79	175	111	111	1001	597	386
	%	43%	94%	131%	65%	107%	69%	62%	98%	86%	171%	107%	114%	97%	107%	82%
Tay	mm	96	68	146	49	112	67	60	77	157	156	225	266	1478	736	521
	%	66%	69%	128%	71%	129%	88%	74%	77%	129%	115%	177%	199%	115%	98%	98%
Forth	mm	79	60	137	54	100	52	54	71	148	134	188	239	1316	629	480
	%	67%	73%	139%	87%	131%	73%	70%	73%	131%	112%	162%	209%	115%	97%	96%
Clyde	mm	150	99	149	124	146	98	86	115	212	190	336	331	2035	880	782
	%	79%	80%	98%	139%	153%	101%	76%	81%	116%	97%	182%	179%	116%	85%	109%
Tweed	mm	53	65	105	49	84	31	52	99	120	110	137	159	1064	577	435
	%	52%	93%	128%	81%	115%	45%	70%	110%	130%	112%	142%	164%	106%	106%	95%
Solway	mm	108	73	182	87	109	74	69	91	169	172	261	236	1631	826	599
	%	71%	72%	153%	110%	124%	87%	74%	75%	117%	109%	179%	157%	114%	100%	98%
Western Isles, Orkney & Shetland	mm	113	85	114	124	96	76	73	73	99	192	184	190	1419	712	540
	%	78%	86%	96%	159%	137%	104%	85%	73%	72%	125%	121%	127%	104%	87%	99%

Evaporation & 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 that would occur from a continuous vegetative cover amply supplied with moisture. Temperature, particularly during the late spring and summer, is the primary influence on evaporative demands, but windspeed, sunshine hours, humidity and patterns of land use are all contributory factors. By comparison with rainfall, evaporation losses exhibit very muted spatial variability but do follow 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 and the creation of what is termed a soil moisture deficit (SMD). Eventually, the ability of plants to transpire 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 they take to restrict transpiration under such conditions. Thus in the absence of favourable soil moisture conditions actual evaporation (AE) rates will fall below 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 re-commence. 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 2006 relies, in large part, on monthly figures derived using the Met Office Rainfall and Evaporation Calculation System (MORECS)[2].

Temperatures and evaporation losses

2006 was the warmest year in the Central England Temperature Series[3,4] which begins in 1659. February and March were a little colder than average but July, September and October were exceptionally warm (relative to the monthly average), and the annual mean temperature was around 1.1°C above the 1971-2000 average. With sunshine hours also above average, especially in northern parts of the UK, weather conditions were conducive to high evaporative demands in most regions. For Great Britain as a whole, PE losses were the 5th highest in the MORECS series (which begins in 1961) with totals exceeding 650 mm across much of the south of the country (Figure 5). Correspondingly, potential evaporation demands exceeded the long-term average across most of the UK with anomalies exceeding 20% in a few areas (see Figure 6). The spatial distribution of summer rainfall contributed to substantial regional, and more local, variations in AE totals (Figure 7) but, nationally, losses were around 550 mm – the 7th highest on record. Below average annual AE losses were confined to a few areas only (e.g. Cornwall and parts of the central Scottish Highlands). By contrast, annual AE totals were notably above average in parts of eastern England, the Lake District and south-west Scotland (see Figure 8).

Figure 9 shows the variation in monthly PE losses (black trace) and AE losses (red trace) for six representative MORECS squares in Great Britain (see Figure 9a). As is normally the case in the wettest parts of the country, monthly AE losses remained very close to their PE equivalents throughout 2006 (see, for example, the plot for MORECS square 55). In the drier areas however, AE losses began to fall below PE totals in the late spring and, with transpiration rates declining steadily, July AE losses were only around half the modelled PE totals in a few eastern areas (e.g. the lower Trent basin). On an annual basis, the shortfall of AE relative to PE (given in Figure 9) was above average across most of the English Lowlands but substantially lower than in 2003 – when sustained hot and dry conditions extended across much of the UK for most of the summer and early autumn.

Soil Moisture Deficits

The development and decay of soil moisture deficits over the 2002-2006 period is illustrated by the cyan shading in Figure 7 – 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 2006 but the very limited rainfall over the November 2005 – February 2006 period allowed significant SMDs to be carried through the winter in parts of eastern, central and southern England (see, for example, the plot for Square 108). Soil moisture variations through the spring and early summer may be generally characterised as: brisk increases in SMDs during April, near-stable soil moisture conditions through the wet May (with deficits declining in some southern areas) and, thence, a steep and more sustained rise in SMDs during June.

In many areas, 2006 maximum SMDs occurred during the mid-summer period, somewhat earlier than is normally the case in much of eastern England. At the end of July 2006, soils were substantially drier than average (for the time of year) across most of the country; deficits exceeded 100 mm across almost all of England & Wales (Figure 10) and, relative to the late-July average, were

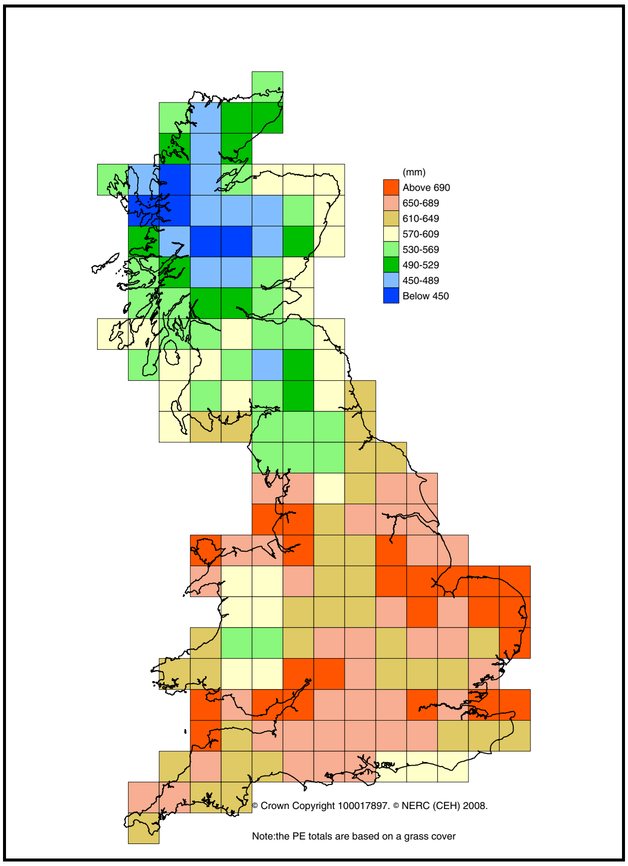

Figure 5 Potential Evaporation totals for 2006
Data source: MORECS

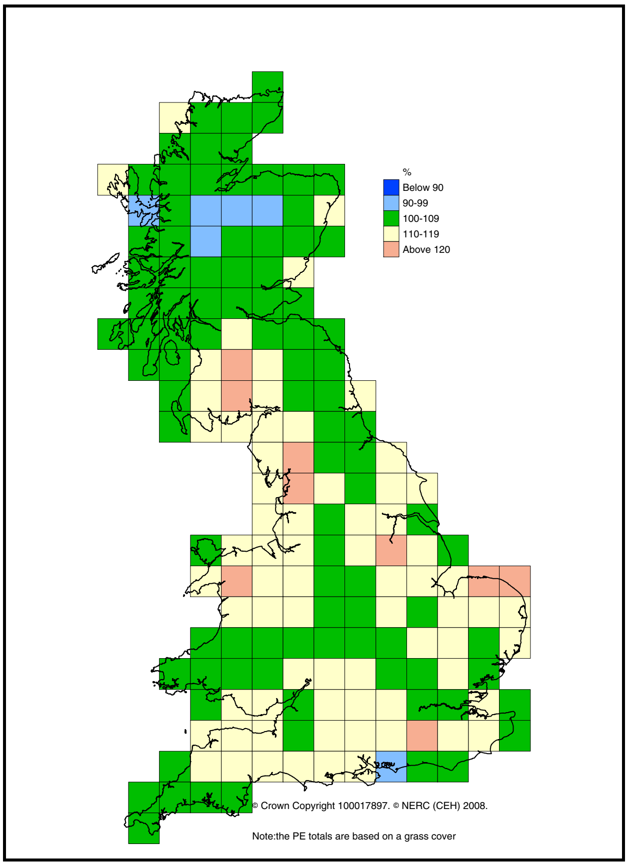

Figure 6 Potential Evaporation totals for 2006 as a percentage of the 1961-90 average. Data source: MORECS

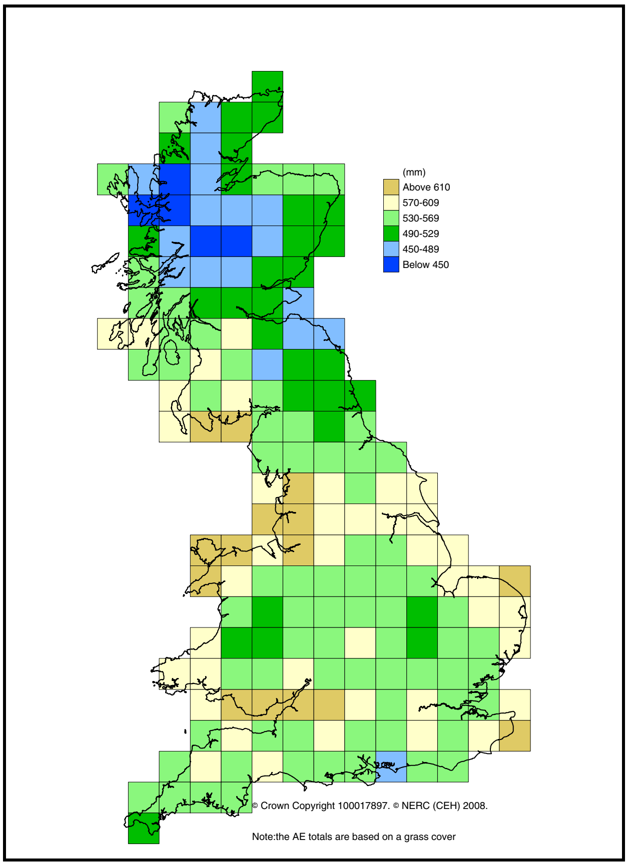

Figure 7 Actual Evaporation totals for 2006
Data source: MORECS

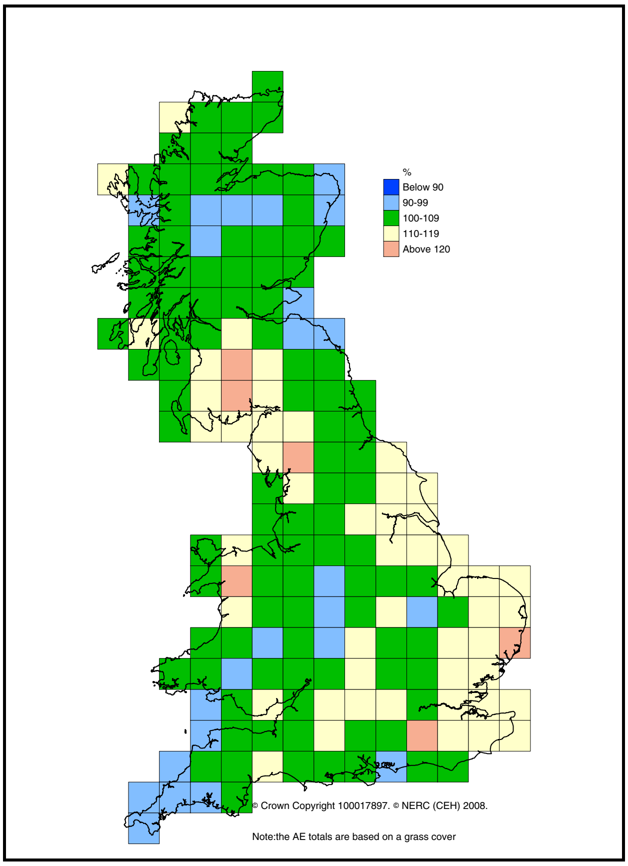

Figure 8 Actual Evaporation totals for 2006 as a percentage of the 1961-90 average. Data source: MORECS

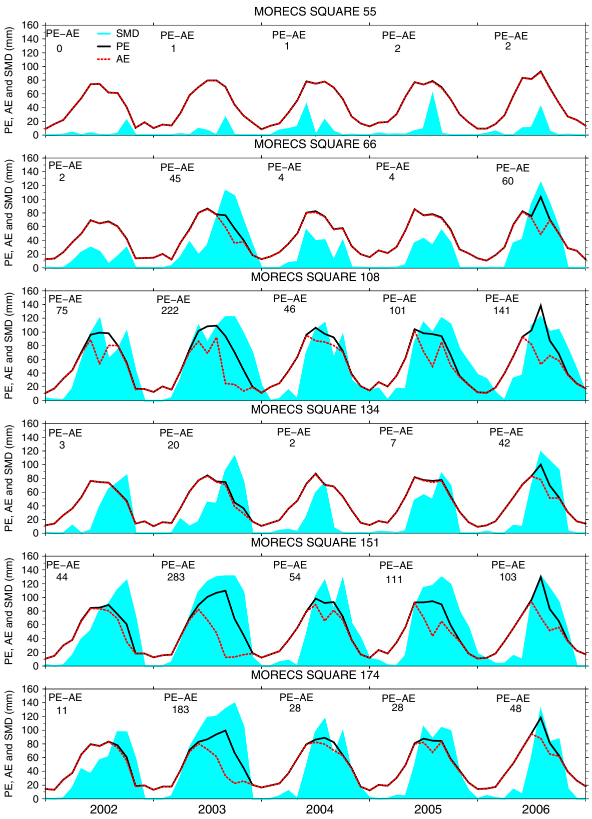

Figure 9 The variation in Potential Evaporation, Actual Evaporation and SMDs for six MORECS squares

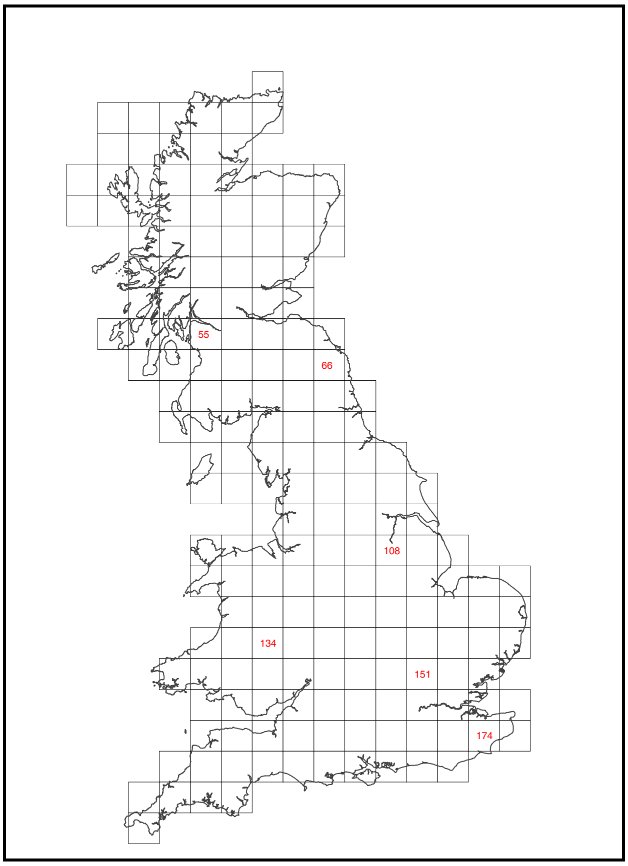

Figure 9a *The location of the MORECS squares featured in Figure 9*

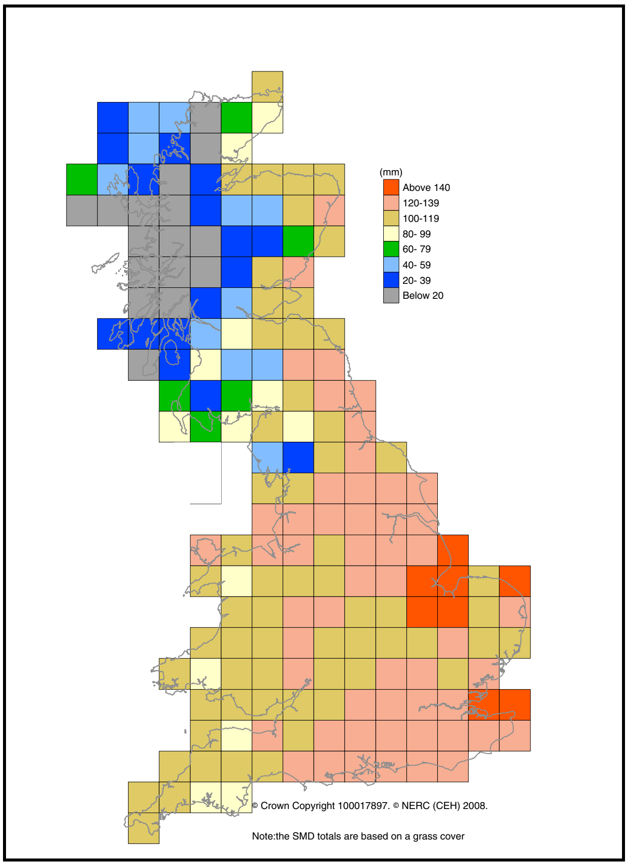

Figure10 Soil moisture Deficits at the end of July 2006
Data source: MORECS

particularly high in parts of the South West, Wales and northern England. In contrast, soils were considerably wetter than average in large parts of western Scotland. August saw SMDs decline across much of England, an exception was the South West where soils remained notably dry. Elsewhere, late-September soil moisture conditions were typical of the early autumn and, thereafter, the sustained wet weather saw deficits decline rapidly. Soils in most areas were close to saturation at year end but there were a few important exceptions in eastern England (e.g. in the lower Trent basin and inland from the Wash). However, the total area with appreciable deficits carried over into 2007 was considerably lower than in an average year.

River flows

Overview of 2006 runoff

Outflows from the UK were below average throughout much of 2006 but, largely due to abundant runoff in the autumn, the annual runoff total was very close to the long-term mean. This typical annual outflow at the national scale disguises substantial regional variability. Runoff from Scotland was appreciably above average for the third successive year whilst Northern Ireland added a further year to a cluster with below average runoff totals. England & Wales, where drought conditions extended into the late summer, registered below average runoff but appreciably exceeded the total for 2005 – when exceptionally low annual runoff totals were registered in several regions.

At river basin scale, annual runoff variations in 2006 were very notable. In broad terms, a modest exaggeration in the normal north-west/south-east runoff gradient across the UK can be recognised (Figure 11). In northern and much of western Britain, runoff totals generally exceeded the average, notably so in western Scotland. By contrast, most rivers in the English Lowlands (the South West also) reported very moderate runoff; the Medway and Kenwyn registered their 2nd lowest annual mean flow in records of around 40 years. Differing rainfall patterns and catchment geology also combined to produce notable within-region contrasts. In the Thames basin for example, the 2006 mean flow for the River Mole, which drains a largely impermeable catchment, exceeded the long-term average whilst the Mimram, which is sustained primarily by groundwater outflows from the Chalk, registered its lowest annual runoff in a record from 1952.

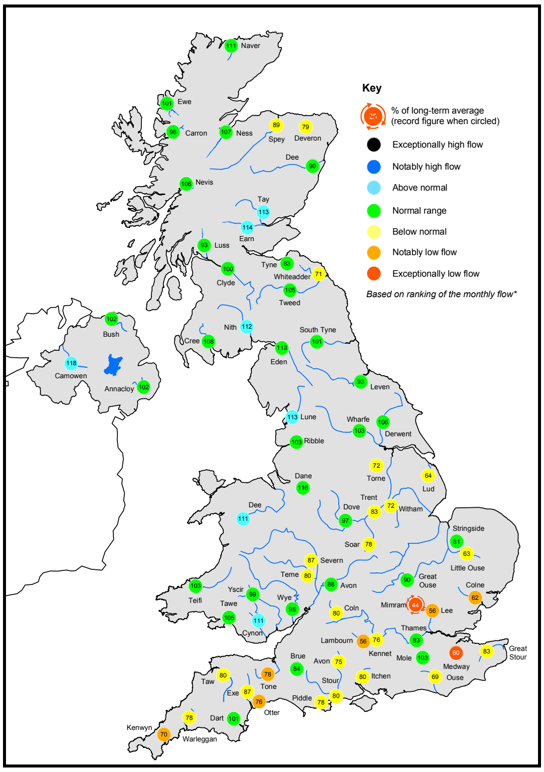

Figure 11 2006 runoff as a percentage of the preceding average

River flow patterns

Figure 12 shows 2004-2006 hydrographs representing the total outflows from Great Britain, England & 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 national scale runoff patterns. 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 serves to give greater prominence to low flow episodes. Daily maximum and minimum flows for the preceding record are also shown – represented by the blue and pink envelopes. The hydrograph for Northern Ireland reflects, in part, the controlled flow releases from Lough Neagh into the Lower Bann (the flow in which constitutes more than a third of the total runoff from the province).

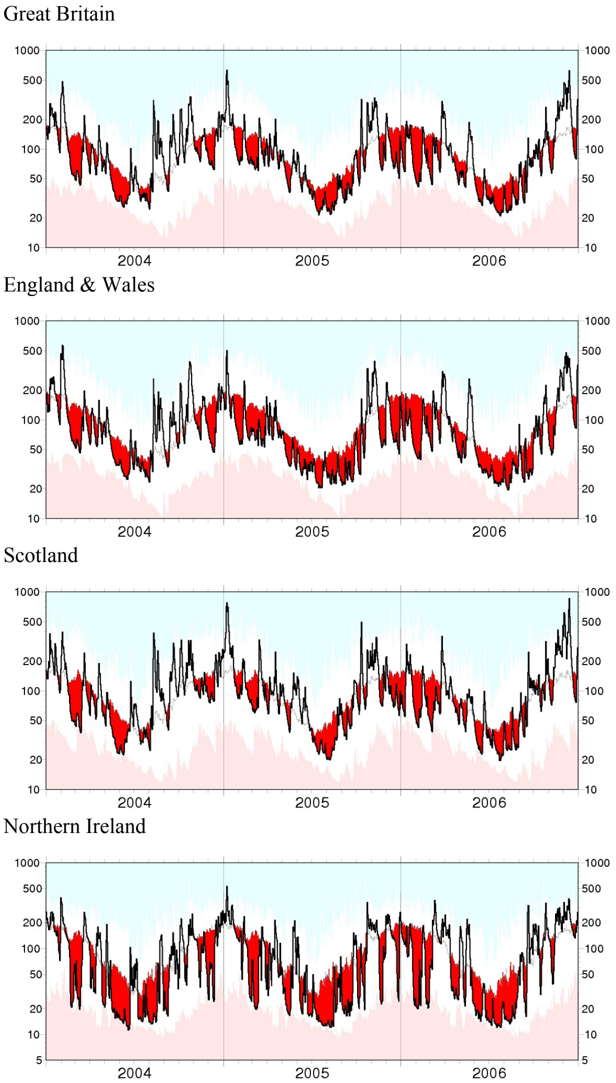

Figure 12 2004-2006 daily flow hydrographs

The hydrographs show that, bar the brief wet episodes in March and May, the year up to October was generally characterised by a continuation of the below average outflows which had prevailed since the autumn 2004. Runoff deficiencies were particularly notable over the late autumn and winter of 2005/06. November-February outflows from Northern Ireland were the lowest on record (in a series from 1981) whilst the December-March runoff from Scotland was the 2nd lowest since 1973; England & Wales reported its lowest winter (December-February) runoff for 30 years.

In hydrological terms, the main features of the 2006 runoff patterns were the predominance of low flows through the summer and early autumn and the low frequency of notable flood events, although spate conditions were very common over the October-December period. The temporal variability of river flows during 2006 largely reflects a transition from seasonally depressed late winter (2005/06) flows to notably high runoff rates in late 2006, in November particularly.

Limited runoff over the first half of 2006 across southern Britain increased long-term runoff deficiencies, prolonging a drought that extended back to the autumn of 2004 (and longer in some areas). Figure 13 shows catchment runoff totals for the November 2004-July 2006 period, expressed as a percentage of the average, for a network of index catchments across the UK. The drought's focus on the South East is clearly evident. For the Thames, runoff over the featured period was the 2nd lowest (after 1990-92) in more than 50 years and new period-of-record minimum runoff totals (in the featured timeframe) were established in a significant minority of southern catchments. Figure 14 confirms that by mid-summer catchment runoff totals were depressed across a substantial proportion of the UK.

A more detailed breakdown of flow patterns during 2006 is provided by Figure 15 which shows annual hydrographs for 16 index rivers across the UK. The long-term daily maximum and minimum flow envelopes (for the preceding record) are also shown. Generally, drought conditions were better indexed by medium- and long-term runoff deficiencies but notably low flows were widely recorded in the summer of 2006 (e.g. in western Scotland) and, to the south, flows approached long-term minima in several catchments (e.g. the Severn and the Taw). Whilst in the majority of index rivers, daily flows remained within the extreme envelopes throughout the year, the overall range of flows recorded was substantial.

Flow regime characteristics

Sustained low flows were a feature of the flow regime in many, mostly southern and eastern, rivers. Drought flows were especially persistent in spring-fed rivers and streams in southern and eastern England. With isolated exceptions, flows remained depressed throughout the year (e.g. in the Mimram) and, entering 2007, monthly flows had remained below average since the spring of 2003 in some small spring-fed rivers and streams (e.g. the Ewelme Brook, Oxfordshire). The depressed flows were accompanied by a substantial contraction in the river network and an associated temporary loss of aquatic habitat[5].

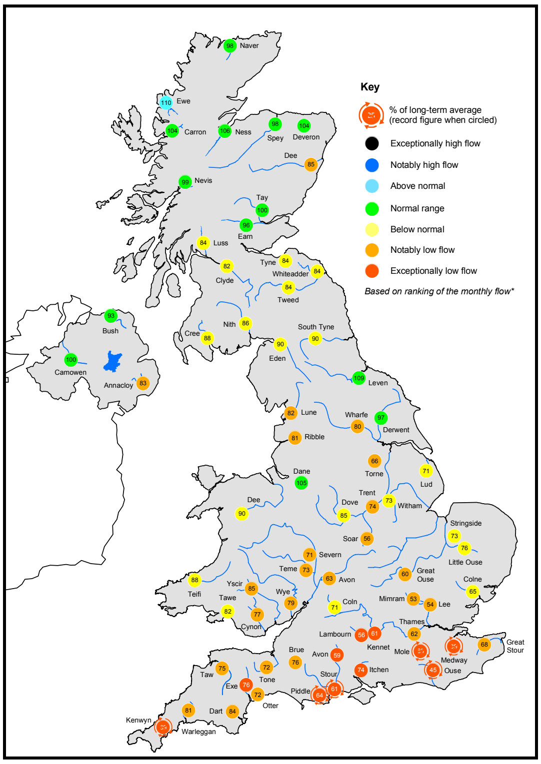

Figure 13 November 2004 – July 2006 catchment runoff totals as a percentage of the previous average

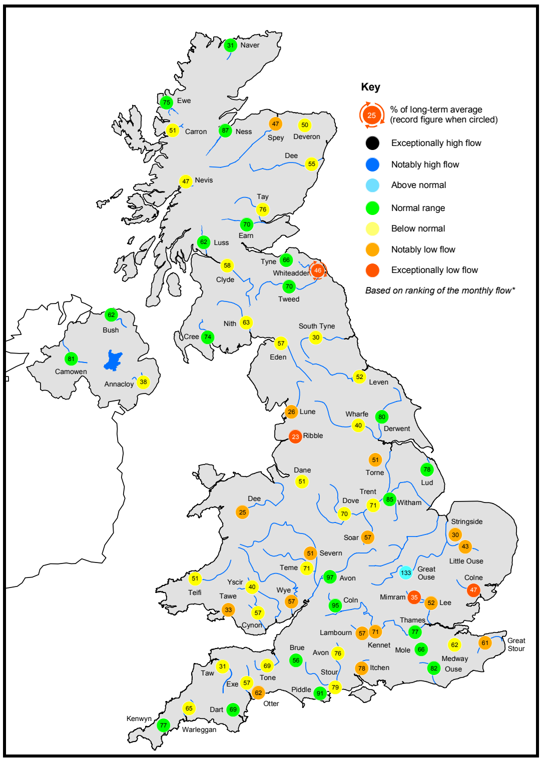

Figure 14 July 2006 runoff as a percentage of the previous monthly average

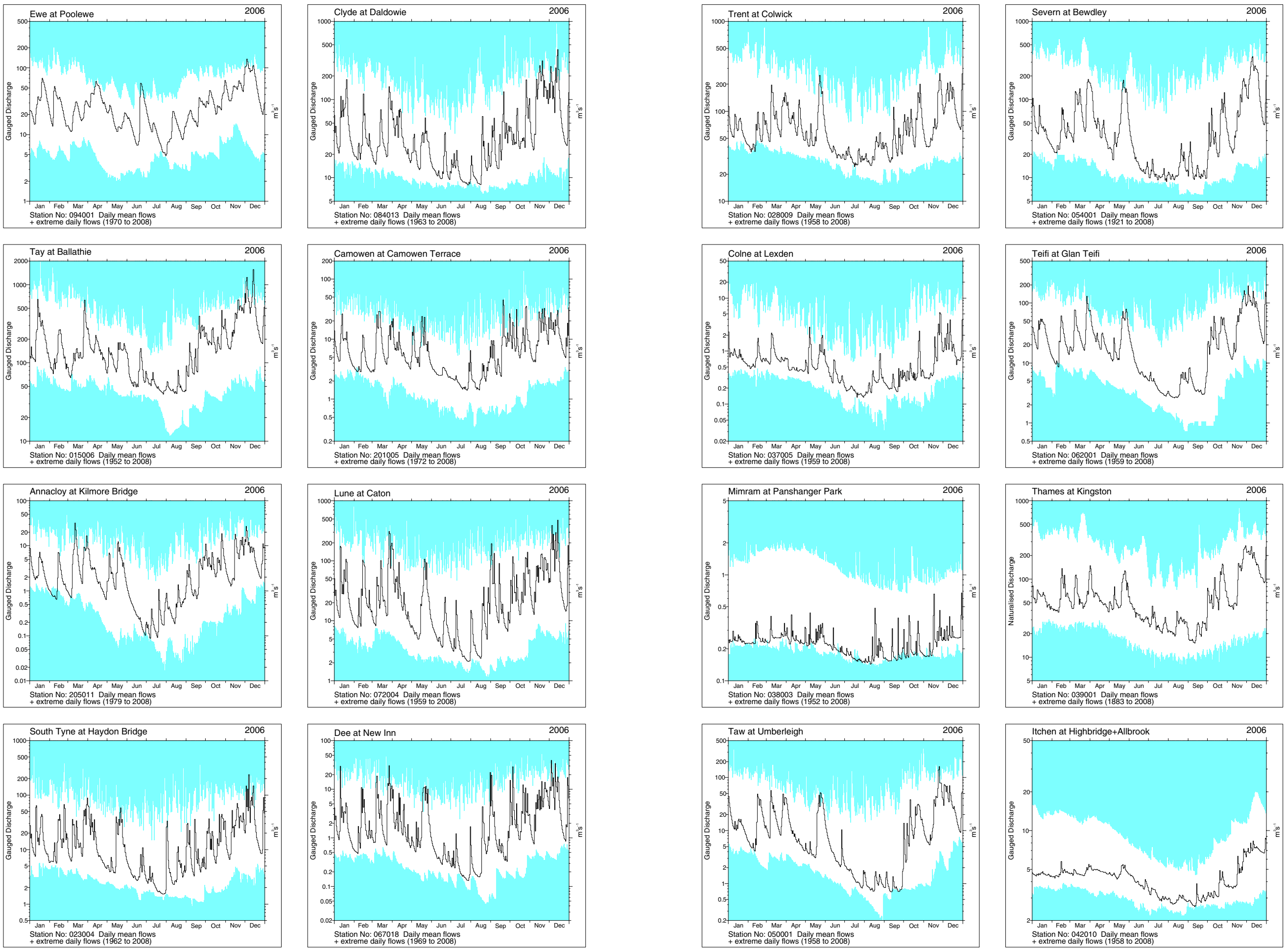

Figure 15 2006 daily flow hydrographs for a selection of UK index catchments

A brisk recovery in runoff rates during the autumn marked the cessation of drought flows in impermeable catchments across the South East. Significant late autumn and early winter rainfall also resulted in some exceptionally high flows in several northern rivers. In Scotland, the Naver exceeded its previous maximum flow (in a 30-year record) on the 26th October and new monthly flow maxima were established on, for example, the Tay and Ness in December. In southern Britain, late-autumn and early-winter spates were common, but mostly modest in relation to seasonal maximum flows.

Flow duration curves allow the proportion of time that river flows are above, or below, any given threshold to be identified and provide a means of comparing the flow regime during a particular year with that for the preceding record. The 2006 'national' duration curves featured in Figure 16 are broadly similar to those for the preceding record. However for England & Wales and, more so, Northern Ireland the curves confirm the preponderance of below average flows in all but the extreme flow ranges whilst for Scotland as a whole, the frequency of high spate conditions over the October-December runoff is evident in the high flow range of the duration curve

Figure 17 shows a set of flow duration curves for a selection of index rivers across the UK; the blue trace relates to 2006 and the black trace to the preceding record. For a significant minority (including the Clyde, Annacloy and South Tyne) the 2006 flow regime closely matches that of the preceding record. By contrast, the 2006 flow duration curves for most rivers depart markedly from their long- term equivalents. Given normal hydrological variability, such circumstances are not unusual but the departures achieved an extreme expression in a few southern rivers and streams dependant primarily on groundwater outflows. In the Mimram, the flow exceeded 90% of the time (Q90) during the 1952-2005 period was exceeded for only around 15% of the time in 2006. This reflects the characteristically slow recovery of such rivers following protracted drought conditions. In more responsive catchments, flows exceeded 95% of the time in 2006 were generally similar to, or greater than, those for the preceding record.

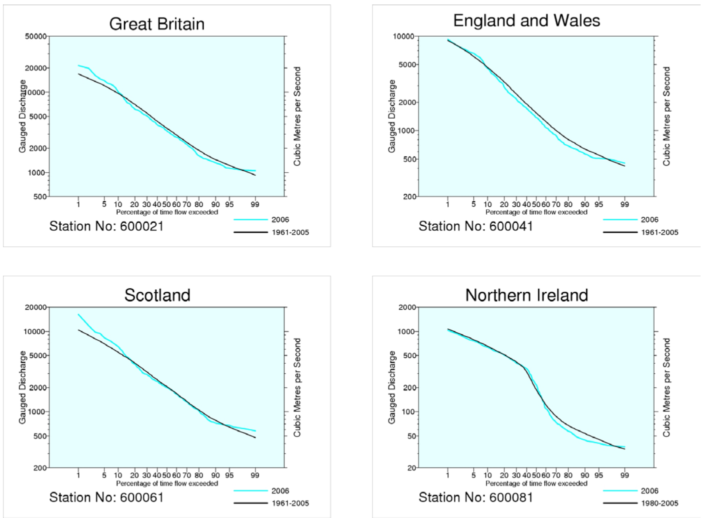

Figure 16 Flow duration curves ('national')

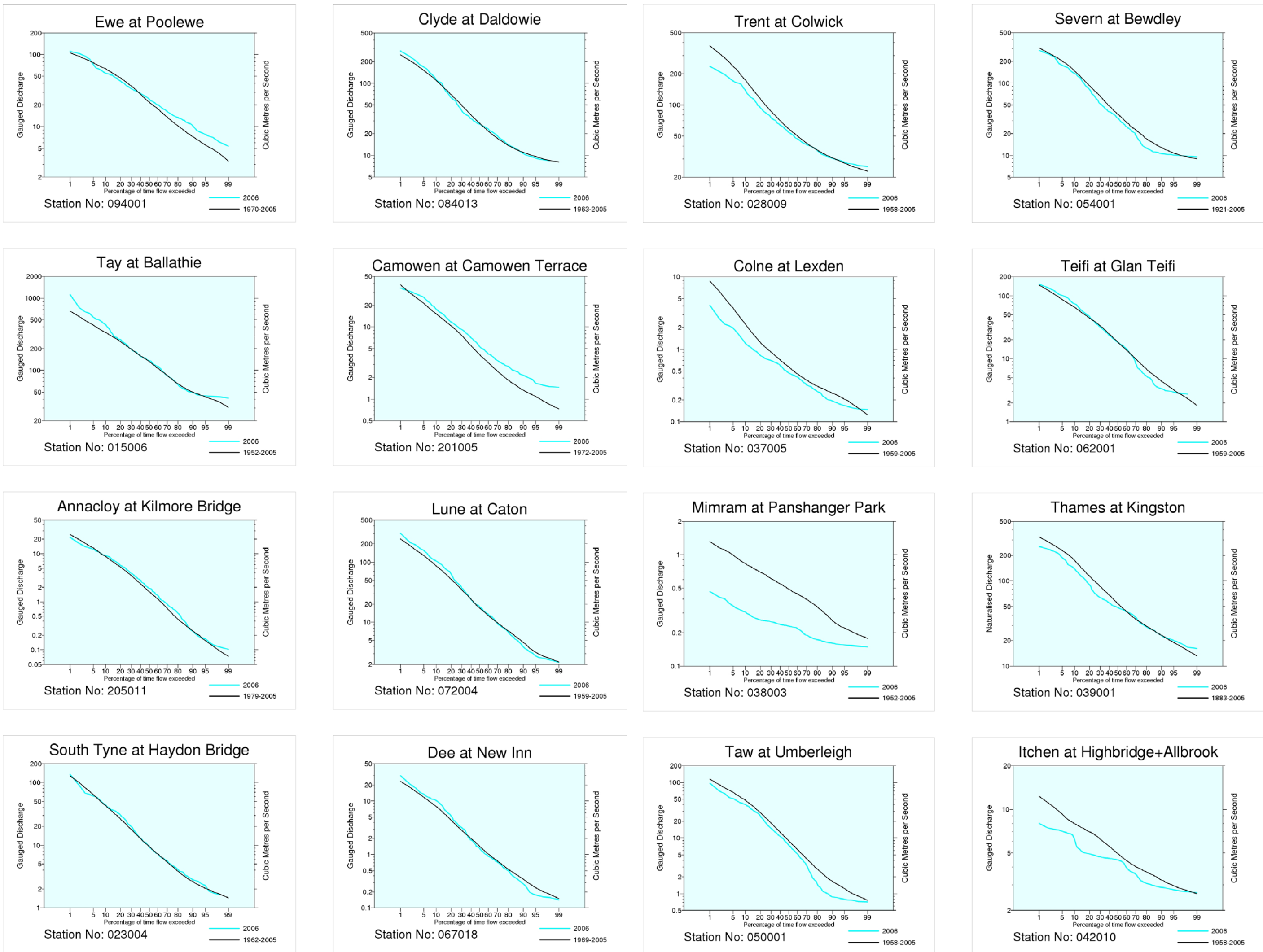

Figure 17 flow durations curves (index catchments)

Groundwater

Background

Most major aquifer outcrop areas (see the Location Map) are in the drier parts of the UK – predominantly 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 most important aquifer. The Permo-Triassic sandstones are also regionally important, especially in the Midlands and North-West. 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 500 mm to less than 100 mm 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 in the drier, eastern outcrop areas. Annual recharge variations thus tend to be much greater than those for rainfall.

The year in brief

Figure 18 shows groundwater level hydrographs for a selection of index wells 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 4-year period is featured because groundwater levels in many areas reflect recharge over a number of winter/spring periods.

Following very meagre recharge over the 2004/05 winter, and a seasonally late onset of groundwater replenishment in the autumn of 2005, groundwater levels entering 2006 were well below average in most major aquifer outcrop areas. Seasonally very moderate recharge rates then typified both January and February. Correspondingly, notably low groundwater levels characterised many outcrop areas during the late winter of 2005/06 (Figure 19 shows the ranking of the February levels and the colour coding indicates departures from the normal range). In some Chalk wells and boreholes, the very moderate groundwater replenishment through the winter served to extend a protracted period of declining groundwater levels (relative to the seasonal mean) which began in early 2004 – see, for example, the hydrographs for Stonor and Washpit Farm. Similarly, in the Permo-Triassic sandstones, the hydrographs for Heathlanes and Weeford Flats show medium-term declines from the above average levels recorded in 2002. The declining levels in the Chalk and Permo-Triassic sandstones are a direct reflection of the very low rainfall totals received in major outcrop areas in successive winter half-years.

A dry April in 2006 signalled the end of the recharge season in some eastern outcrop areas. Elsewhere, sustained May rainfall resulted in a modest but important late pulse of aquifer replenishment – arresting, or locally reversing, the seasonal decline in groundwater levels at a time when recessions are often firmly established (see, for example, the hydrograph for Chilgrove). June saw a more general termination of recharge and below average summer rainfall, together with seasonally above average soil moisture deficits, ensured that groundwater level recessions continued into the autumn. In responsive aquifer units, minimum groundwater levels for 2006 were commonly recorded in September, typically these were below the early September average but above drought minima. However, water tables continued to decline in many of the less responsive aquifer units, resulting in very depressed groundwater levels in a few areas such as parts of the eastern Chalk (see the hydrograph for the Redlands well) and the Permo-Triassic sandstones in the Midlands (see Figure 20).

In some quicker-responding aquifer units, seasonal recoveries in groundwater levels began in September (e.g. at Alstonfield in the Carboniferous Limestone) and levels in most major outcrops were rising very briskly by the late autumn of 2006. Across most outcrop areas, the October-December period was notably wet; rainfall over the Thames basin was the 3rd highest in 25 years. Following a wet late summer and early autumn, this rainfall generated abundant infiltration but large differences in response times (reflecting the storage characteristics of the individual aquifer units and the depth to the water table) are evident in the status of groundwater resources at year end. By December, levels in most boreholes in the Chalk of Dorset, Hampshire and the south eastern counties had returned to above the monthly average, notably so in some western outcrops (e.g. Ashton Farm and Rockley). By contrast, in the Chalk of the Chilterns and East Anglia, groundwater levels remained below average, and relatively depressed in some deep, and slow-responding wells and boreholes (see the hydrograph for Therfield for example). Year-end groundwater levels were well within the normal range across most limestone and Permo-Triassic sandstones outcrops but spatial variability was considerable and levels remained depressed in a few areas (e.g. in some slow-responding wells and boreholes in the Midlands – see the hydrograph for Heathlanes). Nonetheless, entering 2007, the groundwater resources outlook was generally healthy, and markedly better than the overall position 12 months previously.

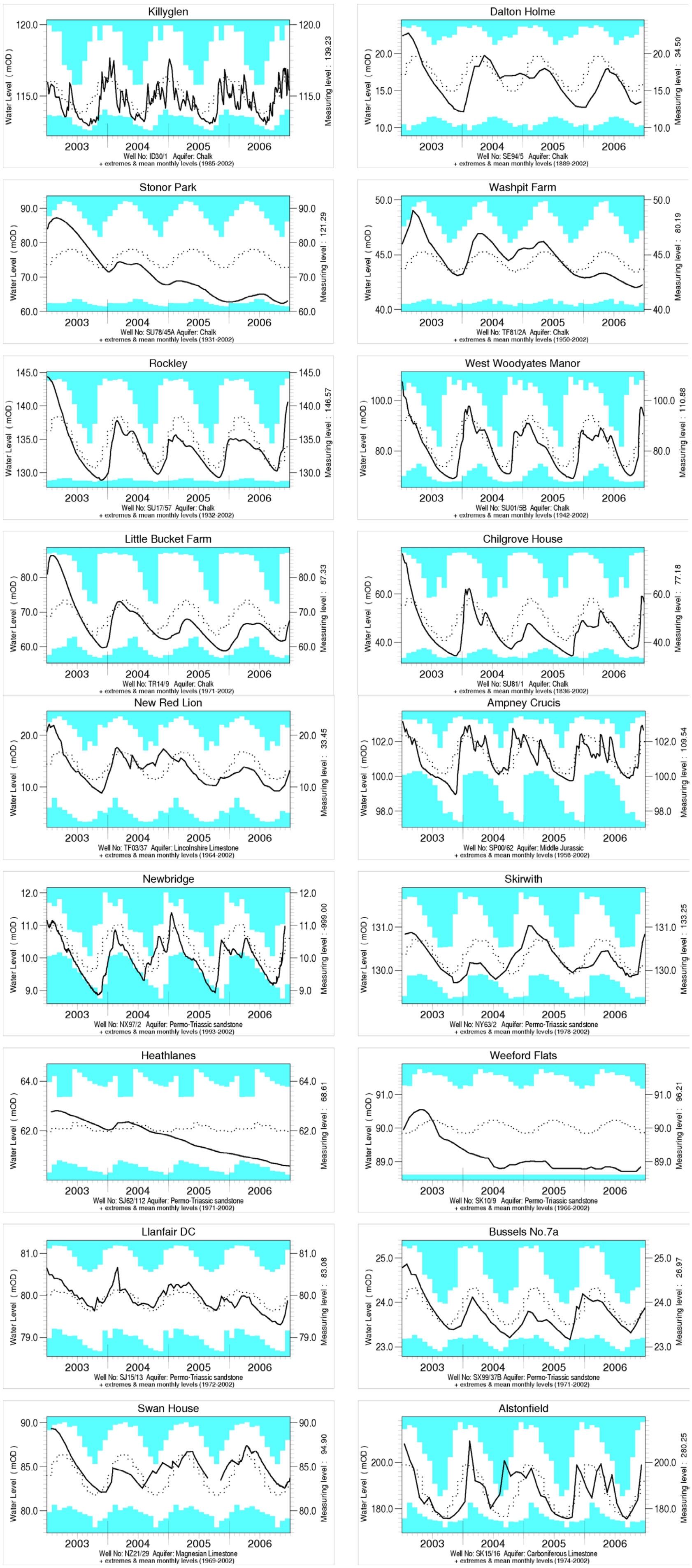

Figure 18 2003-2006 groundwater level hydrographs

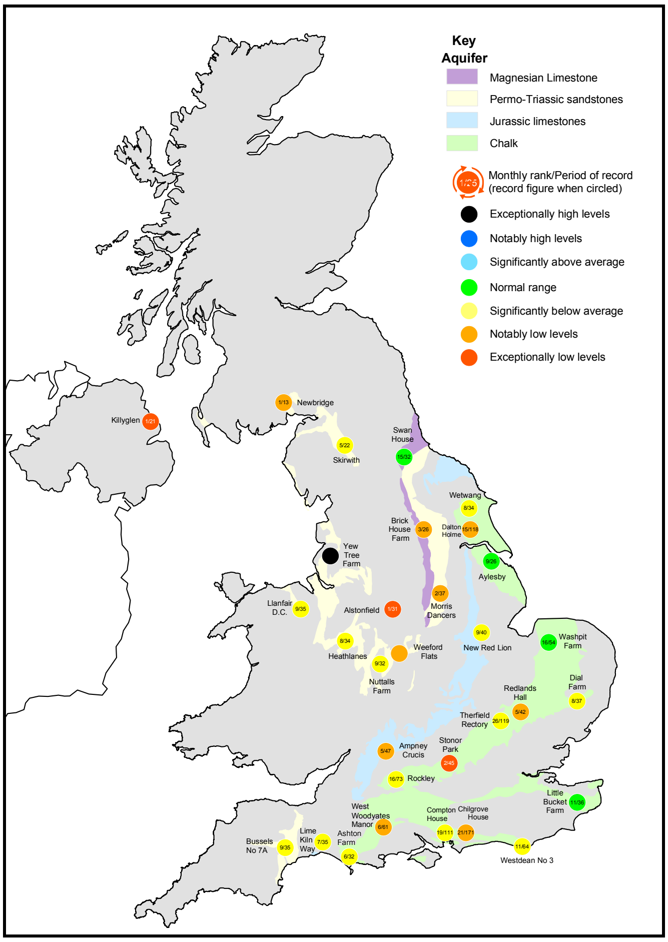

Figure 19 Groundwater levels in February 2006

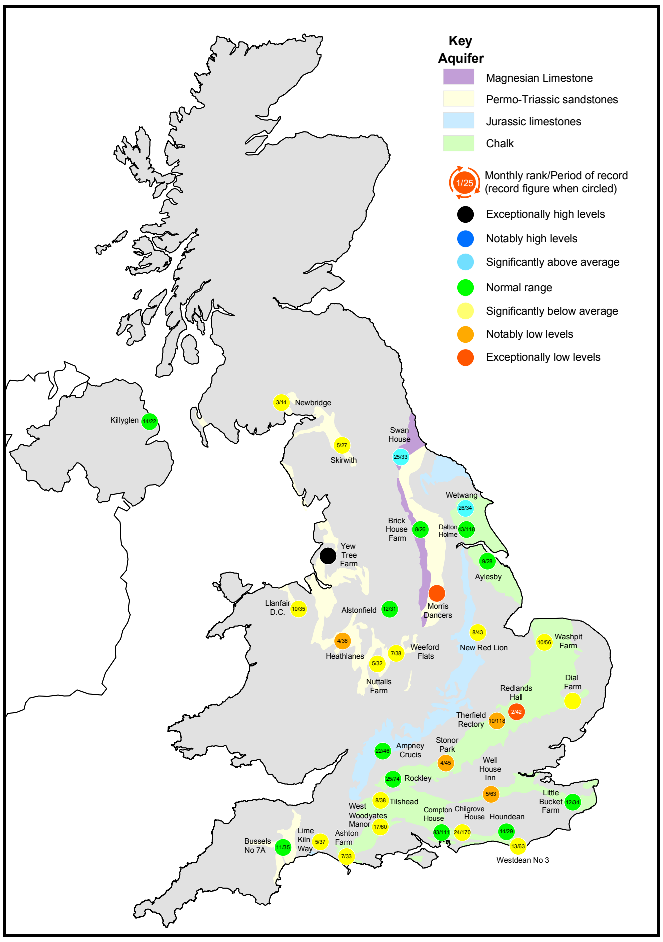

Figure 20 Groundwater levels in September 2006

The impact of long-term groundwater abstraction

The majority of observation wells and boreholes for which data are held on the National Groundwater Level Archive monitor natural variations in levels. However, in several parts of the UK groundwater levels have been influenced by pumping for water supply or other purposes, sometimes over very long periods. 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 some conurbations. Declining abstraction rates is normally the primary cause but 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 however, much reduced abstraction rates have resulted in a recovery of around 40 metres with levels rising by 1-2 metres a year through much of the 1980s and 1990s (see Figure 21). 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.

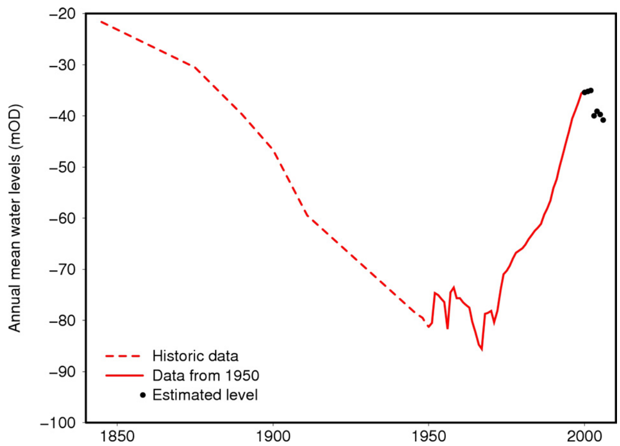

Figure 21 Groundwater levels at Trafalgar Square 1840-2006

Reservoir Stocks

Reservoir stocks in many parts of the UK have shown wide departures from the seasonal average during the early years of the 21st century. Overall stocks for England & Wales were exceptionally healthy throughout the 1999-2002 period but drought conditions then saw stocks decline steeply in the spring and summer of 2003. Subsequently, overall stocks generally remained within the normal seasonal range (see Figure 22) although, regional, and more local, variations in reservoir stocks were particularly notable during both 2005 and 2006.

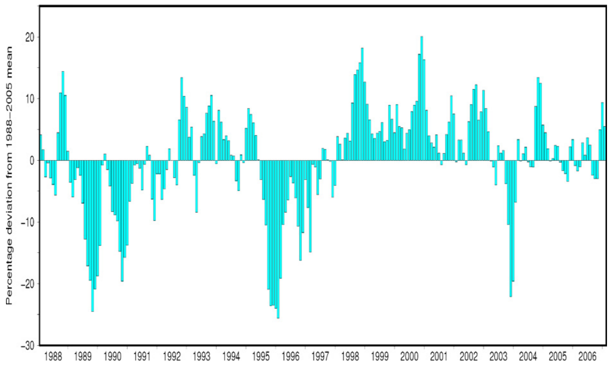

Figure 22 A guide to England & Wales reservoir stocks, 1988-2006 Data sources: Water Service Companies and EA

Entering 2006, reservoir stocks were typically above average across most of Scotland and Northern Ireland, and overall reservoir stocks for England & Wales were very close to the early January average. Importantly however, stocks were depressed in parts of southern England, for example, turn-of-the-year stocks for Bewl Water Reservoir were the lowest on record. Relative to the monthly average, reservoir replenishment during January and February was meagre across much of the country. Nonetheless, overall stocks for England & Wales were still only around 2% below average at the end of the 2005/06 winter (see Figure 23) and well above corresponding stocks in both 1997 and 1992. Seasonally depressed stocks did, however, continue to characterise some southern reservoirs – with a number (including Ardingly, Colliford and Bewl Water) registering their lowest early March levels on record.

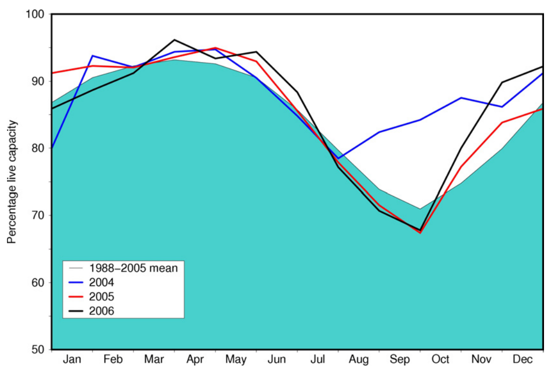

Figure 23 Variation in overall reservoir stocks for England & Wales Data sources: Water Service Companies and EA

March is often a pivotal month in relation to the water resources outlook for the summer and the erratic reservoir replenishment through the preceding winter meant that in 2006, the volume of early spring replenishment would be particularly influential in many southern reservoirs. Whilst sustained March rainfall left overall stocks for England & Wales at their highest (for early April) since 1999, the drought's continuing regional focus was again emphasised by the very moderate storage in a few reservoirs in the South-East. The fragility of the water resources outlook in the drought-affected regions was underlined during a very dry April which triggered further extensions in water-use restrictions that affected around 13 million consumers by the late spring. Fortunately, England & Wales registered its wettest May for 27 years and, despite increasing evaporation losses, reservoir levels generally increased, leaving overall stocks for England & Wales as a whole around 4% above average at month-end.

Helped in some cases by drought mitigation measures (e.g. reduced compensation flows and constrained water demand), early June stocks for most index reservoirs were a little above the early summer average but still seasonally low in a few south-western impoundments. England & Wales then registered its 2nd lowest June rainfall in 30 years and open water evaporation losses were exceptionally high. Correspondingly, reservoir stocks declined appreciably (particularly in Wales) but even in parts of the South-West most reservoirs – although well below average – reported higher stocks than at the corresponding time in 2005. In some, mostly southern, areas surface water sources continued to be preferentially exploited to help protect depleted groundwater resources. This, together with well below average July rainfall, notable evaporation losses and, in some areas, increased water demand contributed to a notable 17% decline in overall reservoir stocks. By early August overall stocks for England & Wales were at their lowest (for the late summer) for a decade but levels in almost all index reservoirs remained appreciably above late-summer minima.

Although August was a wet month across much of southern Britain, reservoir replenishment was meagre (as is usually the case in late summer) and stocks continued to decline. Minimum reservoir stocks during 2006 were generally reported around late September (a relatively common circumstance in northern and western reservoirs). Scotland and Northern Ireland apart, most index reservoirs registered below average stocks for the early autumn, but considerably above drought minima. An exception was Colliford (Devon) which reported its lowest early October level in a 19-year series. The high frequency of vigorous Atlantic frontal systems through the late autumn, when most gathering grounds were close to saturation, helped ensure that November reservoir stocks in 2006 were substantially healthier than in 2005 in most of the drought-affected areas apart from the South West. Further sustained rainfall maintained the recoveries in reservoir stocks and, entering December, overall stocks for England & Wales were around 10% above average. Despite drawdown for flood alleviation purposes in some headwater catchments, reservoir stocks generally remained considerably above average through December. At year-end, only Colliford, of the national index reservoirs, registered stocks of >10% below the monthly average and, entering 2007 overall stocks for England & Wales were around 5% above the early January average.

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Location Map