UK Hydrological Review 2007

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

2007

UK HYDROLOGICAL REVIEW

This hydrological review, which also provides an overview of water resources status throughout 2007, 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 & 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], the Scottish Environment Protection Agency and, in the Northern Ireland, the Rivers Agency. These organisations provided the great majority of the required river 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) (1). Financial support for the production of the Hydrological Summaries is provided by the Environment Agency, the Scottish Environment Protection Agency, the Rivers Agency (Northern Ireland) and the Office of Water Services (OFWAT).

Authors

This report was compiled by: Jamie Hannaford, Felicity Sanderson, and Simon Parry

Note: Necessarily, a significant proportion of this report considers the unprecedented flooding in the summer of 2007. An NHMP publication entitled 'The summer 2007 floods in England & Wales – a hydrological appraisal' (2) and written by Terry Marsh and Jamie Hannaford was released in the months immediately following these events. Whilst much of that report underpins what is written in this review, details and data may have changed as a result of a more comprehensive evaluation.

Cover photo

Tewkesbury Abbey 24 July 2007

Publication Address

Centre for Ecology & Hydrology
Maclean Building
Benson Lane
Crowmarsh Gifford
Wallingford
Oxfordshire OX10 8BB UK
General and business enquiries: 01491 692562
E-mail: nrfa@ceh.ac.uk

[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 & Wales.

CONTENTS

UK Hydrological Review of 2007

2007 Summary

2007 was a very wet year, but the most noteworthy characteristic of the rainfall was its highly irregular and unusual distribution throughout the year. The October 2006-March 2007 period was relatively wet, and terminated the drought conditions which had prevailed in southern and eastern areas since 2004. In stark contrast, April was a very warm and exceptionally dry month – the 4th driest since 1914, and the driest on record in some areas – resulting in late-April soil moisture deficits which were the highest on record in many areas of Great Britain. The defining characteristic of the year, in rainfall terms, was the exceptionally wet summer. The summer half-year (April-September) was the wettest since 1968, although the May-July period was even more exceptional (the wettest on record for England & Wales). An abnormally southerly position of the Jet Stream brought a succession of moisture-laden low pressure systems, which also ensured prolonged downpours which triggered widespread flooding. The unprecedented summer rainfall brought a substantially elevated risk of further flooding entering the autumn. However, another sharp turnaround in weather conditions occurred; the early autumn was notably dry (with many regions experiencing half the normal September-October rainfall). This served to moderate the risk entering the winter, and the year ended with average rainfall over the November and December period.

As a result of the exceptional summer rainfall, there was no substantial water resource stress throughout 2007. The dry period from mid-March to April triggered a decline in reservoir levels, but the May-July rainfall brought about a recovery (very unusual for this time of year). Late summer reservoir stocks were at a 20-year maximum, before declining substantially during the dry autumn. Normal replenishment occurred in November and December, so reservoir stocks were generally very healthy entering 2008. Similarly, levels in most index boreholes were rarely below average through the year, so from a groundwater perspective, the focus of concern was generally on groundwater flood risk rather than water resources stress. Groundwater levels were generally high through the winter of 2006/7 and into early spring; the decline associated with the dry April was very minor compared to the locally spectacular increases seen as a result of early recharge following the summer rainfall. Notably high late summer levels were observed in many index boreholes, which raised the prospect of groundwater flooding in vulnerable localities entering the autumn. However, the very dry late-summer/autumn alleviated this threat.

Consistent with the rainfall pattern, overall runoff for 2007 was well above average – the annual outflow from England & Wales ranks 4th in a series from 1961 – but the summer runoff was truly exceptional, England & Wales registering a May-July runoff total equivalent to three times the long-term average. Whilst the rainfall during this period was prolonged, the most significant falls were associated with three major flood events, all of which affected wide geographical areas: focused primarily on northern England in mid-June and late June, and in central England in mid-July. These devastating flood events were some of the most severe of recent times, associated with several fatalities and bringing widespread disruption, and significant losses to property and infrastructure. The associated summer runoff was remarkable in terms of its magnitude, but a defining characteristic of the event was its spatial extent. New period-of-record maximum flows were established for a range of rivers across England & Wales, ranging from small headwater streams to lower reaches of the largest rivers. Correspondingly, new catchment runoff totals were established for June and July across the length of the UK, and the summer high flow envelopes were redefined for many rivers.

Overview of the recent past

This section places the hydrological conditions of 2007 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. Severe

Table 1 2007 rainfall in mm and as a % of the 1971-2000[a] average — Data source: Met Office

2007		J	F	M	A	M	J	J	A	S	O	N	D	Year	Oct-Mar 2006/07	Apr-Sep 2007
United Kingdom	mm	153	110	89	27	114	136	135	86	67	65	101	114	1197	822	565
	%	131	131	96	40	180	196	204	107	69	58	88	95	110	128	128
England and Wales	mm	111	101	63	13	110	149	136	57	51	47	73	100	1010	632	516
	%	120	154	87	21	191	231	247	82	65	52	80	101	113	124	134
England	mm	96	94	56	11	107	146	125	54	44	45	70	86	934	558	487
	%	116	160	86	19	196	237	240	84	61	55	86	97	114	122	135
Scotland	mm	240	132	140	54	129	109	134	138	100	101	157	142	1575	1211	663
	%	145	112	106	67	177	138	155	139	75	65	99	88	109	136	121
Wales	mm	203	146	104	25	129	168	205	76	92	61	93	184	1485	1098	694
	%	133	133	90	31	169	205	278	75	78	42	61	112	108	131	131
Northern Ireland	mm	129	87	81	29	71	148	131	105	58	57	87	112	1095	692	542
	%	108	101	87	41	105	209	176	115	61	49	79	95	99	108	115
North West	mm	166	90	77	37	94	167	162	81	96	63	97	164	1293	862	636
	%	137	105	77	56	141	213	207	85	93	50	78	125	110	125	131
Northumbrian	mm	105	76	43	15	68	161	111	48	47	30	73	90	869	516	451
	%	128	130	63	26	116	266	194	68	68	40	88	105	105	113	120
Severn Trent	mm	90	86	56	9	111	176	155	37	38	35	61	78	934	507	526
	%	122	159	95	17	207	283	315	59	56	50	86	98	123	124	151
Yorkshire	mm	111	82	43	9	77	218	116	41	49	30	69	88	933	518	510
	%	136	142	63	16	141	347	219	63	72	39	88	98	115	115	141
Anglian	mm	62	63	40	2	115	123	91	49	33	50	40	45	713	350	414
	%	116	169	88	4	250	227	202	96	60	87	71	81	118	114	139
Thames	mm	77	90	51	2	119	93	126	50	28	53	73	61	824	503	418
	%	113	192	95	5	222	166	292	92	43	75	110	85	118	133	130
Southern	mm	75	109	55	2	95	106	110	56	32	43	82	65	830	559	401
	%	91	205	92	4	192	190	247	105	45	48	98	74	106	123	123
Wessex	mm	100	110	64	7	124	111	127	61	38	51	91	98	982	642	469
	%	108	163	93	13	222	185	273	92	50	58	105	96	113	127	130
South West	mm	134	201	97	19	152	153	141	84	53	51	92	152	1329	917	602
	%	95	191	101	27	222	211	229	102	53	40	70	101	110	122	132
Welsh	mm	188	142	102	24	128	166	201	75	86	60	91	173	1437	1047	680
	%	129	136	93	31	172	207	282	76	76	42	62	110	109	130	132
Highland	mm	333	142	190	74	170	87	147	172	136	136	209	179	1977	1551	786
	%	166	97	117	80	218	97	155	157	86	75	104	90	115	142	126
North East	mm	105	108	79	25	111	120	137	105	64	38	152	85	1129	690	562
	%	108	163	102	39	177	182	207	151	73	38	153	93	119	130	135
Tay	mm	200	147	122	35	108	128	145	108	48	64	123	103	1331	1115	572
	%	128	137	102	52	147	186	197	130	43	48	94	73	105	141	119
Forth	mm	195	121	91	29	92	117	130	117	59	72	106	102	1229	968	542
	%	154	134	88	46	138	169	182	143	56	61	93	82	109	143	119
Clyde	mm	294	144	165	72	131	121	121	149	122	138	158	168	1783	1459	716
	%	146	101	103	80	166	136	112	118	74	73	85	86	103	135	109
Tweed	mm	134	87	78	13	96	146	135	84	58	42	86	102	1059	705	531
	%	133	124	97	21	146	224	209	113	72	44	92	98	111	130	129
Solway	mm	185	130	120	41	95	157	120	135	81	81	125	159	1428	1103	629
	%	119	115	98	51	126	199	139	127	65	52	84	99	101	129	114
Western Isles, Orkney and Shetland	mm	228	134	127	76	121	33	117	152	130	126	140	134	1519	1058	629
	%	141	115	97	97	196	47	144	161	97	82	84	85	108	119	121

a The 1971-2000 averages are the mean of monthly, half-yearly and annual averages stored on the National River Flow Archive (and supplied by the Met Office) for the 30-year standard period. They may differ slightly from averages derived using different analytical procedures.

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 (with drought conditions terminating in the autumn of 2006 in most areas). By contrast, annual rainfall totals for these two years were notably high across much of Scotland.

Rainfall

Annual Rainfall

In 2007 much of the UK experienced extraordinary precipitation patterns – in both spatial and temporal terms (see Table 1 and Figure 1). Most regions registered well above average annual rainfall totals and, at the national scale, the May-July period was the wettest on record with remarkable rainfall totals characterising large parts of England.

The UK rainfall total for 2007 was 10% greater than the 1971-2000 average. Whilst it might be expected that this figure may shroud complex spatial variability, precipitation in this year was notable in terms of the significant areal extent over which above average rainfall was received. Whilst precipitation in the Northumbrian, Solway, Clyde and Northern Ireland regions was broadly in agreement with their respective long-term averages, every other UK region received

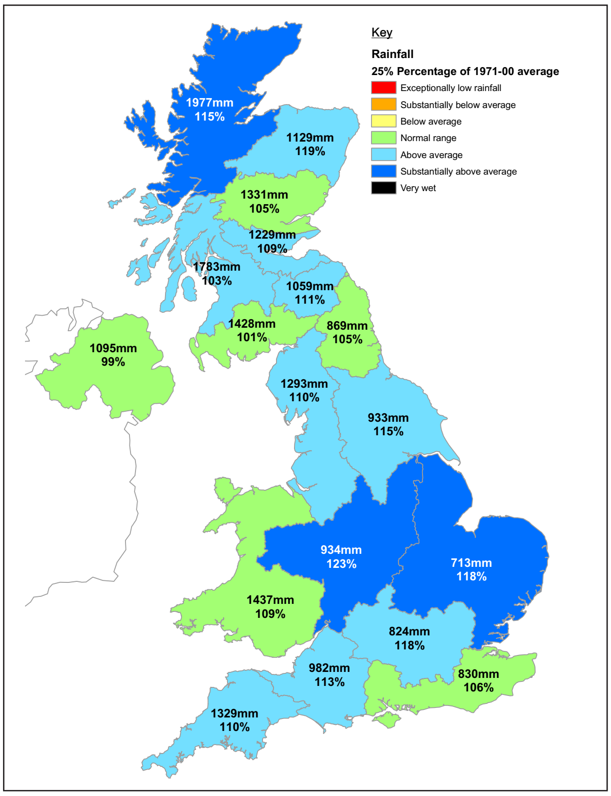

Figure 1 *2007 annual rainfall totals in mm and as a % of the 1971-2000 average.* Data source: Met Office

rainfall exceeding their averages, Severn Trent by more than a fifth (20%). In terms of absolute rainfall totals, precipitation maxima of over 5000mm were experienced in the Highlands of Scotland, with minima of less than 600mm close to the Thames Estuary. Neither the order-of-magnitude difference between these areas nor the associated and inherent northwest-southeast annual precipitation gradient are particularly unusual.

The year in brief

Whilst 2007 as a whole was notable for the relative spatial homogeneity of the annual rainfall anomalies, there were significant temporal variations in precipitation anomalies. Half-year rainfall totals, despite being substantially above the long-term average across most regions and nationally, were not unprecedented, although the summer of 2007 (April-September) was the wettest since 1968. Although less significant statistically, the wet October-March half-year of 2006-07 was certainly noteworthy in a water resources context (see Figure 2). Following the previous two dry winters, it served to terminate a prolonged drought which began in 2004. However, such six-month totals shroud the

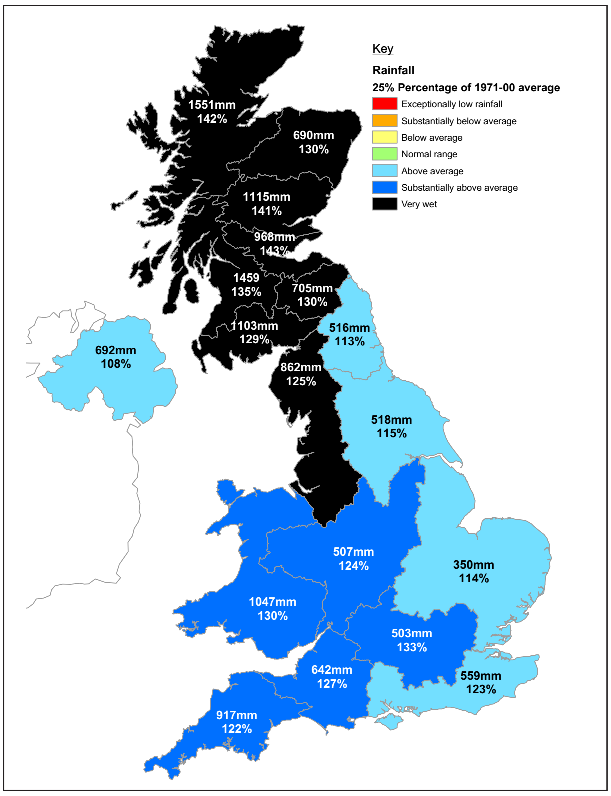

Figure 2 *October 2006 - March 2007 rainfall totals in mm and as a % of the 1971-2000 average.*
Data source: Met Office

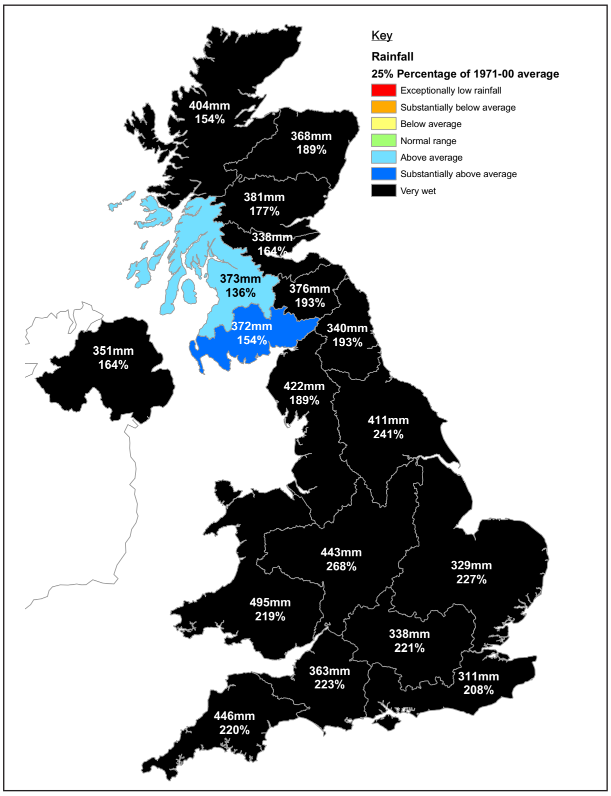

Figure 3 *May-July 2007 rainfall totals in mm and as a % of the 1971-2000 average.*
Data source: Met Office

complexity observed in the temporal variations in precipitation during 2007. Almost the entire country reported above average precipitation in January and February 2007; there have been only six wetter starts to the year in a 94-year series[a]. Rainfall deficiencies began to build in the second week of March and April was an exceptionally dry month. Nationally, April 2007 was the 4th driest in a record from 1914, and it was also the warmest April on record. Only one region in England & Wales experienced greater than half of the 1971-2000 average precipitation for April. The dry spell was especially severe in the English Lowlands; the Anglian, Southern and Thames regions all recording their driest April on record. Yorkshire experienced its driest April since 1938, and 2nd driest April on record.

The prolonged arid episode triggered significant falls in reservoir stocks but concern about the water resources outlook was soon negated by what, in many respects, proved to be unprecedented early summer rainfall patterns. Synoptic patterns shifted abruptly in the second week of May and were largely responsible for the extraordinary precipitation patterns that followed. An unseasonal southerly shift in the Jet Stream, brought a succession of moisture-laden low pressure systems across the Atlantic, depositing extreme rainfall totals (over a wide range of durations) over much of England & Wales. Intense, short-duration storms characterised much of the summer, but the most severe hydrological repercussions were the product of unrelenting heavy precipitation over 10-36 hour periods, often associated with the unusually slow passage of frontal systems. Whilst daily precipitation totals exceeding the monthly average are not that unusual in summer, their frequency and spatial extent in 2007 were extraordinary, resulting in exceptional rainfall over the May-July period (see Figure 3).

The high frequency of intense rainfall events contributed to the wettest May-July period on record for England & Wales, the previous maximum being exceeded by a wide margin (see Table 2). Eight wetter three-month periods (non-overlapping) have been recorded in the winter half-year over the last 100 years but May-July 2007 ranks amongst the wettest three-month periods on record for the summer half-year for England & Wales (see Table 3).

[a] Unless otherwise stated, all national and regional climatological comparisons are based on the corresponding National Climate Information Centre (Met Office) series.

New maximum May-July rainfall totals were established for each of the regions in England & Wales (see Table 4). In addition, significant proportions of the average (1971-2000) annual rainfall were received in this May-July period for all regions, exceeding 50% for the Severn Trent and Anglian regions (see Table 4).

For the UK, May 2007 was the 2nd wettest for 72 years, with many areas reporting more than twice the average monthly rainfall. Such rainfall accumulations were, in part, the product of convective cells incorporated within active frontal systems. Two distinct extremely wet periods could be identified – during mid-month and the 27/28th. These episodes did much to replenish the severely depleted soil moisture levels resulting from the dry early spring. This

Table 2 *Table of maximum May-July rainfall accumulations in a series back to 1766.*

Rank	Year	May-July rainfall accumulation (mm)	% of 1971-2000 average May-July rainfall
1	2007	395	223
2	1789	349	197
3	1879	341	192
4	1828	330	186
5	1782	329	186
6	1797	324	183
7	1830	323	182
8	1766	319	180
9	1768	317	179
10	1860	315	178

Table 3 *Table of maximum three-month rainfall accumulations that fall entirely within the summer half-year (April-September) in a series back to 1766.*

Rank	Period	Year	Rainfall accumulation (mm)	% of 1971-2000 average rainfall for the 3-month period
1	Jul-Sep	1799	487	240
2	Jul-Sep	1775	431	212
3	Jul-Sep	1829	420	207
4	Jul-Sep	1782	411	203
5=	Jun-Aug	1879	409	216
5=	Jun-Aug	1912	409	216
7	Jun-Aug	1829	396	209
8	May-Jul	2007	395	223
9	Jul- Sep	1927	390	192

Table 4 *Table of May-July rainfall accumulations for regions of the UK, relative to their long-term averages (1971-2000), their May-July ranks, and their proportion of the long-term average annual precipitation.*

Region	May-July rainfall accumulation (mm) [previous maximum]	% of 1971-2000 average May-July rainfall	Rank in a series from 1914	May-July rainfall as a % of average (1971-2000) annual rainfall
Northern Ireland	350	164	4=	31.5
North West	423 [387]	190	1	36.0
Northumbrian	341 [325]	193	1	41.0
Severn Trent	443 [293]	268	1	58.4
Yorkshire	411 [297]	241	1	50.5
Anglian	329 [255]	226	1	54.6
Thames	337 [288]	220	1	48.1
Southern	312 [254]	208	1	39.9
Wessex	362 [300]	222	1	41.8
South West	444 [357]	219	1	36.8
Welsh	494 [405]	219	1	37.3
Highland	403	154	3	23.5
North East	368 [359]	189	1	38.8
Tay	380	176	4	30.0
Forth	340	165	6	30.0
Clyde	373	136	12	21.5
Tweed	377 [354]	193	1	39.5
Solway	373	155	6	26.5
Islands	271	128	13	19.3

had important flood risk implications through the ensuing summer.

The Jet Stream remained in an abnormal southerly position into June, and a succession of low pressure systems tracked slowly over central parts of the UK. Supplemented by convective storms, these conditions made June 2007 the wettest June for England & Wales since 1860, and third wettest in a series from 1766 [(3)]. Most regions reported more than 200% of the monthly average rainfall, with a maximum of 350% in Yorkshire, where Sheffield recorded its wettest month on record in a 125-year series. Exceptional localised rainfall episodes occurred sporadically throughout the month; Bangor, Northern Ireland received 20mm in 15mins on 12th, whilst Manston, Kent and Maidenhead, Berkshire were inundated with 50 mm in an hour on 19th. The most intense storm events, and hence the most severe impacts, occurred in two episodes during June; on 14/15th and 24/25th. Whilst an extensive spatial coverage characterised both June events, they also featured significant local variations in rainfall intensity, a response to the occurrence of thunderstorms.

During the former event, a band of heavy precipitation extending across the Midlands to the northeast was responsible for significant flooding around mid-month. Yorkshire was particularly badly affected, with extreme rainfall totals recorded from Sheffield to Ripon on the14/15th; 58.8mm (79.8mm) fell in 12 (24) hours at Harley whilst Lumley Moor received 70.8mm and 96.2mm over 12- and 24-hour periods respectively. This episode left many catchments very vulnerable to any further heavy rainfall.

Arriving just ten days later, another slowly rotating cyclonic weather system with limited lateral movement generated extraordinary precipitation totals from Worcestershire to the North Yorks Moors. Sheffield and other parts of northern England were once again deluged on the 24/25th, but eastern parts of Yorkshire bore the brunt of the most extreme rainfall. At Winestead (east of Hull) a 135mm storm total was recorded, with 100mm falling in a 12-hour period. The former figure represents 20% of the average annual rainfall (and 44% when summed across the June 13-25th period); this storm has an estimated return period of more than 200 years. With the exception of the slightly wetter July 1936, July 2007 was the wettest since 1888 for England & Wales. Whilst precipitation was unrelenting throughout much of the month the most hydrologically significant totals occurred across the 19/20th.

In the third week of July, an unusually slow, moisture-laden airmass moving north across the English Channel became near-stationary over central England, generating extreme rainfall accumulations over periods of 10-20 hours. The Cotswolds, the lower sections of the Warwickshire Avon basin and West Berkshire were most seriously affected; Pershore College (Hereford and Worcestershire) received >10mm of precipitation for six consecutive hours from midday on 20th, accumulating over 16 hours to 134.8mm. Such rainfall totals have a estimated return period of 1000 years[2]. A number of areas, such as Newbury, reported more than 100mm in less than 24 hours, with Langley (Gloucs) receiving 110mm in 12 hours. On the 20th, East Shefford recorded 110.6mm, more than double the amount ever previously recorded in a day. The 19/20th storm generated extraordinary precipitation totals across more than 30,000km^2 of England & Wales, with 3,500km^2 reporting more than 100mm. Similar to the June episodes, there was substantial local variation in intensity of rainfall attributed to the occurrence of embedded convective cells. For example, a very active convective cell produced 51mm in 63 mins in Maidenhead on the 20th. These variations had important implications for the severity of the ensuing floods.

Whilst August remained very wet in Scotland, with all regions receiving significantly above average rainfall, England & Wales witnessed some respite from the extremely wet conditions; Yorkshire and Severn Trent, the two worst affected regions through June and July, received 60% and 57% of their 1971-2000 averages, respectively. Overall, for England & Wales, 2007 was the wettest summer since 1912, and the 11th wettest in a series from 1766.

September and October provided further welcome relief from precipitation; September featured an extended dry spell and the UK received just over half of the 1971-2000

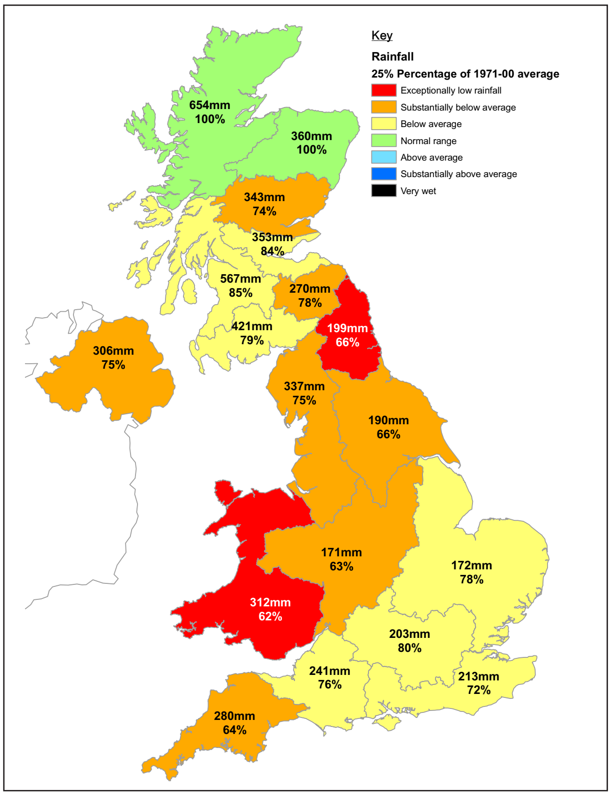

Figure 4 *August-November 2007 rainfall totals in mm and as a % of the 1971-2000 average.*
Data source: Met Office

average, with many regions experiencing less than 50%. Overall, the weather was notably dry (see Figure 4). This relatively dry episode was important in moderating the risk of both fluvial and groundwater flood risk. Average precipitation conditions characterised November and December, and rainfall totals were dwarfed by the unprecedented summer conditions. Northern Ireland witnessed its driest autumn since 1972, and its 6th driest autumn in a 94-year series.

Evaporation and Soil Moisture Deficits

Background

On average, over 40% of UK rainfall is accounted for by evaporative losses – but the proportion varies greatly from region to region, reaching around 80% in the driest parts of the English Lowlands. Evaporation may occur directly from open water surfaces, from the soil or as transpiration from plants. Potential evaporation (PE) is the maximum evaporation that would occur from a continuous vegetative cover amply supplied with moisture. Temperatures, particularly during the late spring and summer, are the primary influences on evaporative demands, but windspeed, sunshine hours, humidity and patterns of land use are all contributory factors. 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 profile 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 the corresponding PE rates, appreciably so during dry summers. When plant activity and evaporation rates slacken in the autumn, rainfall wets-up the soil profile once more – allowing runoff rates to increase and infiltration to groundwater to re- commence. Knowledge of the soil moisture status and evaporation rates is therefore essential for understanding water resource variability.

The following commentary on evaporative patterns and soil moisture deficits during 2007 relies, in large part, on monthly figures derived using the Met Office Rainfall and Evaporation Calculation System (MORECS) [(4)].

Temperatures and evaporation losses

The generally warm conditions in 2007 resulted in typical annual potential evaporation losses across the UK. In contrast, actual evaporation losses were exceptionally high – reflecting the very limited period during which transpiration rates were constrained during the summer months.

The Met Office's National Climate Information Centre (NCIC) regional temperature and sunshine assessments show that the first six months of 2007 were warmer than the 1971-2000 average throughout the UK but July and August were cooler than normal in most areas, September to

December were also warmer than average in all regions. Between October 2006 - March 2007, the UK registered its second highest sunshine hours total, after 2003, in a record from 1929. Generally the first four months of 2007 were sunnier than average (March & April considerably so), May-July were duller (Northern Ireland excepted) and for the rest of the year sunshine levels in England & Wales were above the 1971-2000 average whilst in Scotland and Northern Ireland they were generally lower.

The 2007 annual average temperature was 0.7°C above the 1971-2000 mean, ranking it as the 10th warmest year on record in the Central England Temperature (CET)[5] series from 1659. 2007 was, on average, about 0.35°C cooler than 2006, which recorded the highest annual average temperature on record. More notably, ten of the 15 warmest years occur after 1988. In temperature terms, January and April were exceptional. The former was the 5th warmest January in the CET series and the warmest since 1921 whilst the latter was the warmest April in the entire 349-year series. The 2006-2007 winter half year was also the warmest on record.

Annual total PE losses were well within the normal range with few areas registering totals more than 10% outside the 1971-2000 average (Figure 5b). Due to the wet, dull and cool nature of the 2007 summer, the annual PE total was much lower than in 2006; annual totals exceeded 650 mms in a few coastal regions, mainly in the South West, East Anglia and in the North West. The rankings of annual PE indicate overall very average conditions throughout the regions as a result of the counterbalancing effect of the high winter PE and subsequent low summer values.

Although in some areas there were many problems associated with the wet summer, i.e. waterlogged soils and damaged crops, the plentiful rainfall over the summer months and above average temperatures in the spring and autumn produced conditions which were generally conducive to plant growth and thus notably high transpiration losses. For England & Wales the AE loss for 2007 (approx. 590 mm) ranks second highest in the 47-year MORECS record, only 2004 showed marginally higher AE totals. For Great Britain as a whole, 2007 ranks third highest in the MORECS series, behind 2004 and 1999. In 2007, annual AE totals were below average in some upland areas but exceptionally high in parts of the English Lowlands, especially near the east and south coasts.

The generally mild winter and warm spring had a marked effect on half-year evaporation losses. This is confirmed by Table 5, which shows the rankings of PE and AE for Great Britain, Scotland and England & Wales for various periods. The annual PE totals for 2007 are not notable however the accumulated evaporation total over the winter 6-months (October 2006-March 2007) was the highest in that timeframe for Great Britain in a record from 1961. Conversely, the gloomy conditions in June and a duller and cooler July contributed to lower PE losses, which, for the summer 6-months in 2007 rank 20th in a 47-year record for England & Wales. In contrast the annual AE total for Great Britain ranks 3rd highest after 2004 & 1999. Analysis of the AEs confirms the outstanding evaporation losses over the winter 6-months for Great Britain and England & Wales. In the April-September timeframe, since transpiration was, in some areas, only constrained in the first and last months, the accumulated AE was the 2nd highest on record (after 2004) for England & Wales, summer AEs in Great Britain (moderated by Scotland) were only exceeded in 2004 and 1992.

Table 5 *Showing the rankings of PE and AE accumulations in a record from 1961, rank 1= highest total.* Data Source: MORECS.

	Jan-Dec 07		Oct 06-Mar 07		Apr-Sep 07	
	PE	AE	PE	AE	PE	AE
GB	20	3	1	1	24	3
SCOT	23	19	3	3	28	23
EW	19	2	2	1	20	2

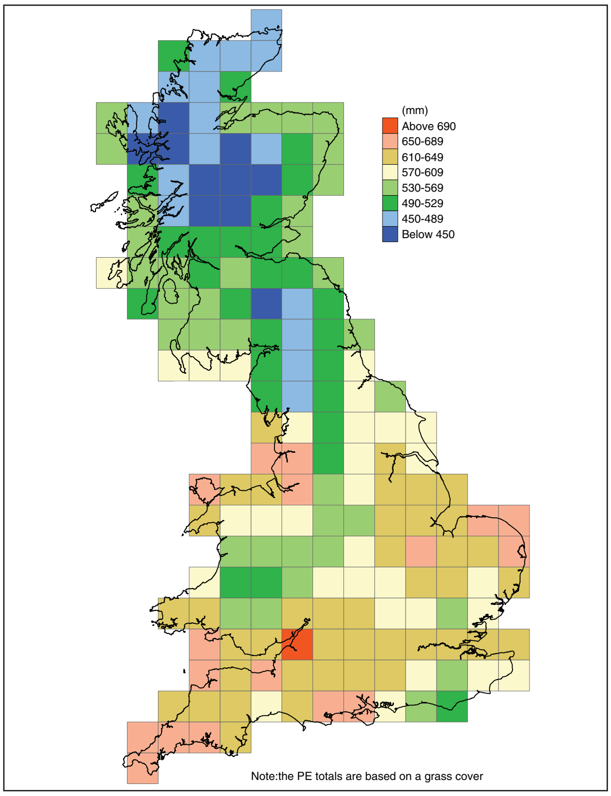

Figure 5 a) *Potential Evaporation totals for 2007.*

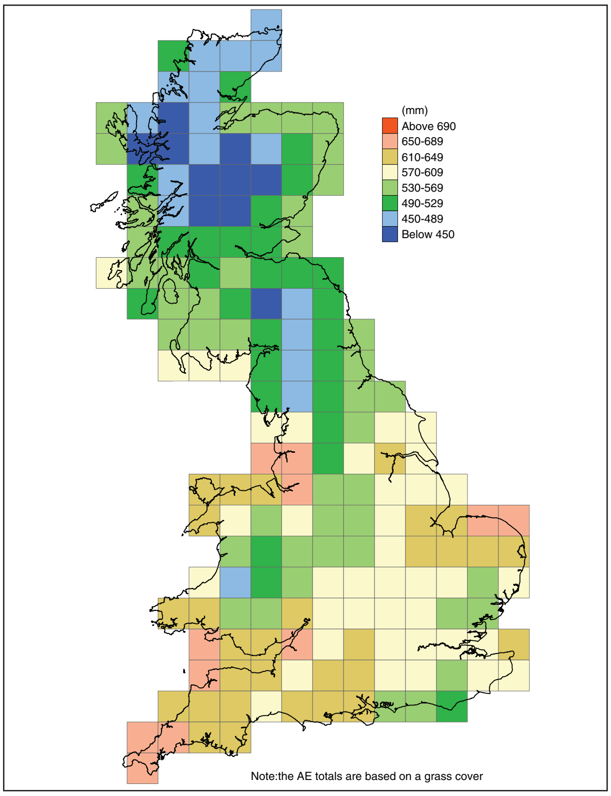

Figure 6 a) *Actual Evaporation totals for 2007.*

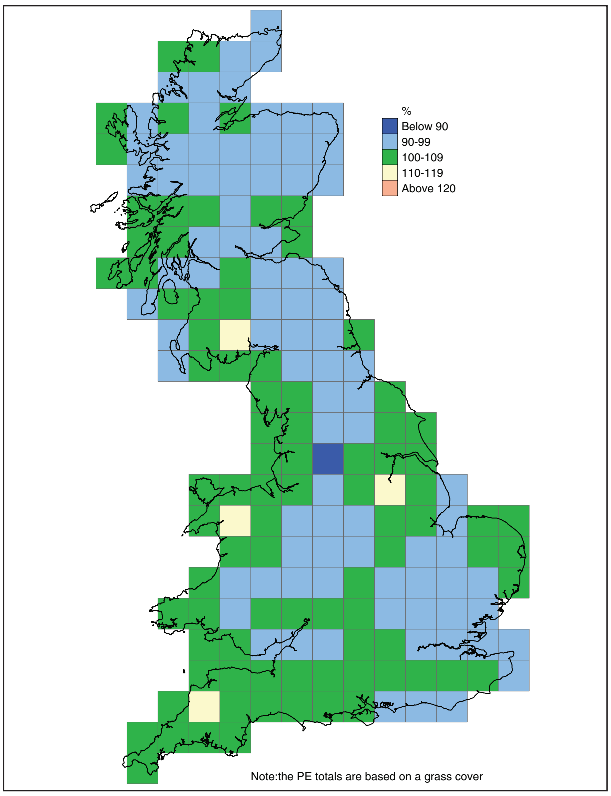

Figure 5 b) *Potential Evaporation totals for 2007 as a percentage of the 1971-2000 average.*
Data Source: MORECS

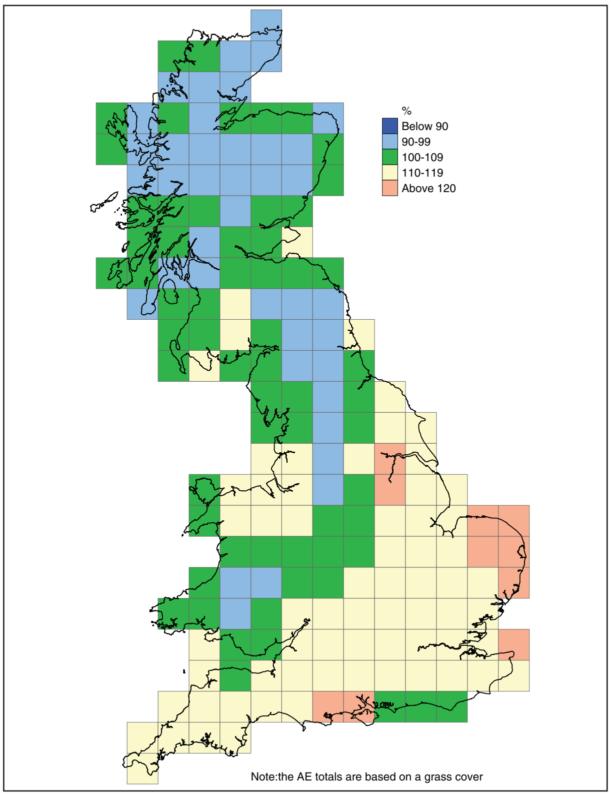

Figure 6 b) *Actual Evaporation totals for 2007 as a percentage of the 1971-2000 average.*
Data Source: MORECS

Figure 7a shows the variation in monthly Potential Evaporation losses (black trace) and Actual Evaporation losses (red trace) for six representative MORECS squares (see Location Map, Figure 7b) in Great Britain from 2003-2007. In a typical year, such as 2006, the difference between the potential and the actual evaporation is readily evident during the summer

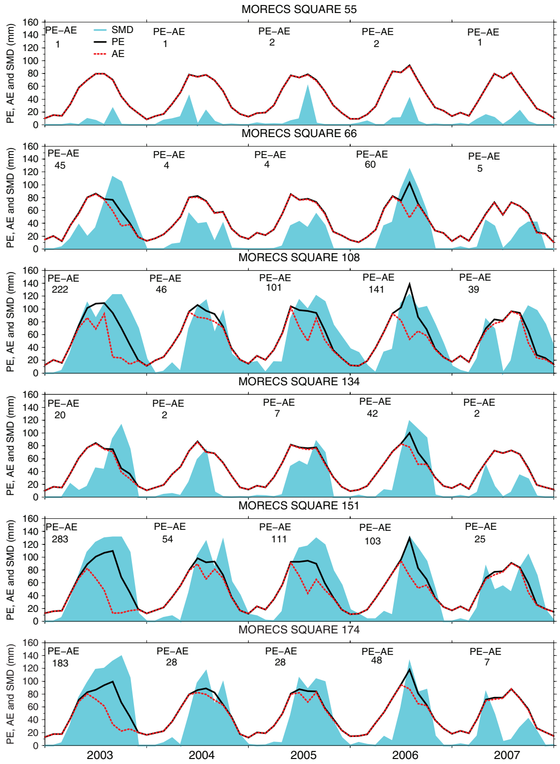

Figure 7 a) *The variation in Potential Evaporation, Actual Evaporation and SMDs for six MORECS squares for 2003-2007.*
Data Source: MORECS

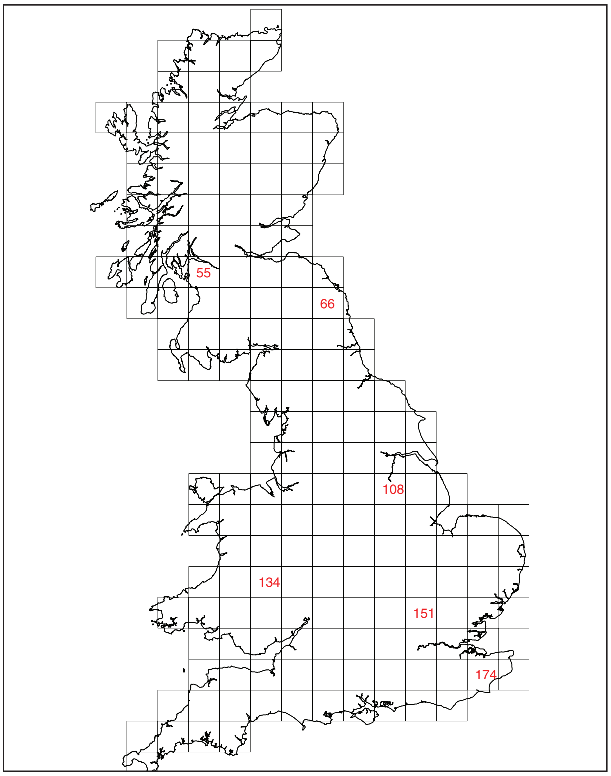

Figure 7 b) *The location of the MORECS squares featured in 7a.*

months. Shortfalls of AE relative to PE typically develop during the peak growing season from June through to September after which they usually reduce through the autumn as sunshine and temperatures decrease and plant growth declines. During 2007, in many areas, monthly AE losses remained close to PE losses, indicating sustained high transpiration rates. This negligible difference between monthly PEs and AEs during the summer of 2007 is more reminiscent of northern and upland regions (eg. Square 55) and underlines the exceptionally wet nature of the 2007 summer.

The difference between the annual totals of PEs and AEs, marked on Figure 7a, is a good general indicator of water stress in the absence of irrigation. In 2007 almost all of Great Britain showed a PE-AE anomaly of less than average. In the driest parts of the country, normally around the Essex coast and the Thames estuary, where PE-AE differences of 130-175mm would be expected, the 2007 values were in the order of 40-60mm. Considering Great Britain as a whole, the annual PE-AE total is the lowest since 1968.

Soil moisture deficits

The development and decay of the of soil moisture deficits (SMDs) from 2003-2007 for six featured MORECS squares are shown by the cyan shading on Figure 7a; the SMDs relate to the end of each month and assume a grass cover. The notably wet summer of 2007 is distinctive, especially across southern Britain, and can be identified by an unseasonal reduction in SMDs over the May-June period. SMDs increased thereafter to September, before declining during the late autumn.

SMDs began to build normally during the early spring; the combination of a relatively dry March (in England) and low rainfall, warm temperatures and plentiful sunshine in April then caused SMDs to increase steeply over much of England & Wales. Almost 40% of Great Britain exhibited either their highest or the second highest April SMDs in a 47-year record. Late-April SMDs were the highest on record for England & Wales, and ranked 4th highest for Scotland since 1961. At the end of April deficits reached over 90mm in several areas, e.g. near Peterborough and also in Hampshire and Surrey – normal values at the end of the month would be in the region of 20-45mm. The map of April SMD anomalies (see Figure 8) shows much drier than average soil conditions throughout most of lowland Britain and especially in southern central England. Very unusually, and due to the extremely dry conditions for the previous eight weeks, SMDs in many areas reached their 2007 maximum by the first week of May.

As a result of the England's wettest May in over 40 years, SMDs decreased briskly but at month-end soils generally remained drier than average, except in a belt from Cornwall & South Wales to East Anglia where wetter conditions prevailed. SMDs continued to decline rapidly during June and soils across almost 60% of Great Britain were close to saturation by the final week. Areas with higher, but still below average, SMDs included much of the English Lowlands and the far north of Scotland; however, in the London area SMDs reached over 70mm. Assessing the SMDs countrywide, both Great Britain and England & Wales registered the lowest end-of-June SMDs in a 47-year record. In Scotland, late June SMDs were the 3rd lowest on record after 1966 and 1999.

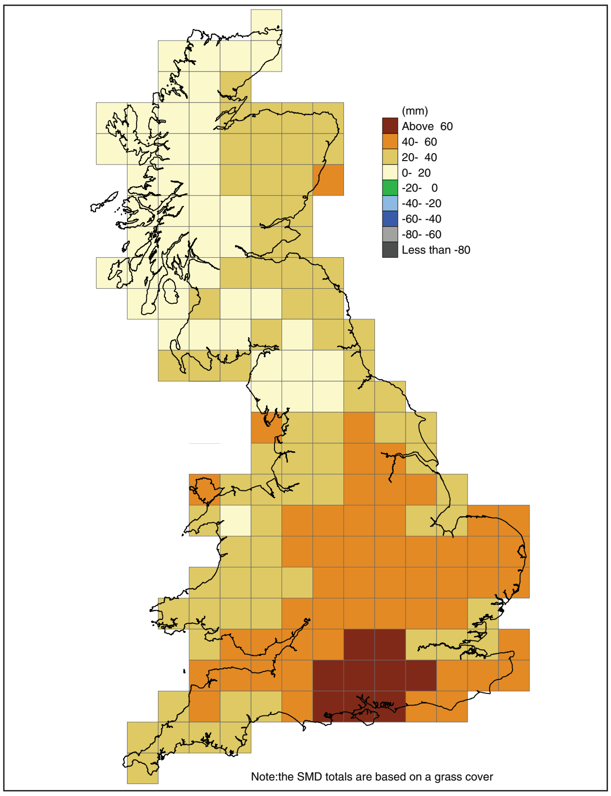

Figure 8 *Soil Moisture Deficits at the end of April 2007 expressed as an anomaly from the 1971-2000 average.*
Data Source: MORECS

July was the third successive month with well above average rainfall. SMDs throughout much of England & Wales were at their lowest on record for the end of July and more typical of mid-April than midsummer. The previous minimum July SMD, in 1968, was eclipsed by a margin exceeding 25mm and SMDs for Scotland as a whole were the lowest since 2002 (see Figure 9). Over a quarter of Great Britain had the lowest, or equal lowest, July SMDs on record, these areas included parts of the Western Highlands of Scotland and much of the English Lowlands.

In August, the weather was cooler, wetter and duller than average in Scotland and Northern Ireland but drier and sunnier in England – where SMDs generally increased. Nonetheless for England, the end-of-August SMDs were the 4th lowest in 47 years and a few, mostly eastern coastal, areas had their 2nd or 3rd lowest late-August SMDs on record.

In contrast to the summer, the autumn was characterised by below average rainfall and above average temperatures throughout most regions of the UK, although with local variations. Soils became drier through much of the country in September and approximately a third of England achieved their highest 2007 SMDs in late September. These areas included the Welsh Marches, the extreme south-west of Britain and along the east coast from Yorkshire

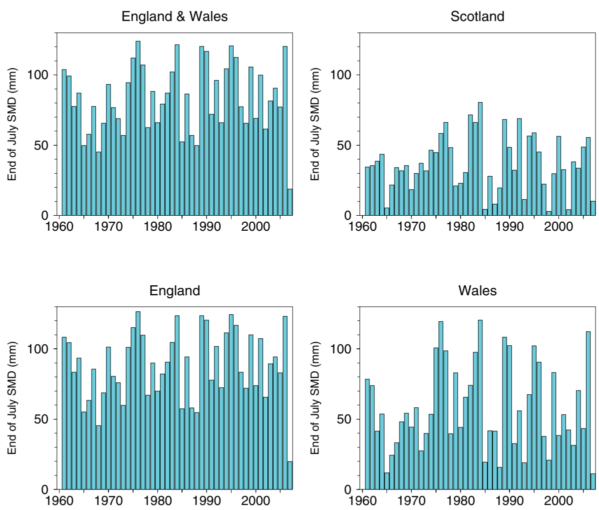

Figure 9 *Shows the end-of-July SMDs on a country basis from 1961-2007.*

to Essex. October was another dry month and, very unusually, maximum SMDs in 2007 were registered in a few areas (e.g. on the east coast) at month-end. Parts of South Yorkshire and Nottinghamshire aside, the wet November left soil moisture conditions in most areas within the normal range. SMDs were largely eliminated by the end of December, however in some areas (e.g. Humberside, adjacent to the Thames estuary and the South West) modest residual SMDs were carried over into 2008.

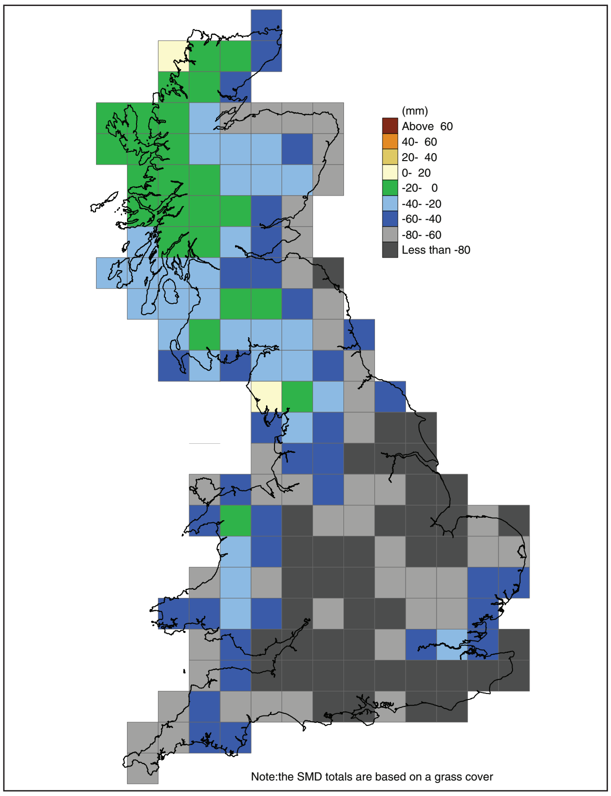

Figure 10 *Soil Moisture Deficits at the end of July 2007 expressed as an anomaly from the 1971-2000 average.*
Data Source: MORECS

River Flows

Overview of 2007 runoff

At the national scale, annual runoff for 2007 was abundant – UK runoff was significantly above average and 2007 outflows for England & Wales rank 4th in a series from 1961. For Scotland and Northern Ireland the runoff totals was less notable although, interestingly, the contrasting tendencies of the last few years were continued in 2007: in Scotland it was the fourth successive year of above average flows whilst Northern Ireland registered a fifth successive year of below average runoff.

Annual runoff totals for individual river basins exhibited less spatial variability than in the drier years of 2005/2006 – unsurprisingly, 2007 runoff totals in almost all index catchments were average or above average – although there were still marked regional contrasts (Figure 11). In Northern Ireland and most of Scotland annual catchment runoff was in the normal range, although some relatively high runoff totals (e.g. in Wester Ross) in the far north contrasted with the very low runoff recorded on the river Luss which drains into Loch Lomond. Average runoff totals were also observed in much of northern and western Britain, and in the far southeast of England. In marked contrast to these comparatively normal conditions, annual runoff totals in a wide band stretching from Yorkshire, through the Midlands to central and southern England were typically well above average and in some cases exceptionally so. This area corresponds with the areas receiving the greatest rainfall totals during the exceptionally wet summer. In a typical year, summer runoff contributes a comparatively minor part of the annual total; in 2007 the remarkable summer runoff was a defining characteristic of the year contributing to notably high runoff totals in some major rivers with long flow records (e.g. the Teme, Wye and Trent). Exceptional annual totals were recorded on the Warwickshire Avon and Great Ouse and the Coln, a groundwater-dominated catchment draining the Cotswolds, registered a new annual runoff maximum in a 44-year record.

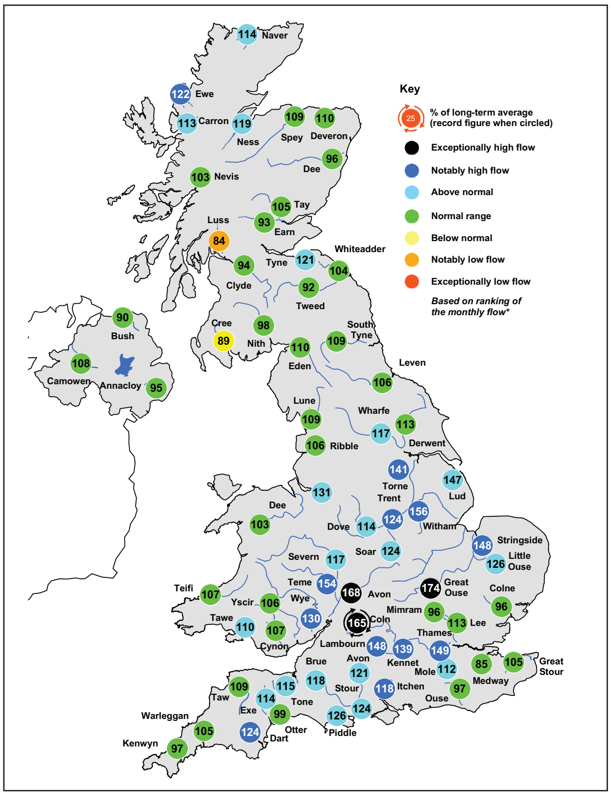

Figure 11 *Map of 2007 annual catchment runoff totals as a % of the preceding average.*

River flow patterns

Figure 12 shows the 2006-2007 hydrographs representing the total daily 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 runoff patterns at the national scale. 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.

For all national outflow series, the first three months of 2007 were characterised by high runoff particularly in January and March and abundant reservoir replenishment. Combined with the notable high flows in late 2006, this runoff sequence resulted in very high winter totals; the 2006/7 winter half year (October-March) was the wettest on record (starting in 1961) for Scotland, and the third wettest for England & Wales. Following the wet start to the year, a significant rainfall deficiency in April

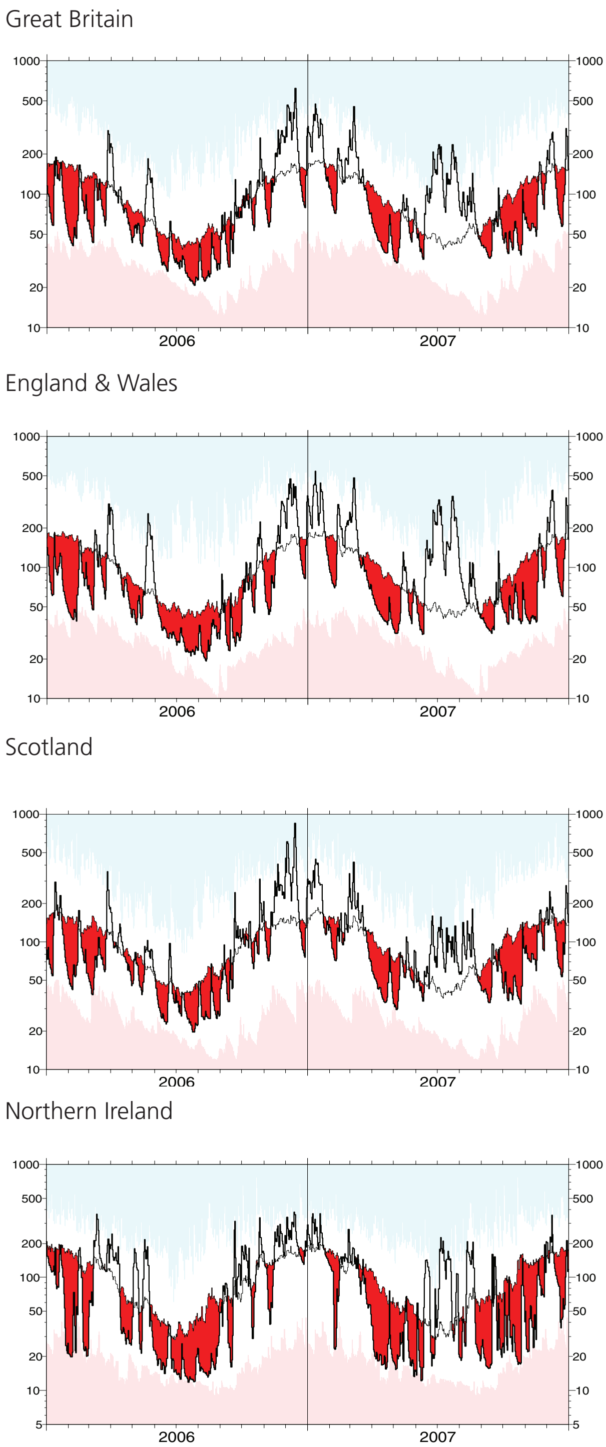

Figure 12 *2006-2007 daily flow hydrographs for the national outflow series.*

resulted in steep recessions in runoff hydrographs (with the April minimum approaching that of 2003 in the England & Wales series). A wet May signified an end to the recessions and the start of an exceptionally wet summer. This produced extremely atypical June-July hydrographs for each of the national series, and significantly redefined the summer high flow envelope in England & Wales; the June/July runoff was nearly twice the previous maximum (in 1968). Correspondingly, runoff for the summer half year (Apr-Sep) was also the highest on record. In both Scotland and Northern Ireland series, the 2007 June-July runoff ranked 2nd highest (behind 2002 in both cases).

The summer runoff was remarkable in terms of magnitude, but a defining characteristic of the event was also the spatial extent of the high runoff, as illustrated by the distribution of record catchment runoff totals for June and July (Figure 13). New maxima for this period were established across the length of the UK, from the Ness, in the north of Scotland to the Dart in southwest England. Across England, a majority of index catchments exceeded their previous maximum runoff, and many rivers reported more than three times their June-July average. The rarity of such conditions is reflected in the extent to which the previous two-month runoff record was eclipsed on some rivers. The Teme registered over four times the previous maximum (in a 37-year record), and on the Warwickshire Avon, the June-July runoff was 80% higher than the previous maximum in a record from 1936; only two two-month periods have generated higher runoff since 1960, and both were in the winter half year.

August saw the end of the seasonally very exceptional cyclonicity and the autumn months were notably dry. The much-delayed seasonal recessions in river flows then became established. The dry spell continued through to November – by the end of which, flows were relatively depressed over wide areas and approaching late autumn minima in many, mostly western, catchments. This is reflected in the runoff accumulation map for August-November (Figure 14). The importance of geological control on runoff patterns is also clearly evident; in rivers draining permeable catchments (e.g. the Coln, Lambourn and Lud), high runoff persisted throughout much of the autumn. Consequently, whilst the period of quiescence runoff patterns in late summer and the autumn allayed fears of further immediate fluvial flooding in most areas, some Chalk catchments remained vulnerable through to the late autumn[8]. The dry spell ended in November, and following the passage

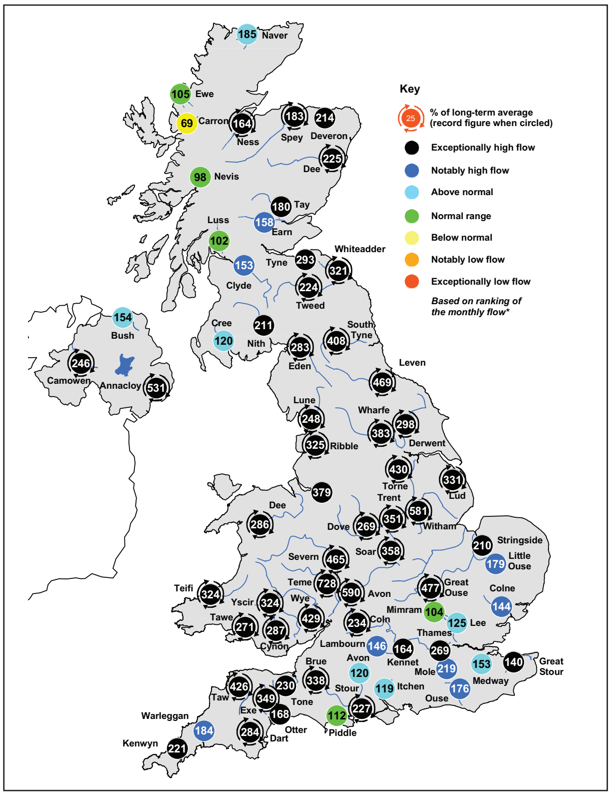

Figure 13 *Map of catchment runoff accumulations for the June-July period for 2007, expressed as a percentage of the previous average*

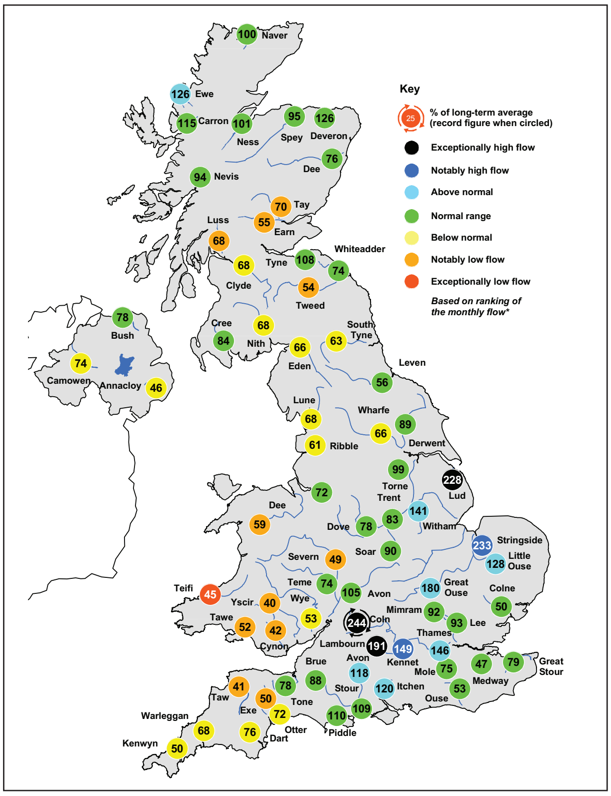

Figure 14 *Map of catchment runoff accumulations for the August-November period for 2007, expressed as a percentage of the previous average.*

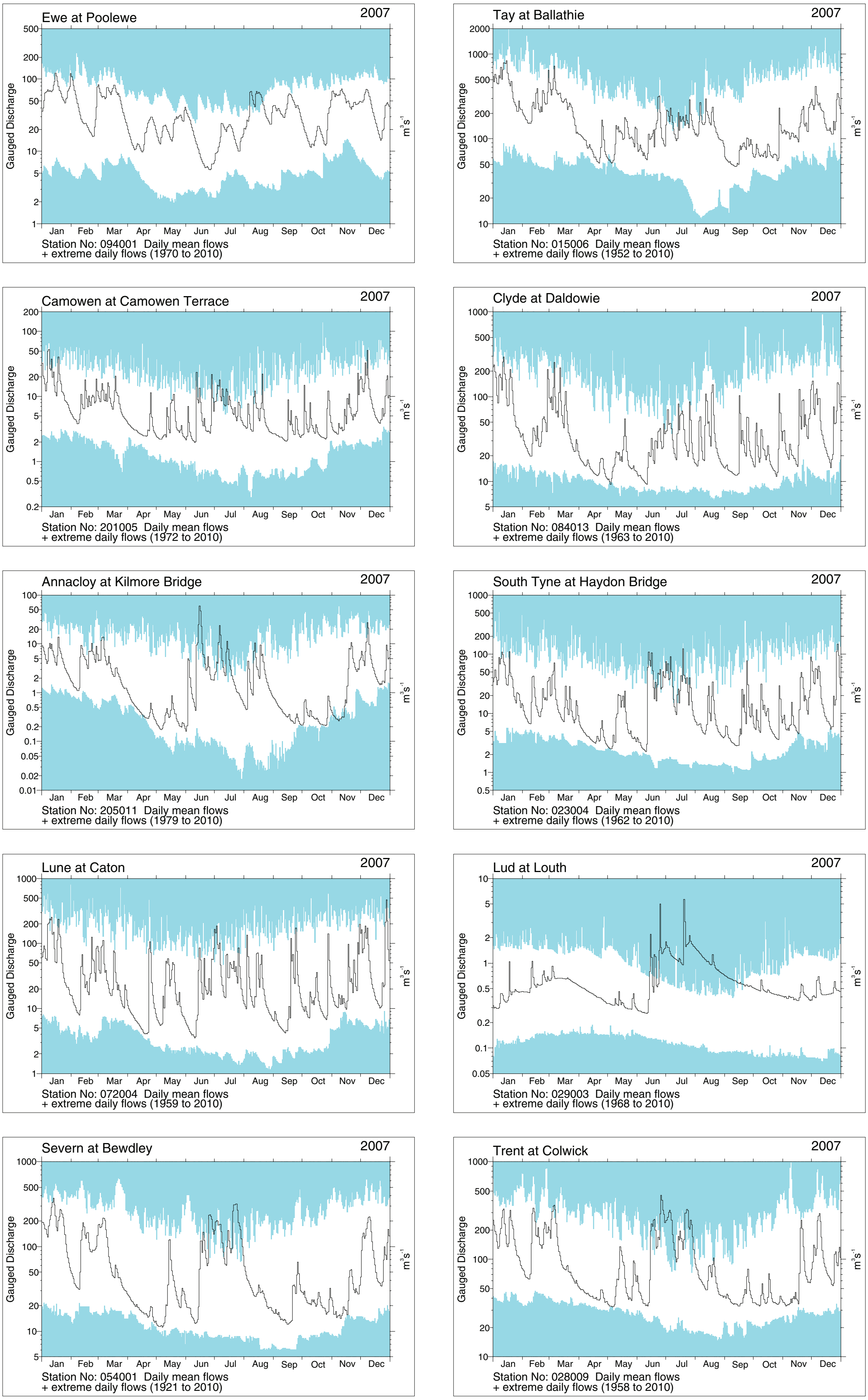

Figure 15 *Daily flow Hydrographs for a selection of index catchments.*

of a sequence of frontal systems in December, many rivers entered 2008 close to bankfull, and vulnerable to further rainfall.

A more detailed breakdown of flow patterns during 2007 is provided by Figure 15, which shows annual hydrographs for selected index rivers across the UK. The long-term daily maximum and minimum flow envelopes (for the preceding record) are also shown. One notable feature is the redefinition of summer flow regimes, with incursions into the high flow envelope evident in many index rivers, including both responsive rivers (e.g. the Annacloy and the Teifi) and those draining the major aquifers (e.g. the Lud and the Coln). In these slowly-responding groundwater catchments, the extent to which the upper flow envelopes are modified is remarkable. On major rivers, such as the Severn and Trent, the multiple spates coalesced to form an extended period of very high summer runoff punctuated with individual flood peaks. The sustained nature of spate conditions is notable even in some rivers outside of the zone of most significant flooding (e.g. on the Tay and South Tyne). Incursions into the low flow envelope were rare in 2007, although periods of depressed runoff in April and the autumn are evident in responsive hydrographs, with seasonal minima approached in a few rivers (e.g. the Taw and the Teifi).

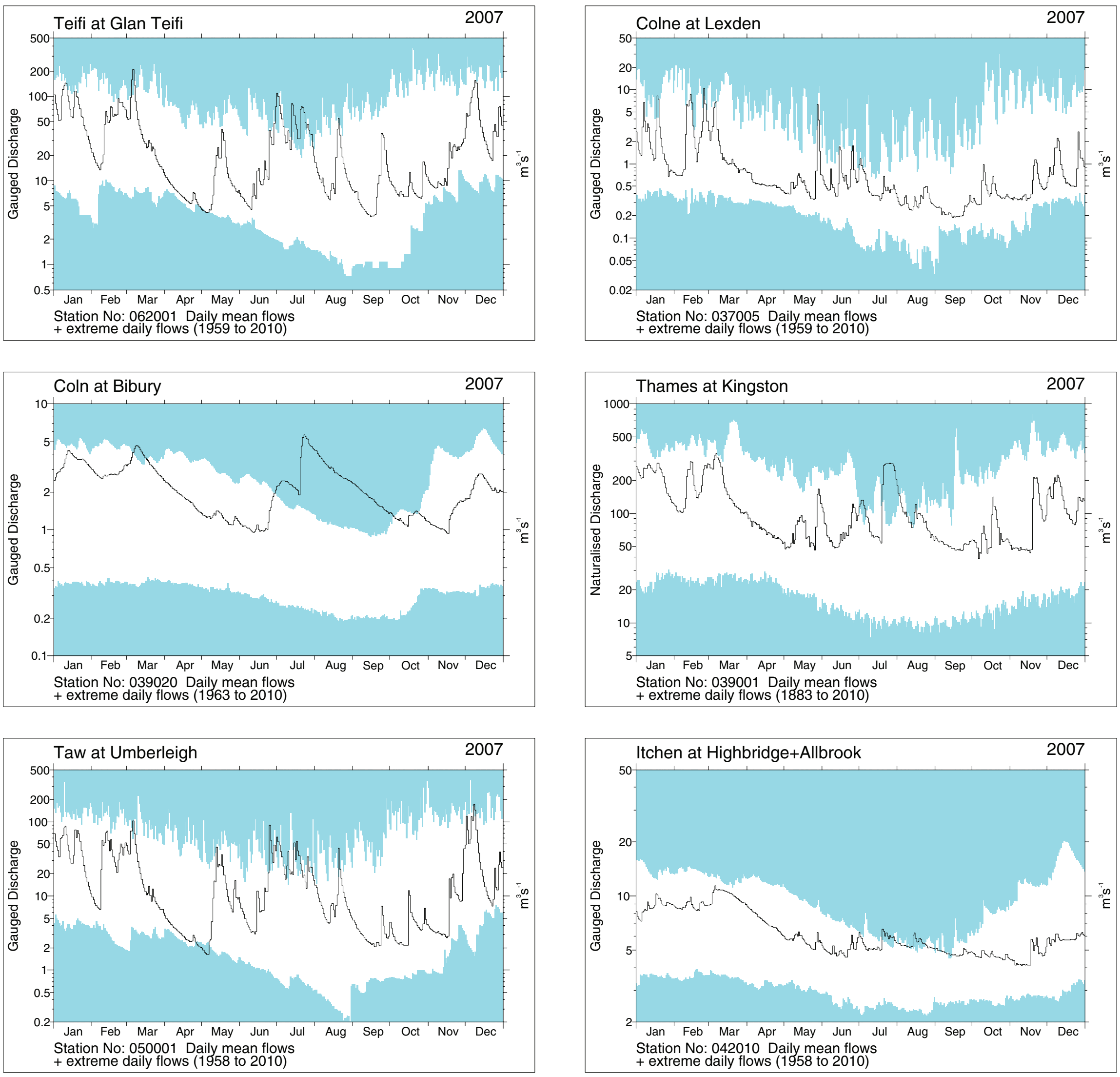

Figure 15 *(Contd.)*

Flow Regime Characteristics

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 previous record. The 2007 flow duration curve for the England & Wales outflow series (Figure 16) shows significant departures from that for the preceding record; flows being higher in 2007 across the entire flow range (the Great Britain curves also follow this pattern). For Northern Ireland, 2007 was qualitatively similar to the previous record. For Scotland, the curves are generally similar except at low flows, with 2007 exhibiting much greater low flows – the Q_{95} being around 50% greater than that for the preceeding record - testimony to a very unusual summer.

Flow duration curves for a set of index rivers are given in Figure 17. Across a diversity of catchment types, one of their most noteworthy features is the extent to which low flows depart from the normal regime. In a year when flooding was the obvious focus, low flows were also unusually high – a function of the timing of the extreme rainfall, which occurred in what is normally the low flow season in many British rivers. In some catchments, flows were in the normal range across the middle and upper end of the flow regime, but at Q_{70} and below the magnitudes were much higher than usual. Examples include catchments as widely distributed as the Taw and Camowen. On some groundwater dominated catchments (e.g. the Lud and Coln), flows were higher than normal throughout the full regime range. In larger catchments within the zones of high summer

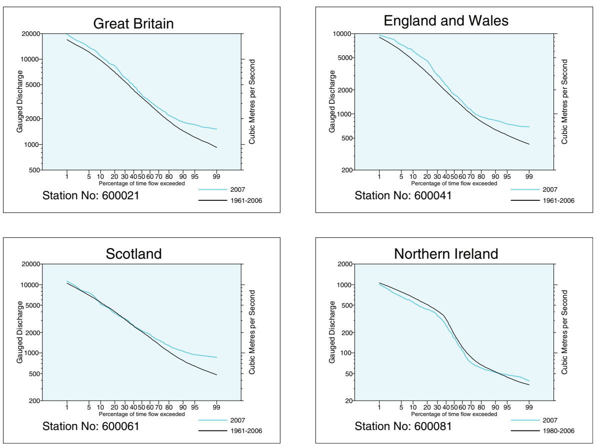

Figure 16 *Flow Duration Curves for the National Outflow Series.*

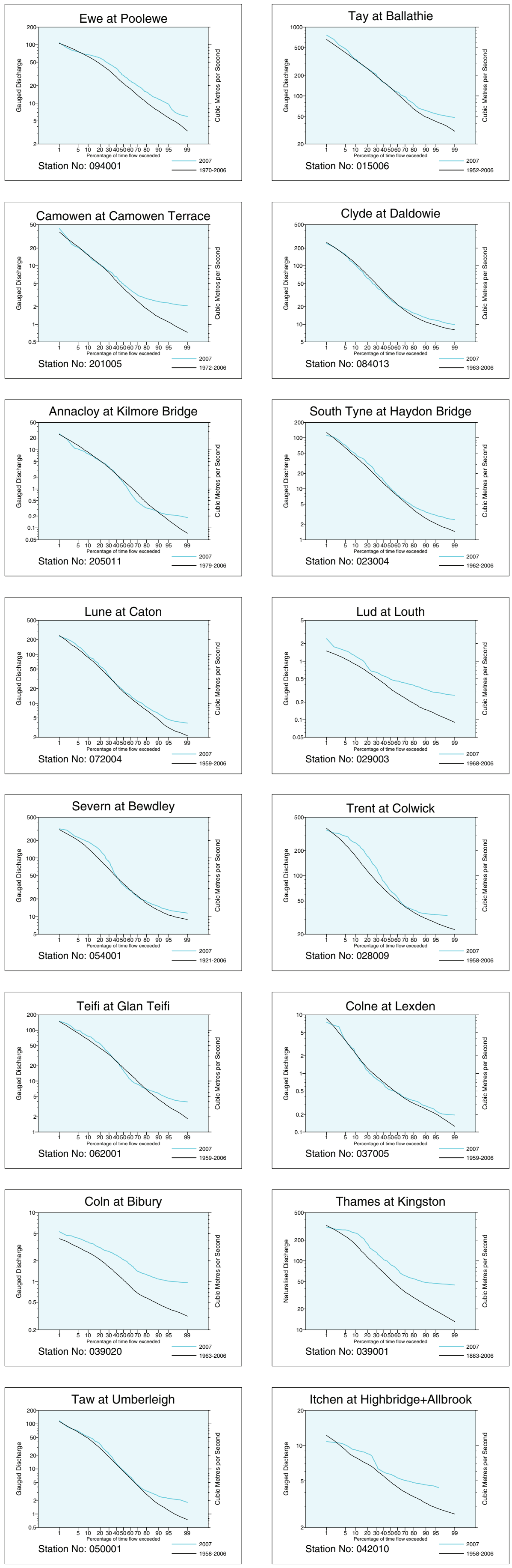

Figure 17 *Flow Duration curves for a selection of index catchments.*

Table 6 *New period-of-record maxima established in 2007*[a]*.*

NRFA Station No	River	Gauging Station	Period of Record	Date	Flow ($m^3 s^{-1}$)
Mid-June Event					
27059	Laver	Ripon	1977-2007	15th June	64.9
27086	Skell	Alma Weir	1984-2007	15th June	106 **
28003	Tame	Water Orton	1955-2007	14th June	128
28066	Cole	Coleshill	1973-2007	14th June	38.8
29001	Waithe Beck	Brigsley	1960-2007	15th June	7.94
Late-June Event					
27021	Don	Doncaster	1959-2007	25th June	350
27025	Rother	Woodhouse Mill	1961-2007	26th June	166
27040	Doe Lea	Staveley	1970-2007	25th June	15.1
27044	Blackfoss Beck	Sandhills Bridge	1974-2007	26th June	23.5
27051	Crimple	Burn Bridge	1972-2007	25th June	9.38
27079	Calder	Methley	1988-2007	25th June	374
27080	Aire	Lemonroyd	1985-2007	25th June	248
28015	Idle	Mattersey	1965-2007	26th June	20.1
28043	Derwent	Chatsworth	1968-2007	25th June	197
28053	Penk	Penkridge	1976-2007	25th June	75.4
28072	Greet	Southwell	1974-2007	25th June	11.5
29003	Lud	Louth	1968-2007	25th June	14.6
29009	Ancholme	Toft Newton	1974-2007	25th June	9.33
34018	Stiffkey	Warham All Saints	1976-2007	26th June	13.4
54024	Worfe	Burcote	1969-2007	25th June	23.9
54040	Meese	Tibberton	1974-2007	26th June	18.9
66005	Clwyd	Ruthin Weir	1971-2007	25th June	26.0
Mid-July Event					
28056	Rothley Brook	Rothley	1973-2007	21st July	20.0
33057	Ouzel	Leighton Buzzard	1977-2007	20th July	19.9
39006	Windrush	Newbridge	1950-2007	23rd July	32.0 **
39008	Thames	Eynsham	1992-2007	24th July	135 **
39019	Lambourn	Shaw	1962-2007	20th July	9.91
39021	Cherwell	Enslow Mill	1965-2007	21st July	85.0 **
39022	Loddon	Sheepbridge	1965-2007	21st July	32.2
39033	Winterbourne St	Bagnor	1962-2007	20th July	2.93
39034	Evenlode	Cassington Mill	1970-2007	21st July	75.0 **
39044	Hart	Bramshill House	1972-2007	20th July	13.2
39052	The Cut	Binfield	1957-2007	20th July	18.7
39081	Ock	Abingdon	1962-2007	21st July	60.0 **
54002	Avon	Evesham	1937-2007	21st July	464
54017	Leadon	Wedderburn Bridge	1962-2007	20th July	240
54018	Rea Brook	Hookagate	1962-2007	20th July	65.5
54029	Teme	Knightsford Bridge	1971-2007	21st July	315
54057	Severn	Haw Bridge	1975-2007	22nd July	1210
55018	Frome	Yarkhill	1968-2007	20th July	26.3
55021	Lugg	Butts Bridge	1969-2007	21st July	77.1
Rest of 2007					
9003	Isla	Grange	1969-2007	22nd November	103

[a] *Table produced following an extensive quality review exercise of the accuracy of these new records, although significant uncertainty remains and flow values are subject to future revision. Where flow values are marked with asterisks (**), flow values are estimates and as such are not featured on the National River Flow Archive. Flow values rounded to three significant figures. Stations included here have at least 30 years of data, except for those new records originally featured in 'The summer 2007 floods in England & Wales – a hydrological appraisal', Marsh, T., and Hannaford, J., 2007, National Hydrological Monitoring Programme, Centre for Ecology & Hydrology.*

rainfall, departures were notable across the flow regime – particularly for the Thames, but the Severn and Trent also showed elevated high flows in comparison to the historical flow duration curve.

New maximum flows in 2007

The exceptional summer rainfall caused widespread flooding in England & Wales[2] and new period-of-record maximum flows were established at more than 100 gauging stations.

Table 6 provides a selection of the new period-of-record maxima established in 2007. The regional extent of the flooding is illustrated by the wide spatial extent of the featured gauging stations. New records were established in a wide range of catchment types: from small headwater streams such as the Crimple, through to major rivers such as the lower Severn, and encompassing both responsive streams (e.g. the Ock), and baseflow-dominated rivers (e.g. the Lambourn).

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 major aquifer. The Permo-Triassic sandstones are regionally important – in the Midlands and North-West especially. Limestone aquifers are also regionally significant and a number of minor aquifers (e.g. the Norfolk Crag) are of local water supply importance.

Away from the more westerly aquifer outcrop areas, groundwater replenishment (or recharge) in a typical year ranges from 500mm to less than 100mm in the most easterly outcrops. Recharge is normally concentrated in the November-April period when evaporation losses are modest. Evaporation losses, which exhibit limited year-on-year variability, result in a non-linear relationship between rainfall and aquifer recharge; a 20% reduction in annual rainfall can result in a reduction of 50% or more in groundwater replenishment in the drier, eastern outcrop areas. Annual recharge variations thus tend to be much greater than those for rainfall.

Year in Brief

Figure 18 shows groundwater level hydrographs for a selection of index wells and boreholes across the UK. The broken line indicates the long term monthly average and the upper and lower shaded envelopes delineate the highest and lowest monthly levels on record. A 5-year period is featured because groundwater levels in many areas reflect recharge over a number of winter/spring periods.

At the start of 2007, groundwater levels were in the normal range in the majority of index boreholes; aquifer levels were generally increasing, continuing the trend seen in late 2006, when aquifers gradually recovered from a long drought period [(6)]. In Chalk boreholes, the relatively wet winter period resulted in levels peaking around March – in most boreholes, these were the highest levels since winter 2003/4. The peak spring groundwater levels in 2007 were generally in the normal range, however, in eastern outcrops, but above average in the southern Chalk. Notably high levels were reached in Rockley, Chilgrove and Ashton Farm. The wet winter also produced some above average winter levels in western Permo-Triassic sandstones outcrops (e.g. in Skirwith and Bussels) and the Carboniferous Limestone. Recoveries were delayed in many slow-responding Permo-Triassic sandstones boreholes in central England; whilst recoveries were typically slow, Heathlanes and Weeford Flats saw increasing levels for the first time since the onset of drought conditions in early 2004.

Following the high early spring levels, some steep declines were seen in Chalk boreholes during the dry April, which appeared to herald sustained late-spring/summer recessions. Across all aquifers, levels fell to average, or below average, in April and May, and in the Killyglen borehole in Northern Ireland, a new May minimum was registered (in a 22-year record). In response to the protracted heavy rainfall seen across wide swathes of England & Wales in June and July, significant, widespread and highly unusual summer recharge occurred. Some of the most outstanding rainfall events during the June-

July period coincided with outcrop areas of the major aquifers – the Jurassic and Carboniferous Limestones, and parts of the Chalk especially.

The sustained rainfall triggered a second peak in groundwater levels, which generally occurred around August/September; a consequence of the time lag between infiltration and recharge. However in northeastern areas affected by the June rainfall some rapid responses were seen (e.g. in July at Dalton Holme). In some boreholes the summer peak levels were much higher than the previous winter maximum, a rare circumstance. Previous maximum summer levels were exceeded in the Chalk of the Yorkshire Wolds and central southern England, see Figure 19. At Dalton Holme, new July and August maxima were established in a groundwater level series from 1889; only in 1912 and 1969 did summer levels approach those of 2007. Summer levels were generally less impressive in the Chalk of East Anglia (Washpit Farm aside), and in Kent and Sussex. Notable summer maxima were also registered in other aquifers. For example, in the Jurassic Limestone of the Cotswolds, the July levels at Ampney Crucis substantially exceeded the previous monthly maximum in a 50-year series. New summer maxima were also established in the Carboniferous Limestone (e.g. Alstonfield). In the slower-responding parts of the Permo-Triassic aquifer, summer levels were generally in the normal range. Whilst the response to the

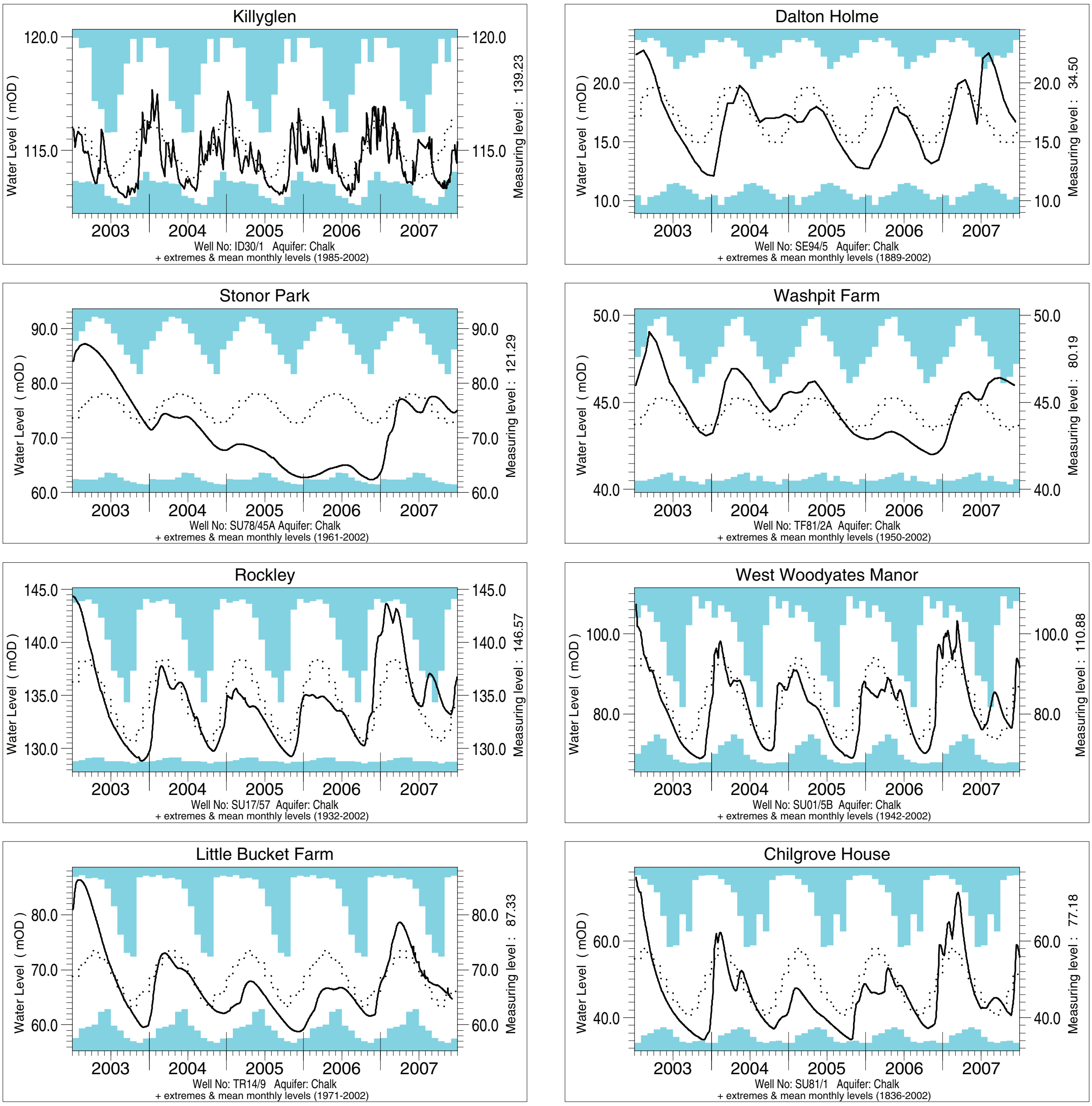

Figure 18 *Groundwater level hydrographs for index boreholes.*

summer rainfall was more muted than elsewhere, it reinforced the impact of the wet 2006/07 winter and reversed the gradual decline manifested following the dry winters of 2004-2006.

With very high groundwater levels at the start of the autumn, there was a considerably enhanced risk of groundwater flooding[7][8]. Fortunately, the autumn was notably dry and in most boreholes with elevated summer levels, recessions were re-established. By November, levels in a majority of index boreholes were within the normal range (Figure 20). Following a relatively wet December,. groundwater levels generally remained in the

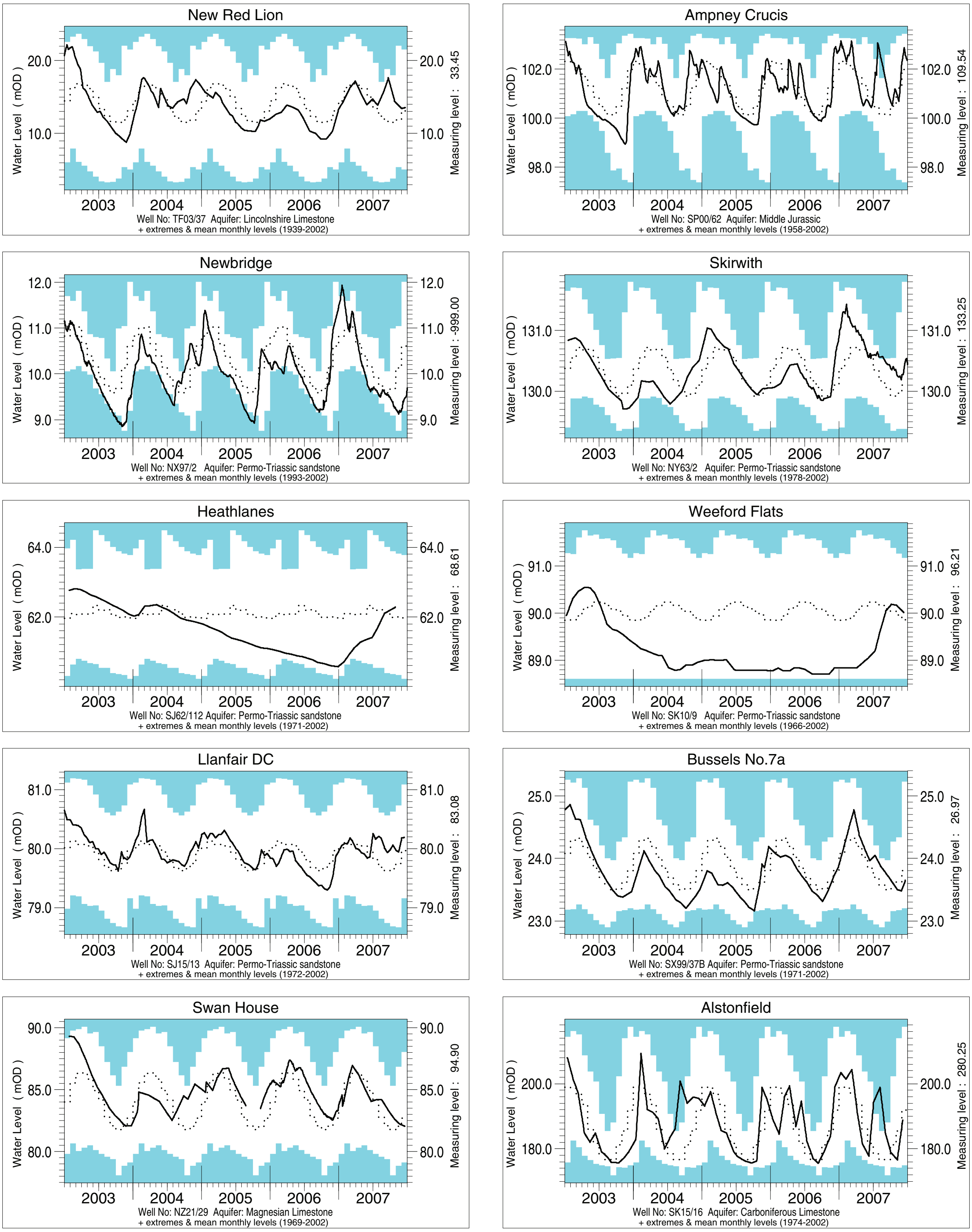

Figure 18 *(Contd.)*

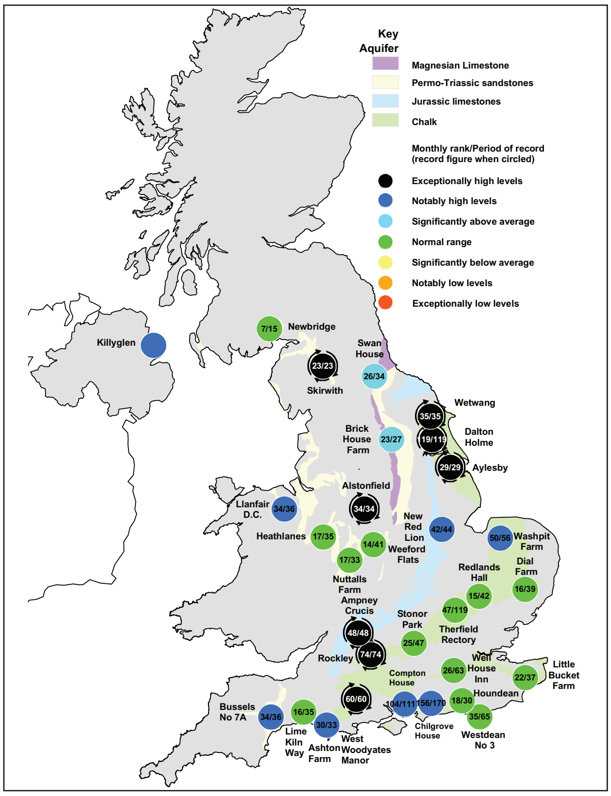

Figure 19 *Map of Groundwater Levels in index boreholes in August.*

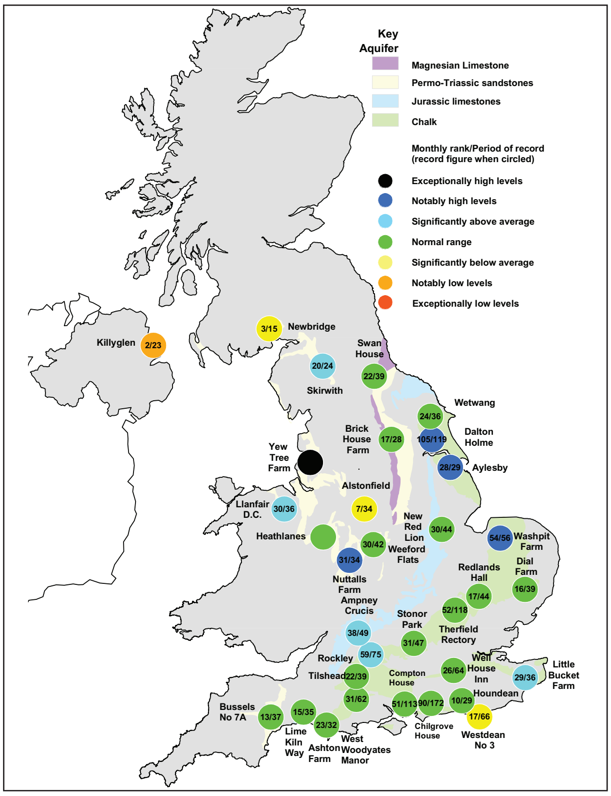

Figure 20 *Map of groundwater levels in index boreholes in November.*

normal range and, at year end, the groundwater situation was relatively favourable, with a much diminished risk of groundwater flooding and a healthy water resources outlook.

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. A decline in 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 70m decline in groundwater levels in the Trafalgar Square borehole. Since the 1950s however, much reduced abstraction rates have resulted in a recovery of around 40m with levels rising by 1-2m a year through much of the 1980s and 1990s (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 contributed to a modest decline, around 5m, in levels at Trafalgar Square over the post-2000 period.

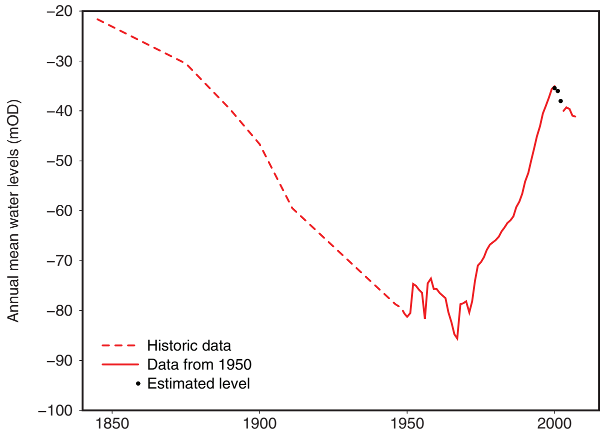

Figure 21 *Groundwater levels at Trafalgar Square 1840-2007.*

Reservoir Stocks

Reservoir stocks in many parts of the country have shown wide departures from the seasonal average throughout the early years of the 21st century. Overall stocks for England & Wales were exceptionally healthy throughout most of the 1998-2002 period but drought conditions then saw stocks decline steeply during the spring and summer of 2003. Subsequently, overall stocks generally remained within the normal seasonal range however, regional, and more local, variations in reservoir stocks were particularly notable during both 2005 and 2006.

Figure 22 provides a guide to the overall reservoir stocks for England & Wales over the period 1988-2007 based on a selection of large reservoirs, or reservoir groups, and is expressed as the difference from the 1988-2006 mean. In 2006 total stocks were very close to the mean for most of the year and following a wet autumn and early winter, stocks for the representative selection of reservoirs in England & Wales were in a healthy state entering 2007.

Figure 23 shows the variation in overall reservoir stocks for a selection of representative reservoirs in England & Wales. The 1988-2006 mean is shown as cyan shading and the years 2005-2007 are represented by different coloured lines.

Entering 2007, overall England & Wales reservoir stocks were healthy; only a few index reservoirs in the South West (Colliford especially) showed levels considerably lower than the early January average. Plentiful late-winter rainfall helped ensure that, by the end of February most reservoirs were close to capacity. However a lack of rainfall extending from early March for around eight weeks caused reservoir stocks to decline briskly across most of the country. By the start of May, overall stocks in England & Wales were just below average but varied considerably across the country. In northern Britain and parts of Wales and the South West stocks were much lower than normal, especially in Lochs Katrine and Daer, Derwent Valley, Brianne, Clatworthy and Colliford. Estimated overall stocks for Northern Ireland (excluding Lough Neagh) dropped to their lowest for the start of May (in a short series – 12 years) and stocks were relatively depressed in parts of western Scotland.

A dramatic change in synoptic patterns then heralded a remarkably wet May-July period (in most areas). This postponed the normal seasonal decline in reservoir stocks and allowed much higher levels to be maintained throughout the summer than would normally be the case in a

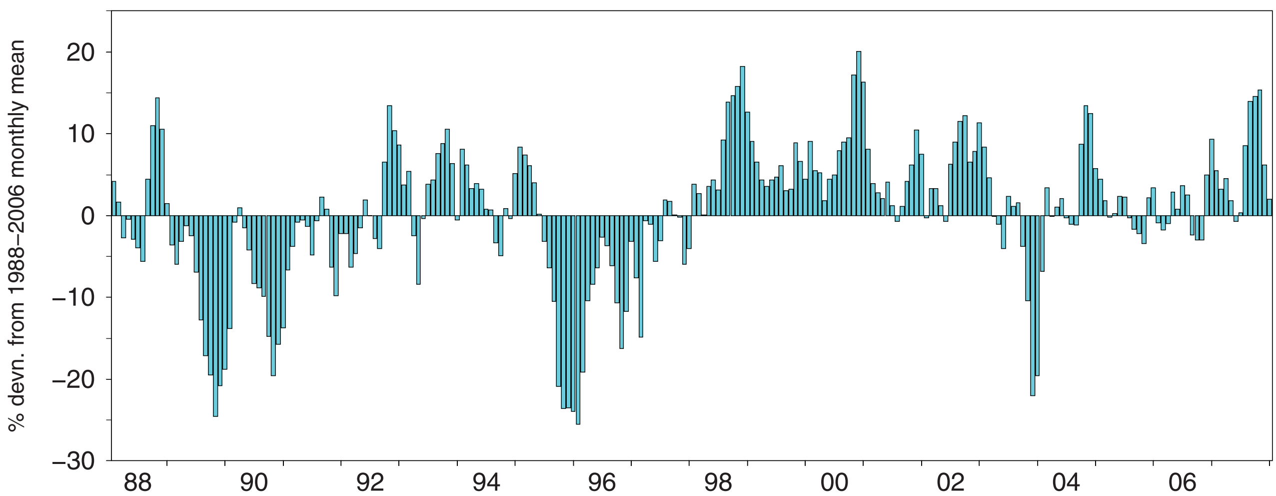

Figure 22 *A guide to England & Wales reservoir stocks, 1988-2007.*
Data sources: Water Service Companies and EA

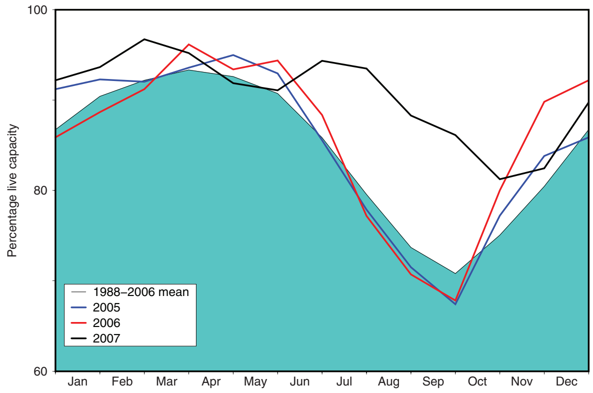

Figure 23 *Variation in overall reservoir stocks for England & Wales.*
Data sources: Water Service Companies and EA

typical summer. The seasonally rare inflows over the summer, together with reduced demand for watering crops and gardens ensured that above average stocks typified most reservoirs until late in the year.

Following high rainfall in May, reservoir levels increased modestly throughout England & Wales, in contrast to normal patterns, but levels were still depressed in parts of western Scotland and also in Northern Ireland where, following a dry May, some reservoirs had their lowest early June stocks since 1996. Most reservoirs registered a seasonally unusual increase in stocks through June. Reservoirs which attained their highest early July levels on record included Kielder, Clywedog, Rutland and the Elan Valley Group. In contrast, in western Scotland where June was much less wet, Lochs Katrine and Thom both had considerably lower than normal early-summer stocks.

Following a third consecutive wet month in many areas, overall reservoir stocks in England & Wales for early August were the highest on record (in a series from 1988). Reservoirs which surpassed their previous highest early August levels were widely distributed and only a few impoundments had below average levels e.g. some reservoirs in the London Group (due to drawdown for scheduled maintenance) and in western Scotland. August was generally dry in England but much wetter in Scotland and Northern Ireland. Although many reservoir levels in England & Wales fell, overall stocks entering the autumn remained close to the previous maximum. In Northern Ireland, overall stocks were at their highest for the start of September, with Silent Valley exceeding its previous early September maximum – a remarkable transformation compared to the depressed status of water resources status in early-June.

After a generally dry September, reservoir stocks continued to decline but stocks for England & Wales still stood at over 15% above the 1988-2006 mean for early October. Some reservoirs e.g. Clatworthy exceeded their previous highest start of October levels. In contrast, levels in Lochs Thom and Katrine had declined rapidly through the dry autumn and by early November reservoir stocks in the west were notably low. Levels were also relatively depressed at Kielder in Northumbria, in this case a consequence of an artificial drawdown for maintenance purposes. Generally in England & Wales reservoir stocks remained above the monthly average – those in the South West being particularly healthy.

November was initially dry but subsequent unsettled weather allowed some significant reservoir replenishment by the end of the month. Overall England & Wales reservoir stocks increased slightly over the month. However in the South West and in East Anglia drier conditions prevailed, causing reservoir levels to decline further and, in Scotland, Loch Katrine registered its lowest early December level in a 14-year series. Rainfall in December was slightly above average in most catchments, the South East excepted, and reservoir stocks generally increased throughout the month, although regional variations were substantial. Grafham ended the year with levels equalling those of 1999/2000 – the highest for December/January since 1988. In contrast, Lochs Katrine and Thom both entered 2008 with their lowest start-of-January levels (in relatively short records) and, in cornwall, Stithians recorded its third lowest end-of-year level since 1988.

Entering 2008, reservoir levels throughout most of the UK were healthy with many index reservoirs in England & Wales and in Northern Ireland at above average capacity; in Scotland some impoundments were lower than normal but recovered well through January.

References

1) CEH Wallingford. (2007). Hydrological Summaries for the United Kingdom. CEH/BGS. http://www.ceh.ac.uk/data/nrfa/water_watch.html. 12 monthly reports.

2) Marsh, T.J. and Hannaford, J. (2007). The summer 2007 floods in England and Wales – a hydrological appraisal. Centre for Ecology & Hydrology. 32pp.

3) Wigley, T.M., Lough, T.M., & Jones, P.D. (1984). Spatial patterns of precipitation in England and Wales and a revised homogeneous England and Wales precipitation series. Int. Jour. Climatol., 1-27.

4) Hough, M. and Jones, R.J.A. (1997). The Meteorological Office Rainfall and Evaporation Calculation System: MORECS Version 2.0 an overview. Hydrol. Earth. Sys. Sci. 1, 227-239.

5) Manley, G. (1974). Central England Temperatures: monthly means 1659 to 1973. Quart. J. Roy. Met. Soc., 100, 389-405.

6) Marsh, T.J., Booker, D. and Fry, M. (2007). The 2004-06 Drought. Occasional Report in the Hydrological Data UK Series. Wallingford, Centre for Ecology & Hydrology.

7) Finch, J.W., Marsh, T.J. and McKenzie, A.A. (2007a). A preliminary risk assessment of the potential of groundwater flooding during the winter of 2007/08. CEH / BGS report for NERC. 20pp.

8) Finch, J.W., Marsh, T.J. and McKenzie, A.A. (2007b). A preliminary risk assessment of the potential of groundwater flooding during the winter of 2007/08 – an update. CEH / BGS report for NERC. 28pp.

Location Map

NATURAL
ENVIRONMENT
RESEARCH COUNCIL

nrfa@ceh.ac.uk
www.ceh.ac.uk

RIVERS Agency

SEPA Scottish Environment Protection Agency

Environment Agency

Met Office