UK Hydrological Review 2009

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

2009

UK HYDROLOGICAL REVIEW

This hydrological review, which also provides an overview of water resources status throughout 2009, 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 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 hydrometric 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 Defra, 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: Terry Marsh, Felicity Sanderson and Jamie Hannaford.

Cover photo

Aerial views of flooding in Cockermouth, Cumbria, 20th November 2009.

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: enquiries@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

Note: the Location Map gives the location of many of the rivers, reservoirs, aquifer outcrop areas and wells and boreholes mentioned in the Hydrological Review.

UK Hydrological Review of 2009

2009 Summary

After two years with very unusual seasonal rainfall distributions, and notable fluvial flood episodes during the summer half-year, 2009 saw a return to somewhat more typical spatial and temporal rainfall patterns. Nonetheless, the spring was notably dry, July was sufficiently wet to trigger both fluvial and flash flooding, and November eclipsed December 1929 as the wettest month for the UK in a series beginning in 1914[a]. This remarkable month contributed to above average 2009 rainfall totals in almost all regions and, for the UK, 2009 was the 4th year in succession which was wetter than average. Although the November rainfall will generally be remembered for the devastating flooding in Cumbria, its legacy in water resources terms was also important. The boost to reservoir stocks and aquifer replenishment was sufficient to ensure a healthy water resources outlook until well into the following year.

The average UK temperature in 2009 exceeded the 1971-2000 average, but it was still the 2nd coolest year since 2001. April and October were notably warm but the 2008/09 winter (December-February) was the coldest since 1995/96. Depressed temperatures early and late in the year resulted in frozen catchment conditions, in the uplands particularly, which contributed to some exceptionally low winter runoff rates. Whilst still a minor proportion of annual precipitation, snowfall was significant in many areas with notable accumulations even in southern England during February. As a consequence, snowmelt was also a component of a number of winter spates, a rare occurrence in the recent past in the English Lowlands.

Generally, potential and actual evaporation losses for 2009 were modestly above the 1971-2000 average and broadly similar to those of recent years. Following two years during which the seasonal development and decay of soil moisture deficits was very unusual, 2009 saw a more normal pattern but there were, again, erratic changes in soil moisture conditions through the summer half-year. Seasonally high soil moisture deficits were established during a notably dry early autumn but these generally declined very rapidly through November.

Total outflows from the UK in 2009 were modest compared to several recent years (2000 and 2008 in particular) but were still appreciably above the 1971-2000 average. This reflects well above average runoff over the late summer and early autumn and, particularly, extreme outflows during much of November. Flooding was extensive in Cumbria and south-west Scotland following a remarkable storm event during which a new maximum 24-hr rainfall total (316mm at Seathwaite Farm, Borrowdale) was established for the UK. However, although local flash flooding incidents were widely reported during the summer half-year, the overall incidence of major fluvial flood events was not unusual.

Seasonally depressed river flows were widely recorded in early January, April, and June but, for the third successive year, summer flows were generally well above the seasonal average, notably so in late August. Depressed flows characterised a few, mostly responsive, lowland rivers in the autumn but Q_{95} flows for 2009 were generally well above average. Sustained high rates of runoff in November and early December ensured that reservoir stocks, which for England & Wales as a whole had briefly fallen below the seasonal average in the spring of 2009, were above average at year end.

Groundwater recharge was below average throughout the early winter of 2008/09 but heavy infiltration in February (together with seasonally high groundwater levels in late 2008) ensured that 2009 groundwater level recessions began from a relatively high base. Commonly, recessions were very sustained (often extending over 8-9 months) but abundant recharge in November enabled groundwater levels to recover very briskly and, for the generality of aquifer outcrop areas, exceeded the early winter average entering 2010.

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

Table 1 2009 rainfall in mm and as a % of the 1971-2000[a] average — Data source: Met Office

2009		J	F	M	A	M	J	J	A	S	O	N	D	Year	Oct-Mar 2008/09	Apr-Sep 2009
United Kingdom	mm	120	60	80	60	82	62	146	115	64	108	216	101	1214	610	530
	%	102	72	86	91	130	89	220	143	66	96	188	84	112	95	120
England & Wales	mm	94	50	45	45	60	58	142	65	33	76	191	102	961	454	403
	%	102	76	62	76	103	90	258	93	43	84	209	103	107	89	105
England	mm	82	53	41	40	54	55	129	59	30	68	171	93	875	411	367
	%	100	90	63	72	99	89	247	92	42	83	209	105	107	90	102
Wales	mm	168	33	68	77	93	75	227	102	53	128	319	154	1496	721	626
	%	110	30	59	95	122	91	307	101	45	87	208	94	109	86	118
Scotland	mm	166	84	149	81	122	71	155	202	128	167	262	103	1690	920	758
	%	101	71	113	101	168	90	179	203	96	109	164	64	117	103	138
Northern Ireland	mm	135	38	65	110	101	59	134	165	41	116	220	77	1260	546	610
	%	113	44	70	155	148	83	180	182	43	101	199	65	113	85	130
North West	mm	133	28	70	50	105	61	183	133	59	103	291	113	1328	650	591
	%	110	33	70	75	158	78	234	140	57	81	233	86	113	94	121
Northumbrian	mm	72	49	39	38	53	69	169	76	43	63	195	100	966	390	447
	%	88	83	57	65	90	113	294	107	62	83	234	116	116	86	119
Severn Trent	mm	70	34	32	43	56	74	132	50	23	58	134	71	778	350	379
	%	94	63	55	80	105	118	268	80	35	82	189	89	102	85	108
Yorkshire	mm	65	45	35	34	64	62	132	59	31	69	173	87	856	363	382
	%	80	77	52	58	118	99	248	89	45	90	220	98	105	81	105
Anglian	mm	46	56	32	17	38	47	87	41	16	45	95	75	595	304	246
	%	87	150	70	37	83	87	194	79	30	79	168	134	99	99	83
Thames	mm	67	64	31	36	39	46	85	47	24	47	149	90	725	339	277
	%	98	136	58	72	73	81	196	86	37	66	225	125	104	90	86
Southern	mm	100	68	40	42	36	30	78	27	30	72	207	125	854	428	243
	%	121	127	67	81	71	54	176	51	42	81	249	142	109	94	74
Wessex	mm	93	70	46	41	37	57	127	57	24	84	189	102	928	445	344
	%	101	104	66	74	66	95	273	87	31	96	218	100	107	88	95
South West	mm	157	82	68	86	68	46	225	69	44	111	249	128	1332	641	537
	%	111	78	70	120	99	63	365	83	44	88	187	85	110	85	118
Welsh	mm	161	34	64	74	90	74	223	97	51	124	302	150	1444	689	609
	%	110	32	58	95	121	93	312	99	44	88	206	95	109	86	118
Highland	mm	186	126	222	84	144	79	150	205	176	202	252	96	1922	1218	838
	%	92	86	136	90	184	88	158	186	111	112	125	49	112	112	134
North East	mm	80	86	83	39	85	82	146	95	105	172	170	109	1253	556	553
	%	82	129	108	61	136	125	221	137	119	170	171	120	132	104	133
Tay	mm	165	50	103	76	123	74	150	168	106	153	269	90	1528	696	697
	%	105	47	87	113	168	107	203	203	94	114	205	64	121	88	146
Forth	mm	124	36	90	54	97	58	149	165	103	96	236	83	1290	592	625
	%	98	39	87	86	147	84	209	201	98	81	206	68	114	87	137
Clyde	mm	211	69	169	121	154	70	166	299	136	183	343	108	2028	1056	946
	%	105	48	105	133	195	79	155	238	83	96	183	55	117	98	144
Tweed	mm	103	53	62	40	64	55	167	139	75	73	227	110	1169	517	541
	%	103	76	77	67	98	85	260	188	93	77	242	105	123	95	132
Solway	mm	205	38	116	101	114	64	194	295	80	142	328	139	1815	898	848
	%	132	34	94	126	151	81	223	277	65	92	220	86	129	105	154
Western Isles, Orkney and Shetland	mm	162	118	139	76	84	45	108	150	95	154	216	95	1442	921	558
	%	100	102	106	97	136	65	132	159	71	100	129	60	102	104	107

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.

Overview of the recent past

This section places the hydrological conditions experienced in 2009 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, a sustained 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 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.

With most rain-bearing frontal systems following more southerly tracks than normal, 2001 witnessed the development of a further drought episode across northern regions of the UK. 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. In 2007 outstanding rainfall over the May-July period, across much of England & Wales, triggered severe fluvial and flash flooding. 2008 was another notably wet year but flooding was much less extensive – the capability of UK rivers to cope naturally with sequences of moisture-laden Atlantic frontal systems was well demonstrated.

The first decade of the 21st century has seen major departures from typical seasonal river flow patterns with a relatively high frequency of sustained spate conditions. For the UK as whole, overall runoff for the 2000-09 period exceeded the 1971-2000 mean by around 7%. This enhanced runoff is complemented by appreciably above average Q_5 flows. However, whilst high flows have been more frequent, and the first decade of the 21st century may be considered flood-rich relative to the previous four, compelling long term trends in annual maximum flows remain elusive. In this context the decline in snowmelt as an exacerbating factor in major flood events has been beneficial. Summer river flows have shown exceptional year-on-year variability over the last ten years but, using Q_{95} as an index, the 2007-2009 period boasts the healthiest low flows at the national scale for any three-year sequence in a series from 1961. Low flows in the English Lowlands (as a whole) were less notable but in only three years in the last decade have they fallen below the 1971-2000 average.

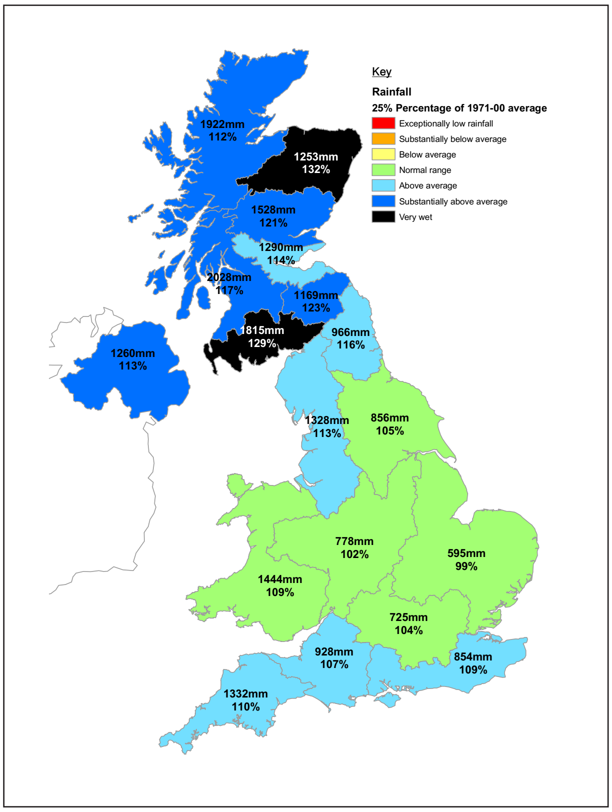


Figure 1 *2009 annual rainfall totals in mm and as a % of the 1971-2000 average.*
Data source: Met Office

Rainfall

Annual rainfall

Annual rainfall figures for 2009, together with monthly and half-yearly totals are given on Table 1. The UK rainfall total, 12% above the 1971-2000 average, is the 10th highest in a series from 1914. Annual rainfall anomalies were particularly high across much of Scotland (Figure 1) where the North East region registered its 2nd wettest year since 1916, contributing to Scotland's 5th highest annual total on record. However, 2008 was wetter and the recent clustering of wet years is exceptional: the 2004-09 period is the wettest 6-year sequence on record for Scotland by an appreciable margin[a]. Though wet overall, 2009 was a year of substantial temporal and spatial contrasts in rainfall patterns. This primarily reflects the more northerly tracks followed by a high proportion of Atlantic low pressure systems. As a consequence, very dry conditions characterised the late winter and spring across most of England & Wales, and extended into the summer across large parts of southern Britain. England recorded its 2nd driest February-June since 1984 (see Figure 2) and for much of the English Lowlands, July was the only month to record above average rainfall in the eight months up to November. However, the July rainfall total was the highest on record for the UK and substantially moderated the rainfall deficiencies which had accumulated through the spring and early summer. Any lingering concerns about the water resources outlook were banished in November.

The year in brief

Generally, the year began with a continuation of a dry spell from mid-December 2008 but was terminated on the 10th as an active depression produced substantial precipitation totals. Western Scotland was especially wet: Inveruglas registered a two-day total of 135.4mm. With Atlantic influences prevailing, January was a moderately wet month but very wintry conditions returned in early February; exceptionally low temperatures were accompanied by the most widespread snowfall since the winter of 1990/91. Accumulated snowfall exceeded 50cm over the first week in a number of upland areas (e.g. Dartmoor); as remarkably, daily totals exceeded 25cm in some low-lying southern districts (e.g. Epsom, Surrey). Across the country, thousands of schools closed – partly due to the major transport disruption. Dry anticyclonic conditions dominated the late winter and both Northern Ireland and the Wales reported their 2nd lowest February rainfall since 1986. At the national scale, the winter (December-February) was the coldest since 1995/96 and many western catchments registered their 5th or 6th driest winters in the last 45 years – such a combination contrasts markedly with the generality of winters in the recent past.

Early March was very unsettled with significant snowfall in Scotland and in western hills to the south. However, notable storm rainfall totals were rare and the most hydrologically significant feature was the extended dry episodes in mid-month. Large areas reported accumulated rainfall totals of < 2mm over periods of 18 days or more. More importantly in relation to water resources, substantial rainfall deficiencies in the November-March timeframe encompassed much of north-east England and eastern Scotland. April was a generally warm month but with exceptional regional contrasts in rainfall amounts: whilst most western areas were relatively wet, the sequence of below-average rainfall months continued in the east and much of the south. In May, most Atlantic frontal systems again followed relatively northerly tracks and, whilst Scotland was wet, much of the English Lowlands experienced breezy and dull conditions but with very little rainfall. Spring (March-May) rainfall totals, though well above average in Scotland, were meagre to the south; England registered its driest spring since 1997.

June featured some notable early summer storms: on the 6th, Exeter recorded 93mm in 12 hrs (including 27.2mm in 1 hr) and a 24-hr total of 78mm was reported for Cardiff. Further torrential downpours, many associated with thunderstorms, were reported around mid-month (e.g. 59mm was recorded in 2-hrs near Cambridge on the 15th). Subsequently, a notably arid episode extended into early July in many areas. Locally, this was terminated when heatwave-induced thunderstorms produced torrential downpours in some areas (e.g. 53mm

a The decline in snowfall (the amount of which is underestimated to a greater degree than rainfall) may be a significant contributory factor.

falling in 40 minutes at Copley, (Durham on the 2nd). Thereafter, a series of slow-moving low pressure systems brought prolonged and heavy frontal rainfall to much of the country. On the 16-17th Cardinham (Cornwall) and Chillingham (Northumbria) recorded rainfall totals of 94mm and 84mm respectively. Existing maximum July rainfall totals were widely exceeded. Weather patterns were more settled in early August but the latter half of the month saw a sequence of low pressure systems, including the remnant of Hurricane Bill, bring substantial pulses of rainfall to northern Britain. On the 20/21st. Eskdalemuir (Dumfries and Galloway) reported 78mm and further rainfall (e.g. 65mm on the 30/31st) contributed to a record monthly total of 392mm. In Scotland, the wetness of the late summer contributed to the highest March-August rainfall total on record. By contrast, August rainfall totals fell as low as 10mm (in Norfolk) and significant areas registered less than 50% of the monthly average. Nonetheless, UK summer (June-August) rainfall was substantially above average and, more notably, the summers of 2007, 2008, and 2009 constitute (at the national scale) the wettest 3-year sequence of summers on record.

In northern Britain, cyclonic conditions continued into the early autumn in northern Britain. On September 3rd, exceptional storm totals were recorded inland from the Moray Firth at Dipple (near Fochabers, Grampian), a 33-hr storm total of 139mm was registered and Skye reported its longest sequence of days (50) with rainfall in a series from 1861. The synoptic conditions experienced to the south were very different. Wallingford (Oxfordshire) recorded <0.5 mm of rain over a 32-day period; the driest sequence for such a timespan since the extreme drought of 1976. Northern Ireland was also very dry – registering its lowest September rainfall since 1986. The regional differences in rainfall patterns were further accentuated in October when parts of North-East Scotland were exceptionally wet in mid-month: Waterside (Esk catchment) reported 90mm on the 21st, and a 5-day total of 182mm. However, much of England again recorded below average October rainfall (<50% in parts of London) and across large parts of the English Lowlands, March-October rainfall totals were substantially below average; the Southern Region reported its 5th lowest rainfall in this timeframe in 80 years.

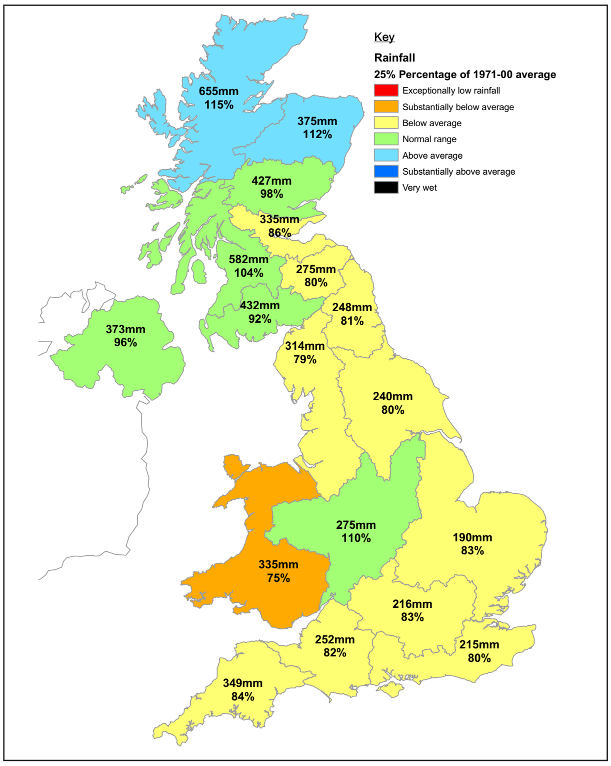


Figure 2 *February-June 2009 rainfall in mm and as a % of the 1971-00 average*
Data source: Met Office

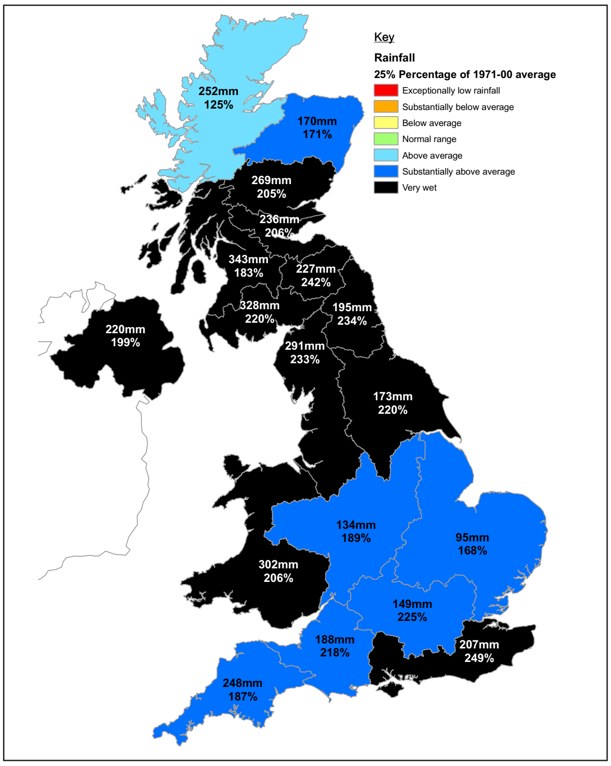


Figure 3 *November 2009 rainfall in mm and as a % of the 1971-00 average*
Data source: Met Office

November saw a relentless passage of vigorous Atlantic low pressure systems across the British Isles. Rainfall was reported on all but two orf three days in most regions and in mid-month a near-stationary weather system allowed an exceptionally warm and moist subtropical airflow to track SSW-NNE across parts of the UK. This, together with substantial orographic enhancement, produced many storm totals of >50mm and culminated in extreme rainfall totals across high ground in the Lake District[1]. A new UK 24-hr record was established at Seathwaite Farm, Borrowdale contributing to a 495mm 4-day total (provisional return period: 3000 years). Existing monthly rainfall maxima were widely eclipsed, particularly in north west England and south west Scotland e.g. Inveruglas (Strathclyde) recorded 561.4mm and Glencaple (Dumfries & Galloway) exceeded, by 80mm, its previous maximum for any month in a 45-yr series. The exceptional late autumn rainfall (see Figure 3) greatly moderated medium and long term regional rainfall deficiencies in most areas. Early December was also wet but from the second week, with high pressure established to the north of the British Isles, northerly or north-easterly winds brought very cold conditions with accompanying snow across much of the country. On the 18th, accumulations of up to 20cm were reported (e.g. on the North York Moors) as bands of snow moved in from the North Sea. Further significant falls were reported later in the month. In Scotland fresh snow on a consolidated snowpack increased the risk of avalanches (one on Ben Nevis on the 30th caused two fatalities).

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. 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 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 2009 relies, in large part, on monthly figures derived using the Met Office Rainfall and Evaporation Calculation System (MORECS)[2].

Temperatures and evaporation losses

Notwithstanding some notably cold episodes, 2009 was generally a warm year; for the UK as a whole the average temperature was 9.2°C, 0.6°C above the 1971-2000 average and a little warmer than 2008, ranking the year equal 15th warmest in the last 100. Most months in 2009 were warmer than average throughout the UK but January and December were, respectively the coldest since 1997 and 1996. Temperatures and sunshine duration during the spring exceeded the average throughout the UK, as did summer temperatures, but sunshine hours were considerably below average during the summer in western districts of England, Wales and southern Scotland.

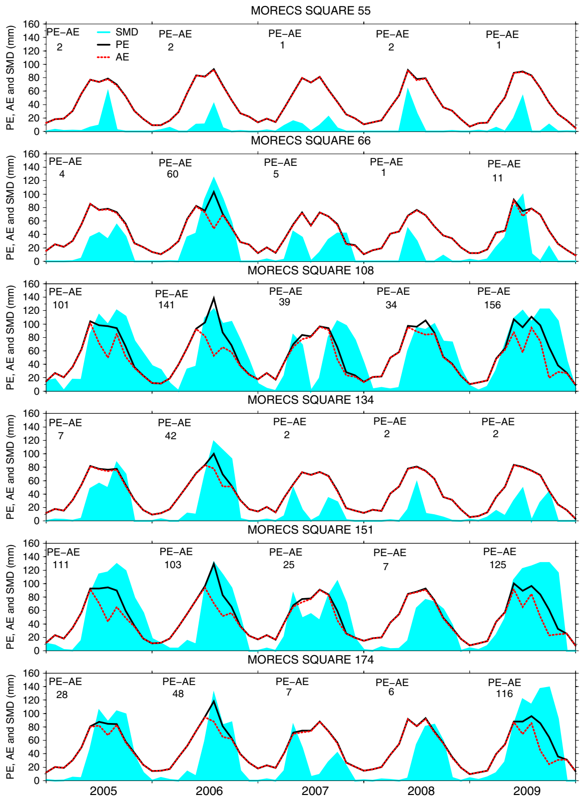


Figure 4a *The variation in Potential Evaporation, Actual Evaporation and SMDs for 2005-2009*
Data source: MORECS

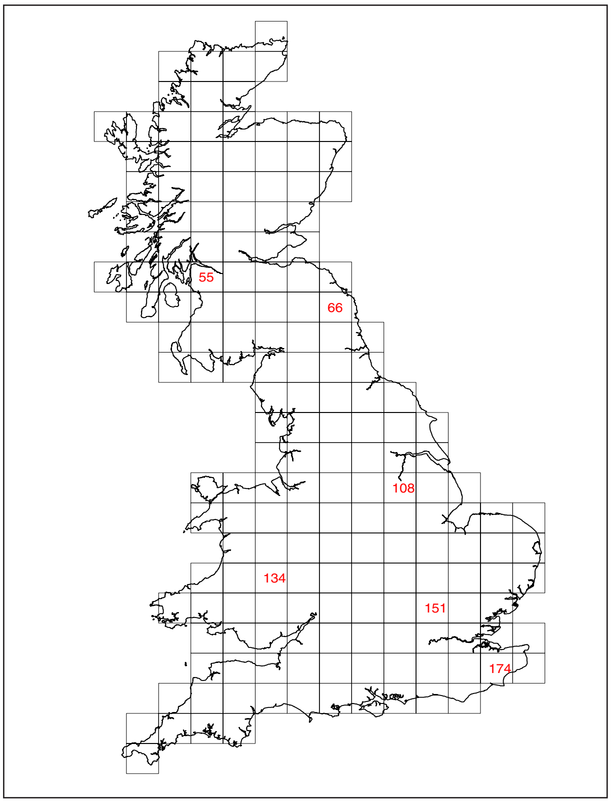


Figure 4b *Location of the MORECS squares featured in Figure 5a*

The variation in monthly PE losses (black trace) and AE losses (red trace) is shown in Figure 4a for six representative MORECS squares; their locations are given on Figure 4b. The normal seasonal cycle in evaporation losses is clearly evident. The plots also testify to a moderate accentuation in the normal contrasts between north-western Britain where, as usual, monthly AE losses matched the corresponding PE totals, and south-eastern Britain where AE losses were constrained by dry soils over the April-October period (see below).

Figure 5a and 5b shows 2009 PE totals and anomalies (relative to the 1971-2000 average) for the network of MORECS squares across the Britain. Annual PE losses ranged from >650mm, mostly in eastern England, to <500mm, predominantly in the uplands of northern Britain. All regions registered only modest anomalies but, at the national scale, PE losses rank amongst the highest 15 in a series from 1961. Figure 6a shows 2009 AE annual totals (for a grass cover) across Great Britain. The totals reflect both the restraints caused by dry soils and the lower evaporative demands which characterise much of northern and western Britain, the uplands in particular. Annual AE totals of below 450mms were largely restricted to parts of Scotland and areas adjacent to the Thames estuary where exceptionally high soil moisture deficits restricted August/September evaporation losses. This is reflected in the annual AE totals (Figure 6a); most 2009 totals were within 10% of the average but below average totals characterised much of East Anglia (Figure 6b).

The difference between the annual totals of PE and AE (given on Figure 4a) is a good general indicator of agricultural water stress (in the absence of irrigation). Areas in which the annual difference was above the 1971-2000 average were restricted to the south east of England, East Anglia and Lincolnshire. Here, differences between PE and AE developed during May and June and persisted until November, substantially later than in 2007 and 2008. In a few coastal areas in East Anglia and around the Thames estuary, where the combined August and September AE losses were the 2nd lowest on record, the annual shortfall of AE relative to PE was in excess of 220mms.

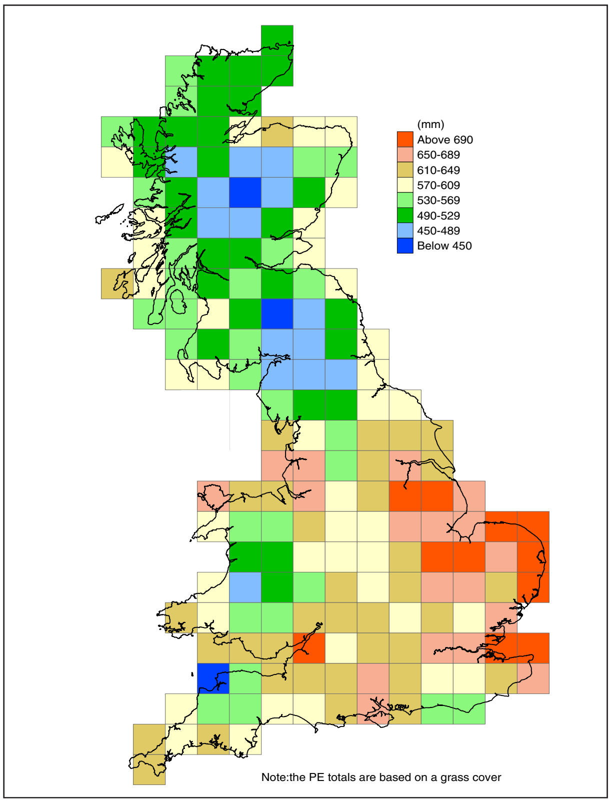


Figure 5a *Potential Evaporation totals for 2009*
Data source: MORECS

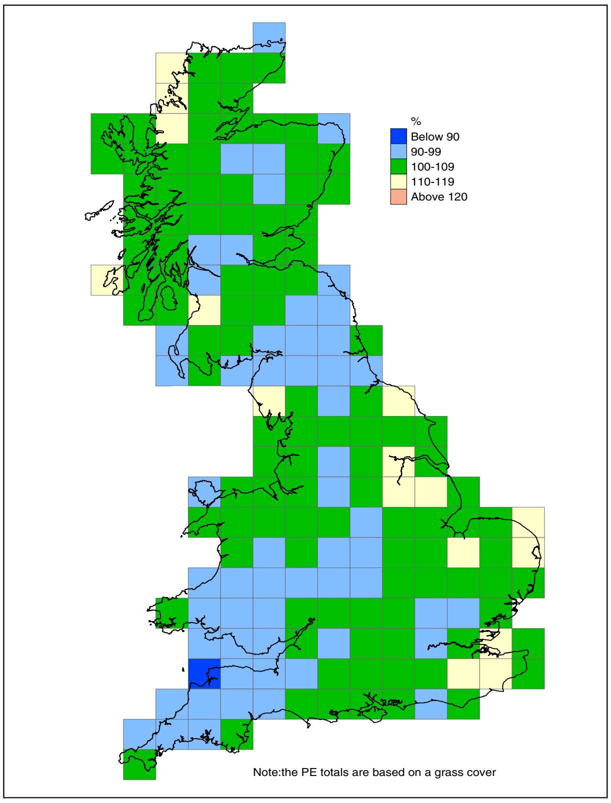


Figure 5b *Potential Evaporation totals for 2009 as a % of the 1971-2000 average*
Data source: MORECS

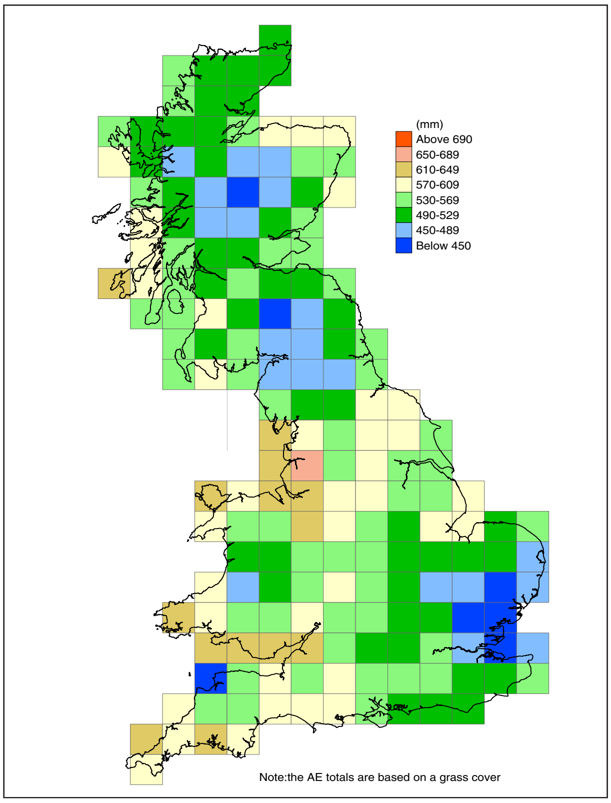


Figure 6a *Actual Evaporation totals for 2009*
Data source: MORECS

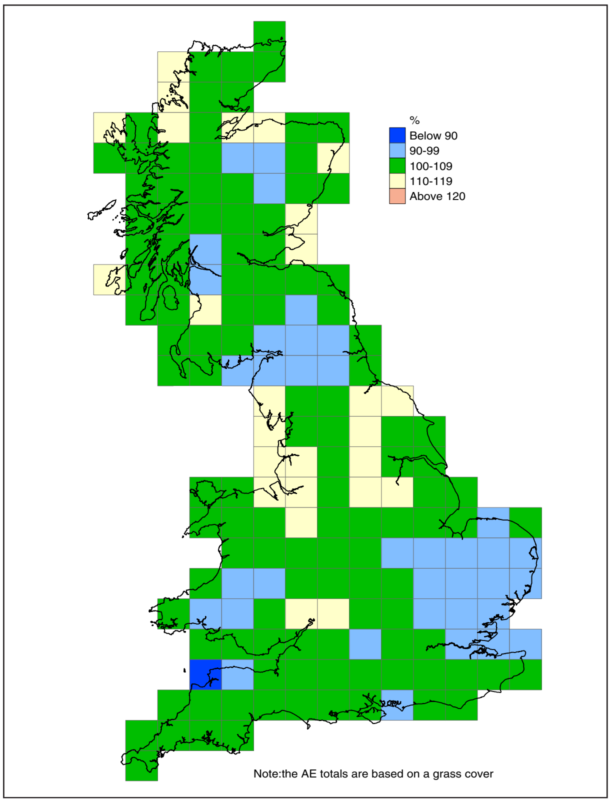


Figure 6b *Actual Evaporation totals for 2009 as a % of the 1971-2000 average*
Data source: MORECS

Soil moisture deficits

Soil moisture deficits began to build in the early spring and climbed sharply during the dry, and warm, April. Deficits then continued a relatively steep seasonal rise throughout May and June before, unusually, declining in some areas during the very wet July. In many places in northern and western Britain the driest soil conditions occurred in late June and early July; a relatively rare circumstance. In these regions the exceptional July rainfall saw a return to near-saturated conditions before modest deficits were briefly re-established in the late summer. End-of-July SMDs for England & Wales as a whole were comparable to those in 2008, but much higher than in 2007. There is no close modern precedent to the 3-year sequence of wet late-July soil conditions.

As is normally the case, smds were considerably higher across most of the English Lowlands than in western and northern regions of the country. The July rainfall only moderately reduced deficits (although within month variability was considerable) and their subsequent further increase through the late summer and early autumn resulted in notably high deficiencies by late September across south-eastern parts of Britain: see Figure 7a. In a zone from Dorset to Kent soils were close to their driest on record for the autumn (see Figure 7b).

By early-October SMDs were the equivalent of 10-12 weeks of effective rainfall across most eastern, central and southern aquifer outcrop areas. In most areas, the November deluge caused a precipitous fall in SMDs leaving soils close to field capacity across almost all of the UK. Modest residual deficiencies remained into December in a few areas (in East Anglia and the Midlands) but, entering 2010, soils were close to saturation across the entire country.

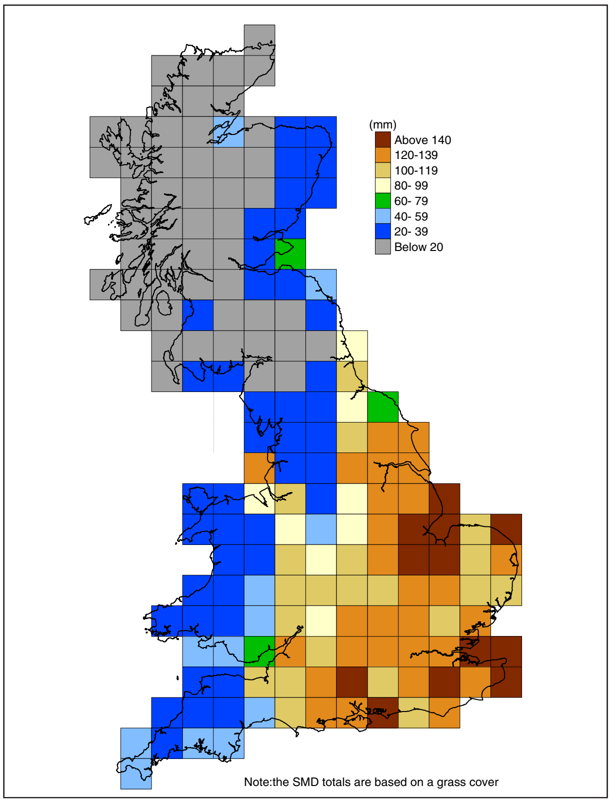


Figure 7a *Soil moisture deficits at the end of September 2009*
Data source: MORECS

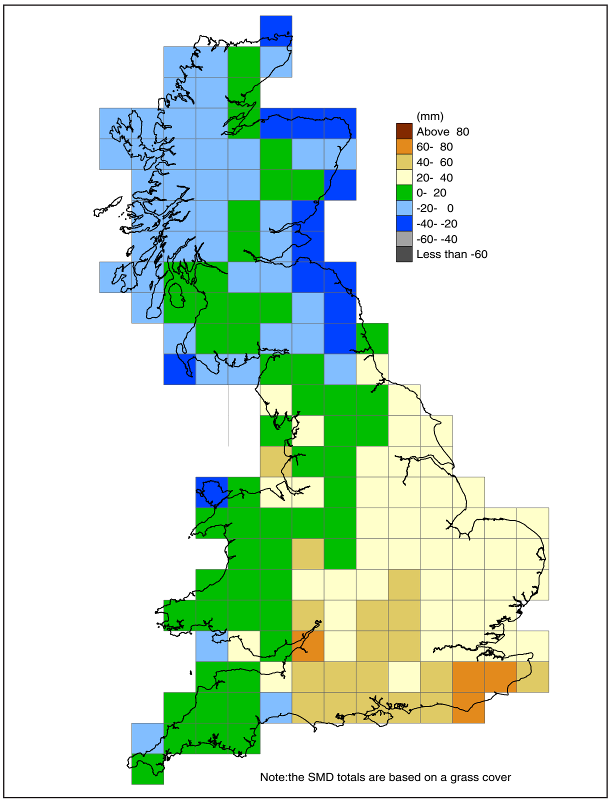


Figure 7b *Soil moisture deficit anomalies (relative to the 1971-2000 average) at the end of September 2009*
Data source: MORECS

River flows

Overview of 2009 runoff

In terms of the UK's annual runoff, 2009 was a fairly typical year – following the deficiencies experienced in 2005 and 2006, and the exceptionally high runoff in 2007 and 2008. Estimated annual outflows for the country as a whole in 2009 were around 7% above the 1971-2000 average with most index rivers registering near- or above-average mean flows.

A fairly muted spatial variability in the annual runoff total anomalies (see Figure 8) masks considerable complexity in the spatial and, particularly, temporal dynamics of streamflow patterns through the year. The most exceptional runoff totals were experienced in rivers draining into the Solway Firth, and from the Sperrin Hills in Northern Ireland. In part, these notable runoff totals reflect the remarkable flows which occurred during November (see below).

Monthly runoff totals were however below average throughout much of 2009, during the spring and early summer in particular. Notably low flows were widely reported in late June when many rivers registered their annual minimum flow – substantially earlier than normal in most cases. Subsequently, an atypical seasonal recovery in flow rates through July and August (associated with some monthly peak flow records and localised flooding) contributed to notably high summer runoff totals for the third successive year. The 2007, 2008 and 2009 June-August runoff totals for Britain as a whole cluster among the highest seven in a 50-year series. Correspondingly, annual minima flows in most rivers (those in the west and north especially) were healthy relative to the long term average.

Generally recessions were re-established in September and runoff during the early autumn was low in parts of eastern England but moderately above average in Scotland. In contrast, runoff during November was extraordinary - particularly over the second half of the month when floodplain inundations were extensive and sustained. The impacts were extreme in parts of Cumbria where the overall cost of the flooding approached £300 million[3]. At the national scale, the November outflows were the 6th highest for any month in the 49-year national outflow series. Existing gauged flow maxima were eclipsed in Northern Ireland, parts of Scotland and, in particular, rivers draining the Lake District (see Table 2).

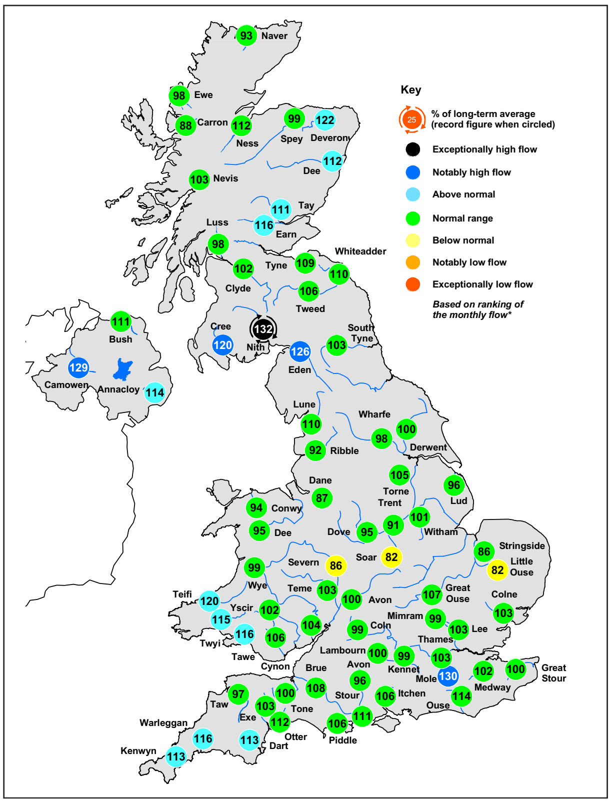


Figure 8 *2009 Annual catchment runoff totals as a % of the previous average*

River flow patterns

Figure 9 shows 2007-2009 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 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. Similar hydrographs for 16 index rivers provide a more detailed breakdown of runoff patterns across the UK (Figure 10).

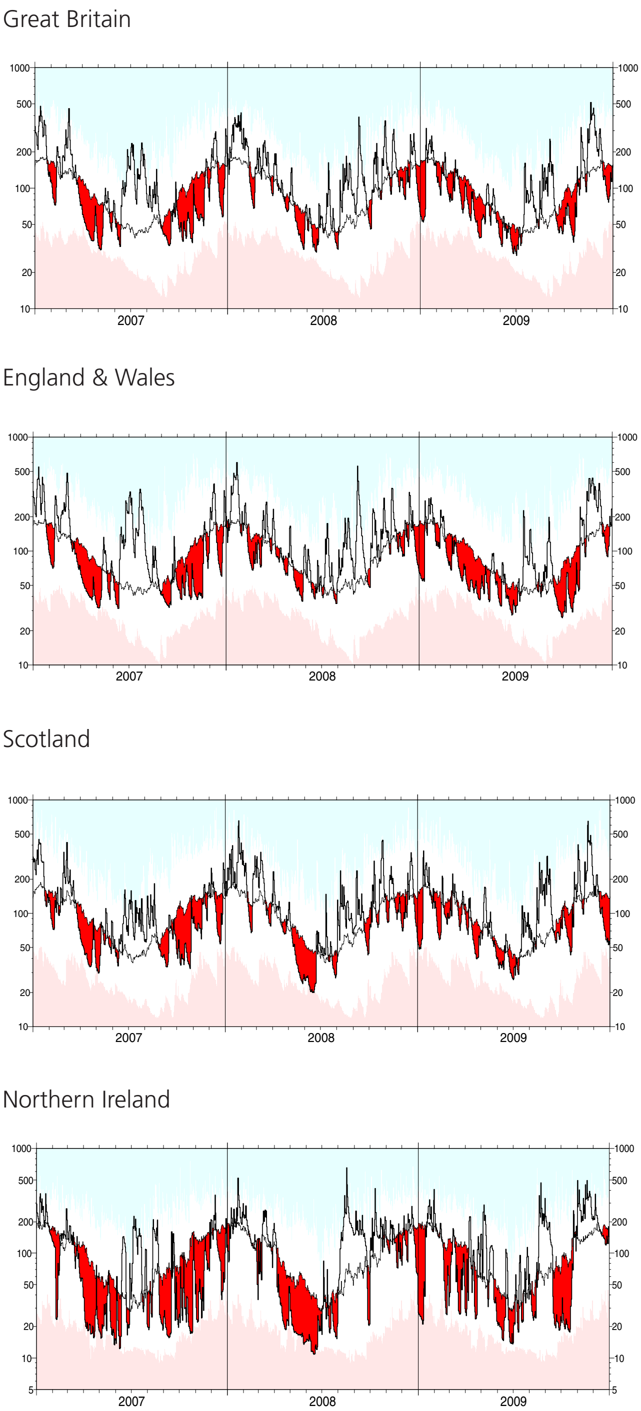


Figure 9 *2007-2009 daily flow hydrographs*

Table 2 features a selection of new high and low flow records established at primary UK gauging stations (with records ≥ 25 years) during 2009. Due to the uncertainties associated with capturing extreme flows, the table is necessarily provisional; individual entries may be subject to significant change following further investigation.

The year in brief

Early January saw a continuation of the steep recessions which began in mid-December 2008, and early January minimum flows were approached or eclipsed in many areas. The recessions were reversed during the second week and spate conditions continued (enhanced by snowmelt in northern catchments) with Flood Watches common around the 23rd. February saw similar flow variations. With headwater catchments frozen, river flows were again seasonally depressed before storms on the 8/9th resulted in new maximum peak flows in some eastern rivers (e.g. the Ter in Suffolk). Existing monthly maximum flows were exceeded in a significant number of southern rivers (including the Kennet and the Taw). Nonetheless, the winter (December-February) runoff totals for most western catchments were below average and Northern Ireland registered its 5th lowest winter runoff since 1981.

After some early March spates in parts of western and northern Scotland flows declined steeply and, by month end, flows in responsive rivers were seasonally depressed over wide areas. In April, a few intense local storms triggered flash flooding (e.g. on the 25th when widespread damage occurred in St. Ives, and three fatalities were reported after a car was trapped in a flash flood near Zennor, Cornwall). Generally however flows continued to decrease and April runoff totals were depressed over wide areas. Recessions continued through May, albeit punctuated by spates (e.g. in Northern Ireland) and, by month-end, flows were approaching late-May minima in some responsive eastern rivers (e.g. the Whiteadder). The dominance of modest flow rates is reflected in the depressed spring (March-May) runoff totals: outflows for England & Wales being the lowest since 1990. More notably in a water resources context, the February-May runoff for Wales was the 2nd lowest in a series from 1961.

Although very dry early summer soils and low antecedent flows exerted a clear moderating influence, flood alerts were in operation in some catchments across southern Britain in the second week of June (e.g. on the Exe and Rhymney). Recessions then became re-established and for many western and northern rivers, accumulated runoff totals since January were notably low (see Figure 11). The depressed early summer flows

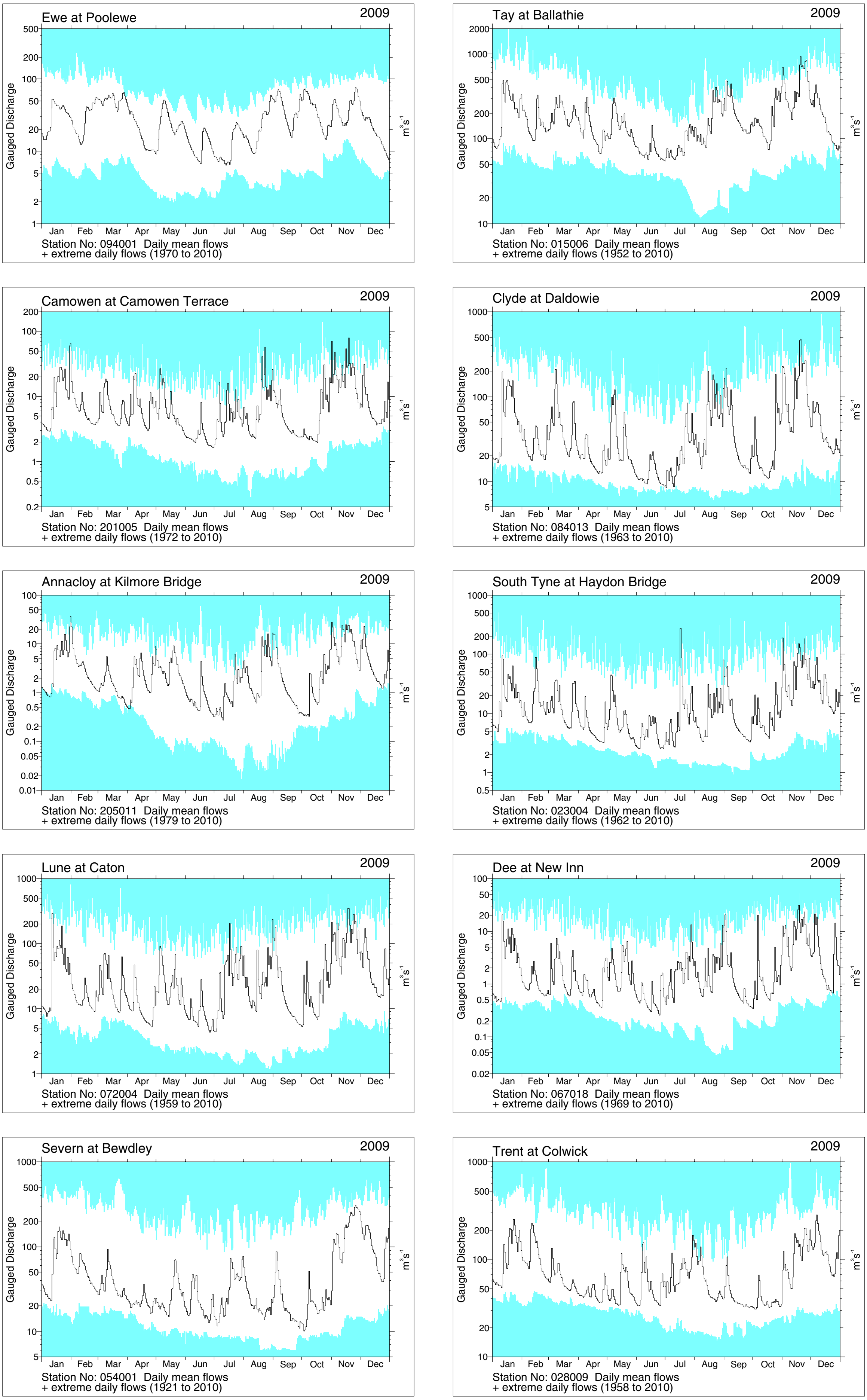


Figure 10 *2009 daily flow hydrographs for a selection of UK index catchments*

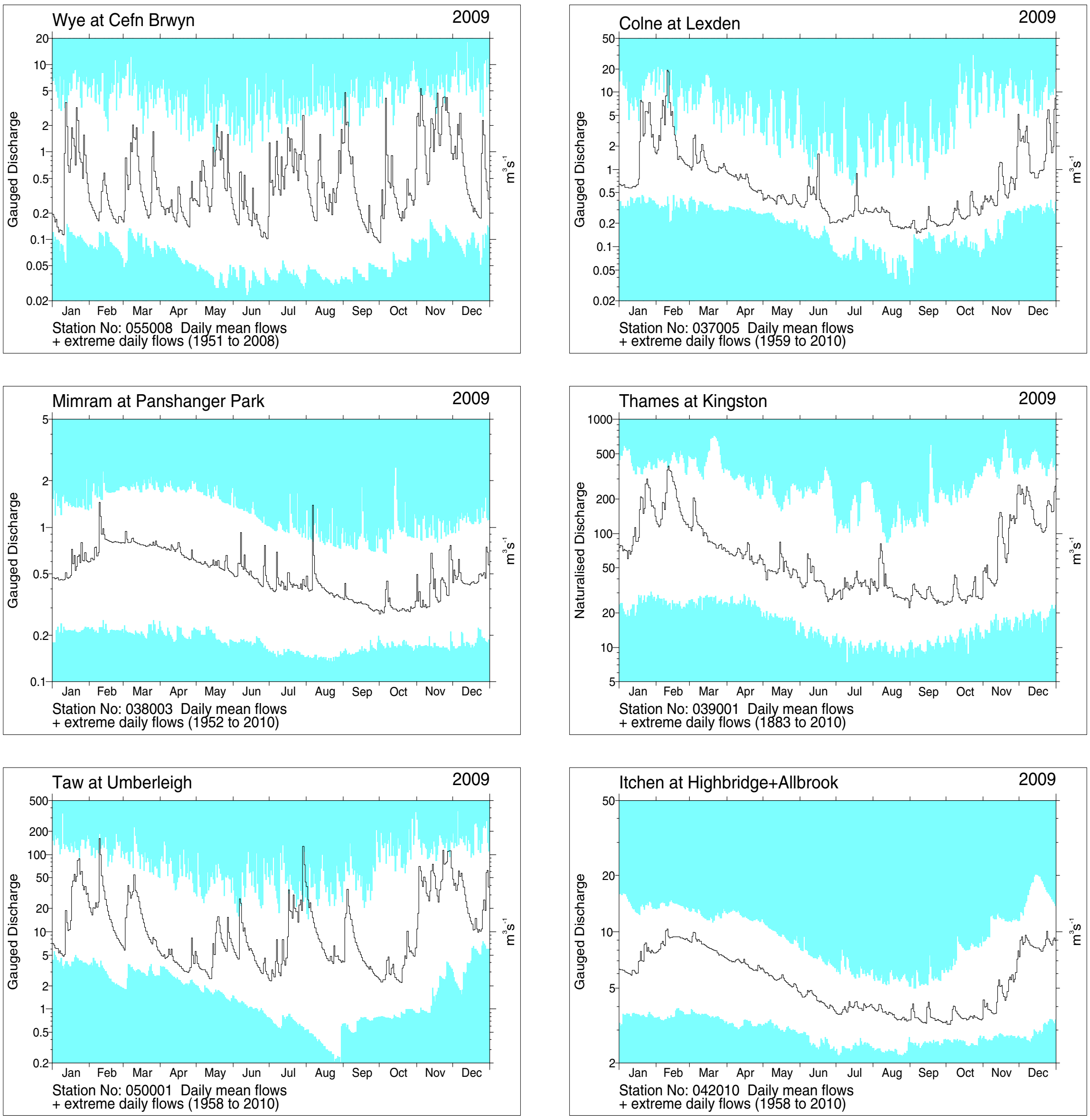


Figure 10 *(contd)*

caused moderate hydrological and ecological stress with a substantial, and seasonally early, contraction in the river network as headwater streams dried up. July saw a dramatic change in hydrological conditions: successive pulses of heavy frontal rainfall triggered high river flows and flash flooding in many areas. On the 7th urban drainage networks were overwhelmed in London causing major transport disruption. Significant fluvial flooding also occurred in western England, south Wales and north-east England – where the Wear reached a new maximum recorded level at Durham; some local geomorphological impacts were dramatic (see Plate 1). New maximum peak flows for July were widely recorded in a number of northern and western catchments (e.g. the Teifi, Taw, Dove and Whiteadder).

Plate 1 *Gorge cut in the alluvial floodplain (just downstream of Durham) by floodwaters returning to the river Wear following the July 2009 flood*
photo: Terry Marsh

Table 2 River Flow records established in 2009
Data sources: Environment Agency, Scottish Environment Protection Agency and Rivers Agency

Station Number	River	Station Name	First Year of Record	New Record (m3s-1)	Date
Highest Instantaneous Flows					
8011	Livet	Minmore	1981	68.508	04-Sep
9001	Deveron	Avochie	1959	315.127	01-Nov
9003	Isla	Grange	1969	121.676	03-Sep
9005	Allt Deveron	Cabrach	1986	45.296	01-Nov
12008	Feugh	Heugh Head	1985	294.711	01-Nov
13001	Bervie	Inverbervie	1979	74.012	01-Nov
14002	Dighty Water	Balmossie Mill	1969	47.241	04-Sep
18002	Devon	Glenochil	1959	120.095	19-Nov
24004	Bedburn Beck	Bedburn	1959	79.200	17-Jul
24005	Browney	Burn Hall	1954	94.800	17-Jul
24009	Wear	Chester le Street	1977	381.000	18-Jul
36002	Glem	Glemsford	1960	21.700	10-Feb
37003	Ter	Crabbs Bridge	1950	10.900	09-Feb
37013	Sandon Brook	Sandon Bridge	1963	20.400	09-Feb
37031	Crouch	Wickford	1976	39.400	09-Feb
39049	Silk Stream	Colindeep Lane	1973	18.800	27-Jun
40013	Darent	Otford	1969	21.200	09-Feb
41001	Nunningham Stream	Tilley Bridge	1950	18.400	09-Feb
42001	Wallington	North Fareham	1975	24.347	09-Feb
60004	Dewi Fawr	Glasfryn Ford	1969	28.500	01-Nov
67018	Dee	New Inn	1969	98.900	18-Nov
73002	Crake	Low Nibthwaite	1963	51.000	19-Nov
73010	Leven	Newby Bridge FMS	1954	239.000	20-Nov
73014	Brathay	Jeffy Knotts	1976	285.000	19-Nov
74008	Duddon	Ulpha	1976	104.000	19-Nov
75001	St Johns Beck	Thirlmere Reservoir	1935	155.000	19-Nov
75002	Derwent	Camerton	1962	700.000	19-Nov
75003	Derwent	Ouse Bridge	1968	378.000	19-Nov
75004	Cocker	Southwaite Bridge	1968	201.000	19-Nov
75005	Derwent	Portinscale	1972	226.000	19-Nov
76001	Haweswater Beck	Burnbanks	1953	63.300	19-Nov
76003	Eamont	Udford	1961	417.000	19-Nov
76015	Eamont	Pooley Bridge	1970	214.000	19-Nov
78006	Annan	Woodfoot	1983	188.618	19-Nov
80002	Dee	Glenlochar	1977	391.982	20-Nov
85002	Endrick Water	Gaidrew	1963	176.344	19-Nov
101002	Medina	Upper Shide	1965	10.758	09-Feb
101005	Eastern Yar	Budbridge	1982	10.340	09-Feb
203010	Blackwater	Maydown Bridge	1970	188.000	20-Nov
Lowest daily mean flow					
027053	Nidd	Birstwith	1975	0.368	29-Sep

Note: The peak values are based on the highest recorded 15-minute flow for each featured gauging station. Many are beyond the confirmed range of the stage-discharge relationship and therefore subject to a wide uncertainty band.

August flow patterns were notable for their large temporal and spatial contrasts. Runoff rates in northern Britain recovered smartly from mid-month and flood alerts were again common. Floodplain inundations were generally modest but estimated outflows from Scotland and Northern Ireland closely approached the late-August maximum. In contrast, end-of-summer flows were meagre in some responsive southern and eastern rivers. In Kent, the Gt. Stour registered its lowest end-of-August flows for a decade. Flows in the English Lowlands remained depressed through much of September; the Little Ouse registered its 2nd lowest September runoff in a series from 1968. Characteristically, runoff rates held up more effectively in many spring-fed streams. Early September also provided a respite from the seasonal spates across much of northern Britain but extensive flooding was experienced in eastern Scotland during the first week. Peak flows in the Deveron and Isla exceeded previous maxima (in records of 50- and 40-years respectively) and flooding on the Lossie (e.g. at Elgin) necessitated the evacuation of many homes.

Seasonal flow recoveries gathered further momentum in most of western and northern Britain from mid-October heralding some exceptionally high flows in Scotland. On 21-23rd the Don registered its 5th highest flow on record. The associated flooding caused severe transport disruption. In much of southern and eastern Britain however flows continued to decline. Flows in the Lud (Lincolnshire) fell to their lowest since the summer of 1997 and end-of-October flow rates were <50% of average in many catchments. For England & Wales as a whole estimated October outflows were the 3rd lowest in over 30 years.

Widespread spate conditions on the 1st November, with flooding in north east Scotland, heralded a remarkable month in runoff terms (see Figure 12). Flood risk remained high across a substantial proportion of the country. Early in the month severe flooding was experienced in Banff and Aberdeenshire; the peak flow on the Deveron (at Muiresk) exceeded its previous maximum (registered in September). With catchments saturated and most responsive rivers in high spate, the extreme rainfall over the 17-20th November triggered a devastating flood

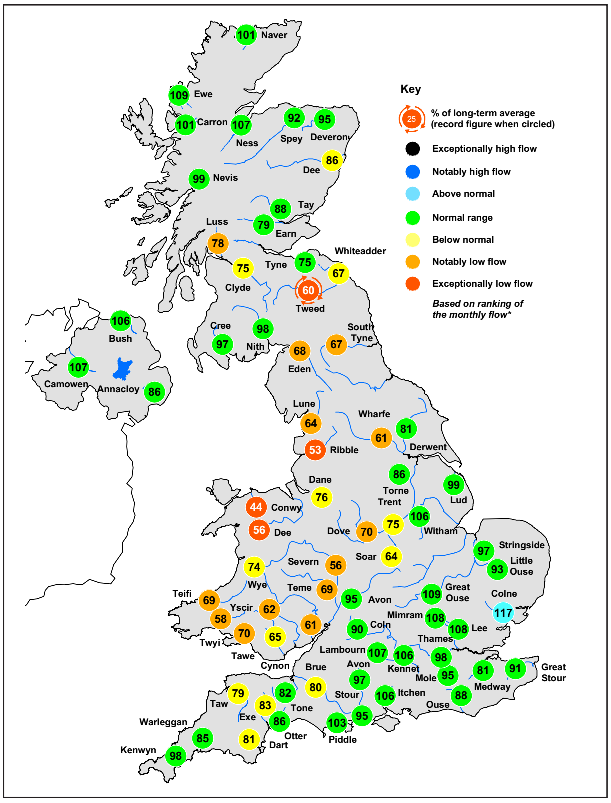


Figure 11 *February - June 2009 catchment runoff totals as a percentage of the previous average*

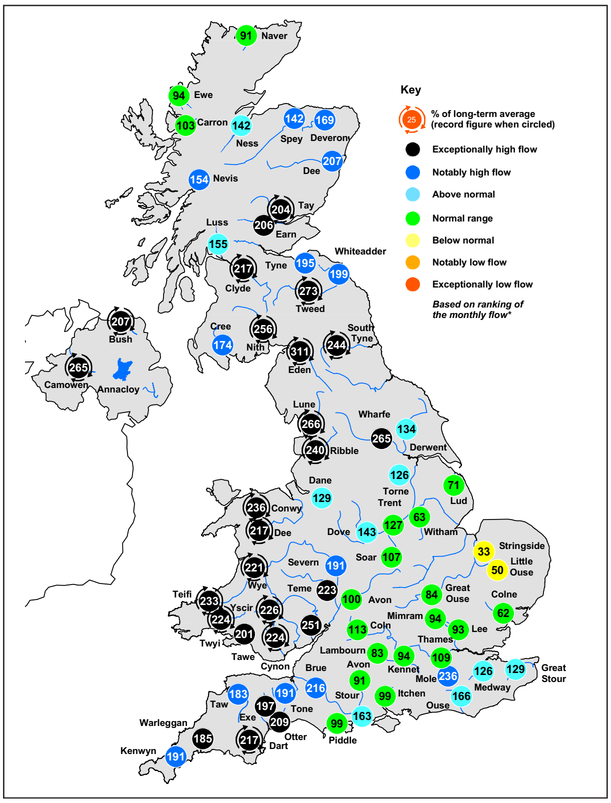


Figure 12 *November 2009 catchment runoff totals as a percentage of the previous average*

episode in Cumbria (and extending into south west Scotland). Many rivers in the Lake District (including the Derwent, Cocker and St Johns Beck) exceeded their previous maximum flow by a wide margin as did outflows from Windermere (in a 70-year series)[4]. Floodplain inundations were both extensive and sustained with very severe impacts on communities (Cockermouth and Workington particularly). Collapsed bridges and landslips contributed to severe transport disruption. Very exceptional flows were also reported in a broad band from north Wales to western Scotland; the Nith eclipsed its previous November maximum in a 53-year series. Flooding was also severe in Northern Ireland (Lough Earn spilled causing extensive agricultural flooding).

December began with more than 100 flood alerts still in operation across England & Wales – but exceptionally steep recessions then ensued before further spate conditions affected southern Britain; snowmelt being a contributory factor in many cases. The rapid passage of most low pressure systems helped moderate storm rainfall totals and, as a consequence, the risk of severe flooding was moderated. However, with considerable snowpack storage (10-30cm across many upland areas), milder conditions (accompanied by rain in some areas) triggered further high flows around the 30th. Boosted by the lagged impact of the late November rainfall (and increasing baseflows in permeable catchments) December runoff totals were appreciably above average across much of the country but relatively depressed in some north-western catchments.

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. Figure 13 provides examples showing flow duration curves for both 2009 and the preceding record for Great Britain, England & Wales and Northern Ireland; for the latter the distinctive shape of the duration curves reflects the major influence of controlled releases from Lough Neagh.

Further duration curves for a selection of index rivers across the UK are shown on Figure 14; they allow variations in 2009 flow regime characteristics between regions and between catchments types to be examined.

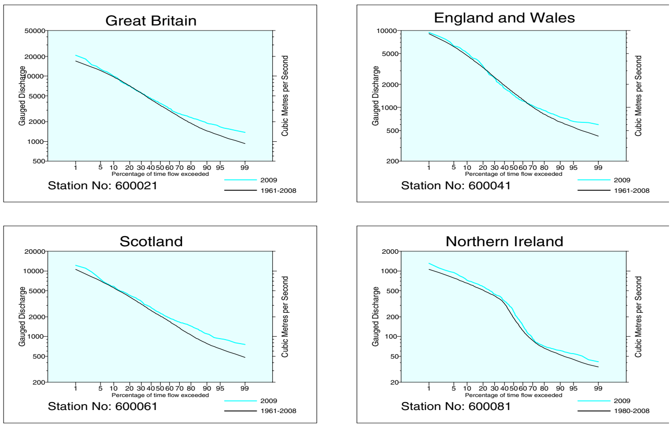


Figure 13 *Flow duration curves (national outflows)*

A common feature of the national flow duration curves, and those for almost all index rivers also, is the relative health of low flows during 2009. The Q_{95} flows for 2009 were typically 20-50% greater than for the preceding record with particularly large anomalies in baseflow dominated southern rivers and across most of northern Britain. For Scotland, the Q_{95} outflow was the 2nd highest since 1985. Median flows (Q_{50}) were generally very close to the corresponding long term values whilst high flows, here taken to imply flows of Q_5 magnitude and above, were mostly a little greater than for the preceding record and notably high in a number of, mostly western, catchments. However, in the English Lowlands high flows were generally less frequent than in a normal year. This was most evident in baseflow-dominated rivers (e.g. the Mimram) where, for the third successive year, the overall range of flows was appreciably narrower than that which characterises most years.

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 over wide areas. 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 the north-west of England. Limestone aquifers are

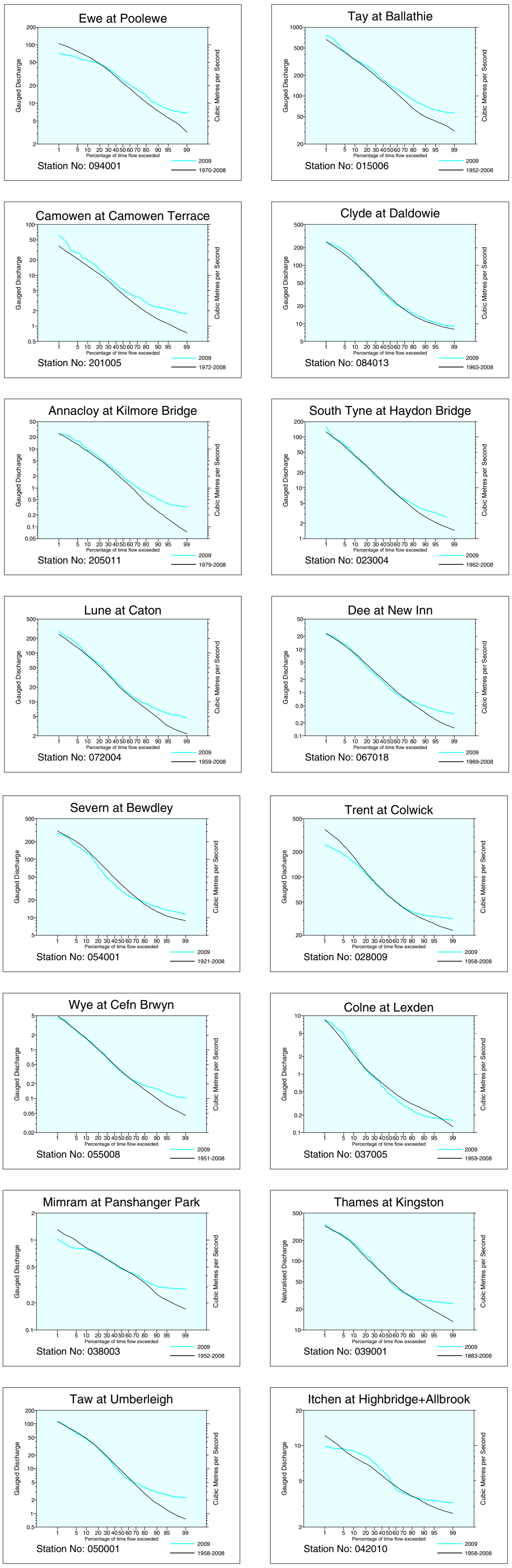


Figure 14 *Flow durations curves (for a selection of index catchments)*

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. Infiltration, and hence variations in water levels, are also affected by the properties of the deposits through which it passes to reach the saturated zone of an aquifer. The fluctuation in groundwater levels is also influenced by its storage characteristics; in those aquifer units with low storage coefficients, recharge with a given volume of water will result in a greater rise in water levels than where storage capacities are higher. Groundwater levels fall naturally through the spring and summer as increasing evaporative demands and drying soils progressively restrict infiltration, and aquifer storage is depleted by natural outflows to rivers and springs but may also decline as a result of abstraction from boreholes.

Evaporation losses exhibit limited year-on-year variability but account for more than half the annual rainfall across many aquifer outcrop areas. Correspondingly there is 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.

Overview of 2009

2009 rainfall totals over the outcrop areas of the main UK aquifers were generally close to the 1971-2000 average (see Table 1). But more importantly in a water resources context, rainfall for the 2008-09 winter half-year (October-March) was 10-20% below average across some outcrop areas (e.g. in the Midlands and Yorkshire). In addition, the spring (March-May) rainfall, which is very influential in determining the onset of the seasonal recessions in groundwater levels, was also considerably below average; the Anglian Region reported its driest spring since 1997. Fortunately relatively heavy, if seasonally rather irregular, recharge in the latter half of 2008 resulted in the 2009 recessions commencing from above average spring maxima for most index boreholes. Notwithstanding the wet summer, the recessions in 2009 were protracted and groundwater levels were notably depressed in some areas through the early autumn (see Figure 15). However, as with surface water resources, the extreme November rainfall was pivotal in determining the groundwater resources outlook. Very steep rises in groundwater levels were registered in most outcrop areas in late November and early December 2009 leaving overall groundwater resources again above average at year-end.

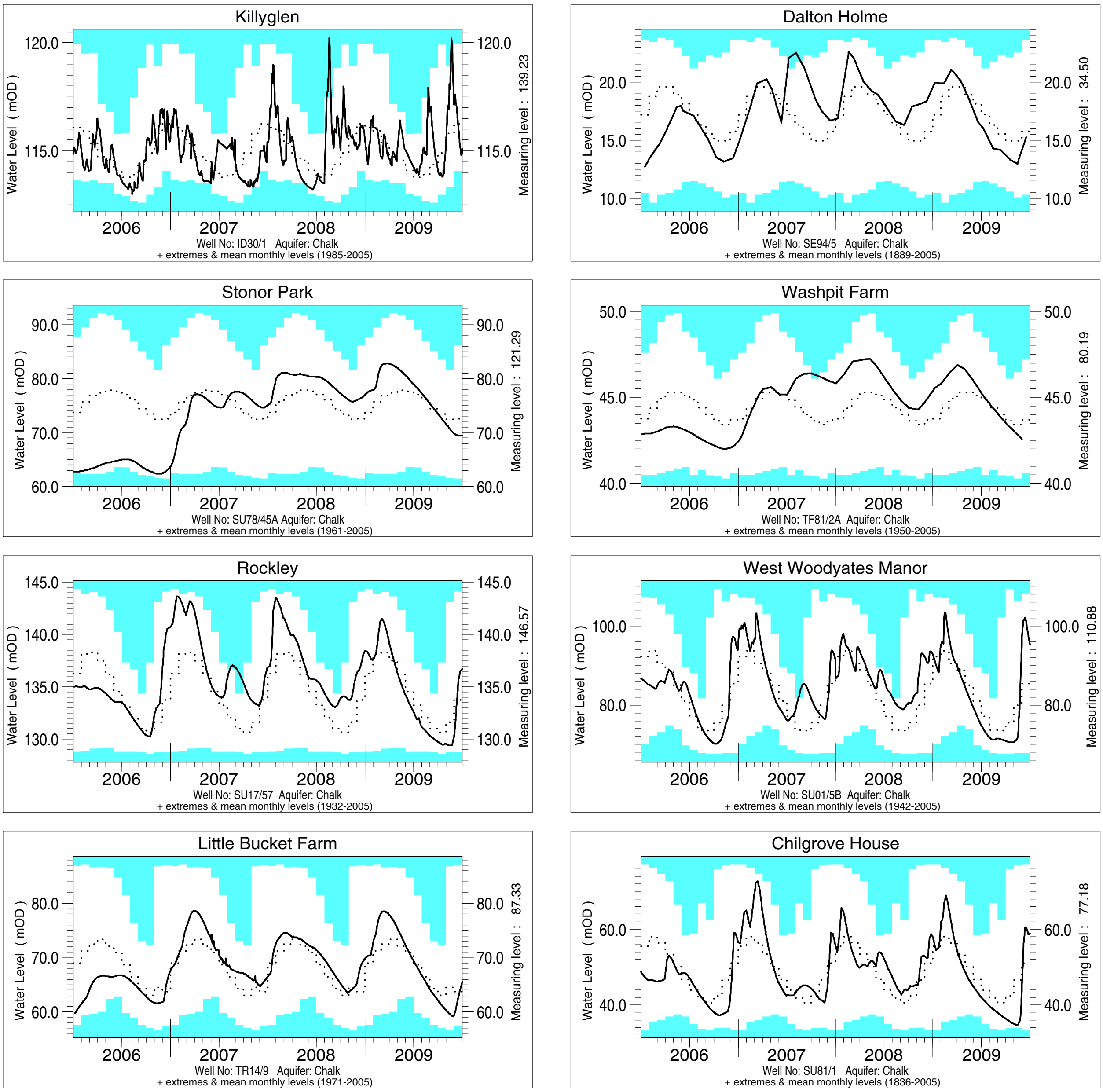


Figure 15 *2006-2009 groundwater level hydrographs*

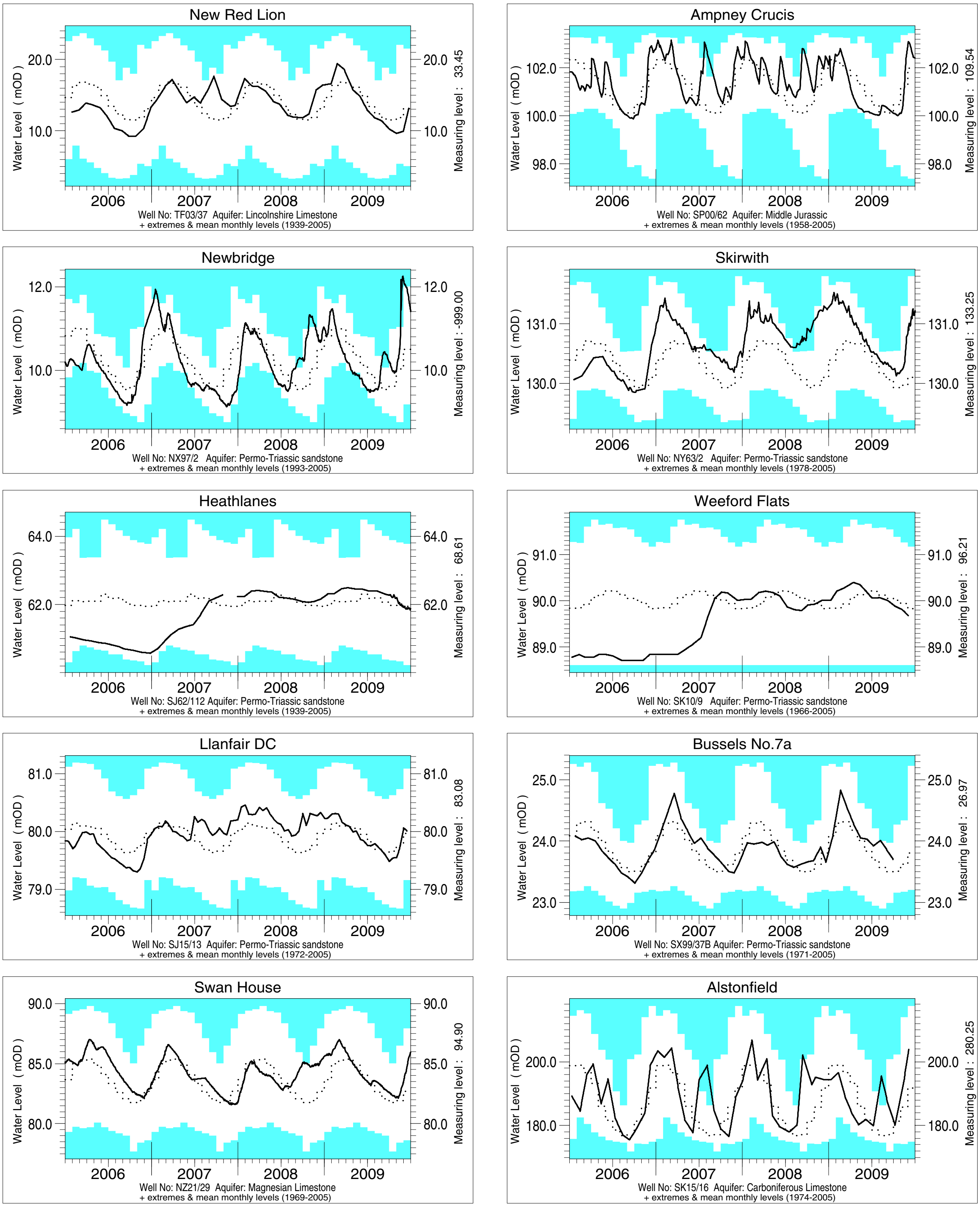


Figure 15 *(contd)*

The year in brief

Late-2008 groundwater levels were generally above the early winter average and January recharge, though limited in the first half of the month, reinforced the healthy resources outlook. February was a relatively dry month nationally but the rainfall distribution was beneficial from a groundwater resources perspective; much of the English Lowlands reported >120% of the monthly average. With soils close to saturation throughout the month, conditions were very favourable for substantial late-winter recharge – although at times frozen ground restricted infiltration. Some exceptional groundwater levels increases were recorded (e.g. in the southern and eastern Chalk) and February groundwater levels were generally above average.

With March rainfall falling below 70% of average in most outcrop areas, aquifer replenishment was less than half the average and the dry start to April signalled the end of the 2008/09 recharge season in many eastern and central aquifer outcrop areas. Although recessions were relatively steep through the early spring, groundwater levels generally remained within the normal range. However the very modest May infiltration left groundwater levels generally below average in the more responsive aquifers, particularly across the limestone outcrops; In the Cotswolds, Ampney Crucis reported its lowest May level since 1976.

Infiltration in June was primarily restricted to a few localities which caught the brunt of the convective storms. By month end, groundwater levels were mostly below the early summer average but healthier in the slow-responding Permo-Triassic sandstones of the Midlands Figure 16. July was notably wet across almost all outcrop areas but generally soil moisture deficits remained sufficient to preclude anything but very localised infiltration across the English Lowlands. By contrast, to the north and west, seasonally rare increases in groundwater levels were reported e.g. at Killyglen (Chalk) and Bussels (Permo-Triassic sandstones).

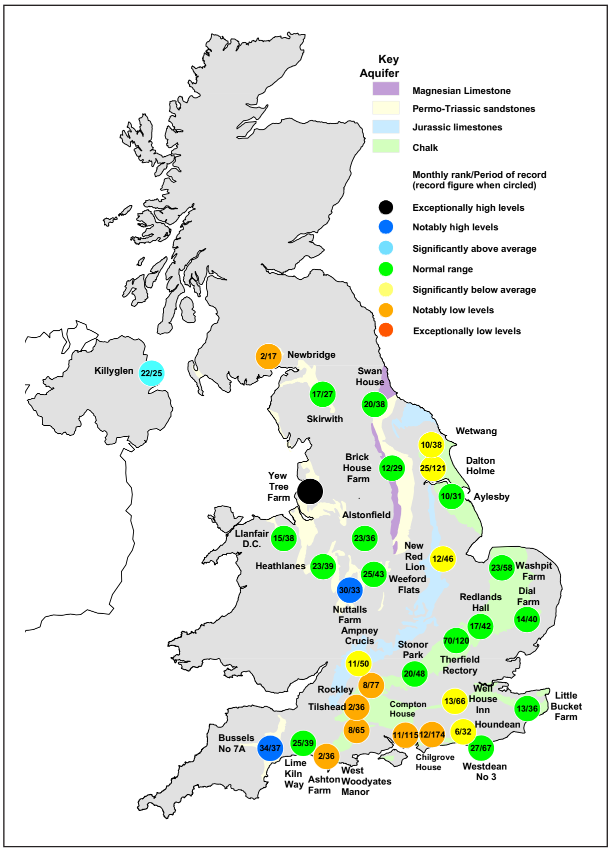


Figure 16 *Groundwater levels in July 2009*

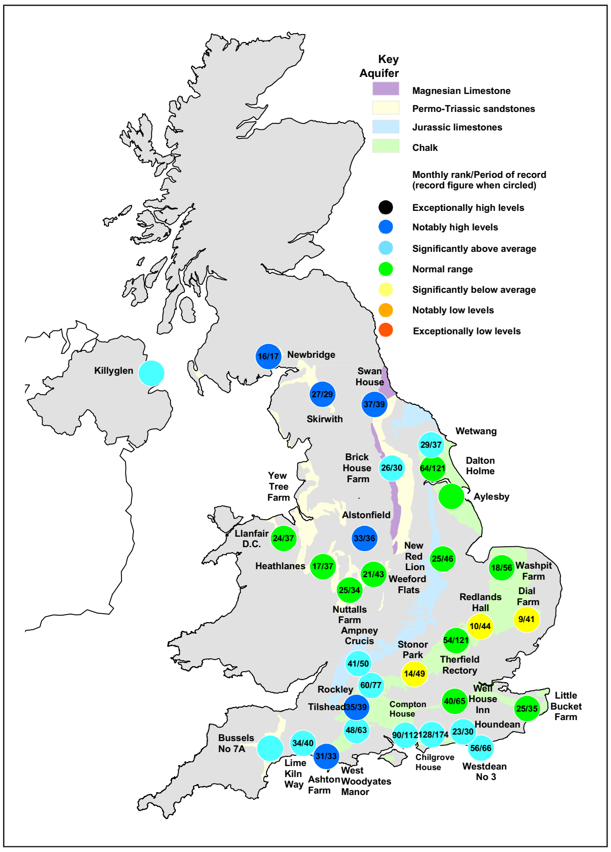


Figure 17 *Groundwater levels in December 2009*

As is normally the case), aquifer replenishment to lowland aquifers during August was minimal but appreciable recharge did occur in a number of western outcrop areas. This, together with the significant July pulse, generated some sharp late-summer rises in groundwater levels (e.g. at Newbridge and Alstonfield where a new August maximum level was reported). By contrast, in the southern Chalk, Tilshead reported its 2nd lowest August level on record.

Groundwater level recessions continued into the autumn and natural base levels were approached in parts of the Chalk outcrop. For example, the Chilgrove and Rockley wells reported their lowest levels since the 2005-06 drought, and levels were relatively depressed across much of the South East. Elsewhere, levels were generally in the normal range but there was concern that the dryness of the lowland soils would substantially delay the seasonal recovery, in the Chalk especially. The sustained November rainfall was therefore very timely. Abundant infiltration characterised the latter half of the month, continuing into December. Exceptionally steep groundwater level recoveries were recorded in parts of the southern Chalk (see, for example, the West Woodyates hydrograph). This pattern was replicated in most of the limestone wells. In south west Scotland, the exceptional November rainfall resulted in the highest recorded level at Newbridge in a 16-yr series.

The outstanding November and early December recharge transformed the general groundwater resources outlook and although infiltration rates were significantly reduced by frozen ground conditions over the latter half of the month, groundwater levels generally continued to rise. Some increases were exceptional: a 15 metre rise in groundwater levels was recorded at Tilshead. Levels across the Chalk were generally within, or above, the normal early winter range (see figure 17) but relatively low in some eastern areas where, for some index boreholes (e.g. Washpit Farm),the seasonal recovery was still awaited. Above average levels also characterised most index wells in the Limestone and Permo-Triassic sandstones aquifers at year end with notably high levels at several locations – including Skirwith which benefited from the extreme November rainfall across Cumbria.

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. 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. Following the 1950s however, a much reduced abstraction rates resulted in a recovery of around 40m with levels rising by 1-2m a year through much of the 1980s and 1990s (see Figure 18). 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 7 metres, in levels at Trafalgar Square over the post-2000 period.

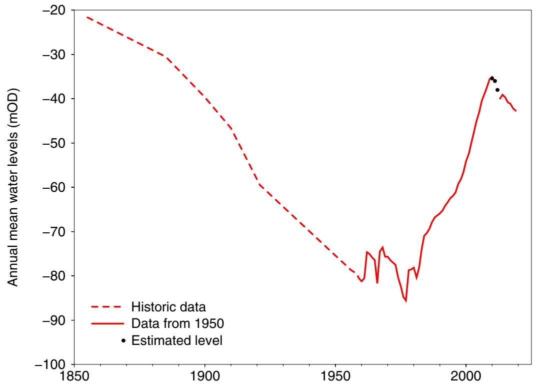


Figure 18 *Groundwater levels at Trafalgar Square 1840-2009*

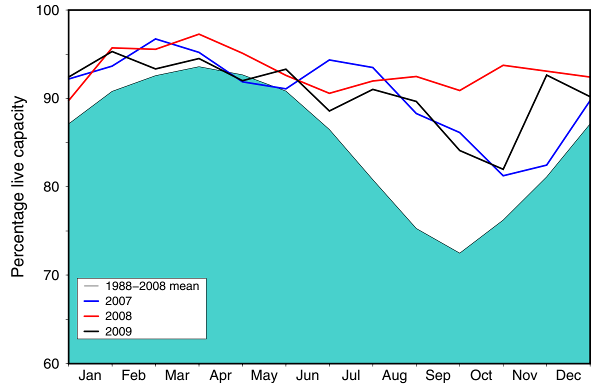


Figure 19 *Variation in overall reservoir stocks for England & Wales*
Data sources: Water Service Companies and the Environment Agency

Reservoir stocks

The recent past

Reservoir stocks have shown substantial spatial and temporal variation over the last 20 years (see Figure 20) but generalising broadly, estimated overall reservoir stocks for England & Wales, were relatively low during the late 1980s and much of the 1990s but subsequently remained above average apart from the intense phase of the 2003 drought and, less extensively, during the 2004-06 drought when particular water resources stress, including hosepipe bans, was experienced in the parts of the English Lowlands. The general picture is similar for Scotland[a] and Northern Ireland (where overall stocks are dominated by storage in Lough Neagh). Stocks remained healthy throughout most of the last 15 years but in the late autumn of 2003, overall stocks for index reservoirs in Scotland fell to below half of capacity, a rare circumstance. Stocks were also low in Northern Ireland but remained above those recorded in the 1995 when, for the only time in a 15-year series, overall stocks fell to below 30%.

a National reservoir contents series for Scotland and Northern Ireland begin in 1994 and 1995 respectively.

Reservoir stocks in 2009

Entering 2009, overall reservoir stocks for England & Wales were around 5% above the early January average, and close to capacity in the majority of index reservoirs across the UK; a legacy of the very healthy stocks throughout most of 2008 (Figure 19). Some reservoir drawdown for flood alleviation purposes was necessary in a few areas during January, and poor river water quality limited the replenishment of Farmoor Reservoir (Oxfordshire). Overall stocks for the UK remained very healthy through the late winter but the limited February rainfall in many western gathering grounds caused significant falls in the level at some large impoundments. In the early spring, stocks in almost all index reservoirs exceeded 90% of the average for the time of year, and most remained close to capacity. The limited March rainfall resulted in seasonally-steep declines in some areas (e.g the Lake District) but overall stocks for England & Wales registered (albeit marginally) their 23rd successive month with above average stocks. In Scotland and Northern Ireland, reservoir levels remained well within the normal seasonal range. As usual, seasonal declines accelerated during April and stocks were relatively depressed at month-end in some western areas (in north west England, stocks in the Northern Command Zone group of reservoirs were the 2[nd] lowest for early

May in a 22-year series (although considerably higher than during the benchmark drought year of 1984). May rainfall was well below average at the national scale but the rainfall patterns generally favoured the catchments of many large upland reservoirs. Some seasonally notable increases in stocks were registered (e.g. in the Lake District and north Wales) and all index reservoirs in Scotland and Northern Ireland reported above average end-of-spring levels.

June was mostly dry and warm but several active frontal systems produced very valuable early summer replenishment to many upland reservoirs. As a consequence, reservoir stocks fell by less than 5% over the month for England & Wales as a whole. There were, however, significant declines in some smaller southern reservoirs (e.g. Ardingly) and, in Wales, stocks at Vyrnwy were seasonally low. The record July rainfall then produced an increase in overall stocks for only the second time since 1988 (they rose in July 2008 also); most of this was due to recoveries in western reservoirs. Entering August, stocks in almost all index reservoirs were within 10% of the average for the time of year. Near-saturated late summer soils encouraged significant inflows to many upland reservoirs (e.g. in the Lake District and western Scotland) and estimated overall stocks in England & Wales, Scotland and Northern Ireland were close to, or above, their previous end-of-summer maximum. There were, however, important regional variations. In the South East, for example, early September levels in several reservoirs remained appreciably below average.

High pressure dominated synoptic patterns in September; this is reflected in a considerable decline in reservoir stocks (for England & Wales) through the month. Nonetheless, by month-end Bewl Water was the only index reservoir reporting stocks more than 5% below average for the time of year. The sustained high runoff rates in November generated an exceptionally high, (>10%) increase in overall reservoir stocks for England & Wales, leaving them at their 4th highest, for early December, in a series from 1988. Estimated overall stocks for Scotland and Northern Ireland were also exceptional; for Scotland the highest (for any month) since March 1997. Below average early-winter stocks in UK index reservoirs were restricted to a few reservoirs in the English Lowlands (e.g. Rutland and Bewl). Some local drawdown to moderate flood risk was necessary during the first 10 days of December (e.g. at Clywedog) but, generally, inflows were plentiful despite a dry latter half of the month. Most major reservoirs were close to capacity entering 2010 with a few exceptions (e.g. Rutland and Clywedog).

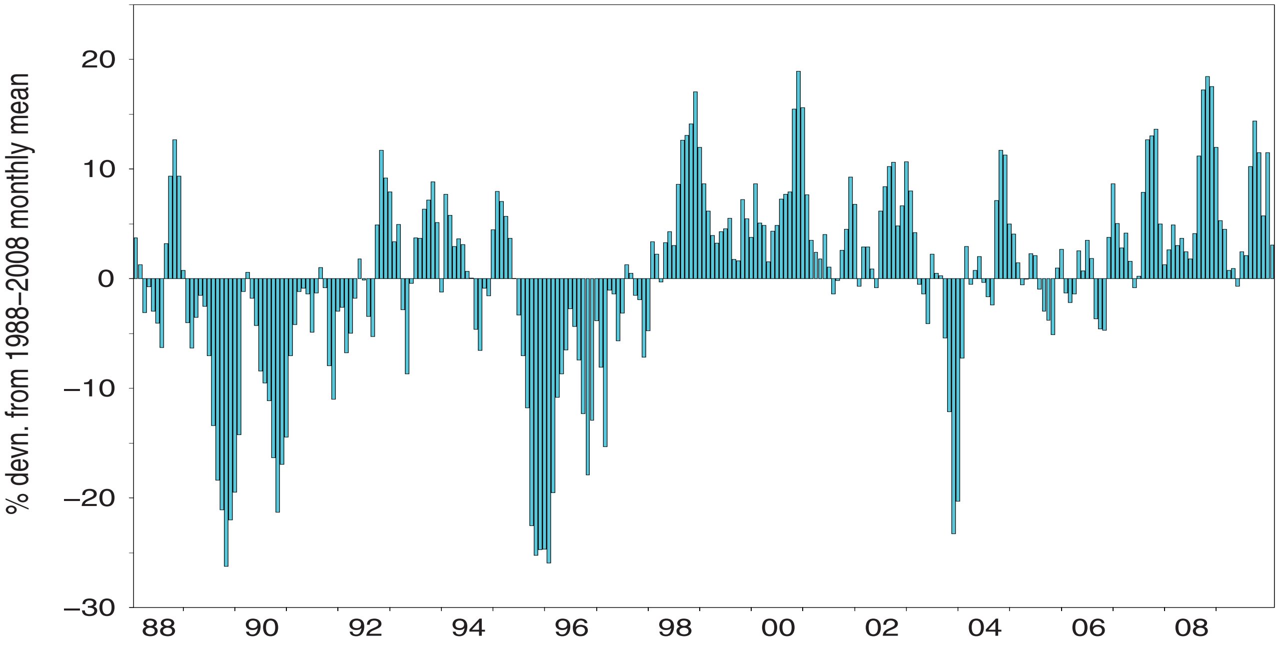


Figure 20 *A guide to England & Wales reservoir stocks, 1988-2009*
Data sources: Water Service Companies and the Environment Agency

References

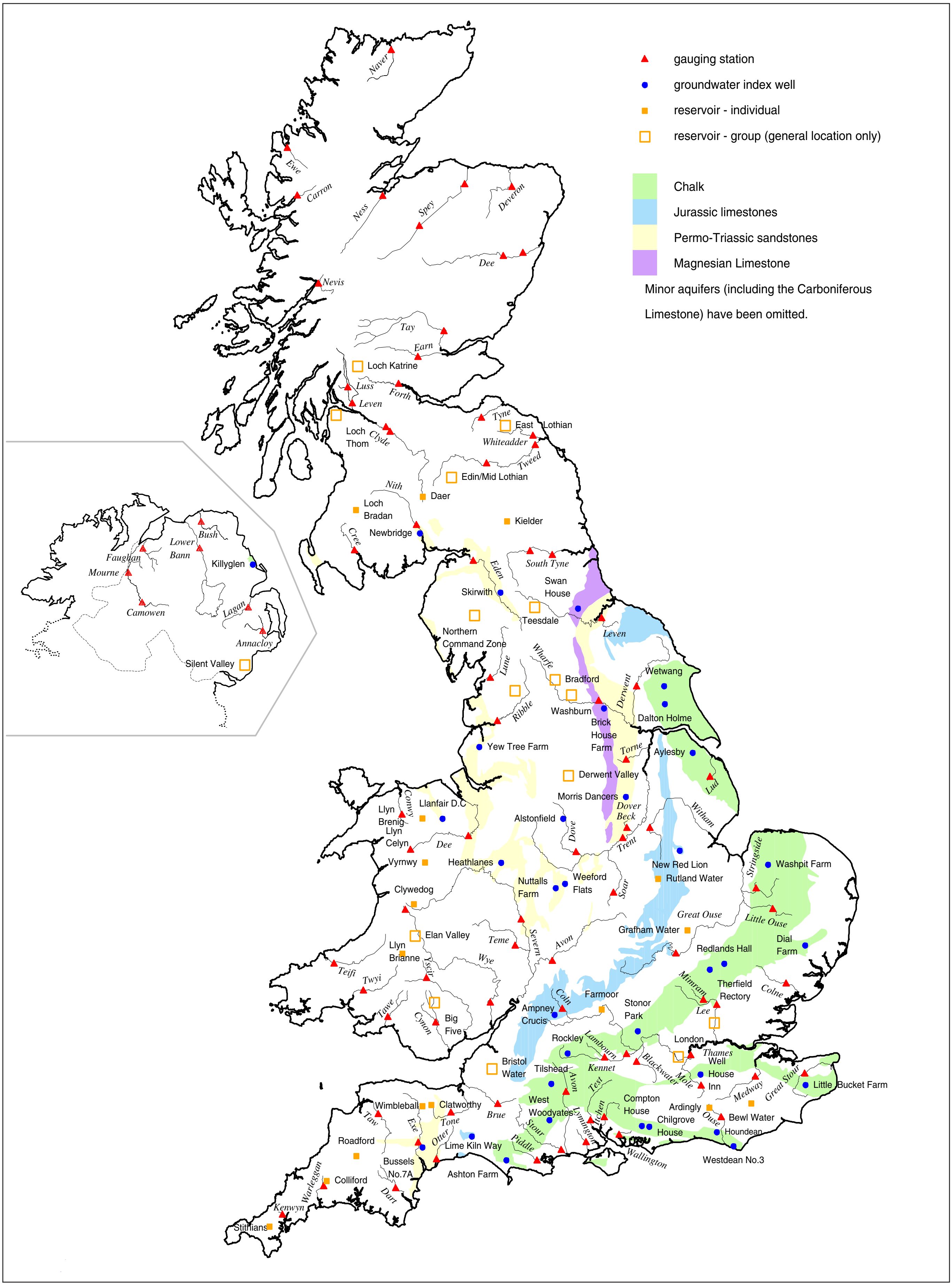
1. Stewart, E.J., Morris,D.G., Jones, D.A., Gibson. H.S. 2010. Frequency analysis of extreme rainfall in Cumbria 18-21 November 2009. Submitted to Hydrology Research.

2. 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

3. BBC News website 19 November 2010: http://www.bbc.co.uk/news/uk-england-cumbria-11791716

4. Miller, J., Kjeldsen, T.J., Hannaford, J., Morris, D.G. 2011. An assessment of the magnitude and rarity of the November 2009 floods in Cumbria. Submitted to Hydrology Research.

Location Map



NATURAL
ENVIRONMENT
RESEARCH COUNCIL

enquiries@ceh.ac.uk
www.ceh.ac.uk

RIVERS Agency
SEPA Scottish Environment Protection Agency
Environment Agency
Met Office