UK Hydrological Review 1997

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Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

1997

UK HYDROLOGICAL REVIEW

This Hydrological Review, which also provides an overview of water resources status throughout 1997, is a reformatted version of the original commentary released as a web report in 1998. Some of the data featured in this report, particularly the more extreme flows, may have been subsequently revised.

The annual Hydrological Reviews are components in the National Hydrological Monitoring Programme (NHMP) which was instigated in 1988 and is undertaken jointly by the Centre for Ecology & Hydrology (CEH) and the British Geological Survey (BGS) – both are component bodies of the Natural Environment Research Council (NERC). The National River Flow Archive (maintained by CEH) and the National Groundwater Level Archive (maintained by BGS) provide the historical perspective within which to examine contemporary hydrological conditions.

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/nhmp/nhmp.html). The river flow and groundwater level data featured in the Hydrological Summaries – and utilised by many NHMP activities – have been provided by the Environment Agency (EA), Natural Resources Wales - Cyfoeth Naturiol Cymru, the Scottish Environment Protection Agency (SEPA) and their precursor organisations. For Northern Ireland, the hydrological data were sourced from the Rivers Agency and the Northern Ireland Environment Agency. The great majority of the reservoir level information has been provided by the Water Service Companies, the EA, Scottish Water and Northern Ireland Water (formerly Water Service). The generality of meteorological data, including the modelled assessments of evaporation and soil moisture deficits featured in the report, has been provided by the Met Office. To allow better spatial differentiation the monthly rainfall data for Britain are presented for the regional divisions of the precursor organisations of the EA and SEPA. The Met Office monthly rainfall series are Crown Copyright and may not be passed on to, or published by, any unauthorised person or organisation. The provision of the basic data, which provides the foundation both of this report and the wider activities of the NHMP, is gratefully acknowledged.

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For further information about the National Hydrological Monitoring Programme please visit: http://www.ceh.ac.uk/data/nrfa/nhmp/nhmp.html

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1997 Summary

Regional rainfall totals for 1997 were close to the 1961-90 mean and it was, like 1996, a quiet year for flood events. But hydrologically 1997 was far from a normal year. Although drought conditions were much less intense than in the summer and late autumn of 1995 long term rainfall deficiencies continued to build in through the early months of 1997, and again in the autumn. Many new long term minimum rainfall totals were established, mainly in the 22-30 month timeframes. For England and Wales, rainfall over the April 1995-April 1997 period established a new 25-month minimum for the national rainfall series which extends back to 1767. Well above average rainfall in November and December produced a very substantial improvement in the water resources outlook but, by year-end, several pockets of concern remained in eastern areas - mostly in a zone from the lower Thames basin to the east Midlands - where dry autumn soils delayed the onset of infiltration and groundwater levels remained close to, or below seasonal minima entering 1998.

Unusually in relation to the last ten years, 1997 summer (June-August) rainfall for England and Wales exceeded that for the previous winter (December-February). The relatively moist summer soils - and above average temperatures - resulted in notably high actual evaporation losses for the year. Correspondingly, effective rainfall totals were low - this is reflected in annual catchment runoff totals in eastern England and, especially, in the depressed groundwater levels which characterised the major water supply aquifers. Nonetheless, the sustained summer rainfall served to ease the hydrological stress, in the lowlands especially, and moderated water demand at a crucial time.

Despite widespread spate conditions near year-end, annual catchment runoff totals were below average throughout the great majority of the UK. A significant proportion of rivers in the English lowlands registered their second lowest annual flow on record. In a year when rainfall totals were only modestly below average, the sustained low flows reflect the very limited groundwater contribution to runoff in many permeable catchments. In north-west Scotland a few rivers reported new minimum runoff totals - a marked contrast to the abundant runoff which characterised most of the 20 years to the mid-1990s. Although the summer rainfall was of limited hydrological effectiveness, it generally contributed sufficient runoff to maintain river flows above drought minima. Nonetheless, many new monthly river flow minima were established during 1997 - in January, April and October especially.

Groundwater recharge through the winter of 1996/97 was well below average for the second successive year in the major aquifers. Late spring/early summer infiltration was especially beneficial in western areas but much of 1997 was typified by sustained low levels in most major aquifer outcrop areas. The magnitude of the overall decline in water-tables from the early spring of 1995 to the late autumn of 1997 is exceptional and has increased the overall range of recorded variability in some parts of the Chalk and Permo-Triassic sandstones aquifers. By November 1997, groundwaters were at historically low levels throughout large parts of Britain. In the English lowlands the depressed levels were accompanied by a widespread failure of springs and a corresponding contraction in network of headwater streams.

After a cold start, 1997 was another very mild year and, in common with most of the last ten years, river flows and groundwater levels showed very wide departures from the long term seasonal average. Such conditions - together with persistence of soil moisture deficits through the autumn in the eastern lowlands - are broadly consistent with a number of favoured climate change scenarios. However, the tendency towards an increased continentality in rainfall distribution - evidenced, in part, by a cluster of hot, dry summers in the last decade - was not reinforced in 1997; the summer rainfall in England and Wales was well over three times that for 1995. Nonetheless, the 1990s thus far have been characterised by very volatile climatic conditions; a few periods during the era of instrumental records with broadly similar rainfall patterns may be identified - e.g. in the 1930s and 1850s - but once account is taken of the elevated temperatures of the recent past, there are no close modern parallels.

Rainfall

The UK rainfall total for 1997 is 1057mm, 98% of the 1961-90 average; mainland regional totals all fell within the 90-110% range (see Figure 1 and Table 1, note: to allow better spatial differentiation the data are presented using the regional divisions of the precursor organisations to the environment agencies). The lowest actual rainfall totals were registered in a zone from the Thames estuary extending well into East Anglia (Figure 2). Generally, the lowest percentage rainfall totals were also found in this region, several areas recording less than 75% of the 1961-90 average. By contrast, localities exceeding 115% showed a wide distribution. Within-region rainfall variability was generally substantial and the distribution of rainfall throughout the year was very uneven. January was remarkably dry; Britain registered its lowest precipitation, for the month, in a 138-year record. As significant,

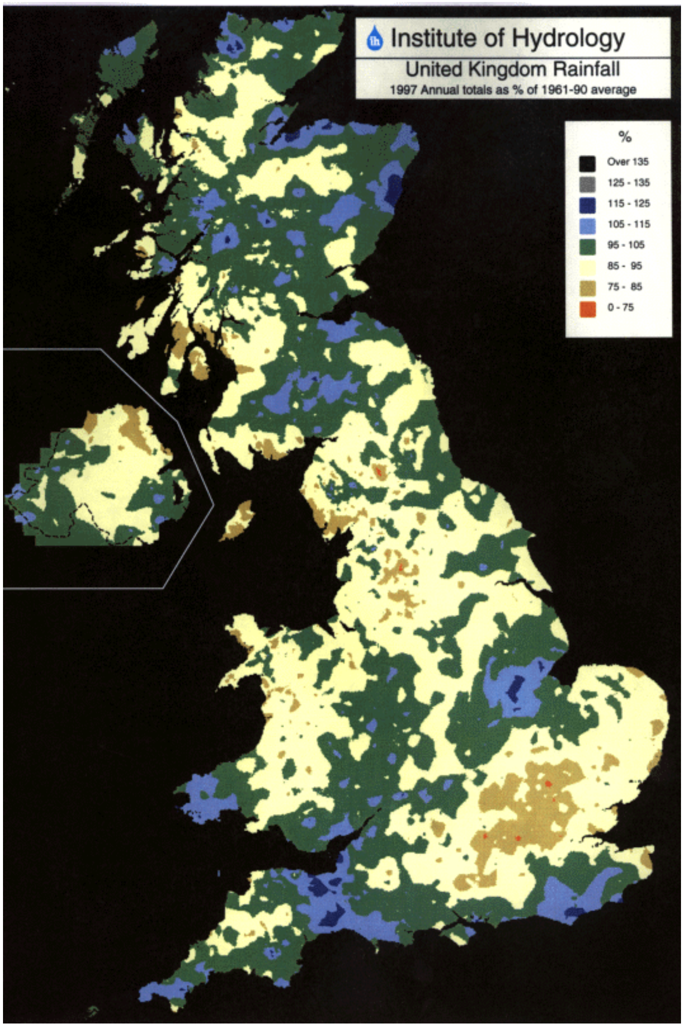


Figure 1 *Annual rainfall for 1997 as a % of 1961-90 mean.*
Data source: UK Met Office.

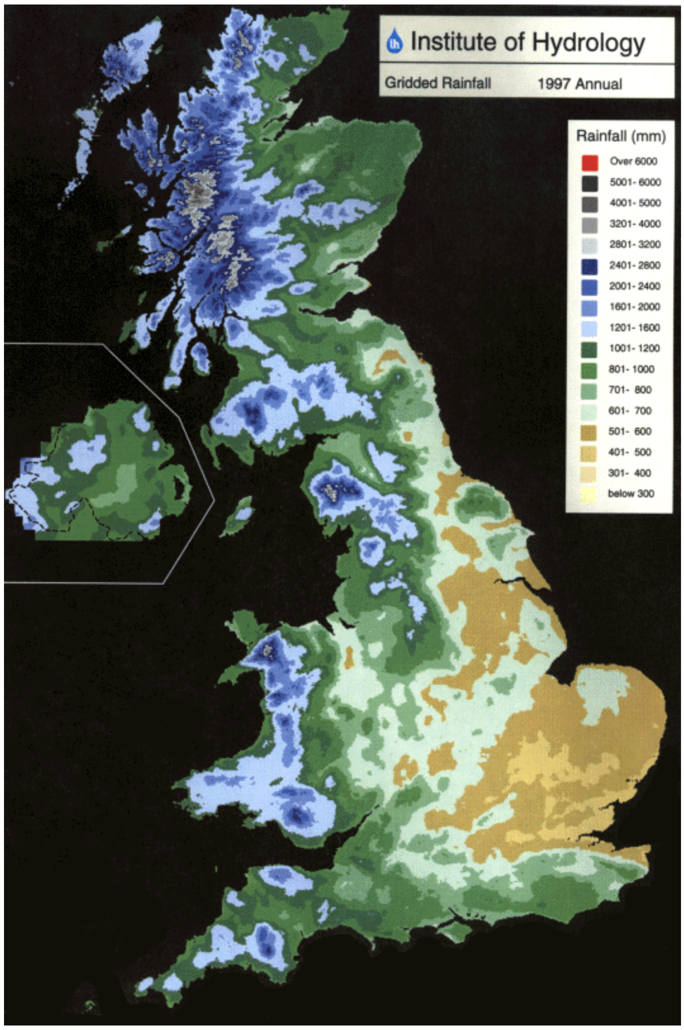


Figure 2 *Annual rainfall for 1997 in mm.*
Data source: UK Met Office.

from a water resources perspective, the combined December 1996 and January 1997 rainfall total was the second lowest since 1879/80. This intensely dry episode provided fresh impetus to the long term drought. At the beginning of February extreme rainfall deficiencies, in the 22-month timeframe, characterised north-west England and parts of the Pennines; over wide areas the deficiencies were the equivalent of 5-6 months average rainfall.

Fortunately, frontal systems on a westerly airflow dominated weather patterns in February which was the third wettest on record for Britain in a series from 1869. Some parts of southern and western Scotland reported over four times the February average; at Sconser on the Isle of Skye an 8-day (17-24th) rainfall total of 487mm was recorded - corresponding to a return period of around 5000 years. The contrast with the January rainfall totals was remarkable, some local differentials were extraordinary (e.g. Plynlimon in central Wales 453mm, Burnbanks in the north-west of England 614mm). March and April were both notably dry, culminating the driest 24-month sequence in the England and Wales rainfall series since at least the 1850s (nominally lower rainfall totals were registered during the drought episodes in the 1780s and mid 1850s but the raingauge networks were too sparse for comparisons to be made with confidence). The exceptional long term rainfall deficiencies triggered concern for the water resources outlook in some regions.

A repeat of the rainfall experienced during the summers of 1989, 1990 or 1995 would have created severe hydrological stress and local water supply difficulties in 1997. In the event, May was very unsettled and rain-bearing low pressure systems continued to cross the British Isles at regular intervals through the summer; the frontal rainfall was augmented by significant convectional rainfall, in July and August especially. The June rainfall total was exceptional, exceeding twice the average in most of eastern Britain; for England and Wales, it was the second wettest June since 1879. On the 26th, a number of raingauges in the South-West recorded rain-day totals in excess of 100mm (see Table 2) and rainfall accumulations over 7-28 days were particularly outstanding in the Yorkshire Wolds; at Wold Newton 171mm fell in the 14 days to the 1st

Table 1 *1997 Rainfall in mm as a % of the 1961-90 average.*

Note UK figures are computed by the Institute of Hydrology.

Data source: UK Met Office.

1997		J	F	M	A	M	J	J	A	S	O	N	D	Year	Oct-Mar 1996/97	Apr-Sep 1997
United Kingdom	mm	28	169	67	43	89	118	65	84	62	73	125	134	1057	619	459
	%	25	222	74	66	124	164	89	93	63	66	114	119	98	102	97
England and Wales	mm	14	120	32	25	75	127	48	95	35	68	117	108	864	439	403
	%	16	190	44	42	117	195	77	125	45	80	130	115	97	89	100
Scotland	mm	55	268	137	76	113	104	90	65	114	80	139	182	1423	977	561
	%	36	263	110	100	131	121	96	56	80	51	92	121	99	117	93
Northern Ireland	mm	32	143	51	47	106	94	100	72	57	83	127	139	1051	566	473
	%	29	183	58	73	149	132	149	79	58	73	123	134	99	95	102
North West	mm	13	212	76	38	105	95	83	65	89	70	108	155	1109	661	475
	%	11	272	80	54	140	117	98	61	77	55	88	125	92	99	89
Northumbrian	mm	18	131	37	18	74	161	72	42	31	40	89	119	832	455	397
	%	21	222	53	32	119	268	111	52	42	53	103	147	98	100	100
Severn Trent	mm	12	85	22	29	79	131	45	88	25	61	89	72	738	339	395
	%	17	157	36	53	134	222	85	131	39	95	125	94	98	85	111
Yorkshire	mm	11	105	29	21	71	141	60	71	28	48	83	104	772	412	390
	%	14	181	43	36	118	235	102	96	41	66	104	125	94	93	103
Anglian	mm	13	45	12	17	49	131	42	62	15	52	62	77	577	251	314
	%	26	122	26	37	102	257	86	113	31	102	107	140	97	84	105
Thames	mm	13	77	12	15	53	101	36	85	15	61	86	71	625	281	305
	%	20	171	21	30	95	184	73	147	25	98	132	101	91	78	93
Southern	mm	19	95	17	10	46	127	24	91	10	89	144	113	785	363	307
	%	24	176	27	19	85	235	50	160	14	111	169	138	101	82	92
Wessex	mm	14	116	29	21	71	103	28	155	20	69	151	103	880	419	396
	%	16	178	41	40	116	181	54	235	28	87	182	111	105	88	110
South West	mm	25	162	40	30	89	132	35	174	44	106	213	147	1197	617	502
	%	18	160	40	43	124	191	51	207	47	91	170	106	102	86	110
Welsh	mm	12	212	52	38	109	142	55	141	71	96	195	150	1273	679	552
	%	8	219	49	48	133	180	71	140	62	70	137	98	97	87	103
Highland	mm	87	340	205	115	120	97	109	76	146	88	122	196	1701	1257	663
	%	46	268	127	126	130	99	103	60	85	44	60	99	97	117	97
North East	mm	29	125	76	37	133	132	81	64	43	38	166	111	1035	567	494
	%	29	192	97	62	193	200	111	74	49	39	168	119	106	107	112
Tay	mm	39	251	101	40	111	111	66	58	84	61	184	161	1267	803	465
	%	27	264	93	65	134	152	86	62	74	47	152	127	103	111	92
Forth	mm	36	222	85	39	102	129	55	45	82	70	97	150	1112	752	455
	%	31	281	90	66	138	187	73	48	75	61	87	136	100	120	95
Clyde	mm	61	309	158	103	89	70	100	62	153	117	142	228	1592	1128	575
	%	32	262	107	123	98	75	92	46	85	61	79	127	94	112	83
Tweed	mm	23	191	53	22	105	161	59	44	55	48	102	148	1011	656	448
	%	23	285	67	39	148	248	81	50	62	51	110	159	104	124	101
Solway	mm	29	256	90	52	123	95	93	68	128	93	151	225	1403	904	556
	%	19	253	77	68	145	113	103	57	90	59	105	152	99	110	93
Western Isles; Orkney and Shetland	mm	103	252	149	84	76	53	63	76	112	90	127	155	1354	1056	464
	%	82	300	148	135	129	87	90	88	93	67	96	121	116	150	101

July - the associated return period exceeds 100 years. Despite high average temperatures and sunshine hours, August was also notably wet in southern Britain. Thunderstorms were common and associated with a cluster of intense rainfall events - in Yorkshire especially: at Sandall (north of Doncaster) 22.8mm fell in 15 minutes (return period > 100 years) and 34.8mm in an hour on the 17th. On the last day of the month, at Bramham (north-east of Leeds) 45mm (+/- 5mm) was estimated to have fallen in only 30 minutes - a remarkable downpour with a return period assessed at around 1000 years.

For England and Wales, the May-August period was the second wettest in 30 years and the summer (June-August) rainfall total, unusually in the context of the recent past, greatly exceeded that for the preceding winter (December-February). The ratio of winter to summer rainfall was the third lowest in over 30 years. Nonetheless, the average of the ratio over the last decade remains well above the historical mean (Figure 3). The decline in the long term rainfall deficiencies was reversed in September when most regions registered rainfall totals 20-50% below average; parts of the South-East were extremely dry. A mild and wet start to October gave way to anticyclonic conditions from mid-month and monthly rainfall totals were again below average in most areas, notably so in parts of Scotland. Over the August to October period Scotland recorded it second lowest rainfall total in 50 years, Northern Ireland was exceptionally dry also. By November, and notwithstanding the wet summer, long term rainfall deficiencies were again towards the extreme of the historical range. Parts of England and Wales (e.g. the North-West and central southern England) had recorded above average rainfall in only 6 or 7 of the preceding 31 months and the April 95-October 97 period (Figure 4) established a new post-1850, 31-month minimum rainfall total for England and Wales. Following below average autumn rainfall - Scotland recorded its second lowest September-November total in 25 years - an exceptionally wet interlude, extending from the second week of December to mid-January, greatly improved the water resources outlook in all but a few parts of eastern England (mostly dependent on groundwater). With weather conditions becoming increasingly boisterous, flood warnings were widespread around the turn of the year and saturated catchments remained vulnerable to further rain, in the west and north especially.

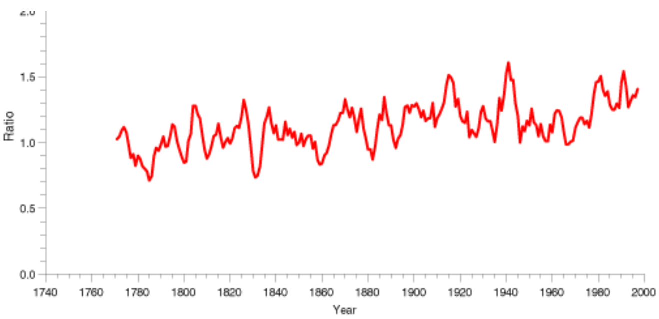


Figure 3 *The ratio of winter half year (October - March) to summer half year rainfall for England and Wales.*

Data source: UK Met Office.

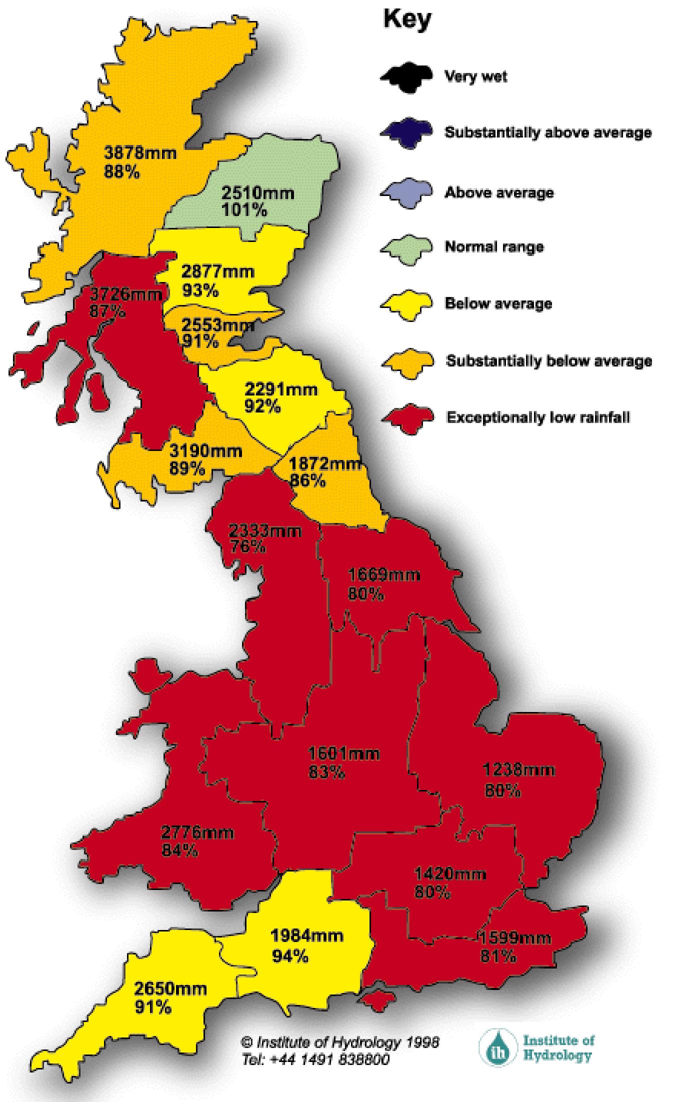


Figure 4 *Annual Rainfall for April 1995 - October 1997 in mm and as a % of 1961-90 mean.*

Data source: UK Met Office.

Table 2 *Daily rainfalls in 1997 with return periods equal to or exceeding 50 years.*

Note: The rain-day totals presented here are provisional and may be subject to change. The Return Periods are based on the methods and findings of the Flood Studies Report as implemented by the Met Office, whereby a return period can be assigned to a catch at a particular raingauge. The return periods in Table 2 have been rounded to the nearest 10 years. Estimated values are preceded by an 'E'.

Data source: UK Met Office.

Date (Rain-day)	Raingauge Number	Raingauge Name	County/Region	Grid Reference	Rainfall (mm)	Return Period (years)
03.02.97	14136	Tindale, Roachburngate	Cumbria	3613 5596	77.5	80
03.02.97	592976	Mungrisdale, Low Beckside	Cumbria	3366 5298	88.6	80
17.02.97	593415	High Snab Farm Logger Station	Cumbria	3222 5190	120.0	50
17.02.97	601303	Burn Banks	Cumbria	3508 5159	116.1	70
01.03.97	698513	Keil	Isle of Man	2008 7650	122.4	90
01.03.97	801844	Inchmore Hatchery	Highland	2301 8125	107.2	100
01.03.97	804797	Drumnadrochit	Highland	2506 8293	72.8	80
17.05.97	172700	Woburn Sands	Buckinghamshire	4922 2367	86.4	240
11.06.97	156194	Tongue End	Lincolnshire	5151 3184	73.1	120
26.06.97	356058	Brompton Regis P.O.	Somerset	2950 1316	111.8	130
26.06.97	356262	Honeymead	Somerset	2797 1392	116.9	70
26.06.97	393324	Challacombe, Brookside Cottage	Devon	2693 1408	121.1	150
26.06.97	394827	South Stowford	Devon	2651 1404	100.4	90
26.06.97	397944	Crowcombe, Halsway Nurseries	Somerset	3124 1382	74.8	50
26.06.97	402547	Bagborough, Shopnoller Farm	Somerset	3164 1325	106.5	320
30.06.97	825489	Bogmuchalls	Grampian	3537 8584	73.3	60
01.07.97	807613	Clunas Tr. Wks.	Highland	2874 8465	83.8	80
01.07.97	807696	Lethen House	Highland	2937 8518	79.0	110
01.07.97	810886	Relugas	Grampians	3003 8494	90.2	180
01.07.97	811991	Glenlatterach Filters	Grampians	3200 8546	80.0	70
03.08.97	378025	St Mawes, Trevennel Farm	Cornwall	1850 0350	78.7	70
03.08.97	379205	Trelissick	Cornwall	1837 0396	90.9	130
03.08.97	379372	Trevince	Cornwall	1737 0402	102.1	170
03.08.97	379547	Stithians	Cornwall	1738 0371	131.8	570
03.08.97	379706	Penryn Reservoir No.2	Cornwall	1776 0336	E117.4	360
03.08.97	379922	Wendron W. Tr. Wks.	Cornwall	1678 0257	124.5	460
03.08.97	380838	Culdrose RNAS samos	Cornwall	1672 0257	79.6	80
03.08.97	382444	Boswyn Resr.	Cornwall	1657 0363	108.5	200
05.08.97	343149	Longburton	Dorset	3648 1132	74.0	60
05.08.97	351123	Burton Bradstock, Bredy Farm	Dorset	3508 0899	E 71.6	50
05.08.97	398512	Henley	Somerset	3438 1076	85.2	100
05.08.97	398880	Seavington, Hurcott Farm	Somerset	3396 1161	88.1	140
05.08.97	399369	Puckington, Manor Farm House	Somerset	3376 1183	84.5	120
05.08.97	399654	Curry Mallet, Manor Farm Cottage	Somerset	3333 1215	69.1	50
05.08.97	401374	Langport, Whatley	Somerset	3420 1266	74.2	90
05.08.97	401483	Wrantage	Somerset	3308 1228	76.0	80
05.08.97	403079	Creech Heathfield	Somerset	3278 1268	E 72.8	50
05.08.97	403115	West Newton Farm	Somerset	3286 1291	75.1	60
05.08.97	406041	Butleigh, Higher Hill Farm	Somerset	3518 1321	65.3	50
06.08.97	284089	Walton W.Wks	Surrey	5117 1684	66.1	60
06.08.97	284702	Burstow S.Wks	Surrey	5305 1437	78.7	100
06.08.97	284951	Redhill, London Rd	Surrey	5281 1512	69.3	50
06.08.97	284974	Earlswood S.Wks	Surrey	5275 1482	69.0	50
06.08.97	286196	Epsom College	Surrey	5223 1601	85.9	180
06.08.97	286260	Banstead, Nork Resr. Logger Sta.	Surrey	5246 1602	E70.0	60
06.08.97	292553	Weir Wood Reservoir	West Sussex	5406 1354	82.5	70
13.08.97	797415	Aigas Dam	Highlands	2475 8435	81.6	210
13.08.97	797616	Kiltarlity	Highlands	2503 8403	85.3	280
13.08.97	804431	Balnain	Highlands	2447 8302	92.0	220
13.08.97	898078	Harthill S.Wks.	Lothian	2907 6649	86.6	180
17.08.97	125416	Maltby, Abbey Lathe S.Wks	South Yorkshire	4538 3903	E79.6	130
18.08.97	178409	Brampton	Cambridgeshire	5223 2709	76.3	160
31.08.97	64281	Bramham	West Yorkshire	4441 4412	67.0	60
02.09.97	627056	Upper Black Laggan Logger Sta.	Dumfries & Galloway	2476 5769	112.0	60
17.11.97	879495	Lochearnhead No. 2	Central	2587 7231	101.9	90
17.11.97	972969	Ballykine, Rockvale	County Down NI	3345 3520	78.1	80

Evaporation and Soil Moisture Deficits

Despite a cold January, 1997 was another notably warm year; the average Central England Temperature (CET) was around 10.5°C. This places 1997 amongst the eight warmest years in a record which extends back to 1659, four of the eight warmest now cluster in the last ten years. Most months registered above average temperatures; relative to the monthly mean the most outstanding were February, August - which was the second warmest (after 1995) on record - and November. Correspondingly, evaporative demands in 1997 were appreciably above average throughout the UK.

Potential evaporation (PE) losses for the year (Figure 5) were typically 10-20% above average with the largest anomalies in the South-East and, locally, in the north-west of Scotland. Annual totals derived using the Meteorological Office's Rainfall and Evaporation Calculation System (MORECS) ranged from around 450mm in parts of the Scottish Highlands to over 700mm in the London area. Throughout much of the English lowlands PE totals were greater than, or similar to, the annual rainfall total. Actual evaporation (AE) losses (Figure 6) were also mostly well above average except for a few areas in East Anglia and the South-East where soil moisture deficits (see below) were sufficient to substantially inhibit transpiration during the April-September period. Generally however, the relatively moist surface soils through the summer allowed transpiration to continue close to the potential rate and AE losses fell only modestly short of the corresponding PE values. For most of the UK, the margin between PE and AE totals for 1997 was one of the lowest on record. Thus, one consequence of the temporal distribution of rainfall in 1997 was to lower its overall hydrological effectiveness - runoff and recharge rates in 1997, expressed as a percentage of the long term average, were substantially more depressed than the annual rainfall totals.

The unusual rainfall distribution during 1997 resulted in an erratic development and decay of soil moisture deficits (SMDs) - see Figure 7. Commonly, maximum deficits during 1997 were recorded in May or September rather than during the summer months. Entering 1997, soil moisture deficits were not fully satisfied in a few areas, mostly in the lower Thames Valley. Very unusually, SMDs increased during January 1997 with significant deficits (>25mm) extending over 20,000 sq km by month end - a matter of concern in relation to the prospects for late-winter aquifer replenishment. Fortunately sustained rainfall in February produced saturated conditions in almost all catchments by month-end but deficits built rapidly in late March and through most of April. In early May, SMDs exceeded 60mm throughout most of England, and reached 120mm in a few eastern areas; this represents exceptionally dry soils for the time of year (Figure 8). Thereafter, deficits fluctuated considerably; thunderstorms producing particularly large local variations. Contrary to the usual seasonal pattern smds soil moisture increased markedly in June when access to sodden fields caused problems for the farming community.

By the end of August, SMDs in most areas had returned to well within the normal range but the brisk decline usually experienced during the autumn failed to materialise. The very mild and dry September saw little increase in soil moisture and, by late October, deficits still exceeded 80mm in much of eastern Britain (Figure 9) - in many such areas deficits were more than 50mm above the seasonal average. Whilst maximum SMDs in 1997 were modest compared with other recent years, the period over which significant deficiencies were maintained in parts of eastern Britain was very protracted. This served to delay the seasonal recovery in runoff and recharge rates throughout much of lowland England and parts of eastern Scotland. In western Britain soils were mostly saturated by October but in the east deficits persisted until well into December (and in a few localities into 1998).

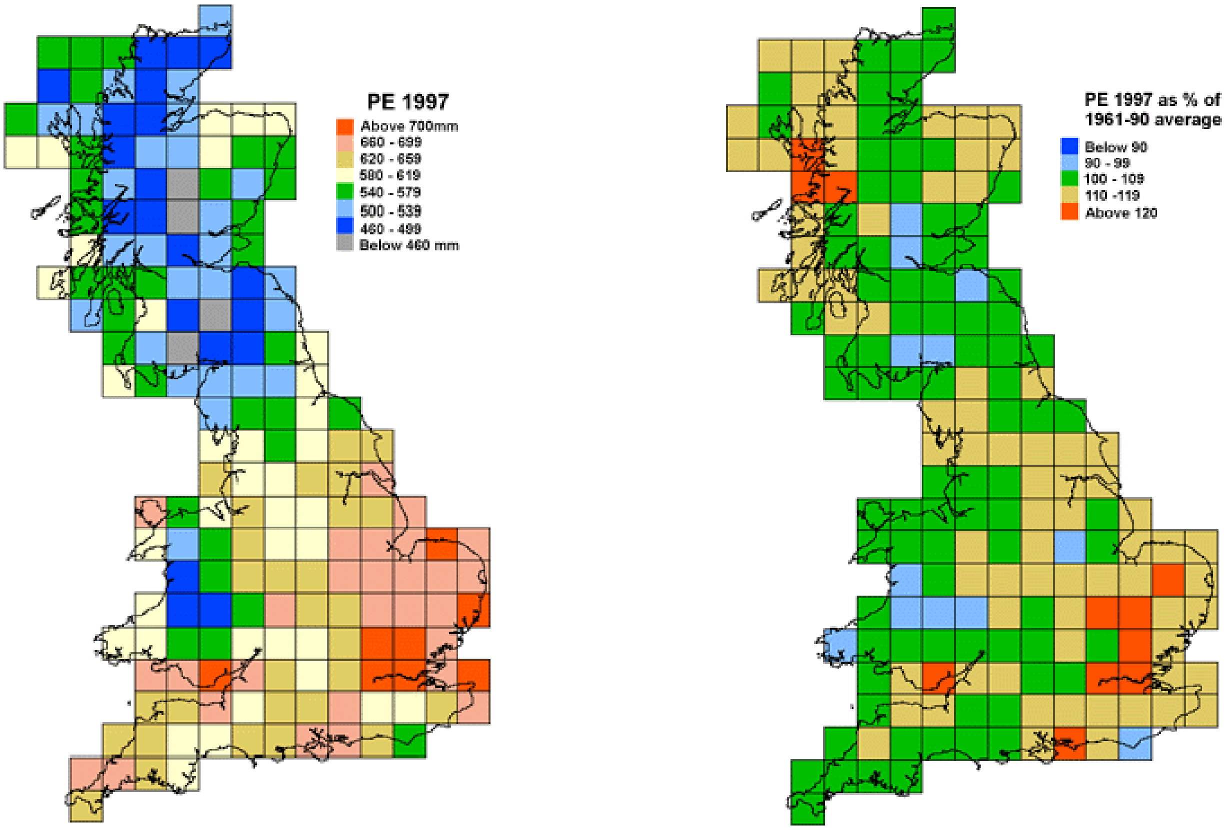


Figure 5 *Potential evaporation totals for 1997 in mm and as a percentage of the 1961-90 average.*
Note: the PE totals assume a grass cover.
Data source: MORECS.

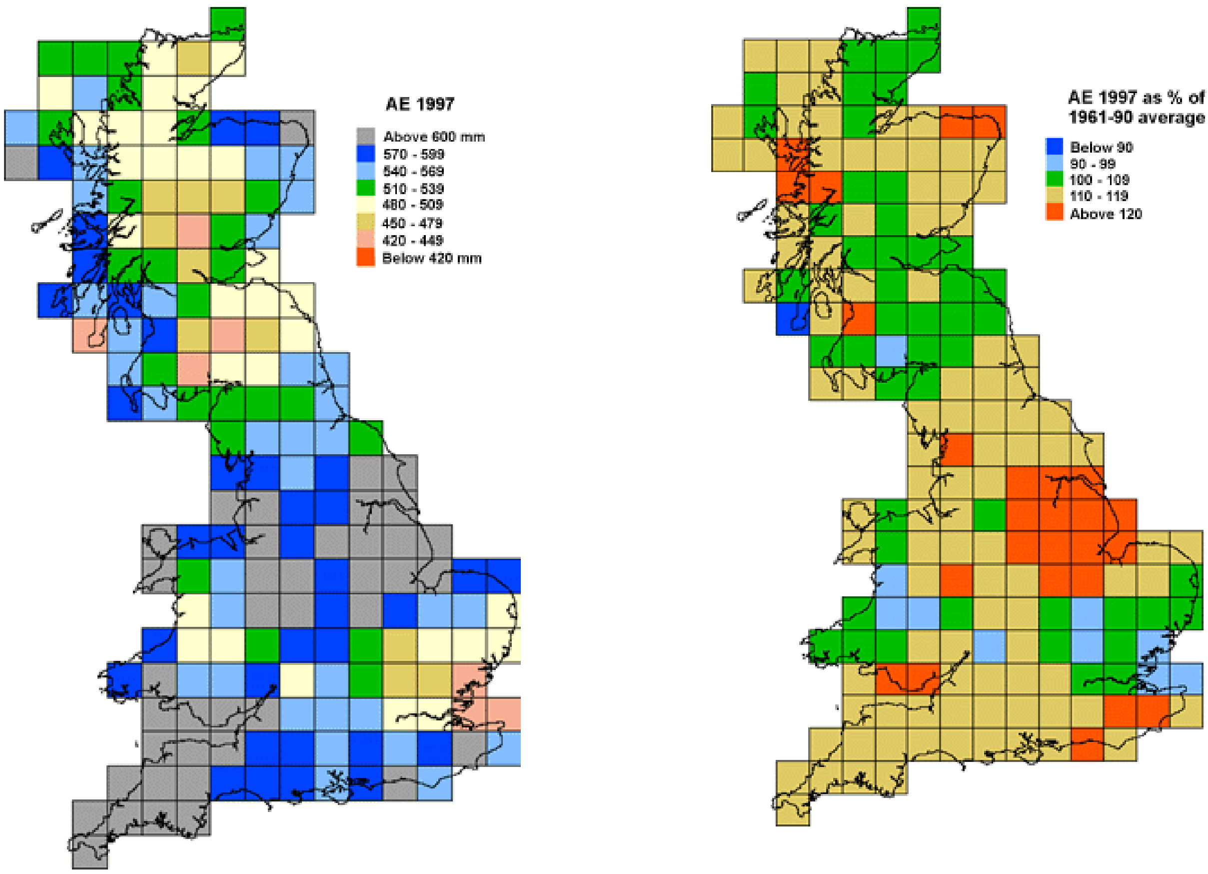


Figure 6 *Actual evaporation totals for 1997 in mm and as a percentage of the 1961-90 average.*
Note: the PE totals assume a grass cover.
Data source: MORECS.

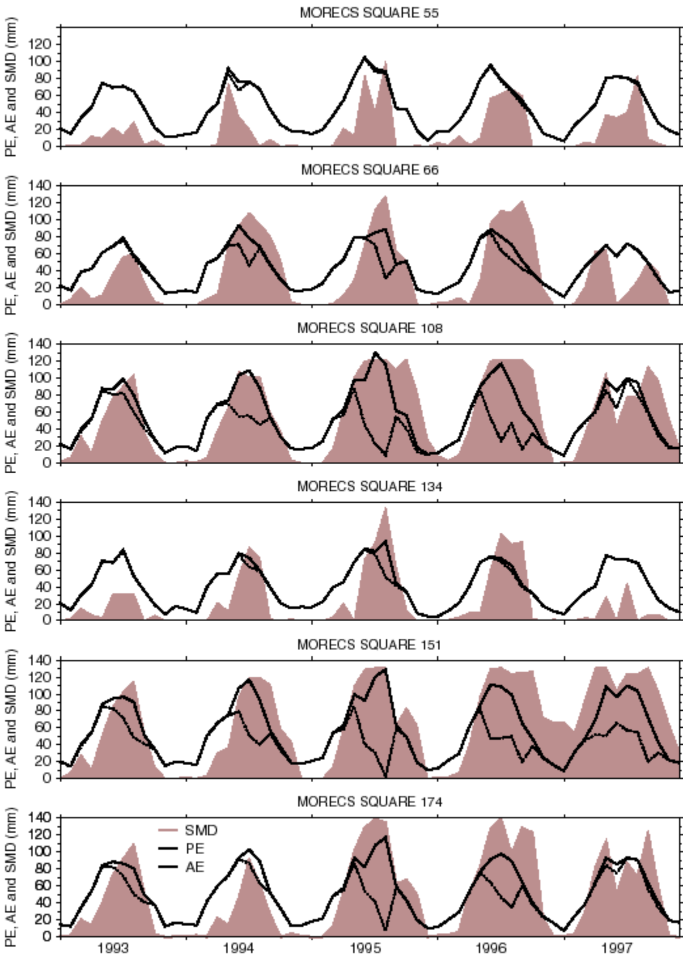


Figure 7a *The variation in potential evaporation, actual evaporation and soil moisture deficits for six MORECS squares.*

Note: the PE totals assume a grass cover.

Data source: MORECS.

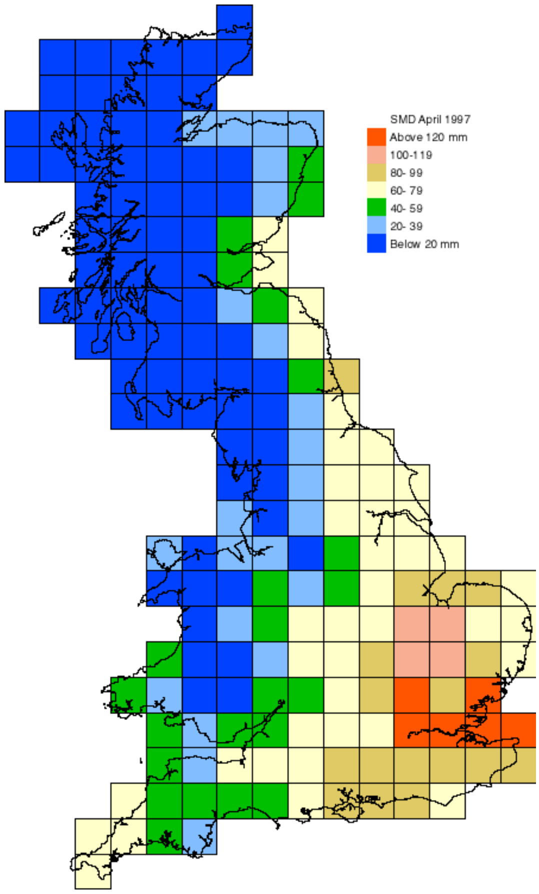


Figure 8 *Soil Moisture Deficits at the end of April 1997.*

Data source: MORECS.

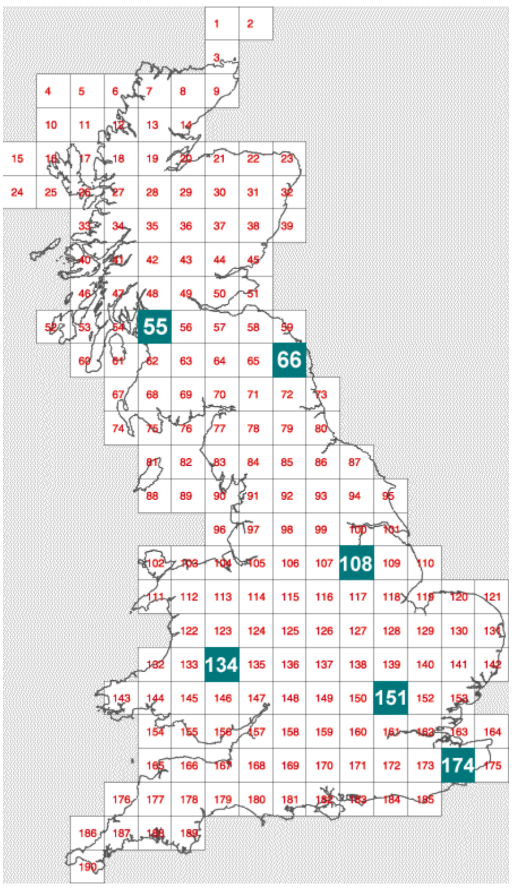


Figure 7b *MORECS Location Map: the location of the 40km squares and their associated reference numbers.*

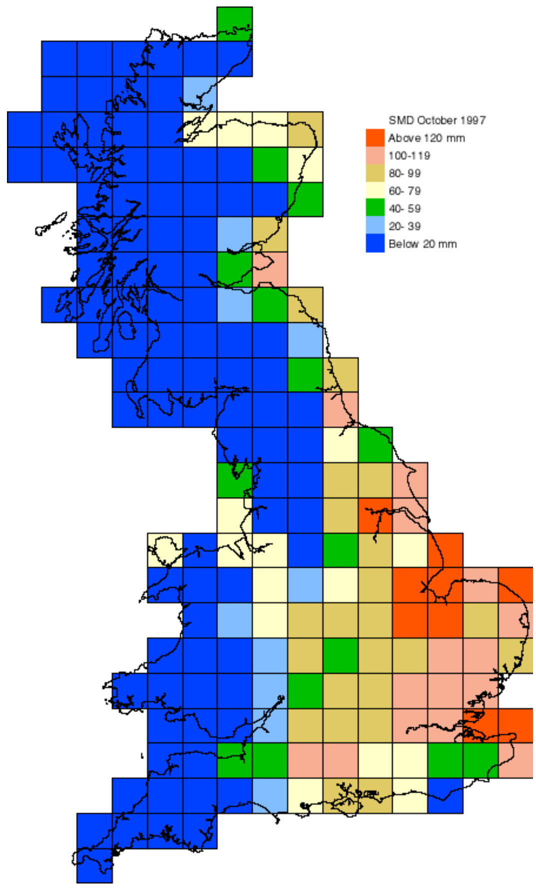


Figure 9 *Soil Moisture Deficits at the end of October1997.*

Data source: MORECS.

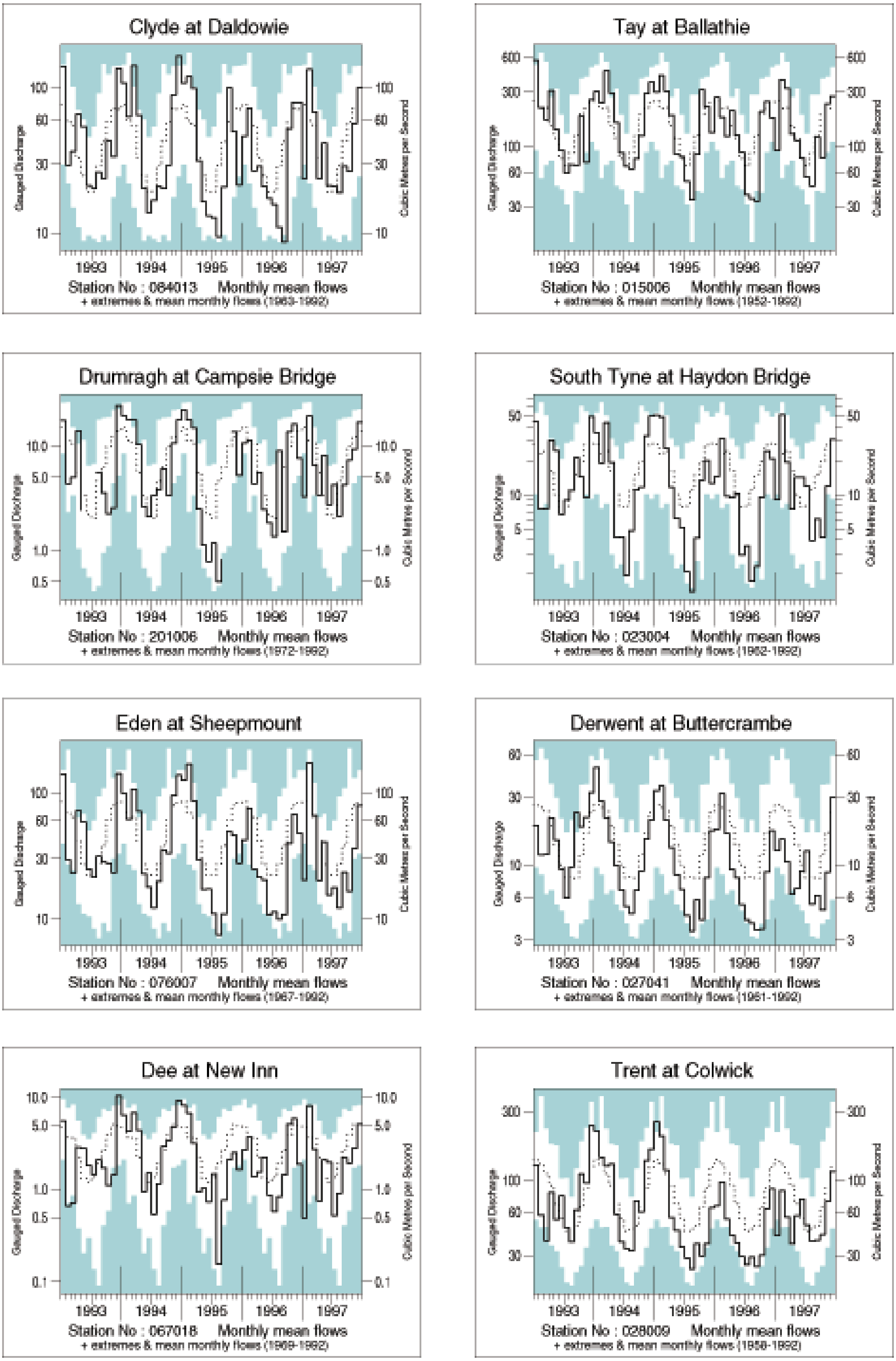
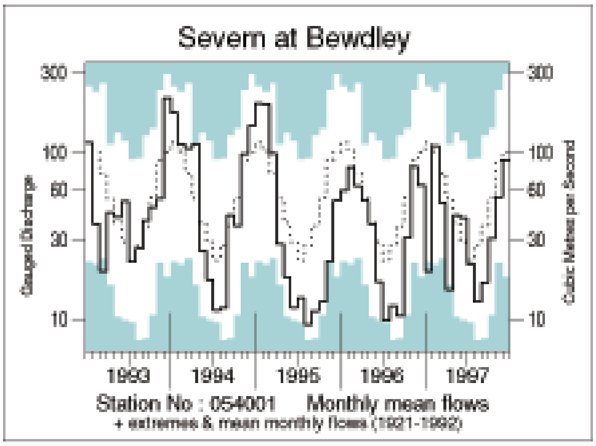
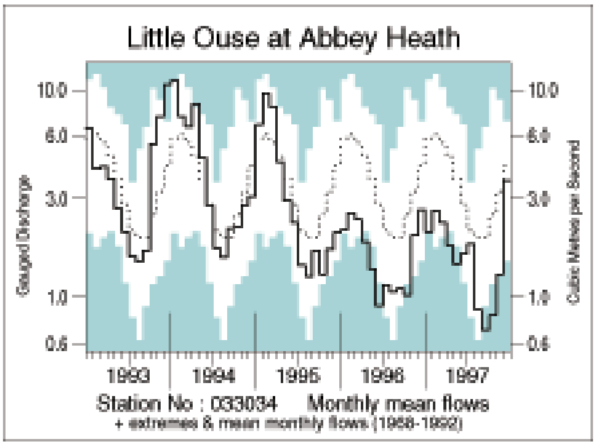


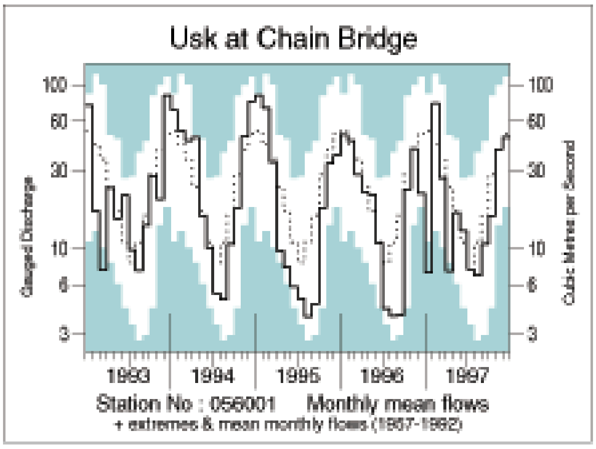
Figure 10 *River flow hydrographs for 1993-97.*

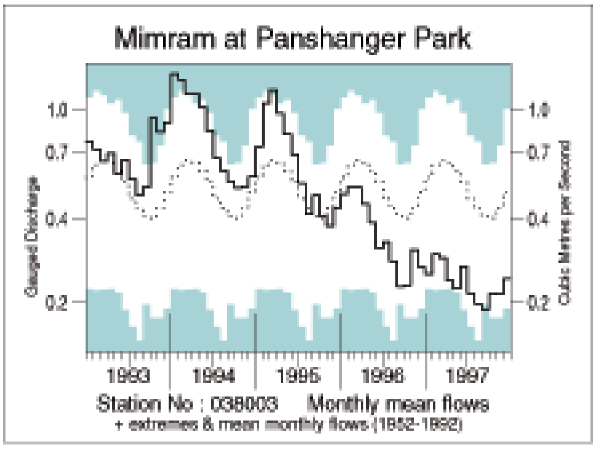
Note: some of the data may be incomplete.

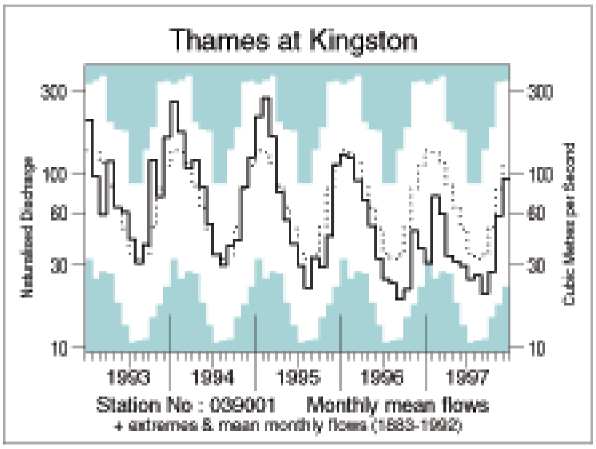
Data sources: Environment Agency/Scottish Environment Protection Agency/Rivers Agency.

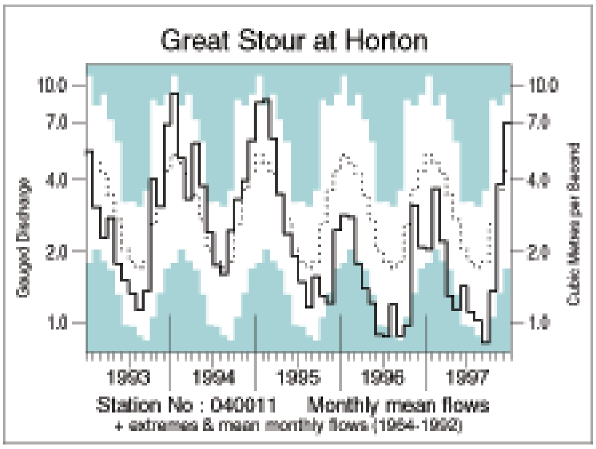


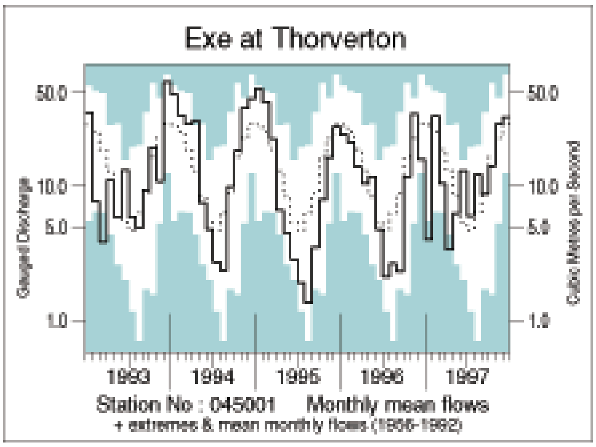












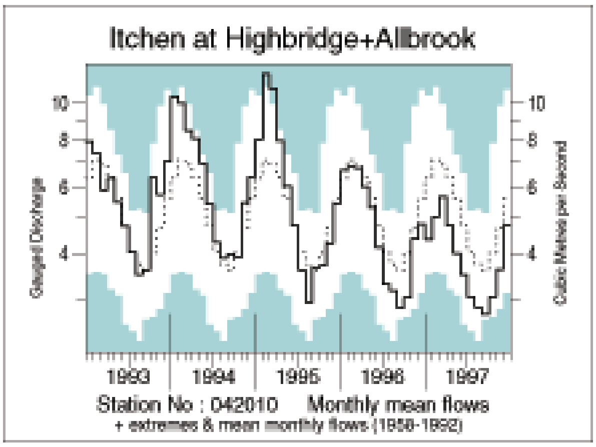


Figure 10 *(Contd.)*

River Flows

As in the preceding year, very few notable flood events were recorded during 1997 and protracted periods of low flows typified many rivers - particularly those draining permeable eastern catchments. The very wide departures from normal seasonal flow patterns - a common feature of the last decade - is evident from the the hydrographs featured in Figure 10. Figure 11 provides a guide to 1997 runoff totals expressed as a percentage of the long term average. Above average totals were confined largely to south-west Wales and parts of southern Scotland. Elsewhere, totals were generally well below average, and exceptionally low in parts of eastern, central and southern England. Depressed groundwater levels caused many winterbournes to remain dry throughout the year - little or no runoff was reported for the headwaters of some Chalk streams (e.g. in Hertfordshire and Cambridgeshire).

The year began with flow rates very depressed in many areas, especially in spring-fed streams in southern Britain and rivers draining frozen catchments in the Pennines and Scotland - see Figure 10. Rivers registering new minimum January runoff totals showed a very wide distribution - including the Thames (in a 115-year record), Severn (76 years), Tay (45 years) and a number of rivers in Northern Ireland. Total outflows from the UK were probably the lowest, for the month, this century. February saw a remarkable transformation; by mid-month spate conditions characterised many impervious catchments and the runoff totals for the month were the highest on record in some catchments - mostly in northern Britain (Table 3). A succession of frontal systems produced very high 4-day rainfall totals (>130mm) in the headwaters of the River Tweed generating exceptional runoff; on the 17th the River Teviot exceeded it previous maximum recorded flow at Hawick - a second notable peak occurred on the 19th - and a large area of agricultural land was inundated. Folklore's 'February fill dyke' was vindicated in much of the English lowlands but with groundwater contributions to streamflow still very modest, flow recoveries were mostly short-lived. The severity and persistence of the drought in river flow terms is underlined by the 24-month runoff accumulations ending in February, the lowest on record for a significant minority of lowland rivers - including the Trent and Soar (Leicestershire).

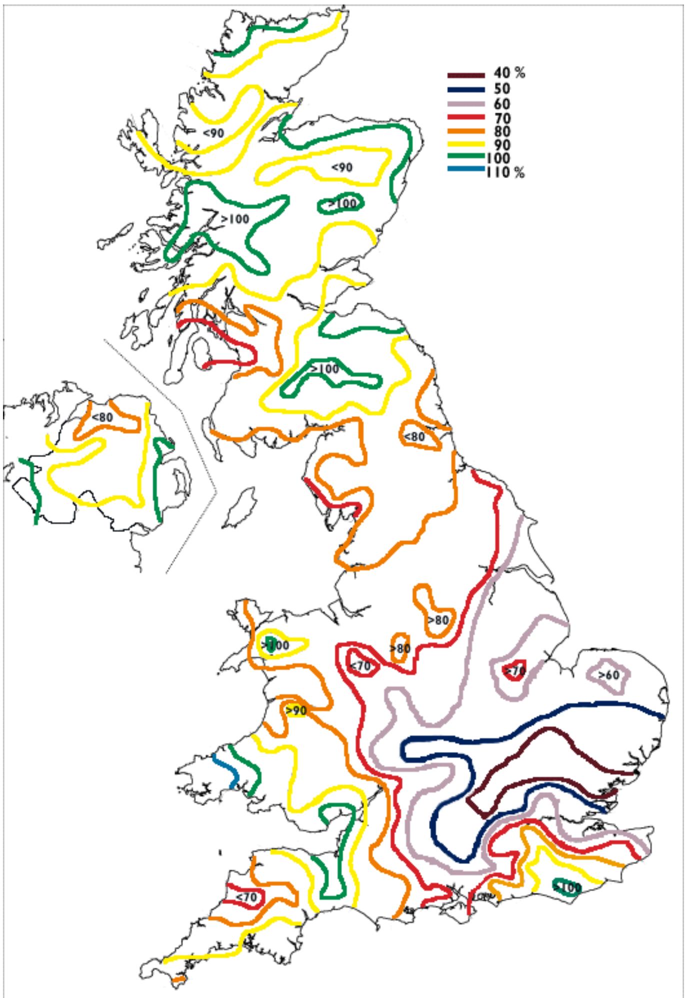


Figure 11 *A guide to 1997 runoff expressed as a percentage of the 1961-90 average.*

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

In most of Scotland very healthy flows continued into March; the peak flow of 1350 m^3s^{-1} on the 1st for the River Tay at Ballathie produced widespread floodplain inundation and added to a cluster of notable floods in the recent past. By contrast, most English rivers were in recession and runoff totals for March were generally below 60% of average. The scale of the medium term runoff deficiency was confirmed by the runoff totals for the winter-half year (October-March) - these were below 50% of average in much of the eastern lowlands. Flow recessions became more general in April when above average monthly flows were largely confined to north-west Scotland. Flows throughout most of England and Wales during April were more typical of the late summer (Figure 10). Many new minimum April runoff totals were established and overall outflows from Britain were lower than in the benchmark drought of 1976. For the 24-months ending in April, accumulated runoff totals of less than half the average typified much of eastern and southern England - flows were particularly depressed in a number of eastern spring-fed rivers. May saw significant flow recoveries in western and northern catchments but the seasonally parched soils in the English lowlands robbed the rainfall of much of its effectiveness and many rivers recorded flow rates which exceeded only the corresponding flows in 1976. Failure of springs was widespread and headwater reaches were contracting steadily.

The exceptional June rainfall produced rapid flow increases in the west, and triggered flood alerts in a few catchments (e.g. in rivers draining from Dartmoor) but,

Table 3 River flow and runoff records established in 1997.

Note: Only gauging stations with at least 20 complete years of data are featured. 1997 flow data for a few areas are awaited.

Station Number	River	Station Name	First year of record	New record (mm)	Pre-1997 record (mm)	Year
Lowest Annual Runoff						
33022	Ivel	Blunham	1959	68	70	1973
33024	Cam	Dernford	1949	41	53	1991
33027	Rhee	Wimpole	1965	17	21	1973
37001	Roding	Redbridge	1950	55	73	1996
37014	Roding	High Ongar	1963	22	23	1973
38013	Upper Lee	Luton Hoo	1960	8	14	1973
38016	Standsted Sp	Mountfitchet	1969	4	18	1992
38017	Mimram	Whitwell	1970	6	19	1992
38024	Small River Lee	Ordnance Road	1973	94	132	1996
38026	Pincey Brook	Sheering Hall	1974	42	61	1996
39001	Thames	Kingston	1883	55	64	1934
43017	West Avon	Upavon	1971	116	123	1973
43019	Shreen Water	Colesbrook	1973	409	434	1991
47008	Thrushel	Tinhay	1969	375	448	1996
47010	Tamar	Crowford Bridge	1972	529	540	1996
54011	Salwarpe	Harford Hill	1961	116	142	1996
54023	Badsey Brook	Offenham	1968	79	92	1976
54024	Worfe	Burcote	1969	79	84	1976
54057	Severn	Haw Bridge	1971	225	229	1976
55028	Frome	Bishops Frome	1971	129	152	1996
84026	Allander Water	Milngavie	1974	877	883	1975

Station Number	River	Station Name	First year of record	New record m^3s^{-1}	Day	Month	Old Record m^3s^{-1}	Day	Month	Year
Highest Daily Mean Flow										
7003	Lossie	Sheriffmills	1963	82.06	1	7	74	17	8	1970
9003	Isla	Grange	1969	73.07	1	7	56.11	25	1	1988
21012	Teviot	Hawick	1963	142.4	17	2	131.7	3	1	1982
42003	Lymington	Brockenhurst	1960	10.65	28	11	10.03	1	5	1978
76015	Eamont	Pooley Bridge	1970	68.64	20	2	67.39	21	12	1985
77003	Liddel Water	Rowanburnfoot	1973	209.7	17	2	191.4	3	1	1982
205005	Ravernet	Ravernet	1972	20.59	26	11	19.59	28	12	1978

Station Number	River	Station Name	First year of record	New record m^3s^{-1}	Day	Month	Old Record m^3s^{-1}	Day	Month	Year
Lowest Daily Mean Flow										
28039	Rea	Calthorpe Park	1967	0.163	5	10	0.167	20	9	1996
33024	Cam	Dernford	1949	0.104	24	8	0.158	25	7	1992
39090	Cole	Inglesham	1976	0.071	23	7	0.081	5	9	1996
40011	Great Stour	Horton	1964	0.504	1	10	0.559	8	8	1996
41002	Ash Bourne	Hammer Wood Bridge	1951	0.009	13	5	0.022	17	9	1988
41013	Huggletts Stream	Henley Bridge	1950	0.005	2	10	0.006	6	10	1972
54012	Tern	Walcot	1960	0.655	24	9	0.941	26	8	1976
55031	Yazor Brook	Three Elms	1973	0.002	29	10	0.005	25	7	1976
84024	North Calder Water	Hillend	1972	0.003	4	6	0.003	6	3	1988

Station Number	River	Station Name	First year of record	New record (mm)[1]	Month	Old Record (mm)	Month	Year
Highest Monthly Runoff								
21017	Ettrick Water	Brockhoperig	1965	427	2	417	1	1975
27034	Ure	Kilgram Bridge	1967	287	2	282	10	1967
27047	Snaizeholme Beck	Low Houses	1972	506	2	444	3	1981
72005	Lune	Killington New Bridge	1969	515	2	471	2	1990
72011	Rawthey	Brigg Flatts	1968	470	2	425	1	1995

Station Number	River	Station Name	First year of record	New record (mm)	Month	Old Record (mm)	Month	Year
Lowest Monthly Runoff								
33024	Cam	Dernford	1949	1.86	9	2.03	9	1949
38016	Standsted Sp	Mountfitchet	1969	0	9	0.11	8	1992
38017	Mimram	Whitwell	1970	0	10	0.54	7	1992
39056	Ravensbourne	Catford Hill	1977	2.81	9	2.94	1	1992
39065	Ewelme Brook	Ewelme	1970	0.06	11	0.38	10	1973
40006	Bourne	Hadlow	1959	5.61	7	6.17	7	1974
40011	Great Stour	Horton	1964	6.21	9	6.33	9	1990
40015	White Drain	Fairbrook Farm	1969	0.22	9	0.57	7	1973
40016	Cray	Crayford	1969	1.44	9	1.47	8	1976
40017	Dudwell	Burwash	1971	2.96	9	3.28	9	1990
41013	Huggletts Stream	Henley Bridge	1950	1.1	9	2.04	10	1972

in the lowlands, notable flows were largely confined to responsive urban catchments. Many spring-fed rivers - including the Lud (Lincolnshire), Kennet (Berkshire) and the Hampshire Avon recorded mean flows of around 50% or less of the June average. With very unsettled conditions continuing into July, surface runoff usefully moderated recession rates and several episodes of localised - mostly urban - flooding were caused by thunderstorms. Far more damaging was a major flood event in north-east Scotland. Two days of virtually continuous rain produced storm totals reaching 150mm in the lowlands to the south of the Moray Firth. The rivers Nairn, Divie, Lossie and Isla (Grampian Region) all registered new maximum recorded flows. Flooding was most severe in the lower catchments and was extensive from Inverness to Macduff; over 1200 people were evacuated and disruption to industry, agriculture and transport was severe - the washing away of an embankment caused the Aberdeen to Inverness railway line to be closed for several days.

Continuing unsettled summer weather contributed to new maximum August flows in South-West Britain (e.g. in the Otter and Tone - which both flooded on the 6th). The hot, humid conditions spawned a number of thundery interludes some of which produced significant urban flooding (e.g. in Glasgow on the 13th). Convective storms provided only a localised boost to flow rates in most eastern rivers however, and many streams reliant principally on groundwater registered their second lowest August runoff on record (after 1976 in most cases); the associated dwindling of the headwater stream network was now substantial. Early autumn saw some minor spates in the west but generally the erratic summer recessions continued, producing remarkably depressed flows in much of central, southern and, especially, eastern England (Figure 10 and Table 3). The zone of maximum drought intensity was broadly defined by those catchments registering new September minimum runoff totals - these included the Little Ouse (Norfolk/Suffolk), Test (Hampshire), Colne (Essex) and the Mimram (Hertfordshire). The latter remained dry at Whitwell throughout the autumn - previous zero flows, in a 27-year record, were restricted to a single day in 1992.

Very modest runoff recoveries began in the east during October but flows were well below average throughout most of Britain. The Dee (Grampian Region) reported its second lowest October runoff in a 68-year record and 30-month runoff totals for many rivers in the English lowlands were unprecedented. A much more

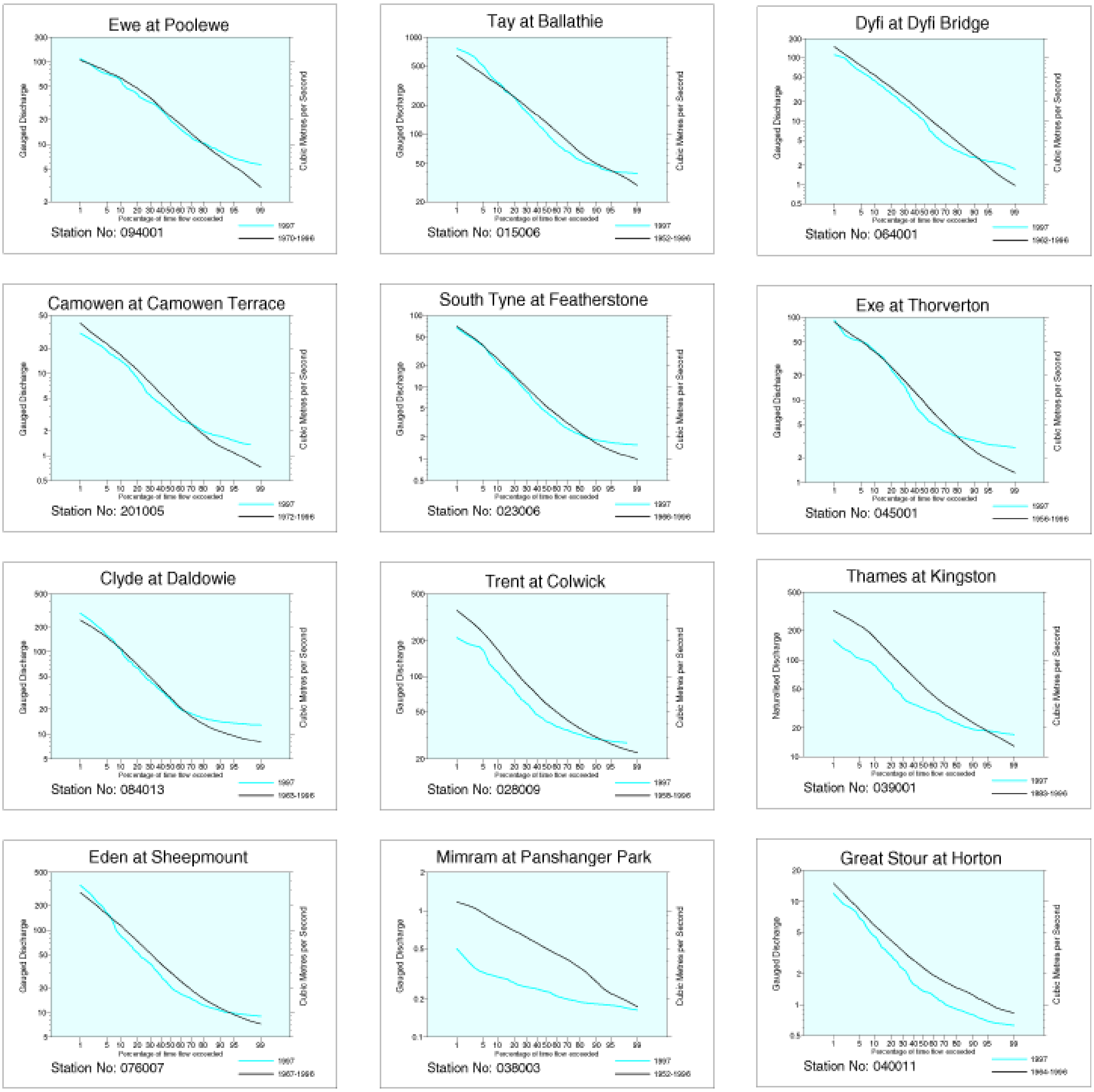


Figure 12 *Flow duration curves for 1997 (in blue) and the preceding record.*

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

general recovery began in November and notably high runoff rates were recorded in parts of Northern Ireland (the Lagan catchment in particular) and in southern Scotland - moderate flooding affected Dumfries on the 17th/18th. Notwithstanding the upturn in flow rates, new monthly minima were established on the Colne and Little Ouse. In broad terms, the seasonal runoff recovery which began in many areas during November stalled in early December but gathered considerable momentum thereafter. By year-end, bankfull flows characterised most catchments and flood warnings were widespread; a succession of gales produced significant tidal flooding, in the south and west especially.

For many eastern rivers December produced the highest monthly runoff total in 1997. Nonetheless, in many permeable catchments mean flows for every month of the year were below average. This was true of the Thames which recorded its lowest annual gauged runoff total (at Kingston) in a series from 1883; the naturalised runoff total (which allows for the water abstracted above Kingston to meet London's water supply) was less exceptional. Annual runoff totals were notably low over wide areas in East Anglia and in parts of southern England. For a few rivers, including the Pincey Brook (Essex) and Thrushel (Cornwall), the previous annual minimum had been established in 1996. Below average annual runoff totals were reported for all index catchments (Figure 11) and a significant minority in the English lowlands registered less than half of the long term average. The Colne, Hampshire Avon and Kennet (Berkshire) fell into this category, each recording its second lowest annual runoff total. In western Scotland, the Luss Water established a new annual minimum in a series from 1976.

Flow duration curves for 12 representative catchments (Figure 12) confirm that very modest runoff characterised much of 1997. The 10% and 50% exceedance flows for the Trent, Severn and Thames were substantially below those for the preceding record. However, the wet summer is reflected in the 95% exceedance flows which, in many areas, were close to the long term average.

Groundwater

Following well below average recharge over the 1995/96 winter and prolonged recessions through the ensuing late-spring and summer, the seasonal recovery of groundwater levels needed to be generated from a very low base in the autumn of 1996 (see Figure 13). Below average September and October rainfall delayed the onset of significant infiltration and, generally, increases in water-table levels were very weak over the last quarter of 1996. Entering 1997, levels in most major aquifers were therefore very depressed. On average, January is the most productive month for aquifer recharge but the extremely low rainfall in January 1997 stalled recoveries in the western outcrop areas and saw recessions continue in the east. January groundwater levels were the lowest on record for a significant minority of wells in the Permo-Triassic sandstones and a few in the southern Chalk outcrop - including Redlands in Cambridgeshire which has a 34-year record. Fortunately, the sustained February rainfall generated brisk recoveries in most northern and western aquifers (e.g. the Carboniferous and Oolitic Limestones). By contrast, the 1996/97 winter recharge was evident only by an inflection in the recessions for wells and boreholes in parts of the English lowlands; at month-end levels were close to previous minima throughout much of the eastern Chalk. In early March saturated soil conditions provided the expectation of further substantial infiltration. But March rainfall totals fell below 25% of the average in many outcrop areas and, with evaporation rates accelerating through the spring, effectively brought an end to the recharge season in parts of eastern England.

By late April the groundwater drought was particularly notable for its spatial extent, water-tables were depressed throughout England and Wales (Figures 13 and 14). New minimum April levels were established in some Permo-Triassic sandstones boreholes (mostly with relatively short records) and levels in the Chalk were very depressed away from the south-western extremities of the outcrop. Wetting-up of the soils allowed some modest, but useful, infiltration in western outcrops during May but the deep Therfield Rectory well, near Royston in Cambridgeshire, went dry for only the second time since the drought of 1921/22 (it was dry in 1992 also). The decline in groundwater levels in the Chalk since the early spring of 1995 has few modern parallels (although it appears less unusual in the context of the very wide departures from the seasonal average which has been a feature of the last decade). After successive winters with replenishment well below 40% of average over large parts of England, groundwater levels began the 1997 summer recession close to drought minima. On the basis of levels in a network of index wells and boreholes, only in 1976 and 1992, in the recent past, have overall groundwater resources in the spring been lower than in 1997.

The June rainfall exceeded actual evaporation losses in almost all regions, a very unusual occurrence in the English lowlands. In the west, this served to extend the recharge season and even triggered some limited, and isolated, recharge to the southern Chalk (e.g. in the South Downs), recoveries were also registered in parts of the Yorkshire Wolds and Lincolnshire. Nonetheless, the overall replenishment for the 1996/97 recharge season was below average in all major outcrop areas, and less than 20% over much of the eastern Chalk. Figure 15 provides a guide to the variation in replenishment across the Chalk outcrop. Groundwater level recessions resumed in July and, save for some very localised responses to thunderstorms in August, continued through the late summer and early autumn. Above average evaporation and limited September rainfall failed to provide the basis for any general recovery and existing monthly minimum groundwater levels were, locally, superseded in the Permo-Triassic sandstones. Levels in the Chalk had declined to close to drought minima in a zone from Hertfordshire to the East Midlands and Norfolk and, as a result of the seasonally very dry soils, recessions continued in eastern Britain during October. By month-end levels in most Permo-Triassic sandstones index wells were also close to period-of-record minima (Figure 16).

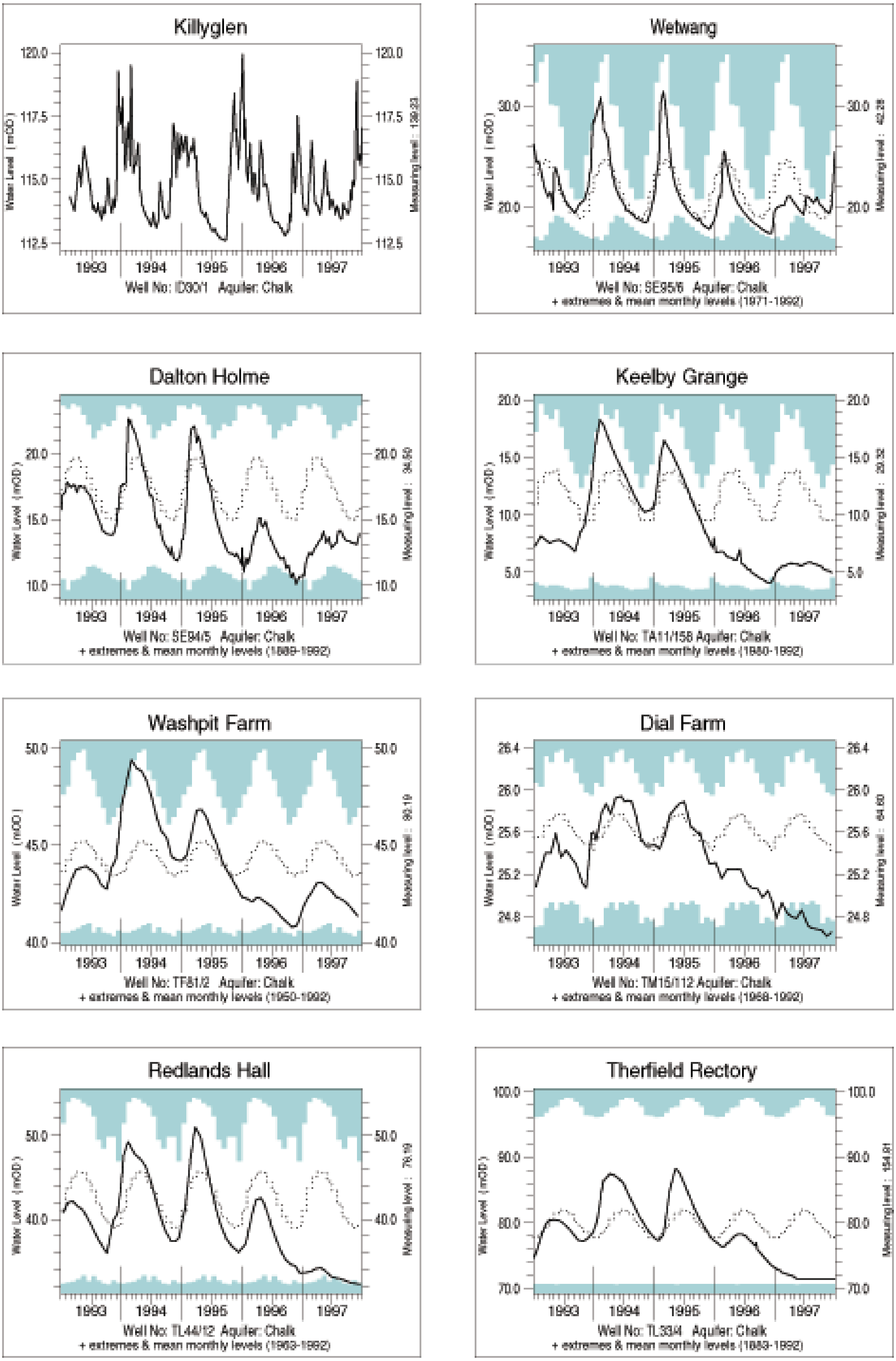


Figure 13 *Groundwater levels for selected observation sites 1993-97.*

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

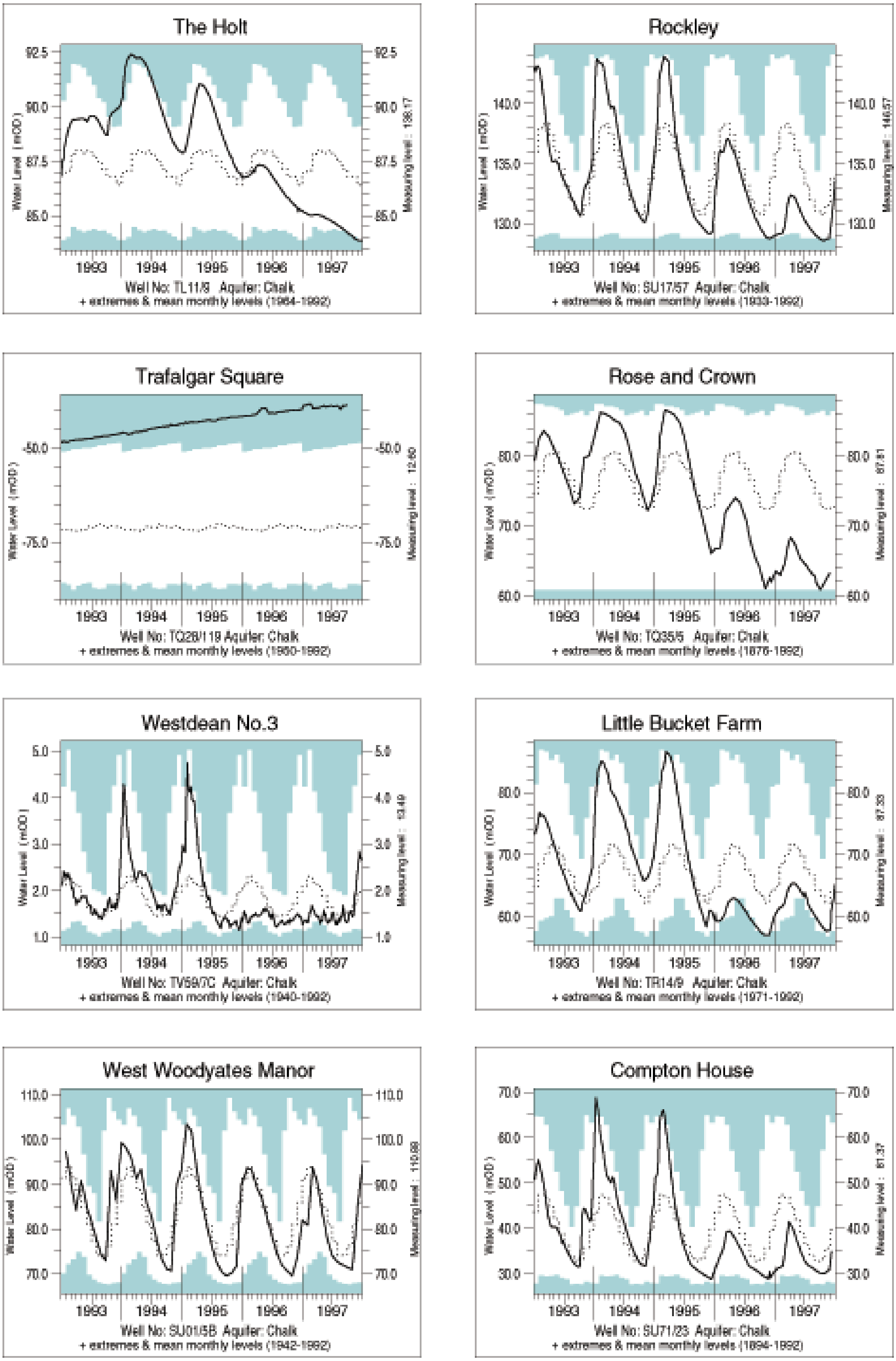


Figure 13 *(Contd.)*

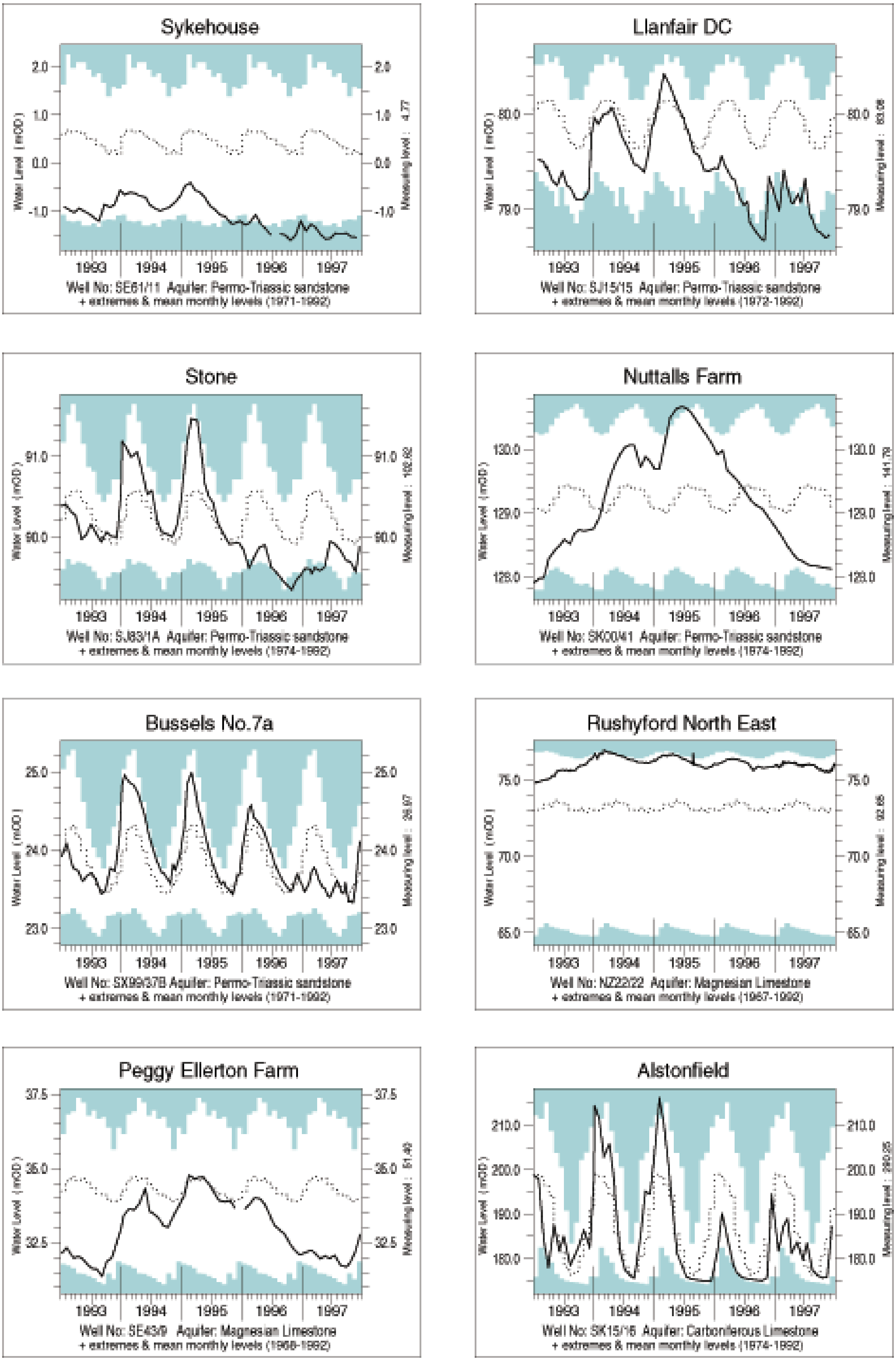


Figure 13 *(Contd.)*

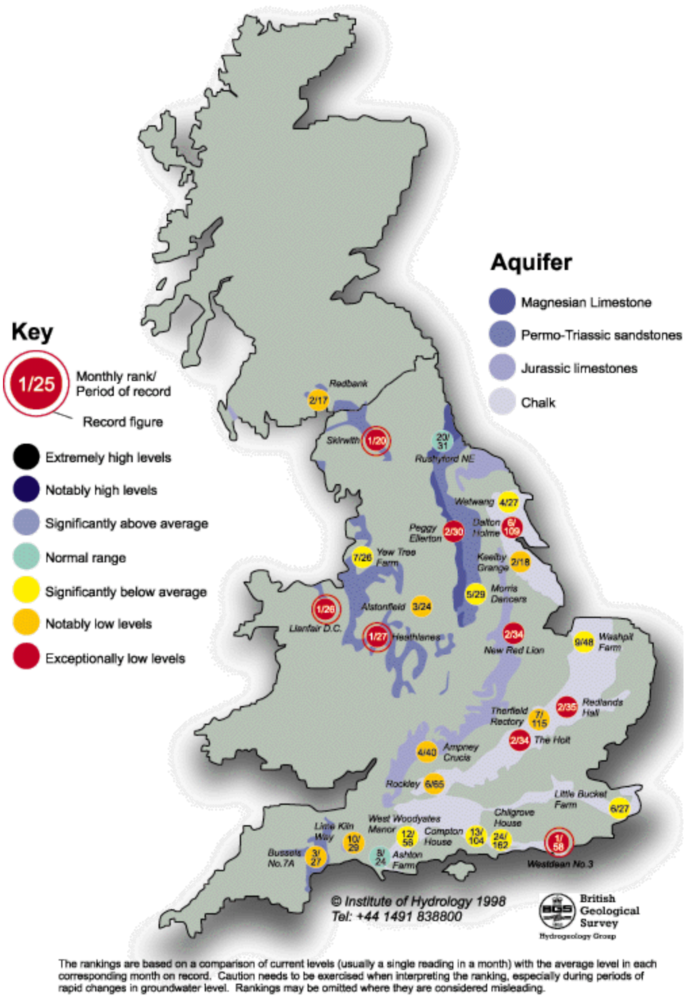


Figure 14 *Groundwater levels at the end of April 1997.*

Data sources: Environemtn Agency/Scottish Environment Protection Agency.

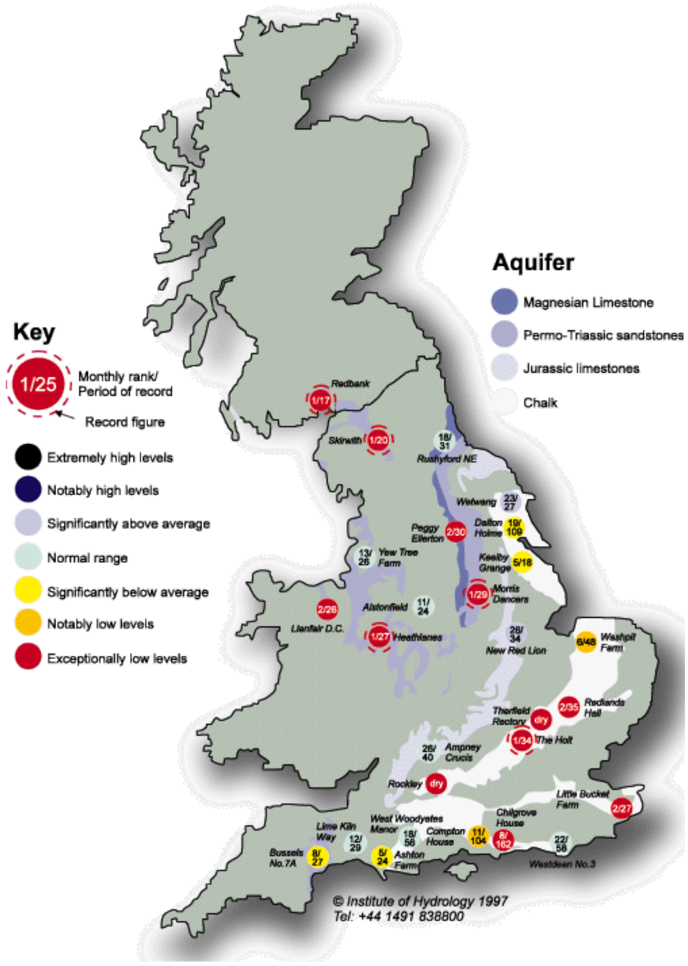


Figure 16 *Groundwater levels at the end of October 1997.*

Data sources: Environemtn Agency/Scottish Environment Protection Agency.

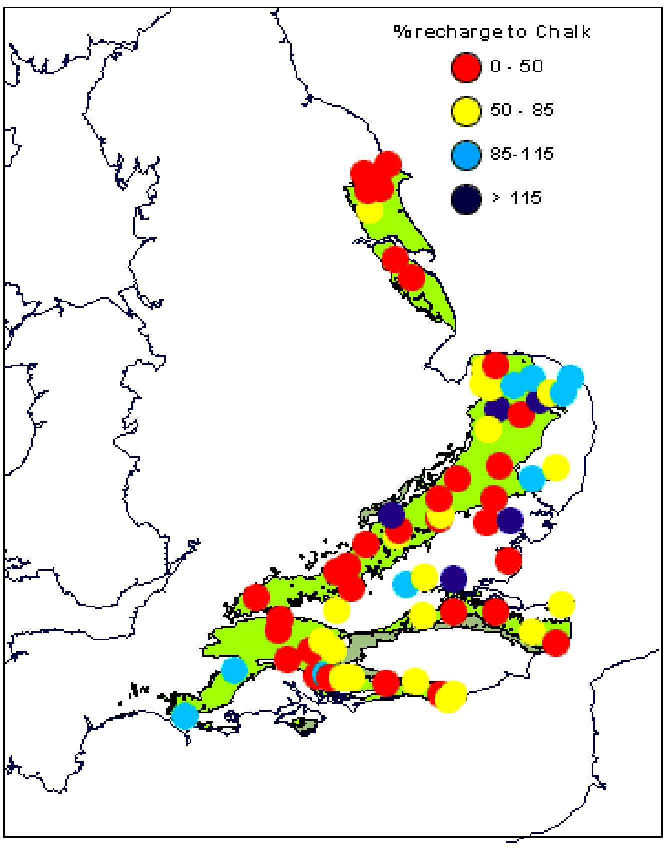


Figure 15 *A guide to 1996/97 recharge to the Chalk expressed as a percentage of the long term average.*

Most regions registered substantial infiltration during November and brisk recoveries were reported from the west. But in many eastern aquifer units (plus some more northerly localities) infiltration rates were still meagre and groundwater levels continued to reflect the long term rainfall deficiency rather than the recent wet spell; many Chalk wells (including Redlands and The Holt) registered new minimum November groundwater levels. Levels were also exceptionally low in some minor aquifers in East Anglia (e.g. the Suffolk Crag and Essex gravels).

Taken together, November and December were the most productive months for infiltration for almost three years in much of the UK. Remaining soil moisture deficits were briskly eliminated in most areas by the middle of December allowing very substantial infiltration over the ensuing four weeks. By year-end levels in most areas were climbing steeply. In most limestone outcrops levels were well above average - in the Cotswolds especially. Some western and southern Chalk outcrops reported dramatic recoveries; water-table rises in parts of Dorset, for example, exceeded the average annual range. Similarly, levels at Rockley (near Swindon) rose from near-record autumn minima to appreciably above average by the second week of January 1998. By contrast, in parts of central and eastern England the seasonally dry soils delayed infiltration (until beyond year-end in a few cases) and levels in the Chalk of the Chilterns, the Lee basin, Cambridgeshire and Suffolk (and a few other eastern outcrops), remained very depressed. December levels were the lowest on record at Redlands and The Holt (near Luton), and the Therfield Rectory well remained dry. Depressed December levels also typified many of the more northerly Permo-Triassic sandstones outcrops and a number of boreholes in the Midlands (especially those in the slower responding confined zones).

The above commentary relates principally to the natural variation in groundwater levels during 1997. In parts of the UK, however, levels have been influenced, sometimes over long periods, by pumping for water supply or other purposes which exceeds the natural rate of replenishment. As a consequence the regional water-table may become substantially depressed. For instance, levels in some parts of the Permo-Triassic sandstones of the Midlands are indicative of a significant regional decline. By contrast, a protracted recovery is evident for the Trafalgar Square borehole (see Figure 17 which penetrates the confined Chalk below central London. As a result of increasingly heavy abstraction groundwater levels declined by around 70 metres between the early nineteenth century and the 1950s. Subsequently, much reduced abstraction rates have allowed groundwater levels to rise, latterly by almost two metres a year. Rising groundwater levels have also been reported from other conurbations in Britain. These again are linked to reduced abstraction rates but leakage from water mains may be a factor in some cases. The implications of rising groundwater levels extend beyond the potential improvement in 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.

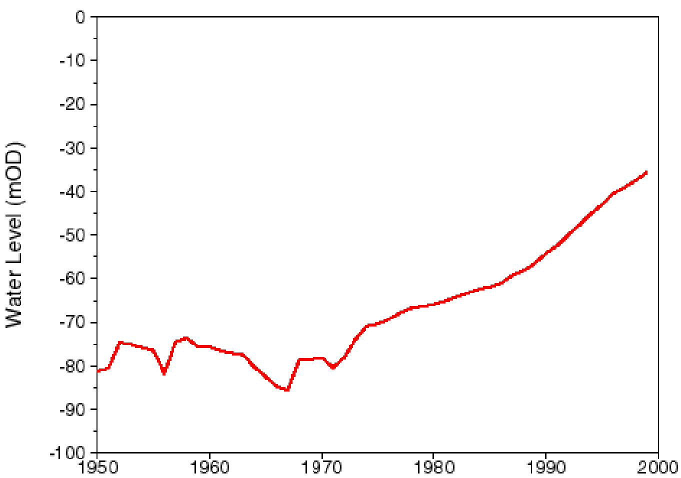


Figure 17 *Annual mean groundwater levels for the Trafalgar Square borehole (from 1950).*

Location Map

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www.ceh.ac.uk