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Hydrological characteristics of summer 1989 and winter 1989/90

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Report to Institute of Terrestrial Ecology, Bush Estate, Penicuik, Midlothian

Chapter 1.3 in "A hot, dry summer (1989) and mild, wet winter (1989/90)"

INSTITUTE OF HYDROLOGY
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Executive Summary

The summer of 1989 was drier than average across most of the United Kingdom and, with the exception of a wet period particularly in the west in October, remained dry right through to the middle of December: recent, notable, droughts had been ended by late September. Potential evapotranspiration rates during the summer were among the highest on record, and soil moisture deficits were accordingly large and long-lasting. The winter of 1989/90 was, like the preceding winter, mild, but was considerably wetter. Winter rainfall was more than 50% above the long term average in many regions, but parts of eastern Scotland and eastern and south east England received, for the second year in succession, below average rainfall. In these regions soil moisture deficits continued through the winter. The rainfall pattern of summer 1989 through to spring 1990 has been notable in two respects. Firstly, the usual difference between the wet west and drier east has been considerably exaggerated. Secondly, the rainfall was very highly concentrated in a relatively short winter period, a feature more typical of Mediterranean climates.

Groundwater levels remained above those recorded in 1976 through the summer of 1989, but unlike in 1976, continued to decline during late autumn. The heavy rainfall between December 1989 and February 1990 led to some very rapid rises in groundwater level, but levels fell very quickly in the dry spring of 1990 so that levels were no higher at the beginning of summer 1990 than they were the previous year after a considerably drier winter. Recharge was limited in those eastern regions with little winter rainfall.

River flows too were higher during the summer of 1989 than during 1976, but continued declining until December (with slight recoveries in some catchments in October). Some rivers experienced very rapid rises from near-record minimum flows in early December to flood conditions in late December, and runoff was the highest on record in February 1990 in many catchments. As with groundwater, however, river flows declined rapidly during the dry spring of 1990, and some reservoirs were in a poorer state at the beginning of summer 1990 than at the same time the previous year. The winter rain fell in too short a time, and there simply was not enough capacity to store all the surplus water. A comparison with the previous winter suggests that a little rain late in spring is more useful for maintaining summer supplies than a lot of rain early in winter followed by a dry spring.

1.3 Hydrological characteristics of summer 1989 and winter 1989/90

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1.3.1 Introduction

The year May 1989 to April 1990 was remarkable for both its spatial and temporal climatological variability. A dry summer followed a dry winter, and 1989 as a whole was the driest since 1976. Like the preceding winter, the winter of 1989/90 was substantially warmer than average, but was, in stark contrast, remarkably wet. England and Wales as a whole had the third wettest December to February period since 1766, but there was considerable variation between the wet west and rather drier east. Over much of south England, between 50 and 60% of the rainfall between May and April fell in a 10 to 12 week period beginning in the second week of December. Evaporation rates and soil moisture deficits were exceptionally high during 1989.

Both groundwater levels and river flows remained higher than in 1976 during June, July and August, but the lack of widespread autumn rain meant that levels and flows in many areas continued to decline until December, frequently reaching new minima. The rise in levels and flows from mid-December was very rapid, and widespread flooding ensued, reaching a peak in most areas in February: many February flows were the highest on record. In parts of eastern Britain, however, the relative lack of winter rain meant that groundwater and surface resources were poorly replenished for the second winter in succession. Groundwater levels and river flows fell rapidly during the dry spring of 1990, leading to fears of a second year of water shortage.

This Chapter summarises the hydrological characteristics of the period from May 1989 to April 1990, drawing comparisons with previous notable years.

1.3.1.1 Data sources

The data inputs to this chapter came from a variety of sources. The Meteorological Office Rainfall and Evaporation Calculation System (MORECS : Thompson et al, 1981) produces weekly and monthly climatic data for 188 40 km by 40 km grid boxes covering England, Scotland and Wales. In addition to this, two long time series of homogenised rainfall for England and Wales and Scotland were provided by the Climatic Research Unit at the University of East Anglia, who also supplied the Central England Temperature record. River and groundwater data are collected principally by the National Rivers Authority and the Scottish River Purification Boards, and are held on the Surface Water and Groundwater archives maintained by the Institute of Hydrology (IH) and the British Geological Survey (BGS) respectively. The monthly Hydrological Summaries for England and Wales, prepared jointly by IH and BGS on behalf of the Department of the Environment, were also used in the analysis.

1.3.2 May 1989 to April 1990

1.3.2.1 Snowfall and rainfall

The winter season 1989/90 produced very little snow. However, the relatively wet conditions of 1989/90, compared to 1988/89 did result in a little more snow than the previous year. A network of 22 sites around Britain record the monthly total of days with snow lying at 0900, and the figures are published in Weather magazine's Weather Log. Of these 22 sites 8 recorded no days with snow at 0900 throughout the entire winter (November to April) of 1989/90. For the shorter definition of winter (December to February) this figure rose to 9 sites. All of these sites lacking snow were south a line joining Liverpool and Norwich.

The only noticeable falls were in Scotland, where Eskdalemuir recorded 21 days with snow lying at 0900 (during the 6 month winter). This compares to the 1988/89 value of 14 and the long term median (1946/47 to 1987/88) of 32 days. Fewer days than this have only been recorded on 8 occasions. The falls were fairly evenly distributed throughout the December to April period with perhaps a minor peak in January. To the south, Lyneham in Wiltshire recorded no 'snow days' compared to median value of four or five and one day during 1988/89. The situation has only arisen once before, during the winter 1975/76.

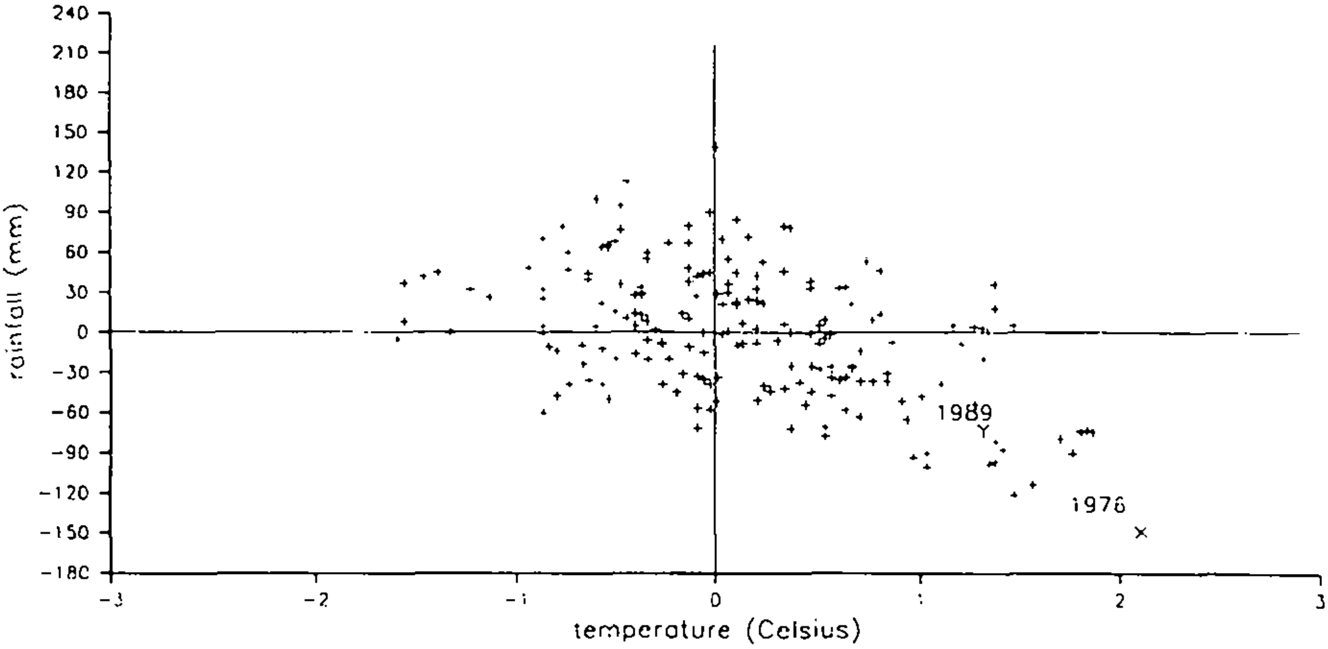
Table 1.3.1 (taken from the May 1990 IH/BGS Hydrological Summary), lists the rainfall (as monthly totals and as a percentage of the 1941-70 mean) for each of the National Rivers Authority (NRA) regions and the River Purification Boards of Scotland. Following a relatively wet spring, May was unusually dry. For example the London Weather Centre recorded only 2% of its May average. Over England and Wales as a whole it was the driest May since 1896, with only 33% of the 1941-70 average. Interestingly May 1990 was also exceptionally dry, recording only 37% of the long term average. Scotland too continued a run of dry Mays with 1989 and 1990 being 64% and 60% of the long term Scottish average respectively.

The following summer months (June to August) produced warm and dry conditions throughout England and Wales. Figure 1.3.1a plots England and Wales rainfall against the Central England Temperature from 1766, for the June to August period. In general, the warmer the summer the less the rainfall, and 1989 proves no exception. Summer 1976 is also plotted to highlight the extreme conditions of that year in comparison to 1989. June 1989 was very warm, although rainfall was about average and only modest drought conditions existed in some southern and western districts. July intensified this situation, extending the drought to many areas and by the end of August moderate to severe drought conditions existed in all but the far north west of Scotland. This five month period ranked as second driest in the England and Wales rainfall series that begins in 1766 (Anon, 1990).

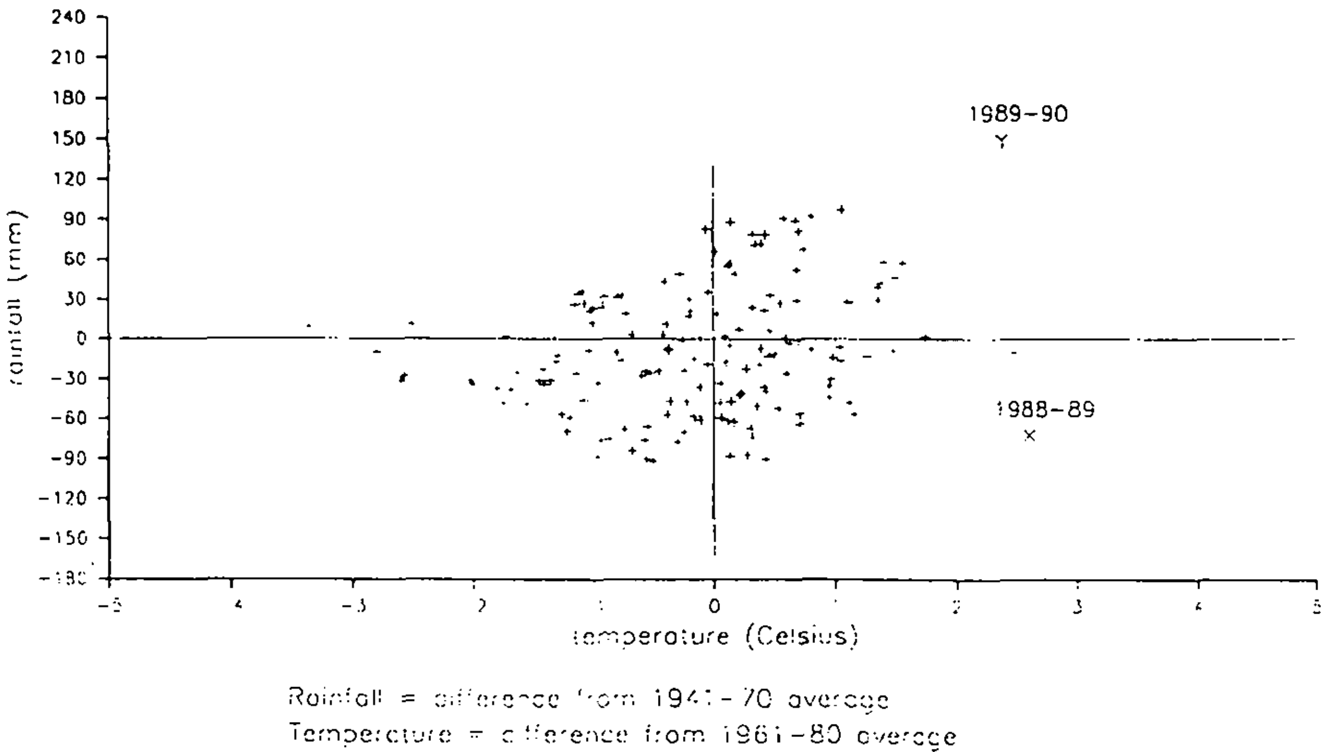
Considering Scotland alone the overall picture was somewhat different. The 1989 summer rainfall total was 325mm, 97.7% of the long term (1941-70) average, but this figure hides a huge variability within Scotland. The north and west received anything up to 150% of average with only about 60% falling in the east. As an illustration of this east/west differential, the

		May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
				1989							1990		
England and Wales	mm	20	55	38	58	41	98	61	134	133	142	20	38
	%	30	90	52	65	49	118	63	149	154	219	34	66
NRA Regions													
North West	mm	37	82	33	116	29	145	84	100	196	187	47	52
	%	45	99	32	93	24	123	69	83	175	231	65	68
Northumbria	mm	22	51	19	77	20	71	35	75	111	133	33	28
	%	34	84	25	76	25	95	37	100	139	202	63	51
Severn Trent	mm	25	53	40	44	38	82	52	135	107	110	21	30
	%	39	95	62	54	57	126	66	193	155	208	40	58
Yorkshire	mm	19	69	43	41	20	77	45	98	118	112	24	24
	%	31	119	61	46	28	112	51	132	153	175	45	43
Anglia	mm	14	56	41	35	30	41	36	98	52	74	15	36
	%	30	114	72	55	58	79	58	185	101	177	37	90
Thames	mm	14	39	37	44	28	65	37	141	91	113	12	35
	%	25	75	62	63	45	102	51	214	147	242	26	76
Southern	mm	5	41	28	29	37	79	50	142	121	135	6	43
	%	9	82	54	40	52	101	53	175	159	238	11	90
Wessex	mm	21	32	37	43	49	101	58	165	124	157	15	35
	%	31	59	60	52	62	123	60	183	148	265	26	65
South West	mm	12	40	31	62	107	148	100	196	195	238	25	47
	%	14	62	37	61	103	131	75	145	151	264	30	66
Welsh	mm	25	67	48	91	62	180	109	199	240	214	37	45
	%	27	82	51	76	50	140	76	137	176	244	42	52
Scotland	mm	53	76	49	184	96	187	60	96	248	291	183	97
	%	59	83	44	143	70	126	42	62	181	280	199	108
River Purification Boards													
Highland	mm	68	90	65	222	118	252	79	109	293	364	395	148
	%	66	82	51	150	75	135	47	56	179	274	346	130
North East	mm	59	57	25	84	57	87	29	54	103	145	87	51
	%	77	81	27	79	66	90	28	53	113	195	140	84
Tay	mm	42	58	30	140	83	136	51	86	236	249	186	62
	%	44	70	29	119	72	111	43	64	200	270	227	83
Forth	mm	36	64	27	144	69	112	39	79	220	221	134	50
	%	43	85	28	124	64	106	36	72	222	287	194	74
Tweed	mm	43	51	23	113	47	68	30	78	166	180	53	47
	%	57	75	27	99	51	77	29	87	179	260	91	77
Solway	mm	35	71	42	176	77	145	59	119	250	282	97	50
	%	38	79	38	135	51	101	41	79	179	303	107	57
Clyde	mm	46	90	63	252	120	244	73	107	316	343	290	144
	%	47	87	48	177	69	133	44	58	196	304	276	140

Table 1.3.1 Monthly rainfall for May 1989 to April 1990 in millimetres and as a percentage of the 1941-70 average.



a Summer: June, July and August



b Winter: December, January and February

Figure 1.3.1: Relationship between Central England Temperature and England and Wales rainfall. The data extend back to 1766.

long rainfall records of Aberdeen (Dyce Met Office) and Ayr (racecourse) may be compared. For the three month summer, Ayr received 31% more than the 1941-70 average, whilst in Aberdeen there was 34% less. Annually, the figures for 1989 at these sites showed that while Ayr received rainfall marginally above average, Aberdeen experienced the second driest year this century, some 38% below average. Only 1921 has been drier. For Scotland as a whole the 1989 total was a little above average.

Unlike 1976, the dry summer did not break in September and a severe five month drought (May to September) existed in the north east, central and southern England and south Wales.

Figure 1.3.2 uses the MORECS data to compare the extended summer months (May to October) for 1989 and 1976. For summer 1989 some areas received below average rainfall in every month: see, for example eastern Scotland, and both north east and south east England. This compares to 1976 when the (meteorological) drought ended abruptly in September.

October saw the return to somewhat wetter conditions with above average rainfalls recorded in most regions. In contrast November was dry throughout Britain with the lowest rainfall figures, in terms of percentages of the long term average, occurring in Scotland. The first half of December continued as November with some places recording a stretch of 30 days with no rain. The rain that started in mid December saw the beginnings of what was to be the third wettest winter (December to February) in England and Wales since 1766 (1914 and 1876 were wetter). Plotting the difference from the long term average for both temperature and rainfall (Figure 1.3.1b) the winter 1989/90 plots in the very extreme end of warm, wet sector, a dramatic change from the winter of 1988/89. The spatial distribution of the rainfall was also very different from that of 1988/89. Figure 1.3.3a shows the MORECS data for this period where only 7 out the 188 boxes recorded below average rainfall, compared to Figure 1.3.3b for the same period during the 1988/89 winter which shows all areas but north west Scotland with below average rainfall. Vast areas of the country experienced rainfall in excess of 50% above the long term mean in 1989/90. Whilst something of a north west/south east gradient still exists, parts of Wales and southern England, as well as north west Scotland received over 200% of their average rainfall. In 1988/89 the areas with this sort of anomaly were very restricted to the far north and west of Scotland. By referring to Table 1.3.1, February 1990 can be seen as the most severe month with 14 of the 17 water regions of Britain receiving over 200% of their average February rain: it was also the wettest month on record over Great Britain as a whole since at least 1869.

The mild winter of 1988/89 was brought about largely by the Jet Stream running in an abnormal position slightly to the north of Scotland. This then directed the weather systems further north than usual over the north and west of the country, giving these areas a mild, wet winter. Southern districts however, under the northern edge of a particularly strong Azores High, experienced a mild and dry winter. Between mid December 1989 and the end of February 1990, however, the Jet resumed its more usual position over the UK, meaning the entire country received the brunt of the winter storms, with rainfall amounts lower in the east in the rain shadow areas. The very warm conditions, and 1989 ranked as the 3rd warmest year since 1633 (CET), had produced anomalously high sea surface temperatures and whether this accounted for the exceptionally high rainfall and run of very severe storms

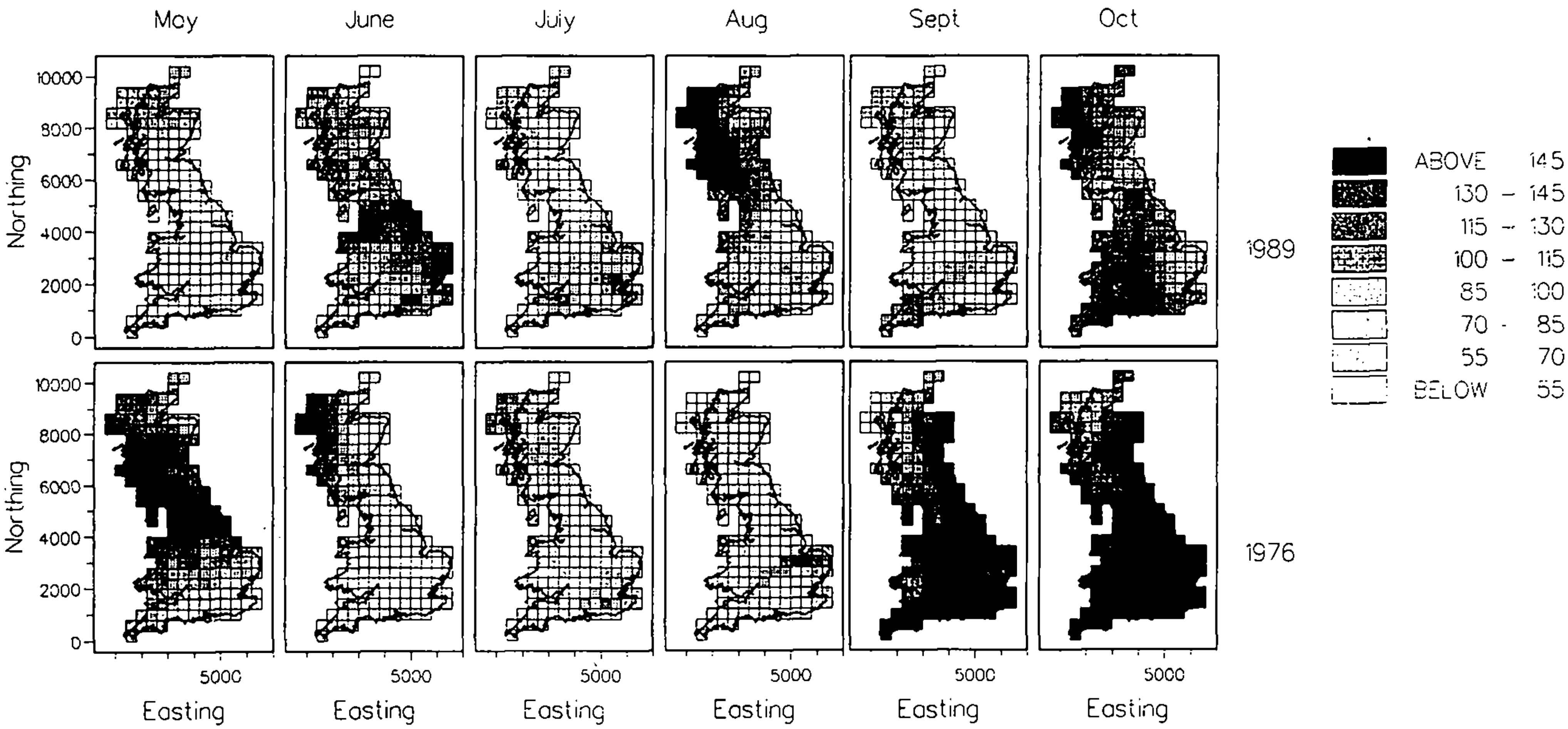
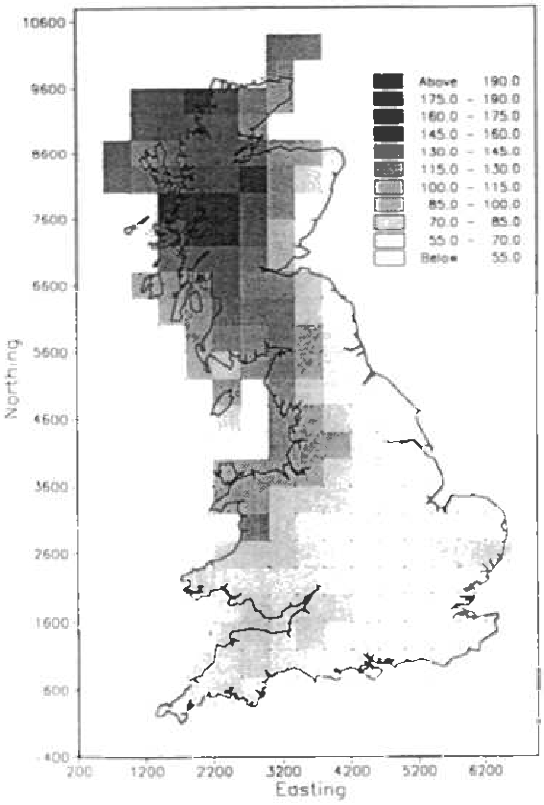
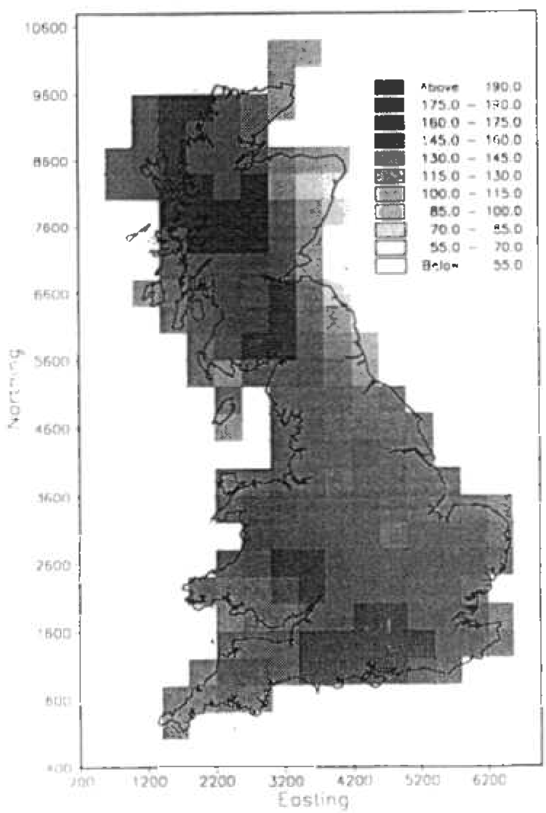


Figure 1.3.2: Comparison of monthly rainfall between summer 1976 and 1989: the maps show monthly rainfall as a percentage of the 1961-1980 mean, and use MORECS data



a: Winter 1988/89



b: Winter 1989/90

Figure 1.3.3: Winter rainfall (December to February) as a percentage of the 1961-1980 average: MORECS data

in January and February is still a matter for debate.

1.3.2.2 Evaporation and soil moisture

During the summer of 1989 (June to August) the high temperatures and record sunshine totals produced potential evapotranspiration rates well above average (1961-80) over the entire country, apart from a small area of north west Scotland. Actual evapotranspiration however, taking into account the availability of water, exhibits an almost reversed pattern. Areas of southern and central England and the Eastern seaboard recorded below average rates for the summer of 1989 reflecting the lack of rainfall. Wales, the North West and much of Scotland recorded greater than average evaporative losses as the rainfall was sufficient to meet these high evapotranspiration demands.

The summer of 1976 provides a very interesting comparison to the summer of 1989 (Figure 1.3.4). In 1976 there was a far more obvious north west/south east pattern. South east England experienced potential evapotranspiration losses of more than 30% above the long term mean over a much wider area then in 1989 (Figure 1.3.4a). The south west, large areas of northern England and Scotland recorded higher potential evapotranspiration in 1989 than in 1976.

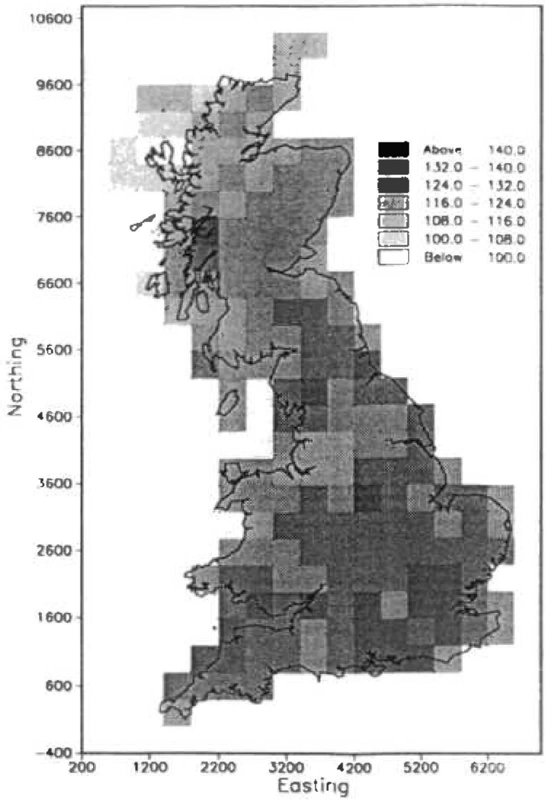
The actual evapotranspiration over the entire country was higher during the summer of 1989 (Figure 1.3.4b) than in the summer of 1976 (Figure 1.3.4d) because of the greater availablity of water in 1989. In 1976 nearly all of England south of Yorkshire had actual evapotranspiration totals less than 65% of the 1961-80 mean. The pattern of actual, like potential evapotranspiration, exhibited a north-west/south-east trend. The north and west of England and Scotland recorded actual evapotranspiration totals above the average highlighting the areas with relatively little water stress. In 1989 these areas occurred much further south.

The shortfall of actual relative to potential evapotranspiration is an indication of water stress and hence is of hydrological significance. During the summer of 1989 the north and west recorded minor shortfalls, whereas southern and eastern districts saw values approaching 200mm. Such figures have only been exceeded in 1976.

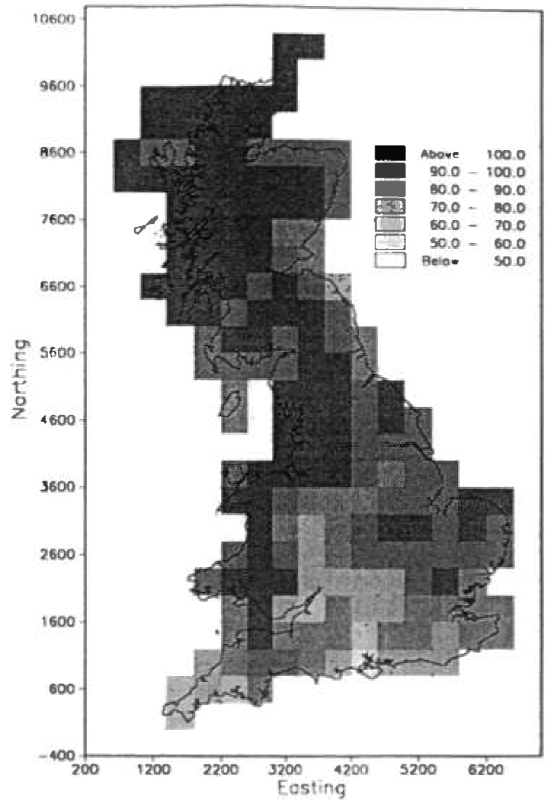
Actual and potential evapotranspiration rates for the winter of 1989/90 were above the 1961 to 1980 average over the whole of the UK, with the highest rates in the north west of Scotland and England and to a lesser extent some central and southern districts of England. The lowest values were found along the western seaboard, apart from the far north. The millimetre differences from the mean during winter were relatively small, only between 5 and 30 mm, and were very similar to the 1988/89 anomalies.

Soil Moisture deficits (SMD) were also extraordinary for the year May 1989 to April 1990. Despite the relatively wet Spring of 1989 field capacity was not reached in many eastern areas and appreciable SMDs were sustained throughout the winter. Figure 1.3.5 shows the positions of five selected MORECS boxes, with Figure 1.3.6 plotting the time series of potential and actual evapotranspiration and SMD from 1985 to March 1990.

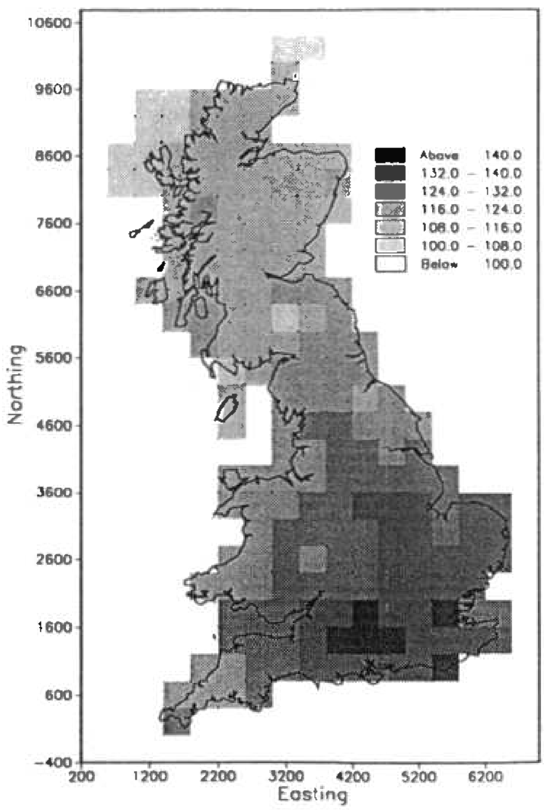
North west Scotland represented by box 41 shows SMD values that are not obviously different from any of the previous four years. It may be observed



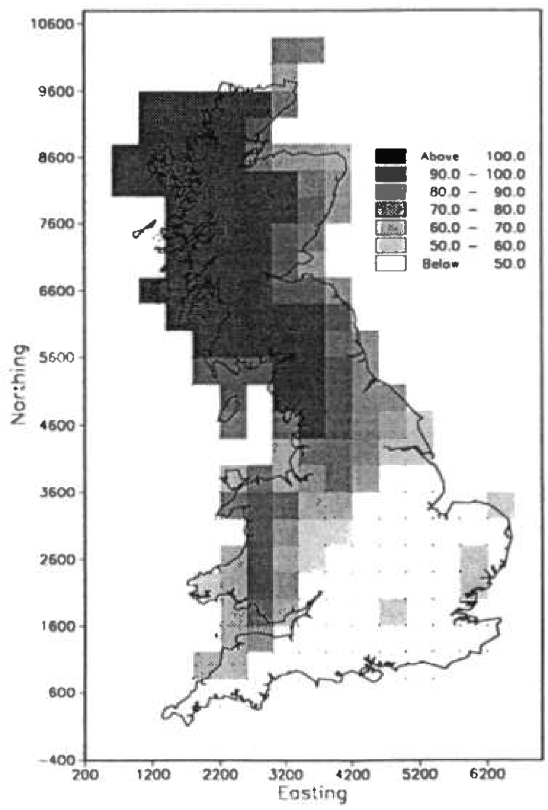
a: Potential evapotranspiration 1989



b: Actual evapotranspiration 1989



c: Potential evapotranspiration 1976



d: Actual evapotranspiration 1976

Figure 1.3.4: Potential and actual evapotranspiration in summer (June, July and August) 1989 and 1976, as a percentage of the 1961-1980 average: MORECS data

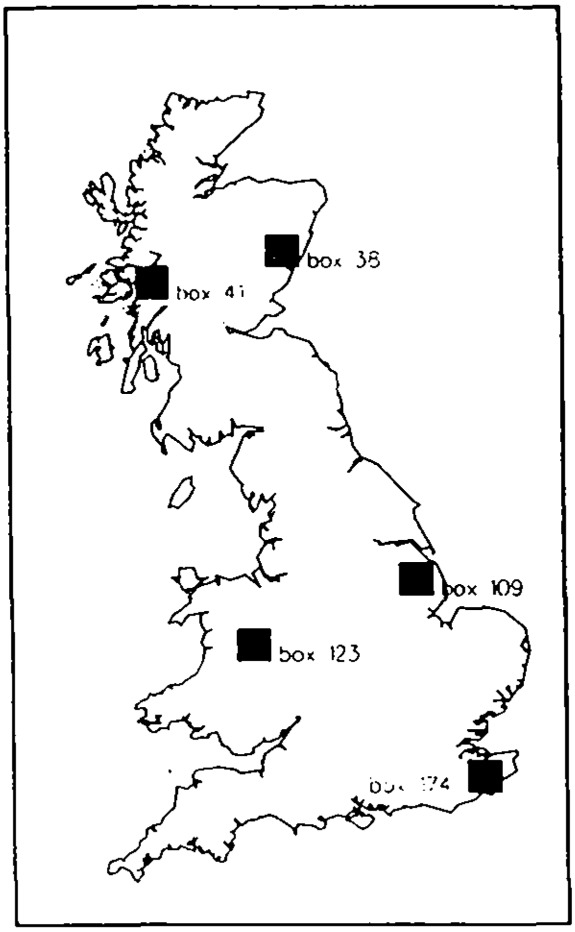


Figure 1.3.5: Locations of the MORECS boxes shown in Figure 1.3.6.

however that both potential and actual evapotranspiration rates were slightly higher, and this is seen to be true of every MORECS box selected.

The rapid decrease in the amount of rainfall from west to east Scotland produces very different SMD patterns. The east coast is represented by MORECS box 38. Unusually, deficits built up in January 1989, following the mild and dry winter. These deficits were removed during the more sustained rain in February. With the very dry and warm conditions of the summer, deficits reached 100mm in many boxes in eastern Scotland by July. This area saw the lowest rainfall of the winter 1989/90 in terms of a percentage of the long term mean and this, coupled with very high potential evapotranspiration rates meant that, unusually, SMDs were maintained throughout the winter.

Moving south the pattern of eastern Scotland is repeated in most of eastern, southern and central England and many areas maintained deficits throughout the February 1988 to January 1990 period. In some districts of Northumbria and the extreme south east of England SMDs were not fully replenished through the winter of 1989/90. The method of calculation of SMDs within the MORECS model puts the maximum possible deficit for grass at 125mm. During the summer of 1989, 55 of the 188 MORECS boxes reached a deficit of 125mm for at least one month, and many of these maintained this maximum between July and September.

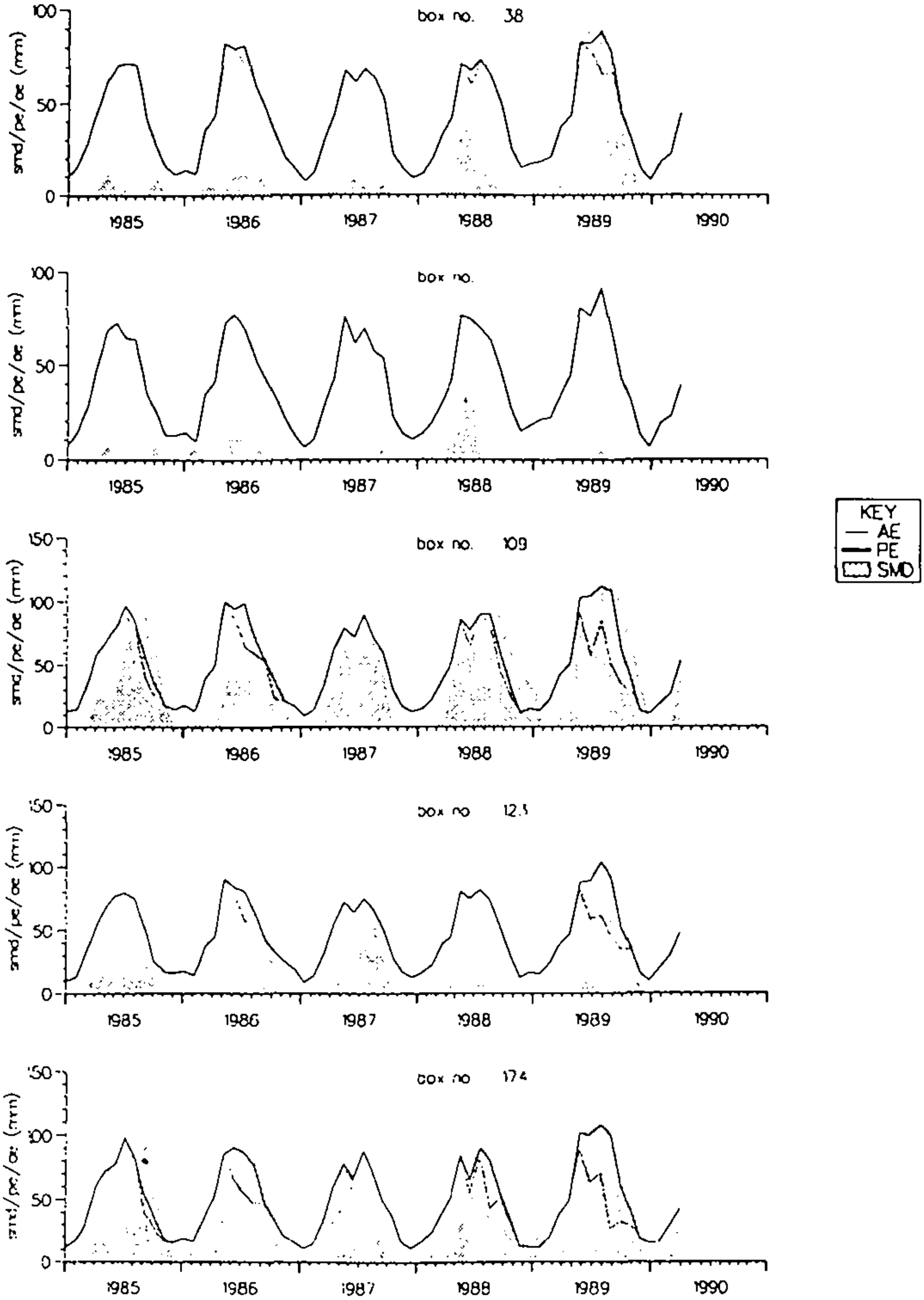


Figure 1.3.6: Soil moisture deficit, actual evapotranspiration and for five MORECS boxes

1.3.2.3 Groundwater

Groundwater resources in Britain typically show a strong seasonal cycle, with recharge largely confined to winter and summers characterised by continued recession (with the lag between rainfall inputs and groundwater response varying between aquifers). The winter of 1988/89 was dry, but infiltration during the spring of 1989 boosted groundwater recharge at a time when levels are more usually falling and groundwater levels across most of Britain were close to average at the start of summer (Arnell et al, 1989). Only in the chalk in eastern and parts of southern England (Yorkshire, Kent and a portion of Sussex) were groundwater levels in May 1989 considerably below average, and here approached levels recorded in 1976 (in some regions, such as in parts of east Devon, groundwater levels were low as a result of a combination of the dry winter and high groundwater abstraction). Through the summer of 1989 groundwater levels remained higher than those recorded in 1976 across most of Britain.

Groundwater levels usually begin to rise again in the autumn as soil moisture deficits are replenished, but the dry November in particular in 1989 meant that there was very little widespread recharge until December. Rainfall in October produced some local recovery in levels, but this proved short-lived. By the end of November, many wells were therefore close to or below their minimum recorded levels: at Dalton Holme in the Yorkshire chalk levels in December 1989 were below the previous lowest in a 106-year record. The groundwater resources at the beginning of the 1989/90 recharge season were in a worse position than at the beginning of the previous winter, particularly in the east.

Once the initial soil moisture deficits were replenished, however, the heavy rain in December led to rapid rises in groundwater levels, particularly in shallow or well-fissured aquifers. In western aquifers (such as the Permo-Triassic sandstones) levels entering 1990 were higher than average, although the recovery was slower further eastwards and was very limited in the extreme east. Groundwater levels rose further following the heavy rainfall in January and February, and in most wells exceeded the seasonal average. The well at Chilgrove in the chalk in Sussex recorded a rise of 20m in seven days in February 1990, a rate well in excess of that terminating the 1976 drought and probably the fastest in a 154-year record (as far as can be ascertained from monthly data). Over most British aquifers, groundwater recharge in the winter of 1989/90 was above - sometimes well above - average. Recharge was, however, below average in the chalk in parts of Yorkshire, East Anglia and Kent, and levels remained below the seasonal mean. The dry March and April meant that groundwater recharge finished earlier than usual, and many well levels fell more rapidly than is usual: in some eastern wells this rapid decline was from an exceptionally low base. By the end of May 1990 groundwater levels across most of Britain were below average, but mostly within the normal range: in the east and parts of the south water tables began the summer of 1990 at an exceptionally low level.

A comparison of groundwater behaviour in 1988/89 and 1989/90 shows the benefit of late, albeit limited, recharge. Rainfall was high during 1989/90 (except over eastern chalk), but the recharge season finished early and levels fell rapidly: levels in many wells were lower at the beginning of summer 1990 than at the same time after the considerably drier winter of 1988/89. The experience of 1989/90 suggests that when recharge is concentrated into a few weeks of intense rainfall, the improvement in resources in some aquifers (and hence ability to sustain summer levels) may not be as large as implied by the increase in levels. Even in well-fissured aquifers a substantial amount of water may be held in intergranular storage rather than in the larger fissures. It is possible that short periods of intense rainfall may appear to be insufficient to recharge this intergranular store, and water levels recede rapidly once recharge ceases. There is also some suggestion that if rainfall is very intense, much of the excess of rainfall over evaporation runs off in floods rather than infiltrates as groundwater recharge. Both these suggestions merit further research.

1.3.2.4 River flows

Rivers in Britain are very heavily managed, and it is difficult to find gauging stations where long records of "natural" river flows have been maintained. Artificial modification of river flow regimes is particularly widespread in dry summers. Licences for the abstraction of water from rivers may be temporarily revoked, for example, or water may be transferred between catchments. Low river flows may be reduced further by increased abstraction from groundwater, and other catchments may be augmented by groundwater abstraction.

Data are available from enough rivers where the net impact of artificial influences is limited, however, to provide the basis for a generalised review of the river flow characteristics between spring 1989 and spring 1990.

Figure 1.3.7 shows monthly flows from May 1989 to May 1990 for several representative catchments (shown on Figure 1.3.8), expressed as a percentage departure from the average flow for each month calculated over the entire period of record. Although there are some considerable differences between the magnitudes of the departures in each catchment, the data (together with data from catchments not plotted) show that flows were below average across virtually the whole of Britain until at least December 1989, with the rainfall in October 1989 producing higher than average flows in some western catchments. The size of the relative departure from average in each catchment depends not just on the deviation in rainfall and evapotranspiration from the norm, but also on the average summer water balance and catchment geological conditions. If summers have, on average, a close balance between summer rainfall and potential evapotranspiration (as is more typical of upland catchments), a reduction in rainfall and an increase in evapotranspiration would have a considerable relative effect on summer flows. If, on the other hand, summers are usually characterised by large water deficits (rainfall less than potential evapotranspiration) and the catchment has little natural storage to provide baseflow support through the summer, flows are low in most years and would be relatively less affected by the unusually dry and warm summer: flows in autumn would show a greater relative effect, because soil moisture deficits would last longer into autumn. These tendencies can be shown by modelling studies, and some supporting evidence can be found from observed data. Data from 28 catchments were used in a multiple regression analysis, which showed that the variation between catchments in the relative departure from average summer runoff during 1989 was influenced by the average summer water balance as well as variations in the summer rainfall anomaly:

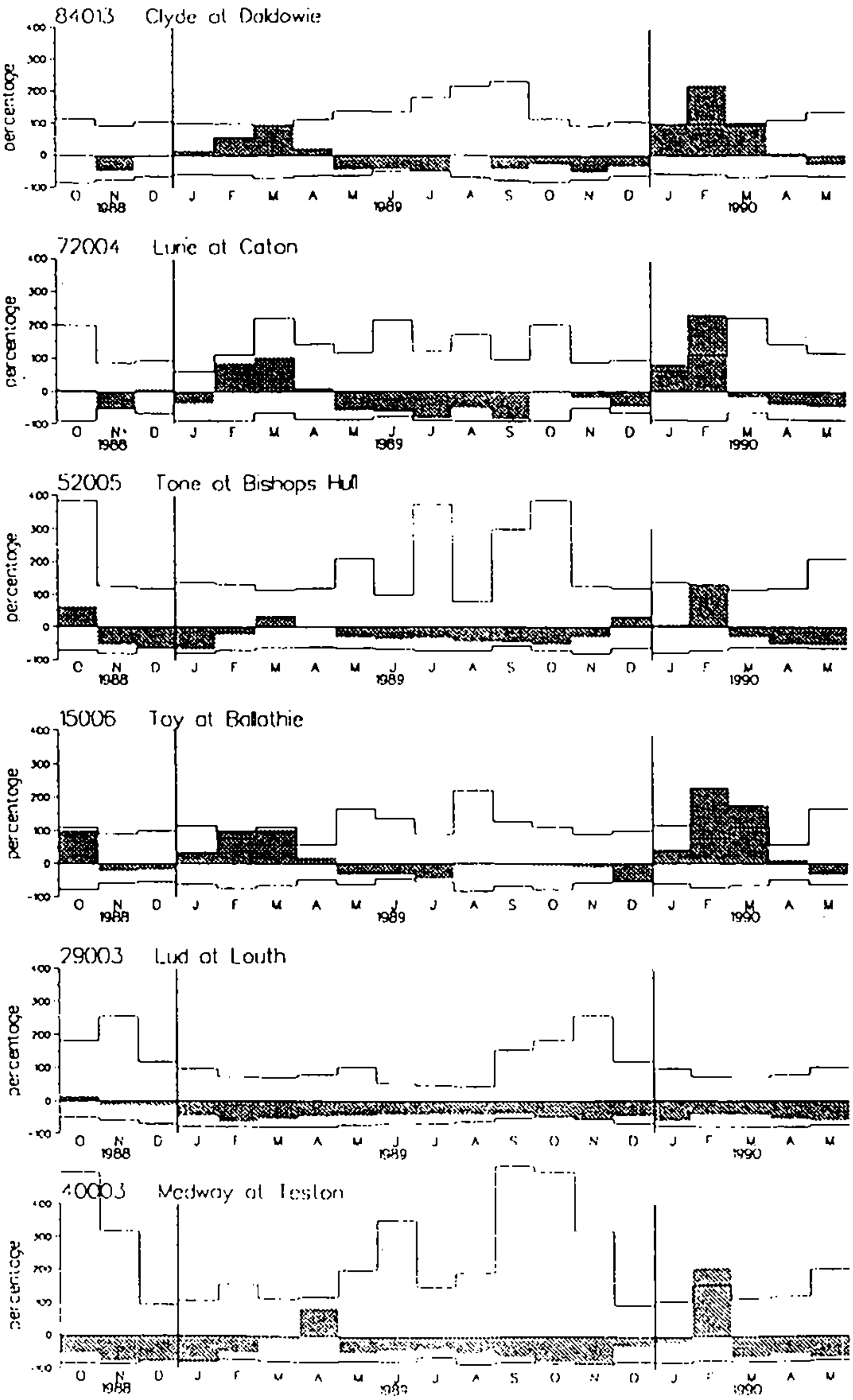


Figure 1.3.7: Monthly river runoff in six example catchments, October 1988 to May 1990, expressed as a percentage departure from the long-term average monthly runoff: catchment locations are given in Figure 1.3.8

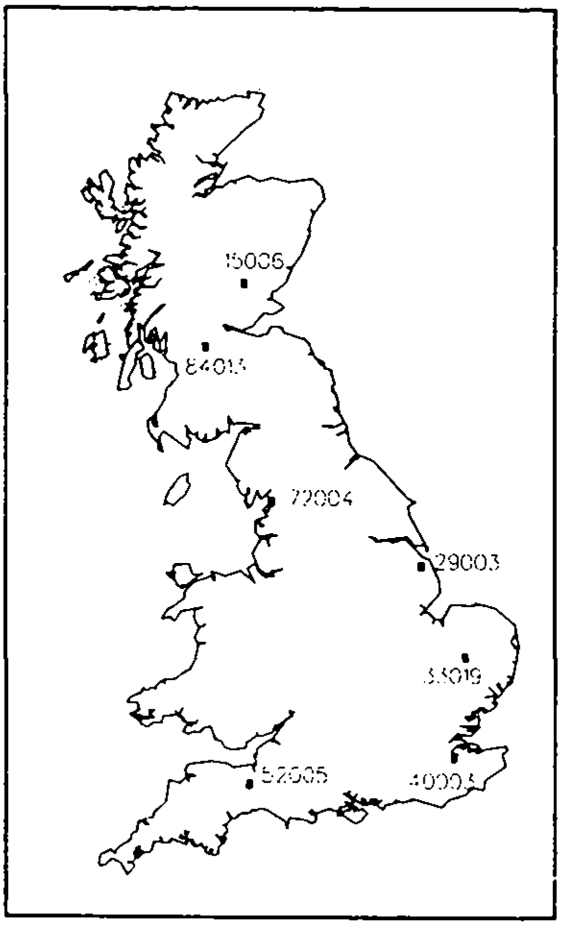


Figure 1.3.8: Locations of the six example catchments shown in Figure 1.3.7.

$$
\begin{array}{llll}
\%\text{runoff} = & -21.5 & 0.17\ \text{Balance} & +\ 0.65\ \%\text{rainfall} \\
 & (6.61) & (0.037) & (0.220)
\end{array}
$$

$$N = 28$$
$$R^2 = 47.8\%$$

%runoff = JJA 1989 runoff as % difference from average
%rainfall = JJA 1989 rainfall as % difference from average
Balance = average summer water balance (JJA rainfall-JJA PE)

The figures in brackets are the standard error of estimate, and are used to indicate the statistical significance of the regression coefficient: all the coefficients are significantly different from zero at the 1% level.

It is important to note that although "drier" catchments may show a smaller *proportional* response to a given rainfall shortage, resources may be under greater pressure in such a catchment than in a more humid catchment and the relative consequences of the rainfall shortage may be rather larger.

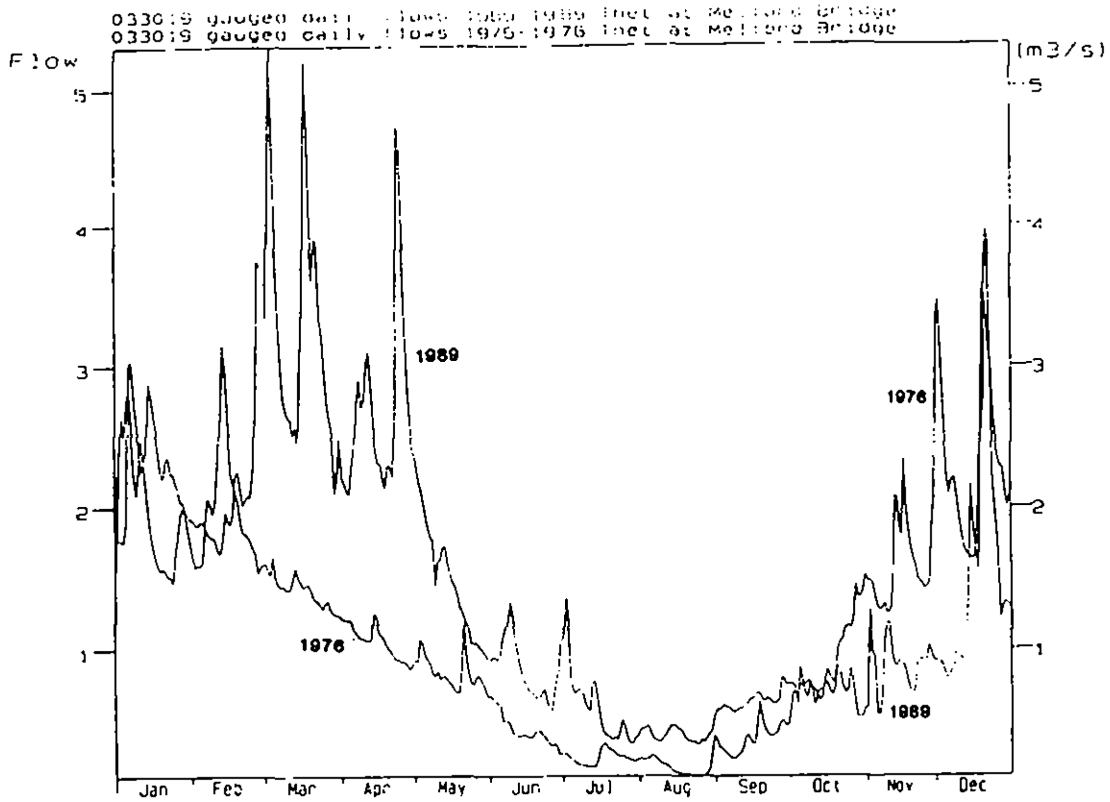
Catchments with a high baseflow component, such as those on chalk, should show a lesser response to summer water shortages, and should be much more affected by winter groundwater recharge: this is unfortunately difficult to test using observed data, because of the variability between catchments in winter and spring rainfalls.

As during the drought of 1976, the rainfall deficit in 1989 was greatest in eastern England and Scotland. River flows during the summer of 1989 were considerably higher than in the region experiencing drought in summer 1976 (the June, July and August total ranging from 30 to 300% higher), but low flow conditions persisted for rather later into the year. In 1976 flows had returned to near-average values during September, but in 1989 the recovery was delayed until December (with no substantial recovery even by then in eastern regions). Figure 1.3.9 shows daily river flows for two example catchments in 1976 and 1989: one catchment (52005) is in Somerset, the other (33019) in East Anglia.

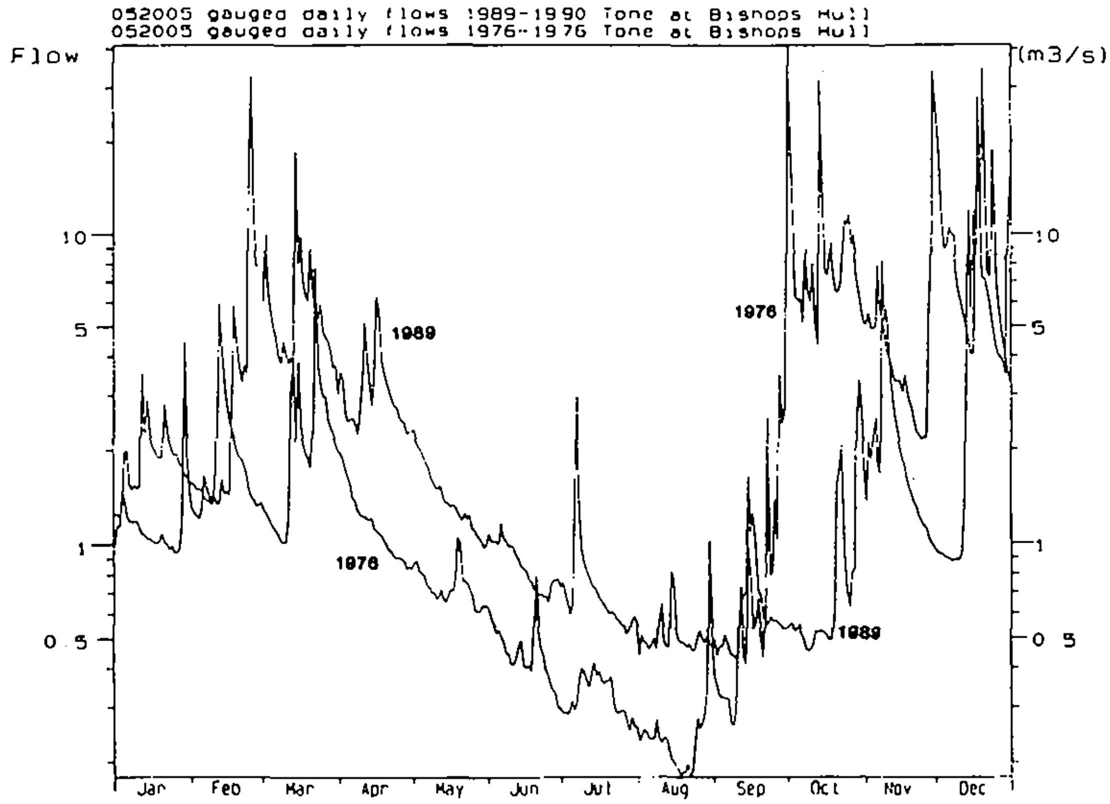
Although there was some recovery in the areas receiving rain in October, the largest and most widespread recovery followed the heavy rainfalls from mid December 1989. The rapid rise in flows during 1989 is shown in both the catchments in Figure 1.3.9. Flows in many rivers increased rapidly from well below the seasonal mean to well above average in a matter of days. A number of lowland rivers recorded their lowest and highest flow rates for the year over the period of a fortnight, a rare event in the UK (Anon, 1990). Flooding occurred in December and, more widely, in February, with the Severn, Thames and Tay catchments being particularly affected. The runoff volume for the Tay for February 1990 is the largest recorded on the Surface Water Archive for any month for any gauging station in the United Kingdom, and river flows remained above 300 m^3/sec on the Thames at Kingston (near the tidal limit) for 17 days, the longest since 1947. February runoff totals exceeded previous maxima in many catchments, and the total runoff from England, Scotland and Wales in February 1990 was the largest recorded in any month over (at least) 30 years. Some catchments in eastern England and Scotland did not share in the high flows, however, and in several flows remained below average through the winter (for example the Lud in Lincolnshire in Figure 1.3.7).

River flows fell rapidly during the dry March and April, however, and by early summer were in many catchments again below the seasonal average. The variation in river flows over the winter from well below average, to record-breaking maxima and back to below average conditions is unprecedented (at least over the forty or so years with widespread, reliable hydrological records).

Although rain during the winter of 1989/90 was late arriving, the winter was considerably wetter than 1988/89 and river flows were accordingly much higher (except in the east). Runoff totals over winter as a whole (December to February) were close to average in many catchments, but this runoff was concentrated in a very few weeks. Reservoirs were generally filled by February, and in many cases could have been filled a second time. However, they began emptying sooner than usual, because of the dry spring and, in a few cases, because they were drawn down for flood alleviation purposes, and by the beginning of the summer of 1990 a number of reservoirs had lower stocks than at the beginning of summer 1989. Figure 1.3.10 shows the contents of a reservoir in south west England over the winter 1989/90 in comparison with both 1988/89 and 1975/76. Surface water storages showed, therefore, a somewhat similar pattern to groundwater reserves: a little



a: Thet at Melford Bridge



b: Tone at Bishop's Hull

Figure 1.3.9: Daily flow hydrographs for 1976 and 1989 for two example catchments: the locations of the two catchments are shown in Figure 1.3.8

rain late in the winter season appears to be at least as beneficial for summer supplies as a larger amount of rain that ceases earlier in spring. Summer supply reliability depends not just on the amount of winter rainfall, but also on its timing.

With the important exception of algal growth in some reservoirs (Chapter 3), there were no unusual water quality problems between spring 1989 and spring 1990. Farm-based pollution incidents were in fact the lowest since 1984, because of the lack of rain to wash silage from fields into water courses.

1.3.2.5 Water management responses during summer 1989

Two types of problems arise with water supply during dry spells. "Resource" problems arise where there is not enough water left in a reservoir or aquifer to satisfy demands. "Distribution" problems arise where the water distribution system cannot meet short-duration high peaks, and reflect constraints in the supply network such as the capacity of service reservoirs and mains pipes. Distribution problems are frequently associated with peaks in demand for garden watering, and can be exacerbated by equipment failure or source contamination. Both "resource" and "distribution" limitations occurred during the summer of 1989.

The water industry in the UK adopts a hierarchical approach in response to water shortage. In principle, the first response to an impending shortage is to implement predefined water management schemes (such as transfer between catchments and augmentation of river flows by groundwater) and to appeal to consumers for restraint. The second stage is to introduce a hosepipe ban, and the third stage is to apply to the Department of the Environment for a Drought Order allowing, for example, reduced releases from reservoirs or increased abstraction from rivers.

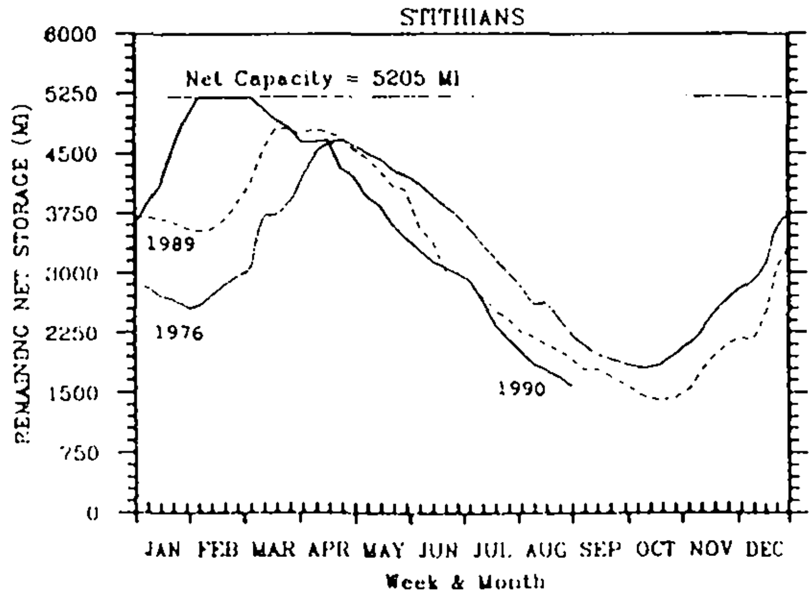


Figure 1.3.10: Reservoir replenishment and drawdown for Stithians Reservoir, South West Water, in 1976, 1989 and 1990.

These Drought Orders do not directly affect consumers, but the fourth stage is to implement Drought Orders which impose restrictions on non-essential commercial uses of water (such as watering of public parks and golf courses). The final stage is to introduce water rationing, either by cutting of supply to consumers for a period in each day or by restricting supplies to standpipes. Such a drastic action also requires Department of the Environment approval.

In practice, however, the progress of response to the developing water shortage in 1989 did not quite follow this model exactly. This was mainly because the drought began, in south east England at least, during a very dry winter. Water management schemes were implemented and some consumer restraint was urged in late winter, but hosepipe bans are of course largely irrelevant at this time of year. The first Drought Order to increase abstractions was applied for in February 1989 by Southern Water in Kent, before a hosepipe ban was applied: the East Surrey Water Company followed soon after.
A number of lowland rivers recorded their lowest and highest flow rates for the year over the period of a fortnight, a rare event in the UK.
The rainfall during late spring eased fears of a serious summer water shortage for a time, but large increases in demand during the very warm and dry May led to hosepipe bans being applied in many areas in southern England. Water companies reported peak demands between 30 and 50% higher than expected in some areas, due largely to the use of garden sprinklers. By the end of August, around 12.5 million domestic consumers in five water company regions (Southern, South West, Thames, Welsh and Severn-Trent, plus several of the smaller independent water supply companies) were affected by a hosepipe ban, and bans were imposed in parts of Yorkshire in October (note that the bans in parts of the Thames region reflected water quality problems at a treatment works rather than a water shortage or distribution problems *per se*). Throughout the summer water companies encouraged restraint amongst consumers through advertising campaigns of varying degrees of intensity: South West Water hired an aeroplane towing a "Save it" banner.

A further batch of Drought Orders was applied for as the dry, warm summer progressed and resource problems towards the end of the year appeared possible if autumn were to turn out dry. By the end of July, Drought Orders were in force in the Southern, South West and North West Water areas (some implemented by the small independent water companies), and Yorkshire Water applied for its first Drought Order in mid-September. Anglian Water applied for its only Drought Order in December 1989 when soil moisture deficits remained unseasonally high (but the Order was not actually implemented).

The fourth stage in drought response was entered on August 1 1989, when Southern Water was empowered under the terms of a Drought Order to restrict non-essential commercial uses in some areas. Further applications for similar Drought Orders were made between August and October by several water companies in central and southern England. In late August South West Water prepared to enter the fifth stage in drought response by installing standpipes in north Cornwall, but rainfall in mid September meant that they were not actually needed.

Restrictions in all but the most southeastern districts were relaxed during November, but many of the Drought Orders remained (albeit not applied).

Resource problems remained likely through the early part of the winter of 1989/90, and the Colne Valley and Rickmansworth Water Company appealed to their customers to conserve water in late January 1990: at the same time, additional Drought Orders were applied for by the Mid Kent and Mid Sussex Water Companies. By the beginning of March 1990 restrictions on public water use were lifted by all water companies (although Drought Orders remained in place). The rain in parts of Kent, however, was below average during the winter, and the first hosepipe bans of 1990 were introduced in early May in the Medway catchment.

1.3.3 Concluding comments

The period May 1989 to April 1990 was one of extremes. The period as a whole was drier than average, but rainfall was concentrated into a short, very wet, winter period. Eastern districts in England and Scotland experienced below average rainfall for the second year in succession, but flooding in parts of the south in February was the most severe for many years.

There are several important contrasts between the water resources situation in the summer of 1989 and in the drought of 1976. Firstly, although the drought of 1989 was less "intense" than that of 1976, it continued later into the autumn. Both the 1976 and the 1984 droughts had broken by September, but the 1989 drought did not break in many areas until December (and in some eastern regions did not break even then). This delay is important, because the responses of water managers to drought are influenced by the date they expect the drought to finish.

Secondly, the demand for water was considerably higher in 1989 than in 1976. Public water demand in summer 1989 was generally between 10 and 20% higher than in 1976 (demand in the Mid-Kent Water Company area was approximately 28% higher), although industrial demand in many areas has declined. Peak domestic demands have increased by an even larger percentage, with additional implications for the reliability of distribution systems.

Thirdly, water managers during the drought of 1989 had the benefit both of a wider range of water management schemes and a more flexible legislative framework than were available to managers during the 1976 drought. Many of the new water management schemes - involving inter-basin transfers and groundwater augmentation of river flows, for example - were a response to the 1976 drought and were implemented for the first time during 1976. Kielder Water and its associated water transfer scheme enabled Northumbrian Water to operate through the dry summer with no distribution or resource problems. Legislation introduced during the course of the 1976 drought (in particular the 1976 Drought Act) enabled water managers to introduce restrictions on supply at an early stage of the 1989 drought, although the detailed effect of the improved legislation awaits further study: a complication is added by the privatisation of the water supply and treatment industry during the course of the 1989 drought.

1989 provided the first test of many of the drought management schemes implemented following the 1976 drought. It also showed the considerable peak demands that may result from garden watering in early summer, and the additional disruption caused by "mechanical" failures in the distribution system. Water managers will be looking closely at the lessons of 1989 (and at the experience of a second, in many regions more intense, drought in 1990), and considering ways of alleviating impacts in the future. Close attention will be paid to the results of the metering trials currently being undertaken in several areas (what effect does metering and unit-based pricing have on use of water during a dry summer?), and plans for new resources will be prepared: as early as January 1990, a consortium of water companies in drought-stricken Kent announced the revival of the long-dormant Broad Oak reservoir project.

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