National Hydrological Monitoring Programme

The 1975-76 Drought

a contemporary and retrospective review

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
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THE 1975-76 DROUGHT

A contemporary and retrospective review

by

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Foreword

The 1975-76 drought was at the time considered the most severe experienced across much of the UK. Given its extreme intensity and broad spatial extent, the documentation of the drought remains relatively limited; this is particularly true in relation to material reviewing the wide range of its impacts.

To redress the balance, Part I of this publication comprises a report on the drought completed in 1977, but previously unpublished, by John Rodda (CEH Fellow and formerly Deputy Director of the Water Data Unit).

The 35-year period since the 1975-76 drought has been one of considerable hydrological volatility with notable drought episodes in 1984, 1989-90, 1991-92, 1995-97, 2003 and 2004-06[1]. The cluster of recent droughts, together with a continuing increase in temperatures has focussed concern on the degree to which climate change may be increasing the vulnerability of the UK to periods of sustained rainfall deficiency. Correspondingly, Part II of this report capitalises on hydrometeorological data collected over the last 35 years to provide a retrospective review of the drought with a particular focus on whether the singular severity ascribed to the 1975/76 requires revision.

Taken together the contemporary and retrospective appraisals of the 1975-76 drought are intended to help those managing water resources, the environment, agriculture and other climate-sensitive areas of endeavour. They may assist politicians and policy-makers prepare for a future when changes in climate and water demand patterns are likely to present challenges of a comparable, or greater, magnitude than those encountered during the 1975/76 drought.

'The 1975-76 Drought – a contemporary and retrospective review' has been added to the range of reports published under the aegis of the National Hydrological Monitoring Programme. The NHMP was established in 1988 to document hydrological and water resources variability across the UK. It is a collaborative programme between the Centre for Ecology and Hydrology, which maintains the National River Flow Archive and the British Geological Survey which maintains the National Groundwater Level Archive. Both organisations are component bodies of the Natural Environment Research Council.

The hydrometric data on which the National Hydrological Monitoring Programme depends are primarily provided by the principal UK Measuring Authorities: the Environment Agency, the Scottish Environmental Protection Agency and the Rivers Agency (Northern Ireland). Most of the rainfall information featured in this report was provided by the Met Office.

A complete set of the NHMP publications can be accessed via:

http://www.ceh.ac.uk/data/nrfa/nhmp/nhmp.html

[1] For further information about these droughts please visit: http://www.ceh.ac.uk/data/nrfa/publications.html

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2 This gives the location of many of the rivers, reservoirs, aquifer outcrop areas and wells/boreholes mentioned in the report.

A Review of the 1975-76 Drought

John C Rodda

This paper describes the progress of the drought and its effects on water resources and water supplies. It provides a brief description of the consequences of the drought for water authorities, the domestic consumer, industry, agriculture, forestry and nature conservation and the impact of drought in terms of fire and subsidence.

Introduction

Attitudes towards water suffered an abrupt change during the summer of 1976. Weeks without rain and periods of unrelenting sunshine resulted in a yellow and brown countryside, empty streams, a rash of notices about the need to save water, restrictions and, in a few areas, shut-offs and standpipes. For the inhabitants of a major part of England and Wales the drought emphasised the considerable value of the wholesome and copious supply of piped water which has been the prerogative of almost the entire population of the United Kingdom for most of the 20th Century and which is normally taken for granted.

The exceptionally dry period, which for many purposes is considered to start in May 1975 and which was extremely hot during July 1976, ended in September 1976. It caused considerable depletion of surface water and groundwater over most of England and Wales as well as neighbouring parts of the Continent, while Scotland and Northern Ireland were much less affected. The drought seriously reduced agricultural production, it caused industry to reuse water, it restricted navigation, it damaged buildings, it made householders become very cautious in their use of water and it provided a severe test of the water authorities (NWC 1977b). There have been other droughts this century; the years of 1902, 1905, 1921, 1944, 1949, 1953, 1955, 1971 and 1973 all experienced particularly low rainfalls. Drought straddled, 1933 and 1934 and also 1943 and 1944, while the three winters 1962-63 to 1964-65 were exceptionally dry. Each of these droughts affected water supplies, in some cases (e.g. 1933-34) some parts of the country were more severely affected than in 1975-76. It is probably however that none of the earlier droughts received as much attention as the recent one, and its severity led to questions about the adequacy of water resources and whether or not the climate was changing to a much drier regime.

What is a drought?

Although drought is one of the worst of natural disasters, there is no universally accepted definition of exactly what constitute a drought. Drought has been defined in various ways according to the purpose, the activity involved and the climate (Murray 1977), and there are arguments for differentiating between meteorological drought, hydrological drought and agricultural drought (Tabony 1977). Most drought criteria employ a measure of the absence of rainfall, but some incorporate mean temperature, soil water and crop parameters, evaporation and other climatic indices (Hounam 1975). For Britain the Meteorological Office adopted the definition 'a period of at least 15 consecutive days to none of which is credited 0.25 mm or more of rain' as an absolute drought. However, it is easy to point to the disadvantages of this and similar definitions. Recent issues of British Rainfall have employed the concept of classifying spells with little or no rainfall in terms of departures from the average in order to depict drought. A similar approach was adopted by Foley (1957), who developed a drought index for use in Australia. A modification of this index has been used to characterise droughts over England and Wales and also Scotland since 1921 (Figure 1).

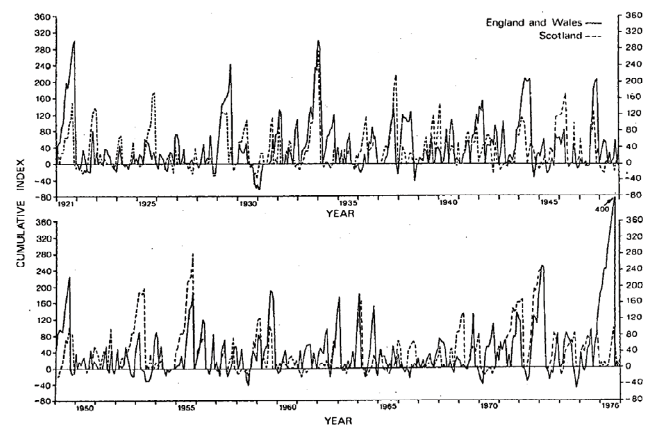

Figure 1: *Modified Foley Index: England & Wales and Scotland 1921-1976*

The most recent drought ranks first in severity amongst other notable drought periods in England and Wales, e.g. 1921, 1933 and 1943-44, but the incidence and severity of droughts in Scotland are seen to be rather different.

Associated with the difficulty of defining a drought, there are the problems of identifying when a particular drought starts and finishes and also in measuring its severity. And, of course, these factors are dependent on what the drought is affecting – drought duration and severity will be different for the dairy farms of an area, for an industrial region, or for a series of reservoirs. Another problem is the areal extent of a drought and the fact that drought duration and severity may vary considerably within the drought affected area.

Ascribing causes to a drought is a further difficulty. Meteorologists often explain drought in terms of atmospheric circulation patterns that are different from the norm, patterns which favour subsidence over a region. However, such explanations merely describe the meteorological motions and processes rather than identify the fundamental dynamic and thermodynamic forces which caused the abnormal patterns (Hounam 1975).

Meteorological perspective

The overall trend in the early 1970s was towards increased anti-cyclonic conditions over western Europe (Morris & Ratcliffe 1976) and increased cyclonic activity in the Arctic Basin. This increased cyclonic activity and westerly winds were associated with a retreat northwards of the Arctic ice which had reached its most southerly position in March 1969.

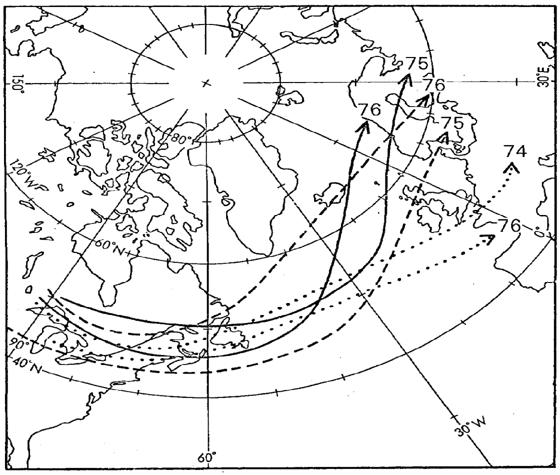

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Figure 2: Tracks of the Jet Stream 1974-1976

During the winter of 1974-75, the main jet-stream across Britain (Figure 2) shifted to a position just north-west of the Hebrides to stay there for most of 1975. Throughout this period and the first part of 1976 positive surface pressure anomalies existed over much of western Europe, and by June 1976 significant positive sea surface temperature anomalies had developed in the eastern North Atlantic (Perry 1976) (Figure 3). As 1976 progressed, the jet-stream in this area swung farther and farther north, so that by August it was located across Iceland (Ratcliffe 1977a). At that time a new jet-stream was developing across the Atlantic south of 50°N. By the last week in August the system was starting to break down; troughs were forming over Canada and western Europe and a strong ridge was developing over the Atlantic south-east of Greenland. "The crucial development was the intensification and extension of the jet-stream from south of Newfoundland to flank the Biscay trough." (Ratcliffe 1977a). It is not clear whether the formation of the southerly jet-stream was a consequence of the extreme northerly position of the jet-stream in August, or whether its formation was a cause of the breakdown of the northerly jet-stream.

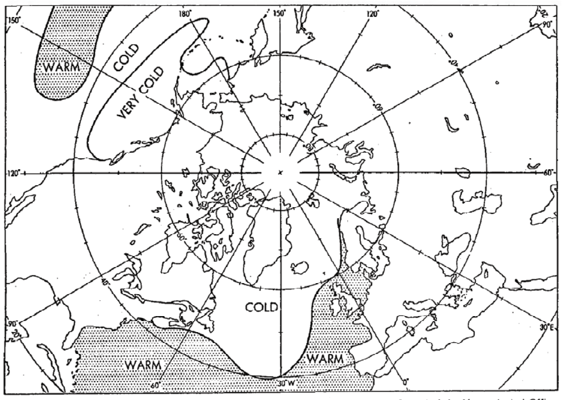

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Figure 3: Sea surface temperature anomalies

Once the circulation had changed, the excessive rains of September and October followed; the high sea temperatures (Figure 3), enabling more moisture and more sensible heat to be transferred to the atmosphere than usual, and the favourable synoptic situation enhancing the process of rain production (Ratcliffe 1977b).

Ratcliffe (1977b) considered that the drought was a result of many inter-related factors and he suggests that the interaction of the important anomalies may have produced the drought situation. The succession of mild winters since 1971 and the displacement of the coldest air to the western side of the hemisphere was the first point to note. Then there was the movement of the jet-stream northwards by 5 to 10 degrees of latitude. The third anomaly was the coldness of the North Pacific (Miles 1977) (Figure 3) and the large amounts of ice it contained in the winter of 1975/76. The fourth was the existence of three areas where the 500 mb flow pattern in the geostrophic circulation for the northern hemisphere was significantly different from average. Two of these areas were close to Britain and associated with the displacement of the jet-stream; the third was over the east central Pacific where there was enhanced flow - a feature which is related to dry summers over Britain. Ratcliffe (1977b) also points to a number of other important points, such as the cooler ocean temperatures off Newfoundland and the excessive dryness of the ground in Britain reinforcing the drought.

There are considerable difficulties in understanding the causes of the drought but forecasting its progress and termination was as difficult. The weather prospects for September, issued by the Meteorological Office at the end of August 1976, forecast dry weather for the whole of the month with one or two disturbed spells with rain, especially in eastern districts. The forecast, in looking further ahead, concluded that there were 'no clear indications of a wet autumn anywhere'.

Rainfall

The summer of 1976 was one of the warmest and driest since records began. The mean rainfall over England and Wales from May to August was 140 mm against a 1916 to 1950 average of 278 mm, while temperatures of over 32°C were recorded each day from 23 June to 8 July somewhere in England (Shaw 1977). This lack of rainfall was made more noticeable and more significant by the low rainfalls for the preceding months (Table 1). In fact, for most periods of up to 24 months before August 1976, the mean rainfall over England and Wales was either the lowest or amongst the lowest recorded since 1820 (Table 2) and probably since the start of records. In this context, it is interesting to note that during the past five years two separate very dry periods of 24 months' duration have occurred, one starting in July 1972 and the other in September 1974. These two periods are amongst the 10 driest 24 months in the last 150 years (Murray 1977). However, the most marked dry period occurred from May 1975 to August 1976; this period, when only 756 mm was recorded, has been assessed as the worst drought on record for England and Wales (Grindley 1977). In contrast, the rainfall for September and October 1976 (313 mm) was the highest recorded for those two months.

From the water resources point of view, it is important to compare rainfall amounts recorded during the 1975/76 drought with those registered during previous droughts over periods which are critical for water supplies. For example, the rainfall in the winter six months are critical for groundwater sources and these amounts are shown in Table 3(c). It can be seen that for all the featured periods except April-September the rainfall recorded during 1975/76 was the lowest since 1900.

The area with the most noticeable rainfall deficits for the 16 months of the drought extended from Devon and South Wales in the west to Flamborough Head in the north and Dungeness in the south east (Figure 4). Within this area, less than 60% of the average was recorded and some parts of Devon, Dorset and Hampshire and also a few areas in the Midlands received less than 50% of the average rainfall. Much of East Anglia and part of the London Basin received 60 to 70% of average, while similar percentage rainfalls were registered over the remainder of England and Wales and some adjacent parts of Scotland. A regional breakdown of the amounts of rainfall recorded during the drought, over a range of durations, is given in Table 4 (the regional boundaries are shown on page 38).

Estimates have been made of the return period of the drought based on analyses undertaken by the Meteorological Office (Tabony 1977b). Table 5 shows the range of estimated frequency of occurrence of specified percentage of the England and Wales mean rainfall for durations of up to 36 months, and the estimated frequencies of the rainfalls occurring during the 1975-76 drought are contained in Table 6. This shows the return period of the 16-month drought to be in excess of 1 in 250 years, but a return period of little over 1000 years has been ascribed to it by Wright (1976), although this interpretation is made with some caution – the error of the estimate is considered to be large (between half and twice the estimated return period).

Table 1: *Rainfall as a % of the 1916-50 average for various periods from 3 to 18 months ending in August 1976 over the UK and its component parts*

	3 months Jun - Aug 76	6 months Mar - Aug 76	9 months Sep 75 - Aug 76	12 months Sep 75 - Aug 76	15 months Jun 75 - Aug 76	16 months May 75 - Aug 76	18 months Mar 75 - Aug 76
United Kingdom	41	64	68	74	73	73	76
England & Wales	35	52	55	63	63	61	70
England	37	52	55	63	63	64	70
Wales	27	50	57	64	64	64	68
Scotland	48	79	83	86	85	83	84
Northern Ireland	48	74	74	80	76	73	75

Source: Murray, 1977

Table 2: *England & Wales rainfall: 10 driest periods of duration from 3 to 24 months, 1820-1976 (starting date and rainfall totals given)*

	3 months		mm	6 months		mm	12 months		mm
1	1928	Feb	56	1921	Feb	179	1975	Sep	570
2	1929	Feb	71	1976	Mar	204	1854	Feb	618
3	1893	Mar	71	1887	Feb	221	1920	Nov	618
4	1868	May	74	1929	Jan	230	1887	Feb	624
5	1854	Feb	74	1870	Apr	241	1963	Dec	637
6	1976	Jun	76	1826	Mar	249	1933	Apr	651
7	1844	Apr	77	1893	Mar	256	1857	Dec	661
8	1947	Aug	82	1959	Apr	261	1904	Mar	667
9	1963	Dec	83	1896	Jan	263	1955	Jul	670
10	1921	May	88	1939	Feb	264	1963	Nov	673

	16 months		mm	18 months		mm	24 months		mm
1	1975	May	756	1975	Mar	908	1853	Oct	1439
2	1854	Feb	811	1853	Dec	933	1932	Nov	1439
3	1933	Apr	855	1887	Jan	997	1862	Nov	1461
4	1887	Feb	857	1933	Apr	1003	1887	Feb	1493
5	1920	Aug	880	1873	Feb	1031	1974	Sep	1496
6	1973	Apr	899	1857	Dec	1032	1972	Jul	1497
7	1857	Nov	907	1863	Feb	1043	1904	Oct	1507
8	1943	Feb	909	1943	Feb	1044	1857	Feb	1512
9	1963	Dec	920	1963	Dec	1047	1920	Aug	1513
10	1869	Jun	928	1921	Jan	1061	1947	Aug	1520

Source: Murray, 1977

Table 3: Rainfall over England & Wales since October 1899 for various periods critical to water supplies

a) 6 driest 6-month periods (April-September) since 1900

Rank	Period	Rainfall (mm)	Resource for which the period is critical
1	APR - SEP 1921	258	small reservoirs
2	APR - SEP 1959	263	
3 =	APR - SEP 1911	292	
3 =	APR - SEP 1940	292	
5	APR - SEP 1933	295	
6 =	APR - SEP 1906	299	
6 =	APR - SEP 1929	299	
9	APR - SEP 1976	321	
24	APR - SEP 1975	364	

b) 6 driest 9-month periods (April-December) since 1900

Rank	Period	Rainfall (mm)	Resource for which the period is critical
1	APR - DEC 1921	459	small reservoirs
2	APR - DEC 1933	483	
3	APR - DEC 1947	514	
4	**APR - DEC 1975**	**523**	
5	APR - DEC 1904	535	
6	APR - DEC 1964	561	
27	APR - DEC 1976	651	

c) 6 driest 6-month periods (October-March) since October 1899

Rank	Period	Rainfall (mm)	Resource for which the period is critical
1	**OCT 1975 - MAR 1976**	**303**	groundwater
2	OCT 1972 - MAR 1973	343	
3	OCT 1943 - MAR 1944	348	
4	OCT 1904 - MAR 1905	350	
5	OCT 1962 - MAR 1963	352	
6 =	OCT 1908 - MAR 1909	356	
6 =	OCT 1933 - MAR 1934	356	

d) 6 driest 18-month periods (April-September) since 1900

Rank	Period	Rainfall (mm)	Resource for which the period is critical
1	**APR 1975 - SEP 1976**	**988**	medium to large reservoirs, groundwater
2	APR 1933 - SEP 1934	1005	
3	APR 1904 - SEP 1905	1091	
4	APR 1928 - SEP 1929	1098	
5	APR 1948 - SEP 1949	1120	
6	APR 1937 - SEP 1938	1130	

e) 6 driest 30-month periods (April-September) since 1900

Rank	Period	Rainfall (mm)	Resource for which the period is critical
1	APR 1904 - SEP 1906	1870	Very large reservoirs, major groundwater sources
2	APR 1947 - SEP 1949	1896	
3	APR 1962 - SEP 1964	1942	
4	**APR 1974 - SEP 1976**	**1949**	
5	APR 1933 - SEP 1935	1968	
6	APR 1975 - SEP 1977	**1976**	

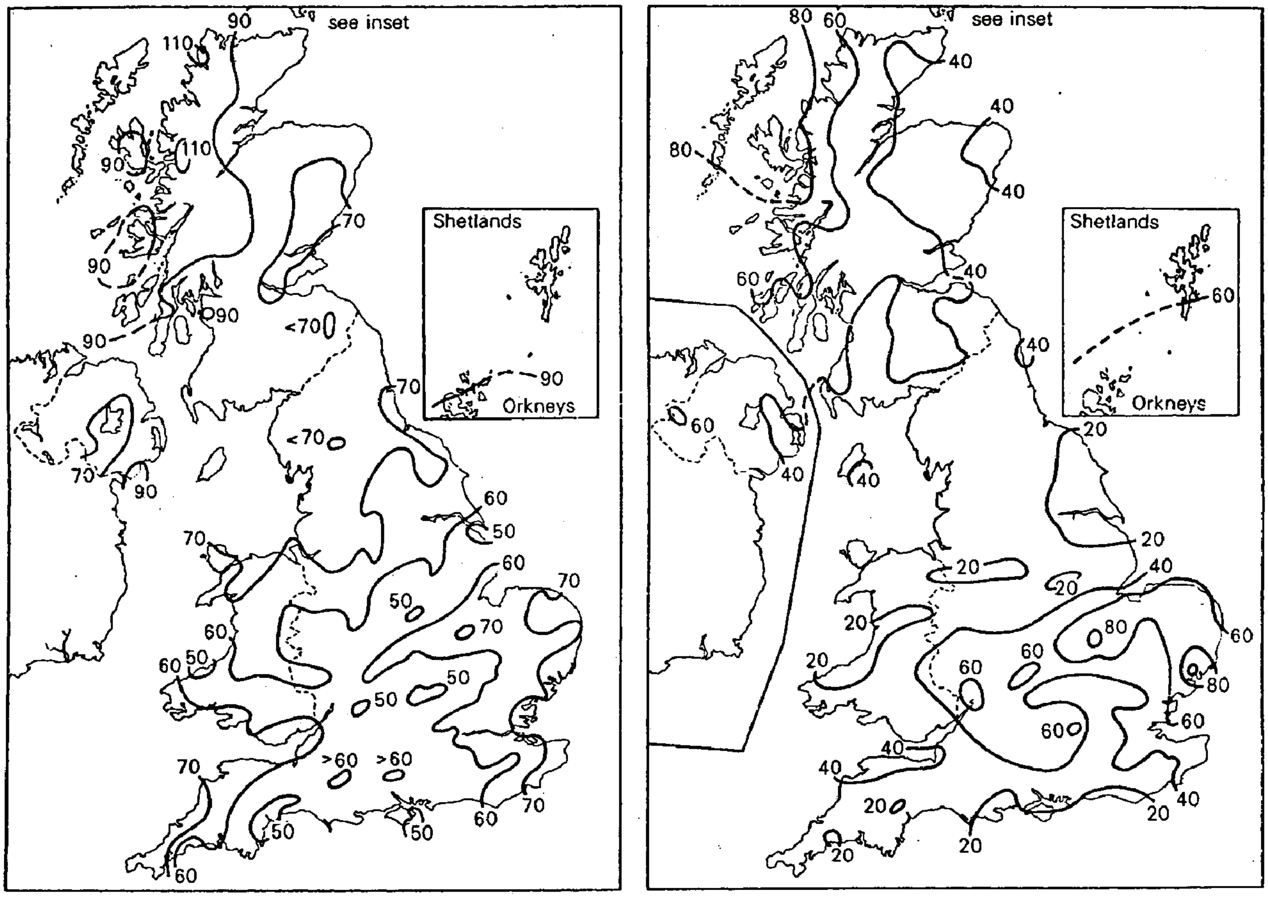

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Figure 4: *Rainfall as a percentage of the 1916-50 average: May 1975-August 1976 (left); June-August 1976 (right)*

Table 4: *Regional rainfall 1975-76 (% of 1916-50 average)*

Water Authority Areas	**Duration in months of dry period to the end of August 1976**				
	3	**6**	**12**	**16**	**24**
North West	37	72	78	77	88
Northumbrian and Yorkshire	28	58	65	69	81
Severn-Trent and Anglian	45	54	63	63	81
Thames, Southern and Wessex	40	41	57	59	84
South West and Welsh National	31	54	61	61	78
England & Wales	35	52	63	64	83

There is also the point that differences occur in the estimate of the return period depending upon whether the analysis is conducted for a given start or a random start. The difficulty of obtaining a precise assessment of the return period is common to any series of extreme events, for the period of record is short by comparison with the established frequency of occurrence of the most extreme event. Because of these problems, it may be prudent to consider that over the country as a whole the return period of the drought was probably in excess of 250 years, but to acknowledge that regionally and locally there were considerable variations in this figure, and that in some areas the return period may have been much longer.

Table 5: Frequency of occurrence of Specified Dry Periods

Duration of dry period (months)	% of 1916-50 Average Rainfall — Frequency of occurrence (1 in x years)							
	5	10	20	50	100	200	500	1000
1	63.1	46.6	**33.6**	20.8	14.2	9.6	5.6	3.7
3	78.3	67.9	59.6	50.5	44.6	**39.3**	33.0	28.9
6	84.4	76.8	70.7	63.9	59.5	**55.4**	50.7	47.4
9	87.2	80.9	75.7	70.0	66.3	62.9	58.9	**56.1**
12	88.9	83.3	78.8	73.8	70.5	67.5	**63.9**	61.4
16	90.3	85.4	81.5	77.1	74.2	71.6	68.4	**66.2**
18	90.8	86.2	82.5	78.3	75.5	73.1	**70.1**	68.0
24	92.0	88.0	**84.7**	81.0	78.6	76.4	73.8	71.9
30	92.8	89.2	86.2	**82.9**	80.7	78.8	76.4	74.7
36	93.4	90.1	**87.4**	84.3	82.3	80.5	78.3	76.7

(Note: figures in boldface represent the approximate severity of the drought up to the end of August 1976)
Source: Central Water Planning Unit, 1976

Table 6: Estimated average frequency of occurrence (once in n years) of rainfall percentages

No. of months ending in Aug 1976	England & Wales 1767-1974	Scotland 1860-1974
3	125	54
6	125	8
9	≥250	8
12	≥250	4
15	≥250	4
18	≥250	6
21	≥250	6

Note: The return periods are for a fixed start.

Evaporation and Soil Moisture

During the 16-month period of least rainfall there were two warm, dry summers, the summer of 1976 being exceptionally hot and sunny. For the months of June to August 1976 over most of England and Wales mean daily maximum temperatures were 3.0°C above average. Sunshine totals were more than 130% of average for almost all the United Kingdom except for some parts of western Scotland and Northern Ireland (Murray 1977). These conditions enhanced the normal summer maximum of potential evaporation and increased soil moisture deficits well above average over nearly all the country.

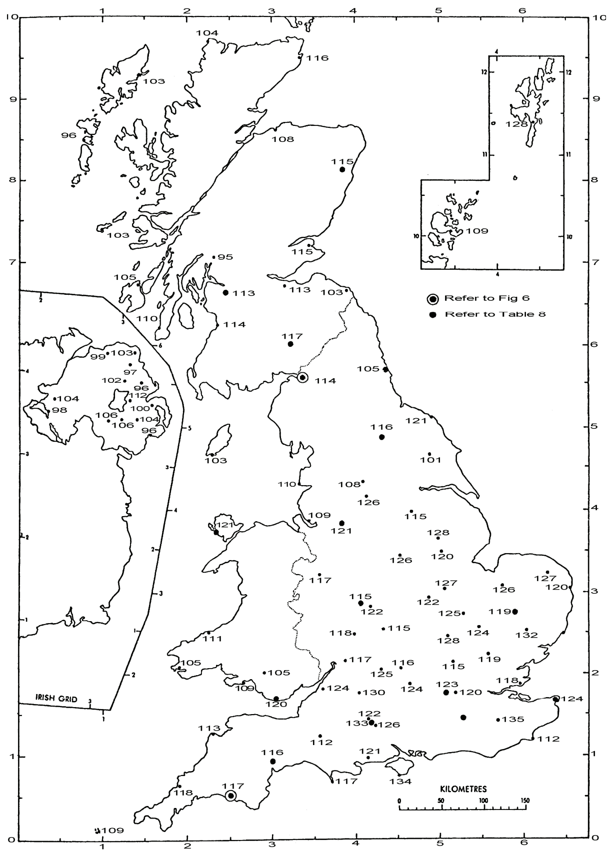

Figure 5: Potential evaporation in 1976 as % of the long term average

Figure 5 shows potential evaporation for 1976 at a number of stations as a percentage of average. Over much of England and Wales amounts were 110 to 125% of average, with some areas in the south east recording more than 130%. A similar pattern existed in 1975 but with percentages ranging from 110 to 120% of average. Monthly totals of potential evaporation for 1975 and 1976 at a number of stations featured on Figure 5 are shown in Table 7. Totals for 1976 were 50 to 80 mm higher than those for 1975 over most of central and southern England, but in the north and in Scotland and also in Wales totals for the two years were more similar. As is usual monthly totals tended to reach a maximum in June during 1975, but in 1976 the highest amounts occurred during July. This later maximum is thought to be an indication of the maintenance of high air temperatures and high daily radiation totals.

Of course, during the drought, over much of the country, actual evaporation amounts were very much lower than potential values which are calculated on the assumption that there is no soil moisture deficit.

Murray (1977) estimated actual and potential values for several sites (two are featured in Figure 6), assuming a grass cover, to show the divergence of these parameters; the potential evaporation being a measure of the water lost that could take place from a grass covered soil surface if an abundant supply of soil moisture were available at all times. At Plymouth the 1975 and 1976 actual evaporation totals for the summer (June-August) were around 130 and 240 mm less than the potential values and there were similar substantial differences over most of southern and eastern England. Differences reduced towards the north, but it is probable that there was no site in the United Kingdom where evaporation took place at the potential rate during the summer of 1976. This is in contrast to the average year when potential rates apply to much of the country north and west of a line drawn from Exeter through Liverpool to Hull.

The progress of rainfall and evaporation through 1975 and 1976 caused a substantial change in the normal pattern of soil moisture deficits. Deficits during the summer of 1975 (Figure 7a) were more extensive than in the average year – the estimated deficit for much of England and Wales was in excess of 100 mm, while parts of Central Scotland experienced similar conditions. Lack of rainfall during the winter that followed caused deficits to persist through the winter south and east of the Tees-Exe line, with values greater than 25 mm pertaining over much of this area in late January (Figure 7b). By 21 April (Figure 7c) a soil moisture deficit had developed over the whole country, this deficit intensified during June and July and by the end of that month the Brecon Beacons, Snowdonia and the north west of England were the only areas in England and Wales where deficits were less than 100 mm. North of the Border much of eastern and central Scotland was experiencing deficits greater than 75 mm at that time.

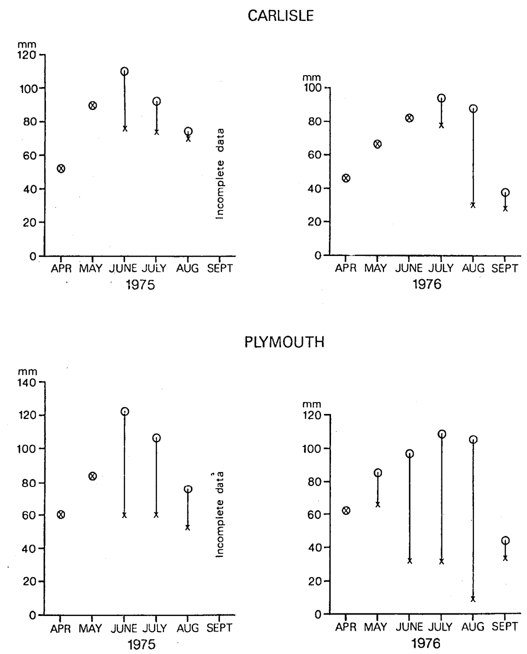

Figure 6: *Potential and actual evaporation in 1975 and 1976* *Source: Murray 1977*

During the month of August there was a continuing rise generally in soil moisture deficits to a peak in the last week (Figure 7d), estimated values reaching a maximum of 150 mm in parts of East Anglia. Even more outstanding were the deficits estimated to be about 100 mm in Snowdonia and the Lake District and about 50 mm in the Scottish Highlands. Table 8 shows the maximum deficits measured at Plynlimon in the hills of central Wales for comparison. During the early part of September deficits were maintained at a high level but they declined rapidly as the month progressed. By the end of October soil moisture deficits were at or below normal values in most areas.

Table 7: Monthly potential evaporation totals (in mm) for 1975 and 1976

			1975												
Station	**Alt**	**NGR**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Dyce	58	38-873125	13.2	9.7	31.3	47.7	84.0	95.9	80.7	78.2	46.9	21.7	8.7	12.6	530.6
Abbotsinch	5	26-480667	17.6	8.8	33.7	51.8	89.0	108.1	89.9	77.7	44.0	24.8	6.6	3.3	555.3
Eskdalemuir	242	36-235026	9.5	3.4	25.1	42.5	76.9	94.9	79.7	64.0	37.2	14.9	3.0	7.0	458.1
Tynemouth	29	45-374694	14.3	12.0	34.4	48.7	69.9	90.7	86.2	75.2	51.7	14.1	8.2	3.6	509.0
Leeming	32	44-305890	17.0	7.6	31.5	55.6	77.8	108.3	97.3	94.6	49.1	19.0	6.1	3.8	567.7
Honington	51	52-889749	17.9	9.0	26.5	56.1	82.0	121.7	115.4	111.5	63.3	25.5	7.5	6.3	642.7
Elmdon	99	42-170835	18.0	8.8	31.0	47.7	80.9	123.0	114.0	99.6	56.8	23.5	7.2	6.2	616.7
Heathrow	25	51-077768	13.7	11.7	30.0	57.0	86.7	138.1	125.5	109.9	60.8	24.1	8.3	4.2	670.0
Gatwick	59	51-265407	11.2	9.6	26.7	52.1	79.5	125.0	115.2	103.6	54.2	21.0	5.6	0	603.7
Manston	44	61-335666	15.4	12.7	29.2	51.9	76.7	116.7	114.4	105.4	61.6	27.4	10.3	4.8	626.5
Boscombe Down	126	41-172393	10.8	12.4	29.8	56.5	86.9	138.9	121.3	102.7	54.8	22.8	7.4	3.5	647.8
Carlisle	26	35-384603	14.2	4.8	28.5	48.9	84.1	109.3	92.4	79.3	43.5	20.1	3.4	3.1	531.6
Ringway	75	33-818850	23.0	7.3	32.6	50.6	91.8	122.5	105.9	97.0	54.2	26.7	6.8	4.2	622.6
Valley	10	23-310758	29.3	14.1	39.9	63.7	100.4	126.2	109.9	89.8	65.1	38.3	22.6	18.2	717.5
Rhoose	67	31-060679	16.6	15.4	37.2	53.1	95.8	127.7	112.9	95.6	53.5	25.9	11.3	8.0	653.0
Exeter	32	20-995937	12.0	12.1	35.4	49.8	86.6	125.9	111.7	88.6	52.0	23.7	9.2	6.0	613.0
			1976												
Dyce	58	38-873125	17.8	16.8	39.1	52.3	68.3	88.0	105.6	74.6	38.5	16.3	0	0	517.3
Abbotsinch	5	26-480667	14.0	19.0	34.4	55.9	73.8	92.2	107.5	84.2	50.3	21.0	3.7	0	556.0
Eskdalemuir	242	36-235026	14.2	10.8	25.2	48.0	55.9	69.7	96.7	75.3	36.9	16.3	2.4	0	451.4
Tynemouth	29	45-374694	21.9	21.6	39.1	50.4	67.9	107.3	101.8	73.3	40.0	18.3	1.3	0.9	543.8
Leeming	32	44-305890	19.2	15.7	35.9	55.7	73.9	113.4	122.9	92.6	45.6	20.8	6.8	0	602.5
Honington	51	52-889749	20.9	15.7	37.8	64.3	98.5	138.8	142.6	106.7	49.5	23.1	5.1	0	703.0
Elmdon	99	42-170835	24.3	13.7	37.5	60.0	87.9	125.4	139.6	104.8	46.5	19.9	4.7	0	664.3
Heathrow	25	51-077768	15.2	15.6	41.0	71.6	107.9	144.4	150.3	123.7	54.2	23.8	6.7	0	754.4
Gatwick	59	51-265407	15.5	12.7	37.7	65.8	102.1	135.0	138.9	110.3	48.3	21.1	5.3	0	692.7
Manston	44	61-335666	17.3	14.0	40.7	65.3	106.5	140.8	141.6	112.5	47.9	28.5	12.5	6.2	733.8
Boscombe Down	126	41-172393	16.6	13.3	40.1	69.9	97.2	132.2	146.7	127.4	50.9	20.2	5.2	0	719.7
Carlisle	26	35-384603	12.3	15.7	34.8	52.2	66.1	91.6	113.6	91.6	41.9	20.3	2.0	0	542.1
Ringway	75	33-818850	19.7	16.7	41.7	61.3	83.3	116.2	132.5	111.1	55.9	30.1	13.0	6.1	690.6
Valley	10	23-310758	31.9	22.0	39.3	67.6	85.3	104.7	116.4	116.0	63.7	34.3	21.4	11.5	714.1
Rhoose	67	31-060679	17.6	12.7	35.6	63.4	82.0	109.2	122.1	122.9	55.9	25.3	8.1	2.2	657.0
Exeter	32	20-995937	21.1	13.4	34.4	60.8	84.1	115.3	123.4	111.9	46.1	23.8	5.3	1.0	640.6

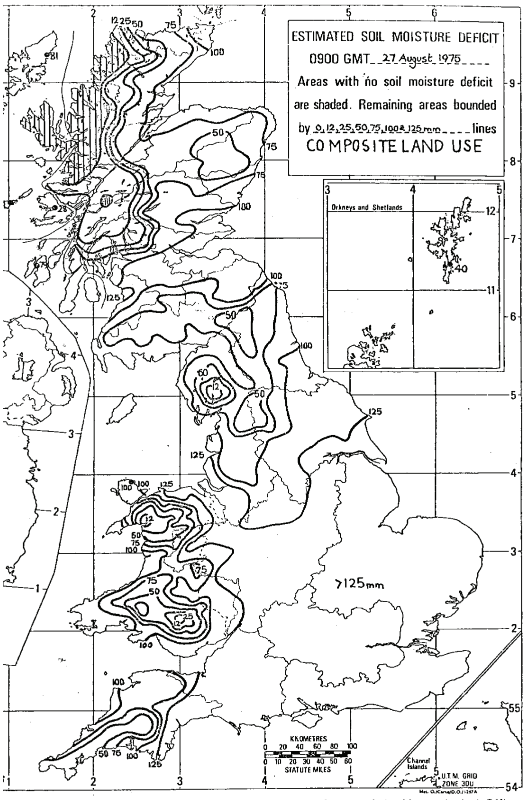

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Figure 7a: *Soil moisture deficits: late-August 1975*

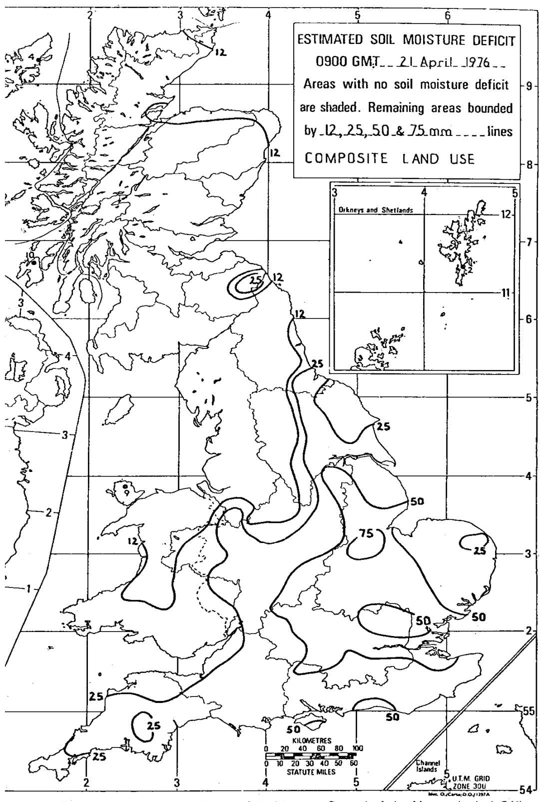

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Figure 7c: *Soil moisture deficits: April 1976*

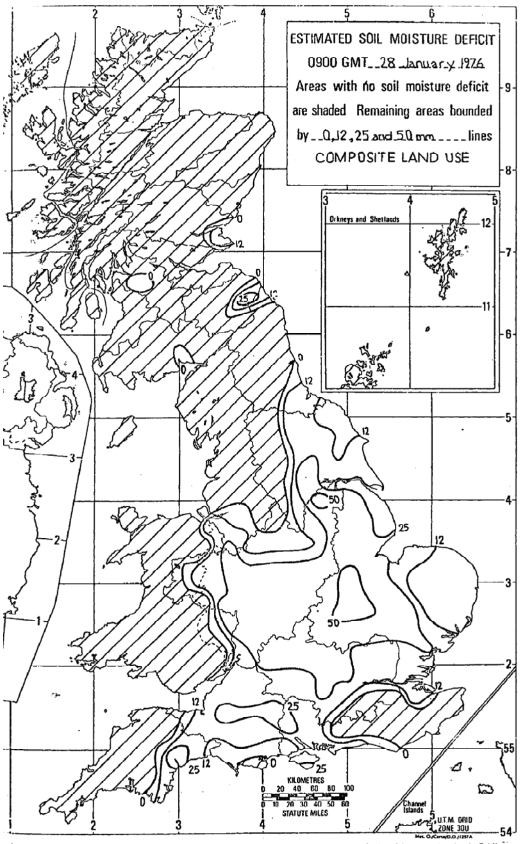

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Figure 7b: *Soil moisture deficits: late-January1976*

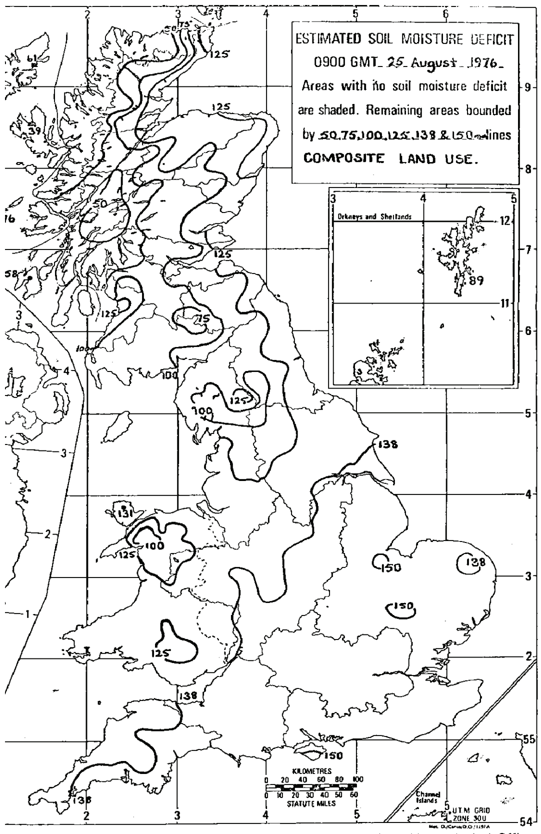

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Figure 7d: *Soil moisture deficits: late-August 1976*

Table 8: *Maximum soil moisture deficits (in mm) in the Wye and Severn experimental catchments as a % of the seasonal maximum*

Year	April-September		
	Wye (Grass)		Severn (Forest)
	Nant Iago	Cyff	y Foel
1975	110 (157%)	86 (215%)	53 (238%)
1976	160 (228%)	132 (330%)	118 (530%)

Source: Institute of Hydrology

To gain an impression of the severity of the 1975/76 drought in terms of soil moisture amounts, Wigley and Atkinson (1977) estimated monthly soil moisture deficits for Kew Observatory from rainfall and evaporation for the period 1698 to 1976. They concluded that the recent drought was amongst the three worst droughts in the 279-year period assessed from the growing season mean soil moisture deficit. They also suggested that since 1920 there was a tendency for droughts measured in this way to occur more frequently (Table 9).

Table 9: *No. of occasions when soil moisture deficit at Kew Observatory averaged over the growing season exceeded 100 mm between 1700 and 1976*

Period	Number	Period	Number
1700-1719	5	1840-1859	4
1720-1739	2	1860-1879	4
1740-1759	3	1889-1899	4
1760-1779	3	1900-1919	2
1780-1799	4	1920-1939	5
1800-1819	0	1940-1959	6
1820-1839	1	1960-1976	8

Source: Wigley and Atkinson, 1977

Note: The growing season is May, June, July and August.

Rivers

During the summer of 1976 the discharges of many rivers in England and Wales fell to levels never reached before for the period of measurements. In the majority of cases, these exceptionally low flows followed a succession of months when new record low discharges had been registered. For the majority of rivers, this general recession of flows commenced in 1975, in some as early as the spring of that year, but in others during the later summer. Figure 8 shows daily flow hydrographs from a number of representative rivers for both 1975 and 1976. The shaded envelopes represent the highest and lowest flows for each day in the record prior to 1975; also shown is the pre-1975 mean flow for each day (grey trace).

Flows of rivers in regions where groundwater contributes a significant proportion of the discharge tended to diminish later in 1975 than for rivers with flows derived mainly from surface runoff. For example, the sequence of below average flows began in the Great Ouse in August and September by comparison with those in the Tamar which fell below average in April 1975. The hydrographs show how the rivers responded to rainfall during the 16 months of the drought; for instance, the higher than average rainfalls of September 1975 caused substantial increases in flows in most rivers, the Tees in particular recorded some high flows. However, the below average rainfalls for the remainder of the year meant that at the end of 1975 river flows were below average or well below average for the time of year, while many small streams had already dried up.

Low flows persisted generally during the early part of 1976, although rivers in the north of the country responded to the larger rainfalls recorded there than elsewhere. Several water authorities under the power of Drought Orders reduced compensation water releases from their reservoirs, e.g. from the Derwent Reservoirs into the River Derwent and from the Taf Fechan Reservoir into the River Taf Fechan. By April or May the flows in many rivers were the lowest on record for the time of year, despite the slightly higher than average rainfall for the month of May. Rivers flows in many areas fell below previously recorded spring minima (Figure 8). A significant saline intrusion had taken place during April in the River Ancholme, but the nitrate and dissolved oxygen levels in the rivers Thames and Lee were considered satisfactory during May. The six-month total flow to the end of June was the lowest on record for that period for a number of rivers in the southern half of the country including the Thames, the Great Ouse and the Trent.

During June further reductions in compensation water releases were made and these affected the flows of a number of rivers such as the Taff and Usk. Transfers of water from the Ely Ouse to Essex were stopped and there was growing concern about river water quality in the Anglian area. Releases from the Clywedog reservoir were being used to regulate the flow of the Severn and releases from the Elan Valley reservoirs to regulate the Wye. Reductions in compensation water were made for additional rivers during July and further Drought Orders were obtained giving authorities powers to increase abstractions from some rivers and to abstract temporarily from others.

The lower reaches of a number of rivers were suffering from high levels of salinity while in others high temperatures and low dissolved oxygen concentrations caused fish kills. The quality of river waters was not causing a risk to public health, although in a number of rivers the bulk of the discharge was made up of treated effluent. During July the Severn-Trent Water Authority started to investigate the possibility that some of the water released from Clywedog reservoir was being lost by infiltration while in transit to the Bewdley gauging station. The general recession of flow continued throughout this month and new record low flows were registered on most rivers.

Flow ceased in a number of rivers early in July, such as the Ely Ouse at Denver and in some other rivers draining the area of the Anglian Water Authority. In rivers which continued to flow these flows reached less than half of the lowest previously recorded for the months of July and August and in some cases only 10-20% of the minimum. The length of river channel containing flowing water diminished considerably and the traditional sources of a number of rivers dried up. Despite the problems of no flow, or flows which were very much reduced, water authorities reported that the quality of the majority of rivers remained satisfactory. For example, the quality of the rivers in Wessex (Table 10) was better than usual and the concentration of nitrates fell to unusually low levels (Toms 1977) and in Yorkshire, while the bacterial population of river water was greater than normal, the E-Coli count did not increase significantly (YWA 1977). For a number of the rivers from which water was continuing to be abstracted, the flows were nearing critical levels for abstraction to be maintained. Releases from regulating reservoirs tended to be reduced during August as were releases of compensation waters. There were further fish kills, particularly in rivers in the east of the country, navigation problems increased in many rivers used for pleasure cruising and there were further closures of British Waterways Board canals. Late in August pumping started of some of the Lambourn boreholes to augment the flow of the Thames (TWA 1977) and pumping back was begun at several weirs along the river. (The former is the groundwater scheme being developed by the Thames Water Authority in the Lambourn area some 30 km west of Reading.)

Heavy rain in some areas towards the end of August caused flows to increase locally. For example, flows in the Medway and several other Kent rivers rose by 50% and in other areas the recession of some rivers was eased, e.g. the Exe and Tamar. Elsewhere flows in many rivers continued to fall and it was not until the second week in September that these falls were arrested. Some rivers, for example the Thames, showed a continuing increase in discharge and flood warnings were issued in the Conway Valley; but for others, such as the Severn, there were reductions in releases from regulating reservoirs. Drought Orders continued to be made during September permitting the decrease of compensation waters and the increase of amounts abstracted. Saline intrusions were a recurring problem in certain rivers in the Anglian Water Authority (AWA 1977). By the end of September most rivers, except those on the Chalk, showed increases in discharge and there was even flooding in Gwent, the flow of the Usk reaching ten times its early September volume. Authorities were abstracting at maximum rates from some rivers, but the rapid rise in the level of nitrate concentrations (Table 10) was causing problems. By October the flows in many rivers had risen considerably and some were even above average for the time of year, the exceptions being some rivers where groundwater contributes a large portion of the flow.

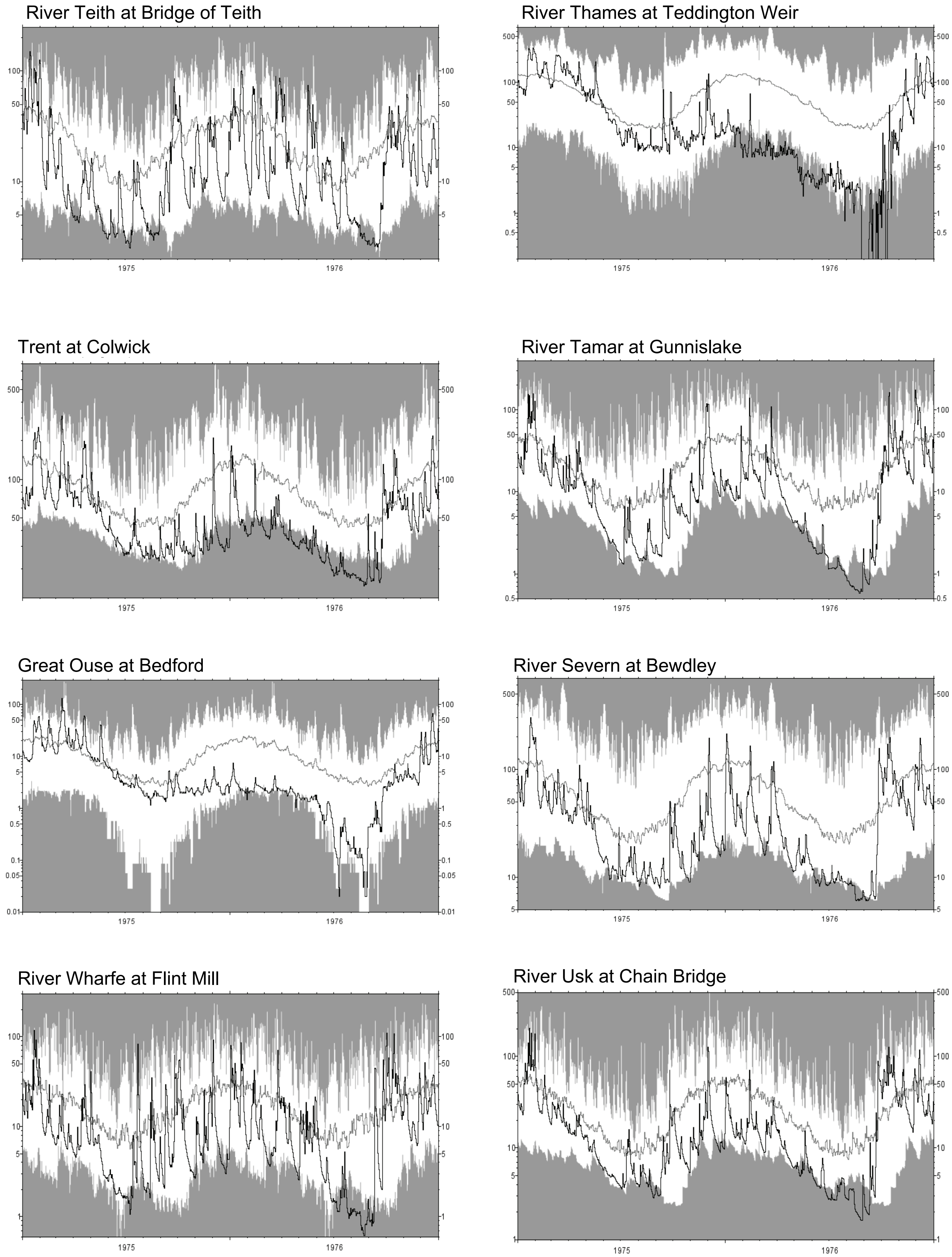

Figure 8: *Daily river flow hydrographs*

Table 10: *Average water quality results for 3-month periods in 1975 and 1976 for rivers in the Wessex Water Authority region*

	Bristol Avon (Newbridge)				**Parrett (Langport)**				**Tone (Taunton)**				**Hampshire Avon (Ringwood)**				**Dorset Stour (Longham)**			
	1975		**1976**		**1975**		**1976**		**1975**		**1976**		**1975**		**1976**		**1975**		**1976**	
	J-S	**O-D**	**J-S**	**O-D**	**J-S**	**O-D**	**J-S**	**O-D**	**J-S**	**O-D**	**J-S**	**O-D**	**J-S**	**O-D**	**J-S**	**O-D**	**J-S**	**O-D**	**J-S**	**O-D**
Temp. C	19	9.5	19.5	10.0	19.7	13	19	11	17.5	8.8	19.5	9	16	9.5	18	10.5	17.5	9	20	8.5
pH	8.1	7.8	8.2	8.0	7.9	7.8	7.4	7.9	8.0	8.1	7.9	8.0	8.4	8.0	8.3	7.8	8.1	8.0	8.1	7.9
Diss. O mg/l	12.8	10.0	8.1	11.0	7.8	8.5	4.3	9.1	10.4	9.3	9.9	8.7	10.8	11.1	9.8	10.1	9.6	10.9	10.6	10.4
BOD mg/l	4.7	3.1	2.6	3.2	1.7	1.9	7.0	1.8	4.5	3.5	3.0	2.1	1.5	1.6	1.1	1.6	1.7	2.5	3.7	2.3
TOC mg/l	7.5	5.5	6.8	5.5	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
NH_3 mg/l N	0.24	0.13	0.17	0.14	0.05	0.43	0.23	0.1	0.23	0.22	0.11	0.25	0.09	0.14	0.03	0.06	0.09	0.15	0.06	0.07
NO_3 mg/l	19.0	34.5	12.4	78.7	12.9	23.9	2.2	55.7	22.1	22.9	11.1	29.6	14.1	19.4	10.2	21.4	14.6	25.2	9.3	39.8
PO_4 mg/l P	0.81	0.94	1.18	0.35	0.88	0.80	1.9	0.2	0.52	0.47	0.38	0.25	0.7	0.6	0.5	0.2	0.7	0.8	0.65	0.12
Cl mg/l	54	51	74	41	47	47	80	32	31	31	44	25	17	19	21	19	33	27	37	24

Source: Toms, 1977

Table 11: *Return periods of low flows recorded during the 1975/76 drought at selected gauging stations*

Gauging station	**River**	**Hydrometric Area**	**Record yrs**	**Approximate return periods (years)**			
				30-day	**60-day**	**90-day**	**180-day**
Norham	Tweed	21	14	15	9	6	2
Bransdale	Hodge Beck	27	26	40	40	30	8
Yorkshire Bridge	Derwent	28	63	25	40	25	10
Claypole Mill	Witham	30	18	55	55	50	25
Old Mill	Harpers Br	32	37	40	35	50	40
Bedford	Gt Ouse	33	44	50	35	20	20
Rectory Bridge	Sapiston	33	16	30	30	25	20
Teddington	Thames	39	94	90	70	50	30
Allbrook	Itchen	42	18	40	40	50	70
Thorverton*	Exe	45	21	70	60	80	35
Semington Bridge	Semington	53	23	40	30	25	20
Bewdley	Severn	54	56	200+	200+	200+	35
Caban Coch	Elan	55	69	100	100	100	70
Pant Mawr	Wye	55	20	15	15	35	30
Chain Bridge	Usk	56	20	200	200	100	100
Stocks Reservoir	Hodder	71	50	20	20	100	9

Sources: Beran & Kitson, 1977 and Hamlin & Wright, 1977.
** Estimates of return periods of flow minima supplied by SWWA.*

An assessment was made of the long-term average monthly runoff for England and Wales and the runoff during 1975 and l976 (Marsh and Littlewood 1978) (Figure 9). The total runoff for the 16 months of the drought was 264.2 mm compared to a long-term value of 495.6 mm for the same period, while for the water year 1975-76 the runoff was 202 mm compared with a long-term average of 428 mm. A runoff of 200 mm in the water year has, on average, an estimated frequency of occurrence of one in 125 to 200 years, while a runoff of 300 mm can be expected once every 20 years.

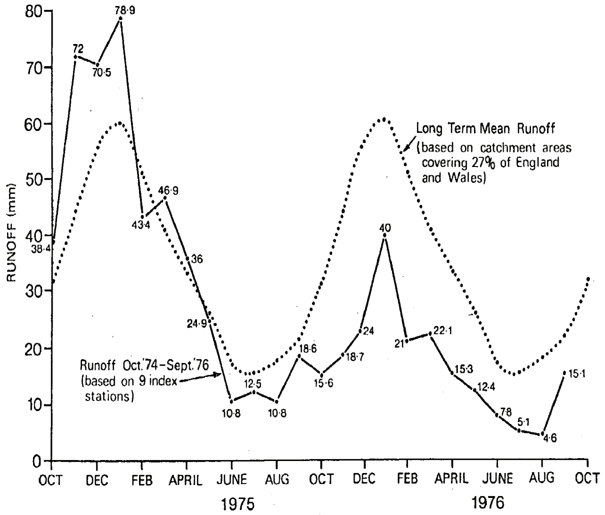

Figure 9: *England & Wales runoff for 1975/76 compared to the long term average*

Assessments have also been made of the return periods of the low flows registered in individual rivers (Table 11). It should be recognised, however, that when river flows are small and declining the problems of measurement increase, rating curves have to be extended and any discharges or abstractions have a growing influence on the natural flow. There is also the difficulty that the period of record at many sites is barely long enough for making a reliable estimate of the return period of the drought. Nevertheless, Table 11 shows the severity of the drought over periods of 30 to 180 days for a number of rivers. The lack of any marked pattern in the return period for the 1976 minima could be a reflection of the difficulties of this type of analysis, but it is more probably an indication of the wide variations in the severity of the drought as expressed by the flows in the different rivers. These in turn were responding to the wide variations locally and regionally in rainfall, evaporation and storage.

Groundwater

Over the whole country the generally drier conditions of the period from 1971 to 1974 were responsible for below average groundwater levels in a number of areas. However, rainfalls during the winter of 1974-75 were generally above average, causing water tables to rise to normal or above normal levels (Figure 10 overleaf; the shaded envelopes show the highest and lowest monthly mean levels prior to 1975). In some areas recharge even continued into the early summer, so that at the start of the drought groundwater reserves were generally at a high level. The low rainfall, from May 1975 onwards, was not reflected in below average water levels until September over much of the Chalk and in the other major aquifers notably the more responsive Permo-Triassic sandstones outcrops, the Jurassic Limestones and the Magnesian Limestone. During this period, the yields of a number of groundwater sources were low and flows from springs were smaller than usual, for example those in the south part of Yorkshire.

Table 12: *Estimated infiltration over the 1975/76 winter*

Aquifer and Location	**Estimated Infiltration Winter 1975-76 (mm)**	**Mean Annual Infiltration* (mm)**	**1975-76 infiltration as % of average**	**Estimated Return Period (years)**
Chalk:				
Yorkshire	73	250	29	20
Lincolnshire	33	190	17	100
Norfolk	24	140	17	100
Chilterns	32	250	13	100
N Downs	122	200	61	10
S Downs	109	260	42	40
Salisbury Plain & Dorset	71	375	19	100
Permo-Triassic sandstones :				
Vale of Eden	228	600*	36	50
Notts	30	240	13	100
West Midlands	58	375	15	100

Source: CWPU (1976)

** Infiltration generally takes place during the winter months but in the west and north, for example the Vale of Eden, some also occurs in the summer.*

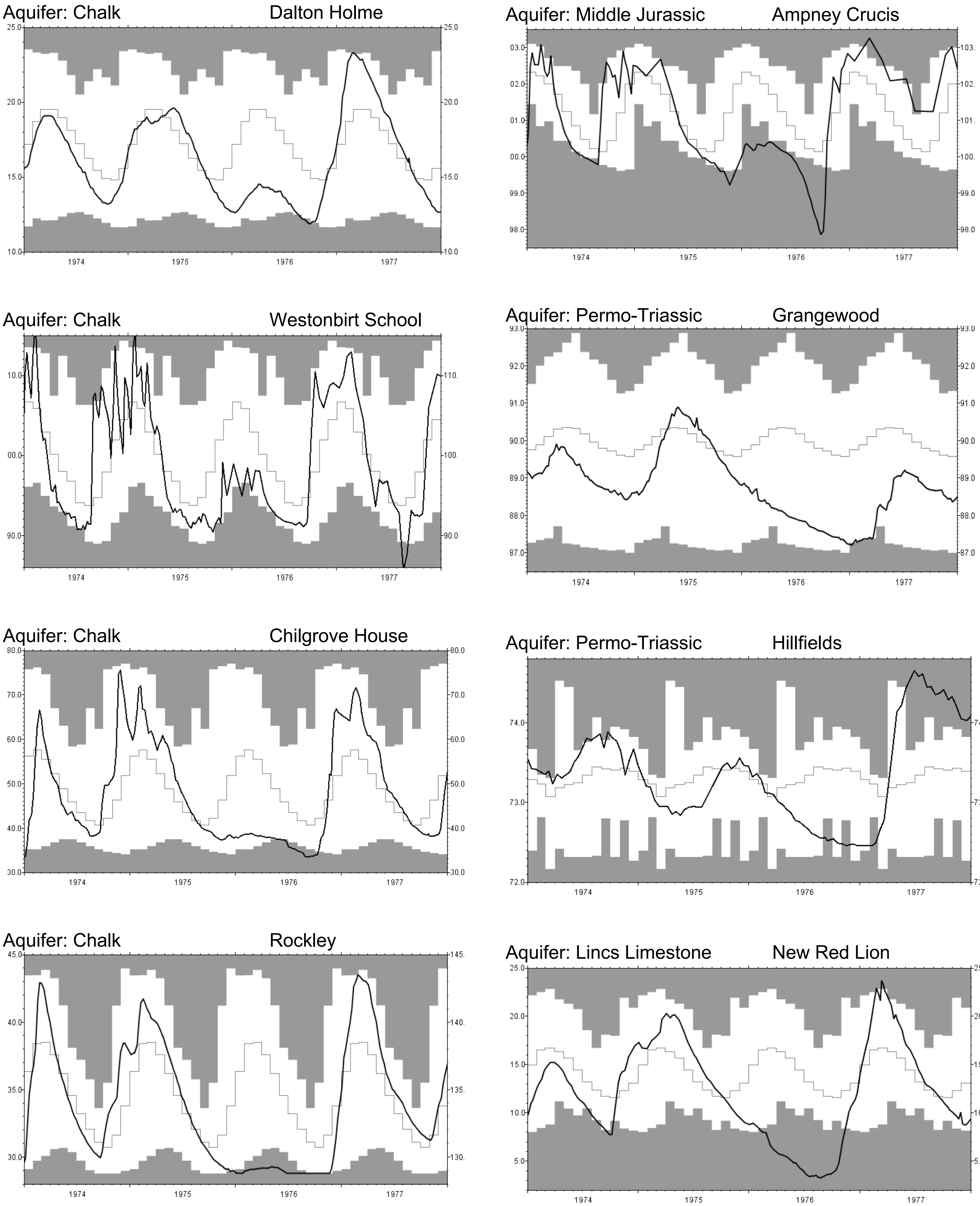

Figure 10: *Groundwater level hydrographs*

Estimates of the amount of infiltration which occurred during the winter of 1975/76 (Table 12) indicated that for many aquifers recharge was less than 50% of the mean and in some cases below 20%. The infiltration measured at three lysimeter sites (Figure 11) is largely in agreement with these estimates and demonstrate just how small were the volumes of infiltration during the 1975/76 winter (Day & Rodda 1977).

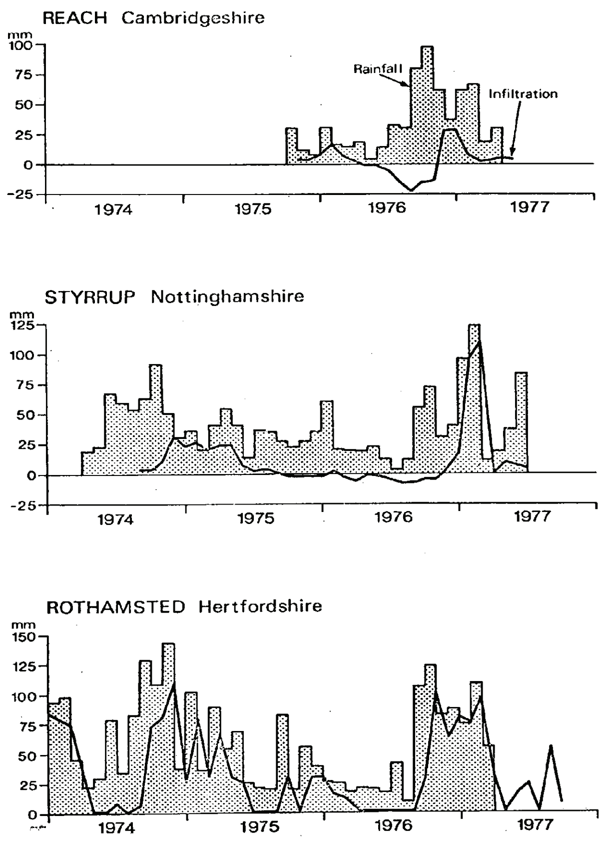

Figure 11: *Rainfall and infiltration (shaded), 1974-77*

As a consequence of the small amounts of infiltration, water levels in the south tended to decline while those in the north showed upward trends. In the well at Rockley, near Marlborough (Figure 10), record low water levels were registered from the beginning of 1976 until the well went dry during the last week of June 1976. The level of the water table in most aquifers continued to decline through the spring of 1976, water levels in wells in the south west being considerably below the lowest previously recorded during April. Falling water tables characterised most aquifers during May, June and July as the drought intensified, but levels in the north of the country were not as depressed as elsewhere. Yields of boreholes fell off in many areas, for example at Newbury and Wantage, in Carmarthen and in the southern Lincolnshire Limestone. During August, levels in the majority of wells and boreholes fell below the previously recorded minima for that month, and a number simply dried up. Yields of pumping wells were reduced and, because of the drought and the large volumes of water being abstracted from underground sources for public supply, the records of a number of observation wells were affected: falls in levels occurred which were considerably enhanced by pumping from nearby sources. For example, in the Lincolnshire Limestone aquifer in the Bourne area levels fell to more than 10 metres below previous minima and this could have been due to the effect of local abstraction of groundwater. In some areas, such as east Kent, nitrate levels were rising in a number of sources, but generally the quality of water from wells and boreholes was maintained and nitrates were not the problem they were to become towards the end of the year (Table 13). In some aquifers, towards the west of the country, for example, the Great Oolite, the decline in water levels was less severe and conditions were about average during August. This example typifies the considerable variations that occurred from one groundwater province to another during the drought and there were also regional and local differences resulting from differences in infiltration, differences in aquifer characteristics and other factors.

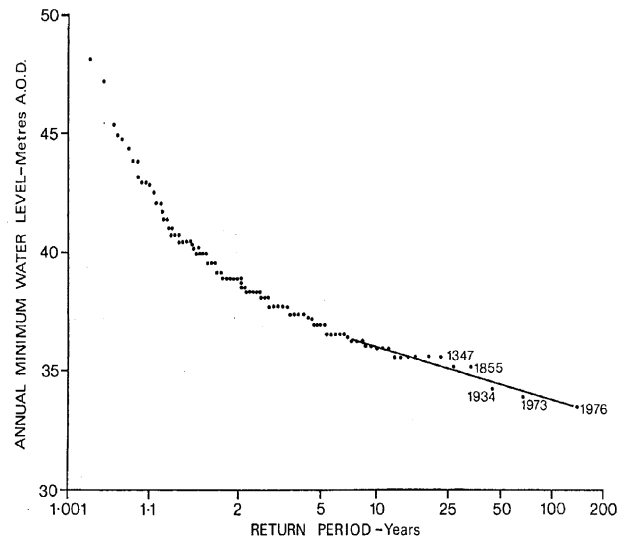

Figure12: *Gumbel extreme value plot for Chilgrove*

The annual minimum levels in the well in the upper Chalk at Chilgrove in West Sussex were extracted from the 140-year record (Speight 1977). These values were plotted on

Gumbel probability paper to indicate the return period of the 1976 level which was the lowest on record (Cotton 1977), see Figure 12. Because of the substantial soil moisture deficits that had developed by late August, the effect of the rain at the end of the month and during September was not to cause an immediate rise in water tables. Some aquifers were responding by the second half of September, but in others, particularly the Chalk, there was a continued decline in water levels during September and it was not until October that the reversal took place. By November most wells had reached average or above average levels, but there were some where it was the end of the year before this position was attained.

Table 13: Nitrates in groundwater in the Wessex Water Authority region

1976	**Boreholes and springs - Nitrates as mg NO_3/l**								
	Washford	**Bradley Head**	**Lytes Cary**	**Paytons**	**Traphole**	**Wastford**	**Empool**	**Bulbridge**	**Lockford Bridge**
January	30.6	9.7	19.9	31.0	21.7	30.1	25.7	24.2	35.9
February	36.8	-	22.1	31.0	21.3	30.1	27.0	24.8	25.2
March	-	16.8	-	32.3	-	31.0	28.8	22.6	27.0
April	38.5	23.0	23.5	32.3	21.3	30.6	30.1	25.2	24.8
May	-	-	-	-	-	-	-	23.9	-
June	34.5	17.1	19.9	-	20.4	-	27.5	-	25.2
July	-	8.9	18.6	31.4	-	30.1	24.4	23.0	18.6
August	27.9	16.8	-	33.2	20.8	30.6	26.1	22.1	21.7
September	19.5	13.7	17.3	31.4	19.9	28.8	23.9	20.8	19.9
October	50.5	64.7	27.5	33.7	34.5	31.4	23.0	19.9	19.9
November	17.3	26.1	37.6	36.3	31.9	31.9	19.9	-	17.3
December	-	35.4	43.0	37.2	25.2	31.0	25.7	16.8	20.8
Depth and type	springs	borehole 24 m	spring/bore 11m	spring	springs	spring	borehole 55 m	borehole 91 m	borehole 76 m
Strata	Upper Marls on Devonian sandstone slates and siltstones	through inferior Oolite to Yeovil Sands	lower Lias Limestone over Rhaetic	Old Red Sandstone	Devonian Red Sandstone	Old Red Sandstone	Tertiary sandstone and gravels over Upper Chalk	Upper Chalk	Upper Chalk

Source: Toms 1977

Reservoirs

At the start of the 16-month period of the drought, reservoir levels were generally satisfactory and, although amounts in storage declined during June 1975, there were difficulties in only a few limited areas. These included some parts of Wales, where reservoir levels fell rapidly, and in the south west, where the reservoirs supplying Barnstable & Bideford had about 50 days' supply left at the end of the month. During July 1975, reservoir levels fell rapidly throughout the country due to high demand and high evaporation rates (Table 14). Reservoirs in the south west supplying Bude, Bideford, Barnstable, Torbay, Minehead and Yeovil were sufficiently low to cause difficulties and there were also problems arising from the limited stocks in southern Yorkshire. In Wales reservoir levels were low (Table 15) and this also applied to some reservoirs in Northumberland and Lincolnshire.

Falls in levels continued throughout August and emergency measures had to be taken to augment supplies in south west England. During September, reservoir levels fell less rapidly, or rose, because of rainfall and emergency pumping, but the dry weather during the following month retarded the recovery of reservoir levels generally. Emergency pumping continued in the south west, where the levels in many reservoirs were very low, for example, Durleigh reservoir, which services the Bridgwater area, held only 11% of its capacity. Levels in Yorkshire were also continuing to decline rapidly. Rainfall during November was sufficient to stop further falls in levels and, in many areas, there were increases in storage. Reservoirs in the Thames and Lee valleys continued to be filled and water stocks in Yorkshire recovered a little. This improvement continued into December but over most of the country reservoirs were far lower than normal for the time of year and there was concern in many areas about water supplies for 1976.

Some replenishment occurred during January and most reservoirs in the Thames and Lee valleys were filled to above 80% of capacity. This was in contrast to other parts of the country where, in general, levels were still well below normal. Similar conditions pertained during February and March, there was replenishment in some areas but in others, such as south east Wales and parts of south west England, the small amounts in storage caused emergency measures to be continued. As reservoir stocks declined during April and into May, supply problems increased in many areas. However, conservation measures helped to reduce demand and substantial amounts of rainfall in the northern half of the country lessened difficulties locally. During June, impounded stocks of water in many reservoirs fell by 10% and more due to continuing demand and high rates of evaporation (Table 14) – about 4 mm a day in the south of England, as measured by evaporation tank. Local sources failed in a number of areas such as the Isle of Wight and in the Usk and Wye valleys, while flows in the rivers Severn and Wye were being regulated by releases from Clywedog and the Elan Valley.

By early July 1976 the amount of water in storage was decreasing rapidly (Figure 13), but the amount remaining in storage varied enormously from one area to another. For example, Farmoor Reservoir (Oxford) was just under 68% full at the beginning of the month and Weir Wood serving Crawley was 40% full. By the middle of the month the Grwynne Fawr and Talybont reservoirs in Gwent were 14% and 22% full and the other 13 reservoirs in the area had a total stock of water which represented 39% of their combined capacity. By the end of July reservoirs in the north of England were being depleted by about 3% of their capacity per week and this and higher figures applied to many in the south, except in areas where measures had been taken to reduce demand substantially. Evaporation from reservoirs continued at high rates - up to 5 mm per day in some areas in the south.

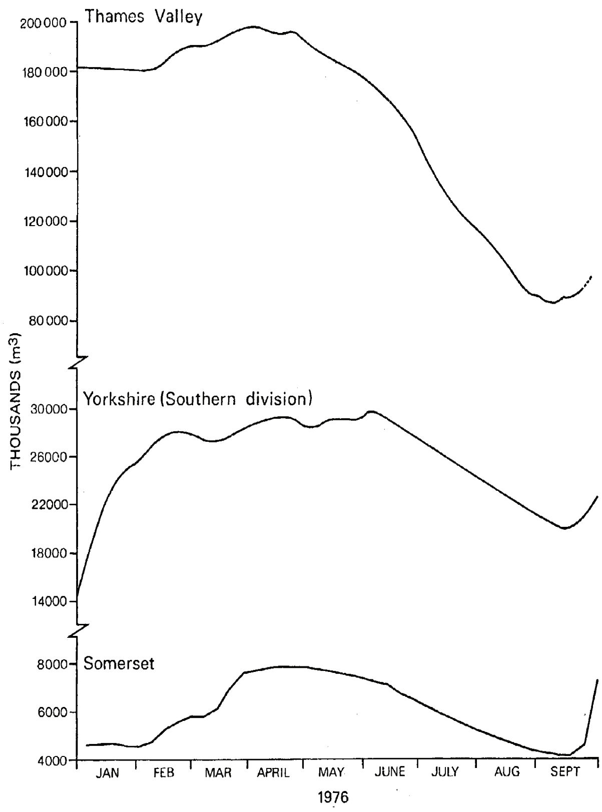

Figure 13: Quantity of water in store for selected areas, Jan-Sept 1976

Table 14: Monthly evaporation (in mm) in 1975 and 1976 measured by Meteorological Office standard tank

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Kew													
1975	13.8	14.9	20.0	42.7	64.4	116.8	106.8	105.6	60.9	27.9	15.7	4.8	594.3
1976	15.9	12.5	41.1	63.2	88.8	128.3	153.2	121.2	53.3	23.4	9.3	3.4	713.6
Wallingford													
1975	11.5	12.7	15.7	40.0	74.0	126.5	123.8	114.6	65.7	26.2	10.9	8.9	630.5
1976	11.7	9.5	36.4	58.6	87.8	130.0	162.0	128.0	53.7	20.6	7.8	3.8	709.9
Bath													
1975	8.1	8.7	22.7	45.3	102.7	155.5	145.2	92.8	51.7	29.9	16.0	4.1	689.8
1976	10.8	9.0	26.3	47.1	88.3	122.9	150.2	146.8	46.9	15.7	2.5	2.0	668.5
Chew Stoke													
1975	13.2	9.3	25.8	40.8	82.3	151.8	112.8	132.8	52.6	24.1	24.5	6.9	677.0
1976	15.2	8.1	30.7	60.6	77.2	104.9	101.3	62.9	24.6	12.8	5.9	9.9	513.7

Table 15: Reservoir contents for the period April 1975 – September 1976

Reservoir	**Volume in store on the first day of the month as a percentage of maximum capacity**																		
	Apr '75	**May '75**	**Jun '75**	**Jul '75**	**Aug '75**	**Sep '75**	**Oct '75**	**Nov '75**	**Dec '75**	**Jan '76**	**Feb '76**	**Mar '76**	**Apr '76**	**May '76**	**Jun '76**	**Jul '76**	**Aug '76**	**Sep '76**	**Oct '76**
Clywedog	93	97	96	86	71	53	45	53	64	79	89	93	96	97	95	32	50	27	29
Vyrnwy	93	95	83	75	69	60	52	56	60	75	86	91	88	83	75	63	50	37	52
Elan Valley	94	96	92	77	68	54	48	52	55	78	88	97	93	88	82	68	53	37	33
Derwent Val	100	100	95	78	65	48	36	30	35	58	93	96	93	93	93	84	72	55	52
Stocks	74	75	63	54	62	45	60	60	60	60	96	88	83	73	76	98	44	30	29
Taf Fechan	96	93	80	61	58	47	50	47	54	55	61	63	61	54	51	42	29	22	35

Source: Hamlin & Wright, 1977

At the beginning of August the reservoirs in the Thames and Lee valleys were 58% full and for the areas supplied in part by Grafham Water there were 140 days' supplies remaining. Supplies to Bedford, Northampton and Peterborough continued to be critical.

Demand tended to reduce in industrial areas and increase in holiday districts such as the Isle of Wight and the south west where stocks were falling rapidly, supplies to North Devon, Plymouth and East Devon being particularly at risk. Reservoir levels in south east Wales suffered marked declines and stocks in Grwynne Fawr had reached 11% of capacity. In contrast at this time Llyn Brianne, which supplies west Glamorgan, contained 70% of its total capacity. Supplies to those areas without reservoir storage were becoming very difficult during August even where consumption had been cut. Tankers were being used to supply isolated communities and private sources in many areas, but only a small proportion of the total population was affected.

By the end of August water levels in most reservoirs were low or very low and despite the success of many campaigns to reduce demand, levels were continuing to fall. For example in the Severn-Trent Water Authority, the total reservoir content decreased by about 13% of capacity during August. Reservoirs in the south west serving much of Devon had between 20 .and 50 days' supply left, and a number of emergency sources were being brought into commission. Stocks in the Bristol Waterworks reservoirs stood at 32% and 43% full. Reservoirs in south east Wales stood at the following levels: Taf Fawr 33%, Llandegfedd 32%, Talybont 11%, Grwyne Fawr 2% of capacity respectively. In parts of southern Yorkshire there were

70 days' supplies remaining, while parts of Lancashire had less than 50 days' supply left. Despite the substantial rainfall in early September, by the middle of the month consumption of water continued to exceed additions to stocks. Demand had been reduced by 20% in many areas and by over 40% in those areas where reservoirs had the smallest reserves through imposed restrictions and voluntary reductions. In terms of surface water stocks being at a minimum, the drought probably reached its zenith in the week commencing 20 September, as during the following week most reservoir levels rose or held steady. However, there were still many areas where reservoir levels were still very low and there was concern over the adequacy of water supplies.

By the middle of October, with rising reservoirs and still reduced supplies, the water supply situation was vastly improved. Impounded stocks of water were increasing rapidly and some reservoirs had reached 80% of the full capacity. At the beginning of November the position had improved even further and later that month, some reservoirs were even overflowing (e.g. Taf Fechan reservoir).

Water Supplies

At the start of the drought in May 1975 there were virtually no problems with water supplies, but by June hosepipe bans had been imposed throughout the SWWA area; in Bridport, Taunton and Minehead; in parts of Yorkshire, Cumbria and Lincolnshire and around Ipswich and Chapel en le Frith. Over much of the country demand had increased by 120 to 140% of the average daily supply (Table 16), which was 14,397 M1/d for England and Wales in 1974 (WDU 1975). This increase resulted in distribution problems in some districts, such as the Thames Valley.

The areas covered by hosepipe bans were enlarged during July to take in a substantial part of Wales, west Somerset and portions of East Anglia. Five Drought Orders were in operation (Table 17), one affecting the Taff reservoirs, and these were kept in force during August. During September several more Drought Orders came into force (four for the South West Water Authority) in response to the continuing level of demand for water and the depletion of reservoir stocks. However, failures of supplies were limited to small sources feeding isolated communities; a more widespread problem was the conveyance of sufficient water through the distribution system to meet the exceptionally heavy demand. In many areas this demand was very largely maintained during October, although the national total fell, more drought orders came into force and wide areas were still covered by a hosepipe ban.

November saw a further decline in the volume of water supplied, but bans on hosepipes remained in many areas, while the number of Drought Orders rose further. Standpipes were erected in Barnsley, but they stood unused, only to be dismantled in December. The amount of water supplied nationally declined again during this month to about the daily average for 1974, but rose slightly during January. Hosepipe bans continued in operation over certain parts of the country and they were introduced throughout the Wessex Water Authority area on 7 February (WWA 1977), but the number of Drought Orders in force fell to 15 for the first two months of 1976. This decline in Drought Orders continued into March, but hosepipe bans were extended and economy campaigns commenced in several areas, e.g. the Isle of Wight and the Bristol Waterworks Company's area. In addition, various conservation measures were commenced such as reductions in pressure.

After the March meeting of the National Water Council a public statement was issued which said: *`This winter has been one of the driest in the last 100 years, with the result that groundwater levels are at a record low in some parts of the country and stocks of water held in reservoirs (and soil moisture levels) are generally below normal for the time of year. Water supply prospects vary from place to place, but, if the dry weather continues, severe restrictions on water use could be required in some places before the summer is out. All water authorities are taking the closest control over their resources, and where precautionary measures are needed they will be advising their customers accordingly. In the whole of the country the advice is "Please use water carefully".'*

During April and May 1976 the amount of water supplied was very much the same as for those months in 1975. Hosepipe bans were in operation, or came into operation during these months which affected parts of the areas served by the following water authorities: Severn-Trent, Yorkshire, Anglian, Southern, Wessex, South West and Wales. Drought Orders were in force in the areas covered by six authorities and these included the powers to supply Barnsley and Sheffield through standpipes. Concern grew over the apparent inequities of hosepipe bans and the limitations that existing legislation imposed on water authorities in responding to a serious drought. The need for new and more flexible legislation was emphasised by the Chairman of the National Water Council and the Chairmen of the water authorities at their meeting with the Secretary of State on 12 May (National Water Council 1977a).

By the beginning of June conservation measures were being taken generally by all authorities other than Thames, Northumbrian and North West. Intensive economy campaigns were commenced in Wessex, south east Wales, Peterborough, Lincoln and Northampton, the Brighton areas and parts of the south west, and these campaigns were extended to other areas as the month progressed. The effect of these economy campaigns and the other conservation measures was to reduce the June 1976 total water supplies by about 500 M1/d compared with the 1975 figure for England and Wales. As in 1975, there were distribution problems in some areas such as the west Midlands and parts of the Thames Valley and Hampshire. Tankers were being used to fill service reservoirs in the Isle of Wight. Three authorities, namely, North West, Northumbrian and Thames were able to satisfy virtually all demands on them during June.

Table 16: *Water Supplies during 1975 and 1976 (Ml/d)*

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
North West	1975	2356	2389	2368	2379	2354	2448	2338	2324	2352	2344	2299	2282
	1976	2327	2395	2388	2350	2312	2387	2369	2266	2045	2102	2198	2245
Northumbrian	1975	970	981	958	961	965	958	954	955	996	994	982	984
	1976	965	1009	999	967	997	1013	996	928	918	949	970	976
Severn-Trent	1975	2142	2142	2136	2147	2130	2320	2238	2215	2176	2177	2166	2100
	1976	2129	2184	2151	2115	2103	2174	2101	1915	1758	1822	1929	1887
Yorkshire	1975	1278	1278	1277	1279	1264	1325	1308	1271	1288	1290	1288	1257
	1976	1250	1304	1291	1243	1209	1221	1198	1106	1066	1116	1179	1200
Anglian	1975	1390	1385	1353	1374	1398	1557	1592	1609	1501	1435	1428	1400
	1976	1418	1452	1429	1401	1402	1531	1473	1304	1203	1203	1287	1371
Thames	1975	3168	3216	3150	3221	3230	3685	3681	3599	3400	3305	3281	3244
	1976	3256	3331	3300	3300	3440	3773	3600	3131	2937	3034	3131	3163
Southern	1975	1024	1043	1038	1052	1063	1221	1210	1194	1099	1049	1038	1028
	1976	1025	1048	1049	1056	1083	1162	1113	1011	905	912	947	965
Wessex	1975	676	679	680	700	683	816	771	764	731	707	689	672
	1976	679	685	680	673	658	702	715	678	588	581	602	623
South West	1975	354	350	345	356	369	415	402	409	382	362	359	360
	1976	360	363	358	360	350	375	372	342	300	306	316	323
WNWDA	1975	961	999	981	986	960	1007	975	974	974	962	950	965
	1976	984	992	981	957	942	946	886	836	856	838	892	905
England & Wales	1975	14319	14462	14286	14455	14416	15752	15469	15314	14899	14625	14480	14292
	1976	14393	14763	14626	14422	14496	15284	14823	13517	12576	12863	13451	13658

Table 17: Approximate number of Drought Orders in force at the end of the month within the area of each Water Authority

75/76	NWWA	NWA	STWA	YWA	AWA	TWA	SWA	SWWA	WNWDA	WWA	Total
Jun	2	-	-	-	-	-	-	2	1	-	5
Jul	2	-	-	-	-	-	-	2	1	-	5
Aug	2	-	-	-	-	-	1	2	1	-	6
Sep	2	-	-	-	1	-	1	4	2	1	11
Oct	2	-	1	-	1	-	1	4	3	1	13
Nov	2	-	3	1	1	-	1	5	4	3	20
Dec	1	-	2	1	1	-	1	5	2	4	17
Jan	-	-	2	1	1	-	1	5	1	4	15
Feb	-	-	2	2	1	-	1	3	1	5	15
Mar	-	-	2	2	-	-	1	1	2	4	12
Apr	-	-	-	5	2	1	-	2	3	4	17
May	-	-	1	6	2	-	1	1	5	5	21
Jun	-	-	3	6	3	-	2	2	5	6	27
Jul	-	-	2	6	8	1	2	2	6	8	35
Aug	-	1	4	7	9	2	4	11	7	17	62
Sep	1	3	11	12	11	7	3	31	7	26	112

At the beginning of July hosepipe bans were covering most of the areas served by the Severn-Trent, Yorkshire, Southern and South West Water Authorities and all the Wessex and Anglian Authorities' areas. During the month these bans were extended to cover completely the Southern, Thames and South West Water Authority areas.

The Drought Bill which was published on 14 July was designed to give extra powers to water authorities and allow their responses to the drought to be more flexible than previously (NWC 1977a). The number of Drought Orders in force rose by the end of the month to 35 and a wide range of emergency measures were being adopted to conserve stocks and maintain supplies. These measures included pressure reductions, shutting off supplies at night, delivery of water by road tanker to isolated consumers whose supplies had failed, completion ahead of schedule of new trunk mains to reduce distribution problems, commissioning of new boreholes, installation of new booster pumps, curtailment of spray irrigation, extra maintenance in order to reduce loss by leakage, selective restrictions on non-essential uses, and the commissioning of new river intakes and treatment plant. In addition, many industrial consumers were reducing their demands by being more economical in the use of water and by recycling. These measures, together with the publicity campaigns that were under way in many areas, reduced the July total amount of water put into supply by over 600 M1/d by comparison with the 1975 figures (Table 16). Virtually all consumers, with the exception of about 100,000 people in Gwent and 2,000 in Dyfed whose water was shut off each night from 19th July, continued to receive an adequate public water supply.

At the beginning of August the Severn-Trent Water Authority extended the hosepipe ban to the whole of its area and in Wales the same ban was applied to new areas so that most of the country was covered. The absence of a large number of people on holiday caused further reductions in demand in residential, industrial and urban centres, but increased it in tourist regions. For example, supply and demand are finely balanced on the Isle of Wight and in many parts of the south west of England. The Drought Act 1976 received the Royal Assent on 6th August with allowed water authorities to apply for orders to the Secretary of State permitting them to curtail non-essential users and provide emergency supplies. Under Section 1 of the Act an authority applying for an order was required to publish notices of its intention and allow 7 days for objections. On the Secretary of State making an order, a 2-day notice of the detailed measures proposed by the water authority were required before they came into force. However, if the Secretary of State considered the application to be required urgently he could dispense with this procedure.

From 9th August nightly shut-offs applied to over 1 million consumers in south east Wales and to some isolated communities elsewhere in the Principality. Advisory committees met for the first time in Plymouth, Paignton, Exeter and Barnstable and the Anglian Water Authority presented drought contingency plans at meetings with county councils, district councils and other bodies. Water rationing started on 15th August in Jersey and installation of standpipes commenced on 16th August 1976 in Bideford (SWWA 1977). From 18th August the area served by the North West Water Authority was subject to a hosepipe ban and on the same day pressure was reduced in the Thames Water Authority's Metropolitan Division. On 23rd August the shut-offs in south east Wales were extended to the period from 1400 hours to 0700 hours and the area increased to bring in Pontypridd which was subjected to nightly shut-offs. On the 24th August Mr Dennis Howell, Minister of State, Department of the Environment, was given special responsibility for the drought, and on the 25th a Drought Information Room was set up to answer questions from the general public on the water shortage (Musgrave 1977). Towards the end of August several authorities were reporting demands which were up to 10% lower than the daily average for the year and this is reflected in the national total for the month which was 88% of the August 1975 figure (Table 16). Further Drought Orders were imposed to bring the total in all areas to 62 at the end of the month. The Southern WA Drought Panel met for the first time on 26th August (SWA 1977).

At the beginning of September industrial and domestic consumers were being urged to make further reductions in their consumption of water and in most areas plans were being considered for coping with a continuing drought. From 1st September industry in north Gwent was asked to reduce consumption by 50%. Erection of standpipes was started in the Yorkshire Water Authority's South Western Division on 3rd September, progress in installing standpipes was maintained in North Devon and installation commenced in the Plymouth area on 6th September. Nightly shut-offs began in parts of Belfast on 8th September. Hosepipe bans covered all of the Yorkshire Water Authority area, all the Severn-Trent area except a small part in the south and all of the WNWDA area except the Conway Valley. About 18% less water than normal was supplied while the corresponding figures in the Wessex and Severn-Trent authorities were 17% and 14-18%. Only a small part of the country was not covered by restrictions by 8th September, supply by standpipe was imminent in Devon and Yorkshire and the applications for Drought Orders being processed indicated that increasingly severe restrictions would apply to even wider areas. However, during the following week the downward trend in consumption (amounting to 20-40% in many areas) and the heavy rainfall meant that further steps to reduce demand and conserve supplies were able to be put back in South Wales and Yorkshire. Plans to introduce a 50% cut for industry in south east Wales were shelved and, although standpipes were still being installed in the Halifax and Huddersfield areas, a decision on when to use them was postponed. In Devon standpipes were brought into use on 15th September to serve some 80,000 people in about 150 centres including Bideford, Barnstable, Ilfracombe, Tavistock and Okehampton (Andrews 1976). The 17-, 13- and 12-hour cuts were continued in south east Wales. Although the water supply situation was serious, in most other areas the majority of consumers continued to receive a near-normal supply of water.

During the remainder of September the downward trend in the consumption of water tended to fall off and even reverse in certain districts, but with the continuing rainfall, the seriousness of the water supply situation was eased in a number of areas. The introduction of supply by standpipes was deferred in certain centres, such as Northampton, Huddersfield, Halifax, Wakefield, Plymouth, Torbay and Exeter. From 28th September in south east Wales normal supplies were restored in North Gwent, the Upper Rhymney Valley, the Rhondda and Pontypridd areas and the remaining cuts were reduced from 17 to 14 hours. By the end of the month the number of Drought Orders in force was almost double the total for August while the total water supplied during the month fell to 85% of the 1975 total.

Continued countrywide heavy rainfall at the beginning of October and savings in the use of water, which ranged from 12 to 25%, considerably eased the supply situation over much of the country. Several authorities did not use, or relaxed their powers to limit the non-essential use of water. Some lifted bans on spray irrigation, but others continued to urge caution. Standpipes were removed from Huddersfield, Halifax and Wakefield, normal supplies were resumed to North Devon on 6th October and all restrictions were lifted in south east Wales on the same date. This was the date that it was announced that the drought had ended.

On 7th October the Anglian Water Authority's RODEO scheme, which had been successfully tested in September, was put into operation to reverse the drainage of the Ely Ouse so that water could be abstracted at Offord for Grafham Water. During the remainder of October the water supply situation slowly returned to normal, restrictions were gradually lifted so that by the end of the month most authorities regarded their position as reasonably satisfactory.

Difficulties were not foreseen for 1977 (NWC 1976b) providing savings in consumption were continued. Supplies to industry were likely to be sufficient to maintain production and employment, even if an extremely dry winter were to be followed by a dry summer. Domestic supplies could be maintained with some restrictions and there was the possibility of rationing in certain limited areas where conditions might be extreme.

Consequences

Although the most immediate consequences of the drought were felt by the water industry and its customers, the drought had an impact on a far wider cross-section of the country's economic and social activities than simply those concerned with the supply and consumption of water. This section attempts to review briefly those activities which suffered most from the drought.

For the water industry the drought brought many problems. It caused existing stocks of water to be husbanded, and new supplies to be made available (AWA 1977), and generally it diverted effort from the longer to the shorter term aspects of resource planning (WWA 1977). Where distribution systems were strengthened to supply areas of critical water shortages, these measures were unusually dealt with as an integral part of the resource development programme. The result generally was to bring forward expenditure: to quote one example, the drought was estimated to have cost the South West Water Authority £1.1m and an ever-increasing proportion of staff effort (SWWA 1977). Very little of the work directed at alleviating the drought under the emergency powers was considered to be abortive; in the case of the Wessex Water Authority some 90% was of permanent value to the region's resources or supply system (WWA 1977).

Gilliland (1977) indicated (Table 18) that the total difference made by the drought to water authorities and water companies in terms of outlay on capital and revenue account and loss of income was £34.3 million in the financial year 1976/77 and an additional £24.5 million in 1977/78. Costs and losses on sewerage and sewage disposal and on pumping and treatment were not included in Table 18 because they were considered to be small or difficult to identify.

Table 18: *Direct financial implications of the drought for the water industry*[3]

	1976/77 ,'000	1977/78 ,'000
Additional capital expenditure	16,177	17,285
Additional revenue expenditure	8,551	3,831
Loss of income	9,583	3,397
Total additional revenue requirement	18,134	7,228

Source: Gilliland, 1977

Table 19 (Gilliland 1977) shows how the additional capital expenditure varied between water authorities – only four authorities spending less than £1m on alleviating the drought in 1976/77. For purposes of comparison, it is worth noting that for the financial year 1975/76 the ten water

[3] Note: the Retail Prices Index increased by a factor of around six over the 1978-2009 period

authorities spent £505 million on capital works and a further £805 million on revenue expenditure, largely in respect of water conservation, distribution and supply, and sewage collection and treatment and disposal (NWC 1976a).

Table 19: *Additional capital expenditure by Water Authorities*

Water authority/ companies	1976/77	1976/77 as a % of capital allocation	1977/78
	£,000	%	£'000
North West	115	0.2	0
Northumbrian	2	0.0	0
Severn-Trent	2,300	3.0	2,275
Yorkshire	2,343	4.0	10,200
Anglian	2,025	3.0	126
Thames	900	1.0	0
Southern	770	2.0	480
Wessex	1,900	8.0	0
South West	1,674	8.0	1783
WNWDA	2,843	5.0	1,576
Water Companies	1,305	N/A	845
Totals	16,177		17285

Source: Gilliland, 1977

The need to augment and to conserve supplies and the measures adopted to pursue these policies caused a large number of operating problems for water authorities. For example, reductions in pressure and variations in pressure led to flushing out of deposits and scale and the ingress of soil bacteria. Deterioration in water quality was serious in some districts and, as a counter-measure, chlorine levels were increased and care was taken to disinfect standpipes where these were used (Toms 1977). The different problems of the methods of rationing are shown in Table 20 (Young 1977).

Fears were expressed during the drought that there could be serious effects on sewage disposal systems and on river water quality. In the event, however, water quality in the majority of rivers held up very well, largely because of the improved quality of the effluent reaching them. It became clear that much of the pollution which rivers receive in the average year results from heavy rainfall causing storm water overflows to operate (YWA 1977). Operational problems were caused by blockages of sewers due to a build up of settled solids following reduction in the volumes of water entering them. At sewage works, sewage strength increased and biological filters tended to dry out.

The drought was of great concern to fisheries, but, despite substantial reductions in compensation waters, very low water levels and high temperatures, most coarse fisheries were considered to have survived remarkably well. Mortalities were high but spawning conditions were good for the coarse fish species and they grew rapidly. The effect on salmon and migratory trout was more severe. Catches were much reduced by comparison with 1975 (Table 21); salmon had to wait until well into the autumn for the rains to swell the rivers and allow them to ascend to their spawning grounds. This, together with the stress on young fish reaching the migration stage in the rivers, may carry implications for future stocks up to 1980/81. It could be that the effect of the drought on fisheries will only become apparent in years to come.

Early in the drought most authorities embarked upon publicity campaigns urging caution in the use of water. The message was put over through leaflets, newspaper advertising, radio broadcasts and on television. Car stickers were employed to a considerable extent and roadside notices were used to warn motorists they were entering a drought-stricken area. When the drought ended some authorities advertised in newspapers their thanks to the general public for saving the water they did.

For the domestic consumer the drought brought most hardship in North Devon and south east Wales, where there was considerable inconveniences and distortion of the normal pattern of life. In North Devon consumers were very bitter over what they called the iniquitous system of distribution through standpipes (Brooker and Mildren 1977) and they maintained that the holiday-makers should not have been allowed seemingly unlimited quantities of water.

Table 20: Problems associated with water rationing and methods of implementation

	A. ROTA CUTS	B. STANDPIPES	REMARKS
1. Extreme situation: only a few days supply left.	Not possible to limit usage when turned on.	Actual rationing possible by supervision at standpipes.	B. Only choice.
2. Less extreme situation.	Flexible, length of cuts can be varied to suit supply position.	Hardship on consumer.	A. Preferred.
3. Reduction in waste.	Yes, as mains are turned off, but frequent valve operations may burst old mains.	No. Mains all charged.	A. Providing mains not too sensitive.
4. Public Health Risks.	Emptying mains and de-pressurising could lead to ingress of pollution.	Providing standpipes sterilized, water at standpipe pure but transit risks to house in receptacles.	B. Probably least risk, but water from A or B should be boiled for drinking.
5. Preparatory work.	Valves and zones must be checked and continuous process industry identified, etc.	All boundary stopcocks must be checked. Probably 20% need repair or replacement. Standpipes to be erected and connections inside gardens made. Notices and danger lamps needed. Priority consumers to be identified.	
6. Operation.	Considerable twice daily effort to operate, strict timing essential.	Mainly dealing with complaints over priority, etc.	
7. Savings Achieved.	Obviously depends on severity. Hong Kong (1963) went to four hours on every 4th day at one stage. Wales went to 17-hour cuts. Saved 50% but a large part due to industry.	Agriculture 40-45%. Overall 33%.	30% could be saved by intensive PR etc. Additional savings not dramatic for effort involved.
8. Dirty Water Complaints.	Widespread initially negating savings. Mains purged after seven days and savings then achieved.	Minimal.	B. Preferable.
9. Public Acceptability	Not selective except between areas. Town centres and factory zones left on but differences less conspicuous than for standpipes. Less adverse reaction.	Selective in theory but combined services confuse issue; shops were left on.	B. Theoretically more selective than A. In practice A preferable to prevent individual comparisons.

Source: Young 1977

In south east Wales the daily routine changed considerably for most families and, while some regarded the absence of water for part of the day as no real loss or hardship once a satisfactory new routine was established, many others were of the opposite opinion. Informal questioning on a limited basis showed that consumers would have paid up to £1 per day for the duration of the shut-offs to have had a normal unrestricted water supply, while a figure of 50p a day over the six weeks was considered a good estimate of acceptable inconvenience cost for the average household.

Most families in South Wales and in the country as a whole incurred extra expenditure from the purchase of buckets and waterbutts and in replacing the plants and shrubs lost during the drought. Then there was the loss of garden produce and the cost of replacing it with fresh food that had risen in price because of the drought. Obviously the sum of these costs varied widely across the country, but probably they amounted to between £20 and £30 for the average household. Otherwise for the consumer the drought brought bricks in lavatory cisterns, fewer baths, unwatered gardens, unwashed cars and other slight changes to his environment and way of life.

Probably because of the priority given to maintaining industrial supplies the impact of the drought on industry was both very limited and local.

Industries where water is used as a raw material, such as brewing and soft drinks manufacturing, called for restrictions not to be applied to them: there were fears that the drought could bring a 3-day working week. Savings in breweries were reported to be between 14 and 25%, whilst in the food industry one company achieved a 30% saving by re-use and another 90% by switching its bottle cleaning from a wet to a dry process (Biggs 1977a). Claims were made that in certain industries, for example laundering, use of novel process technology could reduce demand by more than half.

Andrews (1977b) suggests that some plants reduced water consumption by as much as 95% without any loss of production, and it was claimed that one motor vehicle manufacturer had, since the drought, made savings of over £1 million on the cost of water due to savings instituted during the drought. Industrial concerns with their own reservoirs or boreholes appeared to be in a better position than those supplied from the mains, but there were exceptions to this. The Times of 7th September reported that a seaweed processing factory at Barcaldine near Oban had to lay off its workforce of 125 because its reservoir had dried up and there were other examples of this happening in different parts of the country.

A number of concerns sought additional sources of water when their own reservoirs or boreholes were near failure, only to find that they would face additional abstraction charges. Worries were expressed by water authorities that they would attract less revenue in future if industry were to be successful in maintaining the savings brought about by the drought.

While savings were made by industry in the use of water and on water authority charges, enterprises that took action to circumvent the effects of the drought probably incurred extra expenditure in the purchase or construction of plant and equipment and in its operation. However, it is very difficult to estimate what these costs were, but they could have amounted to hundreds of thousands of pounds.

(Biggs 1976) indicated that the drought had no apparent effect on the total UK volume of production as measured by the index of industrial production (Central Statistical Office 1977) for July, August and September 1976. Neither did the drought cause any dramatic increase in the number of workers temporarily stopped or unemployed. Industrial consumers were worst hit in South Wales where a certain amount of output was lost, but there were also some difficulties in other parts of the country. Water shortages affected industry in three ways (Biggs 1976); in its effect on production processes, on factory domestic services and on the work force at home. Restrictions on water for production processes caused installation of plant for recycling and re-use of water, particularly cooling water, and the elimination of waste. Savings were made by 'good housekeeping' in the case of factory domestic services.

Table 21: Fish catches declared in England & Wales in 1975 and 1976

Type		Rod Catches		Commercial Catches	
		No.	Weight (Kg)	No.	Weight (Kg)
Salmon	1975	25,770	108,298	89,510	338,310
	1976	7,958	33,207	43,754	149,229
Migratory Trout	1975	39,730	44,876	59,825	117,813
	1976	18,372	17,632	58,150	107,832

Table 22: Agricultural production (tonnes/hectare)

	1973	1974	1975	1976
Wheat	4.4	5.0	4.3	3.9
Barley	4.0	4.1	3.6	3.6
Oats	3.8	3.8	3.4	3.4
Early potatoes	20.1	18.8	14.1	16.3
Maincrop potatoes	30.4	31.6	22.3	20.6
Sugar Beet (sugar yield)	6.1	3.6	3.9	4.4
Hay(tonnes X 10^3) – Temporary Grass	3223	2790	2393	2928
Hay(tonnes X 10^3) – Permanent Grass	3857	3223	2844	3510
Turnips and swedes	50.7	53.0	46.7	33.2
Mangols	70.5	66.0	59.5	54.3
Beans	9.6	9.8	8.4	6.9
Lettuce	34.2	32.6	31.0	28.0

Sources: Carter 1977 and CSO 1977

The year 1976/77 was a difficult one for agriculture. A major improvement in production was expected, but this did not occur mainly because of the drought of 1976 (Cmnd 6703) which followed another though less severe one in 1975. In fact the index of agricultural net product at constant prices fell to 89 in 1976 following values of 114 and 100 in 1974 and 1975 (Cmnd 7058). The impact of the drought was felt directly through the effects of the low rainfall, high soil moisture deficits, restrictions on sprinkler irrigation, farm water supplies failing, saline intrusions and the high temperatures on growth of crops and livestock and indirectly in a variety of ways, for example, through the increase in certain pests and the number of fires.

In the case of cereal crops (Carter 1977), although an exceptionally large area was sown and early growth was satisfactory, by late June and early July crops were deteriorating rapidly. The harvest began in mid-July (the earliest on record), yields of wheat were below average and the worst since 1961; while barley fared a little better, quality was poor and yields were the lowest since 1968 (Table 22), although they were not much below those for the intervening years except 1972 and 1974. The total cereal crop was about 0.5 million tonnes less than in 1975 (Cmnd 6703). While the early potato crop yield in 1976 was above that for 1975 the main crop was severely affected by the drought, yields were lower than in 1975 and prices for potatoes rose considerably. Production of the other main root and fodder crops, such as sugar beet, swedes, turnips and mangolds fell as a result of the drought, and most other crop yields suffered in the same way, for example soft fruit yields were about 80% of normal (Carter 1977) and salad vegetable production dropped sharply.

Grassland production was severely restricted in 1976 as it had been in 1975. While growth was adequate in the early part of 1976, by July it had slowed considerably and eventually ceased altogether. This meant that livestock feed had to be heavily supplemented with concentrates, hay and straw were used to supplement the sparse grazing and although animals were very fit during the hot weather, many lost weight. The most severe effects were seen in dairy herds, milk yields and sales of milk falling sharply in August and September (Table 23). Beef cattle gained less weight, and lambs took longer to fatten; and while sheep seemed little affected, pigs suffered from heatstroke and numbers died.

Carting of water became necessary to many farms and the water that was available to livestock was under greater demand. For example, Caster (1977) reported that in one herd dairy cows with an average milk yield of 23 litres, each cow drank an average of 63.5 litres of water during the drought – the average dairy cow under normal conditions drinks about 30 litres per day. There were some reports of sheep on open moorland dying because of lack of water and there were deaths of livestock from drinking saline water.

Because of the drought and its effects on the volume of production and on prices, in a number of sectors the total value of production increased, in the case of horticulture, for instance. In general, the market price of commodities rose, for example, the average ex-farm price of a tonne of wheat rose at constant prices from £59.9 in 1974 to £56.0 in 1975 to £72.4 in 1976 (Cmnd 7058), but it should be borne in mind that this was a period when costs were also rising rapidly. Continental prices were also affected by the drought.

After the drought there was an increase in output in some sectors, the sales of milk for example (Table 23; in this case and others the effect of the drought tended to be lost in the annual totals. These factors together with the charges in support for agriculture given in the form of grants subsidies, guaranteed prices and taxation charges made it difficult to establish the overall cost of the drought to the industry.

Table 23: *Sales of liquid milk off farms*

Month	Year 1974/75	Year 1975/76	Year 1976/77	% change 1975/76 to 1976/77 Million litres
April	1019	949	1086	+ 14.5
May	1172	1145	1237	+ 8.0
June	1075	1054	1093	+ 3.7
July	985	951	925	- 2.7
Aug	919	885	825	- 6.7
Sept	860	830	778	- 6.3
Oct	865	886	897	+ 1.3
Nov	808	871	886	+ 1.7
Dec	843	904	912	+ 0.9
Jan	861	922	925	+ 0.4
Feb	796	875	868	- 1.0
Mar	914	987	1017	+ 3.0
	11117	11259	11450	+ 1.7

Source: Milk Marketing Board

The drought caused considerable problems for forestry, in terms of damage to trees and their destruction by fire. Premature browning and defoliation of trees occurred on shallow soils, sandy soils, and heavy clays and to those on south facing slopes. A large proportion of newly planted hedgerows and woodland died and, especially in Devon, many hedgerow trees growing on banks suffered. The dry weather hastened the decline of trees with diseased roots and assisted the spread of disease such as the sooty bark disease which affects sycamore. Forestry Commission fire losses in the summer of 1976 were the largest since the war (Hamilton 1977) nearly 2000 hectares (Table 24) being destroyed in England and Wales and a further 300 hectares in Scotland. Many of the fires had to be contained by ploughing or dozing as the surface vegetation was in a highly combustible state, water was not available and the fire services were attending to more important emergencies. Serious fire damage occurred on common land and rough grazing – the heathlands of southern England were particularly susceptible and there were severe outbreaks in Wales. One fire near Corwen, in the country of Clwyd, destroyed 1250 hectares of sheep grazing and many kilometres of fencing (Carter 1977). The cost of this fire damage was considerable.

Table 24: Forestry Commission fire losses

	Number of fires per annum	Plantation lost per annum (hectares)	Av. area lost per fire (hectares)	Value lost £1000s
1929-33	345	533	1.54	15.1
1949-53	1,136	160	0.12	14.1
1959-63	2,934	342	0.12	66.1
1969-73	625	380	0.61	115.2
Yr 75/76	125	252	2.02	110.0
1976 only*	245	c1970	8.05	c1,000.0

*For the period 1st January to 1st Sept. *Source: Hamilton 1977*

The Financial Times for 4th January 1978 showed that the cost of all insured fire damage for the first ten months of 1977 averaged £18.5 million per month, while the figure for the months of May, June and August 1976 (the height of the drought) was £25 million per month. This suggests that the cost of the drought in terms of fire damage to insured properties was in the region of £26 million. There would be the costs of fire damage to uninsured property to take into account in addition.

The Nature Conservancy Council (Hearn and Gilvert 1977) considered that fire and the damage from fire fighting were the most serious effects of the drought on nature conservation sites (Table 25). In total, 118 sites were affected, four heathland sites being seriously damaged through the intense heat destroying the vegetation, little humus and peat and offering opportunities for erosion.

Many plant species, particularly on Chalk and limestone grasslands suffered reductions in numbers, growth and flowering in 1976, certain fine-leaved grasses died out, areas were left bare and erosion resulted. Areas of heather in Dorset, Surrey, Suffolk and the Midlands died from lack of moisture and scorching and this in turn was thought likely to affect the invertebrates which depend on the heather and the reptiles and birds (Hearn and Gilbert 1977). Open water habitats dried out and at coastal sites increased public pressure caused increased erosion. There were some beneficial effects of the drought: some plant species not affected by moisture stress responded to the high temperatures and extra insolation by increased growth and flower and seed production, coarse fish increased in numbers; as did many invertebrates, for example lepidoptera; while waders were present in unusually high numbers. It was concluded that only a few suffered permanent damage, the few being those where serious fires occurred, but that generally the effects of the drought would not be significant for very long.

The drought caused damage to roads and buildings and other structures mainly because of movement of foundations and shrinkage of timber. Foundations were affected, particularly on clays, where shrinkage took place and on certain other soils where drying out was exacerbated over limited areas, such as by tree roots. The movement of foundations on shrinkable clays caused widespread cracking of buildings (Building Research Establishment 1976). Many of the cracks were slight, but some were 10 mm or more and exceptionally the damage was severe enough to significantly affect the strength or stability of the building. The Times of 4th January 1977 reported that as many as 40,000 buildings, mostly in London and the South East were believed to have been damaged by subsidence resulting from the drought and that the total insurance payments would be about £60 million. In addition it was considered that there was damage to many uninsured properties: it was estimated that the cost of all damage would be in the region of £100 million.

Table 25: The major effects of the 1976 drought on habitats: relative numbers of sites affected

DROUGHT EFFECT/HABITAT	Coastal	Woodlands	Heathlands	DG	WM	OW	P	U
Marked detrimental effect on dominant spp. in plant community	0	+++[1]	+++[2]	+++	0	++[3]	+	0
Marked detrimental effects on plant spp. of special conservation interest (SCI)	+[4]	0	+	+++	++	0	+	+
Marked beneficial effect on plant spp. of SCI	++[5]	0	+	+	0	0	0	+
Marked detrimental effects on animal spp. of SCI	+[6]	0	+++[7]	0	+[8]	+++[9]	0	0
Marked beneficial effects on animal spp. of SCI	0	0	0	+++[10]	0	+++[11]	+	0
Disease of plant spp.	0	+++	0	0	0	0	0	0
Disease of animal spp. (Botulism)	+	0	0	0	0	++	0	0
Fires (extensive or severe)	+	+	+++	+	+	+	++	+
Serious results from lowering of water-tables	++[12]	0	++[13]	0	++[14]	+++	+	0
Damage from exceptionally heavy grazing pressure	++[16]	+	+	+++	+	0	++[15]	0
Increase in public pressure causing damage to habitat and and plants/Erosion	+++	0	0	+++	0	+++	0	++
Increased salinity levels	++	/	/	/	++	++	0	/
Halting of scrub encroachment	+	+	+++	+++	0	+		0

Key:

C = Coastal
W = Woodlands
H = Heathlands
DG = Dry Grasslands
WM = Wet Meadows
OW = Open Water
P = Peat Lands
U = Uplands

No of sites in which drought affect shown

0 = none
\+ = >5; drought affect noted but not significant
++ = >5; drought effect significant in a few sites
+++ = >5; drought effect severe or widespread

Footnotes:

1 Tree dieback
2 Callunn
3 ymites; aquatics
4 in dune slacks
5 single species
6 Natterjack toads
7 Reptiles, dragonflies
8 Wildfowl
9 Wildfowl and dragonflies etc
10 Dapidoptera
11 Waders
12 dune slacks
13 wet heaths
14 reclamation
15 reclamation
16 marshes

Concluding remarks

On the world scale of extreme climatic events, the British drought of 1975/76 was a rather paltry affair. Widespread crop failure did not occur and herds of livestock were not decimated: malnutrition and starvation did not cause the death of a large part of the population – in fact the mortality rate for the third quarter of 1976 (CSO 1977) was the lowest for any similar period in recent years. In less fortunate countries the fabric of the nation would probably have been unable to withstand a drought of similar magnitude and a major disaster would undoubtedly have resulted. Here, despite the large population, intense industrialisation and the sometimes competing demands on water resources, the water management system was able to cope with the exigencies of the drought. There are, of course, a number of lessons which may be learned from the drought and those pertaining to the water industry have been set out by Crann (1977). The drought caused a number of concepts to be questioned, reliable yield for example, and it demonstrated the variety of expedients which may be available to increase yields and to discourage water use (Walker 1977).

The cost of the drought to various activities has been discussed previously and it is tempting to bring these estimates together. However because there are considerable margins of uncertainty in these figures, not all costs are included, some may be double-counted and the benefits of the drought are not accounted for, no total cost for the drought is given. Benefits accrued to many sections of the community, not least to those individuals who enjoyed the summer sunshine and the opportunities the dry weather offered for outdoor pursuits. Certain industries were able to capitalise on the hot weather, increasing output to match the rise in consumer demand for such products as ice cream, lightweight clothing and certain electrical goods, fans for example. It could be argued that the reduction in the mortality rate during the drought implied a healthier population, but certain sections of the population were under greater stress than normal during the hot weather; especially the very old and the very young. The water authority and local authority officers involved in operations to counteract the effects of the drought were also under considerable stress. Of course, one could argue that had our water supply system in its entirety been able to function normally despite the drought, these costs would have been avoided but this is not so: foundations would have settled, fires would have burned and agriculture would have suffered.

In the case of most environmental hazards, a balance has to be struck between the costs society is willing to incur if an event exceeds a chosen frequency, or level of risk, and the costs incurred in providing protection against events up to that frequency. What level of risk should be selected is a matter of considerable debate, not only for drought and water supply, but for other natural hazards such as earthquakes and typhoons and also for man-made catastrophes such as fires and chemical disasters. At times when an event occurs which exceeds the selected level, pressure builds up to raise the chosen level of risk and invest more in protection. Following the experience of the 1975/76 drought there seems to be little evidence that the level of risk chosen by the water industry should be altered, although much was learned from the experience.

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This review of the 1975/76 drought has been prepared from data from a wide variety of sources. Some of these data have been culled from the Water Data Unit archives and some from the Department of the Environment and the Central Water Planning Unit Water Situation Reports. Some have been obtained directly from water authorities and other bodies such as the Meteorological Office, while some data have been extracted from the literature.

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Appendix I

The Modified Foley Index

To compute the Foley Index the monthly medians and monthly upper quartiles are computed for a given rainfall series. The annual median is obtained from the average and annual figures. The index is obtained by taking the monthly deviations from the median, and dividing them by the annual median, the results being multiplied by a factor of 1000. Deviations above the median are given negative values and deviations below the median positive values. The positive values are accumulated month by month and when the results are plotted the periods of drought stand out significantly.

In the modification of the Foley Index used in this report these monthly standardised values are all accumulated except where a monthly rainfall amount falls at or above the monthly upper quartile. In that instance it is assumed that the drought is terminated and a value of 0 is registered. The advantage of this modification is that any one month is sufficient to end a drought as opposed to the rainfall above the median in the original Foley Index.

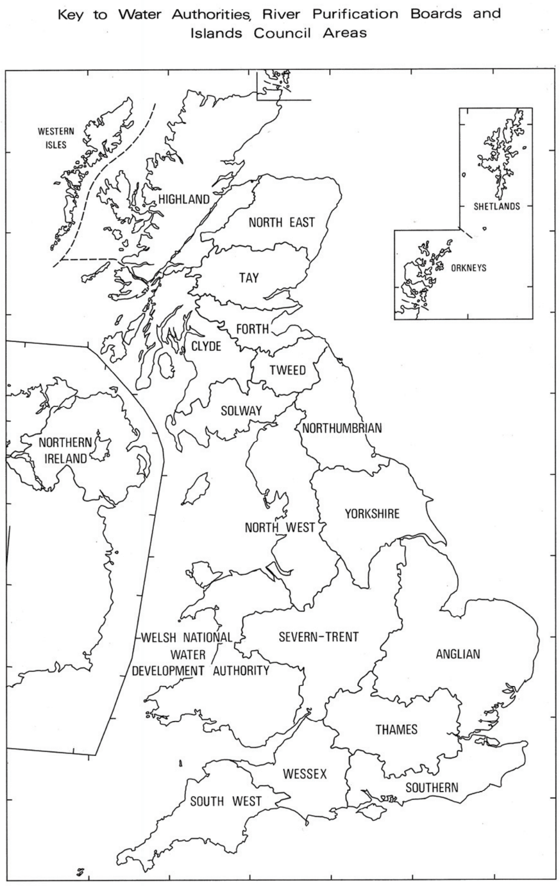


Figure 14: *Regional divisions of the water industry in 1976*

Note: In places the following abbreviations for the regional divisions featured above have been used in the text:

NWA	Northumbria Water Authority
YWA	Yorkshire Water Authority
STWA	Severn-Trent Water Authority
AWA	Anglian Water Authority
TWA	Thames Water Authority
SWA	Southern Water Authority
WWA	Wessex Water Authority
SWWA	South West Water Authority
NWWA	North West Water Authority
WNWDA	Welsh National Water Development Authority

References

Andrews, C.D. 1976. `We didn't wait for the rain.' National Water Council. 48 pages.

Andrews, C.D. 1977. *`Leyland Cars – savings of £1 million on water costs.'* Water, 14, 13-16.

Anglian Water Authority. 1977. Annual report and accounts 1976-77. 61 pages.

Beran, M.A. and Kitson, T. 1977. Assessing the severity of the 1976 river flows: A hydrologist's and a water planner's viewpoints. ICE Hydrological Group Informal Discussion, 7 February 1977.

Biggs, A.I. 1977. The drought and industry. *Water,* 12, 6-8.

Biggs, A.I. 1977. Effect on industry. *Proc. One-day seminar on the operational aspects of the drought of 1975-76.* Institution of Water Engineers and Scientists and Institution of Civil Engrs, 5.1-5.20.

Brooker, F and Mildren, J 1977. *The Drought in the South West.* University of Exeter and Exeter Industrial Archaeology Group. 115.

Building Research Establishment. 1976. Drought damage to buildings. *B.R.E. News*, 38. 2-3.

Carter, E.S. 1977. The effect of the drought on British Agriculture. *Scientific Aspects of the 1975-76 Drought in England and Wales*. The Royal Society.

Central Statistical Office. 1977. *Monthly Digest of Statistics.* HMSO No. 382, October 1977, 190.

Central Water Planning Unit. 1976. The 1975-76 drought - A review of hydrology - and water resources. *Technical Note No. 17.*

Command 6703, 1977. Annual Review of agriculture, 1977. HMSO, 45.

Command 7058, 1978. Annual Review of Agriculture, 1978. HMSO, 44.

Cotton, C.J.N. 1977. Discussion of Speight, H. `Setting the scene.' Proc. One-day seminar on the operational aspects of the drought of 1975-76. Institution of Water Engineers and Scientists and Institution of Civil Engineers, 1.191.10.

Crann, H.H. 1977. *`.Lessons learnt.'* Proc. One-day seminar on the operational aspects of the drought of 1975-76. Institution of Water Engineers and Scientists and Institution of Civil Engineers, 8.1-8.24.

Day, J.B.W. and Rodda, J.C. 1977 *`The effects of the drought on groundwater and aquifers.'* Scientific Aspects of the 1975-76 Drought in England and Wales. The Royal Society.

Foley, J.C. 1957. *`Droughts in Australia.'* Bureau of Meteorology Bulletin No. 43, 281.

Freeman, L. 1977. *`The 1976 drought and all that.'* Water, 14, 17-19.

Gilliland, E.J. 1977. *`Financial implications.'* Proc. One-day seminar on the operational aspects of the drought of 1975-76. Institution of Water Engineers and Scientists and Institution of Civil Engineers, 6.1-6.13

Grindley, J 1977. *`A contrast of rainfall deficiency and excess: authorities faced unprecedented conditions.'* The Times, January 25.

Hamilton, J.M. 1977. *`Forest Fires.'* Forestry, 1999, 13-14.

Hamlin, M.J. and Wright, C.E. 1977. *`The effects of drought on river systems.'* Scientific Aspects of the 1975-76 Drought in England and Wales. The Royal Society.

Hearn, K.A. and Gilbert, 1977. *`The effect of the drought on sites of nature conservation interest in England and Wales.'* Nature Conservancy Council, 219.

Hounam, C.E. 1975. *`Drought and agriculture.'* WMO Technical Note No. 138, 127.

Marsh, T.J. and Littlewood, I.G. 1978. *`An estimate of an annual runoff from England and Wales, 1728-1976.'* Hydrological Sciences Bulletin, 23,1,3

Miles, M.K. 1977. *`Atmospheric circulation during the severe drought of 1975/76.'* The Meteorological Magazine, 106, 154-164.

Morris, R.M. and Ratcliffe, R.A.S. 1976. *`Under the Weather.'* Nature, 264, 4-5.

Murray, R. 1977. *`The 1975/76 Drought over the United Kingdom - Hydrometeorological Aspects.'* The Met. Magazine, 106, 129-145.

Musgrave, D.C. 1977. `*Government action.'* Proc. One-day seminar on the operational aspects of the drought of 1975-76. Institution of Water Engineers and Scientists and Institution of Civil Engineers, 6.1-6.13.

National Water Council. 1976a. `*Annual report and accounts 1975/76.'* 29-66.

National Water Council. 1976b. `*Water Supply Prospect for 1977.'* 29.

National Water Council. 1977a.. `*The 1975-1976 drought - a report by the National Water Council to the Rt. Hon. Denis Howell, MP, Minister of State DoE.'* 48.

National Water Council. 1977b. `*Annual Report and Accounts 1976/77.'* 66.

Perry, A.H. 1976. `*The long drought of 1975-76.'* Weather, 31. 328-334.

Ratcliffe, R.A.S. 1976 `*The hot spell of June-early July 1976.'* Weather, 31. 355-357

Ratcliffe, R.A.S. 1977a. `*A synoptic climatologist's viewpoint of the 1975/76 drought.'* The Meteorological Magazine. 106. 145-154.

Ratcliffe, R.A.S. 1977b. `*The wet spell of September-October 1976.'* Weather, 32. 36-37.

Shaw, M.S. 1977. `*The exceptional heat-wave of 23 June to 8 July 1976.'* The Meteorological Magazine. 106, 329-346

Southern Water Authority. 1977. `*Annual Report and Accounts 1976-77.'* 26.

Southern Water Authority. 1977. `*Annual Report and Accounts for the year ended 31 March 1977.'*

Speight, H. 1977. `*Setting the scene.'* Proc. One-day seminar on the operational aspects of the drought of 1975-76. Institution of Water Engineers and Scientists and Institution of Civil Engineers, 1.1-1.10.

Tabony, R.G. 1977a. `*Drought classifications and a study of droughts at Kew.'* The Meteorological Magazine, 104, 1-10.

Tabony, R.G. 1977b. `*The variation of long duration rainfall over Great Britain.'* Meteorological Office Scientific Paper No. 37, 40

Thames Water Authority. 1977. `*Thames Water Annual Report and Accounts for the year ended 31 March 1977.'* 76.

Toms, R 1977 `*Scientific and technical innovations.'* Proc. One-day seminar on the operational aspects of the drought of 1975-76.. Institution of Water Engineers and Scientists and Institution of Civil Engineers,

Walker, D.L. 1977. `*Possible policies for the future.'* Pre-print of papers for Symposium on Water Services: Financial, Engineering and Scientific Planning.

Water Data Unit. 1975 *Water Data 1974.'* 55.

Welsh Water Authority. 1977. `Third Annual Report - for the year ended 31 March 1977.

Wessex Water Authority. 1977. `*Annual Report 1976/77.* 70

Wigley, T.M.L. and Atkinson, T.C. 1977. `*Dry years in south east England since 1698.'* Nature, 265, 431-434.

Wright, C.E. 1976. `*Once in 1,000 years.'* Water, November 2-6.

Yorkshire Water Authority. 1977. `*Annual Report and Accounts for the year ended 31 March 1977.'* 24.

Young, J.A. 1977. `*User economy and publicity.'* Proc. One-day seminar on the operational aspects of the drought of 1975-76. Institution of Water Engineers and Scientists and Institution of Civil Engineers, 4.1-4.15

The 1975-76 Drought – a retrospective appraisal

Terry Marsh

Introduction

The hydrological volatility of the recent past, particularly the drought episodes in the 1990s, 2003 and 2004-06, has focussed public and political attention on the UK's continuing vulnerability to water resources depletion and environmental stress during periods of scarce rainfall. A particular concern is that climate change may increase both the degree of water resources stress and the range of impacts associated with drought episodes in a warming world.

In modern times, the most intense and wide-ranging impacts were those associated with the drought of 1975-76 which has exerted a major and enduring influence on water management strategies. However, the extreme rarity ascribed to the event implies a substantial measure of resilience to the generality of drought episodes. This retrospective review capitalises on a range of hydrometeorological data to examine whether the extreme return periods associated with the rainfall and runoff deficiencies experienced during the 1975-76 drought may require revision in the light of the conditions experienced over the subsequent 35 years.

Rainfall

As with most UK drought episodes, considerable temporal and spatial variations in intensity could be recognised throughout the 1975-76 drought. Generalising broadly, across much of the England & Wales and eastern Scotland, the drought developed through the late spring of 1975, intensified over the winter and achieved its maximum intensity during the late summer of 1976. The ensuing wet autumn brought an unusually abrupt termination to the drought in almost all of the affected regions.

The England & Wales rainfall series (Wigley, et al, 1984) begins in 1766 and, although the sparseness of the raingauge network prior to the 1830s implies considerable uncertainty in the earliest national rainfall estimates, it provides a unique historical context within which to examine the relative severity of major drought episodes. Table 1, which ranks the driest 16-month sequences (non-overlapping) beginning in any month for England & Wales, confirms that the accumulated rainfall deficiency up to, and including, August 1976 remains the largest by an appreciable margin. Since 1976, the driest 16-month period (February 1995 to June 1996) exceeds the 1975-76 minimum by around 90 mm and for 16-month periods ending in August, no deficiency in the last 150 years has been within 100 mm of that registered in 1975-76. As significantly, and notwithstanding the additional 35 years of data, there has been no correspondingly dry period for timespans of between 7 and 21 months, to those experienced in 1975-76 since the 1850s at least.

Table 1: *Minimum 16-month rainfall totals for England & Wales (1767-2009)*

Rank	End Mth	Rain (mm)	% of av.
1	**Aug 1976**	**745**	**62.2**
2	May 1855	791	66.9
3	Jun 1934	835	69.7
4	May 1888	852	72.3
5	Jun 1996	858	74.0
6	Nov 1921	883	70.2
7	Dec 1785	883	74.9
8	Feb 1845	888	74.0
9	Apr 1781	908	77.2
10	May 1944	919	79.3

Figure 1 maps rainfall anomalies over the full compass of the 1975-76 drought and for two component timespans. The maps provide more spatial detail than those featured on page 10 and illustrate the considerable regional and local variations in rainfall deficiencies throughout 1975-76.

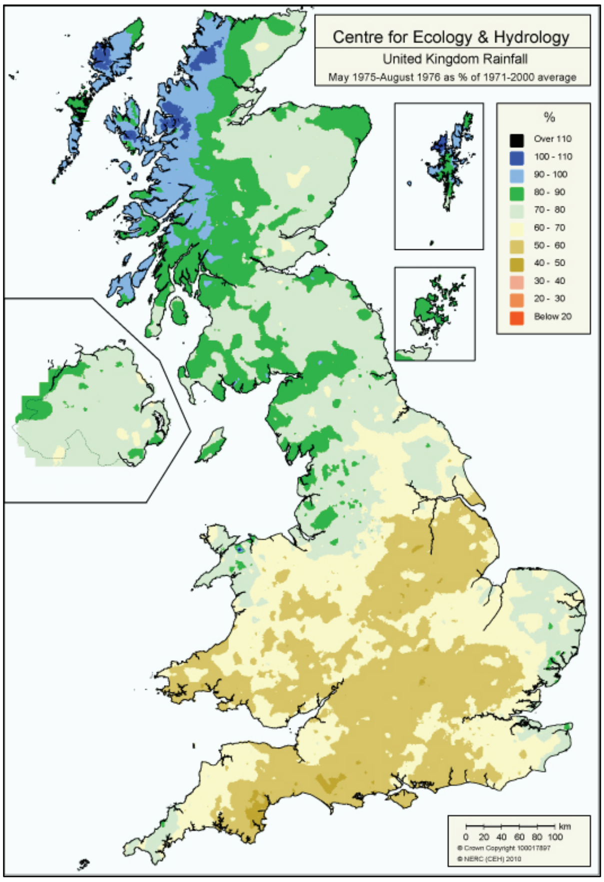


Figure 1a: *May 1975 to August 1976 rainfall as a % of the 1971-2000 average*

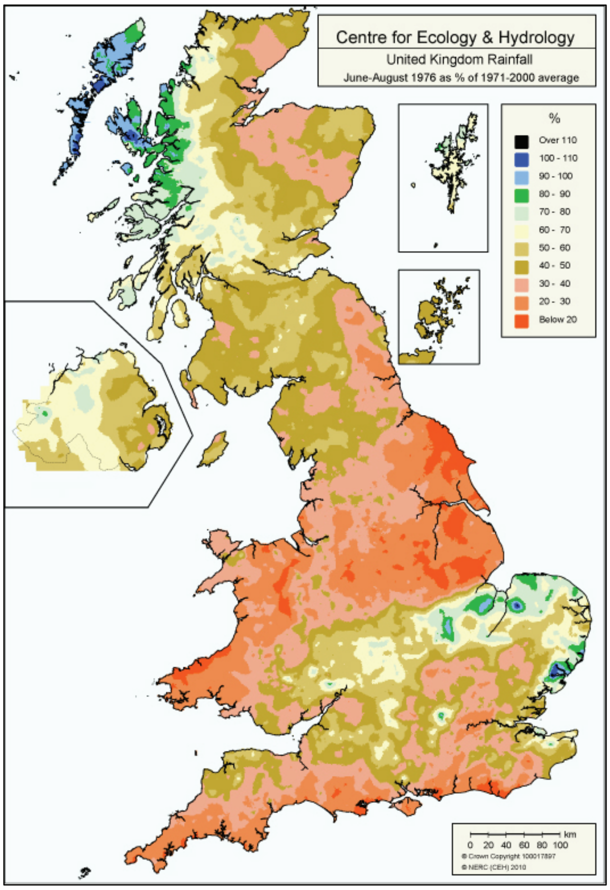


Figure 1c: *June to August 1976 rainfall as a % of the 1971-2000 average*

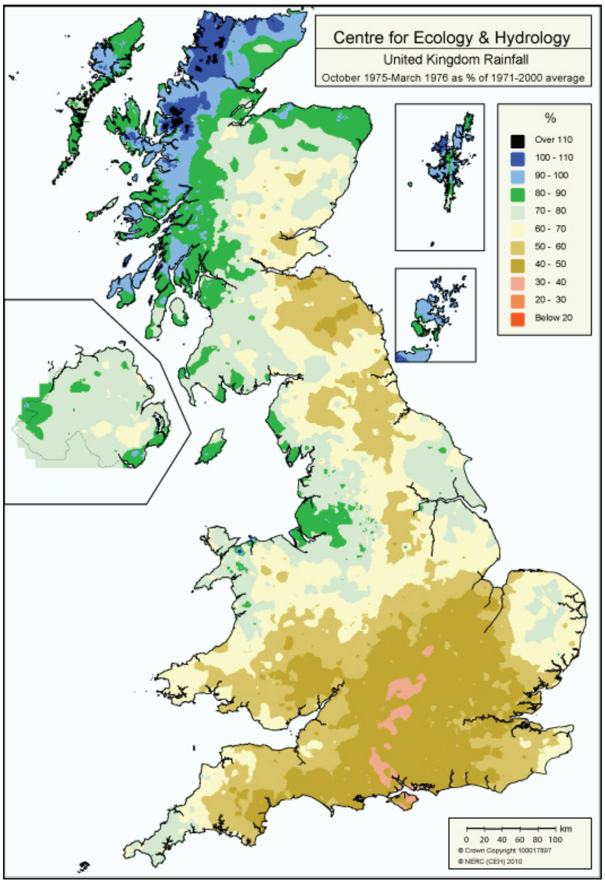


Figure 1b: *October 1975 to March 1976 rainfall as a % of the 1971-2000 average*

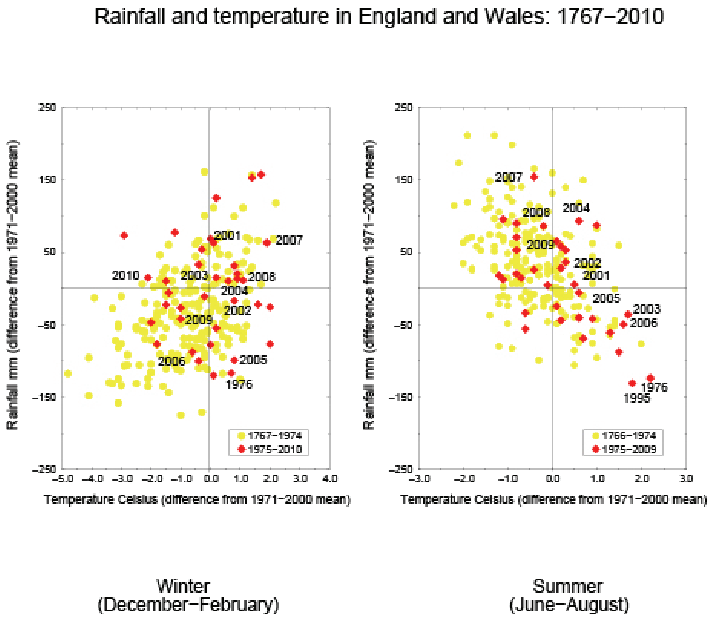


Figure 2: *Winter (Dec-Feb) and Summer (Jun-Aug) CET and rainfall anomalies*

North-west Scotland aside, large or exceptionally large rainfall deficiencies extended across most of the UK over the 16-month period ending in August 1976 (Figure 1a). The most extreme rainfall anomalies were found across southern Britain where, for many catchments, September 1975 was the only month with above average rainfall. Figure 1b confirms that the winter half-year rainfall (October-March) fell below 50% of the 1971-2000 average over wide areas; some parts of central southern England registered less than 40%. Drought conditions intensified through the late spring and climaxed during the summer of 1976 when, remarkably, rainfall deficiencies exceeded 80% in some areas (e.g. the Lincolnshire Wolds – see Figure 1c). However, local storms, mostly occurring during late August, made for particularly large spatial variations in rainfall deficiencies as the drought approached its terminal phase. Although the drought was less extensive in Scotland, it did achieve a notable intensity across the east of the country from the late spring of 1976 and the summer (June-August) rainfall remains the 2nd lowest on record for eastern Scotland[4].

The extreme aridity experienced during the summer of 1976 is emphasised by Figure 2 which shows the December-February and June-August England & Wales rainfall and Central England Temperature (Manley, 1974) anomalies relative to the 1971-2000 average. The plotting positions for the post-1975 winters and summers are show in red. The winter of 1975/76 was mild and exceptionally dry (only 1991/92 has been drier since) and, whilst a number of recent summers have been exceptionally warm (2003 in particular), only 1995 achieved a comparable combination of extremely high temperatures and extremely low rainfall. Using this yardstick, the summer of 1976 remains the most arid in a 244-year series. Adopting the same timespan but focussing on rainfall alone, Figure 3 shows cumulative 12-month rainfall totals for England & Wales colour coded to identify the driest episodes. Apart from the summer of 1976, the only other rainfall deficiency of a similar magnitude was in 1785 when national rainfall assessments could be considered as broadly indicative only. A similar analysis (Burke and Brown, 2010) underlines the particular severity of the 1975/76 rainfall deficiency in south-east England.

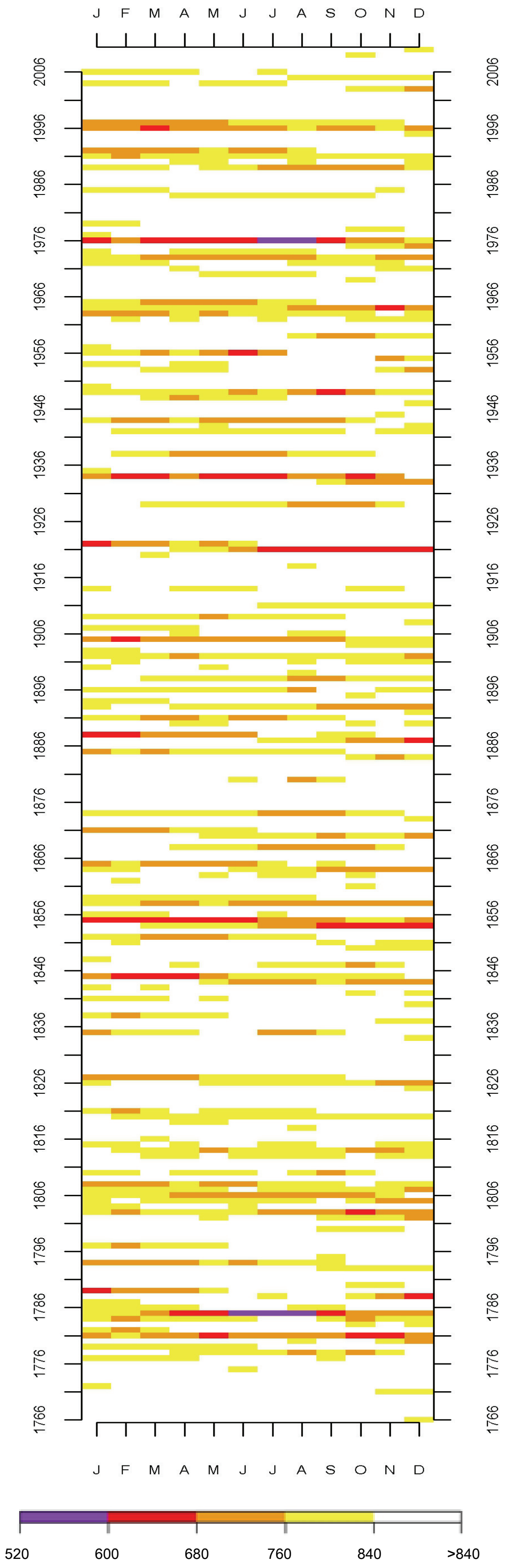


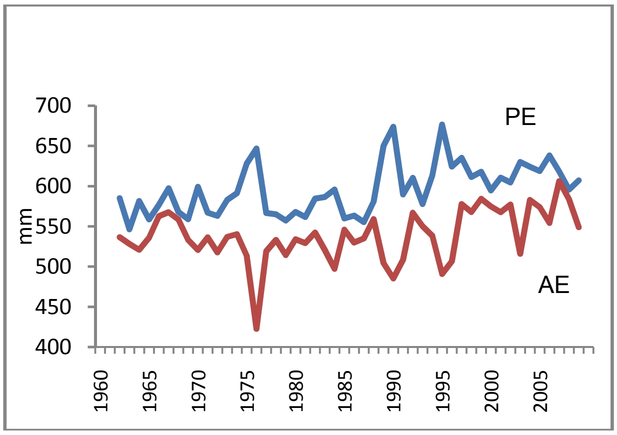
Figure 3: Cumulative 12-month rainfall totals (mm) for England & Wales1766-2010

4 Based on the National Climate Information Centre (Met Office) series from 1914.

Evaporation & soil moisture conditions

Evaporation losses can greatly influence drought severity, either directly (e.g. through increases in evaporation from reservoir surfaces) or, more generally, through reductions in soil moisture which, in turn, decrease rates of runoff and aquifer replenishment. Temperatures are the primary influences on evaporative demands, but windspeed, sunshine hours, humidity and patterns of land use are all contributory factors. On average, over 40% of UK rainfall is accounted for by evaporative losses – but the proportion varies greatly from region to region, reaching around 80% in the driest parts of the English Lowlands.

For the UK as a whole, mean temperatures have increased by more than a degree Celsius over the last 35 years. This represents a very rapid increase in an historical context. Prior to 1975-76, there were only four comparably warm 16-month episodes (beginning in May) in the Central England Temperature series: 1833/34, 1947/48, 1949/50 and 1959/60. Since 1976 warmer such episodes have been common with seven occurring in the first decade of the 21st century.

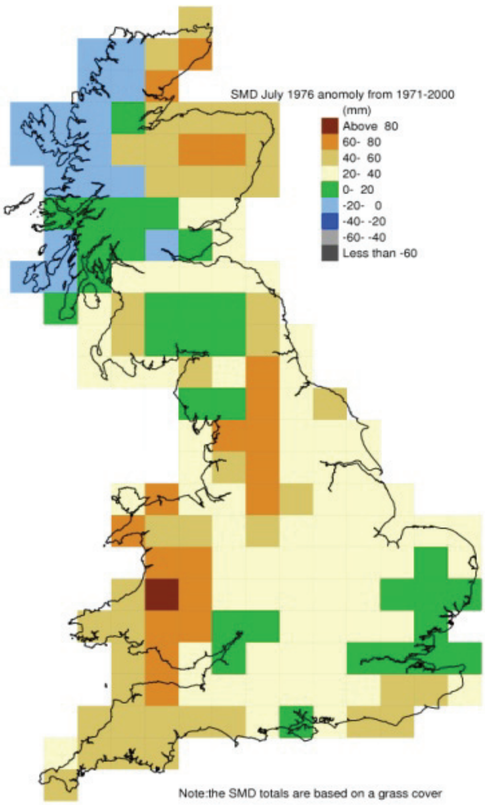


Data source: MORECS

Figure 4: *Water-year (Oct-Sept Potential Evaporation and Actual Evaporation totals for England & Wales*

Monthly assessments of evapotranspiration demands are available from 1961 via the Met Office Rainfall and Evaporation Calculation System: MORECS (Hough and Jones, 1997). These provide a means of placing 1975-766 in the context of evaporative demands over the last 50 years. Figure 4 shows water-year (October-September) Potential Evaporation (PE) and Actual Evaporation (AE) totals[5] for England & Wales as a whole over the1961-2009 period. Water-year PE totals have increased since the 1970s but the total for 1975/76 still ranks the 3rd highest in the series.

The shortfalls of AE relative to PE in Figure 4 are associated with the decline in soil moisture through the spring and summer; as soils dry out the ability of plants to transpire at the potential rate is reduced substantially. Correspondingly, AE losses normally fall below the PE equivalent. The difference can be very substantial during drought episodes and it provides a useful measure of both drought intensity and agricultural stress. In Figure 4 the largest water-year shortfalls of AE relative to PE in the last 30 years are for 1989/90, 1994/95 and 2002/03 when exceptional drought conditions were experienced in the spring and summer. However, despite the compelling upward trend in temperatures, the outstanding shortfall of AE relative to PE for the 1975/76 water-year has yet to be eclipsed.



Data source: MORECS

Figure 5: *End-of July soil moisture deficits (for a grass cover).*

In most of the UK, soils are normally close to saturation by late December but in 1975 significant soil moisture deficits (smds) were maintained throughout much of the winter,

5 Based on a grass cover.

particularly across the English Lowlands. Deficits then increased briskly through the spring of 1976 and, by late July, were close to, or at, theoretical maxima across most of eastern, central and southern England. Deficits were more than 60 mm above the late-July average in parts of Wales and the Pennines (where soils normally remain relatively moist); see Figure 5. Considering England & Wales as a whole, soils in 1976 were the driest on record for late-July and the driest for any month-end with the single exception of August 1995. A similar picture emerges when soil conditions over the full span of the growing season (April-August) are considered. At the national scale, only in 1990 have average smds exceeded those registered in 1976 (see Figure 6).

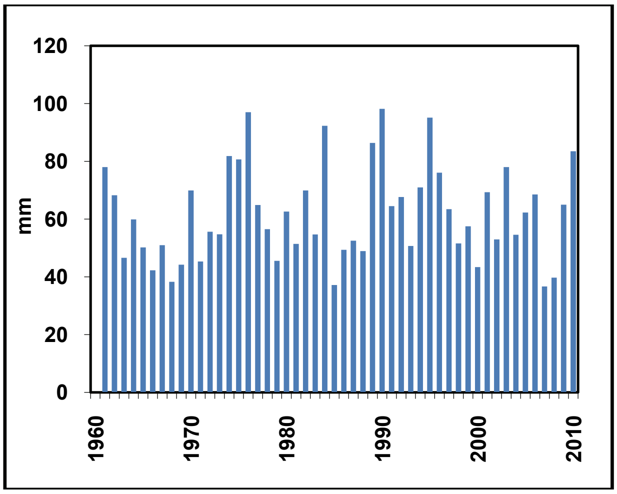


***Figure 6**: Average growing season (April-August) soil moisture deficits for England & Wales*

River flows

River flows integrate the wide range of hydrometeorological processes operating throughout a catchment and generally provide the most compelling indices of hydrological drought severity. This is particularly evident in the UK where rivers are mere streams in a global context, and consequently very sensitive to sustained runoff deficiencies. In 1976, the combination of very limited rainfall, exceptionally dry soils and depressed groundwater levels implied that the drought's impact on river flows would necessarily be severe. By the summer, river flow rates were exceptionally depressed, eclipsing previous minimum flows over wide areas.

At the national scale the singular nature of the 1975-76 drought is confirmed by Figure 7 which shows estimated daily outflows from England & Wales[6] throughout 1976 together with the daily maximum (blue envelope) and minimum (red envelope) based on the full 50-year series. Throughout most of the spring and the entire summer of 1976 daily outflows were the minimum on record. Markedly below average August outflows have been a feature of a number of recent summers (e.g. in 1990, 1995 and 2003) but all are at least 30% greater than that registered in 1976.

The extraordinary nature of runoff patterns during the 1975-76 drought is emphasised by Table 2 which ranks the lowest 12-month (non-overlapping) runoff totals, for England & Wales. Notwithstanding several protracted drought episodes in the last 20 years, runoff for the water-year ending in September 1976 remains outstanding, again more than 30% lower than the second ranking 12-month minimum.

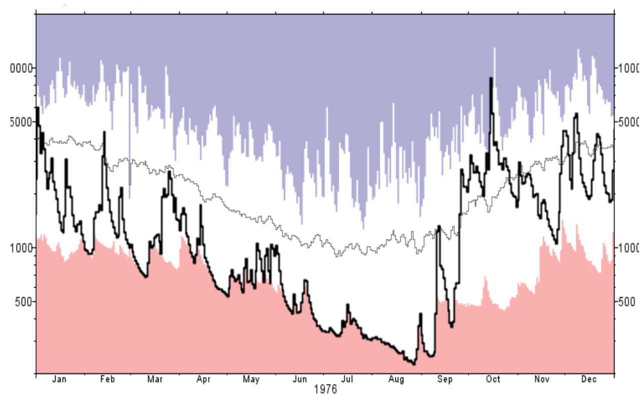


***Figure 7:** Estimated daily outflows from England & Wales in 1976*

Figure 8 provides an equally impressive testimony to the remarkable intensity, and spatial extent, of the 1976 drought. Featuring only gauging stations with records beginning prior to the drought, this map shows the distribution of those where the annual 7-day minimum flow occurred in 1976; a total of some 460. Figure 9 provides a context for this total: It compares the proportion of the extant network for which the period-of-record minima occurs in each particular year from 1940 to 2009. Despite the cluster of drought episodes in the last 20 years, the 7-day minima for almost 40% of the gauging network operating in 1976 remains the lowest on record; a

[6] A series derived from measured flows for a selection of major rivers across the country.

remarkable proportion, emphasising the primacy of the drought in river flow terms.

Table 2: *Lowest 12-monthly runoff totals for England & Wales (1961-2010)*

Rank	End Year	End Month	Runoff (mm)	% of 1971-2000 average
1	**1976**	**9**	**217.5**	**47.8**
2	1996	3	288.8	63.5
3	1997	4	289.0	63.5
4	1964	11	289.0	63.6
5	1973	12	293.1	64.5
6	1963	2	303.2	66.7
7	1992	3	317.3	69.8
8	2004	1	325.3	71.5
9	2006	2	326.9	71.9
10	1991	2	334.1	73.4

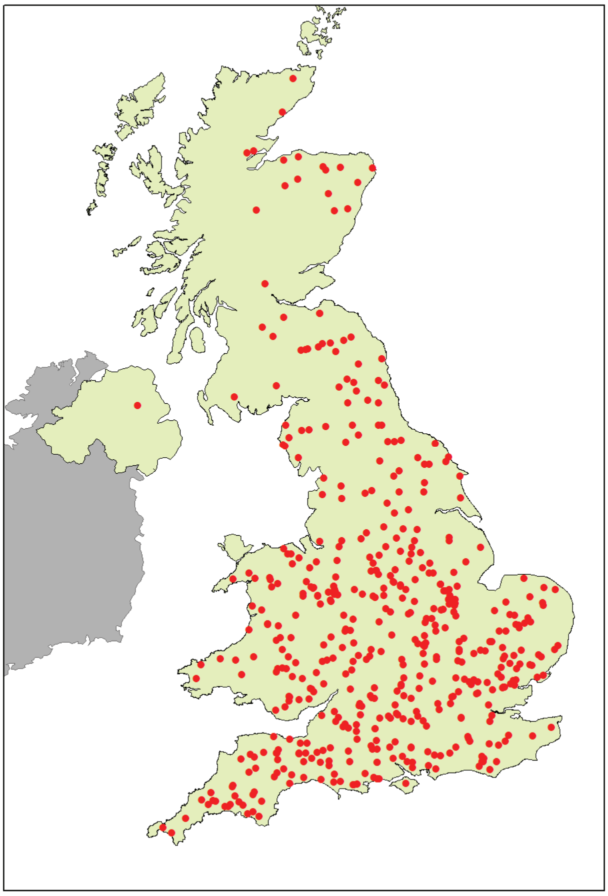


Figure 8: *Distribution of gauging station whose 7-day minimum flow occurred in 1976*

The sparseness of the network and the very uneven distribution of gauging stations prior to the 1960s (Lees, 1985) implies caution in interpreting the relative importance of the earlier drought years. Nonetheless, the low proportion of the 1976 minima which have subsequently been eclipsed testifies to both the areal extent and the intensity of drought conditions during 1976.

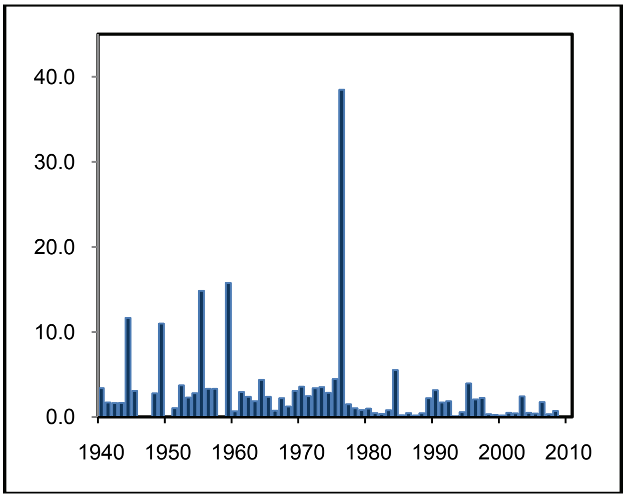


Figure 9: *The proportion of the extant gauging station network for which the period-of-record minima occurs in each year*

Contemporary assessments of the rarity of the low flows recorded in 1976 (see page 18) ascribed extremely long return periods to the river flow minima across the country. However, relatively few gauging stations had flow records exceeding 30 years by the mid-1970s. The limited variability captured by the generality of available time series implies a substantial degree of uncertainty in many contemporary return period estimates of the 1976 minimum flows. Now, with an additional 35 years of flow data available, and with widespread low flows being defining characteristic of a number of recent drought episodes (e.g. 1991/92, 1995/96, 2003 and 2005), the updated series provide a considerably more resilient framework within which to reappraise the 1976 minima.

Table 3 gives estimated return periods derived using standard software (Young et al, 2003) for the low flows experienced in 1976 (generally based on time series extending up to 2009). The return periods are given for a selection of rivers throughout the drought-affected regions; the same range of durations and, where possible, the same rivers as those featured in Table 11 in Part I of this report have been included.

For some western and northern rivers (e.g. the Usk and Tay) and a few in the English Lowlands (e.g. the Great Stour) the updated assessments have moderately reduced the return periods previously associated with the 1976 flows. However, across most of the country, southern and eastern England in particular, the extreme nature of the runoff depletion in 1976 has been underlined (see below). For most of the featured timeframes, the 1976 minima remain the lowest on record and for most responsive lowland rivers the minima registered during subsequent droughts have been considerably above those recorded in 1976. There are exceptions – mostly in rivers and streams which are largely groundwater fed (e.g. the Little Ouse), and therefore more susceptible to multi-winter drought events (see page 49).

The Thames is something of special case. In August 1976 it ceased to flow at Teddington (the tidal limit) for the only time in its 128-year record. This was due to a combination of intense drought conditions and the substantial abstractions to meet London's water supply needs; these abstractions have increased by an order of magnitude since the 1880s. A further complication is that early low flows at Teddington Weir [7] were substantially underestimated (Mander, 1978). Consequently the analyses in Table 3 are based on naturalised flows[8] for the post-1950 period only. For all the featured durations, the return periods of the 1976 Thames minima greatly exceed 100 years. During subsequent drought episodes the naturalised minimum 30-day flows (for example) in the Thames have exceeded those registered in 1976 by at least 70%.

Throughout the core region of the drought return periods associated with the 1976 flows, particularly over timespans of 90 days or less, are now generally greater than those originally ascribed. Many exceed 100 years. Significant uncertainty attends the more extreme return period estimates and caution needs to exercised when comparisons are made between the contemporary and updated return period estimates. Changes in flow measurement capabilities, the hydraulic characteristics of gauging sections and patterns of water use (abstraction rates in particular) can impact significantly on the homogeneity of low flow time series. Nonetheless, the extreme nature of the 1976 drought is emphasised by the n-day minima derived from the England & Wales outflow series (see Table 3): for example, the 30-day minima for 1976 is only 60% of the 2^{nd} ranking low flow in the 50-year series. The discrepancy is even more marked if the analysis focuses on rivers in the English Lowlands. Complementary evidence of the unprecedented scale of the drought impact on runoff rates is provided by Figure 10 which shows annual mean and Q_{95} flows, for England & Wales since 1960 (a) and the Thames since 1950(b); 1976 is a clear outlier in both cases.

The return periods given in Table 3 imply a truly exceptional contraction in the river network by the late summer of 1976 and a very precarious water resources outlook. The rapid transformation in hydrological conditions during the terminal phase of the 1976 drought served to distract attention from the possible consequences of a second successive dry winter. A continuation of substantial rainfall deficiencies into early 1977 would have had severe, and probably unprecedented, impacts on water supplies and the aquatic environment.

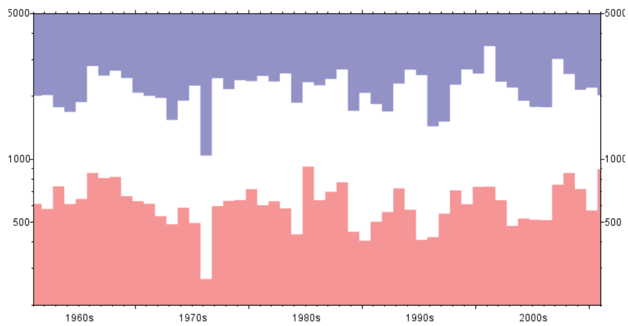


***Figure 10a**: Water-year mean (blue) and Q_{95} flows for England & Wales*

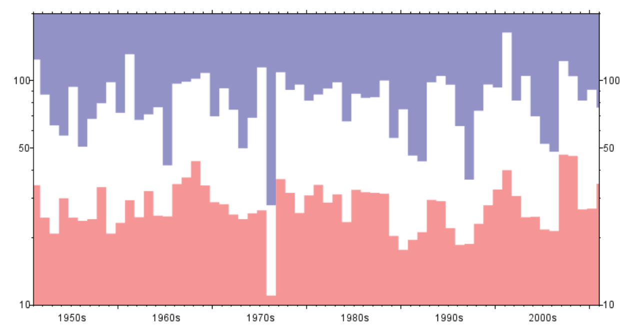


***Figure 10b**: Water-year mean and Q_{95} flows for the Thames at Kingston*

7 1km downstream of the Kingston station which superseded it in the 1970s

8 The naturalised flows take account of the major public water supply abstractions upstream of the gauging station.

Table 3: Return periods of low flows recorded during the 1975/76 drought

Gauging station	River	Hydrometric Area	Yrs of Rec.	Estimated return periods			
				30-day	60-day	90-day	180-day
Ballathie	Tay	15	56	20	10	8	3
Norham	Tweed	21	48	>10	15	8	3
Hayden Br	S Tyne	23	46	18	25	25	5
Colwick	Trent	28	50	>100	>100	>100	35
Claypole Mill	Witham	30	49	>>100	>>100	>>100	>>100
Old Mill	Harpers Brk	32	70	75	60	75	50
Rectory Br	Sapiston Brk	33	60	20	20	30	15
Roxton	Gt Ouse	33	36	>>100	>>100	>>100	>>100
Abbey Heath	LittleOuse	33	41	50	55	7	15
Kingston*	Thames	39	60	>>100	>>100	>>100	>>100
Shaw	Lambourn	39	48	>100	>100	>100	50
Horton	Gt Stour	40	45	10	8	15	12
Allbrook	Itchen	42	51	70	70	70	50
Thorverton	Exe	45	54	>>100	>>100	60	25
Redbrook	Wye	55	73	>100	>100	100	40
Chain Bridge	Usk	56	51	25	20	25	20
England & Wales	Outflows		50	>>100	>100	100	40

Return periods were derived using Wallingford Hydro-Solutions Hydro Tools package (with default options set)

Note: >100 means 100-500 yrs; >>100 means >500 yrs.

Groundwater

Groundwater is a major source of water supply in the UK, particularly in the English Lowlands where aquifers outcrop widely (see the Location Map). It also constitutes a significant component in rivers flows – this is especially important during drought episodes when surface runoff is restricted or absent.

Groundwater replenishment (or recharge) is normally very seasonal, occurring when soil moisture deficits have been eliminated and rainfall exceeds evaporation. Away from the more westerly aquifer outcrop areas, groundwater recharge is concentrated in the November-April period when evaporation losses are modest. As a result groundwater level variations have a strong seasonal cycle but in slower-responding aquifers levels also reflect recharge patterns over several successive winters. Aquifer properties also influence the magnitude of the groundwater level response. In those aquifer units with low storage coefficients, a given volume of groundwater replenishment will result in a greater rise in water levels than where storage capacities are higher. Groundwater levels fall naturally as aquifer storage is depleted by natural outflows to rivers and springs but may also decline as a result of abstraction from boreholes. Minimum groundwater levels are typically registered in the autumn and early winter.

The dearth of aquifer recharge through the winter of 1975/76 was the primary cause of the depressed groundwater levels during the summer and early autumn of 1976. Rainfall over the recharge season (November-April) was the lowest since 1879/80 for England & Wales. Due to the non-linear relationship between rainfall and aquifer recharge (reflecting the impact of evaporation losses and soil moisture conditions), a rainfall deficiency which exceeded 50% in much of the English Lowlands translated into reductions of more than 80% in recharge over wide areas, with little or no groundwater replenishment across aquifer outcrop areas in large parts of eastern and southern England.

Correspondingly, groundwater level recessions in the spring of 1976 began from levels which were already seasonally depressed and, by the late summer, water-tables had reached their natural base levels (when no further drainage to springs and seepages occurs)[9] in some, mostly southern, aquifer units. In 1976, new minimum recorded groundwater levels were established for around two-thirds of the national index wells in England & Wales. Throughout much of the western and southern Chalk, the major limestone outcrops and many aquifer units in the Permo-Triassic sandstones, the 1976 minima were close to, or below previously recorded minima. By the early autumn estimated overall storage in the Chalk fell to its lowest level in a series from 1950 (see below).

However, in assessing the relative severity of 1976 drought it is important to note that the UK groundwater network of observation wells and boreholes was relatively sparse until the 1980s. Although some important long records were available, the majority of groundwater level time series were less than 15 years in length. Thus by 1976 many groundwater level time series may have captured only a limited proportion of the historical variability.

A significant mitigating factor in relation to the 1975-76 drought's impact on groundwater was the exceptionally high rainfall that bracketed the dry 16-month period. Over the November-April period in 1974-75 rainfall was well above average and the wettest such period since 1950-51 across much of the Chalk outcrop. As a result groundwater level recessions in 1975 mostly began from well above average spring maxima (see the groundwater level hydrographs on page 20). Thence, the 3rd wettest September-December for England & Wales since 1935 provided a decisive termination to the drought – generally accompanied by a steep rise in groundwater levels. The 1975/76 drought, though intense, was therefore a single-winter event.

Historical groundwater levels, and, especially, data for the post-1990 period, demonstrate the particular vulnerability of groundwater resources in the UK to clusters of dry winters. Whilst antecedent groundwater levels and evaporation demands can also be influential, the major cause of sustained periods of depressed groundwater levels is sequences of winters with well below average rainfall. Table 4 ranks the lowest November-April rainfall totals for successive years for Central and South East England[10] over the 1961-2010 period. The 1974-76 period does feature but there have been six other two-winter sequences with comparable, or lower, rainfall. Each has been associated with droughts which had a considerable impact, at least regionally, on groundwater resources.

Table 4: Successive 2-year Nov-April rainfall totals for South East and Central England

Rank	Years	Rain mm	% of 71-00 av.
1	2003-2005	640	78.6
2	1986-1988	667	81.9
3	2004-2006	670	82.3
4	1971-1973	686	84.3
5	1972-1974	692	85.0
6	1979-1981	695	85.4
7	**1974-1976**	**705**	**86.6**
8	1995-1997	716	88.0
9	1966-1968	718	88.2
10	1990-1992	738	90.7

Data source: NCIC

In the Chalk during the protracted groundwater droughts of the early- and mid-1990s, depressed recharge rates over period of 2-4 years resulted in groundwater levels in a significant minority of index wells, falling below the minima registered in 1976. Groundwater levels in the eastern Chalk were particularly depressed during the prolonged droughts of the 1990s (Marsh et al, 1994) and in a considerable number of index wells groundwater levels remained below the 1976 minima for many months, see the hydrograph for Redlands in Cambridgeshire (Figure 11). The nearby Therfield Well dried up in both 1992 and 1996, a circumstance that did not occur in 1976.

[9] For many responsive wells and boreholes, base levels are commonly approached in the late summer and autumn – resulting in only minor differences in minimum recorded levels during drought episodes.

[10] Using the NCIC Met Office rainfall series.

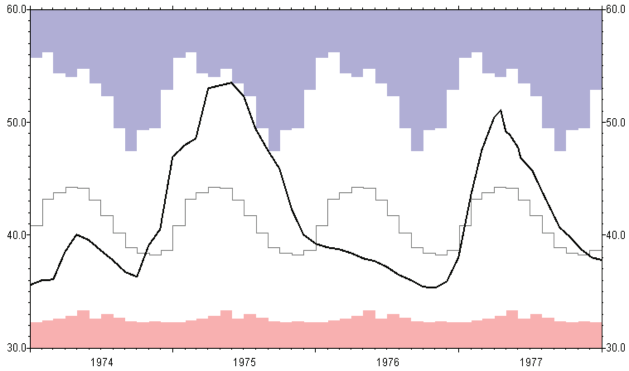


Figure 11a: *Groundwater levels in the Chalk at Redlands 1974-77*

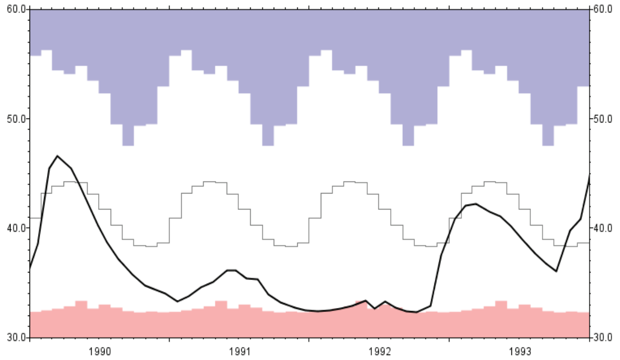


Figure 11b: *Groundwater levels Redlands, 1990-93*

Overall variation in the groundwater resources of the Chalk over the last 60 years can be indexed by combining standardised monthly levels at seven well-distributed wells and boreholes in the Chalk aquifer. Such an index is plotted on Figure 12. It demonstrates that the depression in groundwater resources in during 1976 was matched during the 1990-92 and 1995-97 droughts and, more locally, the drought of 2004-06 (Marsh, et al, 2007). Correspondingly, the 1976 groundwater drought, although very extreme in the timeframe from 1950 to the late 1980s, is less exceptional when the appraisal extends over a broader timespan. An indication of the decline in the drought's relative severity is given by a comparison of Figures 13a and 13b. The former plots the contemporary ranking of the 1976 groundwater level minima; many of the index wells had relatively short records at the time. Figure 13b shows that by 2010 most of the 1976 minima had been eclipsed, primarily in the 1990s. 1976 does however remain the year in which most period-of-record minima were established.

Historically, particularly during much of the 19th century, there have been many clusters of dry winters which would have impacted severely on groundwater levels. Few monitoring wells and boreholes have long enough records to capture the groundwater level responses before 1900 but documentary evidence, particularly of spring flows in the Chalk, strongly indicate that groundwater levels fell below those registered in 1976 during several protracted drought episodes (Bayliss et al, 2004, Limbrick et al, 2002). The most notable of these was the Long Drought of 1888-1910 (Marsh et al, 2007); over this 22-year period the Thames catchment, for example, registered only four winters (December-February) with rainfall totals above the 1971-2000 average.

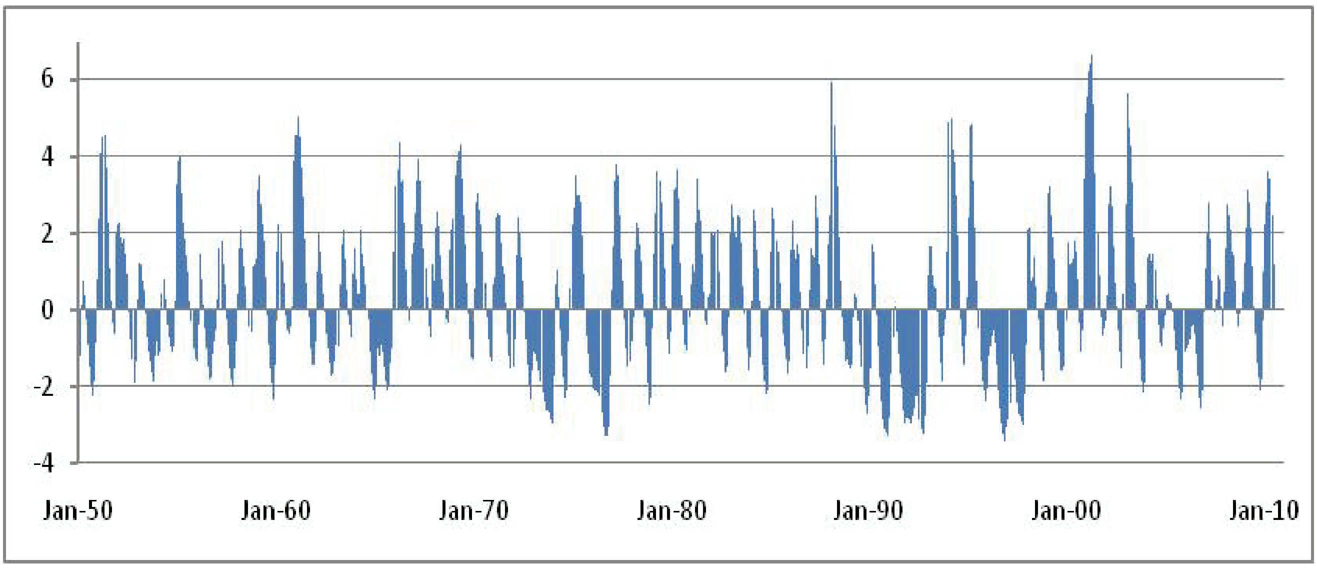


Figure 12: *An index of variations in total storage in the Chalk aquifer*

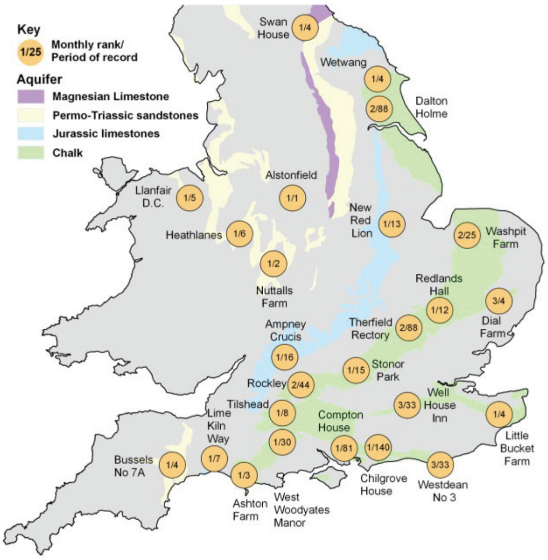


Figure 13a: *Rank of index well minima in 1976*

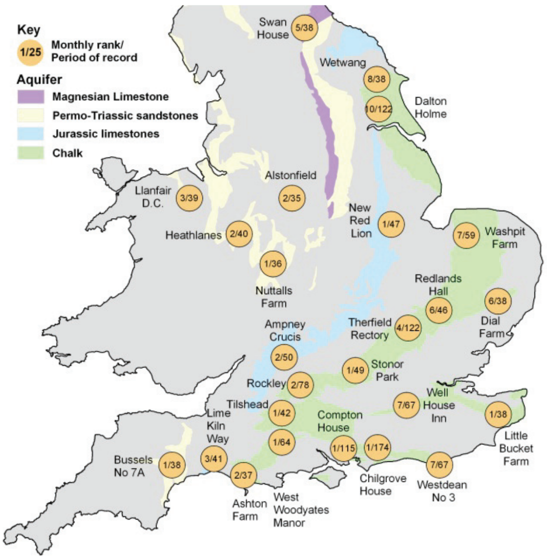


Figure 13b: *Rank of 1976 index well minima in 2010*

Concluding remarks

By their nature major droughts are infrequent events and characteristically display considerable spatial and temporal variations in their intensity and range of impacts. As a result, comparisons between individual drought episodes are rarely straightforward but any tendency for notable droughts to increase in either magnitude or frequency would have important ramifications for society generally and water resources management in particular.

The range and degree of drought impacts have changed substantially over the period for which instrumented hydrometeorological records are available. Agricultural stress (and its impact on food production) was a major factor in the 19th century whilst environmental, ecological and amenity impacts now assume a much increased significance. Over time communities adjust to the vagaries of the climate and the UK's resilience to drought stress since 1975-76 has been reinforced by increased water storage, more flexible regional and local water distribution options, and improved water management strategies. But reconciling the often conflicting demands for water, and meeting increasing public and political expectations regarding both the security of water supplies and the health of the aquatic environment, remains a considerable challenge in a warming world.

Projected temperature increases suggest that the warmth of the 1976 summer will be replicated and exceeded as the 21st century continues (UKCP, 2009) but there is no evidence of an overall decline in rainfall since the mid-1970s (Jenkins et al, 2008). As encouragingly in a water resources context, there has also been no decrease in overall runoff from the UK and, although declines in low flows have been identified is some areas (mostly impervious lowland catchments), the generality of rivers have exhibited no downward trend (Hannaford and Marsh, 2006). This is reflected in the modest number of rivers where the 1976 minima have subsequently been eclipsed.

The UK climate is inherently capricious with temporal variability ranging from sub-daily to multi-decadal timescales. The latter influence the frequency of occurrence of major droughts of which 10 have been identified based primarily on hydrological criteria, over the last 160 years (Marsh et al, 2007). The limited availability of field evidence precluded the inclusion of earlier events but rainfall data suggest that other episodes (e.g. 1782-1785 and 1805-1808) may well also merit 'major' status. In relation to some manifestations of drought stress – the depletion of groundwater resources in particular – the 1976 drought's severity has been at least matched during several protracted drought episodes in the last 20 years. However, the analyses presented in this report reinforce the primacy of the 1975-76 drought in terms of its hydrological severity, spatial extent and its range of impacts. Across most of the UK, and large parts of western Europe (Hannaford et al, 2010, Vidal, et al, 2010), the 1975/76 drought remains the primary benchmark for the design and development of drought alleviation strategies.

Location Map

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References

Bayliss A, Norris J, Marsh T J. 2004. The Wendover Springs record: an insight into the past and a benchmark for the future, Weather, 59, 261-271.

Bryant S J, Arnell N W, Law F M. 1994. The 1988-92 Drought in its historical perspective. *Jour. IWEM*, 1994, 8**,** February 1994.

Burke E J, BrownS J, 2010. Regional drought over the UK and changes in the future. *Jour. Hydrol*., 394, 471-485.

Hannaford J, Marsh, T J. 2006. An assessment of trends in UK runoff and low flows using a network of undisturbed catchments. *Int. Jour. Clim*. 26, 1237-1253.

Hannaford J, Lloyd-Hughes, B, Keef C, Parry S, Prudhomme C. 2010. Examining the large-scale spatial coherence of European drought using regional indicators of precipitation and streamflow deficit. *Hydrol. Process*. In Press.

Hough M N, Jones R J A. 1997. The United Kingdom Meteorological Office rainfall and evaporation calculation system: MORECS version 2.0, an overview. Hydrology and Earth Systems Science, 1: 227-239.

Jenkins G J, Perry M C, Prior M J. 2008. UKCP09 Scientific Report – the Climate of the United Kingdom and recent trends. Met Office/Hadley Centre, UK.

Lees M L. 1987. Inland Water Surveying in the United Kingdom – A short history. In: *1985 Yearbook,* Hydrological:data UK series. Institute of Hydrology. 35-47.

Limbrick K J, Willows J, Marsh T J. 2002. Springflow variability since 1858 in south Dorset, UK. *Weather,* Vol. 57, No. 11, 413-421.

Mander G. 1978. Aspects of unsteady flow and variable backwater. In: Hydrometry, Principles and Practices (Ed: R W Herschy). John Wiley and Sons. 205-246.

Manley G. 1974. Central England Temperatures: monthly means 1659 to 1973. *Quart. Jour. Roy. Met. Soc*., 100, 389-405.

Marsh T J, Cole G A, Wilby R. L. 2007. Major droughts in England and Wales, 1800-2006, *Weather,*Vol. 62, 87-93.

Marsh T J, Monkhouse RA, Arnell NW, Lees M L, Reynard N S. 1994. The 1988-92 Drought. *Hydrological data UK series*, Institute of Hydrology/British Geological Survey, Wallingford, 78 pages.

Marsh Terry, Booker Doug, Fry, Matt. 2007. The 2004-06 drought. CEH Milestone report to NERC. 22 pages. http://www.ceh.ac.uk/data/nrfa/documents/2004-2006_Drought_Review.pdf

Parry S, Lloyd-Hughes B, Hannaford J, Prudhomme C, Keef, C. 2010. The Spatial Coherence of European Droughts. Summaries of Major Historical Droughts. *Environment Agency Science Report* - SC070079/SR1.

UKCP09. 2009 UK Climate Projections: Science Reports. United Kingdom Climate Change Impacts Programme: http://www.ukcip.org.uk/index.php

Vidal J-P, Martin E, Franchisteguy L, Habets F, Soubeyroux J-M, Blanchard M, Baillon M. 2010. Multilevel and multiscale drought reanalysis over France with the Safran-Isba-Modcou hydrometeorological suite. *Hydrol. Earth. Syst. Sci.* 14, 459-478.

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

Young A R, Grew R, Holmes M R. 2003. Low Flows 2000: a national water resource assessment and decision support tool. Water Sci. Tech. Vol. 48, 119-126.

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