Hydrological data UK

The 1984 Drought

INSTITUTE OF HYDROLOGY • BRITISH GEOLOGICAL SURVEY

THE 1984 DROUGHT

BY

TERRY MARSH AND MARTIN LEES

THE 1984 DROUGHT

BY

TERRY MARSH AND MARTIN LEES

An occasional report
in the *Hydrological Data: UK* series which
reviews the drought within a hydrological
and water resources framework

INSTITUTE OF HYDROLOGY

Published by the Institute of Hydrology,
Wallingford, Oxon OX10 8BB

ISBN 0 948540 03 6

Cover:

Haweswater reservoir, 17th September 1984. The substantial drawdown in the water level has revealed parts of the normally submerged village of Mardale which can be seen in the foreground.

Photograph: J. Peckham

FOREWORD

In April 1982, care of the UK national archive of surface water data passed from the Department of the Environment's Water Data Unit (which was closed) to the Institute of Hydrology (IH). In a similar move, the Institute of Geological Sciences (subsequently renamed the British Geological Survey (BGS)) took over the national groundwater archive. Both IH and BGS are component bodies of the Natural Environment Research Council (NERC). The BGS hydrogeologists are located with IH at Wallingford and close cooperation between the two groups has led, among other things, to the decision to publish a single series of yearbooks and reports dealing with nationally archived surface and groundwater data and the use made of them. The work is overseen by a steering committee with representatives of Government departments and the water industry from England, Wales, Scotland and Northern Ireland.

The published series - Hydrological Data UK - will include an annual yearbook and, every five years, a catalogue of gauging stations and groundwater level recording sites together with statistical summaries. These six volumes of the 5-year cycle will be available individually but are also designed to be inserted in a ring binder. Further details of these arrangements are given in the 1981 and 1982 yearbooks which have been recently published.

The series - but not the binder - will also include occasional reports dealing with significant hydrological events and analyses. This account of the 1984 drought is the first of these occasional reports. The main authors - Terry Marsh and Martin Lees - are both senior hydrologists with Water Data Unit experience now working at IH.

J.S.G. McCulloch
Director, Institute of Hydrology

Water Authority or River Purification Board boundary
Hydrometric area number and boundary
HIGHLAND R.P.B.
NORTH EAST R.P.B.
TAY R.P.B.
FORTH R.P.B.
CLYDE R.P.B.
TWEED R.P.B.
SOLWAY R.P.B.
NORTHUMBRIAN W.A.
YORKSHIRE W.A.
NORTH WEST W.A.
SEVERN–TRENT W.A.
ANGLIAN W.A.
WELSH W.A.
THAMES W.A.
WESSEX W.A.
SOUTHERN W.A.
SOUTH WEST W.A.
NORTHERN IRELAND
pt 201
pt 203
pt 235
pt 236
pt226
pt 206
202
204
205
101
102
103
104
105
106
107
108

PREFACE

This report documents the United Kingdom drought of 1984 within a water resources framework. The development, duration and severity of the drought are examined with particular reference to regional variations in intensity. Assessments are made of the likely frequency of occurrence of the drought and its magnitude is considered both in the perspective provided by historical records of rainfall and runoff, and in the context of the recent somewhat erratic climatic behaviour. A specific comparison is made with the great drought of 1975/76.

The structure of the report follows the hydrological cycle with chapters devoted to rainfall, evaporation, runoff and water storage in surface reservoirs and in aquifers.

The report is aimed at a wide audience: all those with an interest in water, it's availability and use, and the sensitivity of water resources to the vagaries of the climate.

For reference purposes a map is presented on page 81 to help locate the rivers, reservoirs and monitoring sites mentioned in the report.

T.J. Marsh and M.L. Lees

ACKNOWLEDGEMENTS

This report would not have been possible without the help and co-operation of a large number of individuals and a variety of organisations. Much of the hydrometric data used in the report was extracted from the surface water archive (Institute of Hydrology) or the groundwater archive (British Geological Survey). Responsibility for the collection of this data rests primarily with the Water Authorities in England and Wales, the River Purification Boards in Scotland and the Department of the Environment in Northern Ireland. A substantial proportion of the information presented in the Chapters on rainfall and runoff was assembled, initially, to help monitor water resources in England and Wales throughout 1984 at the request of the Department of the Environment.

Most of the rainfall data was obtained from the Meteorological Office which also supplied several original maps. Information relating to reservoir contents and water conservation measures was abstracted from the Water Situation Reports compiled by Dr P S Turton (Water Authorities Association). Additional material was provided by the Water Authorities in England and Wales, the Scottish Development Department (on behalf of the Regional Councils) and the Ministry of Agriculture Fisheries and Food in Northern Ireland.

Data on crop yields was obtained from the Home Grown Cereals Association.

The assistance of the above organisations in the compilation of this report is gratefully acknowledged.

Particular thanks are due to Mr R.A. Sargent (Forth River Purification Board) for collecting much of the Scottish hydrometric data; valuable additional data sets were obtained from Mr J.C. Burns (Solway R.P.B.), Mr T. Poodle (Clyde R.P.B.) and Mr J.A. Reid (Tay R.P.B.)

Information and guidance regarding the drought's severity was provided by many individuals in the Water Authorities; a particular debt of gratitude is owed to Dr P.D. Walsh (North West Water Authority). Mr M.A. Ayles and Mrs D.M. Rand (Meteorological Office) advised on the availability of data and responded promptly to requests for rainfall information.

The section on the frequency of low flow sequences was contributed by Dr A. Gustard based upon an analysis carried out by Mr D.C.W. Marshall (both colleagues at IH). Mr R.A. Monkhouse (British Geological Survey) drafted the groundwater chapter assisted by Mr C.S. Cheney (BGS). The data from the research catchments were assembled by the Institute of Hydrology's catchment section, and Dr R.J. Harding provided information and advice relating to soil moisture conditions in the Institute's experimental catchments. Mrs S.E. Morris was responsible for the development of the rainfall and runoff deficiency indices. The archiving and checking of data and the initial preparation of figures and maps for publication was undertaken by Miss S.J. Bryant and Miss J. Peckham, and assistance in the derivation of the computer produced figures was given by Miss G.M. Jones.

The report benefited from many valuable comments and suggestions made at the draft stage. Colleagues at the Institute, particularly Mr M.A. Beran, Dr A. Gustard, Dr M.J. Lowing and Dr J.C. Rodda, provided much constructive advice on the report's structure and contents.

The England and Wales rainfall series dating from 1766, and widely used in this publication, is based upon data published in The Journal of Climatology, 4, 1984, for the Climatic Research Unit, University of East Anglia.

CONTENTS

FOREWORD

PREFACE vi

ACKNOWLEDGEMENTS ix

INTRODUCTION

RAINFALL 5

EVAPORATION AND SOIL MOISTURE DEFICIT 23

RUNOFF 35

RESERVOIRS 55

GROUNDWATER 61

1984 DROUGHT: CONCLUDING REMARKS 65

COMPARISON BETWEEN THE 1984 AND 1976 DROUGHTS 67

REFERENCES 75

APPENDICES

I The computation of rainfall and runoff deficiency indices 77

IIa Meteorological Office Rainfall and Evaporation Calculation System 77

IIb Estimated Soil Moisture Deficit 77

IIc Calculation of Plynlimon soil moisture deficits. 78

III Derivation of the flow frequency curve. 78

IV Storage yield analytical procedure. 78

PUBLICATIONS 82

INTRODUCTION

The climate of the United Kingdom is noted for its short-term variability and sustained sequences of either very wet or very dry weather are rare. Communities tend to adjust to the climate's capricious nature. Only when the normal range of variation is exceeded does any real threat to economic activity become a possibility. Such occasions, though few and far between, can significantly influence the way society views the adequacy of its water resources both in terms of their availability and management. Matthew Paris[1] records that as long ago as 1253

> "there was in the summer a great and prolonged drought, but at the end of the summer and in the autumn, the rivers overflowed their banks and rose to the top of the hills drowning the adjoining places".

Allowing for an element of hyperbole, 1984 showed certain similarities with this historic event. The spring and summer were exceptionally dry and the autumn abnormally wet. A more recent parallel, at least in England and Wales, may be drawn with the drought of 1976. Whilst the parched landscape, high temperatures and restrictions on the non-essential use of water typified both summers, the drought of 1984 was different in character from its precursor. It was notable both for its wide spatial extent and for its large variation in intensity, both regionally and locally.

The most noticeable feature of the drought was its greater severity in those upland regions normally associated with higher, and more reliable, rainfall. Such areas are commonly exploited within water resources systems designed to augment supplies in the drier regions of the country. As a consequence, the potential scale of the drought's effect was large. Certainly the drought's impact was considerable in some areas but, generally, was more limited than the prolonged drought of 1975/76. Primarily, this reflects the relatively short duration of the 1984 drought. However, the lessons learnt in 1976, allied to the increasing integration of water resources systems undoubtedly had a mitigating effect.

1984 RAINFALL SUMMARY

The 1984 rainfall total for the United Kingdom was 1105 mm. This is close to the 1941–70 average but the distribution of rainfall throughout the year was uncharacteristic. Following a wet January, a drought developed in the west of England and Wales, and by April had spread to Northern Ireland and much of Scotland. The drought was broken in late August and September.

Apart from a few localities in the south and east of England, rainfall in the period from February to August was significantly below average throughout the United Kingdom. Most of Wales and much of Scotland had appreciably less than 60% of normal rainfall. Over the seven months starting in February 1984 the United Kingdom drought ranks second to 1976 (Table 1) and is significantly drier than the same period in the droughts of 1921 and 1955. The drought was even more marked over the five months starting in April (Fig. 1); rainfall over the United Kingdom over this period was less than 60% of average, and a deficit can be traced back to June 1983 in many areas (Table 2). The accumulated rainfall total for the five months from April 1984 is 207 millimetres. Table 1 confirms that this represents the driest April to August period over the United Kingdom this century, approached only by 1976.

The drought's severity in Scotland and Wales can be broadly assessed by examination of Fig. 1; less than half the average rainfall was experienced over the larger part of both countries between April and August, and some districts had less than one third. Average rainfall figures for Scotland are available back to 1869 and the five months commencing April 1984 are, again, the driest on record with a more intense rainfall deficit than the notable drought of 1955[2]. A somewhat shorter rainfall series exists for Northern Ireland but the April to August rainfall, totalling only 299 mms, clearly conforms to the general pattern being marginally drier than 1975, which was the previous driest such sequence this century.

Taken in isolation these rainfall figures provide compelling evidence for a very severe drought. This is emphasised by Fig. 2 which suggests that such an exceptionally dry late spring and summer might be expected only once every 200 years or more. Such a frequency estimate, particularly of this magnitude, should be treated with caution since it assumes a sensibly stable climate and is based upon the relatively short United Kingdom rainfall series.

Development of the drought

An examination of the development of the 1984 drought is presented on pages 10 and 11. A timetable provides the synoptic background to the rainfall distribution; the monthly rainfall figures are tabulated for each of the administrative units in Table 3 and rainfall totals for the spring and summer are depicted in Figs. 3 and 4.

A general categorisation of the drought as embracing the spring and summer, which is reasonable for the United Kingdom as a whole, tends to mask important regional differences in the drought's duration. Broadly speaking the drought began in February and March in the Welsh, the North West and the South West Water Authority areas. It had extended to the Northumbrian, Yorkshire, Severn-Trent and Wessex Water Authorities by April when the drought also developed in Scotland and Northern Ireland. May was relatively wet in the south and east of England and, as a result, rainfall deficiencies in the Anglian, Thames and Southern Water Authorities were largely confined to the summer months.

What is a drought?

The concept of a drought is generally well recognised by the public at large but translating this intuitive understanding into a rigorous and objective procedure for assessing drought severity is far from straightforward. Primarily this reflects the difficulties involved in quantifying a phenomenon which varies in its duration and intensity both regionally and locally. In addition, it is possible to differentiate between meteorological droughts, hydrological droughts and agricultural droughts, with the emphasis shifting from rainfall through runoff to the availability of water for crops in the growing season. Furthermore, it may be argued that a drought could be characterised best by its impact on the community; this introduces the need to measure economic, social and environmental stress. A drought may well be viewed in a more sanguine manner by the holidaymaker than the farmer, the water supply manager or the industrialist. Any methodology designed to accommodate all the relevant variables would also need to take account of, on the one hand, the increasing integration in the use of water resources which will ease the impact of a given rainfall deficiency and, on the other, changing attitudes to the inconvenience associated with restrictions on water use; society may well become less tolerant in this regard and perceive relatively moderate droughts as serious events.

Considerable attention was directed to the likely frequency of periods of severe rainfall deficiency following the 1975/76 drought[3,4,5]. Related questions were also raised regarding the possibility of climatic trends or perturbations having a significant influence on the continuing adequacy of water resources in the United Kingdom. Many attempts to assign return periods to the 1975/76 drought were made[6,7]; in the light of more recent events certain of the estimates may be regarded as overstating its rarity. However, comparisons with historical drought sequences have been hindered by the lack of a suitable index for monitoring drought intensity.

Drought indices

Despite the significant limitations, a suitable index of drought severity does provide a starting point for comparisons with previous noteworthy dry spells and, by implication, an opportunity of assessing drought frequency with greater confidence. A prerequisite of a practical index is an appropriate definition of drought. Simple definitions requiring a fixed number of dry days in sequence, although still enshrined in certain official definitions, have generally been abandoned in favour of methods depending on accumulated departures from the mean value linked to some criterion for determining that the drought has ended. This approach was followed by Foley[8] and the procedure has been used by the Meteorological Office as a guide to rainfall deficiency in the United Kingdom[9]. Two specific problems attend the use of indices of this type. First, average rainfall itself is not a constant value; it is subject to random and systematic changes which may reflect climatic trends or oscillations. Taking England and Wales as an example, mean monthly rainfalls, averaged over fifty year periods, may differ by up to 20%. Second, the identification of the end of a drought is seldom as clear cut as in 1984. Isolated months of high rainfall, especially during the summer months, may be insufficient to terminate a drought and a more realistic approach is to consider the rainfall over a two or three month sequence.

Application of drought indices on a countrywide basis

(a) Great Britain

Figure 5 illustrates a drought index, based upon accumulated rainfall deficiencies, for Great Britain from 1869. In common with the other rainfall deficiency diagrams only drought events having a maximum index score in excess of 180 are illustrated. Details of its computation are given in Appendix I.

The recent drought is confirmed as a significant, but not extreme, event at this scale. It is of a considerably lesser magnitude than the droughts of 1887/8, 1921, 1933/34 and 1975/76, which although less severe in the spring and summer all extended over considerably longer periods. In February 1887 a drought developed concurrently in England, Wales and Scotland and was characterised by a relatively uniform spatial intensity until the spring of 1888. It is rare, however, for droughts to embrace all provinces of the United Kingdom although very severe droughts in one country tend to be associated with moderate rainfall deficiencies in the others. In spite of being of only very modest proportions in Scotland, the 1975/76 drought still registers the second highest drought index score.

From a water resources viewpoint an important distinction can be made between winter and non-winter droughts. Rainfall over the winter period, and much of the autumn and spring in highland regions, is hydrologically more effective than summer rainfall, much of which is used to satisfy soil moisture deficits and meet evapotranspiration demands. Consequently, a drought extending through the winter months will limit runoff and infiltration necessary for the replenishment of surface and groundwater reservoirs and pose a potential threat to water supplies in the following seasons. The droughts of 1904/5, 1933/34, 1937/38 and 1975/76 fall into this category. When a rainfall deficiency is essentially confined to a single year as in 1984, the impact is crucially dependent on its duration and the wetness of the previous winter, particularly in the drier regions of the United Kingdom. For instance, the 1921 drought was heralded by a relatively dry autumn and winter, especially in southern England, and an intense drought resulted when rainfall deficits built up from March until the end of the year.

(b) England and Wales

The drought index for England and Wales (Fig. 6) allows comparisons to be made over two centuries, although pre-1850 scores should be regarded as somewhat imprecise because of the relatively sparse raingauge network. Fig. 6 clearly emphasises the pre-eminence of the 1975/76 event and the moderate nature of the 1984 drought when considered on a countrywide basis. This reflects the counterbalancing effect of the near-average rainfalls in the South East and the short duration of the rainfall deficiency in 1984. The problem of direct comparisons between historical periods of rainfall deficiency is illustrated in Fig. 7 which shows the spatial variation in drought intensity for six noteworthy drought periods.

(c) Scotland

In Scotland the greater magnitude and greater reliability of rainfall[11] results in a lower frequency of drought events (Fig. 8). 1984 ranks as the second largest rainfall deficiency since 1955, but is substantially less severe than the droughts of 1871, 1887/88, 1933/34 and 1940/41. Such a ranking undoubtedly underestimates the 1984 drought's real impact since no allowance is made for its particular severity in those parts of Scotland where population and economic activity are concentrated. The drought of 1972/73 merits some comment; this was exclusively an autumn and winter event which was followed by a wet spring. Over most of Scotland, runoff, even in the driest of winters, is sufficient to refill the reservoirs and sustain substantial river flows. Thus the 1972/73 drought, though real in meteorological terms, was rather marginal in terms of impact.

(d) Northern Ireland

Although the year to year variability in rainfall has been shown to be lower in Northern Ireland than in Great Britain the sequence of droughts starting in the early 1970s has continued with significant events registered in 1983 and 1984; the Province has now recorded seven droughts in the last fifteen years (Fig. 9). Furthermore, Northern Ireland is particularly vulnerable to short spring and summer droughts because of the preponderance of small reservoirs and the limited natural storage within catchments which cause river flows to decline rapidly during a drought.

Spatial variation in actual rainfall amounts for the drought period

Generally, examinations of drought intensity are, quite properly, conducted in terms of the departure from average rainfall conditions. It is interesting though to consider the absolute rainfall amounts during a period of substantial rainfall deficiency. Throughout the spring and summer of 1984 the normal pattern of rainfall over England and Wales, which is influenced mainly by elevation and the predominance of a westerly airstream, was very little in evidence. Figure 10 suggests a remarkable conformity in rainfall totals over England and Wales over the five month drought period. This map serves to emphasise that a given precipitation total will represent a severe drought in some regions and adequate rainfall in others.

Regional variation in the drought's intensity

Nationwide assessments of a drought's intensity are of limited value when substantial regional variability is known to be typical of periods of rainfall deficiency. Susceptibility to drought or communities' vulnerability to serious depletions in their local water resources are also subject to wide regional differences. Areas such as the Lake District are likely to experience a 50% shortfall in precipitation over a five month period only once in 250 years. In terms of actual rainfall however, this would still approximate to the average annual rainfall in parts of south eastern England and along the east coast of Scotland. Rainfall and runoff are normally plentiful throughout the upland regions but substantially lower and less reliable in the lowland regions, where the demand for water is concentrated.

A measure of the regional contrasts in rainfall deficiency during the drought can be seen from Fig. 1. While the five month rainfall deficit was substantial throughout northern Ireland and mainland Scotland, the situation in England was more complex. Large areas in the west and north received less than 60% of normal precipitation with the severest shortfall, in rainfall terms, coinciding with the mountains of North Wales and the central Lake District. The South-West peninsular generally had less than half the average rainfall and parts of South Wales only a third; a particularly intense drought affected the Monmouth district. Conversely, a few localities in the east of England, notably along the Norfolk coast and near Bury St Edmunds, had marginally more than average rainfall. More extensive areas in East Anglia and the Thames Valley received between 70% and 90% of normal rainfall.

Apart from Wester Ross and the Hebrides, all regions of Scotland had below 70% of average precipitation with most of the mainland being significantly drier. Over parts of Dumfries and Galloway, the eastern Cheviots, the Clyde Valley and the basin of the River Tay, rainfall was only one third of normal for the period April to August; this represents a remarkably dry spring and summer with unprecedented rainfall deficiencies recorded for many localities.

Administrative framework of the water industry

In Scotland, water supply is the responsibility of the Regional Councils but much of the monitoring of rainfall and runoff is undertaken by the River Purification Boards. Water resources in Northern Ireland are managed by the Department of the Environment. In England and Wales, the ten Water Authorities are responsible for all aspects of water management except when arrangements have been made with private water companies to supply water on a district basis. Water Authority and River Purification Board boundaries follow the catchment divides between major river basins, (see frontispiece). Several strategically important reservoirs export water to neighbouring authorities to help satisfy the needs of major conurbations. Lake Vyrnwy in Wales, for instance, supplies water directly to Merseyside. By and large, however, the demand for water within each authority is met from sources within the group of river basins administered by that authority. The administrative divisions of the water industry thus form a suitable basis for an assessment of the spatial variation in drought severity throughout the United Kingdom. Figures 11 and 12 illustrate the percentage of average rainfall, over the most critical drought periods during 1984, for each administrative unit.

Return periods of rainfall deficiencies

Similar rainfall deficiencies to those experienced in 1984 may be expected once every few years in the English lowlands but the estimated return periods for the April to August rainfall exceeds 200 years for the North West and Welsh Water Authorities (Table 4). For the Yorkshire and South West Water Authorities the corresponding frequency is greater than once in 100 years. Over small regions, for example river basins, rainfall variability is larger and return periods for a given shortfall of rainfall are lower[11]. Figure 13 shows a guide to return periods for the April to August 1984 rainfall, based upon areal rainfall data for 35 index catchments. The estimated return periods for the five month rainfall total often exceeded the length of the available catchment rainfall record; in these circumstances the higher return periods should be regarded as tentative. Return period assessments can vary greatly according to the duration of drought considered and the size of area under examination. Also, estimates from individual raingauges within the same district often show a wide range and regionally smoothed values are generally to be preferred. Nevertheless the spring and summer rainfall totals recorded in 1984 can clearly be expected only on rare occasions, especially in the wetter parts of the United Kingdom.

The variation in intensity throughout the seven month drought period is illustrated in Table 5 which lists the percentage rainfall associated with specified return periods for sequences of 3, 5 and 7 months at four selected catchments; the quoted percentages refer to sequences starting in any month. Percentages of long-term average rainfalls recorded during the 1984 drought are boxed, and the corresponding range of months is also indicated. For both the Haweswater and Vyrnwy catchments the 7 month rainfall, recorded from February to August, has a return period exceeding 200 years, and the driest 5 month sequence was also exceptionally rare. The moderate nature of the drought, away from the upland regions in England and Wales, is shown by the 5 to 10 year return periods associated with the 3, 5 and 7 month driest sequences in the Bedford Ouse catchment.

Rainfall deficiencies at the catchment and local scale

Whilst the regional contrasts in drought intensity can be readily appreciated by comparisons between rainfall data for the relatively large water authority areas, spatial variation within authority areas was also important in 1984. This is of particular relevance in those authorities where the drought's maximum intensity occurred over reservoired catchments. Figure 14 illustrates the percentage of normal rainfall for the North West Water Authority area over the period February to August. A striking feature of this map is the coincidence of the 50% isopleth with the headwaters of the rivers draining from the central Lake District where several strategically important reservoirs are located. Parts of the Lake District were, perhaps, the most relatively dry districts in England and Wales during the drought, particularly if the June 1983 - August 1984 period is also considered. Exceptionally low rainfall in reservoired catchment areas was, however, also recorded in southern Scotland, the Pennines, Wales and South West England.

Those catchments which recorded new minimum rainfall totals for April to August in 1984 often recorded new minima for the February to August period also. An assessment of areal rainfall for catchments throughout Great Britain (Table 6) shows that in Scotland, Tayside and the lower Clyde valley were as dry as the central Lake District.

The application of drought indices at the catchment scale

Drought indices are rather sensitive to the size of the region under examination; on the large scale a very severe drought in one district may be balanced by more profuse rainfall elsewhere. From this viewpoint, a more realistic assessment requires the study of individual river basins. An example is shown in Fig. 15 for the Thirlmere catchment, based upon cumulative departures from the average catchment rainfall. The frequency of drought events reflects the greater variability in rainfall over small areas. 1984 is seen to compare with the driest rainfall sequences in the record and is the fifth significant event in the last 15 years.

For water management, the frequency of drought events may be as important as their magnitude. Emergency conditions stretch the staff and facilities as well as the resources. Were droughts to occur more frequently, it would have ramifications for both the adequacy of the water and human resources to meet the greater stress imposed on the water supply sector.

Single raingauge minima

At the local scale, several notably low rainfall totals were reported for the drought period. In regions where convective rainfall made only a limited contribution to spring and summer totals, results from single raingauges were representative of a large area. At Perth, for example, the April to August rainfall totalled 156 mm, the lowest since 1826; this was typical of the Tay region where 35%

to 40% of average rainfall was recorded at most raingauges. The Perth rainfall would have been even more remarkable but for a fall of 27 mm on the 31 July. In Fife, rainfall records at Loch Leven extend back to 1851 and 1870 is the only year when April to August rainfall was less than the 192 mm recorded in 1984. Corresponding rainfall at Loch Katrine was estimated to have a return period of more than 200 years. Over the same period, new minimum rainfall totals were established at Harrogate and Huddersfield in Yorkshire. The Cantref raingauge in the upper Taff catchment, South Wales, recorded 268 mm for the five months from March 1984. This was, by far, the driest March to July sequence since records began in 1889.

Thirlmere and Haweswater both experienced 5 to 7 month rainfall totals during 1984 which are the driest on record by a considerable margin. For instance, the March to August rainfall at Thirlmere was 90 mm lower than the previous 6 monthly minimum (May to October 1915). Other North West Water Authority reservoired catchments also recorded their driest six months ever and at Haweswater only 34% of average rainfall fell in the period March to August. Such extreme dryness has an estimated return period of about 1000 years (based on available tables for a single raingauge), although the frequency of such rare events cannot be established with confidence; the 1984 event will itself influence future estimates of probability.

The Lake District reservoirs and Vyrnwy in North Wales are large capacity reservoirs and, consequently, the volume of water in storage reflects rainfall and runoff conditions extending over a number of seasons. Table 7 shows that the Dales Head Hall raingauge at Thirlmere recorded above average rainfall for only 3 months in the 16 month period commencing June 1983. A similar rainfall sequence occurred at Vyrnwy where by August 1984 the accumulated deficit was significantly greater than that recorded for the long drought of 1933/34.

Characteristics of rainfall patterns in recent years

United Kingdom rainfall over the period 1979–84 was about ten per cent higher than average (Fig. 16). More significantly this rainfall increase has been accompanied by a tendency towards greater within year variability; wet spring and autumn periods have been a feature of recent years and several of the summers have been notably dry. Figure 17 illustrates a comparison between monthly rainfall since 1978 and the 1941–70 average for the United Kingdom and a typical catchment in south west England. Over the winter period, February is seen to be the only month registering a decrease in rainfall with the October to March rainfall recording an increase of 18%. The last decade has witnessed a remarkable sequence of wet autumns. Three of the five highest September to November rainfall totals have been recorded in the last four years (Table 8) and the autumns of 1974, 1976 and 1980 were also very wet. Such departures from average conditions may testify simply to the inherent variability of the British climate. Certainly undue prominence can be afforded to apparently remarkable sequences of data by the judicious selection of reporting periods. Nonetheless, if a trend towards wetter autumns and drier summers were to become established, it would have important implications extending beyond the water supply industry.

1983 rainfall

Following an extremely wet spring, particularly over England and Wales, 1983 was characterised by below average rainfall for the rest of the year with a notably dry summer. In Northern Ireland, 1983 was the driest summer on record; here, as in England and Wales the June to August rainfall was lower than the corresponding total in 1984. However, the short duration of the drought allied to heavy rainfall in the preceding winter and spring resulted in only minor distribution difficulties for the water industry.

1983/84 winter rainfall

Winter rainfall (October-March) for the United Kingdom was 649 mm or 111% of the 1941–70 average. In percentage terms the rainfall was fairly uniformly distributed with Scotland and northern England being the wettest areas. The regional variation is illustrated in Fig. 18. Antecedent rainfall conditions had an important bearing on the water resources aspects of the 1984 drought; by March 1984 most of the United Kingdom was well placed to withstand a drought of limited duration.

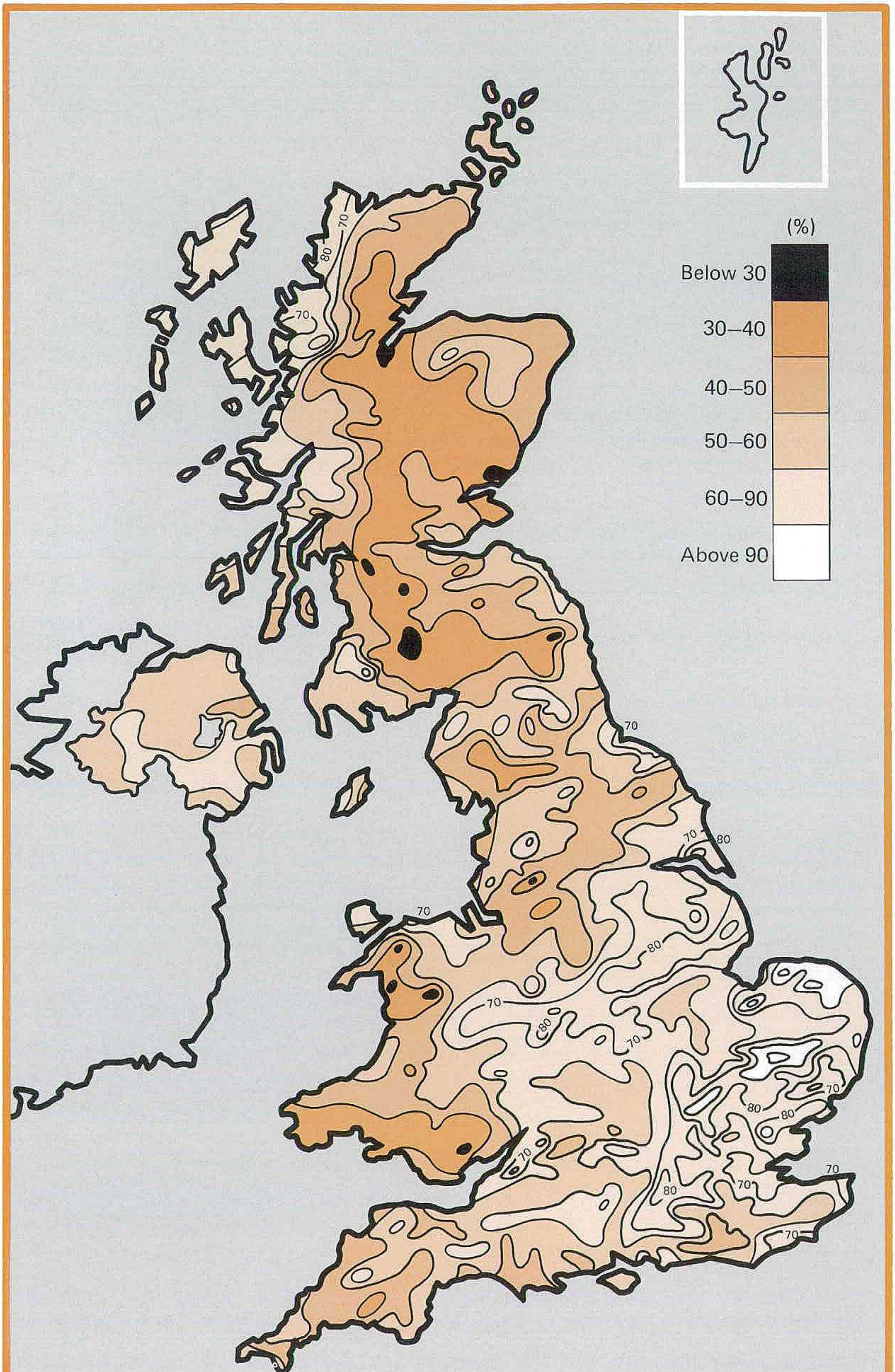


Figure 1. April to August rainfall 1984 as a percentage of the 1941–70 average. (Source: Meteorological Office)

TABLE 1. LOWEST RECORDED RAINFALL TOTALS: FEB-AUG AND APR-AUG

UNITED KINGDOM					ENGLAND AND WALES			
Data Series 1900–1984					Data Series 1766–1984			
Feb – Aug		Apr – Aug			Feb – Aug		Apr – Aug	
Year	Rainfall (mm)	Year	Rainfall (mm)	RANK	Year	Rainfall (mm)	Year	Rainfall (mm)
1976	356	1984	218	1	1976	249	1976	159
1984	370	1976	222	2	1887	277	1870	192
1921	388	1921	275	3	1921	282	1826	192
1955	406	1955	281	4	1870	310	1984	197
1929	414	1933	298	5	1984	313	1887	203
1975	417	1911	298	6	1785	317	1864	210
1959	417	1919	301	7	1929	323	1921	213
1944	432	1975	306	8	1959	333	1844	213
1949	435	1949	310	9	1854	335	1896	228
1911	443	1913	310	10	1949	337	1911	234
	534		379	Average		477		352

SCOTLAND					NORTHERN IRELAND			
Data Series 1869–1984					Data Series 1869–1984			
Feb – Aug		Apr – Aug			Feb – Aug		Apr – Aug	
Year	Rainfall (mm)	Year	Rainfall (mm)	RANK	Year	Rainfall (mm)	Year	Rainfall (mm)
1955	422	1984	255	1	1975	326	1984	229
1887	463	1955	280	2	1976	404	1975	238
1984	469	1869	280	3	1984	412	1983	250
1870	470	1870	312	4	1983	413	1978	268
1869	488	1887	323	5	1952	416	1976	272
1878	508	1976	332	6	1959	422	1977	300
1919	517	1880	351	7	1919	429	1919	304
1875	517	1913	353	8	1911	440	1911	306
1936	518	1915	356	9	1921	447	1959	311
1975	519	1885	356	10	1968	449	1949	312
	641		446	Average		538		389

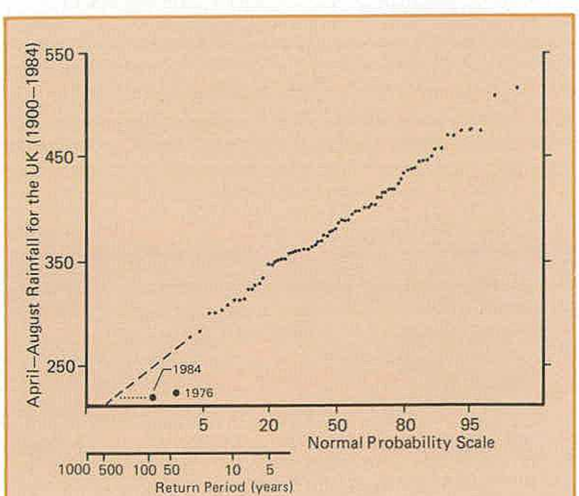


Figure 2. *Return period assessment of April to August rainfall for the United Kingdom. Estimates of the frequency of occurrence of the 1976 and 1984 events may be obtained by locating their ordinates on the extrapolated probability plot (shown dotted for 1984).*

TIMETABLE OF THE DROUGHT

JANUARY	In January the strongest and most persistent westerly winds for many years brought a series of cyclones across the British Isles. Precipitation was more than 150% of average throughout the United Kingdom with large accumulations of snow in the Scottish Highlands.
FEBRUARY	The Icelandic low pressure area deepened and a strong ridge of high pressure developed from the Azores to France. This synoptic pattern resulted in a very variable distribution of rainfall in the United Kingdom. Throughout late February and early March the prevailing winds were from the north and east.
MARCH	These relatively uncommon airstreams helped to establish the regional contrasts in rainfall which were to characterise the drought; March rainfall was above average in southern and eastern England but below average to the west and north. Parts of Snowdonia and the South-West peninsular recorded less than one third of normal March rainfall.
APRIL	The drought became firmly established as a consequence of the extremely low rainfall totals in April and early May. Apart from north-west Scotland and the Sperrin mountains in Northern Ireland, dry, or very dry, conditions obtained throughout the United Kingdom. England and Wales experienced its fourth driest April this century; large areas were restricted to less than 5 mm of rainfall, a few districts recorded zero rainfall.
MAY	With the prevailing winds from the east, a notable rain free period extended well into May. Parts of East Anglia reported five rainless weeks and many localities recorded twenty, or more, consecutive dry days across central England and southern Wales'. The combined April/May rainfall in Northern Ireland was unprecedented. A new May minimum rainfall total was established for Scotland where Galloway and the Clyde valley were especially dry. England and Wales was significantly wetter; the drought's development was slowed by heavy rainfall, often thundery, after the 20 May.
JUNE	Early June rainfall was superseded by another prolonged dry spell which lasted up to ten weeks in some areas. Intense local droughts were developing in regions with general rainfall deficits, for instance in Cumbria, Snowdonia and on Dartmoor. Scotland remained dry, apart from the west coast and the Tweed basin, with the droughts in the Tay and Clyde valleys becoming severe. April to June rainfall was approximately 30 mms less than the previous minimum (232 mms) recorded in 1869. Over the same three months, rainfall in Northern Ireland was the lowest total on record.
JULY	July was the fifth driest this century in England and Wales. The limited rainfall was concentrated at the end of the month and resulted either from weak troughs to the south and west or from thunderstorms. Gwynedd and Gwent received only token rainfall and Yorkshire was also particularly dry.
AUGUST	A slight easing of the drought resulted from widespread rainfall at the beginning of August over England and Wales. The rainfall was associated with a depression over the Irish Sea; this brought moderate to heavy falls to Cornwall, North Wales and northern England. A period of unsettled weather ensued as a series of occluded fronts, with associated thunder activity, crossed Great Britain. In Scotland, August rainfall was locally variable and sporadic in nature; all the River Purification Board areas recorded 50% or less of average rainfall.

SEPTEMBER Apart from Northern Ireland, and a few areas in southern Scotland, the drought was broken by sustained and widespread September rainfall. The month began with thundery conditions and became progressively more unsettled. In the Clyde Valley and parts of South Wales, September rainfall was comparable with the accumulated total for the previous five months. Spatial variability continued to characterise the rainfall pattern though; Thirlmere, for instance, had slightly below average September rainfall.

OCTOBER NOVEMBER Sustained heavy rainfalls served to allay most of the concern regarding the replenishment of water stocks.

TABLE 2. 1984 RAINFALL AS A PERCENTAGE OF THE 1941-70 AVERAGE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	FEB to AUG	APR to AUG	JUNE 1983 to AUG 1984
UNITED KINGDOM	165	100	106	40	61	71	42	54	129	130	156	109	69	56	82
ENGLAND AND WALES	138	80	111	21	104	67	38	62	144	113	146	80	69	57	80
SCOTLAND	147	94	113	67	33	76	58	40	132	150	173	165	69	55	87
NORTHERN IRELAND	173	148	103	44	30	72	53	69	97	106	104	115	74	54	82

TABLE 3. MONTHLY RAINFALL AS A PERCENTAGE OF THE 1941-70 AVERAGE

AUTHORITY	*MONTHS - 1984*												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
NORTH WEST	157	90	79	23	37	88	33	58	136	128	152	88	94
NORTHUMBRIA	154	71	163	25	41	92	42	56	141	97	164	68	94
SEVERN TRENT	158	102	104	15	92	79	31	83	149	106	165	76	99
YORKSHIRE	186	81	130	23	74	78	27	67	165	120	146	59	99
ANGLIAN	161	90	118	33	149	92	39	73	171	94	127	79	103
THAMES	166	83	135	11	145	69	32	56	150	120	141	94	102
SOUTHERN	187	67	152	10	142	54	63	37	96	140	116	119	103
WESSEX	192	86	95	6	115	52	39	56	122	106	153	102	100
SOUTH WEST	188	100	76	13	77	31	50	66	123	123	154	88	100
WELSH	157	92	57	14	59	55	32	62	138	136	145	96	94
HIGHLAND RPB	148	96	89	89	22	67	47	39	127	140	131	109	98
NORTH EAST RPB	179	99	202	38	29	70	63	29	161	130	233	105	113
TAY RPB	180	116	162	39	32	60	38	21	122	142	245	100	109
FORTH RPB	184	112	141	41	40	81	31	29	112	158	213	103	106
CLYDE RPB	168	121	83	62	18	76	47	50	107	151	145	107	102
TWEED RPB	171	87	184	26	33	96	52	32	92	110	211	83	99
SOLWAY	165	119	76	42	20	72	34	45	93	151	148	103	95

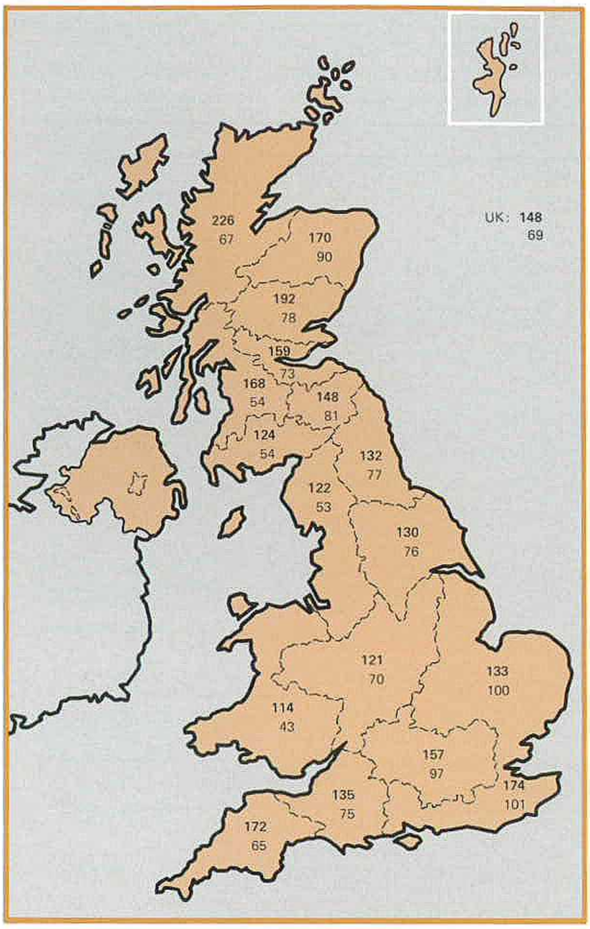


Figure 3. Spring 1984 (March–May) rainfall in mm and as a percentage of 1941–70 average.

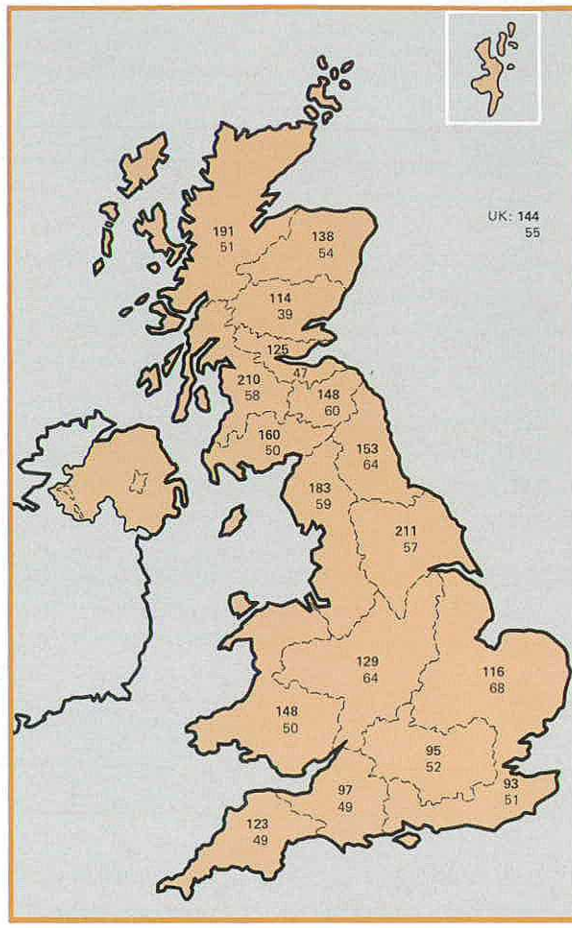


Figure 4. Summer 1984 (June–August) rainfall in mm and as a percentage of 1941–70 average.

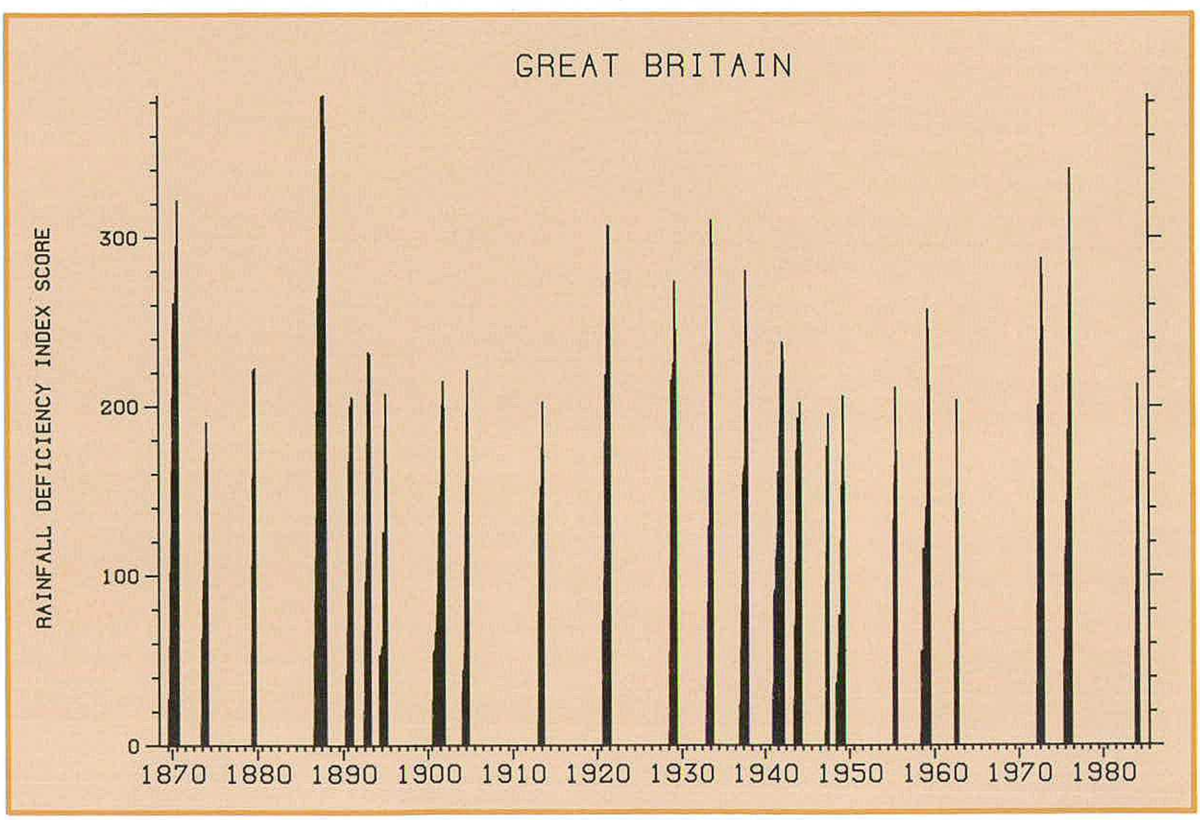
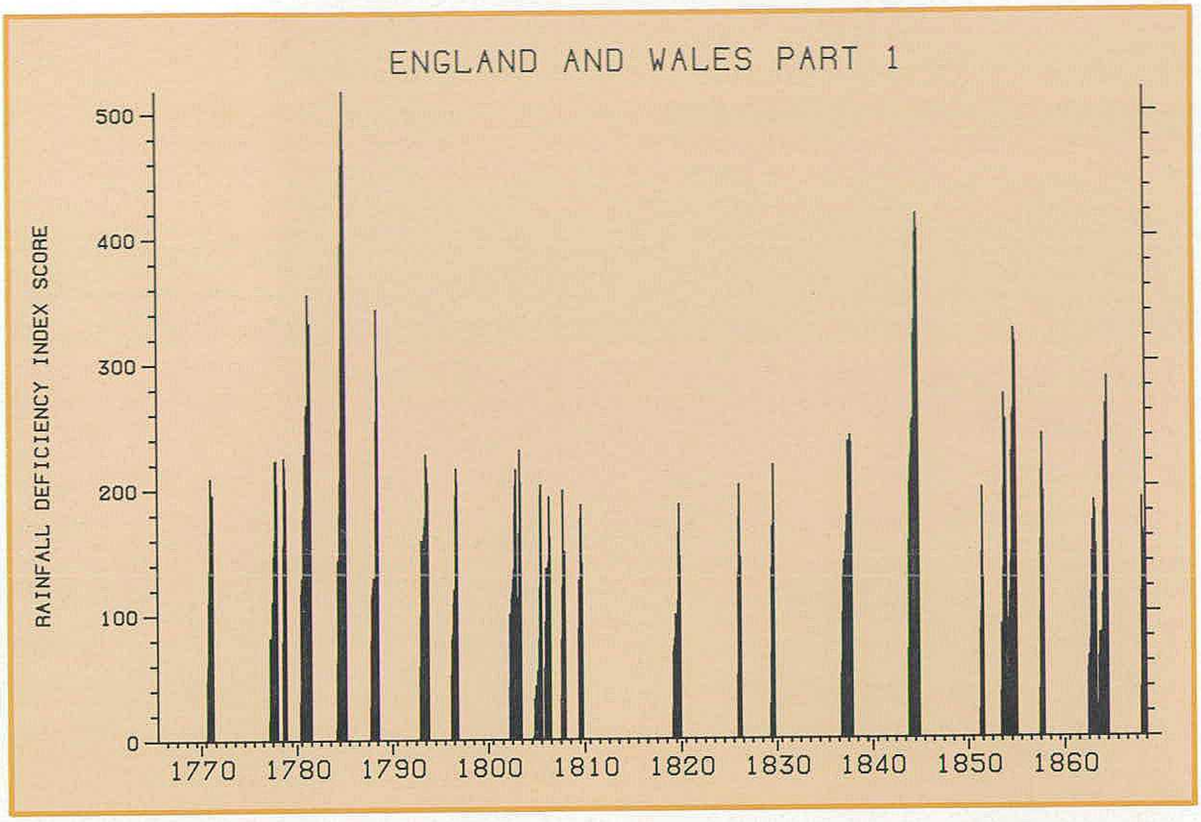


Figure 5. Rainfall deficiency index for Great Britain.



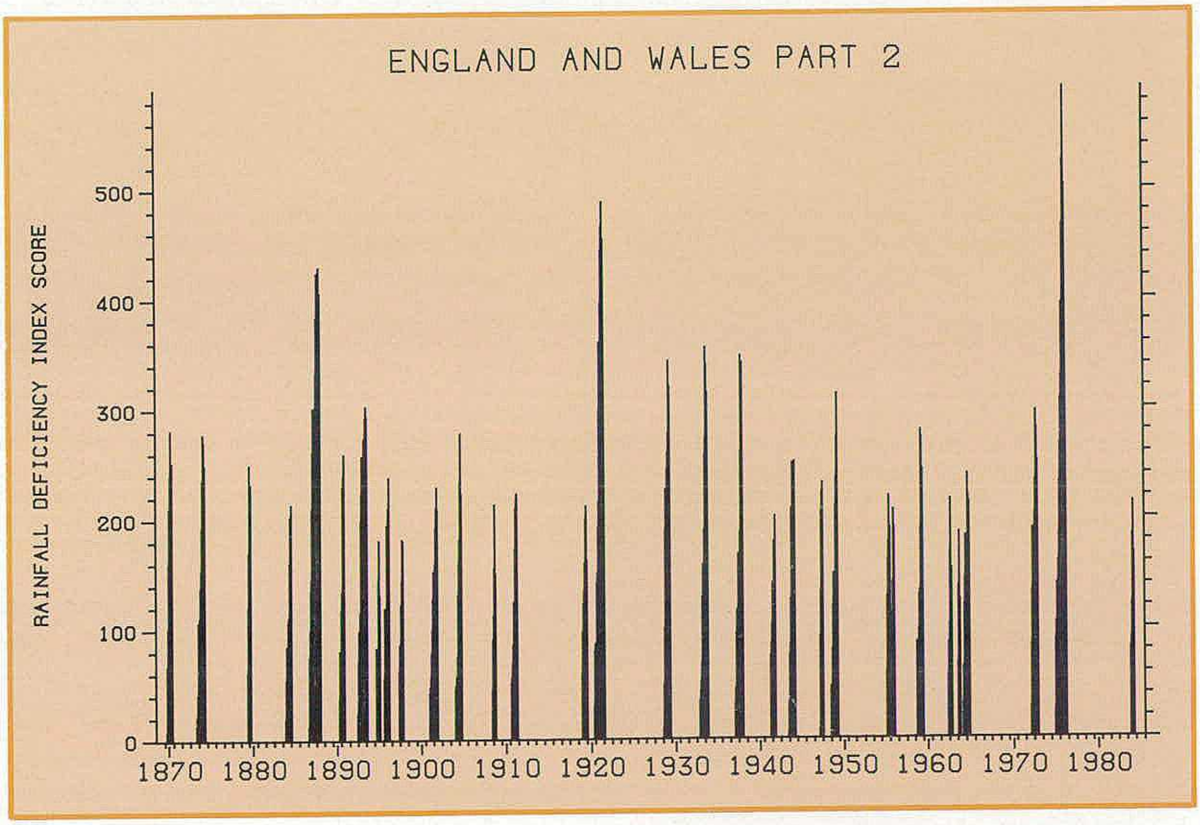
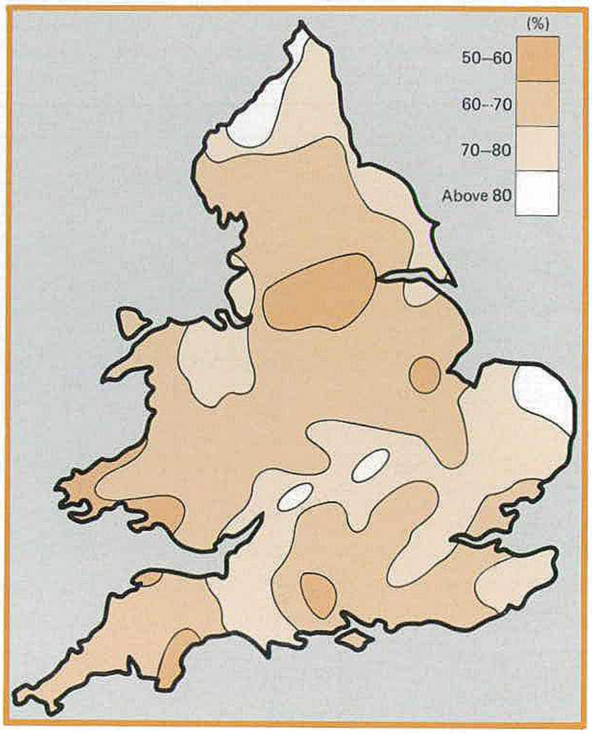
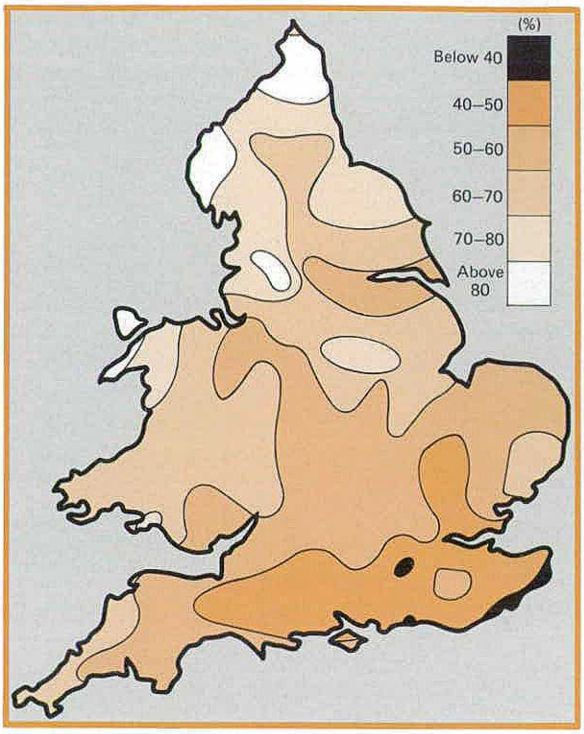


Figure 6. Rainfall deficiency index for England and Wales.

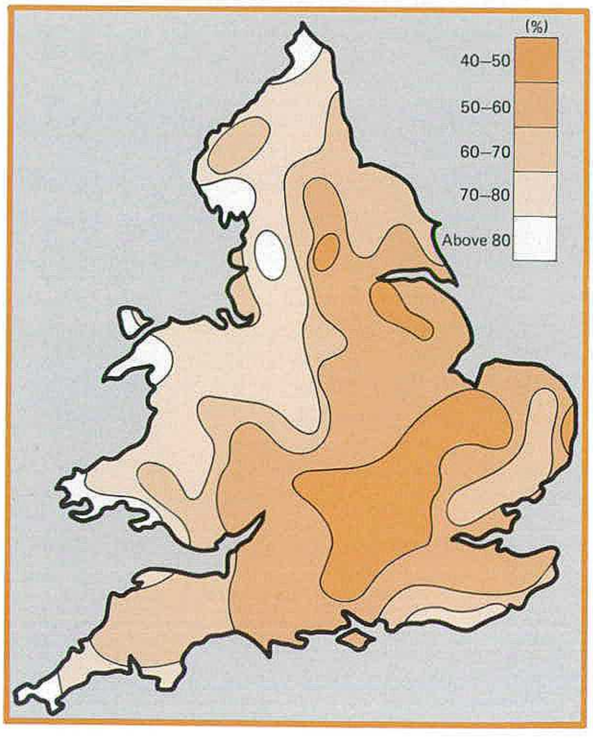


7(a) *Rainfall from February to October 1887 as a percentage of the nine-month mean.*

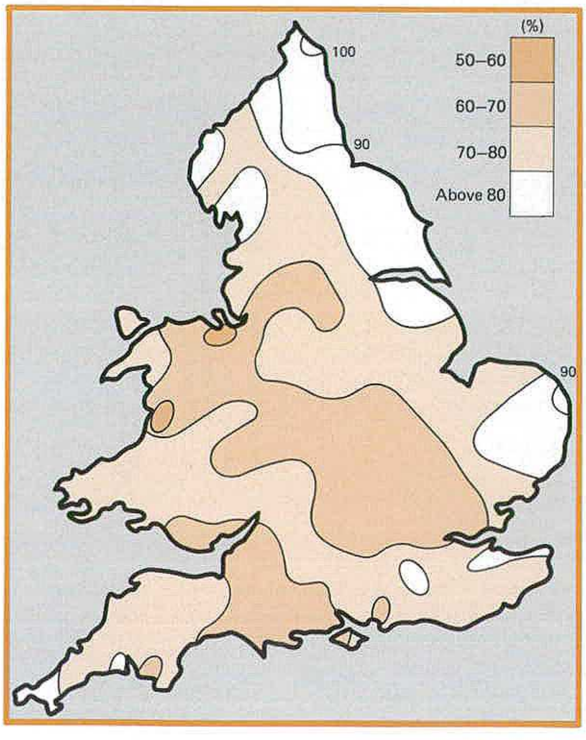


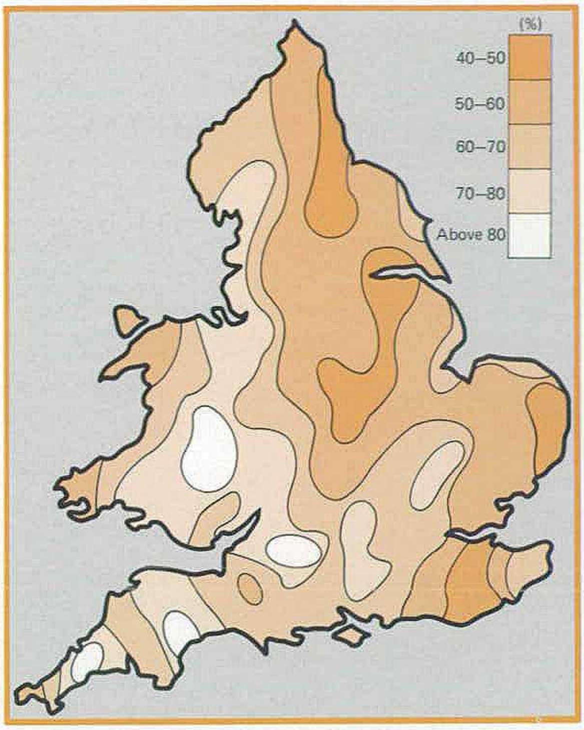
7(b) *Rainfall from February to November 1921 as a percentage of the ten-month mean.*

7(c) *Rainfall from February to September 1929 as a percentage of the eight-month mean.*

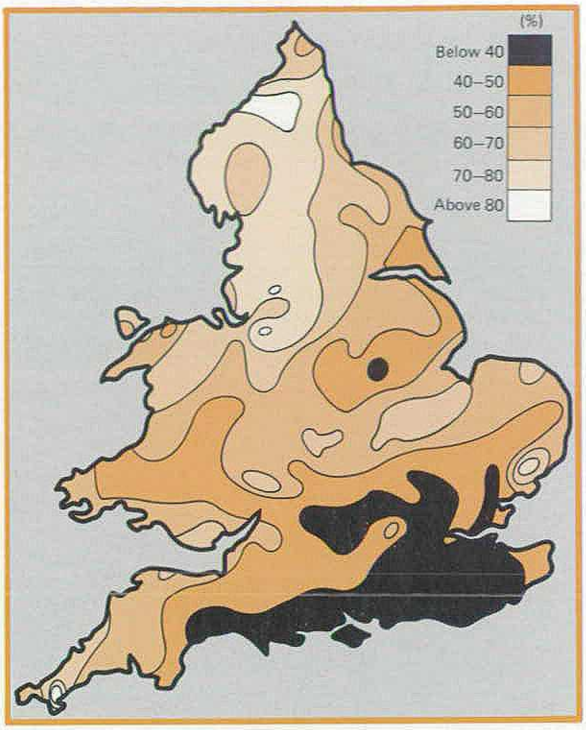


7(d) *Rainfall from April to September 1934 as a percentage of the six-month mean.*





7 (e) *Rainfall from February to September 1959 as a percentage of the eight-month mean.*



7 (f) *Rainfall from January to August 1976 as a percentage of the eight-month mean.*

Figure 7. The spatial variation in drought intensity for drought periods in England and Wales (from reference (10)).

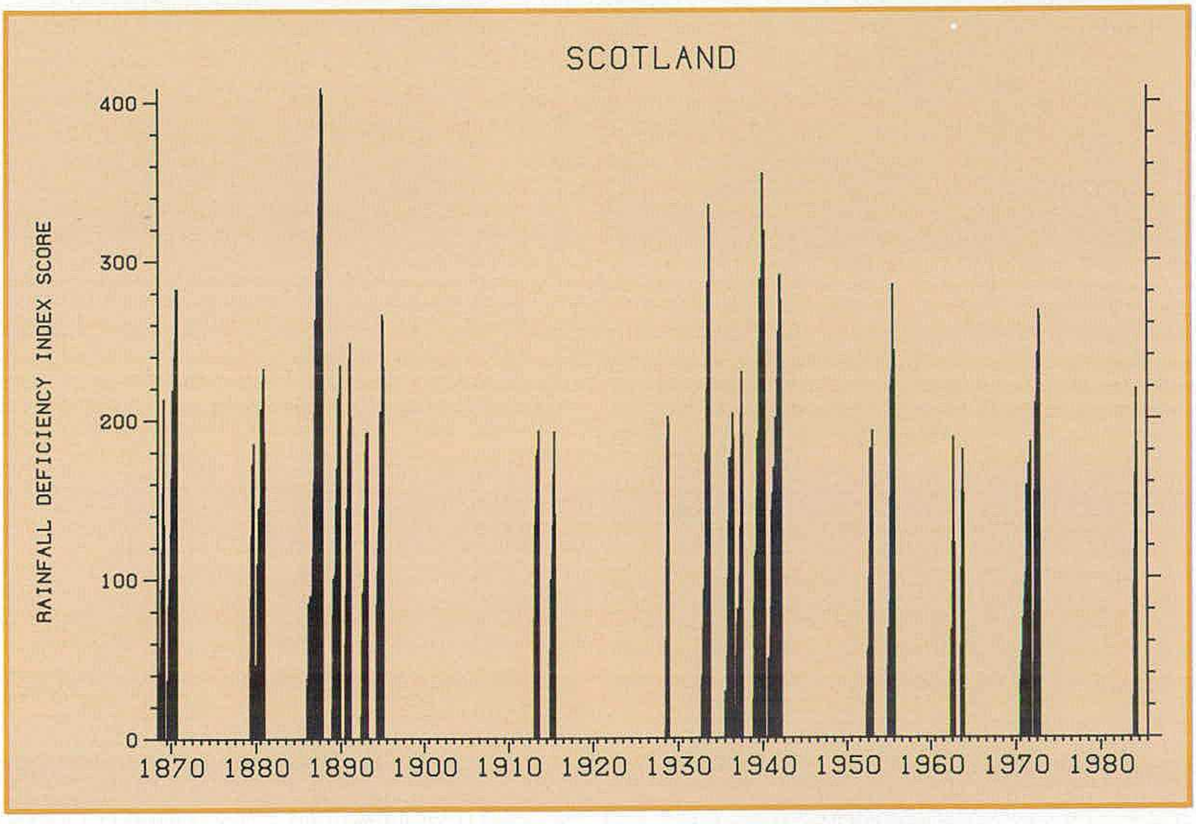


Figure 8. Rainfall deficiency index for Scotland.

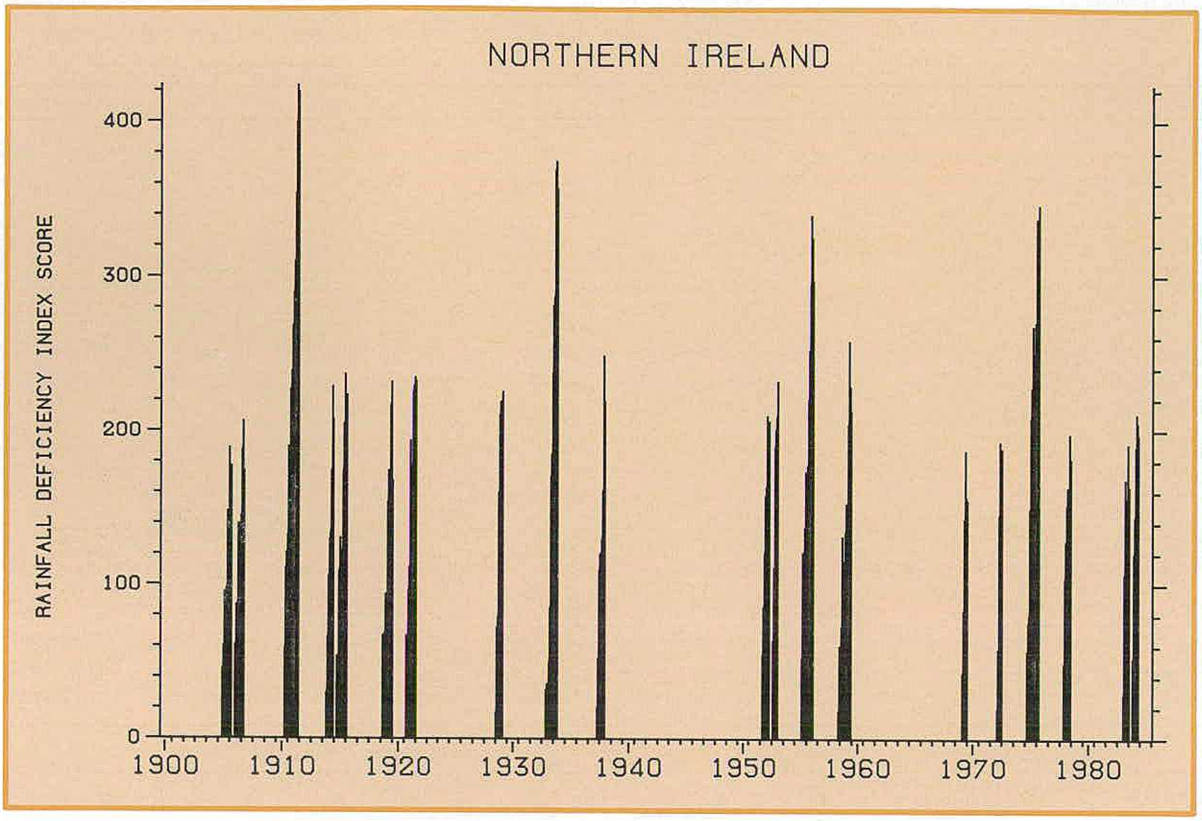


Figure 9. Rainfall deficiency index for Northern Ireland.

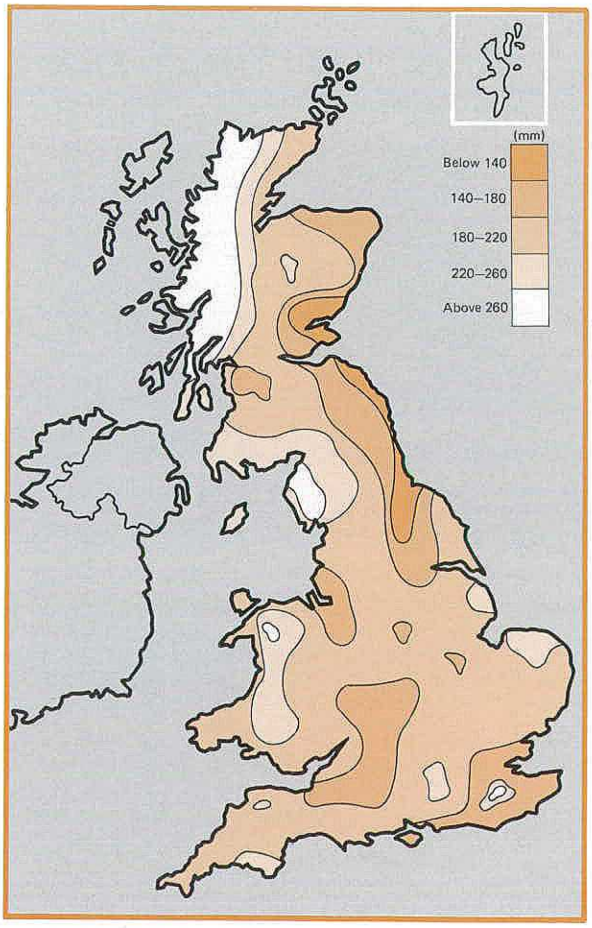


Figure 10. April to August rainfall 1984.

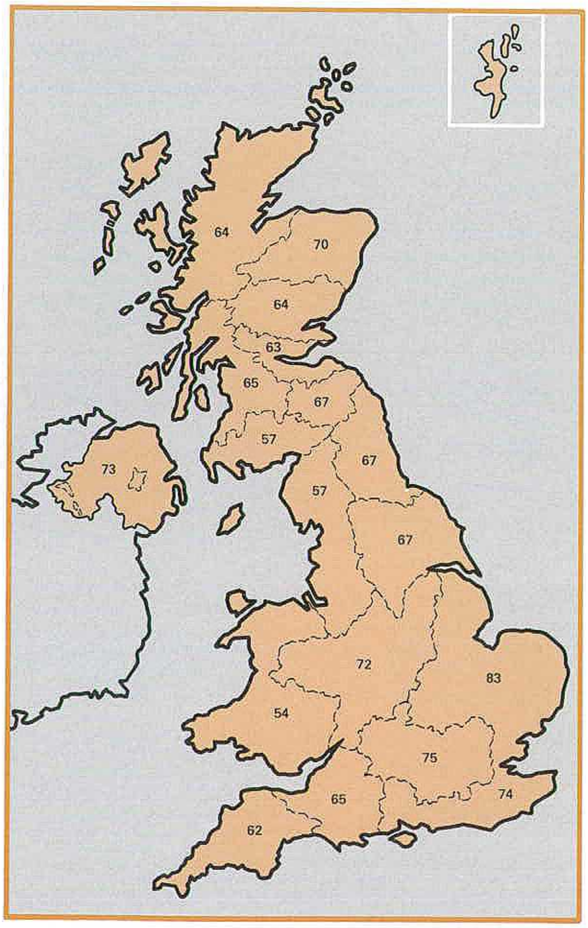


Figure 11. February to August rainfall 1984 as a percentage of the 1941–70 average.

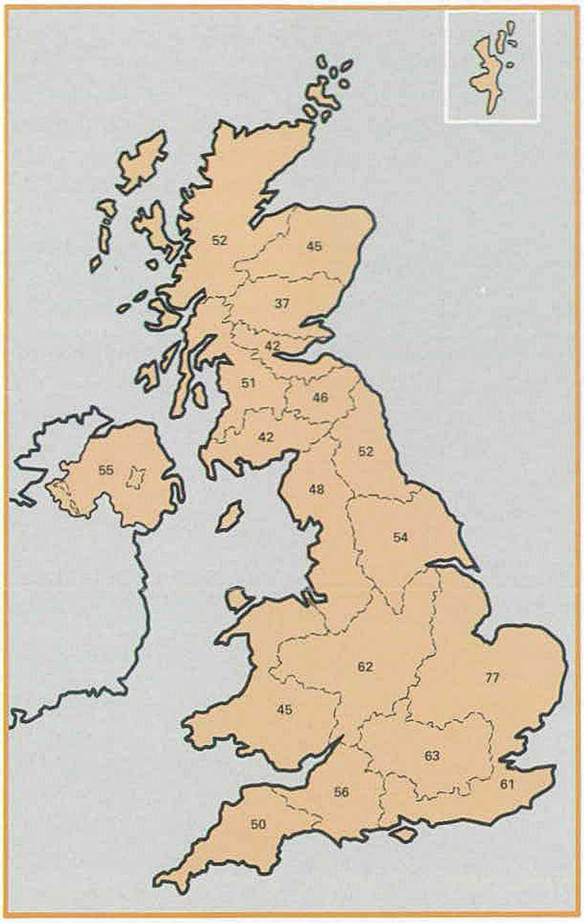


Figure 12. *April to August rainfall 1984 as a percentage of the 1941–70 average.*

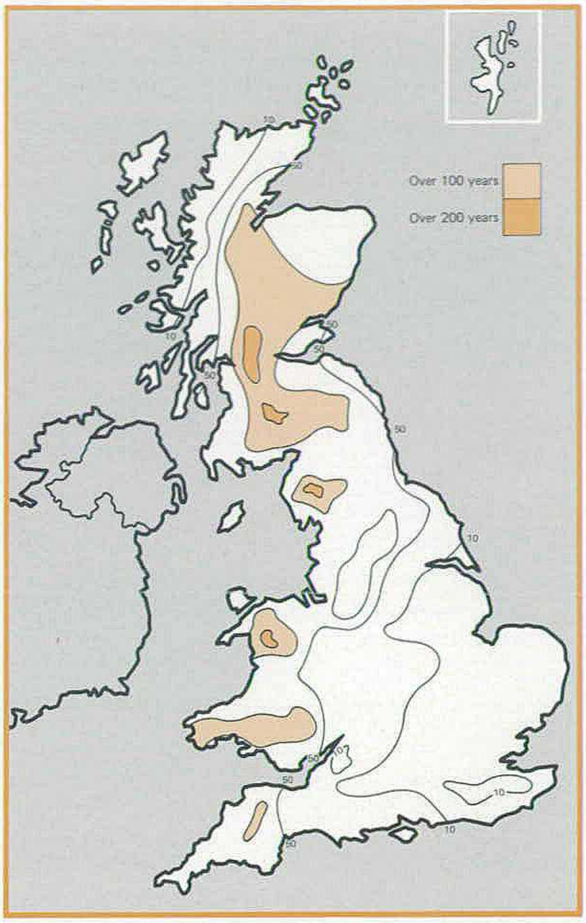


Figure 13. *A guide to the return period of the 1984 April to August rainfall.*

TABLE 4. 1984 RAINFALL AS A PERCENTAGE OF THE 1941-70 AVERAGE AND THE ASSOCIATED RETURN PERIOD

WA	Feb - Aug Rainfall % LTAV	Feb - Aug Rainfall Return Period (Years)	Apr - Aug % LTAV	Apr - Aug Return Period (Years)
North West	56	200–500	47	300
Northumbria	65	40	50	180
Severn Trent	72	10–20	62	20–50
Yorkshire	65	20–50	52	100–200
Anglia	83	2–5	72	5–10
Thames	75	10	65	10–20
Southern	74	10–20	61	20–50
Wessex	65	20–50	56	20–50
South West	60	50–100	49	100
Welsh	53	100–500	44	200–500

The return period estimates are based upon tables provided by the Meteorological Office. Return periods refer to 5 or 7 month deficiencies starting in any month.

TABLE 5. FREQUENCY OF OCCURRENCE OF SPECIFIED PERCENTAGE RAINFALL FOR SELECTED CATCHMENTS

Catchment	Duration 'N' (months)	Frequency of occurrence (1 in X years) 5	10	20	50	100	200	500	Driest 'N' month period in 1984 Period	% Rain	Frequency
HAWESWATER	3	76	64	55	46	39	34	27	May – Jul		
BECK	5	82	72	65	57	52	47	41	Mar – Jul	32.5	(500 yr)
	7	84	76	70	63	58	54	49	Feb – Aug	45.1	(500 yr)
LUNE	3	77	66	58	49	42	36	30	Jun – Aug		
	5	82	73	66	59	54	49	44	Apr – Aug		
	7	85	77	71	65	60	56	52	Feb – Aug		
BEDFORD OUSE	3	74	62	52	41	34	28	22	Jun – Aug		
	5	80	70	62	53	48	43	37	Apr – Aug		
	7	83	74	68	60	55	51	45	Feb – Aug		
VYRNWY	3	76	64	56	46	40	34	28	Apr – Jun		
	5	87	72	65	57	52	47	42	Mar – Jul	37.3	(500 yr)
	7	84	76	70	63	59	55	50	Feb – Aug	45.7	(500 yr)
				% of Av. Rainfall							

Adapted from (4)

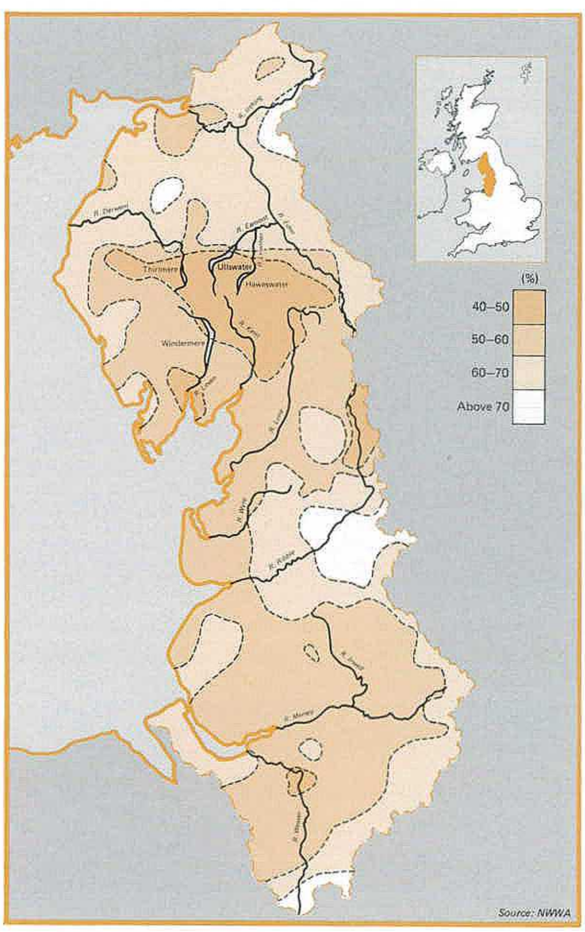


Figure 14. February to August rainfall 1984 for the North West Water Authority as a percentage of the 1941–70 average.

TABLE 6. DROUGHT PERIOD RAINFALL IN 1984 FOR SELECTED CATCHMENTS WITH RANK IN THE PERIOD OF RECORD AND HISTORICAL MINIMA

Gauging Station Number	River Name	No. of years data	Drought Period Feb - Aug:7 Apr - Aug:5	Rainfall (mm)	% LTA	Rank	Driest Sequence (mm)	% LTA	Year
15003	Tay	34	7	495	67	2	437	60	1955
			5	212	43	1	212	43	1984
17002	Leven	13	7	373	93	4	292	73	1975
			5	196	70	1	196	70	1984
21009	Tweed	22	7	377	75	2	366	73	1976
			5	198	56	1	198	56	1984
23004	S Tyne	22	7	449	78	2	409	71	1976
			5	268	67	2	266	66	1976
28010	Derwent	27	7	397	76	4	255	49	1976
				225	62	2	163	45	1976
33002	Bedford Ouse	44	7	291	81	12	160	45	1976
			5	192	72	6	120	45	1976
36006	Stour	22	7	291	92	7	135	43	1976
			5	204	87	6	98	42	1976
38003	Mimram	32	7	302	85	6	136	38	1976
				218	82	7	98	37	1976
39001	Thames	101	7	322	85	26	168	44	1976
				218'	79	19	119	43	1976
40003	Medway	28		286	77	4	139	37	1976
				172	65	2	94	35	1976
42510	Itchen			340	82	2	327	77	1975
				202	71	1	202	71	1984
46003	Dart	26		522	62	3	410	49	1976
				260	51	2	167	32	1976
50001	Taw	26		362	67	2	298	54	1976
				205	57	2	149	40	1976
54001	Severn	64		347	74	7	214	45	1929
				227	67	5	152	45	1976
54003	Vyrnwy			425	48	1	425	48	1984
				189	32	1	189	32	1984
56001	Usk	28		391	61	2	355	55	1976
				224	54	2	208	50	1976
57004	Cynon	27		433	54	1	433	54	1984
				220	42	1	220	42	1984
68001	Weaver			260	64	2	259	63	1976
				176	58	2	157	51	1976
72004	Lune			417	57	1	417	57	1984
				273	52	1	273	52	1984
73010	Leven			519	54	1	519	54	1984
				320	50	1	320	50	1984
76001	Haweswater			495	46	1	495	46	1984
				273	38	1	273	38	1984
79002	Nith			395	58	1	395	58	1984
				194	42	1	194	42	1984
84001	Kelvin	51	7	379	65	1	379	65	1984
			5	190	45	1	190	45	1984

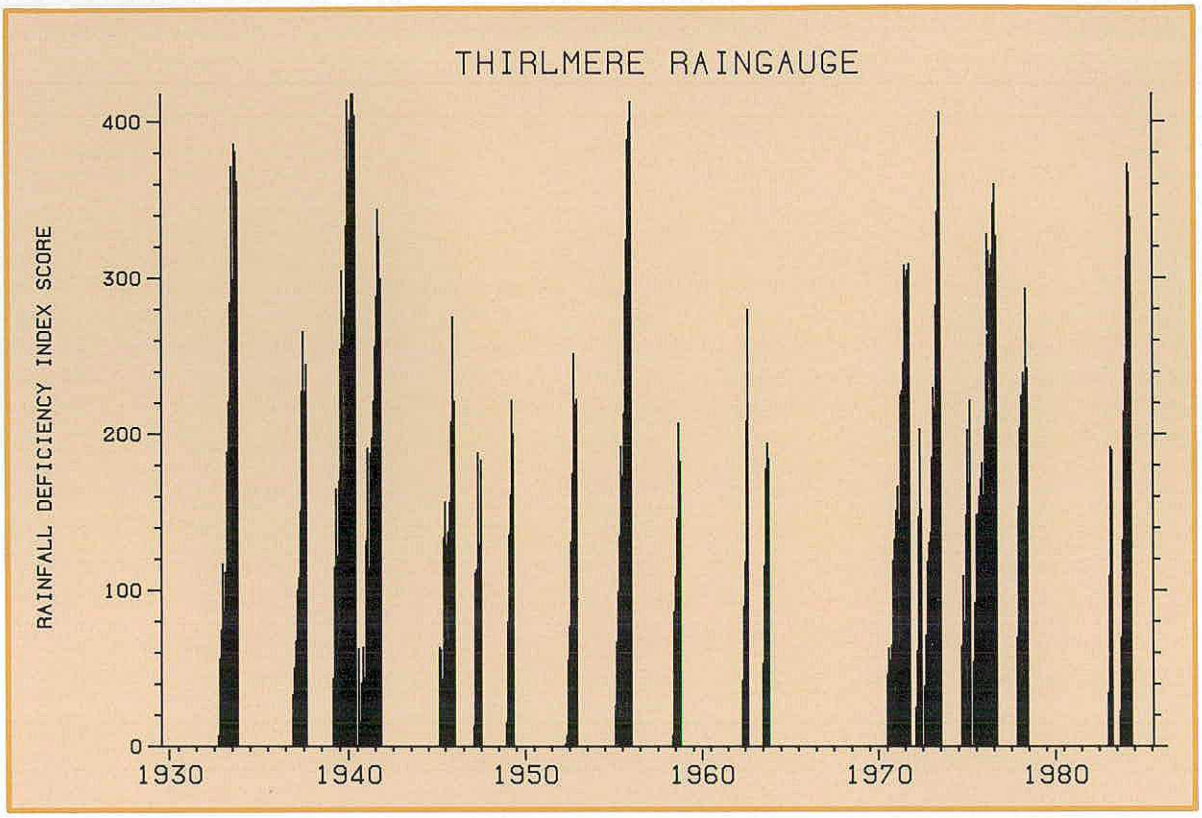


Figure 15. Rainfall deficiency index for Thirlmere.

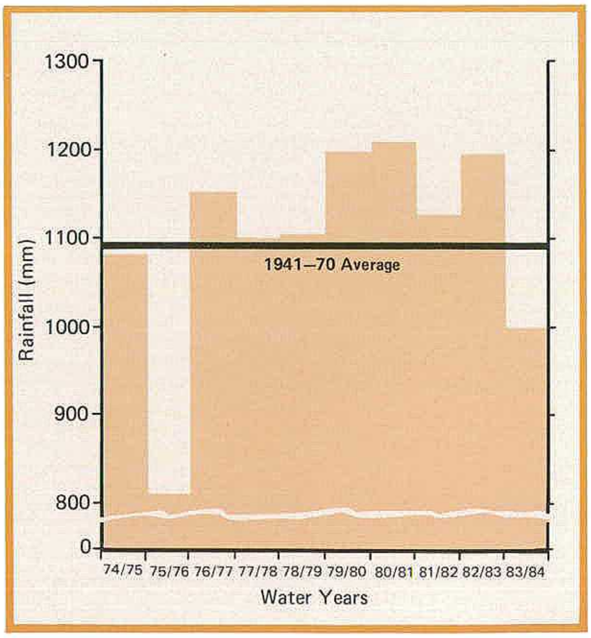


Figure 16. United Kingdom rainfall 1974/75 to 1983/84.

TABLE 7. CUMULATIVE RAINFALL AS A PERCENTAGE OF THE 1941-70 AVERAGE

Date	Rain mm	41-70 Average	% 41 70	Cumulative rainfall as % LTAV starting in month: Feb 1983	Feb 1984	Mar 1984	Apr 1984	May 1984	Jun 1984	Jul 1984	Aug 1984	Sep 1984
(a) Thirlmere Dale Head Hill												
Feb 1983	88	169	52	52								
Mar 1983	175	146	120	83								
Apr 1983	113	147	77	81								
May 1983	194	136	143	95								
Jun 1983	76	126	60	89								
Jul 1983	34	140	24	79								
Aug 1983	28	195	14	67								
Sep 1983	194	233	83	70								
Oct 1983	331	231	143	81								
Nov 1983	83	252	33	74								
Dec 1983	292	257	114	79								
Jan 1984	293	227	129	84								
Feb 1984	124	169	73	83	73							
Mar 1984	78	146	53	82	64	53						
Apr 1984	37	147	25	79	52	39	25					
May 1984	22	136	16	76	44	32	21	16				
Jun 1984	85	126	68	75	48	40	35	41	68			
Jul 1984	47	140	33	73	45	39	35	38	50	33		
Aug 1984	75	195	38	71	44	39	36	38	45	36	38	
Sep 1984	220	233	94	73	53	50	50	54	61	60	69	94
Oct 1984	271	231	117	76	63	62	63	68	75	77	86	106
Nov 1984	357	252	-142	80	74	74	76	82	90	92	101	118
Dec 1984	202	257	78	80	75	75	77	81	88	90	96	108
(b) Vyrnwy Experimental Station												
Feb 1983	75	134	56	56								
Mar 1983	146	109	134	91								
Apr 1983	118	107	110	97								
May 1983	158	111	142	108								
Jun 1983	64	92	69	101								
Jul 1983	71	107	66	96								
Aug 1983	47	133	35	86								
Sep 1983	240	142	169	98								
Oct 1983	237	160	148	105								
Nov 1983	72	170	42	97								
Dec 1983	237	191	124	101								
Jan 1984	334	177	189	110								
Feb 1984	151	134	113	110	113							
Mar 1984	52	109	48	107	84	48						
Apr 1984	11	107	10	101	61	29	10					
May 1984	39	111	35	98	55	31	22	35				
Jun 1984	46	92	50	96	54	35	31	42	50			
Jul 1984	25	107	23	93	49	33	29	35	36	23		
Aug 1984	121	133	91	92	56	44	44	52	58	61	91	
Sep 1984	179	142	126	94	67	59	61	70	78	85	109	126
Oct 1984	232	160	145	97	78	73	77	86	95	103	122	136
Nov 1984	251	170	147	100	87	84	88	98	106	113	129	140
Dec 1984	148	191	78	99	86	83	87	94	101	106	117	122

Source: North West Water Authority

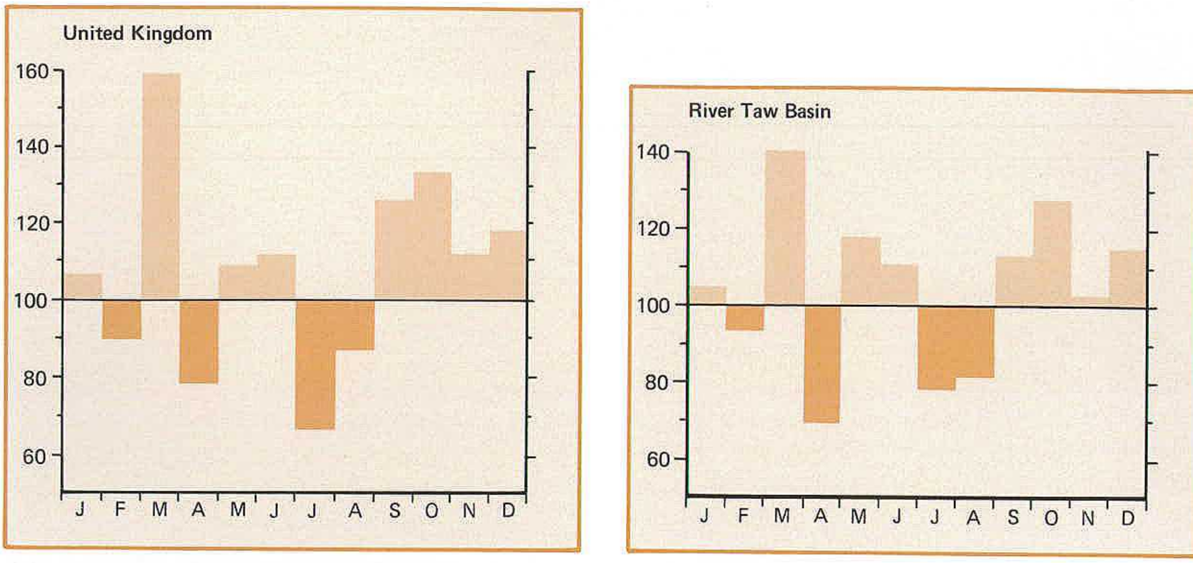


Figure 17. Average monthly rainfall 1979–84 as a percentage of the 1941–70 average.

TABLE 8

UNITED KINGDOM

SUMMER RAINFALL JUN - AUG			AUTUMN RAINFALL SEP - NOV	
Year	Rainfall (mm)	Rank	Year	Rainfall (mm)
1976	104	1	1935	466
1913	131	2	1954	454
1983	133	3	1981	447
1955	141	4	1984	445
1984	144	5	1982	429
1949	164	6	1976	419
1947	172	7	1960	418
1975	179	8	1903	414
1921	179	9	1944	410
1925	182	10	1977	389
	244	Average		311

ENGLAND AND WALES 1900–1985

SUMMER RAINFALL JUN - AUG			AUTUMN RAINFALL SEP - NOV	
Year	Rainfall (mm)	Rank	Year	Rainfall (mm)
1976	75	1	1960	445
1983	110	2	1935	422
1913	115	3	1976	398
1949	125	4	1903	391
1984	127	5	1974	380
1921	133	6	1954	379
1975	136	7	1944	374
1955	142	8	1984	361
1937	146	9	1940	353
1959	149	10	1967	345
1947	149	11	1929	344
1933	150	12	1981	334
1911	150	13	1930	331
1981	152	14	1982	329
1940	153	15	1927	327
	218	Average		262

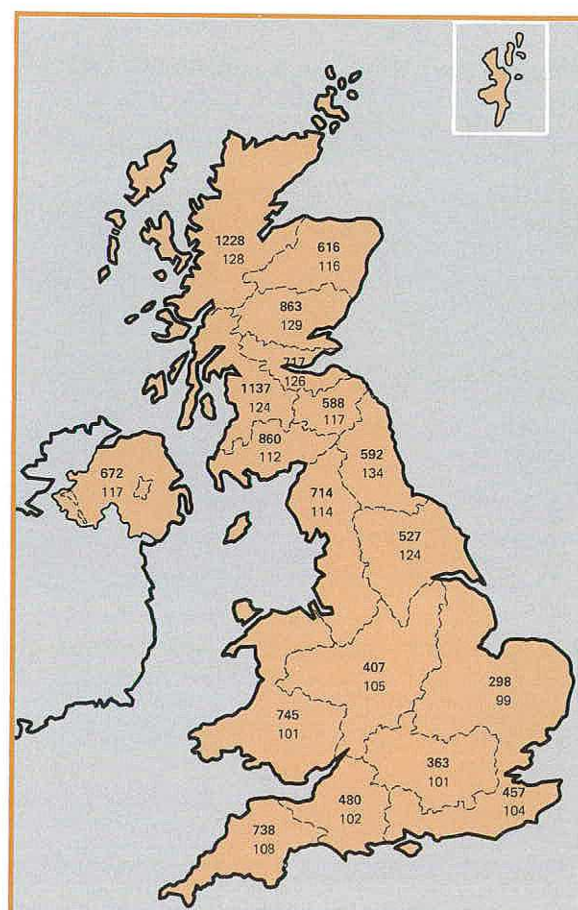


Figure 18. Winter 1983/4 (December–February) rainfall in mm and (second number) as a percentage of the 1941–70 average.

EVAPORATION AND SOIL MOISTURE DEFICIT

Potential evaporation (PE)

Conditions in 1984 were conducive to high evaporation rates; a map of PE over Great Britain is shown in Fig. 19, derived from data produced by the MORECS model (Meteorological Office Rainfall and Evaporation Calculation System) (see Appendix IIa). In the background, isopleths of the annual average potential evaporation are also shown for comparison. MORECS provides areal estimates of PE and other hydrological variables for a network of 40 km squares over Great Britain. PE was above average in all areas, but the greatest departures from average were in the west and north.

Shortfall of actual below potential evaporation

Figure 20 illustrates the shortfall of actual evaporation (AE) below PE for 1984 using data produced by MORECS. In Scotland the Tay basin shows up as well as the Glasgow area and Dumfriesshire (shortfalls would normally be below 40 mm). The Lake District square probably underestimates the shortfall; the synoptic stations whose data define that square in the MORECS model are near the coast, which was wetter and cooler than inland in 1984. Some of the areas to the west, particularly in Wales, do not look as if abnormal conditions obtained. However, many of these areas would have had a very small shortfall in a normal year, and perhaps none at all, paralleling the situation in north western Scotland. In contrast, the squares covering Norfolk appear to be registering low values when compared with the shortfalls inland, emphasising the normal summer conditions obtaining in Norfolk in 1984.

Soil moisture deficits (SMDs)

The magnitude of estimated SMDs unless measured directly using neutron probes are more model dependent than the other hydrological variables; SMDs are usually derived as a result of water budgeting using rainfall, evaporation and a percolation or drainage component. A SMD model characterises the soil moisture profile and is used in conjunction with a PE model to estimate the AE component. The SMD time series which are available on a nationwide basis reflect the varying assumptions built into the SMD estimation models, and the results from such models may not be strictly comparable.

Examples may be selected from the Meteorological Office data sets: MORECS, the most refined, which has been in operation substantially unchanged since 1981; and an older model, ESMD (see Appendix IIb), which has been in operation for specific sites since 1961.

Figure 21 illustrates the variation in PE, AE and SMD for eight MORECS squares for the period June 1981 – December 1984. Their locations and square numbers are shown in Fig. 22. The variable profile of the 1984 drought, relative to the three preceding years, is clearly shown. All demonstrate the effect of the dry April, depicted by higher evaporative rates and higher SMDs. The areas under the SMD curve and between the AE and PE curves illustrate the relative severity and duration of drier conditions; the more notable events are found to the west and north, whilst in the south and east 1983 was of similar proportions to 1984.

In order to achieve a longer historical perspective, individual SMD station data using the earlier Meteorological Office model may be used. The station locations are shown in Fig. 22. The end of month values are highlighted against the period of record extremes and means (Fig. 23). In Fig. 24 the whole period of record is depicted for four sites (three in common with Fig. 23). In the drier parts of the country, where PE approaches AE in magnitude, high SMDs are a regular feature from late spring to autumn, indeed, SMDs are often not satisfied until well into the winter. At Wittering, for example, the mean is closer to the 'maximum' envelope than the minimum. In the wetter areas the higher rainfall throughout the year keeps SMDs modest. However, during rainless periods, were the energy inputs similar, SMDs would increase at a similar rate in these areas as they would in the drier. The plots for Ambleside show the mean closer to the 'minimum' envelope than the maximum, reflecting the increased rarity of the drier events.

The SMD profiles for Renfrew show that 1984 is clearly the most notable single year in the record. Such a pattern is repeated elsewhere in central and southern Scotland. Not as spectacular, but convincing, is the record from Ambleside in the southern Lake District. At this site a zero SMD has occurred in every month at some time in its record. Of the drier areas, SMDs at Thirsk in 1984 were well above average in the spring and summer, and the aggregate SMD ranked fifth in the record. At Wittering SMDs were above average in 1984, through to November. The plot in Fig. 24 shows the main drought events spanning two years, e.g. 1964/65, and 1975/76. The persistence of high SMDs during the winters limits the significance one may ascribe to any individual year. Nevertheless, the aggregate SMDs for 1984 were the highest on record.

An agricultural drought?

It has been shown that SMDs over many areas of Great Britain were high from late spring and throughout the summer of 1984 and one may intuitively expect that crop yields would be adversely affected. Agricultural yields are the result of the interplay between many components from before sowing to harvesting, including the initial and subsequent conditions of soil moisture, climatic conditions such as temperature and wind, and the incidences of pests and diseases. Further, the producer has an influence in when and what he chooses to sow and what technology he employs to counter the checks the above conditions may cause; whether it be by irrigation, growth promoters, or pest and disease inhibitors. Fig. 25 illustrates the annual crop yields for winter sown cereals in the UK from 1961. The general upward trend reflects the move to maximising yields through high input--high output practice together with the development of appropriate cereal varieties. The winter sown cereal yields in 1984 were obviously exceptional; one may infer that among the climatic factors a wet winter, a warm spring and a dry summer with good harvest conditions, whilst ravaging the average lawn, suited these cereals "down to the ground".

Results from research catchments

The Institute of Hydrology maintains a network of experimental catchments in Great Britain. For the Plynlimon catchments in mid Wales meteorological and runoff measurements continue on a routine basis. SMD measurements using neutron probes ceased in 1979, but sufficient data were collected to allow calibration of suitable models for the estimation of SMD.

Figure 26 illustrates rainfall and runoff against their period of record (POR) maxima, minima and means. Although individual monthly minima may have been recorded in previous years, 1984 set new record lows for durations from two to six months for rainfall and runoff for the Wye (predominately pasture) and Severn (predominately forest) catchments (Table 9).

The results from estimating SMD in the two Plynlimon catchments are shown juxtaposed with the daily catchment rainfall in Fig. 27. The estimation procedure is summarised in Appendix IIc. The ability of the long rooted vegetation to extract moisture from deeper soil layers is shown clearly with the development of higher deficits under the forested areas.

Similar results may be seen from neutron probe measurements taken in the Monachyle and Kirkton Glen catchments near Balquhidder in Perthshire. Figure 28 illustrates individual readings taken from three types of cover: grassland, heather and forested valley slope.

Mechanisms which may cover the response of upland catchments to drought have been discussed elsewhere[13,14], considering in detail the effect of the 1976 drought on the IH research catchments.

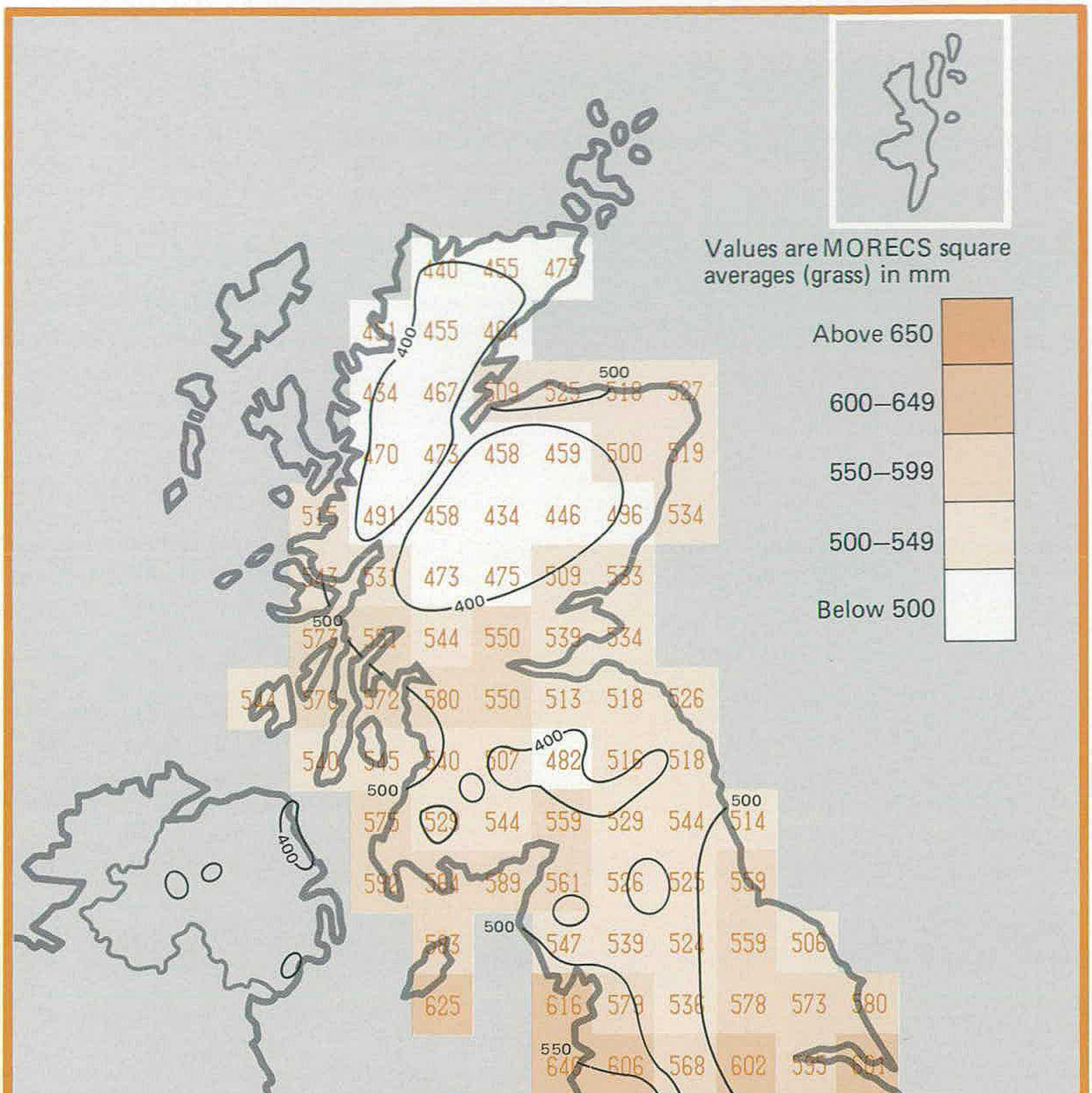


Figure 19. Potential evaporation 1984 and (as isopleths) the annual average pattern.

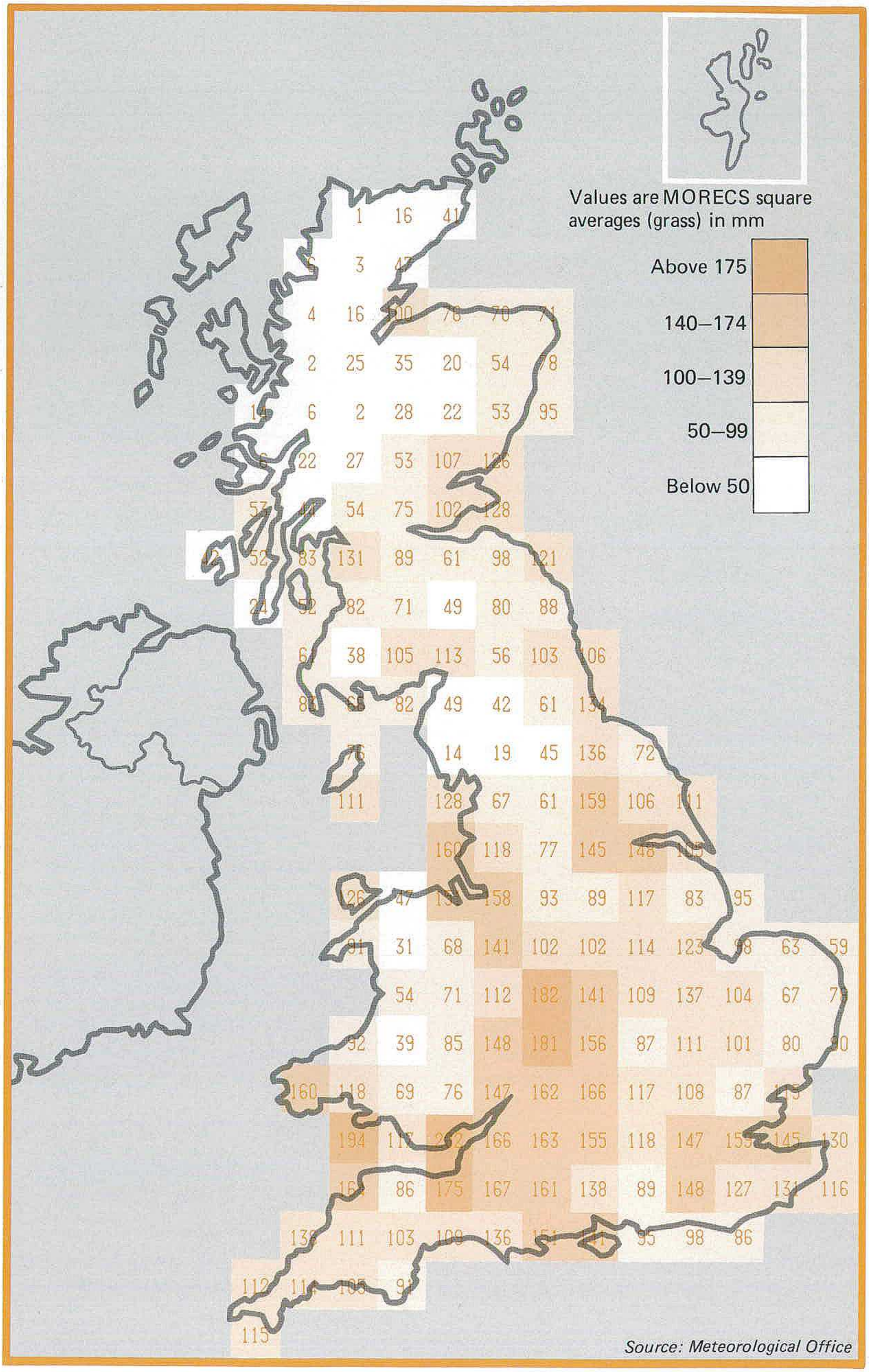


Figure 20. Shortfall of actual evaporation below potential in 1984.

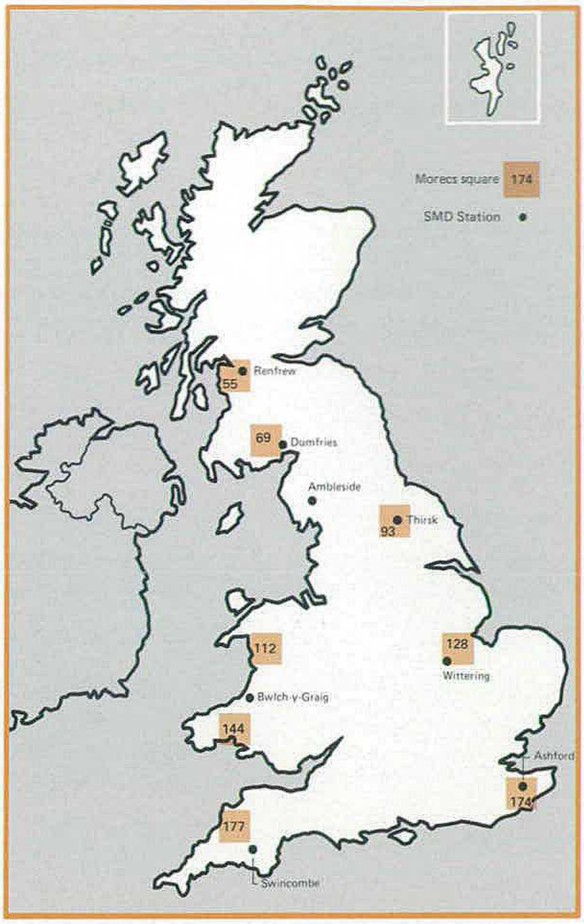


Figure 21. Soil moisture deficit stations—location map for Figs. 22 and 23.

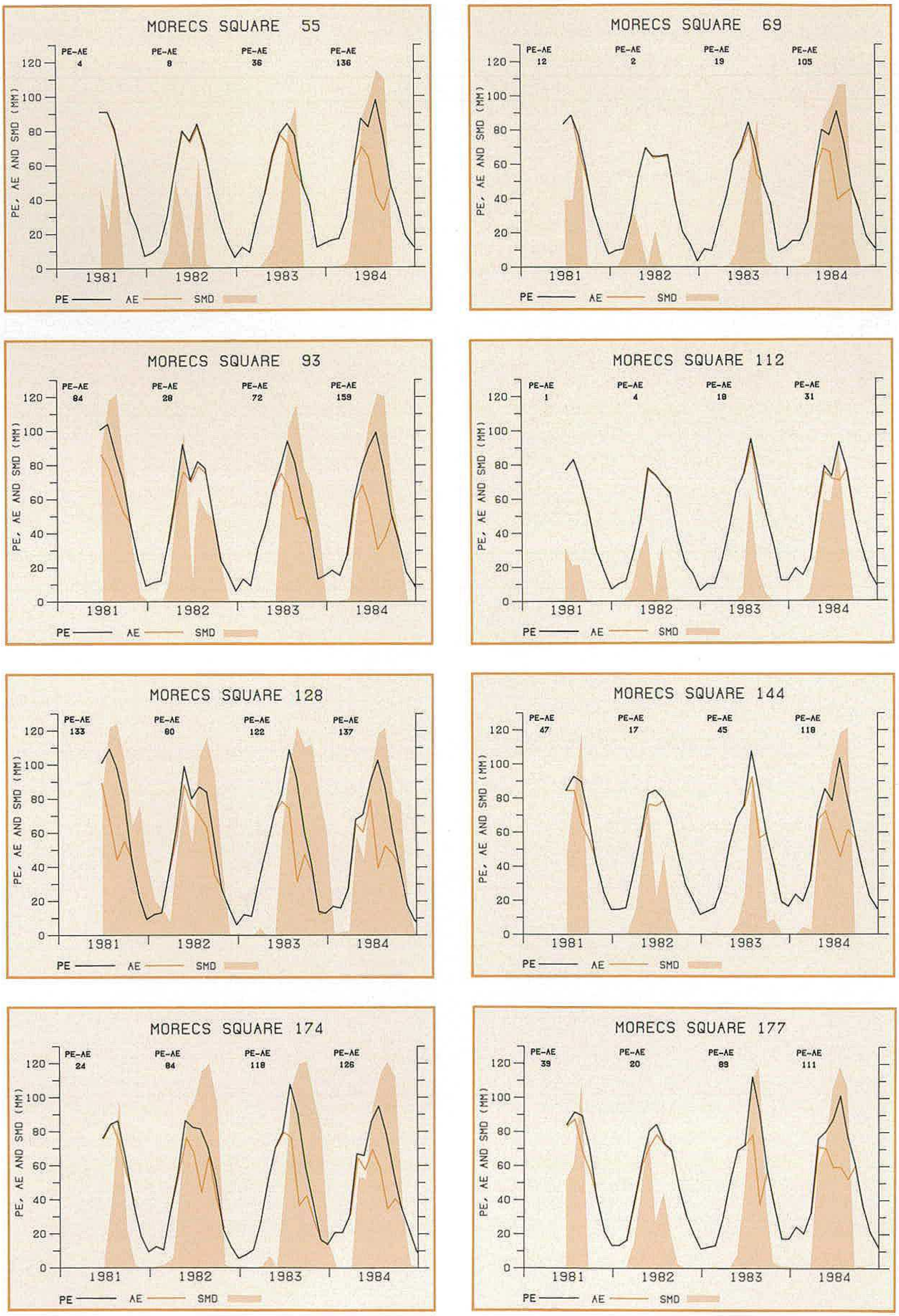


Figure 22. Soil moisture deficit with potential and actual evaporation for eight MORECS squares.

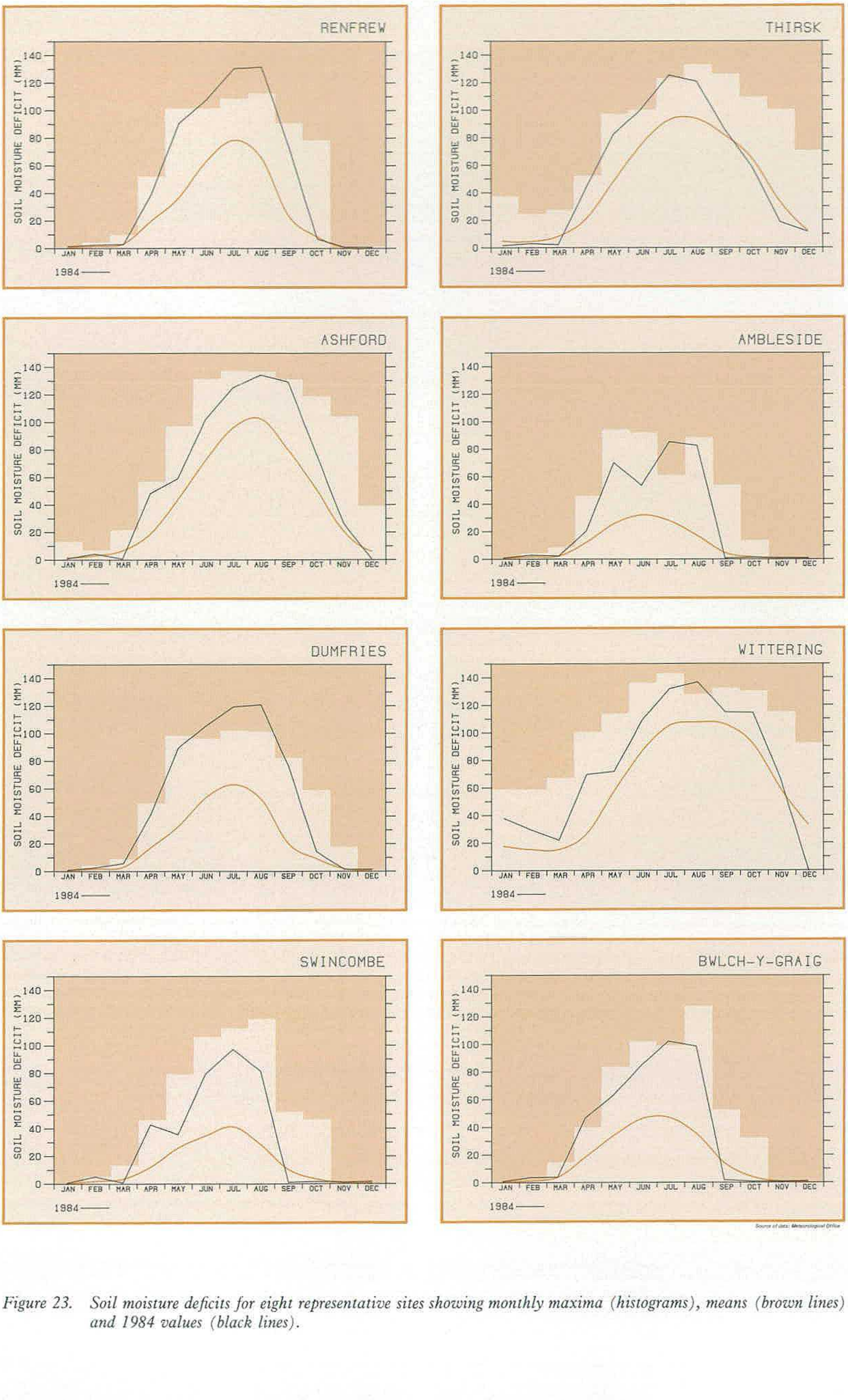


Figure 23. Soil moisture deficits for eight representative sites showing monthly maxima (histograms), means (brown lines) and 1984 values (black lines).

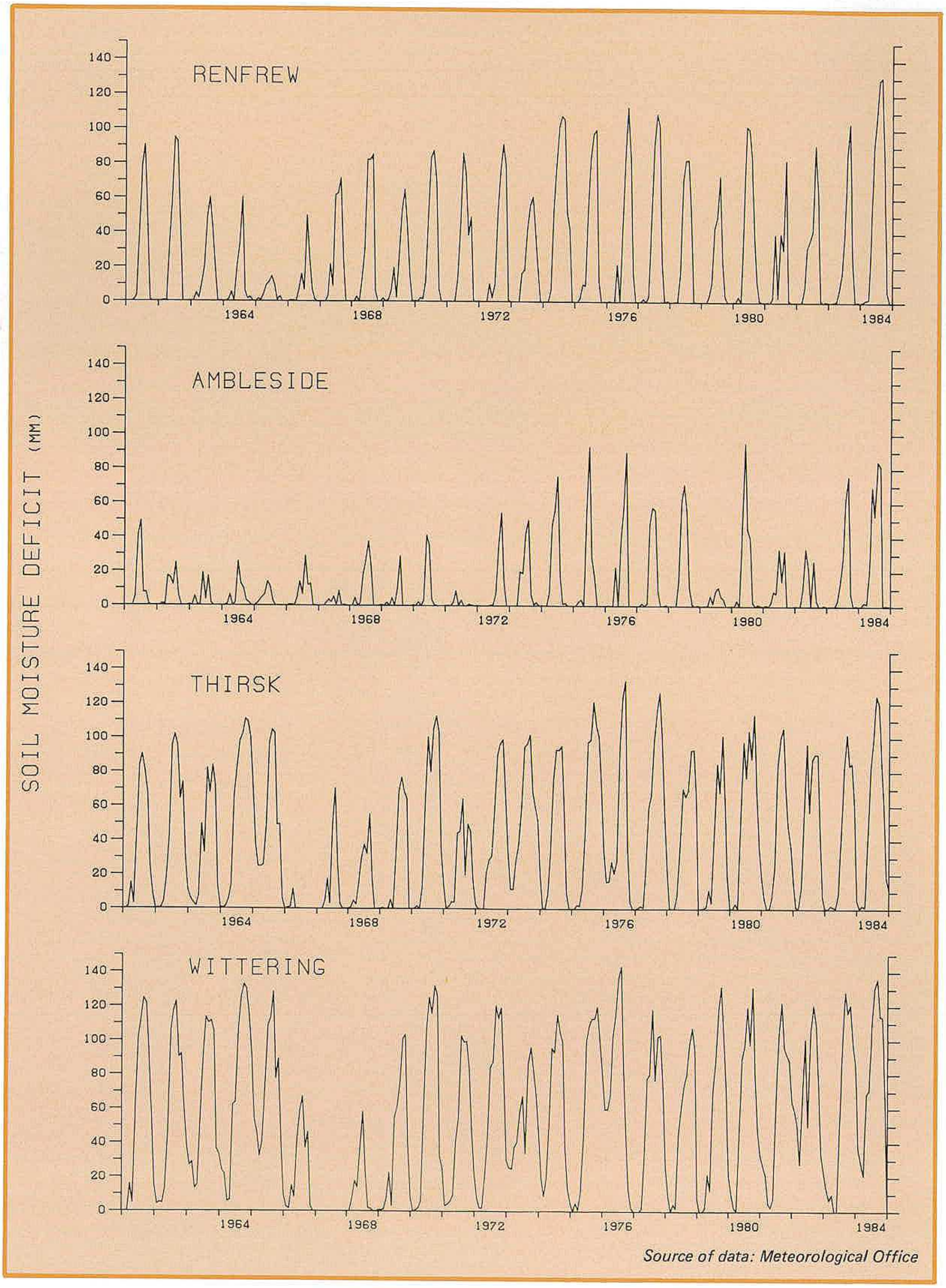


Figure 24. Soil moisture deficit 1961–84 for four representative sites.

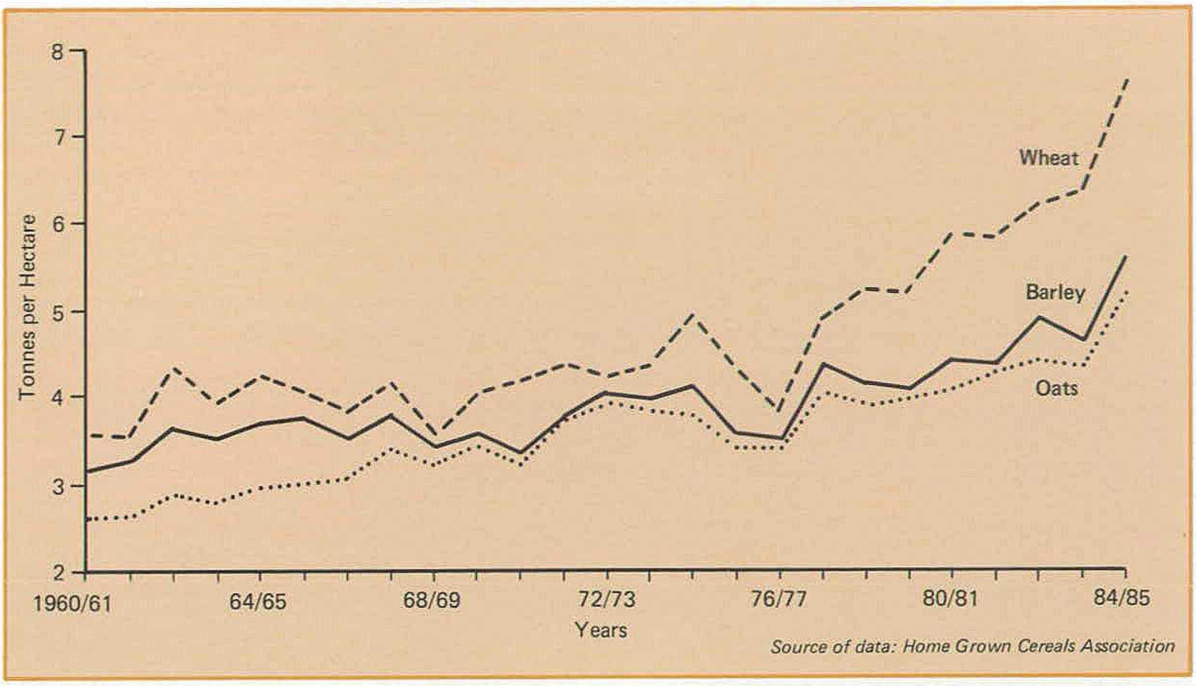


Figure 25. Annual crop yields for winter sown cereals 1960–84.

TABLE 9. CUMULATIVE MONTHLY RAINFALL AND RUNOFF FOR THE TWO PLYNLIMON CATCHMENTS SHOWING THE YEARS OF THE TWO DRIEST OCCURRENCES

CUMULATIVE RAINFALL (mm)

	WYE (data from 1969)				SEVERN (data from 1971)			
Duration (months)	Driest	Year	Second driest	Year	Driest	Year	Second driest	Year
1	12.3	1976	12.4	1974	13.0	1976	16.2	1974
2	71.0	1984	113.9	1976	75.6	1984	136.4	1976
3	117.7	1984	158.8	1976	138.7	1984	181.2	1976
4	167.6	1984	314.4	1976	230.7	1984	342.0	1976
5	214.4	1984	369.8	1976	274.1	1984	379.9	1976
6	383.3	1984	521.6	1976	419.0	1984	538.2	1976

CUMULATIVE RUNOFF (mm)

	WYE (data from 1969)				SEVERN (data from 1971)			
Duration (months)	Driest	Year	Second driest	Year	Driest	Year	Second driest	Year
1	11.3	1976	14.8	1975	11.3	1976	14.0	1974
2	42.3	1984	45.9	1976	34.4	1984	40.4	1976
3	63.5	1984	72.2	1976	51.0	1984	60.6	1976
4	88.9	1984	147.0	1976	74.0	1984	112.9	1976
5	120.9	1984	241.0	1976	100.3	1984	189.0	1976
6	178.8	1984	314.1	1976	152.9	1984	241.6	1976

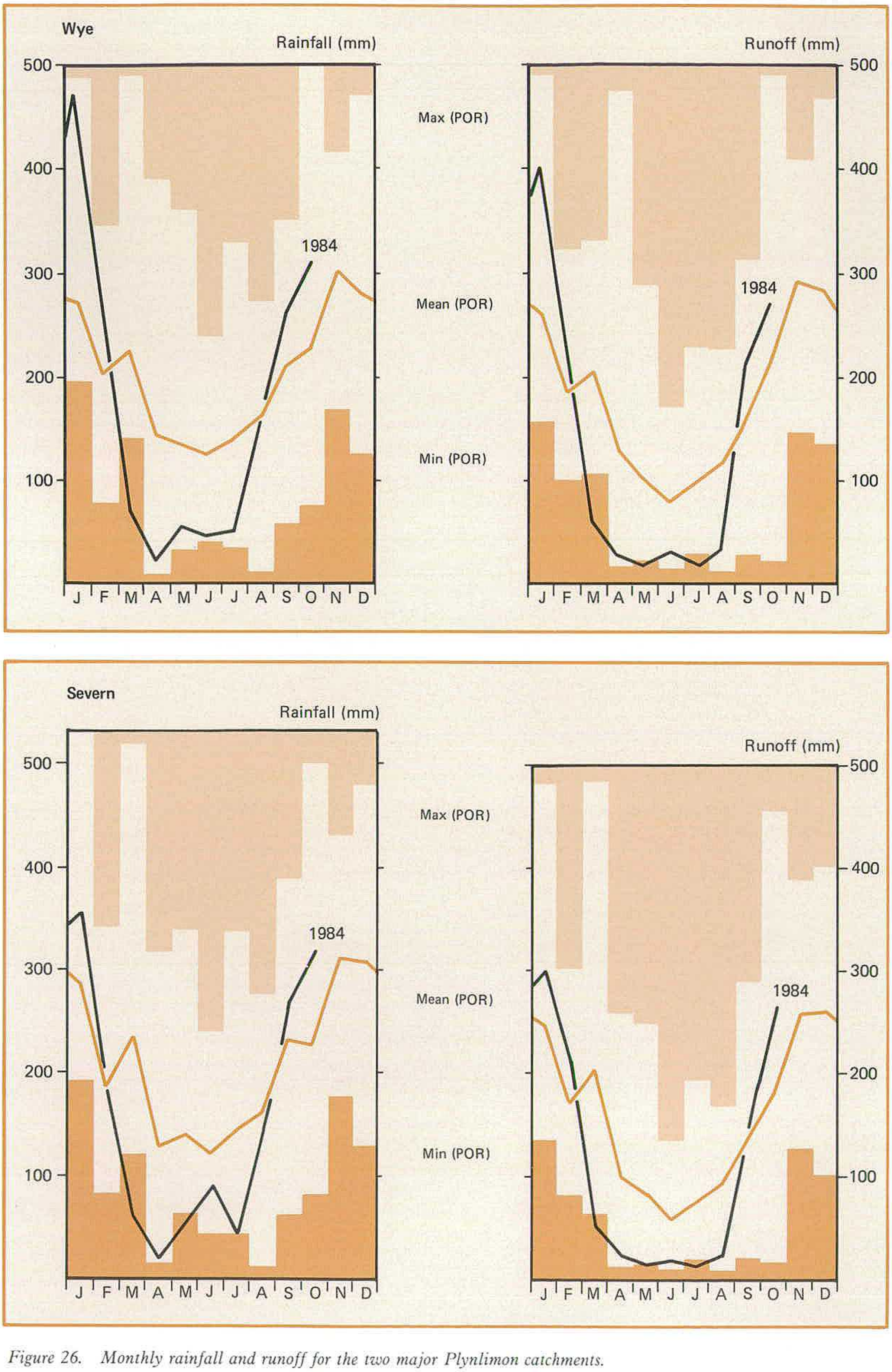


Figure 26. Monthly rainfall and runoff for the two major Plynlimon catchments.

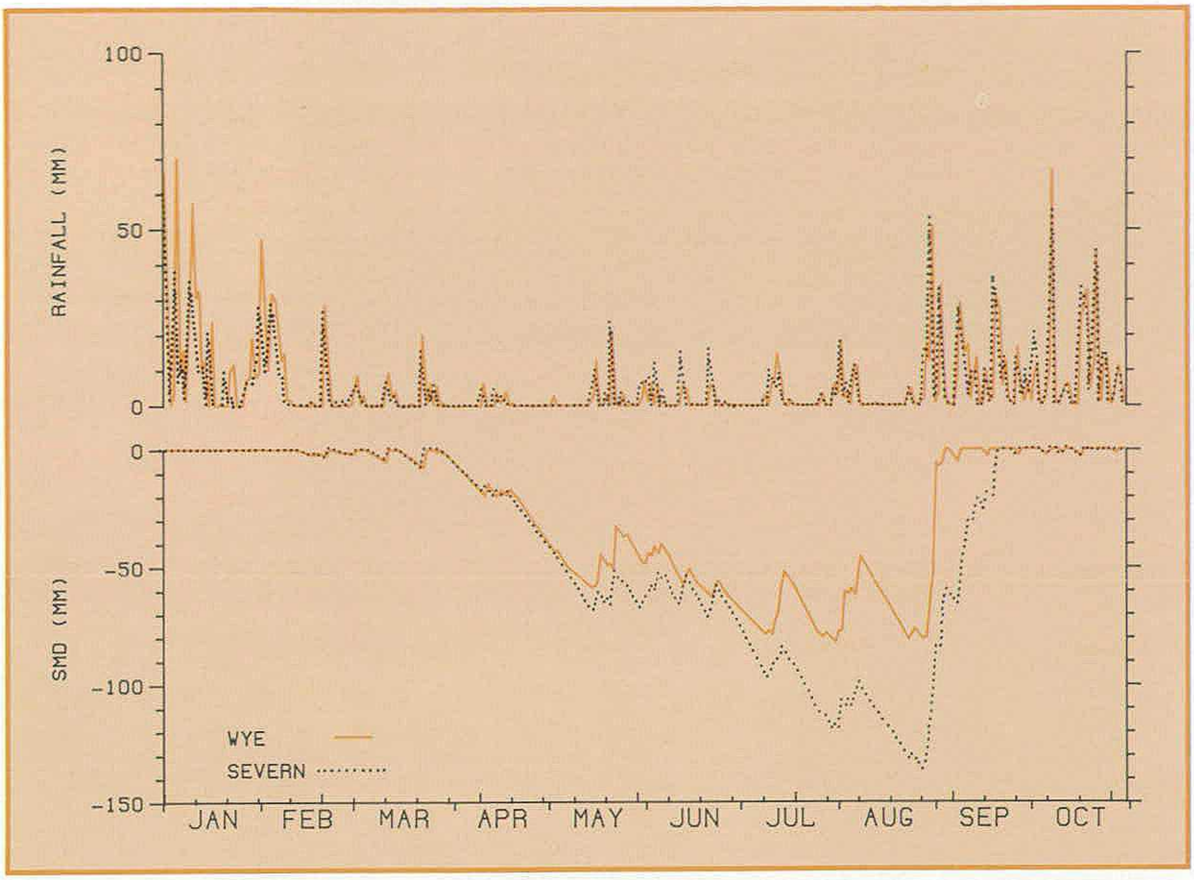


Figure 27. Daily rainfall and soil moisture deficit for the two major Plynlimon catchments.

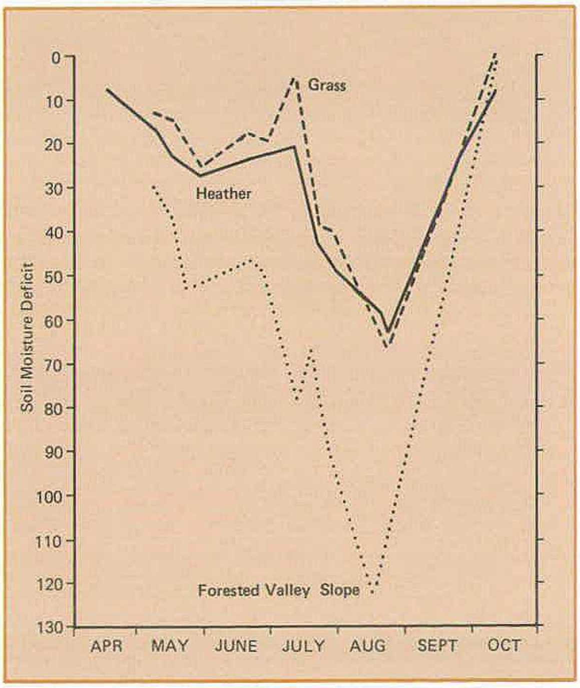


Figure 28. Soil moisture deficits under varying covers, Balquhidder.

It is understandable that drought periods are assessed and compared on the basis of rainfall figures. A dense network of raingauges, many with long records, provides a ready means of depicting dry conditions. In water supply terms, however, runoff is the most significant hydrological variable. The refilling of reservoirs and the availability of sufficient river discharge to sustain direct abstractions, provide for the dilution of effluents and to promote a healthy aquatic environment depends on the adequacy of runoff.

Problems with low flow measurement

It should be recognised that river flow measurements tend to become more imprecise at very low discharges. Minimal velocities and luxuriant weed growth leading to drowning of controls infer insensitive or imprecise stage-discharge relations. These have always been problems; their effects will have been more severe in the earlier years of the longer historical flow sequences. Instrumentation and gauging techniques have improved in recent decades, but lower staff numbers in water authorities means both lower standards of maintenance and less frequent confirmation of stage discharge relation by direct measurement. In addition, it is at the lower flow rates that abstractions and effluent returns have their greatest impact on the natural flow regime. Drought flows, especially in the more densely populated regions, need to be considered against an evolving pattern of water exploitation within individual catchments. Increasingly, flows in rivers used for water supply purposes may be augmented by water transferred from beyond catchment boundaries. Augmentation may be from reservoir networks, other rivers or from aquifers. In 1984 for instance, the River Severn's flow was supported by early implementation of Phase I of the Shropshire Groundwater Scheme.

1984 Runoff summary

The seasonal contrasts in runoff resulting from the greater hydrological effectiveness of winter rainfall were present to an exaggerated degree in 1984. Figure 29 illustrates the distribution of river flow for the Clyde throughout the year compared with the average sequence of flows. Very high flows characterised January and February and the autumn of 1984 whilst extremely low discharges obtained throughout the late spring and the summer. The runoff pattern exhibited by the Clyde was typical of many rivers throughout the United Kingdom; although in southern and eastern England runoff was not greatly diminished in those areas where groundwaters contribute a substantial proportion of total streamflow. Ranked spring and summer runoff for six representative catchments, in the most affected regions, have been assembled in Table 10 together with the corresponding averages for the period of flow record.

A further indication of the abnormality of the 1984 flow regime for a particular gauging station may be obtained by re-assembling the daily mean flows in reducing order of magnitude and constructing a flow duration curve (Fig. 30) which allows the proportion of time a river falls below a given threshold to be identified. Whilst the flow exceeded for half the time in the River Nith at the Friars Carse gauging station was comparable for both 1984 and the whole 25 year record, the flow exceeded 95% of the time in 1984 was less than half the whole record figure. The 95% exceedence flow is commonly used to assess the availability of dilution for effluent discharge and the likelihood that a given level of abstraction can be safely maintained. Table 11 illustrates the impact of the 1984 river flows on the exceedance flow for selected gauging stations in the Clyde River Purification Board's area. Inclusion of the 1984 low flows is seen to reduce the 95% exceedance flow by greater than 15% at sites with limited lengths of record.

Development of the drought

A profile of runoff during the drought is given on pages 42 and 43 and an understanding of the distribution of runoff may be obtained by reference to the 1984 hydrographs on page 73 and the monthly runoff totals given in Table 12.

Scale of the runoff deficiency

In a normal year total runoff over the United Kingdom is approximately 450 mm; runoff from Scotland is about twice that for England and Wales. From October 1975 to September 1976 a record minimum recorded runoff for England and Wales of 202 mm was experienced with a return period which has been variously estimated as between 50 and 200 years[7,12]. Considered over the water year as a whole, 1983/84 was unremarkable with runoff about 20% below average. However, the spring and summer of 1984 witnessed extremely rapid falls in runoff rate and by August even some of the 1976 record low flows had been superseded. Monthly ranked runoff figures are presented in Table 12. New record minima are boxed.

Consistent with the United Kingdom rainfall pattern in 1984, rivers in Scotland, Northern Ireland, Wales and the upland regions of England were the most affected by the drought. Generally these rivers drain catchments which are characterised by relatively steep slopes, thin soil cover and a very limited groundwater contribution to river flow. Consequently any rainfall deficiency quickly results in a decrease of runoff. To a lesser degree flows in the highland regions may be sustained through the spring partly from snowmelt; the accumulation of snow in early 1984 was particularly heavy in the Cairngorms.

Regional variation in runoff deficiency

The regional contrasts in runoff deficiency for England and Wales over the period April to August 1984 are shown in Fig. 31. The map is based on the recorded runoff from thirty index catchments and the rainfall pattern over the whole period. The generalised isopleths are valid on a regional basis but there was considerable variation on a local scale as a result of differing patterns of rainfall and differing potential between catchments for the sustaining of flows during drought. As expected, the runoff deficiency in southern England was considerably greater for rivers draining the clay vales than the Chalk downlands.

Table 13 provides a ranking of the ten lowest April to August runoff totals for a selection of catchments. It confirms that April to August flows in 1984 were the lowest on record in parts of Scotland, Wales and Northern England.

Cumulative runoff as a drought indicator

The cumulative runoff diagrams presented in Fig. 32 emphasise the seriousness of the 1984 drought in important reservoired catchment areas of the Lake District and Wales and its modest intensity elsewhere. On the Thames and Bedford Ouse April to August runoff in 1984 exceeded historical drought sequences by a wide margin. In Scotland the long record available for the natural inflow to Loch Leven, in Fife, shows that runoff from April to August was 65 mm or about 35% of the average from a record extending back to 1855. There have been ten drier five-month sequences from April than that experienced in 1984, but the recent drought is the driest in the last 35 years, with significantly lower runoffs than those recorded during the central Scotland droughts in the early 1970s.

Notable flow sequences recorded in 1984

Whilst the rankings given in Table 13 need to be viewed with caution because of the variable record length of different gauging stations, the drought's impact was clearly marked in Scotland, Wales and Northern England. Elsewhere, 1976 saw lower runoffs, substantially so in the south and east of England. The 1984 drought was of too short a duration to seriously deplete flows on rivers such as the Thames and Bedford Ouse which have large baseflows.

However, flows varied appreciably throughout the spring and summer in 1984. Tables 14 and 15 present minimum 10 day, 30 day, 90 day and 180 day average flows for selected gauging stations ranked alongside the driest such sequences in the period of record. Apart from the Conwy, the 10 day and 30 day minimum flows in 1984 are higher than historical minima, particularly on the River Leven where the 1984 minimum discharge over 30 days ranks only 12th in a 46 year record. Over the longer durations there is a tendency for the 1984 flows to be more notable; the River Tweed, for instance, established a new 180 day minimum by an appreciable margin.

For the Rivers Nith and Taw, the ten highest ranked flow sequences in their records are also listed in Table 16. As a consequence of the remarkable range of river flows recorded in 1984, the year is present in both the minimum and maximum 'n' day sequences.

Frequency of occurrence of low flow sequences

Table 12 provides a rough guide to the likely frequency of low river flows in particular catchments. However, it is possible to examine return periods within a more rigorous statistical framework. The analysis of rainfall has shown that the likely frequency of 1984 sequences depends on both location and the duration being studied. This is also the case with river flows although it is important to note that, because of the natural and artificial storage available in each river basin, the frequencies of low flow events for comparable periods may differ substantially from those established from rainfall data. The frequency associated with the runoff sequence may be considerably greater, particularly for droughts of relatively short duration.

Selection of an analytical scheme

It is usually possible to tailor the analysis of flow data to the characteristics of the water supply scheme or to the water quality problem. The severity of a drought will therefore depend on the precise characteristics of particular resource schemes. The ability to examine drought frequency for specific requirements is illustrated by the following examples:

(a) Water quality considerations: these will generally be related to the minimum river discharge over durations varying between 1 and 90 days when perhaps the dilution of sewage effluent is critically reduced.

(b) Direct supply impounding reservoirs: the cumulative difference between reservoir inflow and yield from the reservoir will determine the volume of reservoir drawdown and hence the severity of the drought. Individual reservoirs will of course have different yields and different storage volumes and hence drought severity may vary between the reservoirs in an area.
(c) Pumped storage reservoirs: if pumping is dependent on river flows being in excess of a prescribed flow, then the number of days the discharge is below this level and when pumping must cease is the critical aspect of the drought.
(d) Regulating reservoir: if a regulating reservoir supports a river abstraction controlled by a statutory maintained flow then the cumulative discharge below this maintained flow is critical.

It can be seen that as the complexity of a supply scheme increases so the estimate of drought severity becomes more site specific. For general water quality, fisheries and simple water supply abstraction schemes, however, two measures or methods of characterising droughts may be used to assess the severity of the 1984 drought. First, flow frequency curves derived from an analysis of annual minima provide a general assessment of drought severity for a wide range of applications. Second, in the case of direct supply reservoirs, a simulation of reservoir behaviour for different yields.

Use of the flow frequency curve

Figure 33 shows a flow frequency curve for the River Nith gauged at Friars Carse for the period 1958 to 1984. The curves show the average interval in years (return period) between which the flow falls below a given discharge. The plots may be derived for the lowest daily discharge in each year or from flows averaged over longer durations. Five such plots are shown for durations of 10, 30, 60, 90 and 180 days. The procedure for producing such diagrams is summarised in Appendix IV and is described fully in the Low Flow Studies Report[15].

The return period axis allows the frequency of any particular annual minimum to be estimated. For instance, the 90 day minimum flow on the River Nith in 1984 has a return period of approximately 50 years.

The above analysis was repeated for a number of rivers and Table 17 shows estimates of the return period of the 1984 drought for each of five durations. Return periods were generally 10 years or less for all stations in central and eastern England, whilst in the north and west the 1984 drought was more severe. Differences in drought frequency in the same river but for different durations were generally small. In south western England and southern Wales the highest return periods are for the 90 days duration; in north western England and southern Scotland, return periods are highest for the longest duration. If one considers Fig. 13 for the rainfall return periods, then one may see that few of the chosen gauging stations are situated within the areas which have high return period rainfalls. This arises because few long record stations exist in such areas. Stations which do gauge the uplands, whether such as Vyrnwy, which is an upland gauge, Newby Bridge or Friars Carse, which contain uplands in the catchment, show return periods in excess of 50 years for the 180 day duration. Many highland rivers could be expected to have experienced flows of comparable severity to the above three examples during 1984.

Storage yield analysis

The severity of the 1984 drought in terms of the depletion of reservoir storage can be estimated by carrying out a computer simulation of how the reservoir would have behaved when subjected to a historical sequence of inflows. The reservoir need not exist; a runoff record and a notional yield from the catchment are all that are required. A constant gross yield (net yield plus the compensation discharge) is assumed; in practice, demand on a reservoir may be reduced as a drought intensifies (see *Reservoirs*, p. 55). An outline of the simulation procedure is given in Appendix IV.

By expressing the yield as a percentage of the mean discharge and the storage as a percentage of the mean annual runoff, storage yield relationships derived from different flow records may be compared and their results applied to nearby reservoired catchments. Figure 34 depicts such a storage yield diagram for the River Nith. The values of the storage requirement for a hypothetical reservoir on the Nith are shown for 1984 corresponding to four different yields. Furthermore, the return period of each storage requirement can be estimated from the figure; for example, to sustain a yield of 40% of the average daily flow (ADF) during the 1984 drought, which had a return period of about 30 years, would have required a reservoir with a notional capacity of about 12% of the annual runoff volume (ARV). This analysis was repeated for a number of different flow records and the results are summarised in Table 18.

Runoff deficiency indices

It is possible to design similar drought indices to those presented in the chapter on rainfall by utilising runoff data to give a more direct estimate of a drought's magnitude in hydrological terms. Unfortunately runoff records tend to be rather short and so largely preclude historical comparisons.

In the wetter highland regions of the United Kingdom drought indices based on rainfall or runoff deficits would show broadly similar results. Large differences could be expected in south eastern England however, where annual potential evaporation approaches total annual rainfall. Additionally, the runoff delay in response to rainfall may be considerable in those river systems draining permeable catchments where baseflow is a significant component of river discharge (see Table 20, p. 69).

A runoff index for the Thames, which has the longest continuous discharge record in the United Kingdom, is presented in Fig. 35; a runoff deficit is considered to start when discharge falls below the monthly average and to be terminated when flows return to 90% of the monthly average. Only drought events having a maximum index score in excess of 180 are illustrated. Because of the buffering effect of groundwater storage there is appreciable persistence in low flows and large departures from the mean may accumulate in dry periods. Isolated months of wet weather, especially when evaporation rates are at their highest, may have a very limited impact on river flows, which consequently can remain below normal for many months. This is illustrated by the 1901/2 naturalised flows (that is, flows adjusted to account for abstractions for London's water supply). The flows were below the mean from May 1901 until March 1903 despite May, June and August 1902 all being relatively wet. The key to the severity of the runoff drought was the very dry winter of 1901/2; similarly large runoff deficiencies have followed the dry winters of 1920/21, 1933/34, 1943/44 and 1975/76 when flows in the Thames remained significantly below average for 14 months. A wet winter has the opposite effect, sustaining river flows throughout the following seasons. A good example is 1984 when the runoff drought was of a negligible magnitude although rainfall itself was substantially below average over the June to August period.

The influence of a wet winter is even better illustrated using data from the river Mimram, a spring-fed chalk stream, where the extremely wet winter of 1974/75 helped to augment flows throughout the ensuing drought (Fig. 36). As a result, the 1975/76 runoff deficit was less severe than the 1973 deficiency. The previous winter's rainfall similarly helped to maintain flows throughout the spring and summer of 1984; the 1984 drought registered a runoff index score of less than 180 but is shown on Fig. 36 to emphasise the modest nature of the drought in catchments of this type.

Characteristics of runoff patterns in recent years

Since the 1975/76 drought, runoff, considered on a yearly basis, has remained above average throughout the United Kingdom and has been associated with an abnormally large seasonal variability in river flows. The apparent trend identifiable in Fig. 37 is primarily the result of the notably low runoff in the twelve months from October 1975. It is clear nonetheless that runoff in the seven years preceding the 1984 drought was substantial, typically 10–20% above average. This enhanced runoff was particularly noticeable in the wetter regions of the United Kingdom, exemplified by the River Nith basin, but was evident also in drier areas like the river Nene catchment. The tendency for summers to be drier and autumn runoff to be high is illustrated in Fig. 38. Both the river Nith in Galloway and the Taw in Devon show a greater range of discharge since 1979 resulting from a seasonal shift in rainfall patterns. An increase in winter runoff and a decrease in summer runoff has also been recognised in an examination of the inflow records to reservoirs in the North West Water Authority area[16]. This shift may be only a temporary feature but it calls into question the degree to which river flow data, much of which has been assembled over the last twenty years, fully represents the complete range of flows to be expected in the rivers of the United Kingdom.

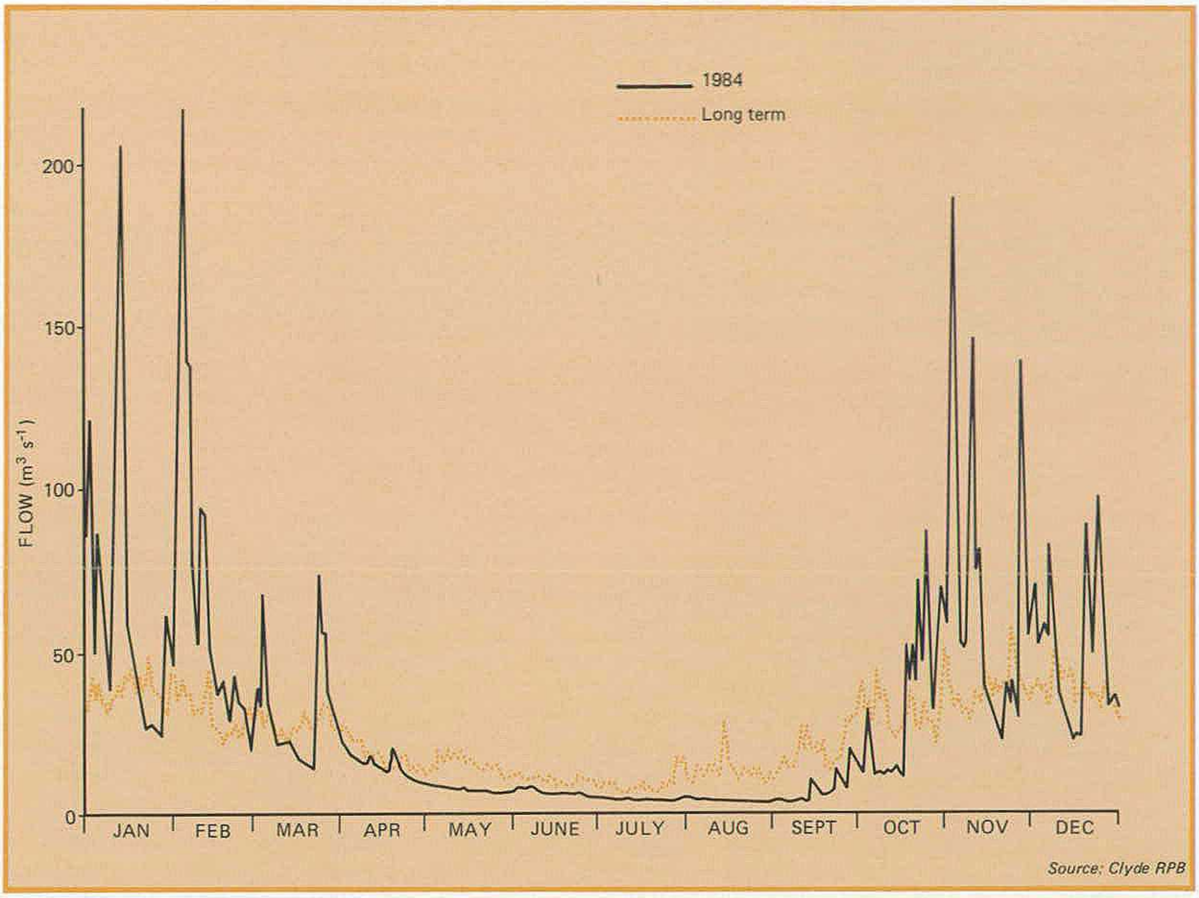


Figure 29. 1984 and average daily flows for the River Clyde at Hazelbank.

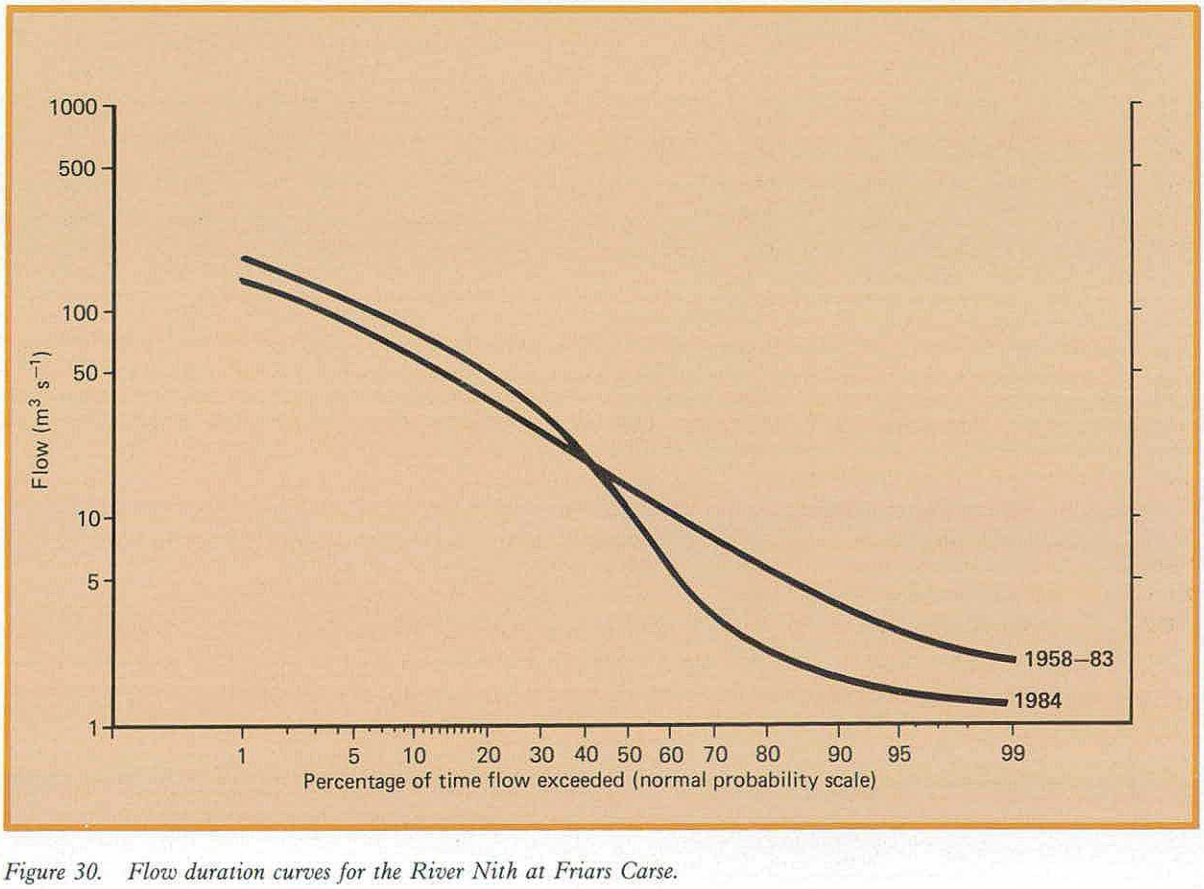


Figure 30. Flow duration curves for the River Nith at Friars Carse.

TABLE 10. 1974 SPRING AND SUMMER RUNOFF FOR SELECTED CATCHMENTS

25006					28018			
March - May		June - August		Rank	March - May		June - Aug	
mm	year	mm	year		mm	year	mm	year
100	1984	18	1976	1	58	1976	23	1976
101	1976	27	1975	2	80	1984	36	1984
112	1974	36	1984	3	91	1973	36	1975
116	1980	46	1964	4	92	1968	40	1977
119	1975	54	1977	5	99	1978	62	1970
134	1973	57	1979	6	109	1975	65	1980
150	1961	60	1968	7	118	1980	66	1978
153	1970	64	1978	8	118	1971	70	1979
154	1971	66	1969	9	120	1962	79	1962
177	1964	71	1970	10	126	1963	81	1969
200		86		Average	127		77	

50001					57004			
March - May		June August		Rank	March - May		June - Aug	
mm	year	mm	year		mm	year	mm	year
48	1984	9	1976	1	85	1965	39	1976
73	1974	10	1984	2	94	1984	40	1984
75	1976	14	1975	3	110	1974	49	1975
78	1973	18	1959	4	129	1958	60	1977
94	1971	21	1961	5	131	1975	68	1978
97	1962	22	1983	6	145	1976	69	1961
98	1965	23	1962	7	158	1973	93	1960
103	1968	26	1974	8	158	1971	97	1965
106	1959	29	1964	9	207	1969	103	1983
120	1961	30	1978	10	209	1964	104	1981
140		48		Average	254		115	

73010					79002			
March - May		June - August		Rank	March May		June - Aug	
mm	year	mm	year		mm	year	mm	year
111	1984	48	1984	1	89	1975	20	1984
180	1974	94	1976	2	108	1971	39	1977
184	1946	104	1983	3	111	1974	41	1975
197	1980	111	1968	4	112	1958	49	1983
206	1953	144	1977	5	113	1984	55	1973
223	1975	144	1940	6	116	1969	56	1978
225	1956	147	1978	7	119	1980	56	1976
235	1944	158	1975	8	135	1962	58	1982
255	1969	158	1941	9	161	1970	64	1974
255	1958	159	1969	10	163	1973	70	1968
341		255		Average	196		100	

25006	Greta at Rutherford Bridge	21 years of record
28018	Dove at Marston on Dove	20 years of record
50001	Taw at Umberleigh	26 years of record
57004	Cynon at Abercynon	26 years of record
73010	Leven at Newby Bridge	46 years of record
79002	Nith at Friars Carse	27 years of record

TABLE 11. THE AFFECT OF 1984 RIVER FLOWS ON THE 95% EXCEEDENCE FLOW (Q95)

Station Number	River	Length of Record Years	Total No. of days ≤ Q95 1984	Total No. of days ≤ Q95 Highest in record	Change in the Q95 flow when 1984 flows are included (%)
082001	Girvan	22	104	104 (1984)	− 9.5
082002	Doon	15	126	126 (1984)	− 4.8
084013	Clyde	22	90	90 (1984)	− 3.5
086002	Eachaig	15	64	64 (1984)	−12.8
084019	North Calder	22	57	62 (1976)	+ 0.5
084022	Duneaton	18	86	86 (1984)	− 7.0
085003	Falloch	15	35	40 (1975)	− 8.9
084020	Glazert	16	93	93 (1984)	−11.4
084023	Bothlin	12	131	131 (1984)	−15.3
084016	Luggie	9	100	100 (1984)	−16.0

Source: Clyde River Purification Board

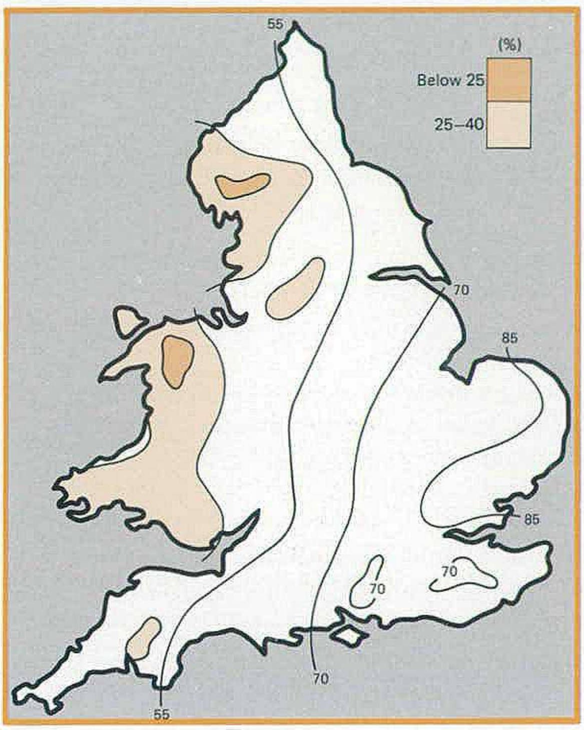


Figure 31. April to August 1984 runoff as a percentage of the average.

SEASON/WEATHER	ENGLAND AND WALES
January-February	
Cyclonic westerlies. January wet; 150–200% of long term average (LTA) February variable, lowest in the north east and the south west where ≤70% LTA	New maximum January runoff recorded in the Tone at Bishops Hull (Somerset). New maximum February runoff recorded in the Taw at Umberleigh (Devon). This is a responsive catchment with low catchment storage.
March-May	
Rain below average in the west, between 60–80% LTA South and the east above average. 4th driest April this century in most areas; ≤25% of LTA. End of May wet.	Runoff generally 50–75% of average in March. River Taw equals lowest recorded March runoff at Umberleigh (see above!). Recessions steep in the west. The Rivers Fowey (Cornwall), Yscir (Gwent), and Conwy (Gwynedd) recorded new minima for March. For these rivers, March 1984 runoff lower than the corresponding totals in March 1976. The very dry April meant that responsive rivers had very steep recessions. In addition to the above, the Wharfe (Yorkshire) flowed at about 25% of normal in April. The Leven (Cumbria) recorded 60% of previous minimum March to May runoff. Baseflow fed rivers were less affected or close to normal; the River Derwent (Yorkshire) draining the oolitic limestone flowed at 60% of average in May; the Mimram (Herts) and the Itchen (Hampshire) were close to average.
June-August	
Wet early June; then generally dry. Thunderstorms most frequent in the south and east. July was the 5th driest this century. Wet start to August.	Substantial runoff in the Rivers Roding (Essex) and Stour (Suffolk) at the start of June. Recessions soon re-established in the west and north. River Fowey recorded the fourth consecutive monthly minimum in June; new record low for the Taw and the Conwy. Oddities in Hampshire; the Test approached the 1976 low flows but the neighbouring Itchen was still at 90% of average in July. River Stour (Dorset) records the second lowest runoffs in July and August. The Wharfe close to the minimum daily low flows in July and August. Yscir and Conwy similarly. The River Lune (Lancs) recorded new daily minima in both July and August. The River Kent downstream of Sedgewick (Cumbria) recorded negligible flows as a sink hole intercepted the bulk of the flow. Similar effects recorded elsewhere in the limestone catchments of the Pennines. Runoff in the period generally less than 25% of LTA and as low as 10% in some areas; a large proportion concentrated in the last two weeks of August. Runoff in Wales and the West Country was as low as 1976 levels. Runoff in North West England unprecedented. The Leven summer runoff at 111 mm was 70 mm less than the previous record in a 50 year span.
September-November	
September rainfall well above average except for Southern Water Authority. October generally average. November well above average.	River flows picked up rapidly in September; most were flowing above average by the end of September. November flows all high and well above average. Flooding reported. River Caldew (Cumbria) overtopped its banks in November, the highest for 16 years.

SCOTLAND AND NORTHERN IRELAND

SEASON/WEATHER

January–February

Cyclonic westerlies. January rainfall 150–200% of LTA.

February 150% LTA in the Province; Scotland about average.

River Agivey (Londonderry), a low storage catchment had record low flows in November 1983. January 1984 was well above average. The River Camowen (Tyrone) recorded its highest January runoff.

The River Nith (Dumfriesshire) recorded a new February maximum. River Agivey recorded new February maximum. Both responsive catchments.

March–May

North west Scotland and the west of the Province the wettest areas in April. The rest of the Province ≤45% LTA. Scotland predominantly ≤40% LTA in May, especially the south-east.

River Agivey at Whitehill records new March minimum! The River Braid (Antrim) has valley gravels which sustain river flows when stage falls; flows being maintained above average well into the spring. Spring runoff in Scotland about normal. Later start to flow recessions than in England and Wales. Significant snowmelt component, especially in the Highlands.
Fish kills reported in the Clyde RPB area resulting from large diurnal fluctuations in dissolved oxygen due to excessive weed growth.

June–August

Scotland generally dry in June.

Nothern Ireland about 70% of LTA but June total≥ April–May

July and August both dry in Scotland. All RPB's ≤ 50% of LTA in August.

Shrinking river networks as headwaters are progressively reduced and springs fail. A number of Scottish rivers reported dry in July. Runoff in parts of the central lowlands down to 0.3 l/s/sq km – corresponding to southern England at the end of the 1976 drought. The River Nith was below previous minimum summer flows from mid July throughout August. Many Scottish rivers have augmented low flows from Hydro-electric power schemes. The Tay area rivers (Tay, Earn, Isla) all recorded new minima since the introduction of the HEP schemes, but the flows were above the (pre-HEP) flows in 1955. Many rivers in the Clyde valley record very long sequences of daily flows below the 95 percentage; periods in excess of 8 weeks are relatively common. The River Dee's (Grampian) lowest flow on 29 Aug. was comparable with that recorded in 1976 at a similar date and represented 25% of the modal flow in August. Spray irrigation increased markedly; in Scotland this is largely uncontrolled and many smaller streams dried up downstream of abstractions or were sustained by sewage outfalls. River Agivey recorded a new minimum in July. River Braid maintained at 80% of average with its large baseflow. Summer runoff over large areas of Scotland unprecedented; below previous minimum by a wide margin.

September–November

Southern Scotland nearly average, the rest well above average in September. Average autumn rainfall in the Province. November in Scotland exceptionally wet.

Rapid changes in flow conditions in the uplands. The River Tay (Perthshire) rose 2 m after rainfall of 50 mm over the catchment. By November rivers above average. On the 3 and 4 November the headwaters of the Tweed (Roxburgshire) experienced 100 mm rainfall and the Rivers Gala, Leader and Jed all recorded new all time maximum flows. Further extremely high flows in the Tay basin. Very high autumn flows have been a feature of the post 1980 period; often, the majority of the highest flows on record have been registered in this period at gauging stations with less than 20 years of record.

TABLE 12. MONTHLY RUNOFF IN 1984 FOR SELECTED GAUGING STATIONS.

Runoff expressed as a percentage of the long term monthly mean with its corresponding rank in the record (Lowest = 1)

River	Gauging station	Record length		J	F	M	A	M	J	J	A	S	Min. Monthly Flow 1984 (month)	Min. Monthly Flow POR (mon yr)
S. Tyne	Haydon Br.	18	runoff	128	161	87	46	23	104	$\boxed{23}$	32	91	1.78	1.51
			rank	15	17	10	4	2	13	1	3	9	Jul	Aug 76
Greta	Rutherford Br.	20		112	220	84	22	12	57	$\boxed{13}$	44	106	0.09	0.09
				14	20	9	2	2	9	1	7	12	Jul	Jul 84
Derwent	Buttercrambe	10		132	130	93	82	58	69	65	55	90	4.45	3.22
				9	8	6	5	3	2	2	2	6	Aug	Aug 76
Wharfe	Addingham	10		123	165	43	38	$\boxed{20}$	81	$\boxed{30}$	25	87	1.25	1.14
				10	9	2	3	1	4	1	3	5	Jul	Aug 76
Derwent (Derbys)	Longbridge	41		160	160	75	63	58	65	43	50	61	4.48	3.18
				40	35	14	7	5	10	3	5	7	Aug	Aug 52
Dove	Marston	19		132	163	75	58	46	53	41	42	47	3.54	1.91
				18	17	6	3	2	3	2	4	4	Jul	Aug 76
Ise Brook	Harrowden	38		115	120	73	63	51	68	43	50	61	0.25	0.11
				25	27	17	12	14	15	7	8	9	Jul	Aug 76
Stour (Essex)	Langham	21		167	157	70	66	89	199	108	119	130	0.93	0.19
				20	18	10	9	14	21	13	14	19	Aug	Jul 76
Roding	Redbridge	33		115	83	85	60	99	97	67	68	110	0.4	0.22
				21	17	15	14	24	25	9	7	26	Jul	Aug 76
U. Lee	Waterhall	12		132	114	106	90	96	133	109	121	147	1.02	0.28
				11	8	5	5	5	11	9	7	13	Jul	Aug 76
Thames (Natura-lised)	Teddington/ Kingston	101		104	95	89	78	93	92	77	81	92	25.37	9.96
		62		59	50	49	37	53	56	34	36	57	Aug	Aug 76
Itchen	Allbrook	23		94	104	101	101	98	95	90	90	90	3.36	2.33
				11	13	12	9	9	9	6	4	7	Aug	Jul 76
Stour (Hants)	Throop	11		140	100	70	70	62	64	58	57	$\boxed{42}$	2.41	1.36
				10	7	4	4	4	4	2	2	1	Sep	Aug 76
Dart	Austins Br.	24		160	111	48	53	39	36	31	26	50	1.17	0.71
				24	15	2	4	4	3	2	2	8	Aug	Aug 76
Fowey	Restormel			133	98	$\boxed{39}$	$\boxed{48}$	$\boxed{39}$	$\boxed{37}$	$\boxed{48}$	37	$\boxed{27}$	0.45	0.34
				8	4	1	1	1	1	1	2	1	Aug	Aug 76
Taw	Umberleigh			176	126	$\boxed{35}$	40	22	$\boxed{25}$	$\boxed{16}$	15	46	0.79	0.42
				26	19	1	3	2	1	1	2	10	Aug	Aug 76
Tone	Bishops Hull			251	131	61	70	59	67	52	72	62	0.64	0.27
				24	19	6	6	3	6	2	4	4	Jul	Aug 76
Severn	Bewdley			134	116	55	44	44	56	43	39	53	10.0	7.46
				51	43	12	8	6	16	4	6	24	Jul	Aug 76
Yscir	Pontaryscir			177	119	$\boxed{31}$	39	28	60	$\boxed{32}$	24	73	0.13	0.10
				11	10	1	2	2	4	1	2	8	Aug	Aug 76
Cynon	Abercynon			182	122	44	35	30	46	$\boxed{34}$	25	36	0.43	0.39
				23	16	3	3	2	4	1	2	5	Aug	Aug 76
Leven	Newby Br.	[illegible]		138	130	40	34	15	47	12	$\boxed{6}$	54	0.7	0.55
				37	31	5	4	2	12	3	1	12	Aug	Jun 78
Clyde	Blairston	26		146	203	104	66	42	52	$\boxed{46}$	$\boxed{28}$	38	6.19	6.19
				20	26	17	7	4	2	1	1	6	Jul	Jul 84
Findhorn	Forres	26		105	147	98	132	48	41	$\boxed{28}$	19	214	2.64	2.48
				16	23	16	16	8	3	1	2	25	Aug	Aug 76
Agivey	Whitehill	10		104	166	77	$\boxed{47}$	$\boxed{12}$	$\boxed{24}$	$\boxed{15}$	41	38	0.11	0.11
				6	8	2	1	1	1	1	3	2	Jul	Jul 84
Camowen	Camowen Terrace	10		121	159	74	63	$\boxed{22}$	$\boxed{33}$	$\boxed{31}$	$\boxed{24}$	33	0.49	0.49
				8	9	3	5	1	1	1	1	2	Jul	Jul 84

TABLE 13. RANKED LOWEST AND AVERAGE APRIL TO AUGUST RUNOFF TOTALS (MM) FOR SELECTED CATCHMENTS

Station	Years of record	Average Runoff (mm)	Driest ranked sequences of runoff (mm)		3	4	5	6	7	8		10	1984 rank (if > 10)
			Year of occurrence										
Tweed at Norham	20	134	57	74	94	105	105	106	117	118	125	127	
			74	84	73	76	75	78	71	70	80	77	
South Tyne at	18	184	76	84	103	107	147	150	160	174	190	195	
Haydon Bridge			74	84	78	76	75	71	64	73	77	70	
Greta at Rutherford	21	190	55	83	117	118	120	141	153	171	177	185	
Bridge			84	76	75	64	74	78	68	180	77	70	
Derwent at		99	52	58	70	75	91	100	102	118	122	136	
Buttercambe			76	74	84	82	75	78	80	77	83	81	
Derwent at		140	67	82	89	89	91	98	100	115	116	117	
Longbridge Weir			76	84	74	57	52	50	59	44	60	40	
Dove at Marston		154	56	77	109	113	116	117	145	149	169	172	
on Dove			76	84	75	77	80	78	63	70	68	62	
Lud at Louth		109	31	52	54	84	85	90	102	106	123	126	
			76	74	73	71	72	82	77	84	75	70	
Nene Kislingbury		50	15	30	38	39	43	45	51	52	52	55	35
Branch			76	74	73	84	82	72	75	78	71	80	(14)
Bedford Ouse		51	8	9	13	17	18	18	21	22	23	24	44
at Bedford			34	76	44	38	45	43	49	56	46	57	(23)
Stour at		42	16	20	23	30	32	32	33	34	35	38	43
Langham			65	76	74	68	73	72	67	66	77	82	(15)
Roding at		45	15	15	21	24	25	25	26	27	27	34	36
Redbridge			76	57	60	53	74	59	56	61	54	72	(13)
Mimram at Panshanger	[illegible]	54	19	23	27	27	40	45	46	49	49	50	
Park			76	73	74	65	60	54	84	57	56	72	
Thames (Naturalised)	101	[illegible]	21	24	26	26	33	34	35	36	36	36	60
at Teddington/ Kingston			76	44	34	21	38	49	1899	29	1896	1891	(40)
Medway at Teston		[illegible]	14	27	29	38	40	40	41	45	47	47	
			76	57	74	61	65	59	72	84	81	62	
Itchen at Highbridge		184	100	130	143	154	165	170	174	175	177	180	
Allbrook Total			76	73	65	74	62	70	60	80	84	72	
Stour at		95	31	54	59	63	79	94	109	115	119	125	
Throop Mill			76	73	74	84	75	82	80	81	77	83	
Dart at Austins		320	104	129	175	191	210	252	276	281	283	299	
Bridge			76	84	75	82	71	80	78	74	77	59	
Fowey at Restormel two		159	72	90	121	133	134	147	151	168	184	231	
			84	76	82	75	74	73	77	80	78	83	
Taw at Umberleigh		120	33	34	50	72	84	91	94	96	97	102	
			76	84	74	82	59	64	62	71	75	73	
Tone at Bishops Hull		112	39	73	77	81	85	88	92	93	95	95	
			76	84	74	75	73	64	62	82	71	65	
Severn at Bewdley		104	39	47	50	52	54	55	60	68	69	73	
			76	84	74	44	21	29	33	75	38	64	
Yscir at Pontaryscir		145	62	67	102	131	162	165	166	169	170	173	
			84	76	75	82	80	77	78	81	74	73	
Cynon at Abercynon		245	84	104	118	152	177	191	203	205	207	220	
			84	76	75	65	77	78	82	74	78	80	
Weaver at Ashbrook			27	33	36	36	39	39	40	45	47	48	
			76	45	84	38	46	44	43	42	40	63	
Leven at Newby Bridge			101	233	243	264	287	308	311	324	330	382	
			84	74	78	82	76	80	40	75	41	83	
Nith at Friars Carse	27	204	57	93	93	106	115	142	166	174	177	183	
			84	75	74	78	82	71	73	76	59	83	

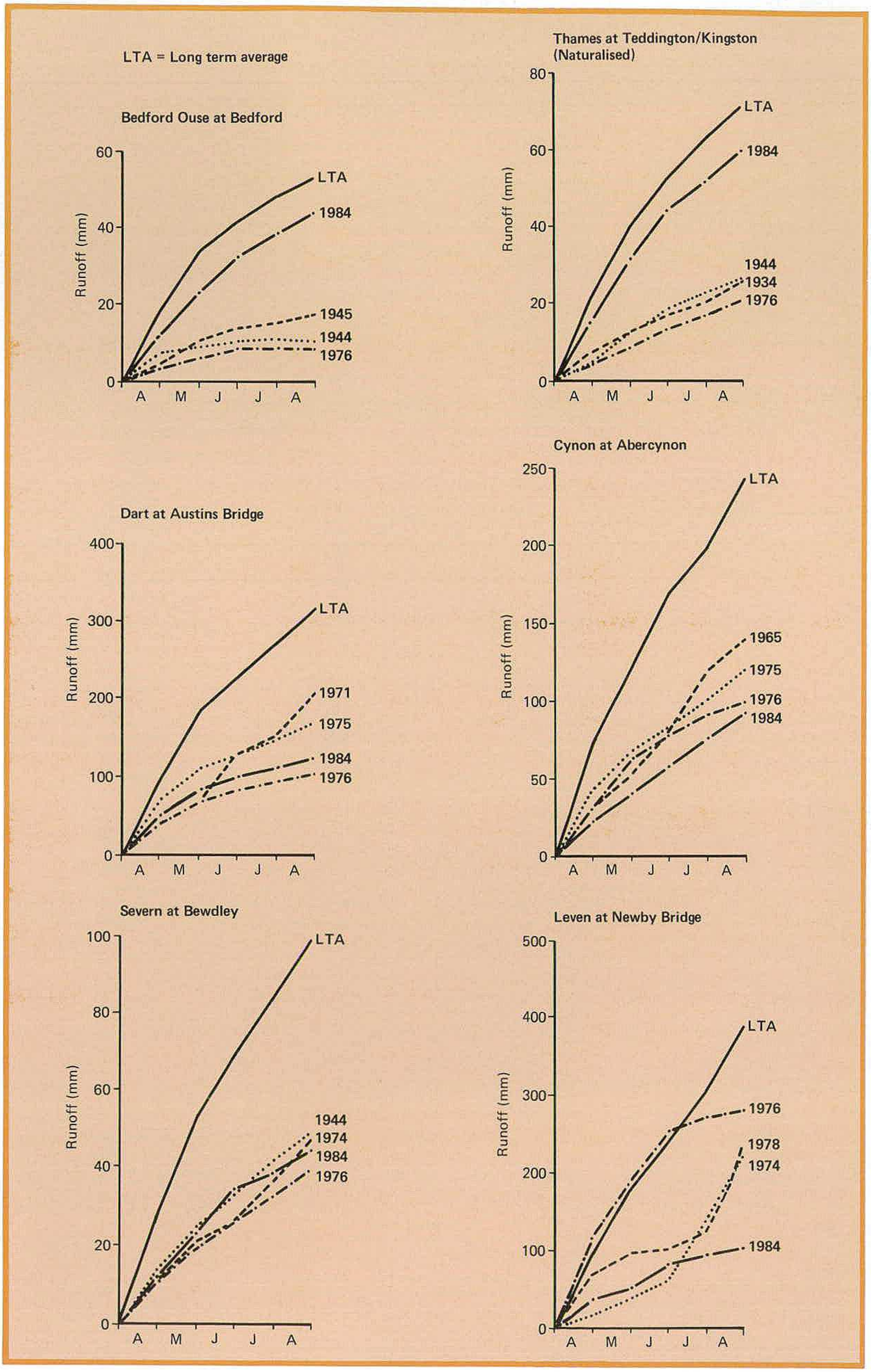


Figure 32. Cumulative runoff diagrams (April to August) for selected catchments.

TABLE 14. RANKED LOWEST AND AVERAGE 'N' DAY ANNUAL MINIMA FOR SELECTED CATCHMENTS (FLOWS IN M^3/S)

			10 day Flow	10 day Year	30 day Flow	30 day Year	90 day Flow	90 day Year	180 day Flow	180 day Year
TWEED AT NORHAM										
021009	24 years of record									
		1	7.963	1976	9.030	1976	11.755	1972	17.918	1984
		2	9.333	1972	9.844	1972	13.012	1984	21.146	1973
		3	10.288	1974	11.267	1984	15.685	1976	22.823	1972
		4	10.533	1984	12.197	1975	16.037	1974	23.242	1974
	Ranked 'N' day	5	10.649	1975	12.731	1973	18.497	1973	33.644	1971
	minima	6	11.770	1973	13.582	1977	18.908	1975	33.780	1976
		7	11.972	1964	14.764	1981	22.330	1977	33.934	1975
		8	12.474	1977	14.974	1964	22.986	1978	34.041	1978
		9	12.984	1981	15.055	1974	24.120	1970	36.797	1969
		10	13.145	1970	15.395	1971	24.174	1964	37.354	1970
	Mean Annual 'N' day minimum		14.135		17.393		26.224		40.399	
GRETA AT RUTHERFORD BRIDGE										
025006	25 years of record									
		1	0.043	1976	0.061	1976	0.111	1976	0.460	1964
		2	0.074	1975	0.091	1984	0.198	1972	0.552	1984
		3	0.082	1984	0.106	1975	0.240	1984	0.622	1976
		4	0.098	1964	0.126	1970	0.256	1975	0.643	1975
	Ranked 'N' day	5	0.105	1978	0.128	1979	0.282	1964	0.821	1977
	minima	6	0.109	1962	0.133	1978	0.293	1977	0.821	1972
		7	0.109	1970	0.135	1972	0.353	1978	0.823	1970
		8	0.110	1972	0.142	1980	0.451	1974	0.841	1969
		9	0.111	1977	0.156	1962	0.482	1970	0.901	1979
		10	0.114	1961	0.162	1971	0.504	1979	0.915	1978
	Mean Annual 'N' day minimum		0.122		0.194		0.611		1.076	
DOVE AT MARSTON ON DOVE										
028018	24 years of record									
		1	1.813	1976	1.862	1976	2.173	1976	3.597	1976
		2	2.618	1977	2.821	1977	3.309	1977	4.010	1975
		3	2.847	1984	3.181	1975	3.385	1975	4.904	1984
		4	3.039	1975	3.225	1984	3.658	1984	4.915	1977
	Ranked 'N' day	5	3.387	1974	3.905	1971	5.244	1979	6.927	1978
	minima	6	3.399	1971	3.999	1972	5.765	1980	7.258	1970
		7	3.670	1972	4.064	1979	5.934	1972	7.477	1980
		8	3.831	1979	4.494	1978	6.238	1978	7.523	1979
		9	3.935	1978	4.675	1963	6.301	1971	8.344	1972
		10	4.064	1963	4.736	1980	6.311	1969	9.042	1969
	Mean Annual 'N' day minimum		4.530		5.029		6.912		8.773	
BEDFORD OUSE AT BEDFORD										
033002	52 years of record									
		1	0.008	1934	0.034	1934	0.126	1934	0.355	1934
		2	0.049	1976	0.115	1976	0.315	1976	0.935	1976
		3	0.156	1944	0.220	1949	0.520	1944	0.968	1944
		4	0.184	1949	0.248	1944	0.525	1949	1.078	1943
	Ranked 'N' day	5	0.252	1959	0.378	1959	0.569	1943	1.402	1959
	minima	6	0.295	1943	0.398	1943	0.876	1959	1.453	1945
		7	0.405	1938	0.566	1933	0.942	1938	1.488	1949
		8	0.558	1945	0.583	1938	1.009	1945	1.509	1938
		9	0.566	1933	0.806	1945	1.064	1947	1.562	1947
		10	0.578	1942	0.809	1942	1.127	1942	1.564	1964
			1.845	1984(42)	2.377	1984(43)	3.437	1984(46)	6.399	1984(48)
	Mean Annual 'N' day minimum		1.274		1.571		2.135		3.234	

TABLE 15. RANKED LOWEST AND AVERAGE 'N' DAY ANNUAL MINIMA FOR SELECTED CATCHMENTS (FLOWS IN M^3/S)

			10 day Flow	10 day Year	30 day Flow	30 day Year	90 day Flow	90 day Year	180 day Flow	180 day Year
TAW AT UMBERLEIGH										
050001	27 years of record									
		1	0.242	1976	0.356	1976	0.740	1976	2.033	1976
		2	0.557	1984	0.704	1984	0.831	1984	2.158	1984
		3	0.692	1983	0.774	1959	1.224	1975	2.253	1959
		4	0.756	1959	0.817	1983	1.323	1978	2.306	1978
	Ranked 'N' day	5	0.771	1975	0.967	1978	1.511	1983	2.435	1975
	minima	6	0.886	1961	1.006	1975	1.551	1959	3.647	1962
		7	0.907	1962	1.139	1962	1.713	1972	4.290	1982
		8	0.932	1978	1.145	1972	2.036	1977	4.685	1977
		9	0.981	1972	1.205	1977	2.131	1974	4.696	1964
		10	0.987	1977	1.381	1960	2.158	1961	4.920	1974
	Mean Annual 'N' day minimum		1.270		1.620		3.269		5.958	
CYNON AT ABERCYNON										
057004	28 years of record									
			0.299	1976	0.332	1976	0.460	1984	0.704	1984
		2	0.332	1960	0.350	1960	0.468	1976	0.793	1978
		3	0.351	1984	0.391	1984	0.624	1975	0.852	1976
		4	0.384	1965	0.422	1959	0.639	1978	0.946	1975
	Ranked 'N' day	5	0.391	1959	0.488	1965	0.766	1977	1.191	1965
	minima	6	0.412	1975	0.499	1975	0.814	1961	1.265	1977
		7	0.438	1981	0.509	1978	0.826	1981	1.323	1964
		8	0.473	1978	0.516	1981	0.916	1959	1.490	1973
		9	0.478	1977	0.532	1977	0.960	1965	1.547	1959
		10	0.484	1980	0.552	1980	0.965	1974	1.684	1974
	Mean Annual 'N' day minimum		0.570		0.664		1.158		1.792	
CONWY AT CWM LLANERCH										
066011	21 years of record									
		1	0.393	1984	0.627	1984	1.353	1984	1.958	1984
		2	0.517	1972	0.738	1980	2.511	1974	6.308	1976
		3	0.552	1980	0.817	1972	2.522	1976	6.764	1974
		4	0.714	1971	0.971	1979	3.437	1983	6.998	1971
	Ranked 'N' day	5	0.744	1979	1.223	1983	4.366	1980	7.109	1980
	minima	6	0.751	1983	1.259	1974	4.585	1978	7.843	1975
		7	0.818	1973	1.300	1976	4.872	1975	8.142	1978
		8	0.848	1974	1.335	1978	4.952	1969	8.386	1969
		9	0.933	1970	1.472	1973	5.005	1979	9.016	1973
		10	1.003	1975	1.501	1975	5.091	1973	9.203	1983
	Mean Annual 'N' day minimum		1.005		1.809		4.568		8.461	
LEVEN AT NEWBY BRIDGE										
073010	46 years of record									
		1	0.213	1972	0.498	1976	1.350	1978	4.430	1959
		2	0.352	1976	0.506	1940	1.661	1984	5.105	1973
		3	0.358	1978	0.507	1972	1.729	1976	5.182	1982
		4	0.402	1947	0.525	1978	1.896	1974	5.207	1976
	Ranked 'N' day	5	0.406	1940	0.553	1959	2.296	1959	5.411	1949
	minima	6	0.411	1959	0.559	1980	2.326	1983	5.531	1984
		7	0.443	1980	0.636	1955	2.511	1972	5.647	1974
		8	0.449	1955	0.679	1941	2.566	1980	5.719	1975
		9	0.504	1975	0.721	1947	3.112	1982	5.770	1978
		10	0.572	1949	0.733	1983	3.418	1940	6.040	1941
			0.572	1984(11)	0.829	1984(12)				
	Mean Annual 'N' day minimum		1.293		2.232		5.214		7.974	

TABLE 16. RANKED HIGHEST AND LOWEST 'N' DAY ANNUAL MAXIMA AND MINIMA FOR SELECTED CATCHMENTS (FLOWS IN M³/S)

			10 day		30 day		90 day		180 day	
			Flow	Year	Flow	Year	Flow	Year	Flow	Year
TAW AT UMBERLEIGH										
050001	27 years of record									
		1	0.242	1976	0.356	1976	0.740	1976	2.033	1976
		2	0.557	1984	0.704	1984	0.831	1984	2.158	1984
		3	0.692	1983	0.774	1959	1.224	1975	2.253	1959
		4	0.756	1959	0.817	1983	1.323	1978	2.306	1976
	Ranked 'N' day	5	0.771	1975	0.967	1978	1.511	1983	2.435	1975
	minima	6	0.886	1961	1.006	1975	1.551	1959	3.647	1962
		7	0.907	1962	1.139	1962	1.713	1972	4.290	1982
		8	0.932	1978	1.145	1972	2.036	1977	4.685	1977
		9	0.981	1972	1.205	1977	2.131	1974	4.696	1964
		10	0.987	1977	1.381	1960	2.158	1961	4.920	1974
	Mean Annual 'N' day minimum		1.270		1.620		3.269		5.958	
		10	87.655	1972	55.260	1962	36.472	1959	23.455	1966
		9	88.460	1983	57.605	1977	36.508	1976	23.981	1983
		8	89.289	1974	58.612	1963	38.278	1967	24.201	1979
		7	94.299	1982	59.268	1971	39.262	1970	24.471	1976
	Ranked 'N' day	6	95.670	1981	59.739	1982	39.445	1981	24.587	1970
	maxima	5	102.468	1978	61.392	1967	39.630	1977	24.908	1977
		4	104.042	1971	65.989	1959	40.769	1974	25.096	1982
		3	105.730	1965	70.694	1984	41.029	1978	26.978	1965
		2	111.329	1967	79.109	1965	44.756	1982	28.043	1974
		1	125.049	1960	79.639	1960	62.751	1960	38.044	1960
NITH AT FRIARS CARSE										
79002	28 years of record									
			1.257	1984	1.519	1984	1.951	1984	4.080	1984
		2	1.567	1976	1.755	1976	2.722	1976	5.653	1975
		3	1.843	1977	1.998	1983	3.142	1977	6.976	1982
		4	1.863	1983	2.200	1972	3.568	1972	7.281	1973
	Ranked 'N' day	5	1.915	1978	2.233	1977	3.578	1978	7.512	1959
	minima	6	1.958	1975	2.273	1959	3.859	1975	7.793	1971
		7	1.992	1972	2.444	1978	4.112	1974	8.095	1974
		8	2.104	1959	2.795	1980	4.129	1983	8.757	1978
		9	2.228	1971	2.841	1975	5.044	1973	9.052	1976
		10	2.319	1974	2.866	1961	5.139	1982	10.531	1983
	Mean Annual 'N' day minimum		2.748		3.718		6.683		11.753	
		10	105.686	1965	71.878	1960	47.075	1963	30.742	1962
		9	106.217	1964	73.752	1967	47.719	1980	30.840	1984
		8	109.013	1982	74.382	1963	48.032	1962	30.985	1966
		7	109.238	1981	77.477	1981	50.667	1959	31.055	1972
	Ranked 'N' day	6	116.828	1975	79.476	1982	52.766	1981	31.213	1981
	maxima	5	118.635	1963	82.387	1984	55.249	1974	31.386	1961
		4	119.358	1974	87.749	1977	56.463	1984	33.519	1977
		3	123.295	1984	89.754	1962	56.558	1977	37.576	1979
		2	138.300	1962	90.022	1975	58.033	1979	39.294	1980
		1	148.980	1977	95.446	1974	68.065	1982	39.460	1982

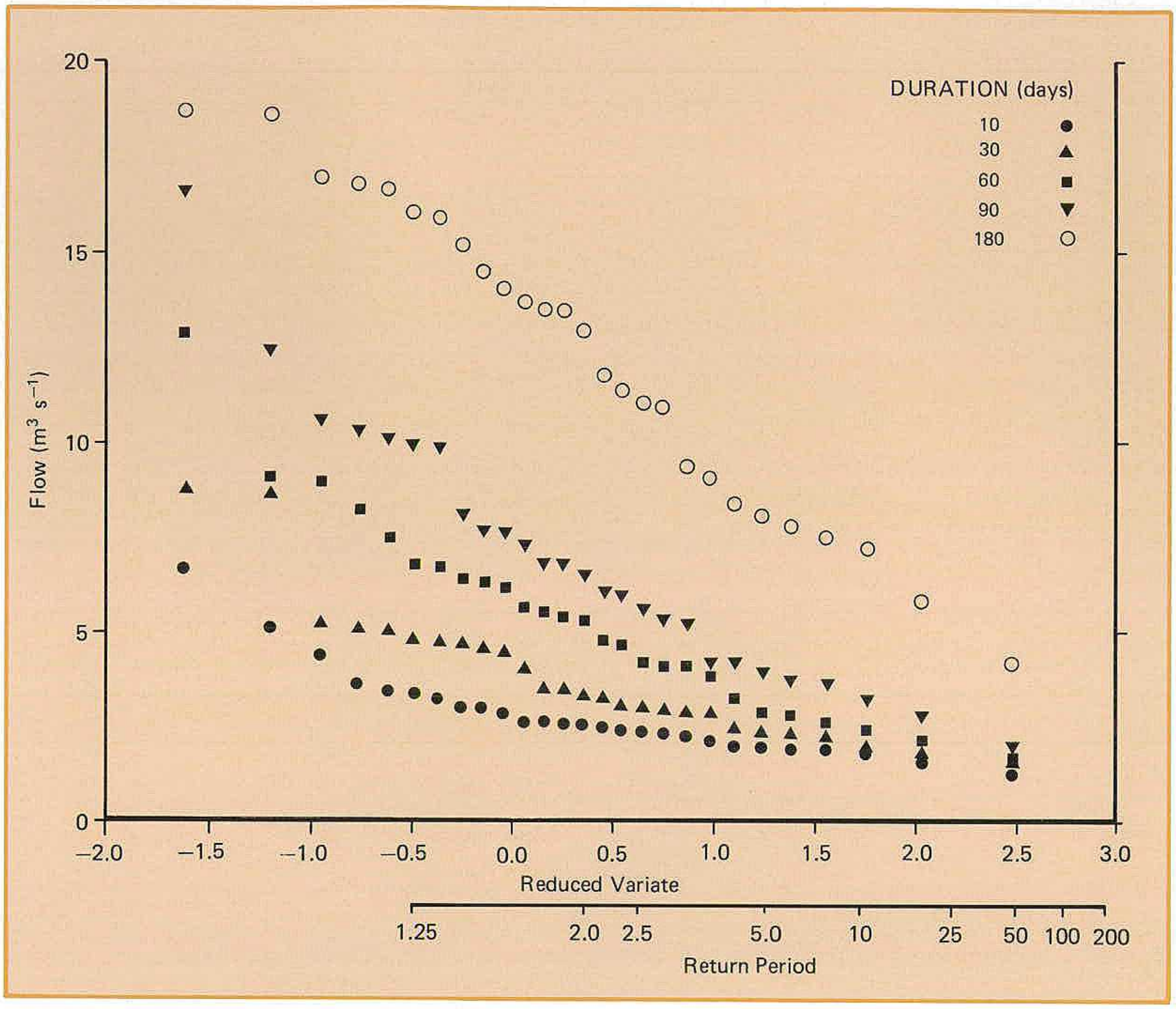


Figure 33. Flow frequency diagram for the River Nith at Friars Carse.

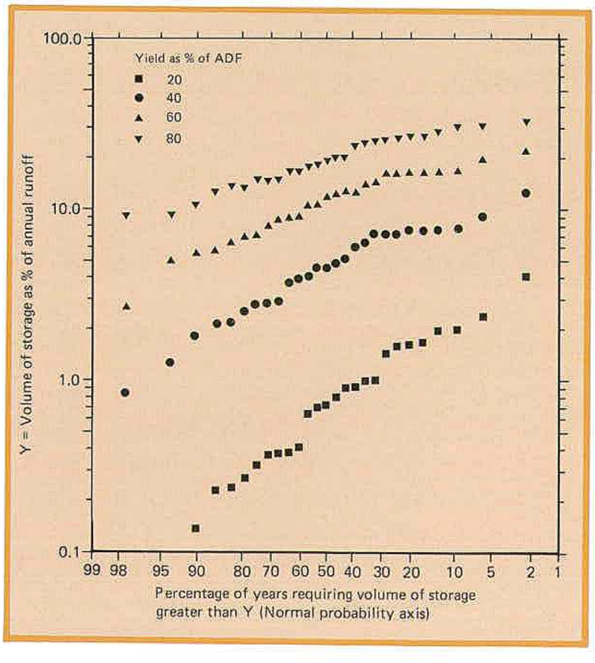


Figure 34. Storage yield diagram for the River Nith at Friars Carse.

TABLE 17. RETURN PERIODS OF 1984 ANNUAL MINIMA

Station No.	Station Name	Years of Record	Return period of annual minimum for a given duration (days) 10	30	60	90	180
21009	Fruid Water at Fruid	20	5	10	10	20	50
23004	South Tyne at Haydon Bridge	18	5	20	5	5	10
25006	Greta at Rutherford Bridge	21	10	10	5	10	10
27041	Derwent at Buttercrambe	11	5	5	5	5	2
28010	Derwent at Longbridge Weir	32	10	10	10	10	5
28018	Dove at Marston on Dove	18	5	5	5	10	5
32004	Ise Brook at Harrowden Old Mill	88	5	5	5	5	2
32008	Nene at Dodford	38	2	2	2	2	2
36006	Stour at Langham	22	2	2	2	2	2
37001	Roding at Redbridge	34	2	2	2	2	2
38003	Mimram at Panshanger Park	31	2	2	2	2	2
39001	Thames at Teddington/Kingston	99	2	2	2	2	2
42510	Itchen at Highbridge	24	5	2	2	2	2
43007	Stour at Throop Mill	12	5	5	5	5	5
46003	Dart at Austins Bridge	24	10	10	10	20	10
50001	Taw at Umberleigh	23	20	10	20	20	10
52005	Tone at Bishops Hull	24	5	5	5	5	5
53018	Avon at Bathford	15	5	10	10	10	10
54001	Severn at Bewdley	62	5	5	10	20	10
54003	Vyrnwy at Vyrnwy Reservoir	54	5	5	5	20	100+
56013	Yscir at Pontaryscir	10	10	10	20	10	10
57004	Cynon at Abercynon	25	10	10	10	50	20
66011	Conwy at Cwm Llanerch	13	20	20	20	20	5
68001	Weaver at Ashbrook	44	5	5	5	5	50
72004	Lune at Caton	22	20	20	20	10	50
73010	Leven at Newby Bridge	46	5	10	50	50	100+
74006	Calder at Calder Hall	17	5	5	5	10	50
79002	Nith at Friars Carse	27	50	50	20	20	50

All return periods have been rounded
+ Return periods well in excess of 100 years.

TABLE 18. RETURN PERIODS OF 1984 "RESERVOIR" DRAWDOWNS

Station No.	Station Name	Years of Record	Return periods of reservoir drawdown for given percentage of average flow as yield 20	40	60	80
				Years		
32004	Ise Brook at Harrowden Old Mill	38		2	2	2
32008	Nene at Dodford	38		2	2	2
33002	Bedford Ouse at Bedford	51		2	2	2
36006	Stour at Langham	22		2	2	2
39001	Thames at Teddington/Kingston	99	*	2	2	2
50001	Taw at Umberleigh	23	20	20	20	10
52005	Tone at Bishops Hull	24	*	5	5	2
53018	Avon at Bathford	15	10	10	10	10
54001	Severn at Bewdley	62	10	20	10	5
54003	Vyrnwy at Vyrnwy Reservoir	54	20	50	20	10
57004	Cynon at Abercynon	25	20	20	10	5
66011	Conwy at Cwm Llanerch	13	100+	100+	100+	100+
68001	Weaver at Ashbrook	44	5	5	5	2
73010	Leven at Newby Bridge	46	100	100+	100+	100+
74006	Calder at Calder Hall	17	20	20	20	50
79002	Nith at Friars Carse	27	50	50	50	50

All return periods have been rounded
+ return periods well in excess of 100 years
* no significant drawdown

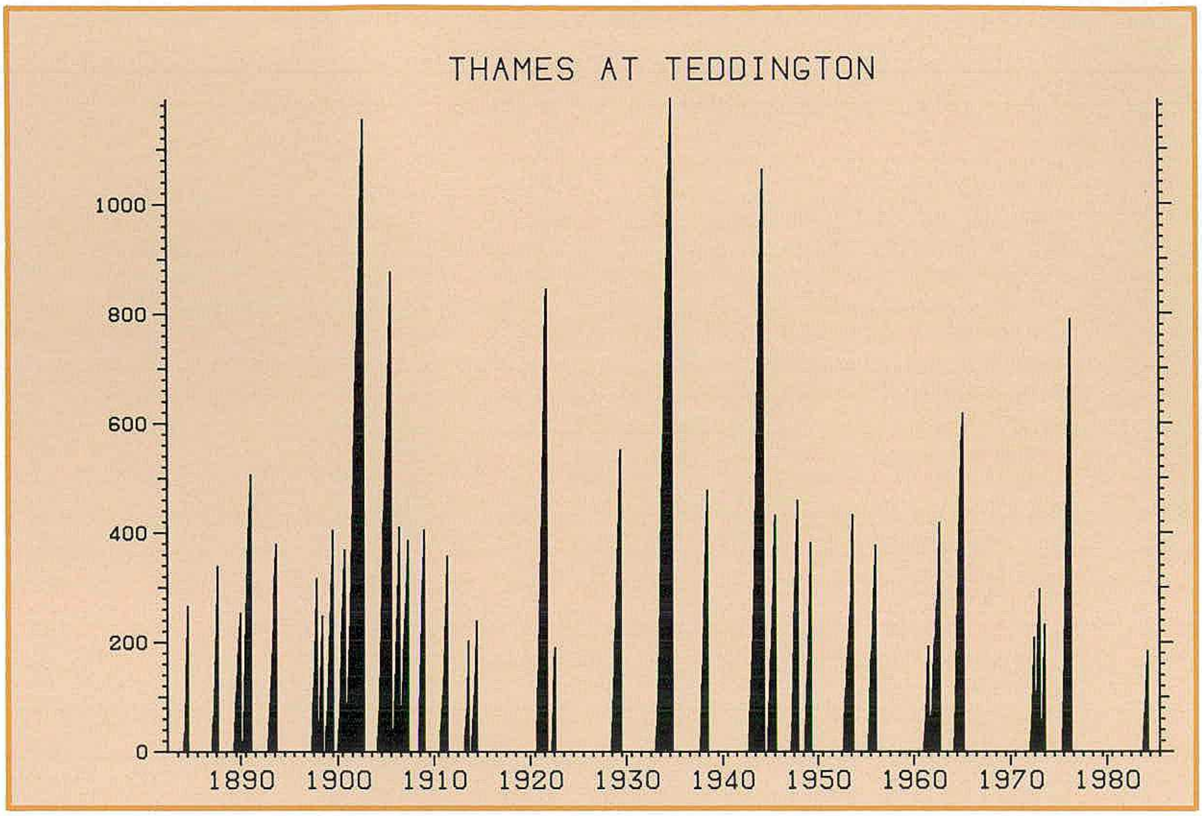


Figure 35. Runoff deficiency index for the River Thames.

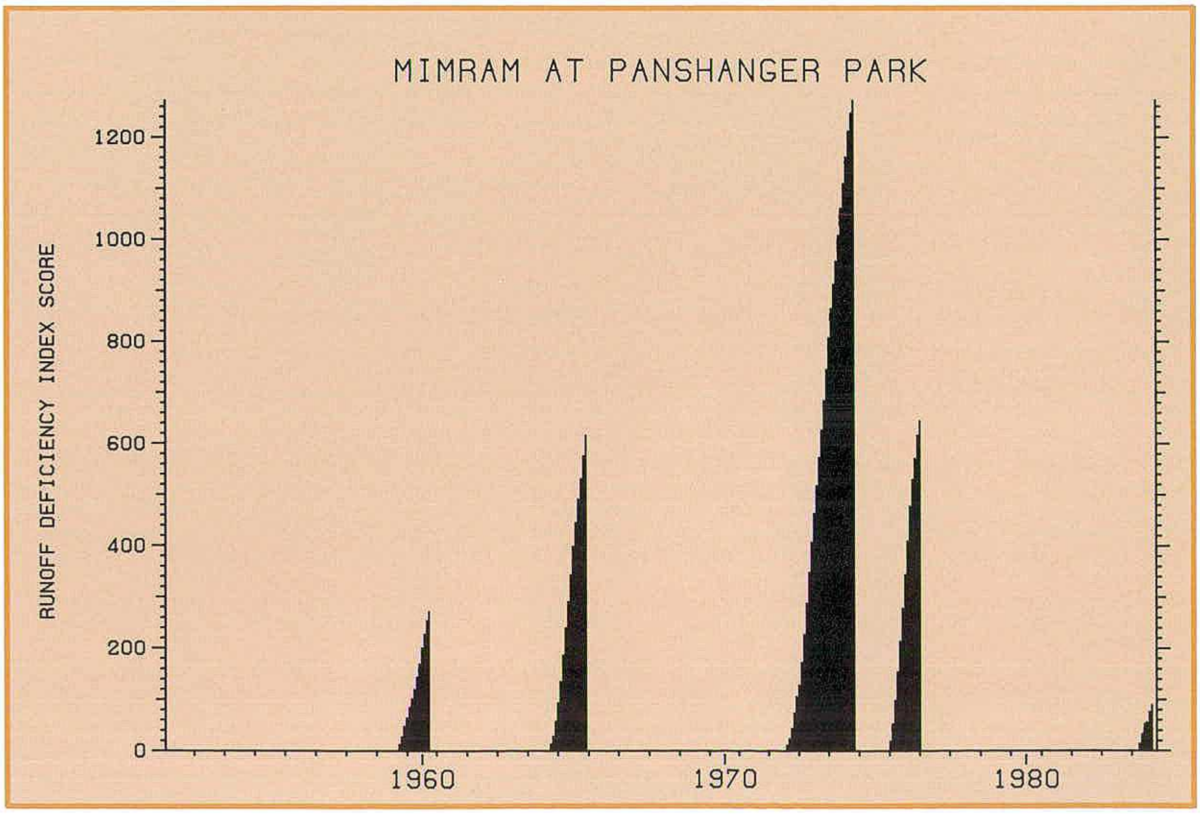


Figure 36. Runoff deficiency index for the River Mimram.

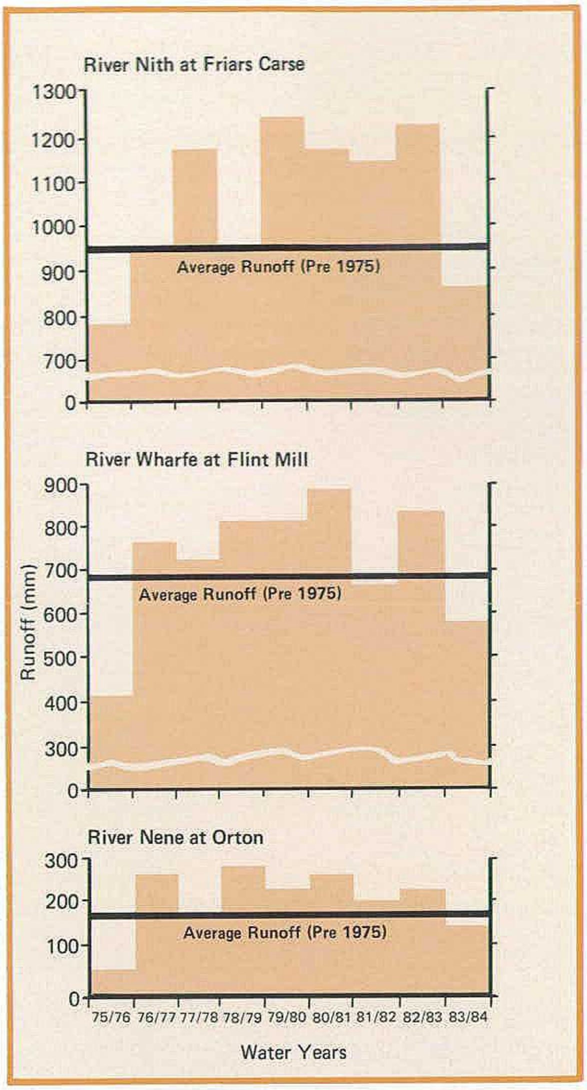


Figure 37. Runoff for selected catchments 1975/76 to 1983/84.

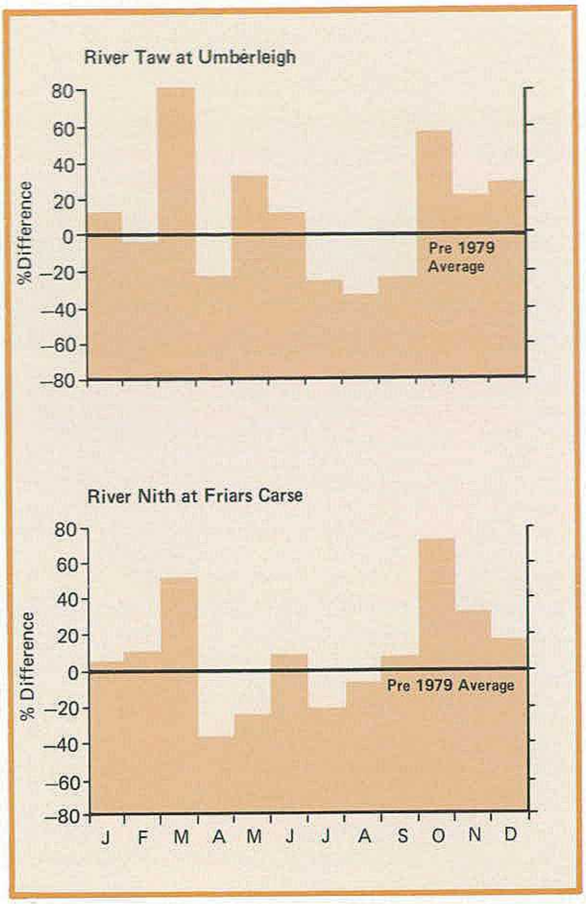


Figure 38. Average monthly runoff 1979–84 compared to the period of record average.

Background

Considered on an annual basis, surface water resources far outweigh the demand for water in the United Kingdom. The seasonal variability in runoff, however, requires that reservoir storage be provided to ensure that supplies can be maintained and, where appropriate, river flows augmented during periods of rainfall deficiency. It is the adequacy of this storage and the effectiveness of its management which largely determine the magnitude of a drought's impact on the community.

Many of the older reservoirs in the United Kingdom were designed to supply water directly to centres of water demand; normally a minimum flow (or compensation flow) had also to be maintained in the river downstream. The emphasis in England and Wales has now shifted towards reservoirs which supplement runoff by means of river regulation. Releases from the reservoir are used to increase river flows and facilitate the abstraction of water from the lower reaches of the river system. Some reservoirs perform both functions and increasingly groups of reservoirs are becoming linked to allow a larger gross resource to be operated more flexibly in response to differing patterns of rainfall, reservoir storage and demand across a water supply area. Often including groundwater storage, this growing integration of resources, together with changes in the demand for water, limits the value of comparing reservoir levels during a drought with the storage available during previous droughts. Where a single reservoir or group of reservoirs are managed as a unit, however, the progress of the drought's development can be charted as the gross storage is depleted.

1984 Reservoir contents

In January 1984 most reservoirs in the United Kingdom were at, or close to, capacity. Exceptions included Stithians reservoir in Cornwall and the Lake District reservoirs; the latter began the year at only 73% of capacity; significant January and early February runoff caused a rise to 95% of capacity. Several small reservoirs in central Scotland, including Daer in Lanark, had been held below full capacity during the winter to facilitate repair work. Throughout England and Wales total impounded storage had been appreciably lower in January 1976 when, as a consequence of very moderate autumn and early winter runoff, reservoirs were typically at 60–80% of capacity. In 1984, the drawdown in reservoir levels started extremely early in many areas, whereas spring rainfall brought some improvement in water stocks in 1976. Substantial depletions were recorded in February 1984 for reservoirs in the southern Pennines and in the South West peninsular. Reservoirs are normally further replenished in March but in 1984 drawdown steepened in the Lake District and South Yorkshire reservoirs, and was particularly rapid in South Wales where Pontsticill in the Taf Fechan group was losing 4% of its capacity each week. Depletion rates increased generally through the very dry April and storage was reduced by 10% of capacity at the strategically important reservoirs of Vyrnwy and the Elan Valley system in Wales, and the Derwent Valley group in Derbyshire. Water levels in Lough Neagh (Northern Ireland) were already below normal summer levels at the beginning of April. The continuing decline through the month resulted in a partial closure of sluice gates at Toome on the River Bann in an attempt to maintain the level in Lough Neagh.

In the northern and western regions of England and Wales reservoir stocks were comparable to the 1976 situation in May and in many areas the rate of depletion was greater. The dramatic fall in reservoir levels, in the drought affected areas, through the spring of 1984 is illustrated by the Taf Fechan group in South Wales where the water level had declined from capacity to little over half full. Without the introduction of conservation measures this would maintain supplies only until the middle of August. Gross storage at Thirlmere and Haweswater decreased by more than 20,000 megalitres in May, equivalent to about 16% of total volume. Table 19 shows the percentage of capacity remaining in selected reservoirs at, or near, the end of each month in 1984. The reservoirs are confined to those water authority areas in England and Wales most severely affected by the drought. Reservoir contents reflect the balance between runoff from the catchment area and depletion resulting from direct abstractions to supply, outflows into the river system and evaporative losses. The depletion curves for the combined Haweswater/Thirlmere reservoirs and Stithians reservoir in Cornwall are illustrated in Fig. 39. Also shown is the depletion curve for Loch Katrine in the Strathclyde region; the greater severity of the 1984 drought can be gauged by comparison with the 1975 drawdown which represents the previously most demanding period for water supply management in central Scotland.

Water conservation methods

It was clear that water stocks would need to be conserved as a contingency against the drought continuing into the autumn; little natural replenishment could be expected through the summer months even under normal rainfall conditions.

Reservoirs are managed within a framework of rules which change progressively as the demand on the reservoir, its remaining storage, and prospects for replenishment change. The more stringent changes in operating procedures to conserve water stocks may require a statutory application to the Secretary of State for implementation. Water authorities may apply for Drought Orders to reduce outflows from reservoirs or to amend the abstraction conditions governing downstream water use. Some reduction in demand can be achieved by reductions in mains pressure, the introduction of hose-pipe bans and by urging the public to conserve water. Where further measures are warranted the Drought Act 1976 empowers water authorities in England and Wales to prohibit the use of mains water for non-essential uses, such as for automatic car washes and the filling of private swimming pools, and in the more extreme circumstances recourse can be made to stand-pipes and rota cuts to directly limit water usage. Under Scottish legislation, there are no intermediate steps between a hose-pipe ban and the deployment of standpipes[17].

Patterns of water demand

Demand for water reaches a maximum in the summer months; the peak is most noticeable in those regions where tourism is important and the period June-August sees a substantial population influx. In hot summers such as 1975 and 1983, when few restrictions were applied, demand in parts of Wales and south-west England may exceed the winter average by 20%. Figure 40 shows the pattern of demand in 1984 and 1983 in the Fal and Tamar supply districts of the South West Water Authority. As with England and Wales generally, demand in 1984 was significantly above the 1983 figures in spring and early summer, which themselves had represented record demand levels, but the impact of water conservation measures are clearly identifiable in July and August. During the hot dry weather from April to June consumption in north western England was normal. Following appeals to the public and the imposition of hose-pipe bans a total reduction of 15% was achieved by early August. The potential savings available through demand reduction varies considerably throughout the United Kingdom. In South Wales, for instance, the scope for limiting demand is rather less than in Cornwall because the relatively large industrial requirements for water are less amenable to rapid reduction.

Evaporative loss from open water

Whilst some control was exercised on water demand, evaporative losses from reservoirs were becoming substantial as the hot summer of 1984 progressed. From June to September, evaporation can be a larger contributor to the depletion of reservoir stocks than normal compensation releases. Although transpiration was restricted by the limited availability of soil moisture, evaporation from open water surfaces could proceed at the potential rate, which in 1984 was high. At Aberporth weather station, for example, PE from April to September 1984 was a record, being marginally greater than the corresponding figure for 1976[18]. Evaporation alone caused drops of around 20 mm per week in lakes and reservoirs in north western England during July and late August and impoundments in Devon and Cornwall were estimated to be losing between 2% and 5% of capacity in August for this reason.

Drought Orders

Faced with a continuing and rapid decline in reservoir storage through June, water authorities applied for Drought Orders to reduce compensation releases from a number of reservoirs in north western England and the Pennines. The Taf Fechan and Taf Fawr reservoirs in Wales were similarly permitted to reduce compensation flows from the 20 June, and Stithians, which was at half-capacity, implemented a Drought Order at the same time. Other than a few local distribution problems, supplies in the English lowlands were not giving rise to any concern. In the Southern Water Authority area the Bewl Bridge and Bough Beech reservoirs were both 75% full and a number of small reservoirs were at more than 85% capacity. At the beginning of July the major reservoirs in the Thames Valley held over 90% of gross capacity.

By the end of July Drought Orders were applied widely in the west and north of England and Wales, and in many cases a second Order was implemented to further reduce compensation flows. In addition emergency sources were increasingly exploited to ease the pressure on reservoir stocks. Four Drought Orders had to be made in the Strathclyde region of Scotland which contains half the country's population. One enabled pumping from Loch Lomond to be maintained after the lake had dropped below the level at which abstraction is normally discontinued. A second provided for a reduction in compensation releases to the River Teith from the Loch Katrine complex, the major supply source for Glasgow. Two compensation reservoirs in the system almost emptied and, exceptionally, Loch Katrine and Glen Fingles had to be used for compensation purposes.

With reference to the return periods quoted in the storage yield analyses (p. 51) it must be remembered that these return periods have been calculated after the event had finished. However, at the height of the 1984 drought reservoir operators had no knowledge when the drought would end. Hence the measures taken to reduce demand and restrict reservoir compensation flows were necessary contingencies even for locations which with hindsight experienced relatively low return period droughts.

How depleted did reservoirs get?

Replenishment in August was minimal because the rainfall, which was significant in the second half of the month, was utilised to reduce the very high soil moisture deficits that existed throughout most of the United Kingdom. Reservoir levels continued to fall with capacity reductions typically in the range 2% to 5% per week. By the end of the month, Thirlmere and Haweswater retained a mere 13% and 16% of capacity, respectively. Other North West Water Authority reservoirs, particularly those located in the Pennines, registered well under 25% of gross storage. The supply remaining was typically between 50 and 60 days and significantly less for some small reservoirs.

In Northumbria the Tees and Wear groups of reservoirs were low for the time of year but the very large capacity of Kielder reservoir, which remained about 90% full, provided security against all but the most localised of water supply problems. The Usk, Talybont and Pontsticill reservoirs were amongst those in South Wales less than 25% full, and the Taf Fechan group as a whole remained below the corresponding 1976 levels for the third month in succession. In Devon and Cornwall, Stithians and Siblyback stood at about 33% of capacity with stocks still being depleted. Some stabilisation of levels in Yorkshire resulted from the impact of Drought Orders, and some runoff augmentation in the Leeds group by pumping from the River Ouse. Nonetheless, reservoirs in the Bradford, Leeds and Halifax/Huddersfield groups were appreciably below 40% of capacity. The drought's intensity varied very considerably throughout the Severn-Trent region and reservoir contents reflected the contrasts in rainfall deficiency. The Clywedog and Elan Valley reservoirs were worst hit, registering about 33% of capacity in early September; water levels in the Elan system were lower than in August 1976. Further east reservoir stocks were generally above 40% of total storage. Gross reservoir storage in the Wessex Water Authority area stood close to 60% and, generally, the larger reservoirs in eastern and south eastern England held more than adequate stocks.

By mid-September 1984 the levels in most reservoirs in central and south western Scotland fell to or approached all time lows. The volume in storage ranged from 10 to 40% of capacity, compared with the normal range of 50 to 75% of capacity at that time of year. A few, for example, the Burncrooks and Carron reservoirs in the Strathclyde region, registered new minimum levels for every month from the early spring. Prospective supply periods were becoming short; the Glendevon group of reservoirs in Fife contained less than one month's supply by the end of August, given normal consumption rates; in Strathclyde a few reservoirs were below 15% of capacity, and some were virtually out of use. Depletion continued throughout October in some areas in Scotland; the Watch Water reservoir in Berwickshire, for instance, reached its minimum level, one third of its capacity, at the beginning of November.

Lough Neagh in Northern Ireland is a large, shallow expanse of water and was particularly affected by high evaporation rates throughout the summer. The water level declined until the 11th of September when the lake surface was at its lowest elevation since the present system of sluice control was installed.

Recovery of water stocks

The weather in the third week of September was very wet with most of the drought affected areas receiving more than 50 mm of rainfall. By the end of the month soils were at field capacity in most of the upland regions of the United Kingdom although significant soil moisture deficits remained in south western England and parts of South Wales. Reservoir levels began to recover generally from mid-September. Replenishment was modest, initially, in the impoundments managed by the Severn-Trent, Welsh and South West Water authorities. In Yorkshire, however, increases of over 5% of total capacity per week were typical and several reservoirs in the north west of England, including Thirlmere, registered increases of 10% or more in the week ending the 24 September. There were a few important exceptions to the general trend. For instance the Llysyfran reservoir in south western Wales and Stithians in Cornwall were still decreasing in capacity.

Heavy autumn rainfall allied to diminishing rates of evaporation resulted in a rapid improvement in water stocks, especially in November. Most reservoirs had reached, or were approaching, capacity by the end of the year although a dry December postponed total replenishment in some areas; the Washburn Valley group of reservoirs in South Yorkshire, for instance, was at 80% capacity entering 1985.

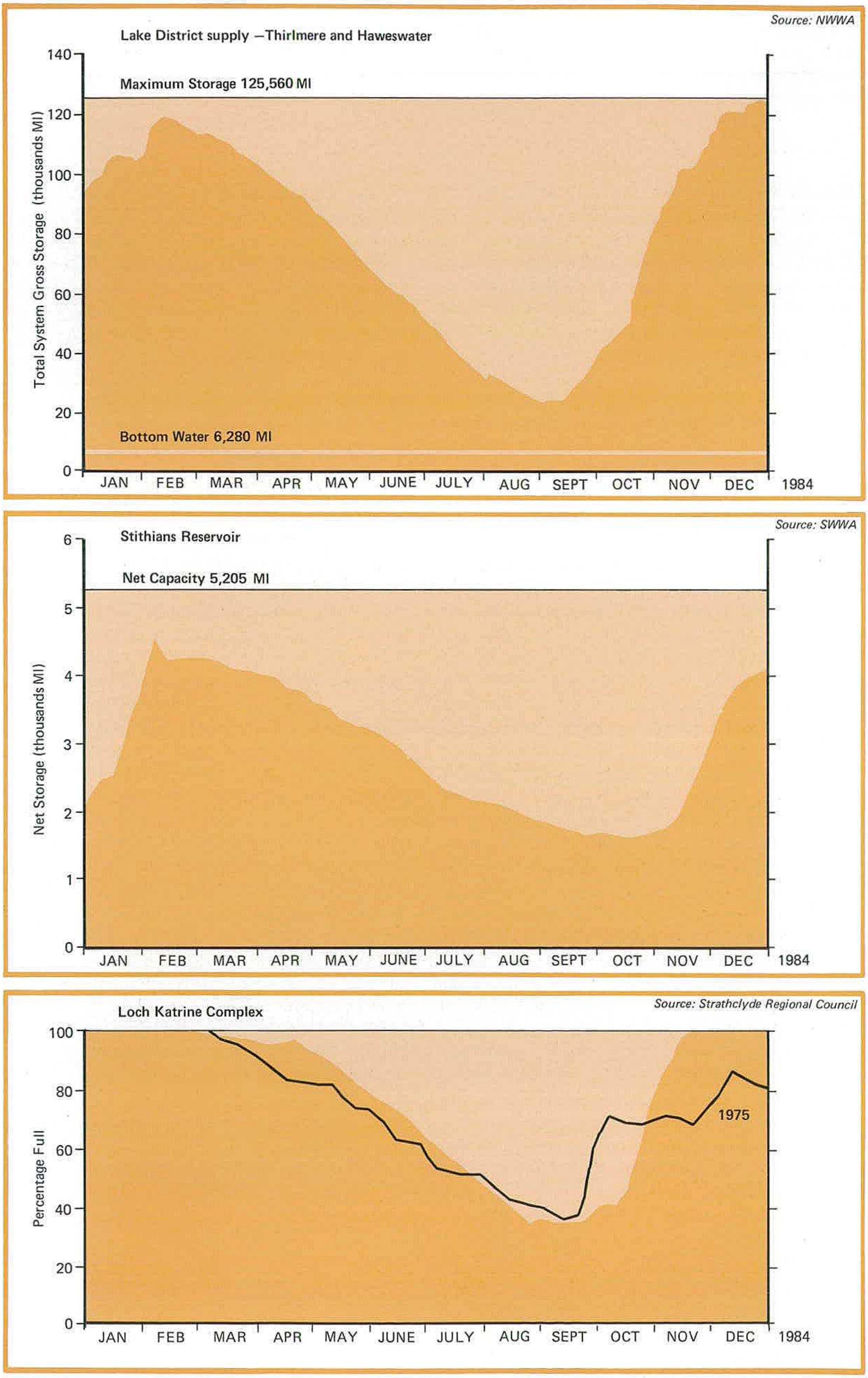


Figure 39. Reservoir depletion curves 1984.

TABLE 19. RESERVOIR CONTENTS FROM JAN TO DEC 1984; PERCENTAGE OF USEABLE CAPACITY

Site	Capacity (ML)	J	F	M	A	M	J	J	A	S	O	N	D
Lake district	125,560	83	90	82	70	53	38	24	15	28	64	89	98
Pennine supply district	13,840	98	92	82	64	48	40	29	22	44	63	96	95
Vyrnwy	59,700	97	96	90	81	69	59	46	38	46	77	93	89
Clywedog	49,924	88	87	85	84	84	78	52	33	34	52	75	88
Elan valley	99,100	100	99	93	83	69	60	46	35	50	75	100	100
Derwent valley	46,345	94	96	98	88	77	68	57	48	55	67	93	94
Nidd valley	14,778	91	90	90	73	53	37	29	26	44	86	97	95
Loxley valley	6,718	100	99	99	90	78	69	55	44	42	51	91	100
Washburn valley	15,625	100	94	93	82	58	41	30	29	33	46	76	77
Llysyfran	16,600	100	100	98	97	83	71	56	45	37	49	99	100
Pontsticill	15,200	100	100	84	65	46	36	26	17	19	47	81	99
Stithians	5,205	76	81	77	69	61	48	42	35	32	33	60	80
Burrator	4,210	100	99	92	86	76	61	50	55	57	83	100	100
Loch Lomond	86,374	100	100	83	93	66	42	23	9	55	100	100	100
Loch Turret	18,184	94	100	99	100	88	78	63	47	39	56	100	100

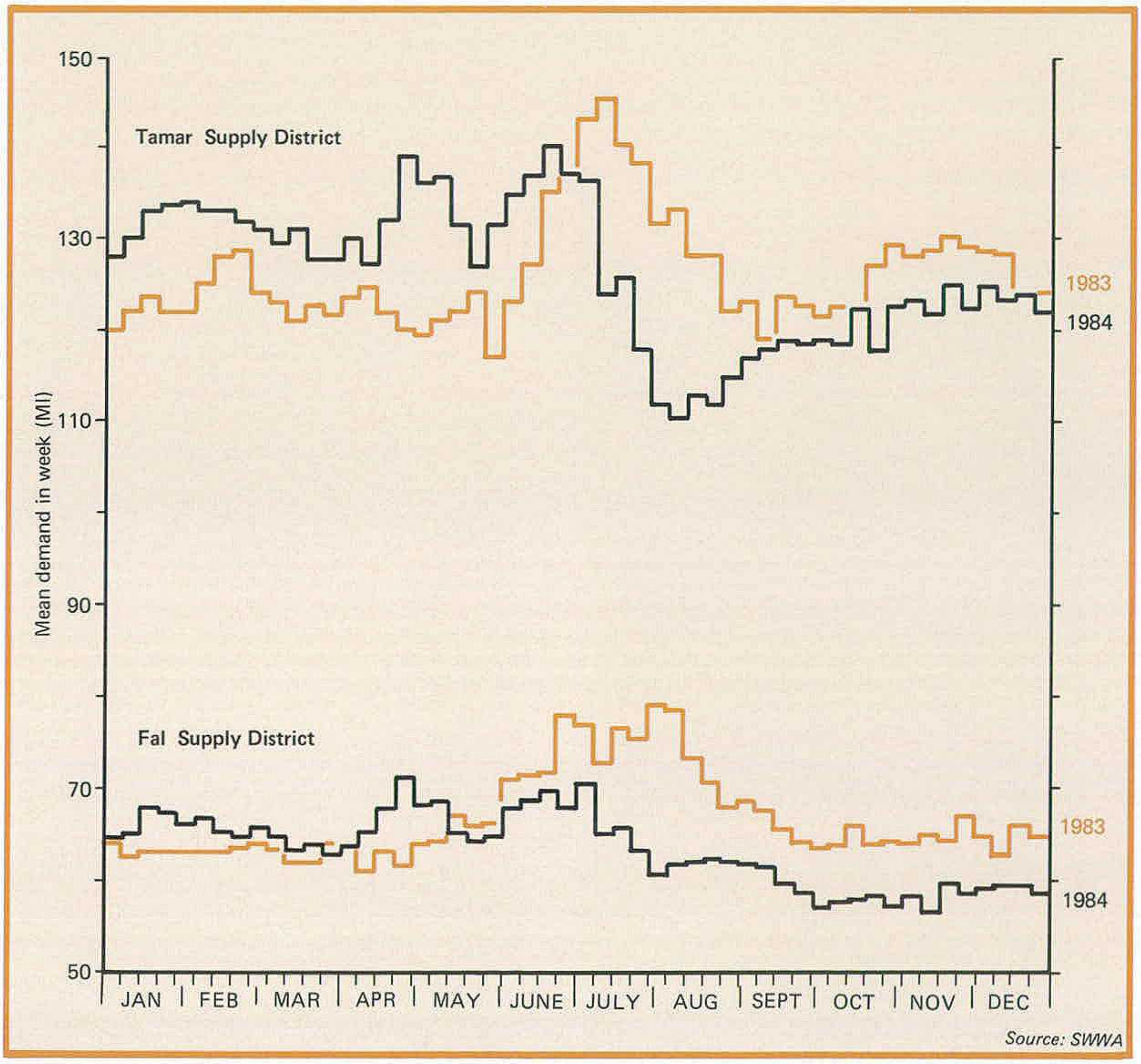


Figure 40. Water demand in the South West Water Authority.

Background

Groundwater makes a substantial contribution to water supplies in England but is less important in Northern Ireland and of local significance only in Scotland and Wales. Over one-third of the demand for public water supplies in England is met from groundwater and it is the principal supply source in central and southern England. Groundwater may be abstracted directly from wells and boreholes or indirectly from rivers whose flow has been augmented by spring discharge or, artificially, by pumping from groundwater sources. Of the British aquifers, the Chalk and Permo-Triassic sandstones are the most important (Fig. 41).

Since the drought of 1976 when unprecedented water levels were recorded throughout both major and minor aquifers[19, 20], water tables have generally stood at above average levels. This reflects the recent sequence of wet winters. Each of the last eight have registered above average rainfall and, consequently, high infiltration. Figure 42 shows water year residual rainfalls (which approximate to infiltration) for three catchment areas with extensive Chalk outcrops in the south of England. Infiltration in 1983/84 was appreciably less than the preceding seven years but substantial percolation after the December and January rainfall contrasted with the minimal aquifer recharge which occurred during the winter of 1975/76.

1984 groundwater levels

By the spring of 1984 groundwater levels were generally above, or well above, the seasonal average. The ensuing drought was mild in the south and east of England where groundwater is a major source of public supply. Both these factors combined to ensure that the 1984 drought, in groundwaters, was a relatively minor event. Groundwater levels in 1984 stood at very low levels for only a short length of time and the water table recovered rapidly following the autumn rainfall. Borehole and well hydrographs (Fig. 43) for representative sites in England and Wales illustrate the 1983/84 levels in comparison with the average and extreme monthly water levels for the period of record.

In the Chalk of southern and north-eastern England groundwater levels generally remained above average until late spring or summer. Local differences in winter recharge were, however, evident in some districts. In Hampshire, for instance, groundwater levels in the Test Valley were well below average by May whereas in the neighbouring Itchen basin levels were normal for late spring. The recession of water levels in the Chalk extended over about nine months with a total fall considerably greater than in a normal year; clear similarities with the 1975 recession can be recognised at several sites. By the autumn all the index sites with the exception of Therfield, which responds approximately four months after rainfall, were registering levels well below the seasonal average. At the Dalton Holme observation borehole the November level was approaching the levels obtaining in the drought years of 1905, 1921, 1949, 1959 and 1976. Low autumn levels were also recorded at Rockley but should be compared with the 1976 record where there was a virtual absence of standing water throughout the year, the seventh occasion on which the well has dried up since 1933.

Entering 1985 water levels in the Chalk of southern England were substantially above average. Further north, normal groundwater levels were attained in the spring.

Water table fluctuations in the Chalk were broadly paralleled by those in the Lincolnshire Limestone. This aquifer is very sensitive to changes in the rate of infiltration as evidenced by the small flexures in the hydrograph for the New Red Lion site. Overall, 1984 levels remained well within the range of normal seasonal variation with the spring and summer recession some eight metres above the corresponding levels in 1976. At Peggy Ellerton Farm, near Leeds, the water table in the Magnesian Limestone aquifer remained above the average throughout 1984 with only a modest recession through the summer and autumn.

In the Permo-Triassic sandstone aquifer at Dale Brow, south of Manchester, groundwater levels were at a seasonal maximum for a four month period during the winter of 1983/84. They stayed above the average until November 1984. The drought was more intense in parts of Yorkshire and the water table in the Triassic sandstone near Selby declined rapidly through the spring and summer and, by mid-October, established a new minimum level, marginally below that recorded in July 1976.

In those areas where surface water stocks were seriously depleted, minor aquifers assumed a greater importance during the drought. Their potential to meet local or district water supply needs was exploited in many areas. Typically groundwater levels in the less developed aquifers were about, or just below, average in the winter of 1983/84. Minimum levels recorded in the ensuing drought were generally well above those registered in 1976 except in those few localities where recharge in 1984 was delayed into autumn. For instance, the well hydrograph for the George Hill borehole in the Permian Sandstone of Devon (Fig. 44) shows that a new November minimum was established before recharge increased rapidly at the end of 1984. The Stretton Sugwas borehole, which monitors the water table in a superficial gravel deposit near Hereford was rather more typical, recording levels only just below the mean and considerably above the minimum throughout most of 1984; over the period January to August the minima correspond to the 1976 levels (Fig. 44).

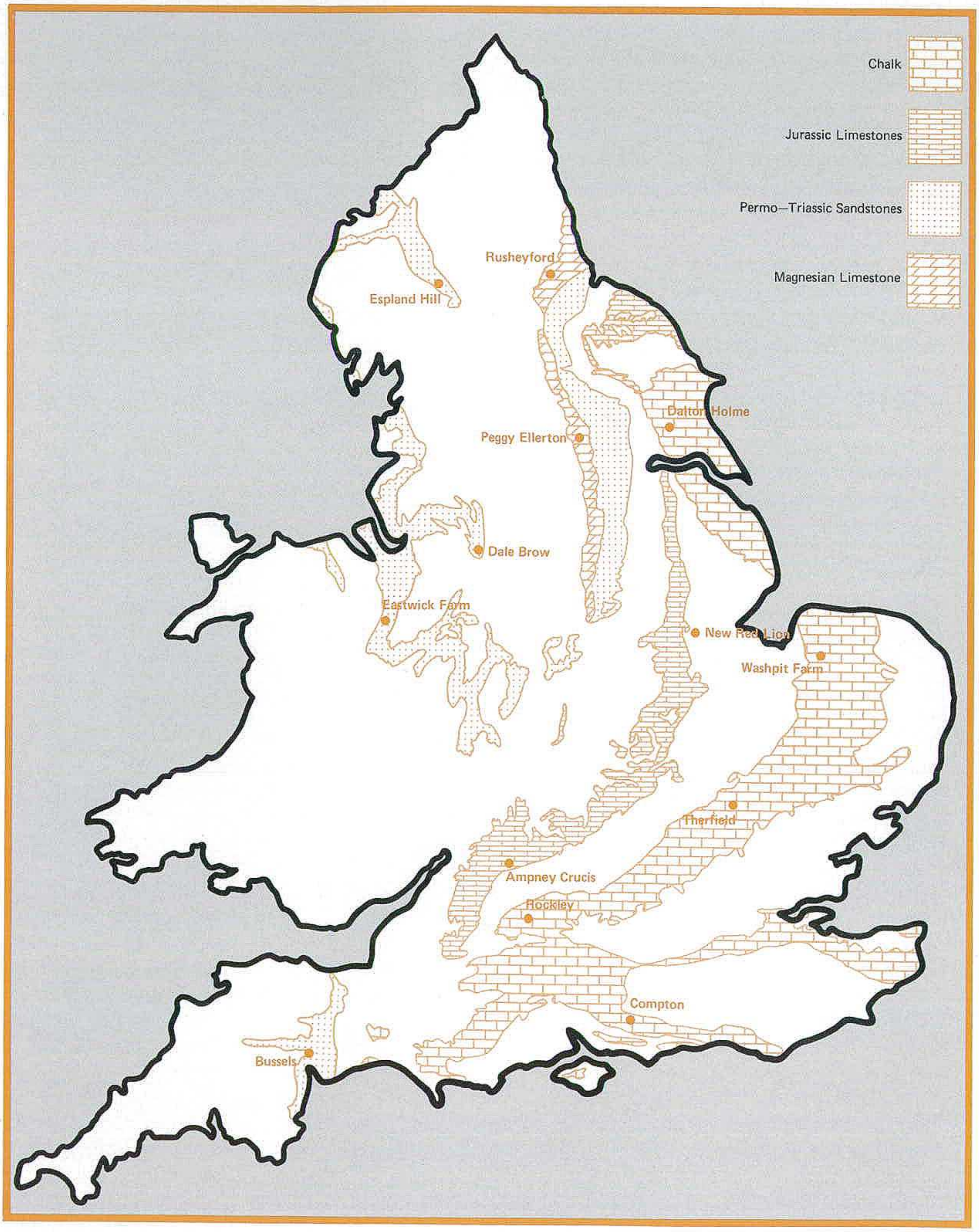


Figure 41. Principal aquifers and representative borehole locations.

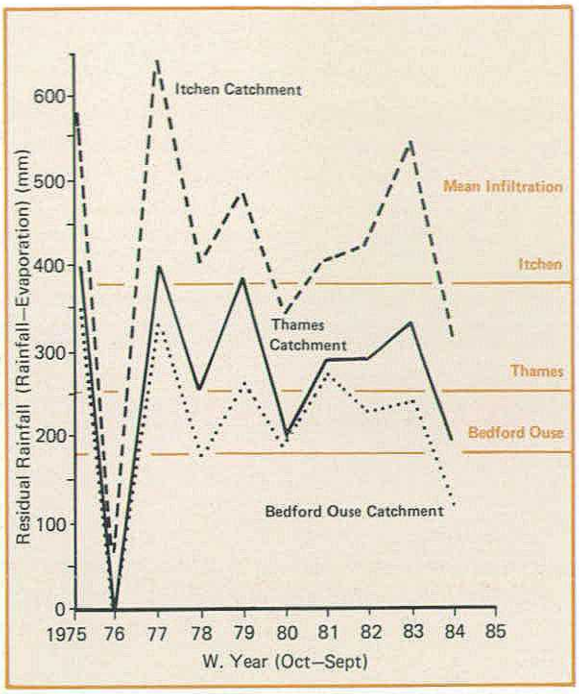


Figure 42. Residual rainfall for three groundwater catchments 1975–84.

(Figure 43 is overleaf)

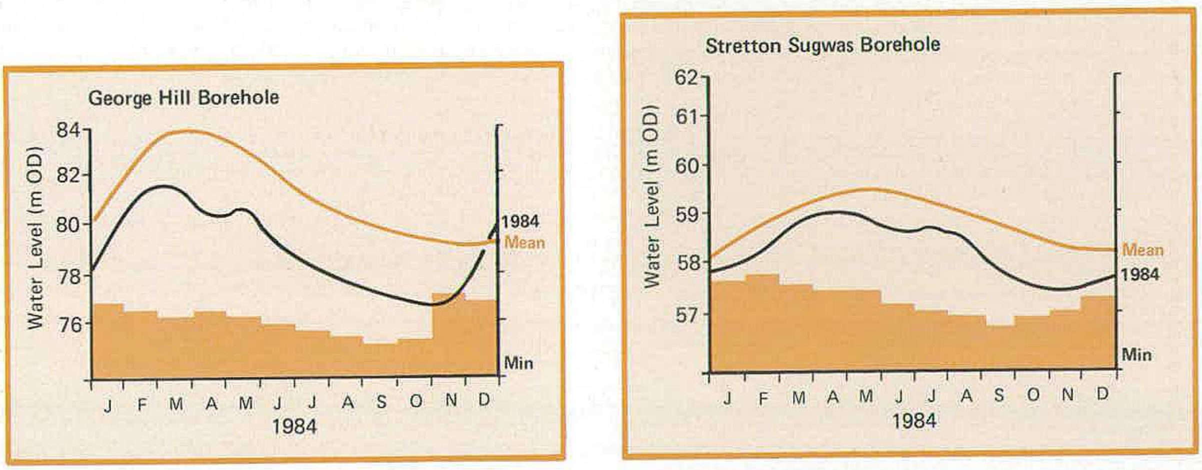


Figure 44. 1984 groundwater levels in minor aquifers.

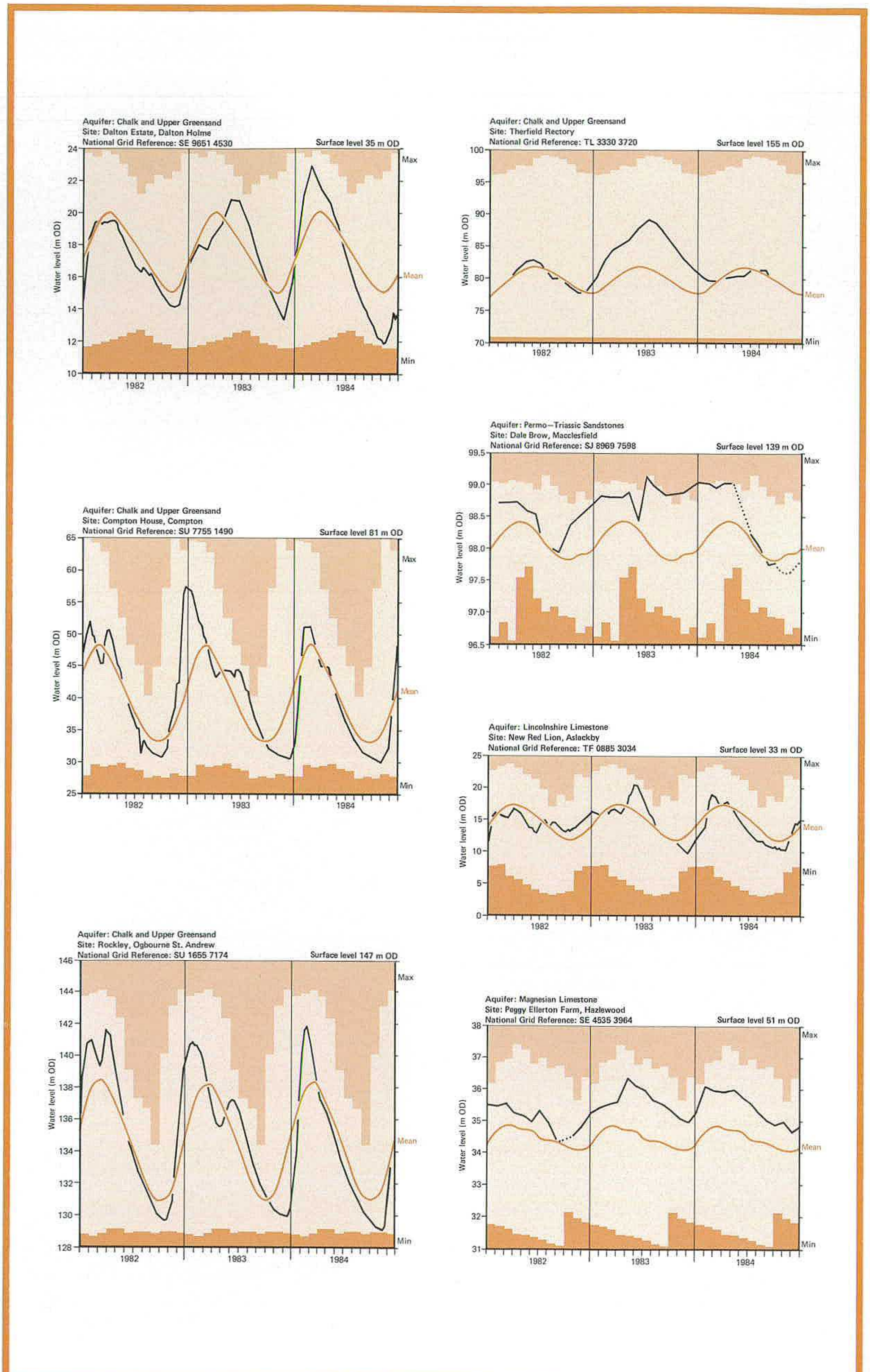


Figure 43. Borehole and well hydrographs for representative sites.

1984 DROUGHT: CONCLUDING REMARKS

In attempting to assess the significance of the 1984 drought, it is necessary perhaps to stress its very minor magnitude when considered on the world scale. Droughts in the United Kingdom are not accompanied by the collapse of agriculture and a widespread threat to lives and livelihood. We are fortunate that rainfall deficiencies inflict only modest inconvenience to the populace; over much of the globe droughts can be amongst the worst of natural disasters. Geographical location is the principal reason for the marginal impact of drought on the fabric of life in the United Kingdom. However, in a country where a continuous and adequate supply of wholesome water is taken for granted, such a limited impact is a tribute to the way in which water resources have been developed and managed over the last 150 years.

Action taken by the water authorities to limit demand and conserve water stocks helped to ensure that supplies were maintained through the critical July–September period in the 1984 drought. A greater ability to supplement supplies in those districts in most need owes much to the networking of resources in recent years, particularly following the 1976 drought in England and Wales and the 1975 drought in central Scotland. The value of integrated resources, including groundwater, at the regional level, was well demonstrated in 1984. For instance, water abstracted from the Permo-Triassic sandstone and the River Lune in Lancashire allowed the Lancashire Conjunctive Use Scheme to feed water into the Thirlmere aquaduct to relieve pressure on the Lake District reservoirs.

In Scotland, water from the Loch Lomond aquaduct was transferred to the Loch Katrine aquaduct, utilising a pipeline installed in 1975, and in south-east Wales the Wye to Usk link was commissioned early in order to supplement depleted resources. River to river transfers were also used to good effect in the South West Water Authority area; water from the Tamar, for instance, was exported to the neighbouring Tavy basin to ease the water supply problems of Plymouth. The Yorkshire Water Grid is a network of reservoirs, rivers and supply pipelines designed to allow surplus capacity in one district to be used to counteract shortages elsewhere. In 1984 the system proved its value, serious supply problems being largely restricted to the Halifax and Huddersfield area which has yet to be incorporated into the grid.

In several regions new, or standby, sources were brought into operation to augment local supplies and an enterprising approach to the development of temporary and emergency sources prevailed. For instance, in Fife, three supply boreholes were brought into service to reduce demand on the Glendevon reservoirs. Rarely used wells and spring sources were utilised and pumps were installed in old mineshafts and quarries especially in Cornwall. Temporary barrages to raise water levels to facilitate abstractions were deployed; for instance on the Avon in Dorset and at Ullswater. These measures were complemented by further exhortations, through the media, to the public to limit its water use.

Nowhere in the United Kingdom did it become necessary to use standpipes or rota cuts to restrict demand in 1984; contingency powers to adopt these measures were requested covering parts of the South-West peninsular, Wales, the Strathclyde region in Scotland and the Huddersfield and Halifax area of Yorkshire. Prohibitions on the non-essential use of water did however become necessary throughout the major part of the North West Water Authority area, much of Devon and Cornwall, large areas in northern and southern Wales and some districts in Yorkshire. Over 100 Drought Orders relating to compensation flows and abstraction conditions had been made effective by September and hosepipe bans were applied extensively throughout the west and north of England and Wales. In total some 23 million people were affected by hose-pipe bans although a few in southern England were the result of local distribution problems rather than being directly related to the drought[21]. The impact upon water users was greater during 1976. Routine rota cuts of up to 17 hours a day affected one million people in south-eastern Wales and standpipes were brought into use for 80,000 people in north Devon. Rota cuts were also introduced in parts of Belfast and water rationing became necessary in Jersey[22].

Reservoirs throughout the United Kingdom were close to capacity at the beginning of the 1984 drought. Under normal operating conditions most of the larger reservoirs would reach maximum drawdown over a period of 6–18 months in drought conditions. Many reservoirs are sensitive to rainfall deficits of about nine months starting early in the year. The drought's duration of five to seven months fell short of the critical period and prospects for water supplies would have been appreciably worse had the drought continued into the autumn as happened for instance in 1921, 1959 and 1964.

The possible trend towards greater total runoff in recent years is reassuring in the water resources context but equally important is the increased variability that has been evident in the United Kingdom over the last decade. Spells of very wet or very dry weather appear to be occurring with an increased frequency and this implies a greater likelihood of river flows in the very low and the flood ranges. Whether the somewhat erratic climatic conditions currently experienced represent a rare occurrence in an otherwise reasonably stable climate, or whether we are undergoing a measure of climatic change perhaps influenced by man's activities remains uncertain. Advances in the understanding of the mechanisms of climatic variability may provide guidance regarding the degree to which historical data series can be assumed to characterise current, and future, conditions.

COMPARISON BETWEEN THE 1984 AND 1976 DROUGHTS

The 1976 drought has been extensively documented[3, 4, 5, 6, 13, 14, 20, 22], and only a brief comparison will be made between the differing characteristics of the 1984 drought and its predecessor.

The two events may be contrasted by distribution and duration. Figures 45 and 46 illustrate the distribution of rainfall and runoff respectively for April to August for both events. As a rough guide, a line drawn from Flamborough Head to Lizard Point demarcates the two droughts, with the severest conditions to the east of the line in 1976, and to the west in 1984. Devon, Cornwall and South Wales were similarly affected in both events. The 1976 drought was, therefore, concentrated in a region of low average rainfall, which also has significant groundwater resources, extensive areas of prime agricultural land, and the largest concentration of population.

The 1984 drought was of too short a duration and too late a start (Feb–Mar) to significantly perturb the base flow contribution to rivers in southern and eastern England, especially following the wet winter (Dec–Feb) of 1983/84. Table 20 indicates the lag times between rainfall and runoff for selected catchments; the importance of antecedent rainfall and its timing may be readily appreciated. The duration of the '1976' drought is considered to be 16 months from May 1975 to August 1976. This is the driest 16 month period on record in England and Wales (Fig. 47), and included a winter period (Dec–Feb) with only 61% of average rainfall. Relevant winter rainfalls for the two events are given in Table 21 for the United Kingdom and its component countries. The dry winter following the dry summer of 1975 led to much reduced infiltration to augment groundwater storage (see Fig. 42, p. 63); the continuing drought led to the most laggardly responding rivers showing substantially reduced flows in 1976. Figure 48 shows the extreme reduction in groundwater levels in two chalk wells during 1975 and 1976, and the comparatively modest effect of the 1983/84 drought at these sites.

Four SMD records are depicted in Fig. 49. The site at Wittering is most representative of the areas most affected in 1976, showing the carry-over of significant deficits from the autumn period of 1975 and their exceptional development in 1976, resulting in adverse affects upon vegetation.

Ascribing a relative severity to the two events is difficult owing to their different durations and varying areal distributions. Various 'durational' records can be selected for both events in specific areas (Tables 1 and 6 for rainfall; Tables 9, 11 and 12 for runoff). Comparisons have already been made in the section describing drought indices (see p. 4).

Frequencies of occurrence may be qualified similarly to the above (see also pages 6 and 37). For rainfall at a catchment scale Tables 5 and 22 may be compared, taking note of the different durations. For runoff, Tables 23 and 24 show the results of performing the annual minima and reservoir storage analyses on 1976 and 1984 data. The 1984 sites are a subset of those in Tables 17 and 18. Both approaches indicated that the 1976 drought was both more widespread and for most of eastern, southern and south west England more severe than the 1984 drought. Indeed, insofar as river flows are concerned the 1984 drought left most of eastern and southern Britain little affected. The areas where 1984 was more severe than 1976 were parts of Wales, north western England and Scotland with some catchments experiencing droughts with return periods of greater than 100 years. Figure 50 presents hydrographs of daily mean flows for three upland rivers, the Fowey, Yscir and Greta. The latter two are useful indicators of a drought's severity as man's effect on the flow regime is minor. Marked similarities in the recessions of 1976 and 1984 may be recognised.

As regards overall impact, the drought of 1976 must be considered as more severe. Agricultural impact was significant in 1976; cereals, grassland and many arable crops were adversely affected with much reduced yields (see Fig. 25 for cereal production). Livestock production was similarly reduced in 1976 and supplementary feeding much increased. In 1984, agriculture was affected only modestly, if at all.

A similarity between the two events was in their sudden and thorough endings; autumn rainfall in both cases was above average. Water resources, as depicted by reservoir contents and groundwater levels were at satisfactory levels moving into 1977 and 1985.

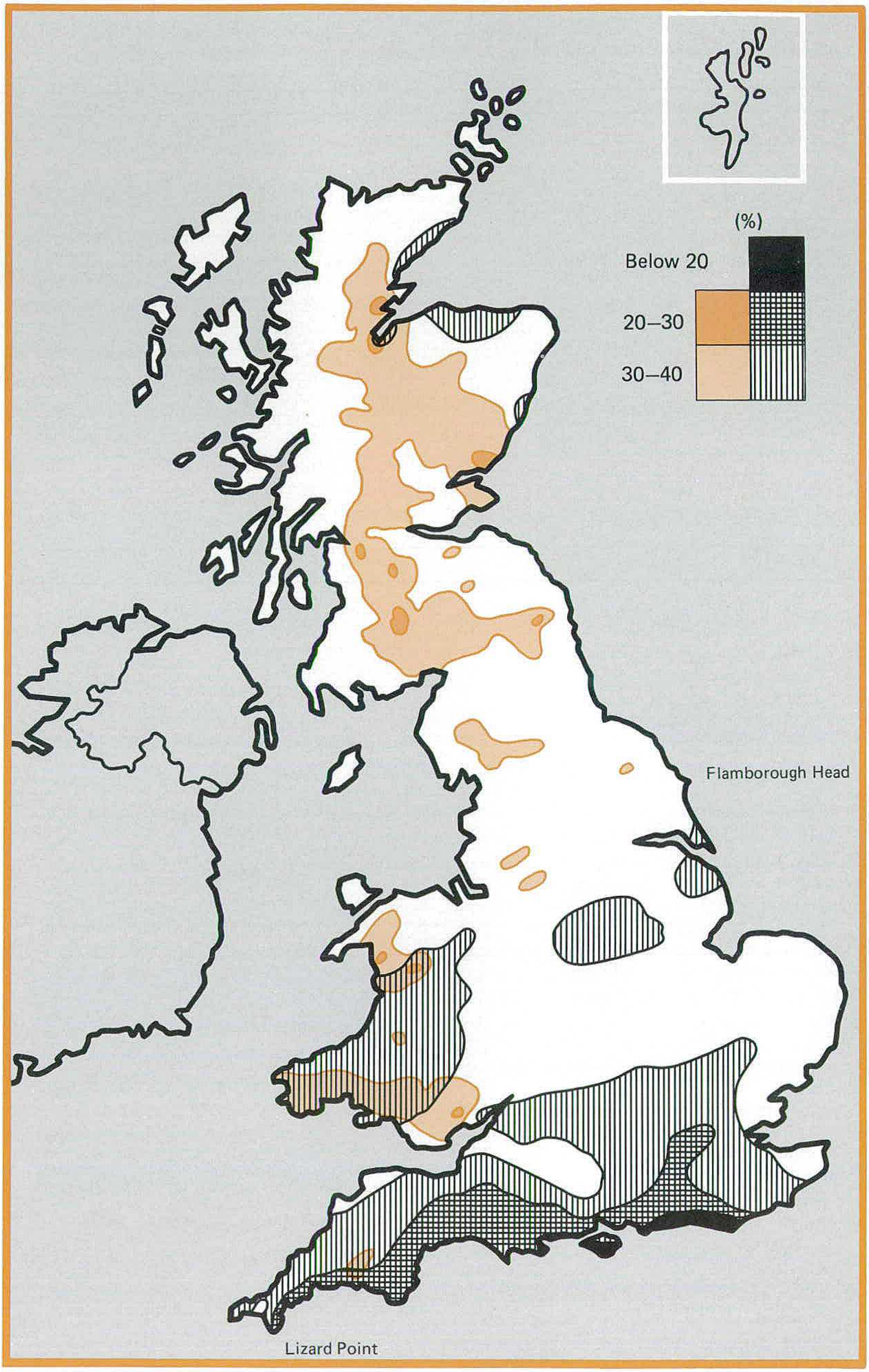


Figure 45. April to August rainfall; a comparison between 1984 (brown) and 1976 (hatched).

TABLE 20. DELAY TO REDUCTION OF RIVER FLOWS

Hydrometric area and station number	River	Station	Catchment area (km²)	Effective delay of catchment (months)			
				2–2	3–5	6–9	10+
23001	Tyne	Bywell	2180		×		
25001	Tees	Broken Scar	818		×		
28001	Derwent	Yorkshire Bridge	127			×	
28010	Derwent	Longbridge Weir	1120			×	
32001	Nene	Orton	1630				×
33002	Great Ouse	Bedford	1460				×
33035	Ely Ouse	Denver	3570				×
39001	Thames	Teddington/Kingston	9870				×
39008	Thames	Eynsham	1620				×
39016	Kennet	Theale	1030				×
43005	Avon	Amesbury	324			×	
43008	Wylye	South Newton	445				×
45001	Exe	Thorverton	601		×		
47001	Tamar	Gunnislake	917		×		
52006	Yeo	Pen Mill	213			×	
53003	Avon	Bath	1600			×	
54001	Severn	Bewdley	4330			×	
54003	Vyrnwy	Vyrnwy Reservoir	94.3	×			
55006	Elan	Caban Coch	184	×			
56001	Usk	Chain Bridge	912		×		
71002	Hodder	Stocks Reservoir	37.6	×			
72001	Lune	Halton	995	×			
76001	Haweswater Beck	Thornthwaite	33.9	×			

Source: Reference (4)

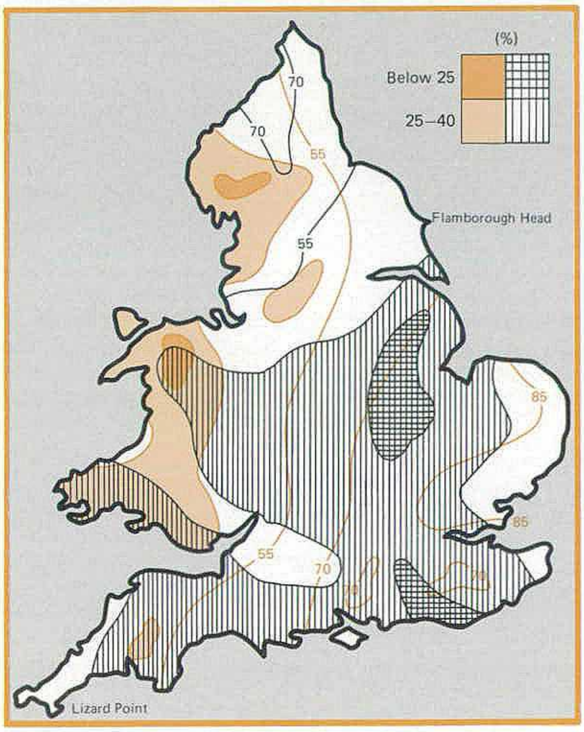


Figure 46. April to August runoff; a comparison between 1984 (brown) and 1976 (hatched).

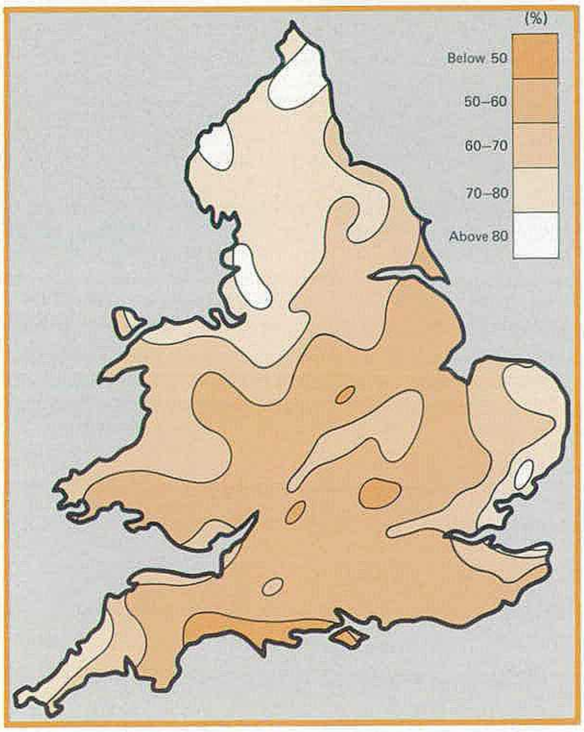


Figure 47. May 1975 to August 1976 rainfall as a percentage of 1941–70 average (from reference (4)).

TABLE 21. WINTER RAINFALL (OCT - MAR) FOR THE UNITED KINGDOM FOR SELECTED YEARS

	UK		E & W		SCOTLAND		NI	
Year	mm	% LTA	mm	% LTA	mm	% LTA	mm	% LTA
1941–70 LTA	295		241		397		293	
1974/75	328	111	231	96	519	131	294	100
1975/76	221	75	147	61	362	91	213	73
1983/84	394	134	312	129	542	136	430	147

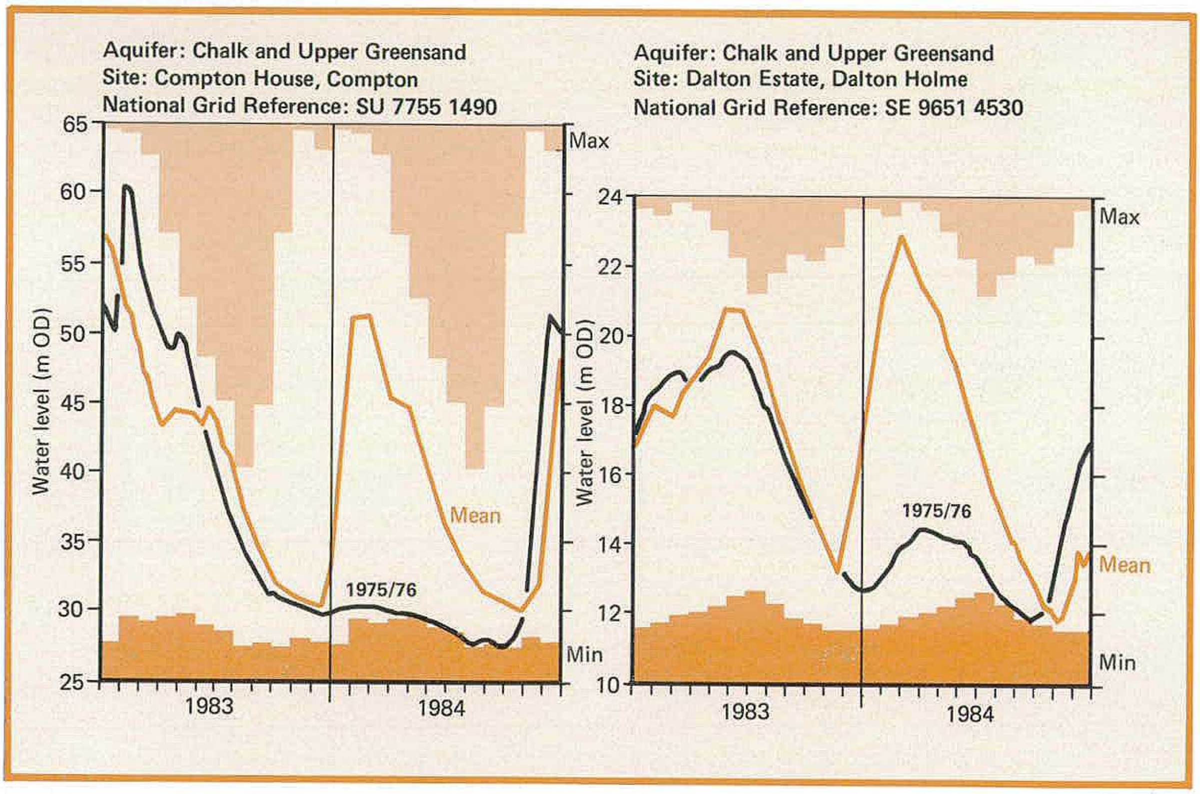


Figure 48. Groundwater levels in 1983/84 and 1975/76.

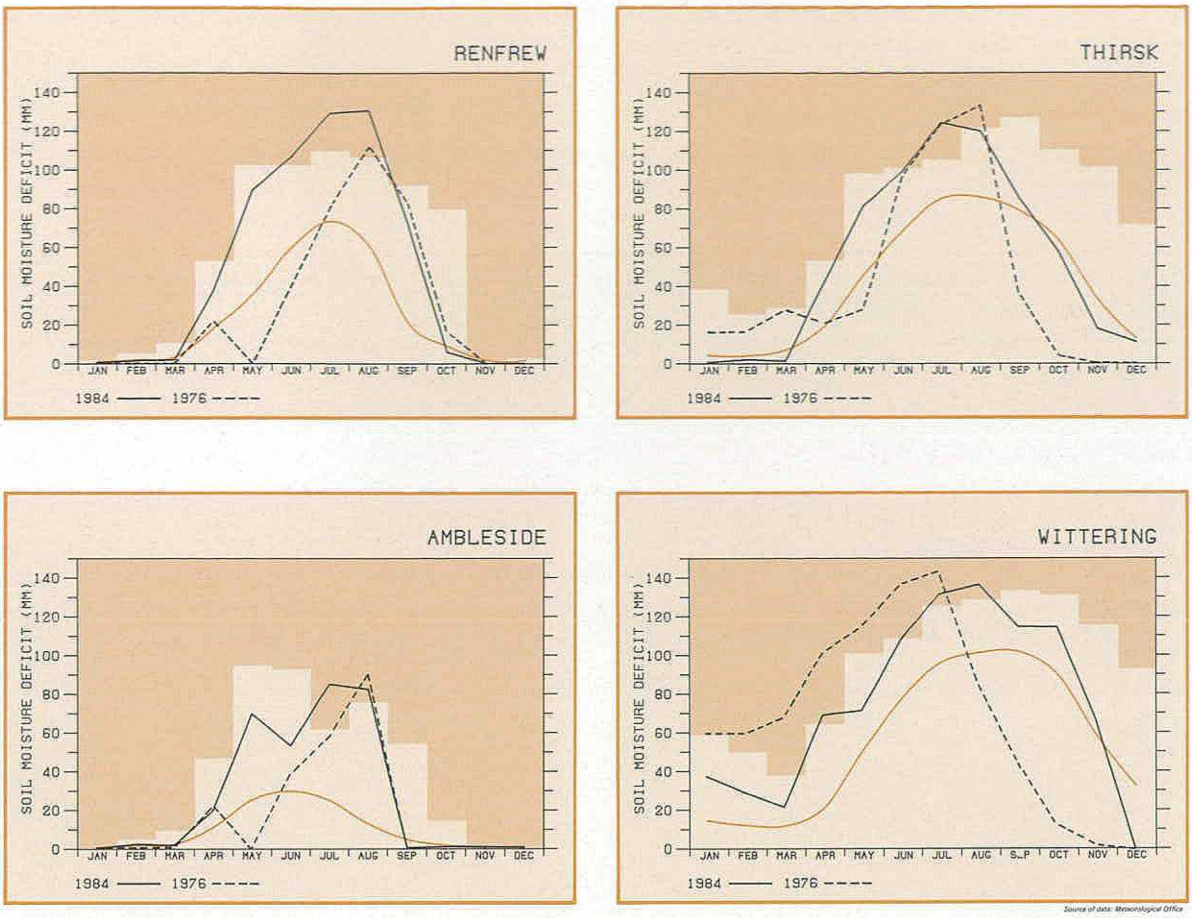


Figure 49. Soil moisture deficits in 1984 and 1976 for four representative sites.

TABLE 22. FREQUENCY OF OCCURRENCE OF SPECIFIED DRY PERIODS FOR SELECTED CATCHMENTS STARTING IN A GIVEN MONTH

Catchment area	Duration (months)	Frequency of occurrence (1 in X years)							
		5	10	20	50	100	200	500	≥500
Haweswater	4	78.9	68.9	60.9	52.1	46.5	41.3	35.3	
Beck to	8	84.9	77.5	71.6	65.0	60.7	56.9	52.3	
Thornthwaite	12	87.6	81.4	76.5	71.0	67.4	64.1	60.2	
	16	89.2	83.8	79.4	74.6	71.4	68.5	65.1	
Great Ouse	4	77.4	66.5	57.8	48.4	42.2	36.6	30.1	
to	8	83.8	75.9	69.4	62.3	57.7	53.5	48.5	
Bedford	12	86.7	80.1	74.7	68.8	64.9	61.3	57.1	54.2
	16	88.4	82.6	77.9	72.7	69.2	66.1	62.4	59.8
Thames to	4	77.7	67.3	59.0	49.9	44.0	38.8	32.5	
Teddington/	8	84.1	76.4	70.2	63.3	58.9	54.9	50.1	46.8
Kingston	12	86.9	80.5	75.3	69.6	65.8	62.4	58.3	55.5
	16	88.6	83.0	78.4	73.3	70.0	67.0	63.4	60.9
Vyrnwy to	4	78.7	68.9	61.0	52.5	46.9	42.0	36.2	
Vyrnwy	8	84.8	77.5	71.6	65.1	60.9	57.2	52.7	
Reservoir	12	87.5	81.4	76.5	71.0	67.5	64.3	60.4	
	16	89.1	83.8	79.4	74.6	71.5	68.6	65.2	

% of 1916–50 average rainfall

Adapted from reference (10)

TABLE 23. RETURN PERIODS OF 1984 AND 1976 ANNUAL MINIMA

Station No.	Station Name	Years of record	1984 10	1984 30	1984 60	1984 90	1984 180	1976 10	1976 30	1976 60	1976 90	1976 180
			Return period of annual minimum for a given duration in days									
25006	Greta at Rutherford Bridge	21	10	10	5	10	10	100+	100	100	50	10
28018	Dove at Marston on Dove	18	5	5	5	10	5	100	50	50	50	20
36006	Stour at Langham	22	2	2	2	2	2	100+	100+	100+	100+	10
43007	Stour at Throop Mill	12	5	5	5	5	5	100+	100+	100+	100+	20
50001	Taw at Umberleigh	23	20	10	20	20	10	100	100	50	20	50
52005	Tone at Bishops Hull	24	5	5	5	5	5	100+	100+	100+	100+	50
54003	Vyrnwy at Vyrnwy Reservoir	54	5	5	5	20	100+	100+	100+	100+	100+	50
57004	Cynon at Abercynon	25	10	10	10	50	20	20	20	20	20	10
73010	Leven at Newby Bridge	46	5	10	50	50	100+	20	100	10	20	5
79002	Nith at Friars Carse	27	50	50	20	20	50	50	50	20	50	10

All return periods have been rounded
+ Return periods well in excess of 100 years.

TABLE 24. RETURN PERIODS OF 1984 AND 1976 RESERVOIR DRAWDOWNS

Station No	Station Name	Years of record	1984 20	1984 40	1984 60	1984 80	1976 20	1976 40	1976 60	1976 80
			Return period of reservoir drawdown for a given percentage of LTA flow as yield							
36006	Stour at Langham	22	*	2	2	2	20	10	10	5
50001	Taw at Umberleigh	23	20	20	20	10	20	20	100	100
52005	Tone at Bishops Hull	24	*	5	5	2	50	50	100+	100+
54003	Vyrnwy at Vyrnwy reservoir	54	20	50	20	10	100	50	20	20
57004	Cynon at Abercynon	25	20	20	10	5	20	20	20	50
73010	Leven at Newby Bridge	46	100	100+	100+	100+	10	10	10	50
79002	Nith at Friars Carse	27	50	50	50	50	20	5	5	5

All return periods have been rounded
+ return periods well in excess of 100 years
** no significant drawdown.*

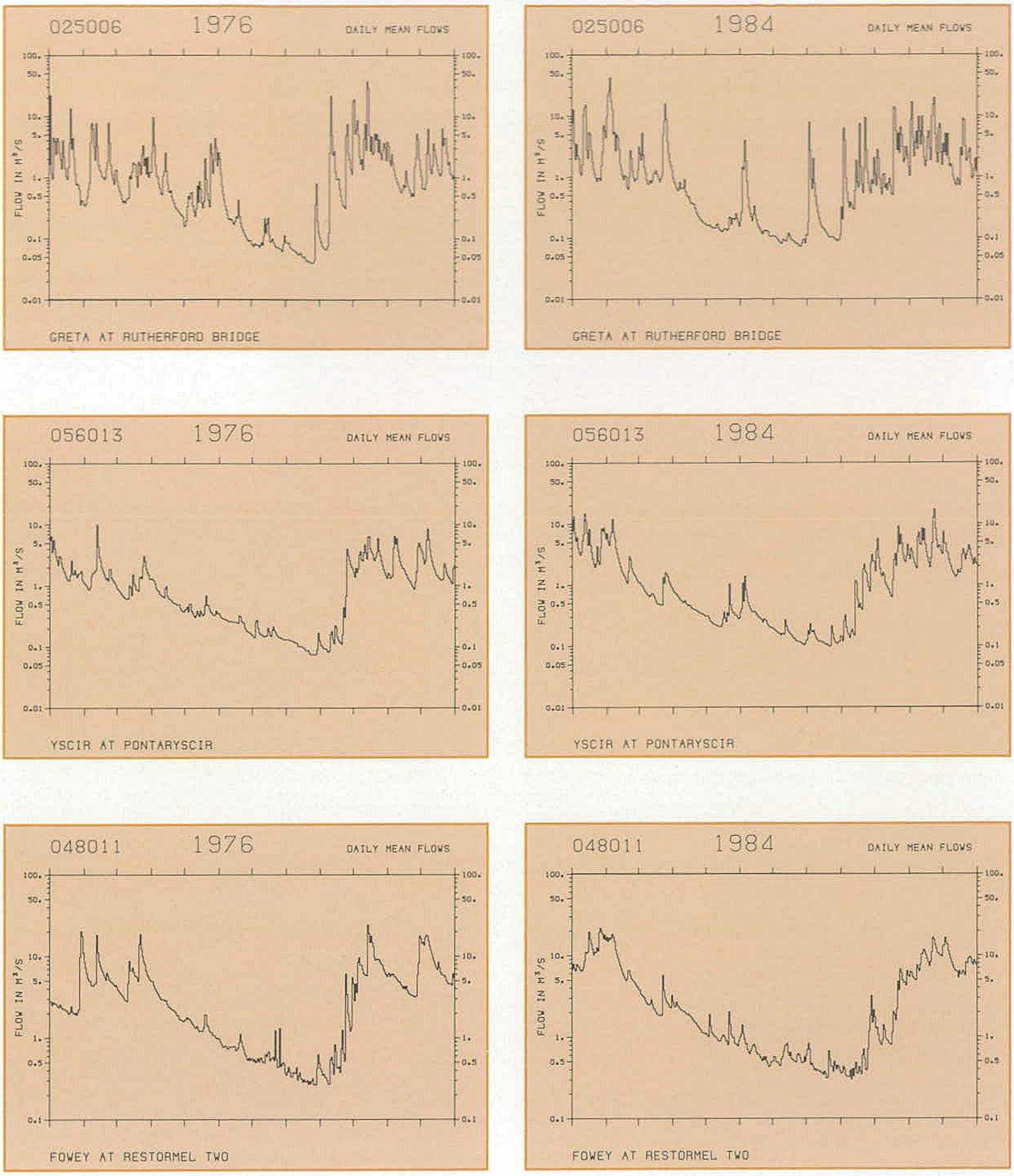


Figure 50. 1984 and 1976 hydrographs for three upland catchments.

REFERENCES

1. Paris, M. (1872) Matthaei Parisiennsis Monachi Sancti Albrani, *Chronica Majora V. Rolls Series* 1872-84.
2. Grindley, J. (1985) Drought was more severe over Scotland and the North West. *The Times*, 31.1.1985.
3. Meaden, G.T. (1977) North West Europe's great drought - the worst in Britain since 1252/53? *J. Met.***1**, 379-383.
4. Central Water Planning Unit (1976) The 1975-76 drought: a hydrological review. *Technical Note No. 17*, 35 pp.
5. Doornkamp, J.C. & Gregory, K.J. (eds) (1980) *Atlas of Drought in Britain 1975-76*. Institute of British Geographers. 87 pp.
6. Wright C.E. (1976) Once in 1,000 years? *Water*, (11), 2-6.
7. Marsh, T.J. & Littlewood, I.G. (1978) An estimate of annual runoff from England and Wales 1728-1976. *Hydrol. Sci. Bull.* **23**, 1,3.
8. Foley, J.C. (1957) Drought in Australia. *Bureau of Meteorology, Bull. No. 43*, 281.
9. Anon (1978) Water Data 1977. Water Data Unit. 88 pp.
10. Wright, C.E. (1978) Synthesis of river flows from weather data. *Central Water Planning Unit, Technical Note No.26*. 118 pp.
11. Tabony, R.G. (1977) The variability of long duration rainfall over Great Britain. *Met. Office Scientific Paper No. 37*.
12. Hamlin, M.J. & Wright, C.E. (1978) The effects of droughts on river systems. *Proc. R. Soc., London A.*, **363**, 69-96.
13. Clarke, R.T. & Newson, M.D. (1978) Some detailed water balance studies of research catchments. *Proc. R. Soc. London. A.*, **363**, 21-42
14. Newson, M.D. (1980) *Atlas of Drought in Britain 1975-76*. Institute of British Geographers, 37-38.
15. Institute of Hydrology (1980) Low Flow Studies. *Inst. Hydrol., Wallingford.*
16. Walsh, P.D. (1985) *Personal communication.*
17. Lucas, S. (1984) The Scottish Drought. *Water Bulletin* **2**, 8-9.
18. Welsh Water Authority (1985) Drought Report: A review of the effects of the 1984 drought on the Welsh Water Authority. *Welsh Water Authority*. 60 pp.
19. Anon. (1984) Groundwater: United Kingdom 1980. *Department of the Environment, HMSO.* 135 pp.
20. Day, J.B.W. & Rodda, J.C. (1978) The effects of the 1975-76 drought on groundwater and aquifers. *Proc. R. Soc. London A.*, **363**, 55-68.
21. Water Authorities Association (1984) Water Situation Reports. *Water Authorities Association*, July-Sept.
22. Rodda, J.C. (1978) A review of the 1975/76 drought. *Unpublished memorandum. Water Data Unit.*
23. Penman, H.L. (1948) Natural evaporation from open water, bare soil and grass. *Proc. R. Soc. London A.*, **193**, 120-145.
24. Thompson, N., Barrie, I.A., & Ayles, M. (1981) The Meteorological Office Rainfall and Evaporation System: MORECS (July 1981). *Met. Office Hydrological Memorandum No.45*, 72pp.
25. Grindley, J. (1969) The calculation of actual evaporation and soil moisture deficit over specified catchment areas. *Met. Office Hydrological Memorandum No.38*, 3 pp.
26. Calder, I.R. (1977) A model of transpiration and interception loss from a spruce forest in Plynlimon, Central Wales, *J. Hydrol.*, **38**, 247-265.
27. Calder, I.R., Harding, R.J. and Rosier, P.T.W. (1983) An objective assessment of soil-moisture deficit models. *J. Hydrol.*, **60**, 329-355.
28. Calder, I.R., Hall, R.L., Harding, R.J., Rosier, P.T.W. & Wright, I.R. (1984) Upland afforestation progress report. Process studies 1983-1984. *Unpubl. internal report, Inst. Hydrol., Wallingford.*

APPENDIX I

The computation of rainfall and runoff deficiency indices

The drought indices presented in the chapters *Rainfall* and *Runoff* are based upon a measure of the degree of deficiency in either rainfall or river flow from the average conditions.

Both the rainfall and runoff indices are derived from monthly data. A dry period is defined by the departure of the monthly totals below the average value. Where a sequence of monthly values is less than the mean, the percentage deficiency is accumulated. Thus, as the dry period progresses the cumulative index steadily increases.

A period of rainfall deficiency is considered to be terminated if:

(i) one month exceeds 200% of the mean or
(ii) two months together exceed 250% of the mean or
(iii)three months together exceed 300% of the mean.

When any of the three termination criteria are met, the cumulative index returns to zero. If rainfall exceeds 100% but falls below the termination threshold the percentage above the mean is subtracted from the accumulated score. Thus, the rainfall index may fluctuate as the drought progresses and the most intense period of the drought (*eg* maximum score) may not necessarily coincide with the final month.

In the report, period averages have been selected to permit direct comparison between indices for individual countries or catchments. Table 25 gives the means used for each area.

TABLE 25 PERIOD OF RECORDS AND AVERAGES USED IN THE CALCULATION OF THE RAINFALL DEFICIENCY INDICES

Area	Period of record	Base periods for rainfall averages
England and Wales	1760-1984	1781-1880, 1831-1880, 1881-1930, 1931-1980
Great Britain	1869-1984	1901-1930, 1931-1980
Scotland	1869-1984	1901-1930, 1931-1980
Thirlmere	1930-1984	Single period of record mean

APPENDIX II

(a) MORECS: Meteorological Office Rainfall and Evaporation Calculation System

MORECS, in its operational form, uses daily meteorological data from about 130 synoptic stations in Great Britain to produce weekly and monthly estimates of evapotranspiration, soil moisture deficit and hydrologically effective rainfall (HER) for each square of a 40 km x 40 km grid superimposed on Great Britain. Grid square estimates of the meteorological data input to the system are found by using interpolation methods. A modified version of the Penman-Monteith combination equation is used to calculate evapotranspiration for each grid square for a range of surface covers from bare soil to forest. A two reservoir model is used to simulate plant extraction of water in the SMD calculation and allow the derivation of actual evaporation. Calculations are made for three levels of soil permeability. Outputs are a series of maps with grid square averages of the meteorological inputs, and also PE, AE, SMD and HER for grass and real land use, and tabulations of the same quantities for individual surface types.

An extended description of the system, covering its philosophy, assumptions and equations is presented by Thompson et al[24].

(b) ESMD: Estimation of soil moisture deficit

The earlier estimation of SMD is described by Grindley[25]. It utilises a series of Penman root constants which are specified for various land use types. Certain land use types (eg riparian, urban etc) have individually defined evaporative behaviour. "Areal land use" (cf. "real land use" in MORECS) considers that 50% of the area carries short rooted vegetation (root constant 75 mm), 30% carries long rooted vegetation (root constant 200 mm) and 20% is riparian (evaporation always proceeds at the potential rate). One level of soil permeability is used. Simple allowances are made for development of vegetative cover in the spring and for post harvest conditions.

(c) Calculation of Plynlimon soil moisture deficits

The soil moisture deficits under forest and grassland for Plynlimon were calculated using a daily accounting model similar to that used by Calder et al (1983):

$$SMD_{i+1} = SMD_i - R_i + E_i \text{ when } SMD_i \geq 0$$
$$\text{or } SMD_{i+1} = SMD_i \text{ when } SMD_i \leq 0$$

where i is the day number,
R_i is the rainfall on day i and
E_i is the evaporation on day i.

The evaporation was calculated from the potential evaporation and, in the case of the forest model, the rainfall. The potential evaporation used was the mean climatological, this is based on the average Penman[23] (1948) potential evaporation for the southern UK; Calder et al (1983) found that this formulation gave predictions which agreed well with the grassland soil moisture observations from Plynlimon.

The grassland evaporation model uses a layer root constant model in which the evaporation is assumed to be at the potential rate until the SMD reaches 70 mm; the evaporation is then set equal to one half the potential rate (a full description of this model is given in Calder[27]).

The forest evaporation model uses an interception ratio of 0.35, this being the measured value from the Severn catchment, and assumes the evaporation is equal to 90% of the potential during the dry periods[27]. On raindays the number of hours with a dry canopy (and hence the hours in which transpiration can take place) is calculated from the rainfall assuming a mean rainfall rate of 1.4 mm per hour. This model has been tested against actual soil moisture observations at sites elsewhere in the UK where it has performed well[28].

APPENDIX III

Derivation of the flow frequency curve (p.37).

To derive the flow frequency curve for a duration of 'n' days from a record of daily mean flows:

(1) find the lowest average discharge in each year for the duration 'n' of interest
(2) rank these annual minima, lowest flow = rank 1
(3) assign a plotting position W to each ranked discharge
(4) draw a smooth curve through the plotted points

The probability axis of Fig. 33 is linear in the Weibull reduced variate, W, which has been found to produce approximately linear plots and assists extrapolation to lower discharges. The return period axis is also shown enabling the frequency of any particular annual minimum to be estimated.

APPENDIX IV

Storage yield analytical procedure (p.37).

Given a runoff record of daily mean flows and a notional yield from the catchment, the simulation is carried out by calculating S_i, the volume of water required to fill the reservoir, representing the storage needed to maintain a given yield, from the following daily water balance.

$$S_{i+1} = S_i - I_i + Y_i$$

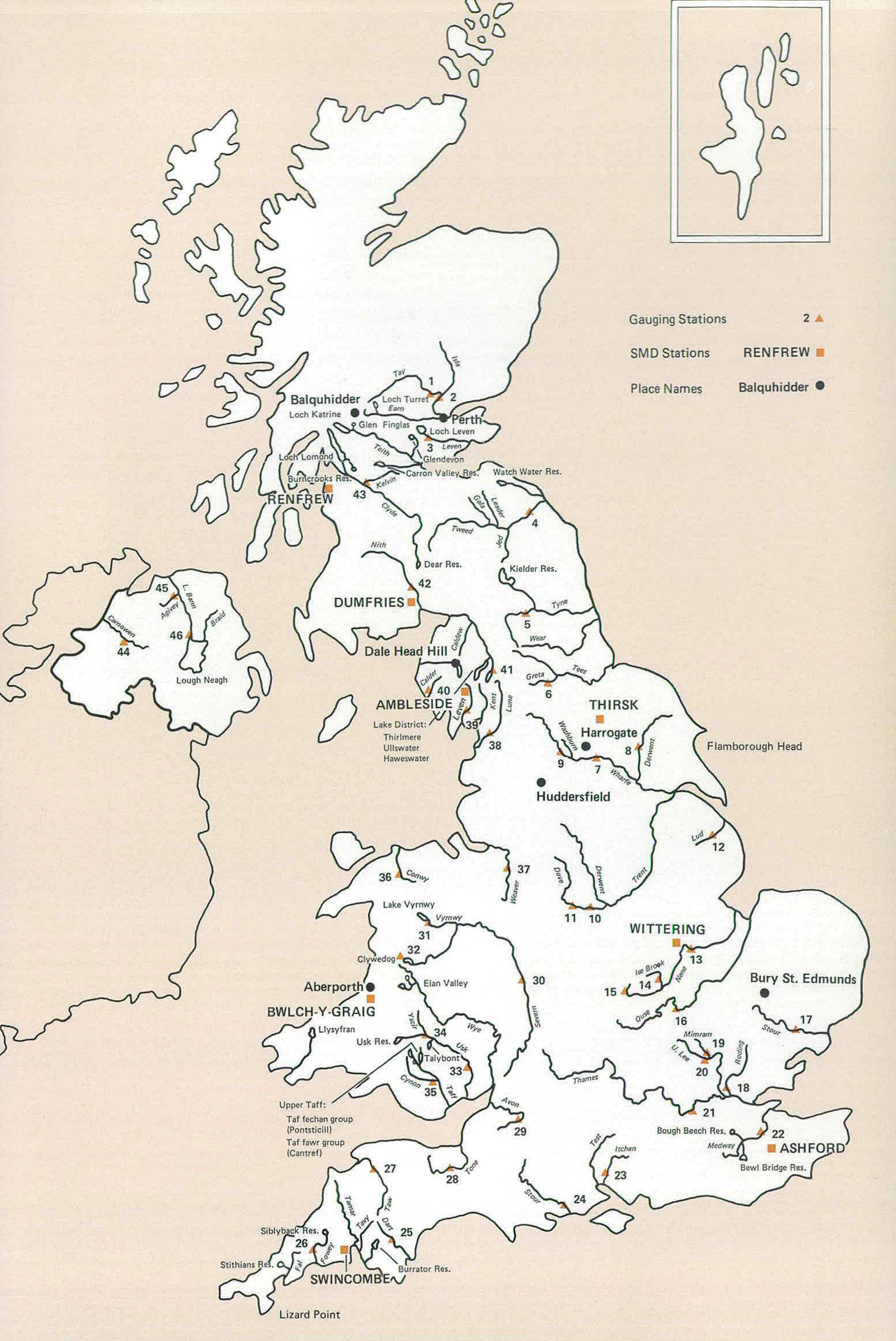
(For $S_{i+1} \leq 0$ the reservoir spills and S_{i+1} is set to 0; no upper limit is set on S_i although in practice this is of course controlled by the maximum volume of reservoir storage).

S_{i+1}	storage requirement at the end of the ith day
S_i	storage requirement at the beginning of the ith day
I_i	inflow in ith day
Y_i	constant yield on ith day

From the series of S_i values the annual maximum S_i values are calculated, the values are ranked and plotted using a logarithmic storage axis and a normal frequency axis. By expressing the yield as a percentage of the mean discharge and the storage as a percentage of the mean annual runoff, storage yield relationships derived from different flow records may be compared and their results applied to nearby reservoired catchments.

Key to gauging stations referred to on facing page

SITE NO.	STATION NUMBER	RIVER AND STATION NAME
1	15003	Tay at Caputh
2	15006	Tay at Ballathie
3	17002	Leven at Leven
4	21009	Tweed at Norham
5	23004	South Tyne at Haydon Bridge
6	25006	Greta at Rutherford Bridge
7	27002	Wharfe at Flint Mill Weir
8	27041	Derwent at Buttercrambe
9	27043	Wharfe at Addingham
10	28010	Derwent at Longbridge Weir
11	28018	Dove at Marston on Dove
12	29003	Lud at Louth
13	32001	Nene at Orton
14	32004	Ise Brook at Harrowden Old Mill
15	32008	Nene (Kislingbury) at Dodford
16	33002	Bedford Ouse at Bedford
17	36006	Stour at Langham
18	37001	Roding at Redbridge
19	38003	Mimram at Panshanger Park
20	38018	Upper Lee at Water Hall
21	39001	Thames at Teddington/Kingston
22	40003	Medway at Teston
23	42010	Itchen at Highbridge
24	43007	Stour at Throop Mill
25	46003	Dart at Austins Bridge
26	48011	Fowey at Restormel
27	50001	Taw at Umberleigh
28	52005	Tone at Bishops Hull
29	53018	Avon at Bathford
30	54001	Severn at Bewdley
31	54003	Vyrnwy at Vyrnwy Reservoir
32	54022	Severn at Plynlimon Flume
33	56001	Usk at Chain Bridge
34	56013	Yscir at Pontaryscir
35	57004	Cynon at Abercynon
36	66011	Conway at Cwm Llanerch
37	68001	Weaver at Ashbrook
38	72004	Lune at Caton
39	73010	Leven at Newby Bridge
40	74006	Calder at Calder Hall
41	76001	Haweswater Beck at Thornthwaite
42	79002	Nith at Friars Carse
43	84001	Kelvin at Killermont
44	203028	Agivey at Whitehill
46	203616	Lough Neagh at Toome


Gauging Stations 2
SMD Stations RENFREW
Place Names Balquhidder
Tay
Isla
1
2
Loch Turret
Earn
Balquhidder
Loch Katrine
Perth
Glen Finglas
Loch Leven
3
Leven
Teith
Loch Lomond
Glendevon
Carron Valley Res.
Watch Water Res.
Burncrooks Res.
Kelvin
43
RENFREW
Clyde
Gala
Leader
4
Tweed
Jed
Nith
Dear Res.
Kielder Res.
42
45
L. Bann
Agivey
Braid
DUMFRIES
Tyne
Carnowen
46
5
44
Wear
Caldew
Dale Head Hill
Lough Neagh
Tees
41
Greta
6
Calder
40
AMBLESIDE
Kent
Leven
Lune
THIRSK
39
Lake District:
Thirlmere
Ullswater
Haweswater
38
Washburn
Harrogate
8
Derwent
Flamborough Head
9
7
Wharfe
Huddersfield
Lud
12
36
Conwy
37
Weaver
Dove
Derwent
Trent
Lake Vyrnwy
Vyrnwy
11
10
WITTERING
31
Clywedog
32
13
Ise Brook
14
Nene
15
Aberporth
Elan Valley
30
Bury St. Edmunds
BWLCH-Y-GRAIG
Severn
Ouse
16
17
Llysyfran
Yscir
34
Wye
Stour
Usk Res.
Usk
Mimram
19
Talybont
U. Lee
Roding
33
20
Cynon
Taff
35
Thames
18
Upper Taff:
Taf fechan group
(Pontsticill)
Taf fawr group
(Cantref)
Avon
29
21
Bough Beech Res.
22
Test
Itchen
Medway
ASHFORD
27
28
Tone
Bewl Bridge Res.
23
Tamar
Taw
Stour
24
Tavy
Dart
25
Siblyback Res.
26
Fowey
Stithians Res.
Fal
SWINCOMBE
Burrator Res.
Lizard Point

PUBLICATIONS

Title	*Published*	*Price* (inclusive of second class postage within UK) *Loose Leaf*	*Bound*
1. Yearbook 1981.	1985	£10	£12
2. Yearbook 1982.	1985	£10	£12
3. The 1984 Drought.	1985		£12

The Yearbooks are available as bound volumes or as sets of pre-punched sheets for insertion in a ring binder designed to hold five yearbooks and the five-yearly catalogue with summary statistics. The ring binder may be purchased for £28 to include the 1981 and 1982 yearbooks. Organisations and individuals purchasing the ring binder will be entitled to receive free updates of the data sheets for individual Yearbooks when a significant revision to the published data is made. The revised data sheets will normally be issued on an annual basis.

All the Hydrological data: UK publications and the ring binder may be obtained from:-

Institute of Hydrology
Maclean Building
Crowmarsh Gifford
WALLINGFORD
OXFORDSHIRE OX10 8BB

Telephone: Wallingford (0491) 38800

Enquiries or comments regarding the series, or individual publications, are welcomed and should be directed to the Surface Water Archive Office at the above address.

Natural
Environment
Research
Council

The Institute of Hydrology and the British Geological Survey
are component establishments of the
Natural Environment Research Council

Design: P A Benoist

Graphics: AP Graphics

Typeset by Burgess & Son (Abingdon) Ltd.