

BRITISH HYDROLOGICAL SOCIETY

ASSESSMENT OF DROUGHT SEVERITY

Compiled and Edited
by
John Mawdsley, Geoff Petts
and Susan Walker

BHS Occasional Paper No. 3

BHS Occasional Paper No. 3

ASSESSMENT OF DROUGHT SEVERITY

Compiled and Edited
by
John Mawdsley, Geoffrey Petts
and Susan Walker

BRITISH HYDROLOGICAL SOCIETY

© Copyright
British Hydrological Society
ISBN 0948540 60 5

BHS Occasional Paper No 3

Produced by the Institute of Hydrology,
Wallingford, Oxon OX10 8BB,
on behalf of the British Hydrological Society.

March 1994

BHS Occasional Paper No. 3

ASSESSMENT OF DROUGHT SEVERITY

CONTENTS

Preface *iii*

Acknowledgements *iv*

Glossary *v*

1 Droughts - issues, problems and indicators *1*

1.1 What is a drought? *1*
1.2 The hydrological cycle *1*
1.3 Hydrological characteristics of the UK *3*
1.4 Water resources strategies *5*

2 Indicators of drought severity *7*

2.1 Types of indicator *7*
2.2 Descriptive, comparative and statistical measures *7*
2.3 Environmental indicators *8*
2.4 Water resource indicators *12*
2.5 Key indicators of drought severity *14*

3 Drought classification *15*

3.1 Drought categories *15*
3.2 Classification of environmental droughts *16*

Appendix 1 Data sources *21*

Appendix 2 Drought Order summary 1989-92 *23*

Appendix 3 Useful addresses *29*

PREFACE

The climate of Great Britain is characterised by considerable variability but long periods of exceptionally dry weather are relatively rare. Communities are used to the expected range of rainfall deficiency. Only occasionally, when this range is exceeded, do the public become fully aware of our continuing vulnerability to the threat of drought.

Droughts in the UK do not pose the threat to lives and livelihoods which a failure of rainfall constitutes throughout large parts of the world. Nonetheless, in a society where a continuous supply of wholesome water is taken for granted and the ecological, environmental and amenity value of freshwater is more fully appreciated than ever before, there is a clear need to increase public awareness of the complex nature of droughts and to provide practical guidelines for assessing their severity.

Following the very severe drought of 1975/76, Great Britain's climate entered a wet phase; the 1980s is the wettest decade on record for the country as a whole. However, from a water resources viewpoint at least, the decade will be best remembered for the exceptional rainfall shortage in 1984 and the even more severe event which began in late 1988 and brought drought conditions to much of southern and eastern Britain in 1989 and, again, in 1990, 1991 and 1992. The hot and dry conditions throughout the extended summers between 1988 and 1992 served to focus public and media attention on the likely frequency of such events and, more speculatively, the degree to which they represent a move away from the climate patterns with which this generation has become familiar.

Attempts to describe the severity of these events, particularly in the national media, have produced apparently contradictory and often misleading statements for what, in the public's view, is the same drought event. This problem arises because water users perceive the drought severity through its impact on their own activities and the severity of this impact is strongly influenced by the way the water companies operate their sources in their attempt to maintain supplies.

Thus, drought severity may be viewed in three ways:

(i) from a scientist's viewpoint, drought severity should be assessed using indicators which are neither subjective nor unduly influenced by water companies' operational strategies. Whenever possible, hydrological data for this type of assessment should ideally be natural or naturalised to account for any artificial influences;

(ii) those involved in water supply may prefer to analyse derived data, such as abstracted quantities or regulation releases from reservoirs, despite the influence of the operating policy on these data;

(iii) individuals affected by the drought may find an analysis based upon the impact on their social and economic activity (e.g. gardening, fishing, agricultural production) more appropriate.

Because of these disparate views of droughts, there is no single method of assessing and describing drought severity which will be suitable for all circumstances and users. Neither are there any national UK guidelines as to what are the most appropriate data sources and descriptive terms to be used for any particular situation.

This publication seeks to provide some guidance as to the indicators which could be used and gives a brief introduction to the types of measures available; where appropriate the limitations of particular drought indices are considered. It is recognised that there is considerable variation in

the techniques applied by different organisations in the UK to evaluate drought severity. Hence it is anticipated that this document forms an initial introduction. It has been compiled by a panel of experts, all members of the British Hydrological Society working within the National Rivers Authority, the Water Companies, the Universities and the Institute of Hydrology. The text has been written to reach a wide audience, including those untrained in hydrology.

In Chapter 1, the issue of "what is a drought" is considered and a brief introduction to the hydrological cycle is given for the non-specialist reader. The hydrological characteristics of the UK are described, as are water resources strategies. Chapter 2 considers the meteorological and hydrological measures that may be appropriate for a scientific analysis of drought severity. Measures that may be more appropriate for water supply interests and those that are most likely to be relevant to agricultural, domestic, industrial, or environmental users are discussed. Chapter 3 describes the different types of measure that may be used to describe drought severity. For those interested in the analysis of drought severity in the UK, key sources of data are listed in Appendix 1. Appendix 2 is a summary of Drought Orders for the period 1989-92, and finally, some useful addresses are to be found in Appendix 3.

This document provides a companion volume to the detailed analysis of the 1988-92 drought carried out by the Institute of Hydrology and the British Geological Survey. The resulting report, *The 1988-92 Drought*, has been published in the *Hydrological data UK* series and is available from the National Water Archive Office at the Institute of Hydrology.

ACKNOWLEDGEMENTS

This Occasional Paper is the outcome of a Workshop organised by the British Hydrological Society in Loughborough in 1992 involving participants representing the spectrum of hydrological perspectives: academics, research scientists, consultants, officers of the National Rivers Authority and the water service companies; and meteorologists, climatologists, hydro-geologists, surface-water hydrologists and water-supply engineers. The paper is a synthesis of their views. The workshop followed a four-year drought monitoring programme instigated jointly by the Institute of Hydrology and the British Geological Survey (both component bodies of the Natural Environment Research Council) at the request of the Department of the Environment. It has also benefited from contributions from many members of the Society, especially Allan Lambert, Terry Marsh and Jerry Sherriff. To everyone, we extend our thanks.

GLOSSARY

There are a number of terms used in this publication which have specific meaning within the water industry and definitions are given below:

Annual licensed total This is the volume of water which an abstractor is allowed to abstract over the period of a year under the terms of each Abstraction Licence.

Compensation flow When a reservoir is built, it is normal for there to be a statutory requirement for the reservoir operator to make releases into the river downstream of the reservoir, in order to help ameliorate the effects of the reservoir on river flows. Such releases may be specified on a daily or seasonal basis and may be linked to the volume authorised for abstraction from the reservoir.

Drought Order Drought Orders are made by the Secretary of State upon application by the National Rivers Authority or a water undertaker, under powers conferred by Act of Parliament, to meet deficiencies in the supply of water due to exceptional shortages of rain. The terms and conditions under which Drought Orders may be obtained are given in Sections 73-81 of the Water Resources Act 1991. Drought Orders are subdivided into "Ordinary" and "Emergency" Drought Orders. An "Ordinary" Drought Order could contain provisions such as to authorise abstraction from an unlicensed source, override the conditions pertaining to an abstraction licence, limit the amount of water which may be taken from a source or vary discharge conditions. An "Emergency" Drought Order might allow the prohibition of use of water for particular purposes, to allow a ban on non-essential use of water, for example in car washes, or to introduce the use of stand-pipes.

Hands-off flow In addition to annual limits on abstraction, specified in an Abstraction Licence, the daily volume which may be abstracted is often specified. In the case of a river abstraction, this may be further limited to prevent abstraction if river flows fall below a threshold level. This threshold level is known variously as "hands off" flow, "prescribed" flow or "residual" flow. It is set to protect downstream abstractors and environmental "in river" requirements.

Maintained flow An abstraction licence may require the maintenance of a river flow at a specified threshold value, as a condition of the abstraction. Water is normally released from a reservoir or pumped from a groundwater source in order to support river flows in this way.

Naturalised flow A 'naturalised' flow is a gauged streamflow adjusted to allow for the estimated effects of known abstractions and effluent discharges into the river. A special case of naturalised flow is the calculation of "derived reservoir inflows" whereby the inflows to a reservoir are calculated from the change in reservoir storage and outputs from the reservoir, such as abstractions, compensation flows and spill from the reservoir.

Chapter 1
Droughts — Issues, Problems and Indicators

1.1 What is a drought?

The consequences of drought (Figure 1) are readily recognised by the public at large, the objective evaluation of drought severity is a complex problem. Scientists have no agreed definition of a drought in anything other than general terms. One of the more useful general definitions is provided by Beran and Rodier[1]:

"The chief characteristic of a drought is a decrease of water availability in a particular period and over a particular area."

Whilst failing to specify when a dry spell becomes a drought, this definition identifies two crucial aspects of water deficiency which have to be addressed when assessing drought severity: i) the duration of the dry period and ii) the region or location considered. What is required is a more objective assessment of the severity of a drought which can be understood by professionals and a lay audience alike.

To appreciate how and why a water deficiency can create drought conditions which vary considerably in their impact in different parts of the country, it is necessary to understand a little of the hydrological cycle (section 1.2), the hydrological characteristics of the UK (section 1.3) and the water resources strategies that can be adopted to ameliorate drought conditions (section 1.4).

1.2 The hydrological cycle

Figure 2 shows how water is continually circulating through different phases of what is known as the 'Hydrological Cycle'. The land surface can be divided into river basins - catchments - delineated by a topographic divide, the watershed. Rainfall is the basic source of freshwater within each river basin, although other forms of precipitation, especially snow, can be important in some catchments or during some years. However, the annual rainfall (recorded as a depth in mm) is a poor indicator of water availability because water

[1] Beran, M. & Rodier, J.A. 1985. Hydrological aspects of drought. *Studies and report in hydrology 39*. UNESCO-WMO, Paris.

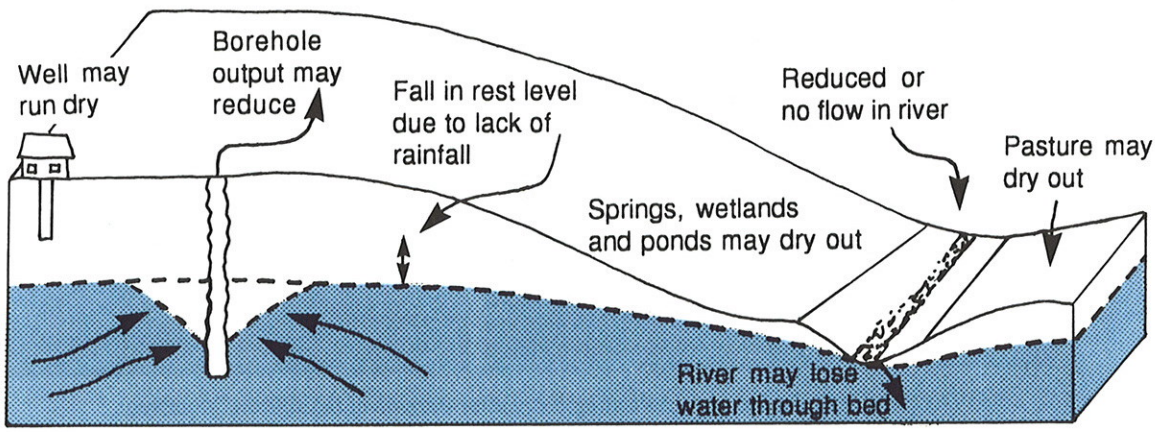


Figure 1 *Environmental characteristics of drought in a catchment with important groundwater resources*

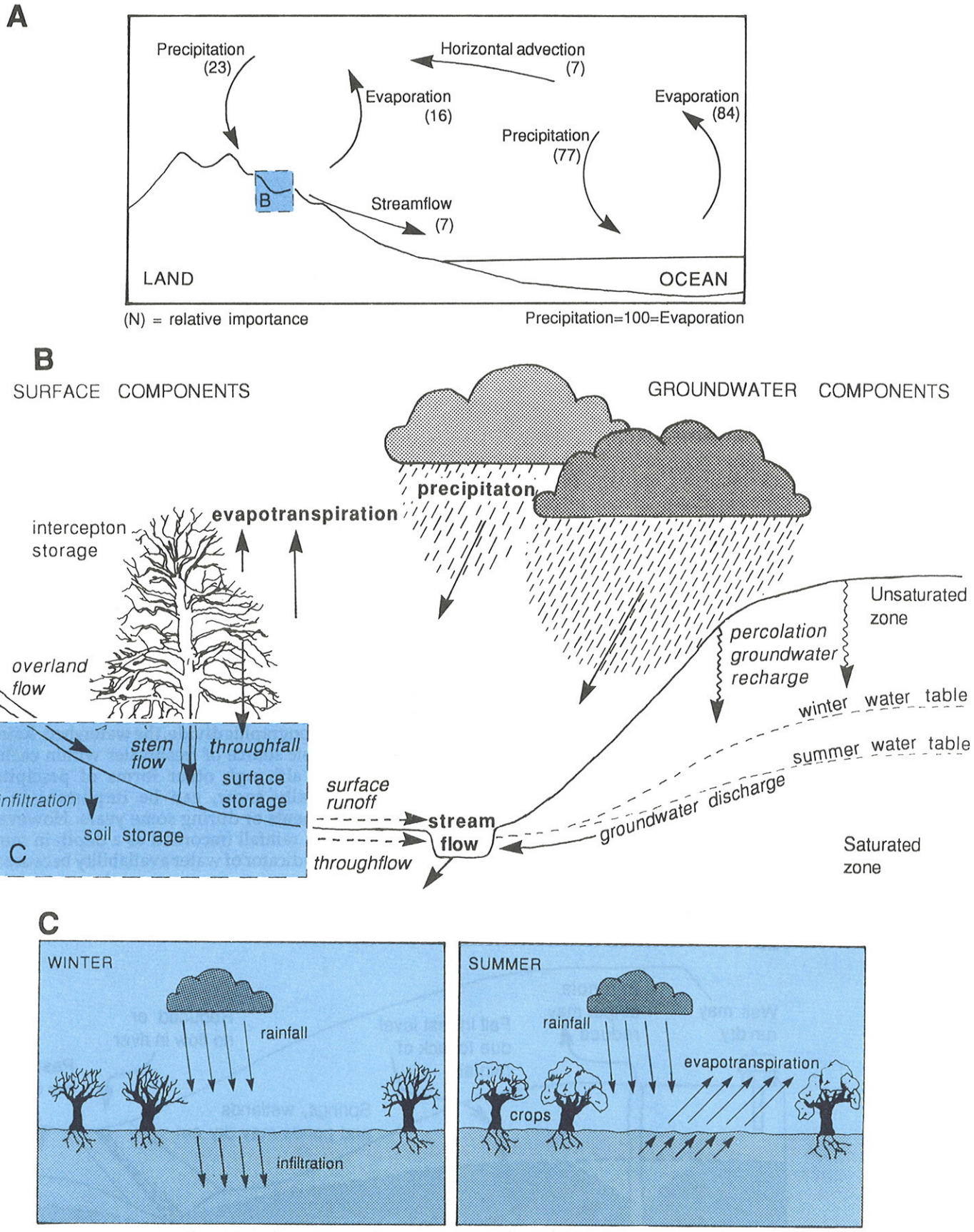


Figure 2 *(A) The global hydrological cycle, indicating the relative strength of the different processes; (B) hydrological components within a river catchment; and (C) the seasonal influence of evapotranspiration on the effective rainfall (see text for definitions).*

is lost by evaporation. Evaporation from natural storage back into the atmosphere occurs either directly from the land surface or by transpiration through trees and other surface vegetation. All these processes together are known as 'Evapotranspiration'.

When the evaporation process is not limited by the supply of water in the soil and plants, the rate of loss is known as the potential evapotranspiration. However, the process is often affected by the limited availability of water in the soil, and the actual evapotranspiration is usually much less than the potential rate.

Over an average year, the simple 'water balance' for a catchment is defined as:

Rainfall – Evapotranspiration = Streamflow
(mm) (mm) (mm)

However, this simple water balance masks important variations during a year, between years, and from decade to decade caused by changes in the weather. Variations within a year and in some catchments from year to year are also caused by time-lags between rainfall and runoff, time-lags that reflect the pathway of water movement from the land surface to the streams and to the presence within catchments of natural and artificial water storages (Figure 2B).

The difference between rainfall and actual evapotranspiration is known as the 'Effective Rainfall' (see 2.3.5) and for any one year, the water balance will be:

Effective rainfall ± Change in catchment storage = Streamflow

This emphasises the complexity of the link between rainfall and runoff, and the importance of catchment characteristics in determining when and where 'drought' occurs. Rainfall may be temporarily stored as ice/snow, in ponds and lakes, in the soil or in groundwater. These sources of natural water storage sustain the flows in streams and rivers during periods when no rain occurs. In general terms, the higher the amount of natural storage, the higher will be the rate of streamflow during "dry" periods but also the longer the time-lag between rainfall deficiency and the occurrence of extreme low flows in rivers.

The soil is a particularly important rainfall-runoff regulator. It receives inputs from rainfall, and loses water by evapotranspiration, natural drainage to streamflow, and deep percolation to groundwater if the underlying rock is permeable. Even in 'normal' years, evapotranspiration exceeds rainfall for most summer months in the drier parts of the UK. At such times all incoming rainfall is evaporated and the soil moisture is gradually depleted. On occasions there will be insufficient moisture for plants and 'potential' evaporation rates will not be achieved.

Where the underlying rocks are permeable (e.g. sandstone, chalk, greensand) they can retain large volumes of water. Unlike soil moisture, this groundwater is usually too deep down to be subject to evaporation. If the water also moves through these 'aquifers', it may emerge as springs or seepages which may form the major source of streamflow in dry summers. Generally, the water-table reflects the topography in muted form with very modest seasonal variations in lowland valleys.

Recharge of the groundwater store occurs during the winter direct from rainfall or through stream beds where the rock outcrops at the surface or by percolation through the soil at times when soil moisture is near saturation. Aquifer replenishment is affected by the nature of the deposits through which water must pass to reach the saturated zone of an aquifer. Where the deposits have low permeabilities there will be a consequent reduction in the amount of replenishment and an increase in the time before the water levels begin to rise. Similarly, where the unsaturated zone is of considerable depth, the lag between the commencement of infiltration and water-table response may be several months. Conversely, in some limestone and sandstone aquifers where recharge is principally via fissures, the rise and fall in the water-table may be rapid.

From the start of a dry period, drainage from the soil to streamflow gradually causes the rate of streamflow to fall. Rates of streamflow dwindle as the soil moisture diminishes and groundwater levels decline. The rate of flow decline is known as the flow recession. The hydrological condition of a catchment is reflected by the soil moisture level but it is difficult to measure either directly or in absolute terms because of its natural variability from place to place. It is easier periodically to calculate the Soil Moisture Deficit (SMD) for large areas, i.e. the amount in mm by which the soil moisture is less than saturated, using rainfall and evapotranspiration data. Large soil moisture deficits will be associated with low natural flows in streams and rivers, and deficits in the winter with a lack of recharge to groundwater.

1.3 Hydrological characteristics of the UK

Some of the important hydrological characteristics of catchments in the UK are illustrated in Figure 3. For its size, the UK experiences large regional and temporal variations in rainfall and runoff. The highest precipitation totals are associated with the maritime west—annual rainfall exceeds 4000 mm in parts of the Scottish mountains, Lake District and Snowdonia. The east—within the rain shadow of the Scottish Highlands, Pennines and Welsh mountains and less frequently in the path of

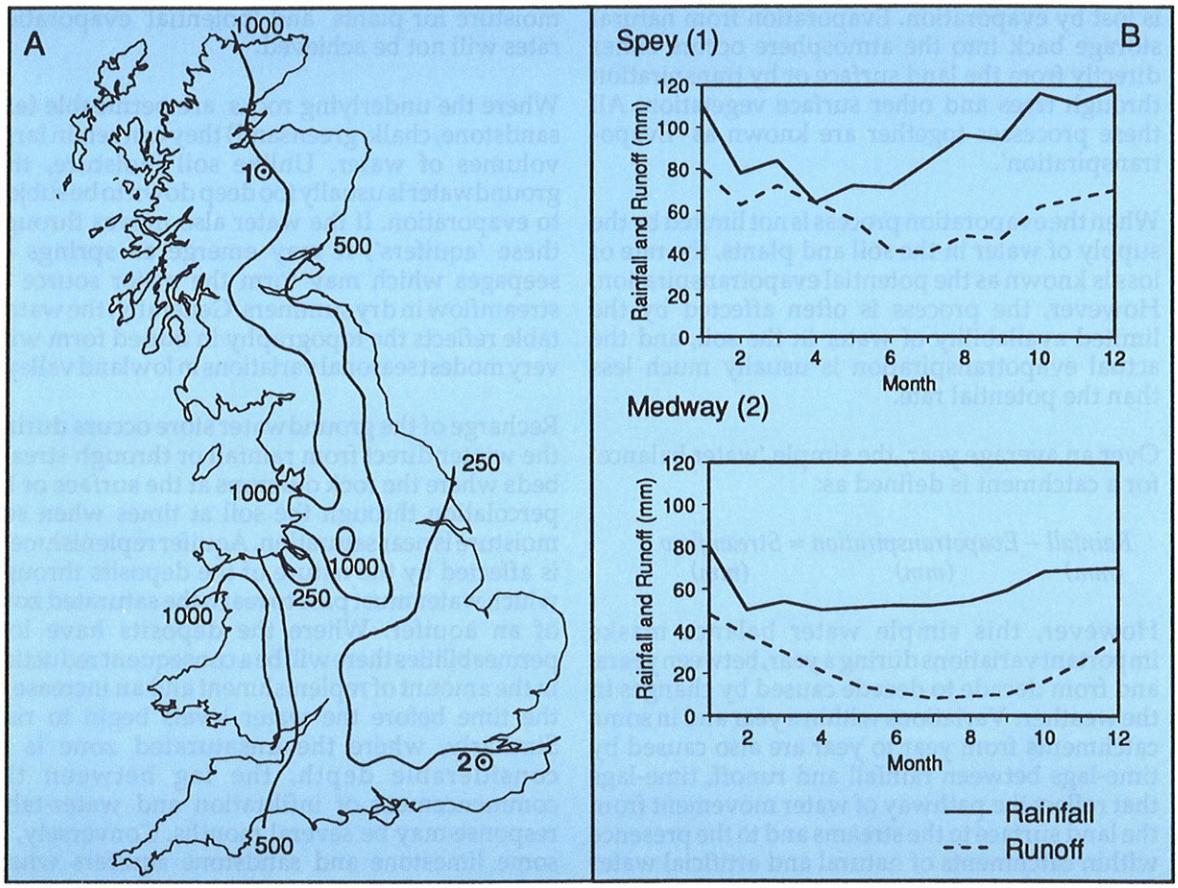


Figure 3 *(A) Variation of runoff across the UK (mm) and (B) examples of typical flow regimes and associated monthly rainfalls*

rain-bearing depressions — becoming progressively drier with decreasing elevation. Annual rainfall totals of less than 600 mm characterise much of the English lowlands with totals of below 500 mm around the Thames estuary.

The drainage pattern in Great Britain is largely a response to regional contrasts in geology. The principal upland areas, mostly in the west, are developed on the oldest rocks. These are generally impermeable, promote rapid runoff response and the associated relief affords opportunities for natural or artificial impoundments to exploit the abundant rainfall in strategic reservoir systems. Lowland Britain on the other hand, is mostly founded on relatively young strata. The occurrence of extensive porous and fractured rocks interleaved between beds of impermeable clays is a major feature of much of southern and eastern England. Springs and seepages are major components in the discharge of many lowland rivers and this baseflow makes for a relatively stable flow regime and can sustain flows through extended dry periods.

However, throughout much of the country, rainfall varies little from month to month but an appreciable seasonality may be recognised in the west where November, December and January are the wettest months (Figure 3B). During summer a substantial proportion of the rainfall is accounted for by evaporation, not least during droughts. As a result of these losses, less than 50 per cent of annual rainfall is available throughout much of England and Wales, and eastern Scotland, to sustain river flows, to replenish reservoirs and infiltrate through the soils to recharge aquifers. In parts of eastern England the proportion of rainfall that becomes runoff may be as little as 10% of the annual total.

The variation in evaporation rates through the year imposes a marked seasonality upon rate of runoff and the rate of aquifer recharge which is concentrated in the winter and early spring. Groundwater levels tend to rise from late autumn through winter into spring, and then to fall from spring through summer into autumn.

The greater the amount of natural storage (soil water and groundwater) relative to the rainfall in the catchment area, the less is the seasonal variation in discharge rates. Summer minimum flows during drought years normally occur in upland catchments without substantial groundwater

flows. However, during winter cold snaps, annual minimum flows may occur in January or February due to precipitation falling as snow and due to the freezing of catchments.

Drought is manifest by unusually low flows, abnormally low groundwater levels, and exceptionally low reservoir levels. However, as a consequence of the geographical contrasts, the susceptibility to drought varies considerably across the country. In the west, dry conditions for two or three months can lead to very low river flows; large rainfall deficiencies beginning in the spring and persisting for five to seven months can seriously affect small reservoir systems (usually full at the end of the winter).

In the east, short-term rainfall deficiencies normally have little impact upon river flows (although low levels of soil moisture may severely impact plant growth). However, a substantial deficiency of winter rainfall reduces groundwater recharge leading to reduced baseflows during the following summer and a lower base from which to commence the next recharge cycle.

Winter droughts can also be a problem in the west especially where water resources are based on minor surface supplies. However, these droughts are usually short-lived. Runoff will probably be stored in the catchment as snow and ice, and winter precipitation is often considerable, even in a dry year. Hence, reservoirs are still likely to fill to acceptable levels and should provide supplies through all but the severest spring and summer droughts.

Because of these geographical contrasts, there is usually substantial variability even in what may be perceived to be drought events. For example, 1984 was the worst drought in history in north west England but it was a notably wet year in eastern Scotland. In 1990, the English lowlands experienced extreme rainfall deficiency and low, often unprecedented, river flows and groundwater levels whilst for Great Britain as a whole, rainfall was above the long-term average - only 1954 and 1960 being appreciably wetter in the last 60 years - and Scotland registered its wettest year on record!

1.4 Water resources strategies

Until the 1970s many of the water resources in the UK were individual reservoirs, river abstractions or groundwater sources which were operated independently of each other. They were particularly vulnerable to drought since, typically, only one source served each supply area. River abstractions were particularly vulnerable since they are unable to save water from times of plenty to times of drought unless an associated pump-storage reservoir existed.

Experiences during the droughts of 1973 and 1976 led to the strengthening of the water resources infrastructure of England and Wales. The water industry has developed a range of storage mechanisms and operational strategies to maintain water supplies, linked to the likelihood of droughts occurring. New reservoirs have been developed and these, together with the increased networking of supply sources, often involving cross-basin transfers or the further integration of surface and groundwater supply schemes, provides a large measure of flexibility in local or regional shortages.

As well as strengthening the water resources network, a range of management options are used to deal with droughts. These include network management which involves re-distribution of supplies, pressure reduction and rescheduling of non-essential maintenance. Customer consumption may be reduced through voluntary savings by domestic and industrial users or hosepipe bans may be introduced.

Under Drought Order powers (see Glossary), abstractions from specified sources may be increased, alternative resources may be brought into service, any 'hands-off' flow below which water may not be abstracted may be relaxed, and licensed abstractions may be limited. As an example of their use, a listing of Drought Orders issued for England and Wales during 1989, 1990, 1991 and 1992 is given in Appendix 2. Table 1 gives the date of the first Drought Order by region and illustrates the development of the water-resource drought across the country.

The above management options are more appropriate to a sustained summer drought than a winter drought since, for example, the impact on consumption of banning hosepipes is minimal in winter. At this time the only real mechanism for reducing consumption is to target repairs of bursts which cause substantial additional leakage during, and just following, cold spells. Management

Table 1 Earliest Drought Orders made during the 1988-92 drought [See also Appendix 2]

NRA Region	*Month Drought Order made*
South West	June, 1989
North West	July, 1989
Welsh	July, 1989
Severn Trent	September, 1989
Yorkshire	November, 1989
Anglian	January, 1990
Southern	May, 1990
Thames	October, 1990
Wessex	November, 1990
Northumbria	None

options may be limited during winter droughts, but in the north and west their key feature, usually short duration compared with summer events, means that in most cases their impact is short-lived.

In the south and east, winter droughts can be impressively protracted. Rainfall deficits over a series of winters can promote severe low flow problems especially in lowland catchments dependent upon springflows from groundwater storages. Refill of reservoirs may also be a problem if a winter drought combines with low flows during the preceding or succeeding summer, establishing a drought event of long duration, as occurred between 1988 and 1992.

The complex configuration of water resources systems and the numerous options for their operation during a drought event, mean that the relationship between rainfall deficiency, stress on water resources and impacts on the community is not a direct one. A range of drought indicators are required for different purposes.

A detailed account of the 1988-1992 drought, including analyses of its spatial and temporal characteristics, is presented in *The 1988-92 Drought* published in the *Hydrological data UK* series by the Institute of Hydrology and the British Geological Survey.

Chapter 2
Indicators of Drought Severity

2.1 Types of indicator

In trying to describe drought severity, a variety of indicators may be used. So far, however, there have been no successful attempts to devise a system of indicators that provide clear and unambiguous information about the gravity of a drought which is clearly understood by water supply managers, hydrologists and the public at large. Furthermore, whilst they may provide a direct measure of drought, specific data may not be readily available, this being a special problem when assessments are required during rather than after a drought.

Drought indicators can be classified as two types:

(i) Environmental indicators are those hydro-meteorological and hydrological indicators which measure the direct effect on the hydrological cycle.

(ii) Water resource indicators measure severity in terms of the impact of the drought on the use of water in its broadest sense, for example, impact on water supply for domestic or agricultural use, impact on fisheries or impact on recreation.

It should be recognised that environmental indicators measure the severity of a "natural" drought; the water resource indicators imply an element of human interference and may reflect as much a lack of resilience in a water resources system or mismanagement of water supplies, as a lack of rainfall or runoff.

It should also be recognised that whilst water resource indicators *should* be most meaningful, especially to the public or other non hydrologists, in that they reflect the impact of a drought, they often suffer from an inability to express a drought in clear and unambiguous terms. It is often difficult to define a quantitative measure and data are often not readily available. As these indicators are not a direct measure of severity, they are unable to distinguish between an absolute drought and a drought which is unjustified in hydrological or meteorological terms but which has developed due to imprudent management of the water resource system.

In contrast, meteorological and hydrological indicators are often easier to measure and can be compared using a range of statistics; they may be consistently interpreted by experienced specialists but less readily understood by the general public.

During a drought event, water users are usually more interested in the severity of the impact of the drought on their activities, rather than being interested in the scientific or statistical assessment of drought severity based on the analysis of meteorological or hydrological parameters. That said, it should be recognised that public awareness on water issues is increasing steadily and there is, largely as a result of climate change projections, considerable need for objective guidance regarding changes in drought frequency and severity.

2.2 Descriptive, comparative and statistical measures

Typically, drought indicators used to define the severity of a drought, may be qualitative or quantitative. These need not be mutually exclusive and any individual drought measure may be defined by more than one type of indicator.

Qualitative indicators include linguistic definitions of drought severity. Often they are descriptive. For example, "the reservoir level is so low as to

make a previously submerged village visible" and "it has been hot and dry for the last month". These types of indicator are rarely used by hydrology specialists as they are open to misinterpretation and confusion. However, they can be valuable for a non-specialist audience. Alternatively they may be comparative allowing a drought to be placed within the context of notable events in the historic record. Comparison with historic events can be useful, especially when there have been publicly perceived, severe events in recent history. People find it easier to relate to their own experiences than to abstract terms. Hence, a statement that "this event is drier than the 1984 drought" is meaningful and generally understood (usually more so than a description based upon statistical probabilities of its severity!). However, with all such qualitative indicators there is scope for misrepresentation. Such statements do not say over what duration, or time of year, and on what determinand the comparison has been made. Qualitative statements are acceptable as brief statements to the public and media if they are based upon quantitative information such as reservoir levels or river flows. Even for technical staff, the ranking of a current drought in the context of the historical rainfall or runoff record can be useful with statements such as " ... driest event on record" or "as dry as [a known recent severe event]".

Quantitative indicators require the use of statistical forms of analysis to assign scientific assessments of drought severity. They lead to statements such as "based on rainfall events starting in March, of seven months duration, this drought has a return period of 1 in 50 years". The choice of an analytical tool is wide and whilst statistical analyses are more objective than alternative indicators, they are less well understood by a wide audience and they may contain inherent weaknesses which can easily be overlooked by those not well versed in statistical methods.

2.3 Environmental indicators

2.3.1 *Rainfall*

Rainfall is the primary source of available water. It is the dominant forcing function for other indicators such as soil moisture deficit, groundwater recharge and river flows. One of its main merits as a parameter for assessing drought severity is that long-term records are often available (in some cases back to the 17th century), and recorded data are usually available for immediate analysis. Lack of rainfall is readily perceived as a measure of drought. In the UK the meteorological definition of a drought is in fact only 15 days without measurable rain, but this is usually too simplistic in relation to water resources systems.

Rainfall data are a useful broad indicator of drought conditions. They are, for example, necessary to be able to show that there has been an exceptional shortage of rain before a Drought Order can be sought. They also have some limitations as a measure of water availability in droughts. Measurements over short periods (e.g. 1 month) take no account of initial ground conditions or seasonal evaporation variations, so do not reflect true water availability in terms of natural storage, or streamflow. Percentages of the average rainfall can be misleading in terms of absolute water availability, due to large regional variation in average rainfall (10% of 2000 mm is the same as 40% of 500 mm). Point rainfalls are extremely variable in summer (e.g. due to thunderstorms) so averages over an area should be analysed. Whilst recognising that "effective" rainfall may be more elegant as a drought indicator (2.3.5), the directness and clarity of rainfall as an indicator of drought, together with the timely availability of data makes rainfall the most suitable single indicator of drought severity.

2.3.2 *Temperature*

Summer droughts in the UK are normally associated with higher than average air temperatures, arising from high pressure leading to clear skies, sunshine, increased demand for water and higher than average evapotranspiration. However, over longer periods of time, higher temperatures do not necessarily mean less rainfall; the 1980s was not only the wettest decade on record for Great Britain, but also the warmest! As an indicator of drought, however, temperature can be a useful parameter to indicate when a water resources system is under stress due to a drought and thus may be a useful indicator in conjunction with other measures. Temperature is of course well understood by everyone and correlates strongly with public perception of drought. Although it is a very clear indicator, however, it is a less direct measure than rainfall, but the high availability of data during and following a drought means that is well suited to being a useful secondary drought indicator.

2.3.3 *Evapotranspiration*

Evapotranspiration is influenced by such factors as temperature, solar radiation, wind speed, relative humidity of the air, type of surface and plant cover, and amount of water available in a catchment for evaporation to take place. Evaporation varies seasonally, being greatest in summer, and in the UK can be up to 600 mm/year, or 90% of annual rainfall in some lowland areas. As it is difficult to measure directly, evaporation is usually calculated on a daily basis using equations which take into account the relevant factors. These give an estimate of evaporation from a small area only, and it is difficult to extend this value over a whole catchment. Evapotranspiration is a concept which is not easily understood by the public and this, combined with its indirect nature and lack of readily available data, means that it is not in widespread use as an indicator of drought severity.

However, it is useful when estimating effective rainfall (2.3.5) and deficit of moisture in soils (2.3.6).

2.3.4 *Weather patterns*

The analysis of weather patterns could theoretically be a very good indicator of drought severity since it has the value of integrating different weather conditions. However, the difficulties of data availability and of interpretation, together with the actual logistics of carrying out the analyses, even by experts, means that synoptic patterns are unsuitable for use as an indicator of drought severity, except in very specialised applications.

2.3.5 *Effective rainfall*

Effective rainfall is defined as the difference between actual rainfall and actual evapotranspiration, and is a measure of changes in natural water availability to the land surface from the atmosphere. It represents the net water input from the atmosphere to the land surface, and may be positive or negative in different parts of the UK over any particular period. Because of the difficulties in estimating actual evapotranspiration, effective rainfall is rarely used to assess drought severity, though it is significant in assessing groundwater recharge in aquifer areas.

2.3.6 *Soil moisture deficit (SMD)*

If evaporation exceeds rainfall, the soil will get drier and the soil moisture deficit will increase over the period. However, if rainfall exceeds evaporation, the soil will become wetter, and perhaps reach field capacity (zero SMD).

The Meteorological Office Rainfall and Evaporation Calculation System (MORECS) provides weekly maps and tables of evaporation, effective rainfall, soil moisture deficit and the weather variables used for their calculation on a 40 km grid square basis. Data exist in time series for each grid square back to 1961. The variation of SMD is illustrated in Figure 4.

SMD typically varies widely across the country even under non-drought conditions. Hence, absolute comparisons of SMD values for different locations should only be used with care. Often the period over which high calculated SMDs are maintained is as significant as the values themselves. Deficits exceeding about 50 mm sustained throughout the late autumn may be expected to greatly delay the seasonal recovery in river flows and reduce the scope for groundwater replenishment through the winter.

2.3.7 *Groundwater recharge*

A simple and useful application of MORECS data is the calculation of 'recharge' in winter. Though this indicator has less relevance in areas served by surface water resources, in groundwater areas this is a direct measure of drought. The concept may be a little difficult to grasp but no more so than the idea of groundwater in general. There are substantial differences in the way recharge is calculated in different parts of the country, so there is still potential for misunderstanding and confusion.

2.3.8 *Groundwater storage*

Whilst at first sight groundwater storage may seem an obvious choice of drought indicator in aquifer areas, in practice it is most unsuitable because data are not readily available and the use of groundwater storage can lead to ambiguous and confusing statements to the public and technical specialists alike. Groundwater level is a much more helpful indicator.

2.3.9 *Groundwater level*

The soil in many parts of the UK (notably the upland areas) is underlain by impermeable rocks, and the groundwater storage in such areas is negligible. In other areas where aquifers exist, the natural 'recharge' of the underground storage is greatly affected by the type of soil; for example, impermeable clay will prevent any significant recharge taking place from rainfall or soil water.

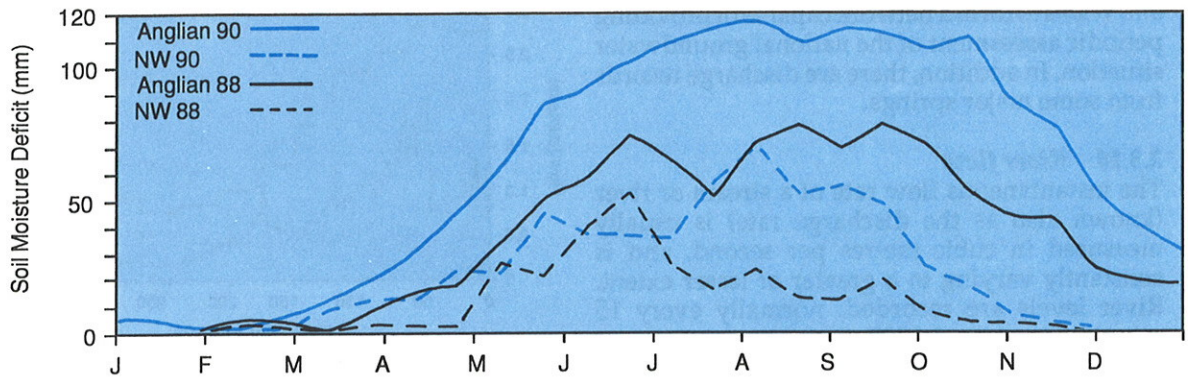


Figure 4 *Variation of the soil moisture deficit (SMD) in Anglian and North West regions during 1988 and 1990, derived from Meteorological Office data for areal land usage*

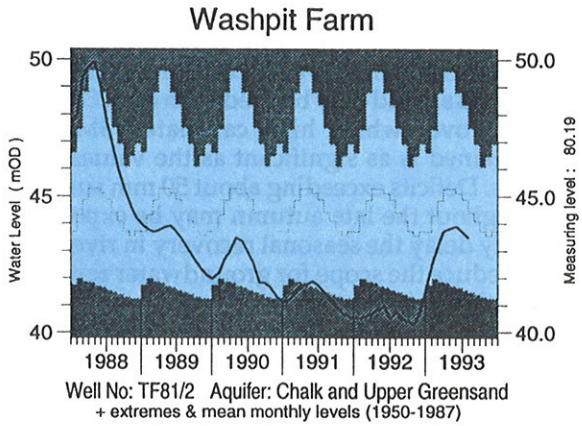


Figure 5 *Well levels for the Chalk and Upper Greensand aquifer at Washpit Farm, north Norfolk during 1988-1993, compared with extremes and mean monthly levels (1950-87)*

As it is not practical to measure groundwater storage, groundwater levels are used instead as an indication of drought severity (e.g. Figure 5). Aquifer recharge usually occurs during the winter but in some dry winters there is almost no recharge to some aquifers in the south east. Aquifer storage is depleted naturally by spring flows, and artificially via borehole abstractions. The groundwater levels in any particular part of an aquifer therefore fluctuate seasonally and annually over ranges of up to 40 metres. However, it is often difficult to separate natural variations from those caused by human interference as there are relatively few substantial aquifers in the UK which have not been used for abstractions to supply agriculture, commerce and water undertakers.

Groundwater level is the most direct and suitable indicator of drought severity in an aquifer area. Data are usually available, though may need modification to remove any critical influences depending upon the use to which the data will be put. The British Geological Survey have selected 175 observation wells and boreholes in England and Wales to form a network capable of providing periodic assessment of the national groundwater situation. In addition, there are discharge records from some major springs.

2.3.10 *River flow*

The instantaneous flow rate of a stream or river (known also as the discharge rate) is usually measured in cubic metres per second, and is constantly varying to a greater or lesser extent. River levels are recorded, normally every 15 minutes, at around 1200 river gauging stations located across the country. Using a relationship between level and discharge rate, each level value can be converted to a discharge rate. The individual discharge values can be averaged over any chosen period. The normal basic period for archived storage is one day. Data are typically compared on the basis of mean daily flows.

Despite the large number of sites in the UK at which streamflow is measured continuously, there are very few for which there has been no change in the catchment conditions (for example: drainage, afforestation, urbanisation), no interference with natural flows (abstractions or effluents), and where there have been accurate low flow measurements in all historic droughts for at least 80 years. This makes estimation of drought severity difficult, although it should be recognised that for many purposes (e.g. effluent dilution, environmental impacts) drought impacts need to be assessed within the context of contemporary flow conditions.

For some catchments, average monthly measured streamflows can be naturalised and expressed in millimetres of 'runoff', a measure which is in the same units as rainfall, evaporation and soil moisture deficit. Overall, river flow (either measured or naturalised) is a widely available and suitable indicator of drought severity (e.g. Figure 6). Its meaning is very clear to the public and technical specialists alike.

2.3.11 *Reservoir inflows*

For assessing the severity of drought events, daily streamflow data from river gauging stations can often be supplemented by derived 'naturalised' runoff for catchment areas of upland reservoirs. In deriving runoff from these reservoired catchment areas, the measured drawoffs, overflows and controlled releases to the river are adjusted to take account of changes in reservoir storage over 'n' days.

There are several long-term records of this type going back over 100 years, calculated on either a calendar month or daily basis. The figures do not represent true natural runoff, but rather the cumulative effect of inflow and evaporation from the reservoir surface (for which further adjustment

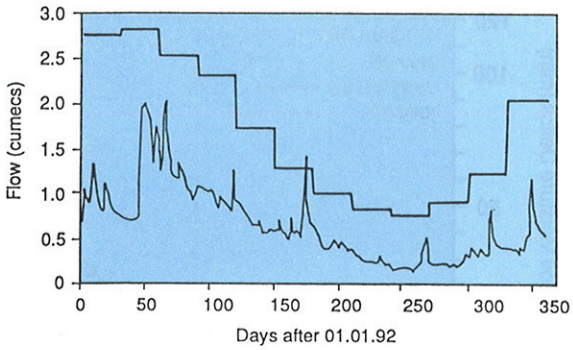


Figure 6. *Streamflow hydrograph for 1992 on the River Babingley, a Chalk stream in north Norfolk, compared with the long-term median monthly flow (1956-88)*

may be needed in a few cases). The period of calculation (n days) should be long enough for likely inaccuracies in assessment changes in reservoir storage not to significantly affect the calculated runoff. The advantage of reservoir inflows as a data set for assessing drought severity is that such catchments have typically had little interference in their management over the period of record (other than perhaps afforestation) making the data record consistent over a long period allowing better statistical analysis of drought severity. Unfortunately very few such records exist for the English lowlands.

2.3.12 *Reservoir storage*

Reservoir storage is a most useful drought indicator which is readily understood and clear (e.g. Figure 7). Data are available often on a daily or at least weekly basis. Whilst absolute reservoir storage is useful, these data are strongly influenced by how the reservoir has been operated. When reservoir storage is combined with predicted inflows (either on a maximum historic or probabilistic basis) it is quite a powerful indicator of drought severity.

In defining drought severity in relation to reservoir systems, it is essential that the critical period of the system is considered. This is the period over which the reliable yield of the source can be just sustained under design conditions and it is therefore the duration of drought to which the system is most sensitive. For water resources managers responsible for a variety of different water resources types, the need for drought vigilance may extend from a period of a few weeks to five years! The need to monitor long critical period sources will continue after the shorter critical period sources have refilled and indeed drawn down again.

In upland Britain, most reservoirs are known as one or two-season critical sources. In the former cases, reservoirs are sensitive to droughts lasting through one summer season, usually of six to nine months duration. Many of the Pennine reservoirs are one season critical. Reservoirs with a higher storage to runoff ratio are critical to droughts lasting through two summers and the intervening winter, giving a typical critical period of eighteen months. Some of the largest reservoirs may be up to five- season critical sources.

Surface-water reservoirs are replenished by natural inflows from their catchment areas (e.g. Elan Valley) or by pumped input from adjacent sources (e.g. Grafham) or by a combination of both. Drawoff is either by direct pipeline (direct supply schemes, e.g. Thirlmere) or by releases to the river system downstream to support abstractions in the lower parts of the catchment (regulation schemes, e.g. Kielder); some reservoirs are used for both purposes (e.g. Vyrnwy).

Analysis of minimum reservoir storages over the period of historic record is often used as a measure of drought severity. This is usually naturalised to take account of historic abstraction patterns.

2.3.13 *Abstractable quantities/regulation release quantities*

For water supply managers a drought indicator which makes allowance for operational practices is necessary because actual variations of storage in surface water reservoirs are strongly influenced by operational practices during any particular drought event. Data on reservoir storage does not normally constitute a reliable source for drought severity analysis. The usual practice for a direct supply reservoir or river intake, is to undertake a simulated calculation to determine the maximum quantity which *could* have been abstracted in a particular drought, taking into account the naturalised flows at the site.

River abstractions will generally be subject to legal constraints on their operation, e.g. a 'hands-off' flow condition. When the river flow rate exceeds this, some (or all) of the excess may be abstracted.

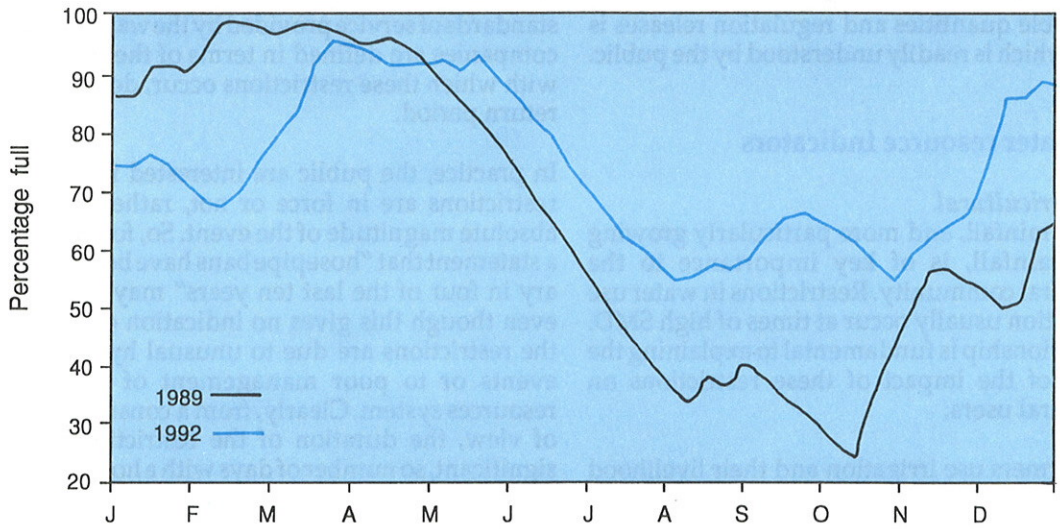


Figure 7 *Variation of Haweswater Reservoir stocks (North West Water) during 1989 and 1992*

When the river flow falls below 'hands-off', the abstractions must cease. The start date, duration and end date of flows below 'hands-off' are the critical drought parameters for such abstractions.

In regulated rivers, abstractions can continue at times of low natural flows because releases are made from storage (reservoirs or groundwater) to supplement the river flows. Each regulation scheme has its own 'rules' for such releases, and the critical drought parameters for such schemes are usually the start date, end date and 'effective release requirement', i.e. the volume of water which needs to be released in any particular period, assuming no regulation 'losses' as the water travels down to the abstraction point.

The 'effective release', together with any allowance for freshets (short-term releases, often for fisheries) and special releases, represents the varying demand on the regulation storage. Because the measured river flows are usually significantly different from the natural flows, it is necessary to calculate a daily set of 'naturalised' flows at the end of each year which are used retrospectively to determine the effective release requirements.

There are two main types of regulation 'rules'. Firstly, in the 'put and take' case, when the river flow falls below a specified threshold (the hands-off) flow, the abstraction must not exceed the regulation release. Secondly, in a 'maintained flow' situation when the river flow falls below a specified threshold, the regulation releases must be sufficient to sustain the abstractions *AND* ensure that the residual flow downstream does not fall below the maintained flow.

Abstractable quantities and regulation release quantities are quite direct measures of drought severity. However, their use is restricted during drought events because the data are calculated rather than measured and the calculations are normally done after a drought event rather than in near real time during an event. The concept of abstractable quantities and regulation releases is not one which is readily understood by the public.

2.4 Water resource indicators

2.4.1 Agricultural

Summer rainfall, and more particularly growing season rainfall, is of key importance to the agricultural community. Restrictions in water use for irrigation usually occur at times of high SMD. This relationship is fundamental to explaining the severity of the impact of these restrictions on agricultural users.

Many farmers use irrigation and their livelihood can be affected by restrictions in water use. Therefore, the frequency and duration of restrictions is an important indicator of drought severity from a water user point of view. Individual farmers may be affected when, under the terms of their abstraction licence, they are restricted from abstracting water, for example if they are abstracting from a river which falls below the prescribed flow. Alternatively, the NRA may impose a ban on all spray irrigators in an area.

From a farmer's point of view, a restriction applied to an individual would probably indicate a more severe drought than one where all competitors in the same area were similarly affected, though in meteorological or hydrological terms the latter may be the most severe event. Clearly, the timing of the restrictions in relation to the cropping season has a significant effect on the impact of the restrictions on water use and hence the economic loss that may be sustained. It may be possible for farmers to estimate the crop damage or loss, or even the economic loss sustained during such restrictions, which from their point of view would be the clearest indicator of drought severity. However, in practical terms it is hard to distinguish the relative impact of drought on crop productivity and quality from the impacts of other factors.

Farmers also use soil moisture deficit as an indicator of drought severity, since this is used by many farmers on a day to day basis to determine irrigation needs. Typically, irrigation is applied in relation to certain SMD thresholds for different crop types. Hence, a useful indicator is the number of days when irrigation is necessary and the volume of irrigation applied.

2.4.2 Domestic customers

Domestic customers may define a drought as occurring when requests for conservation of water take place. Alternatively, they may perceive a drought to exist when their use of water is restricted, for example, due to pressure reductions, hosepipe bans or ultimately, by the introduction of rationing through rota cuts or standpipes under Drought Order procedures. In terms of returns to the Director General of Water Services, the standards of service provided by the water services companies are defined in terms of the frequency with which these restrictions occur, described by return period.

In practice, the public are interested in whether restrictions are in force or not, rather than the absolute magnitude of the event. So, for example, a statement that "hosepipe bans have been necessary in four of the last ten years" may be useful, even though this gives no indication of whether the restrictions are due to unusual hydrological events or to poor management of the water resources system. Clearly, from a consumer point of view, the duration of the restriction is also significant, so number of days with a hosepipe ban in force may be an appropriate measure of drought severity. Time of year is also an important element, since the loss of availability in September when

little garden watering is carried out would be perceived as less important than restrictions on use in the main garden-watering season. Little work has been done yet to assign a financial value to this loss of service to the domestic customer.

2.4.3 *Commercial customers*

Commercial customers include industries other than agriculture. Restrictions on water use may take the form of requests for voluntary savings or more critically, the enforcement of reductions by restrictions on the non-essential use of water through the Drought Order procedures. "Non essential use bans" prohibit the use of water by businesses such as car valeting companies, golf courses and ornamental gardens (excluding horticulture).

For those whose livelihood is affected by restrictions in commercial water use, the frequency and duration of restrictions is an important measure of severity. In some cases, it may be possible to gauge the magnitude of the event by the loss of income, the increased expenditure the restrictions caused, or the volume of product lost or damaged. Clearly, for those industries dependent on warm, dry weather for sales, such as ice cream or soft drinks manufacturers, increase in turnover or profits could also be an economic indicator of drought magnitude and severity.

2.4.4 *Environmental interests*

The impacts of droughts on environmental interests are too wide ranging to be fully discussed in this publication and are in any case subject to ongoing research. Nevertheless, brief reference will be made to some features commonly associated with drought.

Many streams begin as small seepages through the channel bed and the location of this 'streamhead' moves upstream with rising groundwater levels during the winter and moves downstream during the summer as groundwater levels fall. Thus, headwater valleys that contain small streams in winter may become dry during summer. During droughts, the contraction of the stream network can be highly significant, causing a loss of amenity and aquatic habitat. For example, the stream network of the River Wreake in Leicestershire was reported to have contracted to 20% of its normal winter level during the 1976 drought.

The length of dry channel and the degree of stream network contraction during droughts provide clear measures of drought magnitude. However, there are several problems in using either as a measure of drought severity: stream network contraction (i) is highly variable locally, reflecting (a) geology and land use or (b) abstractions (especially from groundwater) and effluent discharge; and (ii) little information exists on the ranges of streamhead migration during a 'normal' hydrological year.

Salmon and sea-trout normally enter rivers from the sea throughout the summer and autumn during spates (high river flows caused by intermittent heavy rainfall). During droughts, there may be no significant spates for several months, and the fish remain around estuaries, with the possibility of higher commercial net catches and diminution of stocks. Anglers on game fish rivers therefore tend to assess drought severity in terms of poor fish catches, whilst fisheries interests can become concerned at the reduction in breeding stock. In contrast, commercial net fisheries may interpret drought severity based on increased income associated with larger catches. To varying degrees, fish are vulnerable to high water temperatures, low dissolved oxygen and pollution, and during severe drought may need to be removed (e.g. by electro-fishing) to other sites. Hence, drought severity may be assessed by the amount of stress experienced by fish; by the number of fish kills or poor quality of fish migrations or spawning.

In terms of water quality, the surface layers of some lakes and reservoirs which receive water containing high levels of nutrients from agricultural land, experience major algal blooms during drought. Restrictions on abstractions may be necessary because of the inability of water treatment works to function with the high algal concentrations. Clearly the frequency and duration of restrictions on water use due to the prevalence of algal blooms is an indicator of drought severity which may be coupled with potential loss of income from recreation water users or increased expenditure associated with treatment of water for water supply.

In terms of in-river use of water, both the magnitude and the duration of a drought may be significant where particular fauna and flora have restricted habitat ranges. Hence, in defining impact severity it may be appropriate to define the drought in terms of the minimum instantaneous or mean daily flow which occurred during the drought. More significant may be the total number of days below a certain flow threshold, for example, the survival flow of particular fauna. Similar measures can also be considered in relation to reservoir levels, groundwater levels or soil moisture deficits where the magnitude and duration beyond a particular threshold, are important drought indicators.

Often low flow alone is not the critical factor causing environmental degradation. The increased temperatures or increased concentration of pollutants caused by the low flows can be most important. Nevertheless, 'low flow' remains a valuable indicator of environmental stress.

2.4.5 *Navigation*

Whilst commercial navigation is not as important in the UK as elsewhere, there can be significant impacts of droughts on recreational navigation.

Reduced flows in canals and lowland rivers can make some elements of the navigation system impassable. This is a special problem in those waterways used for recreational purposes such as the Norfolk Broads or much of the British Waterways canal system. In terms of defining drought severity, the main criteria would be the length of time particular reaches are impassable and the frequency with which this occurs. Where business is affected, it may be possible to express drought severity in terms of loss of revenue or increased expenditure, for example because of the need to carry out dredging operations.

2.4.6 Recreation and amenity

Surface water resources systems are used for a wide range of recreational and amenity activities which can be adversely affected by drought. Traditionally, the main water-based recreational activity was angling. However, with the greater availability of leisure time, active recreation — for example canoeing, sailboarding, water ski-ing — and passive recreation such as bird watching and visits to interpretative centres have increased the recreational value of water resources systems. Hence any change in the water regime instigated by a drought can have an effect on recreational use. Water-quality problems may also have an impact on recreational uses. In 1990 algal blooms in some reservoirs were so severe that recreational uses had to be limited because of the health hazards of the untreated water around the margins. Reduced lake or reservoir levels may isolate landing stages and make boating facilities inoperable. An exacerbating factor is that recreational demand for a range of water-based activities may be expected to increase at a time when water levels and flow rates are most depressed. In contrast, regulation and compensation releases from reservoirs may increase flow sufficiently to provide canoeing facilities in the downstream river that would not be available under natural drought flows.

In terms of estimating drought severity, the critical measure is the frequency and duration of the non-availability or reduced quality of a recreation and amenity facility.

2.4.7 Water demand

Water demand responds to the weather with increases resulting from dry, warm weather due to, for example, increased use of hosepipes. Therefore in general terms an increase in water demand could be a drought indicator. However, this is not straightforward as during a drought demand reduces in response to calls for savings in water use or actual bans in the use of water for certain purposes. Equally, water demand may increase due to bursts or leakages. Overall, therefore, water demand *per se* is not a good indicator of drought severity, although it may be helpful alongside other indicators.

2.5 Key indicators of drought severity

From the preceding sections it is clear that numerous indicators can be used to define the severity of a drought. The most appropriate may vary depending upon the use which is to be made of the severity assessment, the availability of data and the water resource system (both type and site specific) under consideration. Whilst it is apparent that no one indicator of drought severity can be prescribed, it is very clear that in terms of custom and practice, the drought indicators which find most favour and application are:

- Rainfall,
- Reservoir storage,
- Groundwater level, and
- River flow.

These share the qualities of clarity and directness as indicators of drought; for the most part data are normally readily available, both during and following a drought. In practice however, it is more likely that it will be necessary to use a 'basket of indicators' which allows the allocation of a drought into a particular drought category. In order to effect this it is necessary to define drought categories and these will be explained in more detail in the next chapter.

Chapter 3
Drought classification

In the previous chapter it has been shown how droughts vary regionally and over time, with often very different impacts on different types of water users in the same area. With these attributes, it is little wonder that the hydrological community has had difficulties communicating to the public the true extent and severity of a drought; the use of different measures of drought severity will often yield apparently conflicting messages about a drought.

To help overcome these problems, lessons can be learned from seismologists who use the Richter scale to describe the severity of an earthquake, and from our colleagues who have chosen to use a colour-coded warning system for floods. By the use of these simple scales the complexities can be reduced to understanding the significance of different values on the chosen scale or classification system. This type of approach is recommended for drought analysis in the UK whilst recognising — as is emphasised in earlier chapters — that any full characterisation of such multi-faceted events may be expected to involve a range of hydrological and other, indices.

Unfortunately, with droughts application of this type of approach is a little more difficult as there are essentially two types of users impacted by the water shortage. First, there are those who are affected directly by a shortage of rainfall, compounded possibly by high evaporation. Secondly, there are those who are affected indirectly as consumers of water from water companies. For the latter, the presence and management of water storage facilities has a major effect on the impact of a drought on the water user; indeed, poor management could cause water shortages during times of adequate rainfall.

Nevertheless, it is recommended that droughts should be classified by **type**, **intensity** and **duration**.

3.1 Drought categories

First, droughts should be classified either as an **environmental drought** or as a **water supply drought**. An environmental drought measures the significance of the drought for those water uses directly affected by the rainfall shortage, e.g. ecology, fisheries, those in agriculture, those affected by low river flows, gardeners. The water supply drought measures the significance for those indirectly affected, e.g. domestic consumers, industrial consumers. In many cases a drought will be classified as having both environmental and supply impacts.

Secondly, a drought of either type should be further classified according to its intensity — **1 (moderate)**, **2 (serious)** and **3 (severe)**. These would be associated with a colour code — possibly **yellow**, **amber** and **red** respectively, to coincide with the colours chosen for flood warning. Thus, a drought in a particular catchment could be a class 2 (serious / amber) environmental drought but a class 1 (moderate/yellow) water-supply drought. This would be reflected locally by perhaps some water-conservation measures imposed by the water company, but in the garden the soil would be getting very dry and the flow in the river would be very low. If the drought continued to become a severe environmental drought (class 3/red), the river may dry up and there would certainly be environmental damage; it would also probably be one of the worst droughts on record. The fact that as a water supply drought it is less serious than its intensity as an environmental drought could reflect either that the water company has a large amount of storage in groundwater or in surface reservoirs, or the supplies for this water-supply zone are coming from further afield where the environmental drought is less severe.

Some people think that the term 'drought' can only apply to a naturally-induced event, so that

shortages of supply in the absence of a shortage of rainfall are not drought but bad water management. In the above classification system, the environmental drought reflects the naturally occurring event which can have significant impact on private water supplies dependent upon springs, stream intakes and shallow boreholes. The water supply drought is the more complex combination of a natural shortage of precipitation, historical decisions concerning the strategic systems development of major water resources, and recent operational management decisions. Perhaps for the consumer the causes of the shortage are less important than the fact that their water consumption is restricted — thus for them it will appear to be a 'drought" if restrictions are imposed. But if there was a serious water-supply drought (affecting not just the small localised supplies) without even a moderate environmental drought, questions would certainly need to be asked of the water companies about their strategy for the management of the water supply system.

Thirdly, the length or duration of a drought should be incorporated into the classification system. This has been shown to be significant in the previous chapters mainly because the critical period of the water-supply system is so closely related to it. Generally the exact duration is less important than whether the drought lasts one summer or lasts several summers and includes the intervening winters. To keep the classification reasonably simple, the duration of the drought is to be included as either a short drought or a long drought: short indicates that the drought lasts for only one season and long is for all droughts longer than this.

The duration can be particularly informative. For example, if the water supply in a catchment is largely from groundwater, which is not sensitive to droughts lasting only one summer, and if the environmental drought is short, one would not expect a significant water-supply drought. On the other hand the drought could be a long one with only a limited intensity, which may not register more than a moderate environmental drought but could cause serious water-supply problems for groundwater sources.

3.2 Classification of environmental droughts

To adopt the classification system described, a measure of droughts is required to define the class. For environmental droughts the precipitation, generally rainfall, is very important and is the main driving force, but as shown earlier, evaporation is also important. At this time there is no definitive objective measure of drought severity. The only measure for defining the class of drought that is generally acceptable to all interested parties is a simple measure of rainfall. Accepting that a rainfall measure alone may be a little misleading on occasions, it can be used as an illustrative device, rather than a strictly objective measure. One illustrative tool is that proposed by Bryant, Arnell and Law[3] (see Table 2 below) which defines the drought severity index (DSI) as:

> *the accumulated monthly deficit relative to the mean for a standard period — in this case the 1951-1989 mean.*

A drought is terminated when the three-monthly rainfall total exceeds the three-monthly mean for these months. From a scientific viewpoint, the setting of the termination criterion is much more of an art than a science — with emphasis upon credibility than objectivity. Great care must be taken in using the index because the chosen termination rule has an important impact on the

[3] Bryant, S.J., Arnell, N.W. and Law, F.M. 1992. The long-term context for the current hydrological drought. *Proc. IWEM Conf. on the Management of Scarce Water Resources.*

Table 2 *A classification of environmental drought*

Class of drought	Duration	Return period	Start of drought
1 — YELLOW (Moderate)	Short	5 - 20 years	after October *
	Long	5 - 20 years	> one season
2 — AMBER (Serious)	Short	20 - 50 years	after October *
	Long	20 - 50 years	> one season
3 — RED (Severe)	Short	> 50 years	after October *
	Long	> 50 years	> one season

* *October of the previous year*

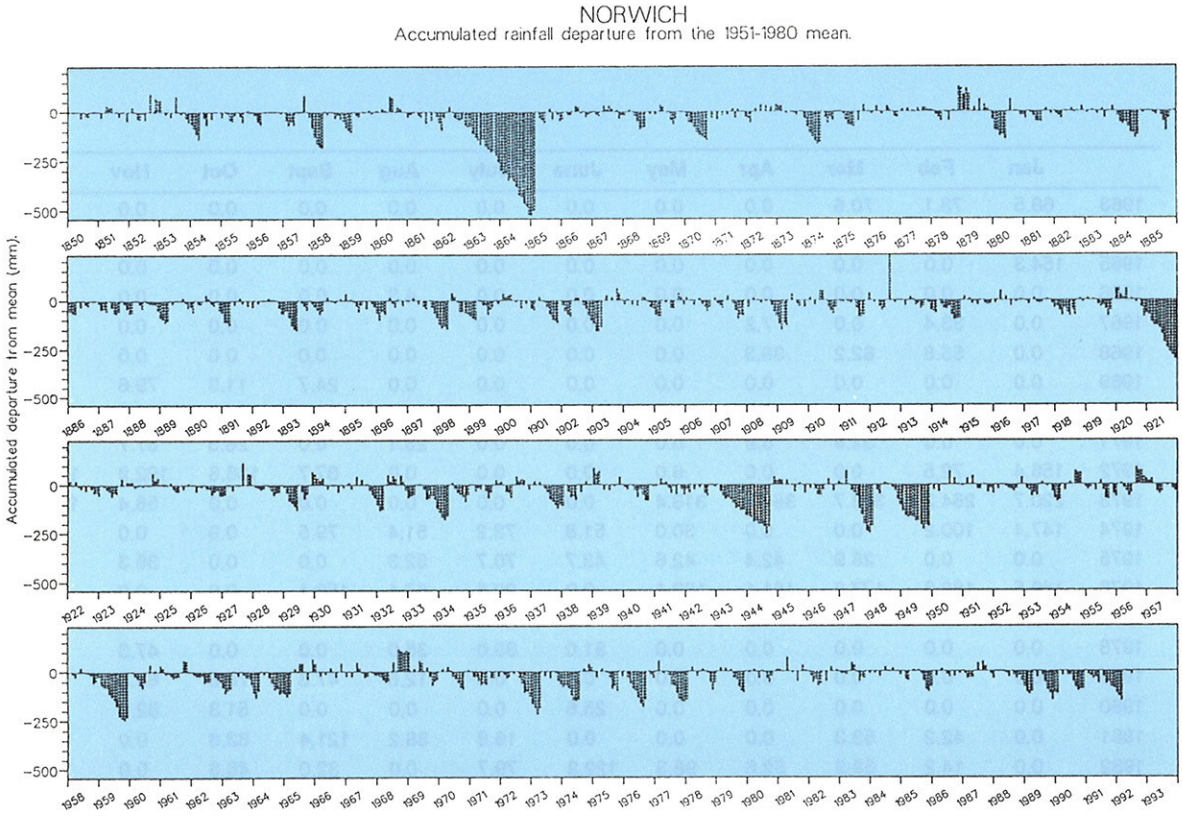


Figure 8 *A Drought Severity Index applied to the 1850-1992 record for East Anglia*

drought index — different termination rules can produce different impressions of drought severity. This is especially true for droughts of long duration.

This classification system shows how rare the meteorological events have been and gives some idea of how a drought has been unusual. It does not directly indicate the impact on the environment, as this will depend on natural buffering by the local soils and rocks, but the titles of moderate, serious, and severe should approximate closely to the relative degree of environmental impact in most parts of the country.

3.2.1 Examples

To illustrate how the environmental drought classification can work, examples have been chosen from Norwich in East Anglia and from the north-east of England. For the Anglian example, a Drought Severity Index (DSI) index has been applied to the record from 1850 to 1992: the results are shown graphically in Figure 8. This shows the length of the droughts and the severity by the size of the accumulated departure towards the end of the drought. As Bryant *et al.* (1992) stated "The deficit does identify tolerably well the main 20th century droughts as well as bringing into view those forgotten from the late Victorian era".

By analysing the deficits at the end of each of the droughts in the record, a return period can be established. The analysis has to be carried out separately for short and long droughts. For short droughts for this data set a moderate drought will occur when the index exceeds a value of 120, a serious drought when it exceeds 160, and a severe drought when it exceeds approximately 220. Using these values, the DSI correctly defines two severe droughts in the record — 1947 and 1959 — and the well known drought of 1976 is defined as a class 2 drought.

For long droughts the classes could be defined by different DSI values — namely class 1 when DSI>120, class 2 when DSI>210, and class 3 when DSI>280. However, again there would be only two class 3 long droughts in the record — 1920-21 and the very obvious drought of 1862-65. The most recent class 2 long drought in Norwich was 1972-73. This event would have been a moderate class 1 drought in 1972, just developing into a class 2 long drought in early 1973.

The droughts experienced during the last few years would have been class 1 short moderate droughts in 1989 and 1991, and 1990 would not have been defined as a drought year. This highlights the problem with this simple index: the drought termination criterion is inappropriate for some long-duration events. From a hydrological perspective, the 1988-92 drought at Norwich should have been classified as Amber/Red in

Table 3 *Drought Severity Index (accumulated departure, mm) for Waskerley catchment in the north-east of England*

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1963	68.5	73.1	70.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964	0.2	66.9	103.1	54.5	0.0	0.0	0.0	22.1	47.3	81.6	129.5	177.5
1965	154.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1966	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	0.0
1967	0.0	33.4	0.0	7.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1968	0.0	55.8	62.2	36.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1969	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.7	11.9	79.6	0.0
1970	11.9	0.0	9.9	0.0	0.0	22.3	57.7	64.8	73.0	95.6	116.8	87.5
1971	0.0	0.0	32.9	5.9	0.0	0.0	0.0	26.1	0.0	26.3	67.7	93.7
1972	156.4	72.5	0.0	0.0	6.0	0.0	0.0	0.0	87.7	136.6	192.9	191.5
1973	220.7	264.2	308.7	364.9	313.4	0.0	0.0	0.0	0.0	0.0	56.4	124.0
1974	147.4	100.2	0.0	0.0	30.0	51.8	73.2	51.4	79.5	0.0	0.0	0.0
1975	0.0	0.0	28.9	42.4	42.6	43.7	70.7	52.3	0.0	0.0	36.3	88.0
1976	149.5	162.8	177.8	181.1	193.1	0.0	20.5	67.1	150.1	0.0	0.0	0.0
1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.4	0.0	67.9	77.0	57.6
1978	0.0	0.0	0.0	0.0	0.0	31.0	38.0	35.0	0.0	0.0	47.3	86.3
1979	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.6	47.6	78.5	66.9	64.5
1980	0.0	0.0	0.0	0.0	0.0	25.6	0.0	0.0	0.0	51.3	32.0	33.0
1981	0.0	42.2	53.3	0.0	0.0	0.0	16.8	38.2	121.4	83.6	0.0	0.0
1982	0.0	14.2	59.9	52.6	98.3	122.8	79.7	0.0	32.0	45.6	0.0	0.0
1983	0.0	0.0	12.9	14.3	0.0	0.0	0.0	0.0	123.2	108.6	124.4	178.0
1984	126.4	0.0	0.0	0.0	18.7	54.8	54.4	109.0	126.2	96.2	0.0	0.0
1985	0.0	0.0	89.6	65.8	52.0	0.0	0.0	0.0	0.0	0.0	29.7	29.5
1986	38.7	0.0	0.0	0.0	0.0	0.0	0.0	41.4	0.0	8.7	0.0	83.0
1987	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1988	0.0	0.0	9.0	0.0	37.3	45.2	87.2	0.0	0.0	0.0	13.0	0.0
1989	11.1	81.4	61.4	65.7	0.0	17.8	26.9	84.0	119.4	171.0	179.9	236.5
1990	232.3	203.2	0.0	0.0	0.0	77.3	67.9	105.7	105.0	129.1	0.0	0.0
1991	0.0	0.0	0.0	0.0	0.0	17.3	25.6	52.9	114.9	148.2	141.5	130.1
1992	0.0	58.5	93.9	40.7	0.0	0.0	10.8	16.4	29.7	0.0	0.0	0.0

character. The rainfall accumulations, for any start month, in the 44-60 month time-frames were the lowest since the 1860s, temperature and evaporation rates were very high, runoff and groundwater recharge were extremely depressed. In environmental terms — and especially in relation to the contraction of stream networks and the loss of aquatic habitat — it was very probably the most severe event this century. However, there were several wet months in the intervening winters which, with this index, were sufficient to terminate the droughts. In such circumstances, drought severity may be better determined using selected local river flow or groundwater level data, notwithstanding the relative shortness of the available hydrological record.

The index should be more suitable for application to upland locations in western and northern areas. Some of the results from an example taken for the north east of England are shown in Table 3. The droughts in this part of the country show somewhat different characteristics as demonstrated by the generally larger values of DSI, particularly for long droughts. A moderate (yellow), long drought in this part of the country will occur when the index exceeds 145, a serious (amber) drought when it exceeds 400, and a severe (red) drought when it exceeds 570.

The above examples show that the DSI is quite sensitive to the definition of the end of a drought. For example, if the three-month total had to exceed the mean by a significant amount — say 60 mm — before the drought was ended, a number of single season droughts become joined into long droughts with the consequent increase in DSI values: e.g. the maximum DSI value increases from 700 to 990 (1941-1944).

3.2.2 *Summary*

As with any simple measure of hydrological events, there will always be some events that are inadequately defined and application of the DSI must be the responsibility of an experienced hydrologist who is able to properly interpret the

values obtained. The value of rainfall data alone is limited because the rainfall distribution during a year, particularly in relation to the periods of high evapotranspiration, has a significant impact upon groundwater levels and streamflow. In summer, especially, when rainfall in a month may be high, but *effective rainfall* may be low; despite the high rainfall, effects on resources may be negligible. A large deficit of effective rainfall or streamflow can be easier to accumulate than a large cumulative deficit of rainfall.

Potentially, *effective rainfall* could be a most useful indicator of drought, but long records of this measure do not generally exist. At the present time, a measure of accumulated rainfall deficit, despite its limitation, is the best available option for general application. Where local, and reasonably long, runoff or groundwater level records are available these are preferred for the assessment of drought severity except where artificial disturbances significantly detract from the consistency of the hydrometric series.

We recognise that some measure of professional judgement will always need to be exercised but we hope that the research hydrologists will try to define a better index which will overcome many of the deficiencies. In the meantime we recommend the use of the index of Bryant *et al.* By analysing a number of rainfall records from around the country, termination rules and values of the DSI to be used for classifying environmental drought could be determined for all regions.

3.3 Classification of water-supply droughts

This method of classification is designed to indicate the risk of a serious water shortage to the public water-supply consumers. If there is a moderate or serious environmental drought, there is likely to have been imposed a hosepipe ban or other similar demand reduction measures. But possibly of even more concern to the consumer is the chance of serious restrictions being imposed in the future, such as stand pipes in the streets. The water supply drought measure is designed to indicate this risk (see Table 4 below). This excludes short-term problems where water companies are unable to meet excessive peak demand for short periods due to limitations of the distribution system.

A moderate water supply drought is defined as one where demand restrictions are necessary to reduce the total consumption by the public consumers by approximately 10%. This corresponds to a level of service defined by OFWAT which should only be imposed on consumers once every 8-10 years on average and to a level of restriction that may be achieved by a hosepipe ban, for example.

Serious and severe water-supply droughts relate to the risk of stand pipes being imposed in the foreseeable future. The difference between them relates to the risk of this happening: a serious drought occurs when this risk is greater than 20%, and a severe drought when it is greater than 50%. In the first case one would expect Drought Orders to be sought or in place, and in the second some Drought Orders should already be in place.

As with the environmental drought measure, a qualification as to the duration is also relevant, but in this case it refers to the future and not the past. For a 'short' class of drought, the risk of standpipes refers to the risk within the current year; for a 'long' class of drought, the risk is highest for standpipes to be imposed in subsequent years.

The risk of standpipes being imposed should be assessed by reference to available water storage, that is using the reservoir levels, or groundwater levels, at the time of the assessment and the expected inflows to the reservoir over the foreseeable future (or groundwater recharge over the same period).

This classification system relates to the OFWAT levels of service: it refers to hosepipe bans and standpipes in the streets, the most serious restrictions considered. With a user measure such as this,

Table 4 *A Water Supply Drought Classification*

Class of Drought		Duration	Risk %	When restrictions	Type of risk
1 — YELLOW	Moderate	-	100	now	Demand reduction
2 — AMBER	Serious	Short	>20	this year	Standpipes
		Long	>20	future years	
3 — RED	Severe	Short	>50	this year	
		Long	>50	future years	

the class of drought will depend on a complex combination of meteorological effects and water management decisions. The measure will not allow these factors to be separated and reflects only the risk of shortages as a result of the combination. However, a comparison between the environmental drought classification in the area where the consumer's water comes from — e.g. for Manchester some water comes from the Lake District — and the water supply drought class may indicate the likely cause of the potential shortages.

The assessment of the risk of shortages will be complex and will have to be undertaken by the water companies and the NRA. Examples of how this can be carried out are given in Walker *et al.*[4]

3.4 Summary

As emphasised throughout this publication, droughts are multi-faceted events. The full characterisation of these events may be expected to involve a range of hydrological, environmental and operational indices. The recommended approach involves classification of droughts according to their environmental and water-supply characteristics, and to use a colour-coding system to describe the severity of each type. At the present time, the approach should be used only at the regional scale.

Future research developments should enable the development of more sensitive measures of drought severity applicable at the local scale. For example, although care must be taken to assess the degree to which artificial influences significantly detract from the consistency of the hydrometric data, local runoff and groundwater level records may be used to provide a better assessment of environmental drought severity. We recognise that a degree of professional judgement will always need to be exercised but recommend that the drought classification system proposed here should be adopted.

[4] Walker, S., Jowitt, P.W. & Bunch, A.H. 1993. Development of a decision support system for drought management within North West Water. *J. Instn Wat. & Environ. Manage.* **7**, 295-303.

APPENDIX 1: DATA SOURCES

Rainfall and Climatological Data
The Meteorological Office maintains the national archives of rainfall and climatological data at its headquarters at Bracknell. Specific items, such as daily and hourly rainfalls from gauges and weather radar (from the PARAGON system) may be obtained by application to the Commercial Services Division. Summaries of the data are also published regularly and a list of current titles is given below:

1. *Rainfall 19../..*
This contains monthly and annual rainfall totals for some 5000 raingauges and is available approximately one year after the title year.

2. *Snow Survey of Great Britain 19../..*
This contains the daily and monthly reports of snow conditions from selected stations covering the winter.

3. *Monthly Weather Report*
This is published monthly and contains climatological means for more than 550 UK observing stations. In addition, an introduction and annual summary are produced yearly. The publication should be available six to nine months after the month concerned: it is available from Her Majesty's Stationery Office (HMSO) or their stockists.

4. *MORECS (Meteorological Office Rainfall and Evaporation Calculation System)*
This is a weekly issue of maps and tables of evaporation, soil moisture deficit, effective rainfall and the weather variables used to calculate them. The data are used to provide values for 40 km squares and various sets of maps and tables are available according to customer requirements.

Further information about these and other publications may be obtained from:
Meteorological Office
Commercial Services
London Road
Bracknell
Berkshire RG12 2SZ
Tel: (0344) 420242

The National Water Archive
The National River Flow Archive (maintained by the Institute of Hydrology) and the National Groundwater Level Archive (maintained by the British Geological Survey) are major components in the recently designated NERC National Water Archive based at Wallingford.

River Flow Data
Most river flow measurement in the UK is carried out by regional measuring authorities. These comprise the Regions of the National Rivers Authority in England and Wales, the River Purification Boards in Scotland and the Departments of Agriculture and Environment which undertake a joint operation in Northern Ireland. Additional hydrometric monitoring is undertaken by the water service companies and various research and academic organisations.

Typically, river flow data are processed and archived regionally and then sent routinely for incorporation in the national archive. Monthly catchment areal rainfall totals are stored alongside the flow data and naturalised flows are archived also. The database now comprises over 27000 station years of data for around 1400 gauging stations. A comprehensive data retrieval service had been developed to meet the requirements of a broad spectrum of data users. The retrieval facilities are described in the *Hydrological data UK* series of publications which was launched in 1985. Each Yearbook in the series brings together the principal data sets relating to river flow, groundwater level and areal rainfall throughout the UK; some water quality data are also featured. Comprehensive reviews of the development and decay of the 1988-92 drought have been included in recent editions. A companion publication — the *Hydrometric Register and Statistics* volume — is published on a five-yearly cycle: the edition for 1986-90 was published in 1993. This reference volume includes maps, tables and statistics for river basins and representative observation boreholes throughout the United Kingdom. The principal objective of the Register is to assist data users in the selection of monitoring sites for particular projects or investigations and to allow more effective interpretation of analyses based upon the raw data. To this end, concise gauging station and catchment descriptions are given for the featured gauging stations — particular emphasis is placed on hydrometric performance in the low flow range and on the net effect of artificial influences on the natural regime.

Groundwater Level Archive
The National Groundwater Level Archive incorporates water level data for approximately 170 representative observation wells and boreholes throughout Great Britain. Historical data (pre-1982) are also stored for about 3000 observation boreholes. The data are made available through the groundwater retrieval service details of which are given in the *Hydrological data UK* series of publications. A number of wall charts have also been published showing long term groundwater level fluctuations for representative boreholes.

In addition to the national archive, large volumes of groundwater level data are systematically stored

by the Regional offices of the NRA, the private Water service companies and by a number of other public and private organisations.

Contact points for the national archives and the Hydrological data UK publications:
Surface Water Archive Office/
National Groundwater Archive
Institute of Hydrology/
British Geological Survey
Maclean Building
Crowmarsh Gifford
Wallingford
Oxfordshire OX10 8BB

Scientific assessment of severity of a drought event is normally limited until the drought is over, but the National Rivers Authority maintains a monitoring capability for England and Wales based upon their monthly Water Situation Reports and the Institute of Hydrology (in association with the British Geological Survey) have prepared monthly Hydrological Summaries for Great Britain, on behalf of the Department of the Environment, since the inception of the drought. The water service companies and their Associations also produce regular Press release and information bulletins, but these are usually more orientated towards the consequences of drought, rather than the scientific assessment of severity.

After previous droughts (1975, 1976, 1984) there were usually numerous symposia, published papers, Government reports, water services company reports, etc. which seek to ascribe a severity to the drought event, and to document conclusions and recommendations for action. The Institute of Hydrology publication on the 1988-92 drought is a major report[5] on the recent drought and its consequences.

[5] *The 1988-1992 Drought*. Hydrological data UK series. Institute of Hydrology, Wallingford. *1994*.

APPENDIX 2: DROUGHT ORDER SUMMARY 1989-92

Number of Drought Orders made for Water Authority/Company regions from 1988 to 1992
(The figures in brackets give the number of orders, out of each overall total, which restrict the non-essential use of water.)

	1988	*1989*	*1990*	*1991*	*1992*
Anglian	-	1	3	-	-
Northumbrian	-	-	-	-	-
North West	-	21	-	1	-
Severn Trent	-	5 (2)	-	-	-
Southern	-	19 (6)	25 (10)	18 (7)	11 (3)
South West	-	21 (2)	10	-	1 (1)
Thames	-	-	2 (1)	-	3 (3)
Welsh	-	13 (1)	1	-	-
Wessex	-	-	3 (1)	-	-
Yorkshire	-	9	17	9	1
Total	-	**89 (11)**	**61 (12)**	**28 (7)**	**16 (7)**

Year	*Date*	*NRA Region*	*Water Company*	*Location*	*Action*
1989	16 June	North West	North West Water	Sinen Gill, Keswick	Temporary maximum abstraction
1989	23 June	South West	South West Water	River Axe No.1 Whitford Bridge	Prescribed flow reduction
1989	30 June	North West	North West Water	Ennerdale Lake	Allow abstraction by means of pumping
1989	6 July	North West	North West Water	River Greta	Temporary maximum abstraction
1989	6 July	North West	North West Water	Glenderaterra Beck	Temporary maximum abstraction
1989	6 July	South West	South West Water	Meldon Reservoir	Compensation flow reduction
1989	21 July	South West	South West Water	River Dart No.1	Prescribed flow reduction
1989	21 July	South West	South West Water	Avon Reservoir	Compensation flow reduction
1989	25 July	South West	South West Water	River Tavy	Decrease prescribed flow
1989	27 July	South West	South West Water	Upper Tamar Lake No.1	Decrease compensation flow
1989	28 July	South West	South West Water	River Torridge	Prescribed flow reduction
1989	29 July	Welsh	Welsh Water	Cray Reservoir	Reduced flow compensation
1989	3 August	South West	South West Water	Venford and Swincombe Reservoir	Compensation flow reduction
1989	4 August	South West	South West Water	Tamar-Lumburn Transfer	Temporary abstraction
1989	10 August	South West	South West Water	Lower Tamar Lake No.2	Temporary abstraction
1989	10 August	South West	South West Water	River Axe No.2 Whitford Bridge	Prescribed flow reduction
1989	16 August	Welsh	Welsh Water	Prescelly Reservoir	Reduce compensation
1989	18 August	North West	North West Water	Lamaload Reservoir	Maximum release reduced
1989	18 August	North West	North West Water	River Wyre	Authorise abstraction of water discharged into river from boreholes
1989	18 August	North West	North West Water	Stocks Reservoir	Maximum abstraction
1989	22 August	South West	South West Water	Challacombe	Temporary abstraction

Year	*Date*	*NRA Region*	*Water Company*	*Location*	*Action*
1989	23 August	North West	North West Water	Coldwell Reservoir	Decrease compensation flow
1989	23 August	South West	South West Water	Colation Raleigh	Prescribed flow reduction
1989	23 August	Welsh	Welsh Water	Nant Selsig and Rhondda Fawr	Increase abstraction
1989	23 August	North West	North West Water	Tytherington Boreholes	Increased abstractions
1989	23 August	North West	North West Water	Flyde Boreholes	Abstractions allowed when levels are below "hands-off"
1989	23 August	Welsh	Welsh Water	Talybont Reservoir	Reduce compensation
1989	23 August	North West	North West Water	Blackmoss Reservoir	Decrease compensation water flow
1989	24 August	Welsh	Welsh Water	Aled Isaf Reservoir and River Aled	Reduce compensation
1989	24 August	Welsh	Welsh Water	Llwynon Ana Taf Fechan	Reduce compensation
1989	31 August	South West	South West Water	River Yealm	Decrease prescribed flow
1989	1 Sept	Welsh	Welsh Water	River Usk (No.1)	Reduce compensation
1989	1 Sept	South West	South West Water	Fenworthy Reservoir	Compensation flow reduction
1989	1 Sep	South West	South West Water	River Dart Littlehempton	Prescribed flow reduction
1989	2 Sept	Welsh	Welsh Water	Bachway Brook	Increase abstraction
1989	6 Sept	Severn Trent	Severn Trent Water	Buxton abstraction	Licence exemption of river
1989	6 Sept	North West	North West Water	Podnet Tarn overland pipeline	Temporary abstraction and
1989	7 Sept	South West	South West Water	Tamar lakes No.2	Decrease compensation flow
1989	8 Sept	Severn Trent	Severn Trent Water	Tittesworth Reservoir	Re-allocation compensation flow
1989	8 Sept	South West	South West Water	Bude Canal	Temporary abstraction
1989	30 Sept	Severn Trent	Severn Trent Water	Clywedog Reservoir	Reduce maintained flow
1989	30 Sept	Welsh	Welsh Water	River Usk (No.2)	Reduce compensation
1989	4 October	North West	North West Water	River Lune	Abstract, provided quantity abstracted does not exceed 1/3 residual flow at Skerton Weir
1989	4 October	North West	North West Water	Ullswater	1. Construct weir to raise level in Ullswater to 476 ft A.O.D. 2. Modify prescribed flow 3. Disregard annual licensed total
1989	7 October	Severn Trent	Severn Trent Water	River Derwent	Decrease compensation flow
1989	7 October	Severn Trent	Severn Trent Water	River Derwent	Increased abstraction
1989	7 October	Severn Trent	Severn Trent Water	River Derwent	Decrease prescribed flow
19892	4 October	Welsh	Welsh Water	Taf Fechan Llwynon Reservoirs No.2	Reduce compensation
1989	November	Yorkshire	Yorkshire Water	Harrogate Area Reservoirs	Reduce compensation flows
1989	November	Yorkshire	Yorkshire Water	Skipton Area Reservoirs	Reduce compensation flows
1989	November	Yorkshire	Yorkshire Water	Bradford Area Reservoirs	Reduce compensation flows

Year	*Date*	*NRA Region*	*Water Company*	*Location*	*Action*
1989	November	Yorkshire	Yorkshire Water	Calderdale Area Reservoirs	Reduce compensation flows
1989	November	Yorkshire	Yorkshire Water	Lindley Wood Reservoir, Nr Otley	Reduce compensation flows
1989	November	Yorkshire	Yorkshire Water	Underbank Reservoir, Nr Sheffield	Reduce compensation flows
1989	December	Yorkshire	Yorkshire Water	River Wharf	Amend abstraction
1990	January	Yorkshire	Yorkshire Water	East Yorks River Hull	Reduce residual flow
1990	10 January	Anglian	NRA	River Ely Ouse	Reduce minimum residual flow at Denver Sluice
1990	May	Southern	SWS	Medina-Yar Boreholes	Increase abstraction
1990	May	Southern	Mid Sussex Water	River Ouse at Barcombe	Increase abstraction
1990	May	Southern	SWS Kent Division	Medway and Thanet Supply	Prohibit or limit the use of water for any purpose specified in the order
1990	May	Southern	NRA	R.Stour at Wye	Control flow letter
1990	May	Southern	NRA	R.Medway at Teston	Control flow letter
1900	May	Southern	NRA	Romney/Walland MarshNew Sewer	Section 45- WRA 1963
1990	May	Southern	Mid Kent Co	Stour Valley (G/W) Hoplands Area (G/W) Stockbury Area (G/W)	Increase abstraction
1990	5 May	Southern	Mid Kent	Hoplands Borough Green Nepicar Charing. Charing No.5	Increase daily and annual abstraction from boreholes
1990	5 May	Southern	Mid Kent	Ryarsh Harple Lane Stockbury	Abstract from unlicensed sources
1990	12 May	Southern	SWS Kent Division	Medway-N.Kent Chalk	Abstract from unlicensed sources
1990	12 May	Southern	SWS Kent Division	Thanet Chalk Sources	Increase daily abstraction from licensed boreholes and allow abstraction from unlicensed borehole
1990	12 May	Southern	SWS Kent Division	River Stour at Plucks Gutter	Reduce prescribed flow
1990	17 May	Southern	SWS Kent Division	Medway	Reduce prescribed flow
1990	June	Southern	Mid Kent Water Co	Whole Area	Prohibit or limit the use of water for any purpose specified in the order
1990	June	Southern	Mid Sussex Water Co	Whole Area	Prohibit or limit the use of water for any purpose specified in the order
1990	June	Southern	SWS Sussex Division	Coastal	Prohibit or limit the use of water for any purpose specified in the order
1990	June	Southern	SWS Sussex Division	Western and Eastern	Prohibit or limit the use of water for any purpose specified in the order
1990	June	Southern	SWS Ltd	Tamar Lake	Increase abstraction

Year	*Date*	*NRA Region*	*Water Company*	*Location*	*Action*
1990	June	Southern	SWS Kent Division	Kent specified G/W sources Pluck Gutter springfield	Increase abstraction
1990	June	Southern	Mid Kent Folkstone and Dover Water	Specified G/W sources Romney Marsh	Increase abstraction Section 45 issued against spray irrigation to restrain abstraction
1990	19 June	South West	South Water Services Ltd	River Axe	Reduce prescribed flow
1990	19 June	South West	South Water Services Ltd	Lower Tarmar Lake	Temporary abstraction
1990	25 June	South West	South Water Services Ltd	River Dart	Reduce prescribed flow
1990	26 June	Yorkshire	Yorkshire Water	East Yorks	Drought order - increased abstraction
1990	28 June	South West	South Water Services Ltd	Roadford	Temporary abstraction
1990	29 June	Southern	SWS Ltd	- N. Kent Chalk - Thanet Chalk - Medway Scheme	Increase abstraction
1990	July	South Water	South Water Services Ltd	Venford Reservoir	Reduce compensation flow
1990	3 July	South West	South Water Services Ltd	Avon Reservoir	Reduce compensation flow
1990	16 July	South West	South Water Services Ltd	Fernworthy Reservoir	Reduce compensation flow
199021	July	South Water	South Water Services Ltd	Leswidden pit	Temporary abstraction
1990	21 July	South Water	South Water Services Ltd	Metherall Quarry	Temporary abstraction
1990	21 July	South Water	South Water Services Ltd	Polteggan Well	Temporary abstraction
1990	August	Yorkshire	Yorkshire Water	Harrogate	Reduce reservoir compensation discharge
1990	August	Yorkshire	Yorkshire Water	Lindley Wood Reservoir	Compensation flows
1990	2 August	Anglian	NRA	River Wensum	Emergency river support boreholes
1990	4 August	Yorkshire	Yorkshire Water	Calderdale Reservoir	Reduce compensation flows
1990	8 August	Yorkshire	Yorkshire Water	Leeds River Ouse	Increase river abstraction
1990	11 August	Welsh	Dur Cymru Cyf	Bachawy Brook	1.65 m/day abstract (max)
1990	15 August	Welsh	Welsh Water	Bachawy Brook Ports of Powys	Drought order emergencies
1990	15 August	Southern	Folkstone & District	Stonehall & Holmestone Supply Area	Vary conditions
1990	15 August	Southern	NRA	R. Itchen Augmentation Scheme	Vary conditions
1990	15 August	Southern	Eastbourne W Co.	R. Cuckmere	Reduce prescribed flow
1990	15 August	Southern	Eastbourne	R. Rother	Drought order - restriction from:- 1) Taking water from any source 2) Discharge of water 3) The supply of water 4) The filtration or other treatment of water

Year	*Date*	*NRA Region*	*Water Company*	*Location*	*Action*
1990	25 August	Anglian	NRA	River Nar	Emergency river support boreholes
1990	31 August	Yorkshire	Yorkshire Water	Sheffield (under bank)	Reduce compensation flows
1990	September	Yorkshire	Yorkshire Water	East Ness Borehole Ryedale	Use new borehole
1990	September	Yorkshire	Yorkshire Water	Brow Grains B/H (Huddersfield)	Use new borehole
1990	8 Sept	Yorkshire	Yorkshire Water	River Nidd Harrogate	New river abstraction
1990	8 Sept	Yorkshire	Yorkshire Water	Eagle Level Adit Pateley Bridge	Reduce residual flow
1990	8 Sept	Yorkshire	Yorkshire Water	River Ure North	Reduce residual flow increase Allerton Thirsk abstraction
1990	8 Sept	Yorkshire	Yorkshire Water	River Wharf	Reduce residual flow
1990	15 October	Thames	Thames Water Util.	Cotswolds/Swindon Faringdon	Abstractions from additional boreholes; relaxation of flow Marlborough constraint
1990	18 October	Anglian	NRA	River Ely Ouse	Reduce minimum residual flow at Denver Sluice
1990	November	Yorkshire	Yorkshire Water	March Ghyll Reservoir	Reduce compensation flows
1990	23 Nov	Wessex	Bristol Water Works	Cheddar Yeo River Kenn	Reduce compensation flows
1990	13 Dec	Wessex	Bristol Water Works	Congresbury Yeo - River Chew	Emergency abstraction
1990		Southern	Mid Sussex	R. Ouse at Barcombe	1. Relax controls governing abstraction 2. Essential use
1990		Southern	SWS	River Axe	Prescribed flow restrictions
1990		Yorkshire	Yorkshire Water	Sheffield (Morehall)	Reduce compensation flows
1990		Yorkshire	Yorkshire Water	Keld Head Borehole	Increase abstraction
1991		Yorkshire	Yorkshire Water	River Ouse for Leeds	Increased river abstraction
1991		Yorkshire	Yorkshire Water	Harrogate Area Reservoir	Reduce compensation flows
1991		Yorkshire	Yorkshire Water	Underbank Reservoir Nr. Sheffield	Reduce compensation flows
1991		Yorkshire	Yorkshire Water	River Nidd, Harrogate	New river abstraction
1991		Yorkshire	Yorkshire Water	Eagle Level Adit at Pateley Bridge	Reduce residual flow
1991		Yorkshire	Yorkshire Water	River Ure Northallerton/Thirsk	Reduce residual flow
1991		Yorkshire	Yorkshire Water	River Wharfe	Reduce residual flow
1991		Yorkshire	Yorkshire Water	Morehall Reservoir, Nr Sheffield	Reduce compensation flows
1991		Yorkshire	Yorkshire Water	Calderdale Reservoirs	Reduce compensation flows
1991		Yorkshire	Yorkshire Water	Lindley Wood Reservoir	Reduce compensation flows

Year	*Date*	*NRA Region*	*Water Company*	*Location*	*Action*
1991		Yorkshire	Yorkshire Water	Brow Grains Borehole Huddersfield	Use new borehole
1991		Yorkshire	Yorkshire Water	East Ness Borehole, Rydale	Use new borehole
1991		Yorkshire	Yorkshire Water	March Ghyll Reservoir	Reduce compensation flows
1991		Yorkshire	Yorkshire Water	Keld Head Borehole	Increase abstractions
1991		Yorkshire	Yorkshire Water	River Hull, East Yorks	Reduce residual flows
1992	January	Southern	NRA Kent	N.Kent Tong Mill Stream	Increase restrictions
1992	January	Southern	Folkstone & Dover Water Services	Chalk boreholes within supply area	Increase restrictions
1992	28 January	Southern	East Surrey Water Co.	R. Eden to Bough Beech Res.	Increase resources
1992	31 January	Thames	East Surrey Water Co.	Bough Beech Southern Region	Relax residual flow
1992	19 April	Yorkshire	Yorkshire Water	R. Hull East Yorks.	Reduce residual flows
1992	30 April	Southern	Mid Kent Co.	Stour Valley G/W Sources	Suspend or modify from any sources
1992	1 Nov	Southern	SWS Kent SWS Kent SWS Kent SWS Kent	Thanet GW Medway Scheme Springfield Smallbridge	Relax flow constraint Constraint variation on abstraction
1992	1 Nov	Southern	NRA Hampshire	Hants G/Water support for R.Alre	Variation on abstraction
1992		Southern	East Surrey	River Eden	Restrict suppply (Type 1)
1992		Southern	NRA Kent	North and East Kent Chalk Stream	Restrict supply (Type 1)
1992		Southern	East Surrey	River Eden	Restrict supply (Type 1)
1992		Southern	Folkstone water Co.	Whole Area	Restrict supply (Type 1)
1992		Yorkshire	Yorkshire Water	Harrogate Area Reservoirs	Reduce compensation flows
1992		Yorkshire	Yorkshire Water	Sheffield Area Reservoirs	Reduce compensation flows
1992		Yorkshire	Yorkshire Water	Leeds/Bradford River Wharfe	Reduce residual flow
1992		Yorkshire	Yorkshire Water	Pennines (Res)	Reduce compensation flow
1992		Yorkshire	Yorkshire Water	Leeds (R.Ouse)	Remove prescribed flow condition
1992		Yorkshire	Yorkshire Water	Sheffield (More Hall Reservoir)	Reduce compensation flow
1992		Yorkshire	Yorkshire Water	Leeds (Lindley Wood Res.)	Reduce compensation flow
1992		Yorkshire	Yorkshire Water	Ilkley (March Ghyll Res.)	Reduce compensation flow

APPENDIX 3:USEFUL ADDRESSES

NATIONAL RIVERS AUTHORITY

National Rivers Authority
Head Office, Rivers House
Waterside Drive
Aztec West
Almondsbury
Bristol BS12 4UD
Tel: 0454 624400
Fax: 0454 624409

National Rivers Authority
Anglian Region
Kingfisher House
Goldhay Way
Orton Goldhay
Peterborough PE2 0ZR
Tel: 0733 371811
Fax: 0733 231840

National Rivers Authority
North West Region
PO Box 12, Richard Fairclough House
Knutsford Road
Warrington WA4 1HG
Tel: 0925 53999
Fax: 0925 415961

National Rivers Authority
Severn Trent Region
Sapphire East
550 Streetsbrook Road
Solihull
West Midlands B91 1QT
Tel: 021 711 2324
Fax: 021 711 5824

National Rivers Authority
Souther Region
Guidbourne House
Chatsworth Road
Worthing
West Sussex BN11 1LD
Tel: 0903 820692
Fax: 0903 821832

National Rivers Authority
South Western Region
Manley House
Kestrel Way
Exeter Devon EX2 7LQ
Tel: 0392 444000
Fax: 9392 444238

National Rivers Authority
Thames Region
Kings Meadow House
Kings Meadow Road
Reading
Berks RG1 8DQ
Tel: 0734 535000
Fax: 0734 500388

National Rivers Authority
Welsh Region
Rivers House
St Mellons Business Park
St Mellons
Cardiff CF3 0EG
Tel: 0222 770088
Fax: 0222 798555

National Rivers Authority
Yorkshire & Northumbrian Region
Rivers House
21 Park Square South
Leeds LS1 2GQ
Tel: 0532 440191
Fax: 0532 461889

RIVER PURIFICATION BOARDS

Scottish River Purification Boards Association
1 South Street
Perth PH2 8NJ
Tel: 0738 27989
Fax: 0738 30997

Clyde River Purification Board
Rivers House
Murray Road
East Kilbride
Glasgow G75 0LA
Tel: 035 523 8181
Fax: 035 526 4323

Forth River Purification Board
Clearwater House
Heriot Watt Research Park
Avenue North, Riccarton
Edinburgh E14 4AP
Tel: 031 449 7296

Highland River Purification board
Strathpeffer Road
Dingwall
Ross and Cromarty IV15 9QY
Tel: 0349 62021

North East River Purification Board
Greyhope House
Greyhope Road
Torry
Aberdeen AB1 3RD
Tel: 0224 248338

Solway River Purification Board
Rivers House
Irongray Road
Dumfries DG2 0JE
Tel: 0387 720502
Fax: 0387 721154

Tay River Purification Board
1 South Street
Perth PH2 8NJ
Tel: 0738 27989
Fax: 0738 30997

WATER SERVICE COMPANIES

Anglian Water Services Ltd
Compass House
Chivers Way
Histon
Cambridge CB4 4ZY
Tel: 0223 372000
Fax: 0223 372271

North West Water Ltd
Dawson House
Great Sankey
Warrington WA5 3LW
Tel: 0925 234000
Fax: 0925 233360

Severn Trent Water Ltd
2297 Coventry Road
Birmingham
B26 3PU
Tel: 021 722 4000
Fax: 021 722 4800

Southern Water Services Ltd
Southern House
Yeoman Road
Worthing
West Sussex BN13 3NX
Tel: 0903 64444
Fax: 0903 62100

South West Water Services Ltd
Peninsula House
Exeter
Devon
EX2 7HR
Tel: 0392 219666
Fax: 0392 434966

Wessex Water
Wessex House
Passage Street
Bristol BS2 0JQ
Tel: 0272 290611
Fax: 0272 293137

Northumbrian Water Limited
Abbey Road
Pity Me
Durham DH1 5JF
Tel: 091 383 2222
Fax: 091 384 1920

Thames Water Utilities Ltd
Nugent House
Vastern Road
Reading RG1 8DB
Tel: 0734 591159
Fax: 0734 593203

Welsh Water (Dwr Cymru)
Plas y Ffynnon
Cambrian Way
Brecon
Powys LD3 7HP
Tel: 0874 623181
Fax: 0874 624167

Yorkshire Water Services Ltd
West Riding House
67 Albion Street
Leeds LS1 5AA
Tel: 0532 448201
Fax: 0532 44071

SCOTTISH REGIONAL COUNCILS

Borders Regional Council
Directorate of Water and
Drainage Services
West Groves, Waverley Road
Melrose
Roxburghshire TD6 9SJ
Tel: 0898 822056
Fax: 0986 822702

Central Regional Council
Department of Water and Drainage
Woodlands
St Ninians Road
Stirling FK8 2HB
Tel: 0786 44300

Central Scotland
Water Development Board
Balmore
Torrance
Glasgow G64 1AJ
Tel: 0360 20511

Dumfries and Galloway Regional
Council
Water and Sewage Department
Marchmount House
Marchmount
Dumfries DG1 1PW
Tel: 0387 61234

Fife Regional Council
Fife House
North Street
Glenrothes KY7 5LT
Tel: 0592 754411

Grampian Regional Council
Department of Water Services
Regional Office
Woodhill House
Westburn Road
Aberdeen AB9 2LU
Tel: 0224 682222

Highland Regional Council
Regional Buildines Glenurquhart Road
Inverness IV3 5NX
Tel: 0463 702542
Fax: 0463 702549

Lothian Regional Council
6 Cockburn Street
Edinburgh EH1 1NZ
Tel: 031 229 9292

Orkney Islands Council
Council Offices, Kirkwall
Orkney
Tel: 0856 873535
Fax: 0965 874615

Shetland Islands Council
Town Hall
Lerwick
Shetland ZE1 0HD
Tel: 0595 3535

Strathclyde Regional Council
Sewerage Department
Strathclyde House
20 India Street
Glasgow G2 4PF
Tel: 041 204 2900
Telex: 777237

Tayside Regional Council
Water Services Department
Bullion House
Invergowrie
Dundee
DD2 5BB
Tel: 0382 562581
Fax: 0382 561062

Western Isles Islands Council
Council Offices
Stornoway
PA87 2BW
Tel: 0851 703773
Fax: 0851 705349

OTHER USEFUL ADDRESSES

Water Services Association
1 Queen Anne's Gate
London SW1H 9BT
Tel: 071 222 8111
Fax: 071 222 1811

Department of the Environment
Romney House
43 Marsham Street
London SW1P 3PY

Department of the Environment
for Northern Ireland
Water Services Headquarters
North Land House
3 Frederick Street
Belfast
Northern Ireland BT1 2NS
Tel: 0232 244711

Scottish Office
Environment Department
St Andrew's House
Edinburgh EH1 3DE
Tel: 031 244 4045

Welsh Office
Environment Division
New Crown Building
Cathays Parks
Cardiff CF1 3NQ
Tel: 0222 825111

Office of Water Services (OFWAT)
Centre City Tower
7 Hill Street
Birmingham B5 4UA
Tel: 021 625 1300
Fax: 021 625 1400

British Waterways
Greycaine Road
Watford
Herts WD2 4JR