UK Hydrological Review 1998

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Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

1998

UK HYDROLOGICAL REVIEW

This Hydrological Review, which also provides an overview of water resources status throughout 1998, is a reformatted version of the original commentary released as a web report in 1999. Some of the data featured in this report, particularly the more extreme flows, may have been subsequently revised.

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

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

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

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Hydrological Review of 1998

1998 Summary

1998 was an exceptionally warm and, in most parts of the UK, a notably wet year. The high temperatures, combined with unusually moist soil conditions in the summer encouraged high transpiration rates and annual evaporation losses were close to the maximum on record over wide areas. Entering 1998, groundwater levels remained depressed in a few eastern outcrop areas - the consequence of long term rainfall deficiencies and limited opportunities for recharge since the winter of 1994/95. Following a dry February there was some concern regarding the water resources outlook in such areas. However, the spring was remarkably wet and the focus of hydrological concern switched rapidly to the threat of flooding. A major flood event in April heralded well above average river flows through most of the summer half-year. Unsettled weather patterns, in June and July especially, helped contain the normal seasonal increase in water demand and water supply stress was minimal. Seasonal recoveries in runoff and recharge rates began earlier than usual and further widespread flooding occurred in October. Spate conditions were more subdued thereafter but overall reservoir stocks remained close to the seasonal maxima as they did throughout most of 1998 (Figure 1) and, in most aquifers, groundwater recoveries in the early winter were brisk and sustained. By year-end the water resources outlook was very healthy.

1998 continued a sequence of notably warm years, most being characterised by persistent and significant departures of monthly runoff and recharge rates from the seasonal average. However, the recent tendency for an increase in the proportion of overall rainfall falling during the winter half-year did not continue in 1998 and the arid soil conditions, which have been a common feature of the eastern lowlands during the summers of the early 1990s, were also absent. In water resources terms 1998 served to emphasise the very different recovery rates of surface water resources and groundwater resources following a lengthy drought episode (that of 1995-97). It also underlined the importance of spring rainfall in determining the water resources outlook for the summer and autumn. Taking a broader hydrological perspective, 1998 - together with much of the last decade - demonstrated the complexity of the interplay between rainfall patterns, evaporative demands and soil moisture conditions in determining runoff and recharge rates. This underpins the need for continuing careful monitoring of river flows and groundwater levels to identify any significant hydrological trends.

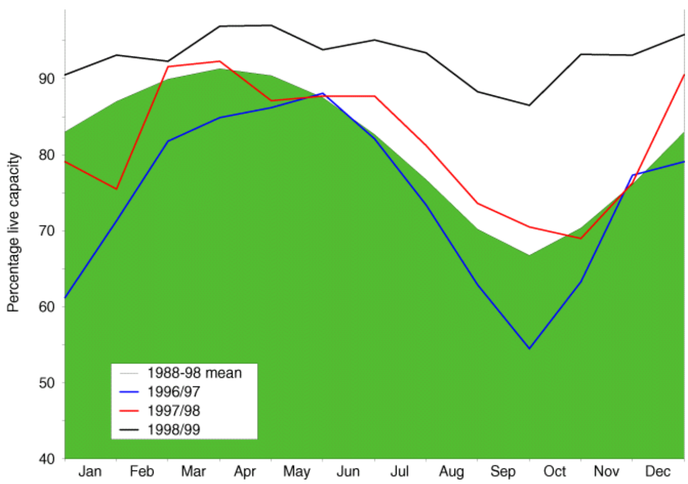


Figure 1 *Comparison between overall reservoir stocks for England and Wales in recent years.*

Data sources: Water Service Companies, Environment Agency.

Rainfall

The provisional annual rainfall total for the UK in 1998 is 1259mm, 117% of the 1961-90 average. Most regions received substantially above average rainfall - reflected in the provisional totals for England and Wales (1026mm - 115%), Scotland (1718mm - 120%) and Northern Ireland (1179mm - 111%). On the basis of provisional data Great Britain registered its third wettest year this century and Scotland its third wettest in a series from 1869 (but 1990 and 1992 were both wetter). Some caution is necessary in interpreting these rankings, the final rainfall figures may differ appreciably from the provisional estimates and artifacts in both the Great Britain and, in particular, the Scottish rainfall series mean that recent totals may be overestimated relative to earlier annual figures.

The 1998 regional rainfall totals varied between 114% and 134% of the 1961-90 average (see Figure 2). Almost all major catchments received above average rainfall with only sheltered parts of south Devon/ Dorset having less than the annual mean, although rainfall totals were only marginally above average in the Fort William area. Throughout the driest parts of the country - the English lowlands - rainfall totals were typically 20% or more above average. The overall area registering annual rainfall totals of less than 600mm was the second lowest in the last 30 years.

In percentage terms the regional rainfall totals show considerable spatial coherence but temporal variations in rainfall through the year were considerable. February, May and August were relatively dry whereas April, June and October were notably wet. February 1998 was dry throughout most of England and Wales - the fourth driest February in the last 33 years - with the Southern and Anglian regions receiving less than 20% of the 1961-90 mean. By contrast Sconser on the Isle of Skye

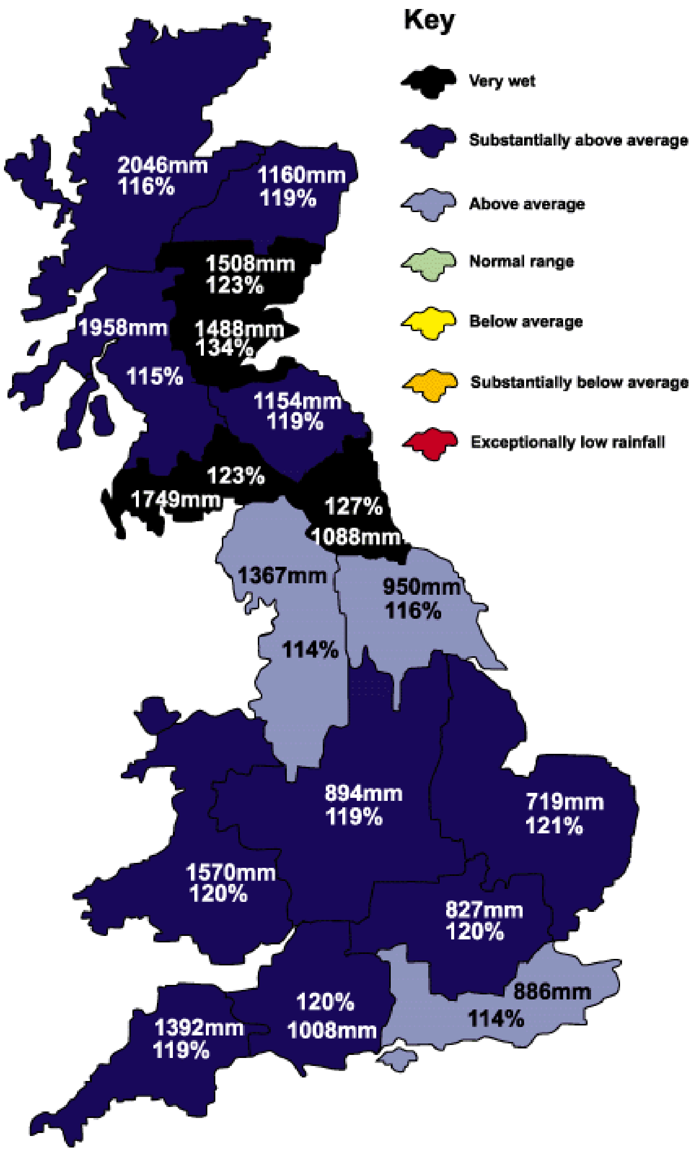


Figure 2 *Annual rainfall for 1998 in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.

logged a monthly rainfall total of 646mm, greater than the average annual rainfall over most of eastern England. For England and Wales, April was the wettest since 1818, some districts - mostly in the Midlands - recording more than three times the monthly average. On the 9th, a frontal system aligned along a broad swathe from The Black Mountains (South Wales) to the Wash became very slow moving and many catchments received the equivalent of an average month's rainfall (45-70mm) in around 10 hours; maximum 48-hour totals of 90mm in Pershore and 97mm in Peterborough were recorded. Extensive flooding ensued (see River flows).

May was the equal 12th driest this century for England and Wales; parts of eastern Wales and Essex registered less than a quarter of the monthly average rainfall. Westerly airflows returned to dominate weather patterns in June which for England and Wales was the third wettest in the last 120 years; some western locations e.g. Valley (Anglesey) and Plymouth (Devon) established new rainfall maxima for the month. Well above average rainfall totals were recorded for most catchments in July also; Scotland had its wettest July for 10 years. August provided a notably dry interlude in England with some southern districts, which escaped the thunderstorms, receiving less than 10mm. In September, a sequence of vigorous frontal systems crossed southern Britain producing double the average September rainfall in some parts of the English lowlands, much of western Scotland, by contrast was notably dry. October was very wet throughout the UK. Treherbert, at the head of the Rhondda valley in South Wales, recorded a monthly rainfall total of 550mm, its second highest rainfall there for any month in the past 30 years. Serious flooding occurred in South Wales and the Severn Basin.

November was also unsettled and the provisional autumn rainfall total for Great Britain was the highest (along with 1992) since 1984. December rainfall totals were a little below average in most parts of England and Wales but, with soils remaining close to saturation, the seasonal recovery in river flows and groundwater levels was maintained. One consequence was that stocks in almost all strategic reservoirs were near capacity entering 1999.

Evaporation and Soil Moisture Deficits

On the basis of the Central England Temperature (CET) series which extends back to 1659, 1998 was the 12th warmest year on record, and the 8th warmest this century. February, March, May and September each ranked amongst the warmest 10 on record. The average temperature in 1998 was 10.3°C, some 0.8° above the 1961-90 mean and over 1.2° above the average for the nineteenth century. 1998 added to the cluster of warm years in the recent past; five of the eight warmest have occurred in the last decade. The mean CET temperature over the last ten years is higher than for any other 10-year sequence.

As a consequence of the warm conditions evaporative demands were again very high - commonly 20% above average (Figure 3). Annual potential evaporation (PE) totals (based on the MORECS model) for 1998 exceeded 700mm in a few coastal districts in southern Britain, this is becoming a common occurrence. However, as in 1990 or 1995, elevated PE totals have often been accompanied - in the eastern lowlands especially - by low actual evaporation (AE) losses, a consequence of the inhibiting effect of very dry summer soils on transpiration rates. By contrast, in 1998 and to a lesser degree in 1997, evaporation rates were maintained

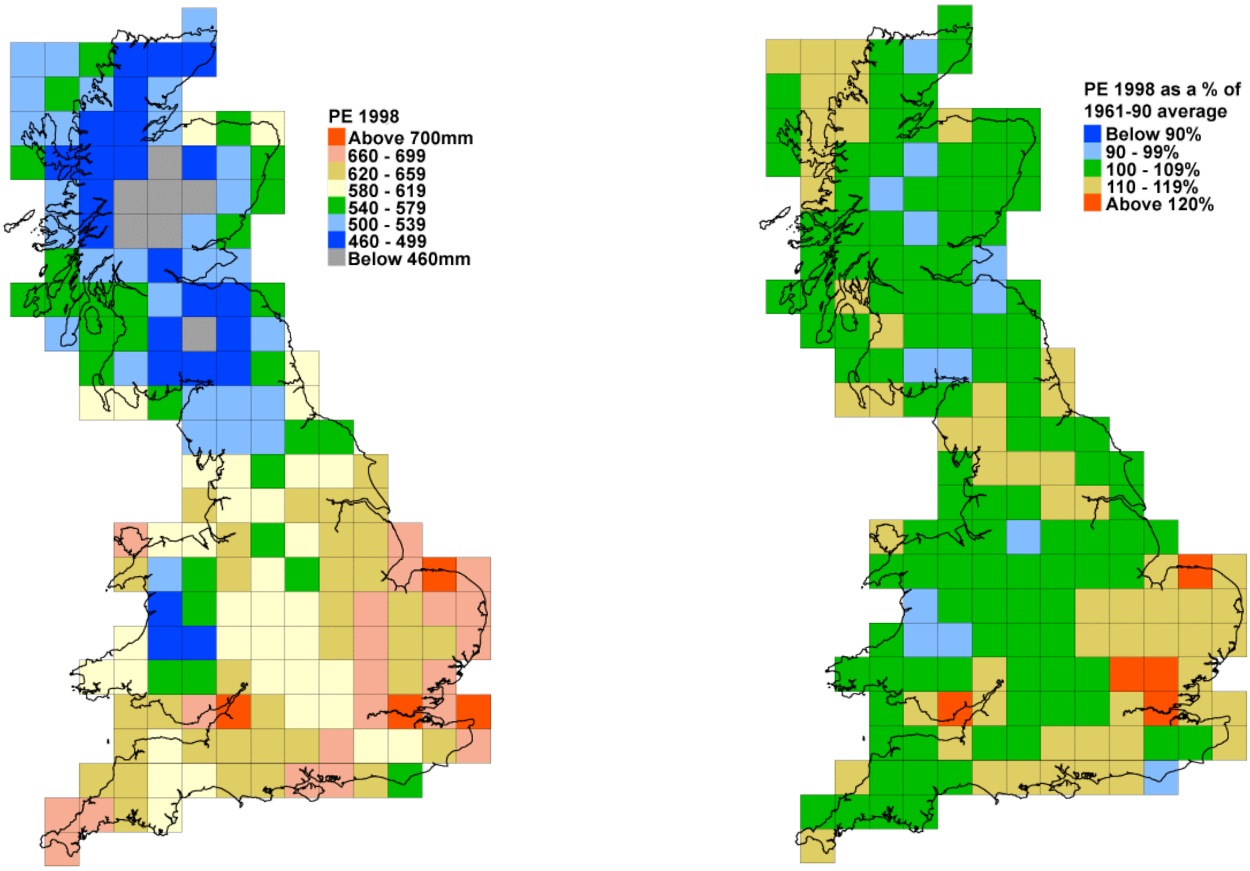


Figure 3 *Potential evaporation totals for 1998 in mm and as a percentage of 1961-90 average.*

Note the PE totals assume a grass cover.

Data source: MORECS.

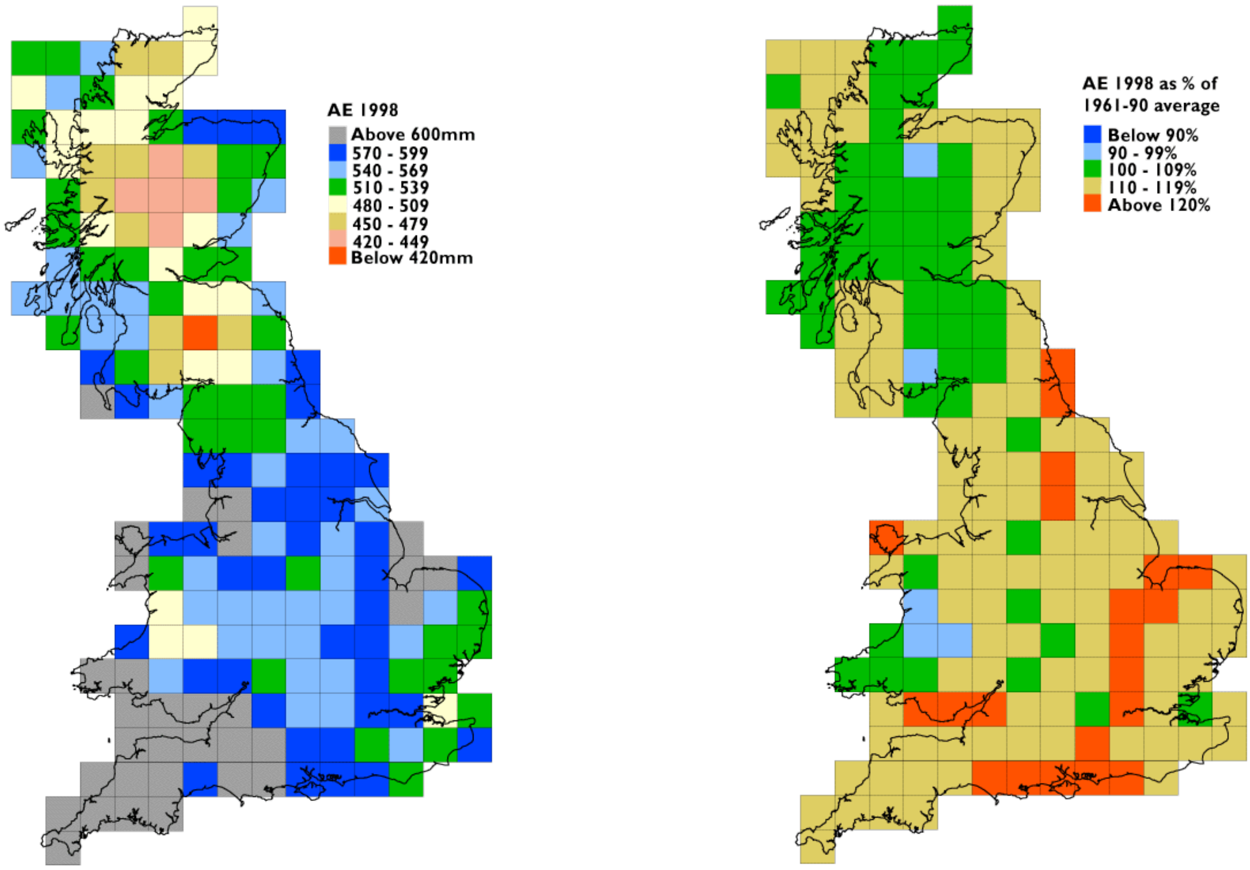


Figure 4 *Actual evaporation totals for 1998 in mm and as a percentage of 1961-90 average.*

Note the AE totals assume a grass cover.

Data source: MORECS.

close to the potential rates and actual evaporation losses for the year exceeded 600 mm in districts close to the Wash, as well as in much for the South-West (Figure 4). For the former area this loss represents more than 85% of the annual rainfall total.

The development and decay of soil moisture deficits (SMDs) during 1998 was unusual (see Figure 5). At the start of the year residual soil moisture deficits

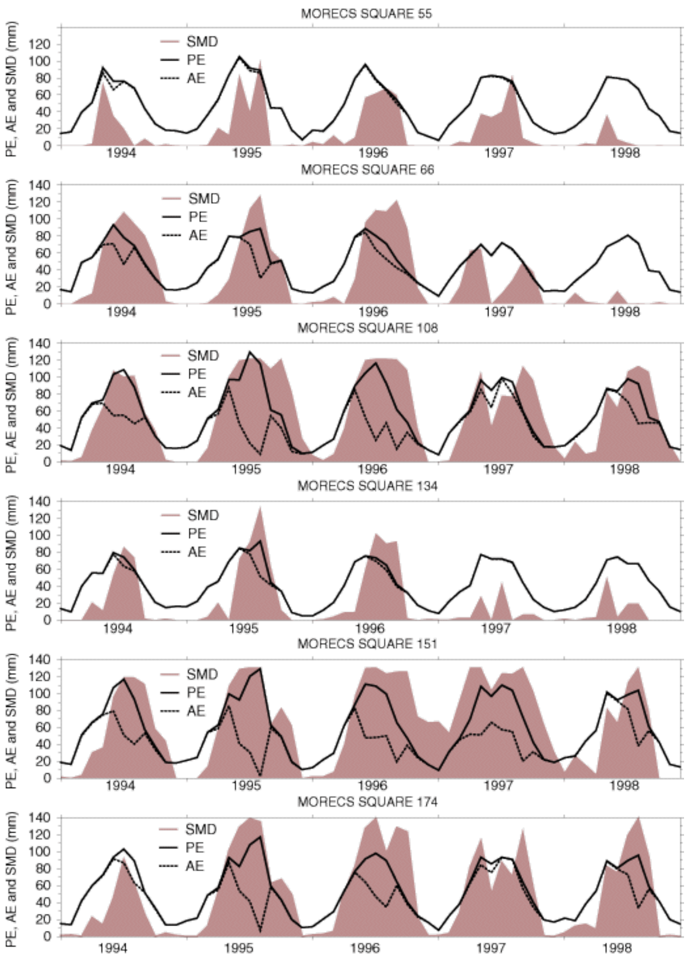


Figure 5a *The variation in potential evaporation, actual evaporation and soil moisture deficits for six MORECS squares.*

Note the data relate to a grass cover.

Data source: MORECS.

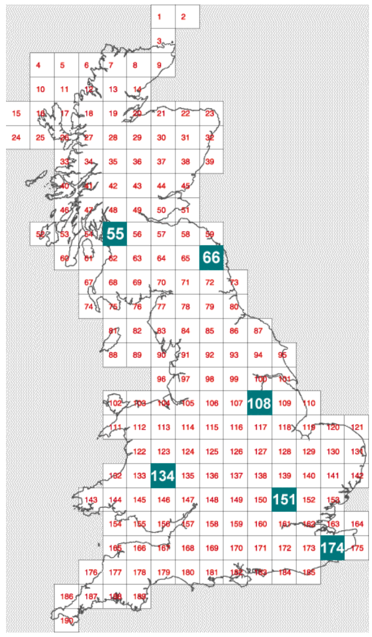


Figure 5b *MORECS Location Map: the location of the 40km squares and their associated reference numbers.*

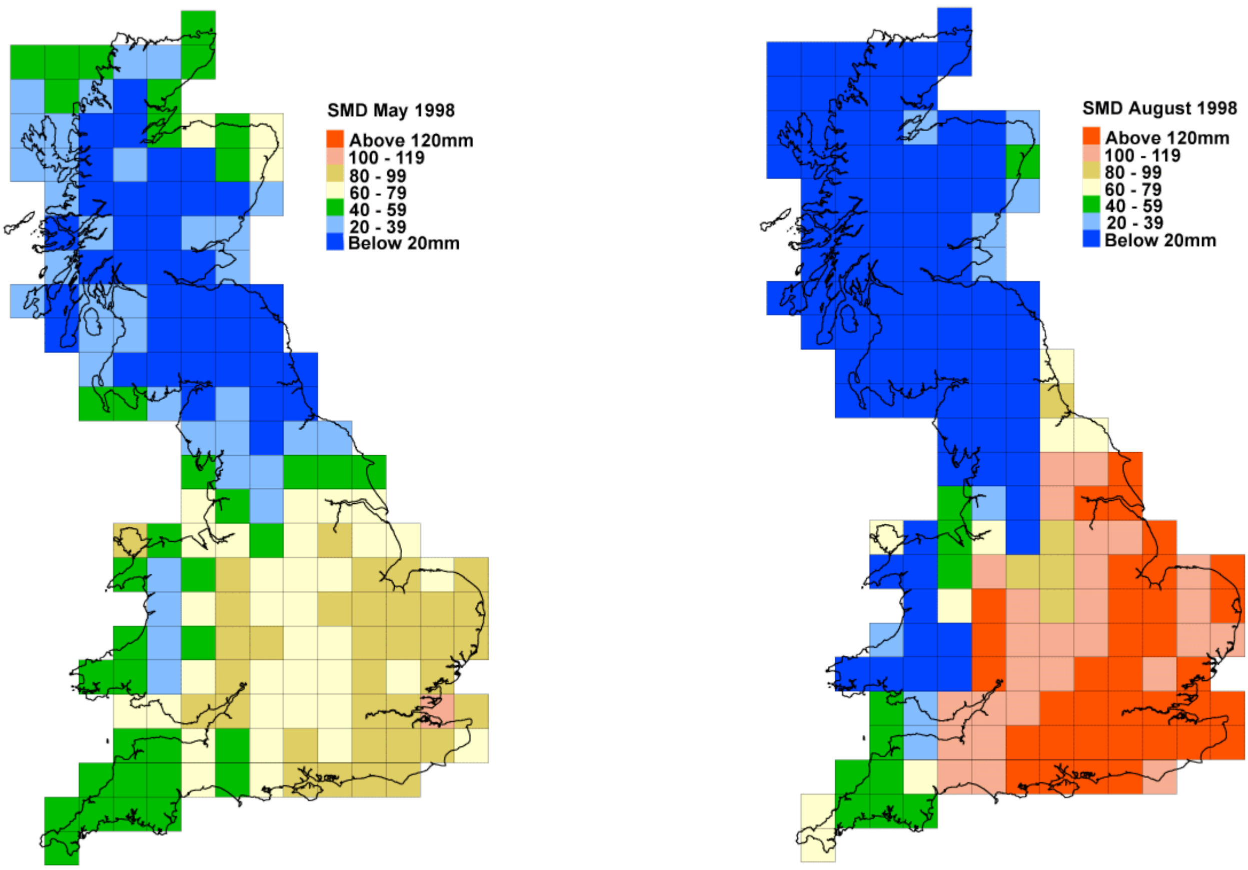


Figure 6 *Soil Moisture Deficits at the end of May and August 1998.*

Data source: MORECS.

were largely confined to an eastern coastal zone from Lincolnshire to the Lower Thames basin. Almost all were eliminated in January and in large parts of north-west Britain month-end deficits never exceeded 40mm throughout the entire year. The very wet early spring delayed the onset of significant deficiencies until late May (see Figure 6) and the sustained June rainfall produced, unusually, a decline in smds through the month. Large deficiencies were confined to late August (Figure 6) and early September; they were sustained only briefly before declining steeply in October. Soils in most areas were close to saturation through the late autumn and, by the end of the year, deficits remained only in a few eastern areas - they were of particular hydrological significance where, as in parts of Nottinghamshire, they corresponded with aquifer outcrop areas (see groundwater).

River Flows

Catchment runoff totals for 1998 were broadly consistent with the corresponding rainfall totals in much of western and northern Britain. In the east however, where many rivers are sustained principally from groundwater, above average catchment rainfall corresponded with runoff totals which were well below average. For the River Mimram, to the north of London, 1998 rainfall was around 110% of average but river flows remained depressed throughout most of the year and the annual runoff total ranks seventh lowest in a series from 1952; a direct reflection of the low groundwater levels throughout 1998. Runoff totals in impermeable catchments were much healthier throughout the UK and new maximum annual totals were established for a significant minority of rivers including the Whiteadder, Cree and Cynon (see Location Map). Notably high annual runoff totals characterised much of western Scotland contributing to an exaggeration in the north-west/south-east runoff gradient across the country - a recurring feature of the last 20 years.

The pattern of monthly river flows during 1998, and over the preceding four years, is shown in Figure 7. February flows were generally very modest but, contrary to the normal seasonal pattern, flows increased through March and April. With catchments saturated, inflows to reservoirs were heavy and overall stocks for England Wales were close to capacity through into the late spring. From mid-March many catchments were particularly vulnerable to further significant rainfall. The notable storm on the 9th April (see Rainfall) produced rainfall intensities which on impermeable, sodden catchments meant that severe flooding was inevitable. The resulting flooding was the most severe ever recorded in a number of rivers with headwaters in the south and east Midlands (e.g. the Leam, Warwickshire Avon, Nene and Cherwell); return periods of 50-150 years were ascribed to the most extreme peak flows. Overall, it was the most damaging flood episode in the UK since the summer floods of 1968 in southern England. Five fatalities were attributed to the event and the total cost was assessed at around £350 million. Around 4500 people were made temporarily homeless (some homes were lost permanently) and the associated disruption was exacerbated by the fact that most flood peaks occurred at night (and during the Easter break). The unprecedented flooding prompted a wide-ranging review of existing flood warning procedures, flood alleviation strategies and planning constraints on floodplain development (the growth in the number of river-side caravan sites being a particular concern).

Flows in most rivers remained above average through most of the summer and, following a short low-flow interlude in August and early September, began a strong seasonal recovery early in the autumn - this gathered momentum in October and over the period of the 20-25th a second major flooding episode - less extreme but more extensive than in April - produced notable peaks over wide areas. Damage was especially severe in South Wales where in some catchments it was the worst for 20 years; issues highlighted included the effect of increasing urbanisation (e.g. in the Merthyr Tydfil area) on runoff rates and, locally, the exacerbating influence of the depositing of tip material (following the 1966 Aberfan disaster) on the floodplain of the River Taff. In larger catchments it was a complex event with multiple peaks and the flood risks extending over periods of a week or more.

Runoff rates during the last two months of the year were generally closer to the seasonal average but November flows in many permeable catchments reflected a lagged response to the very heavy late-October rainfall. The November runoff total was the highest for 24 years for the Thames despite the catchment rainfall being less than 90% of the monthly average. December began with most rivers in recession but widespread spates occurred in the week following Christmas - in eastern Scotland, the Earn recorded its second highest December flow in 32 years and bankfull flows were very widespread. Flow rates on the Mimram exceeded the December average at year-end after a very lengthy sequence of below average monthly runoff totals - establishing a new 36-month runoff minimum for the catchment.

The flow duration curves featured in Figure 8 confirm that in most flow ranges, flows exceeded the average in 1998. Exceptions included many rivers in northern Britain where the flows exceeded 10% of the time were close to the average - and, more notably - flows in spring-fed lowland rivers which, though remaining above drought minima, were especially depressed - relative to the seasonal average - during the first quarter of the year.

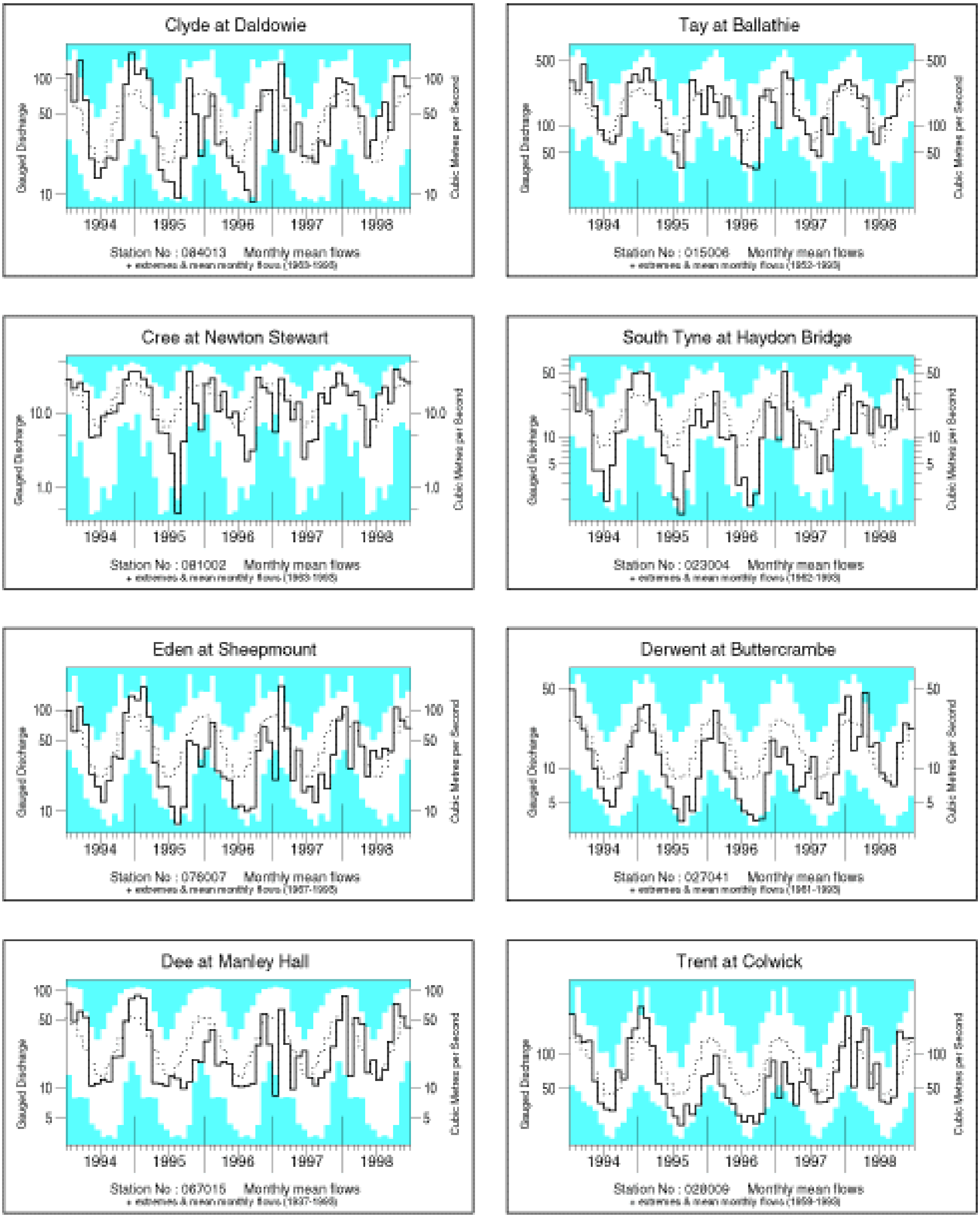


Figure 7 *River flow hydrographs 1994 - 1998.*
Note some of the data may be incomplete.

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

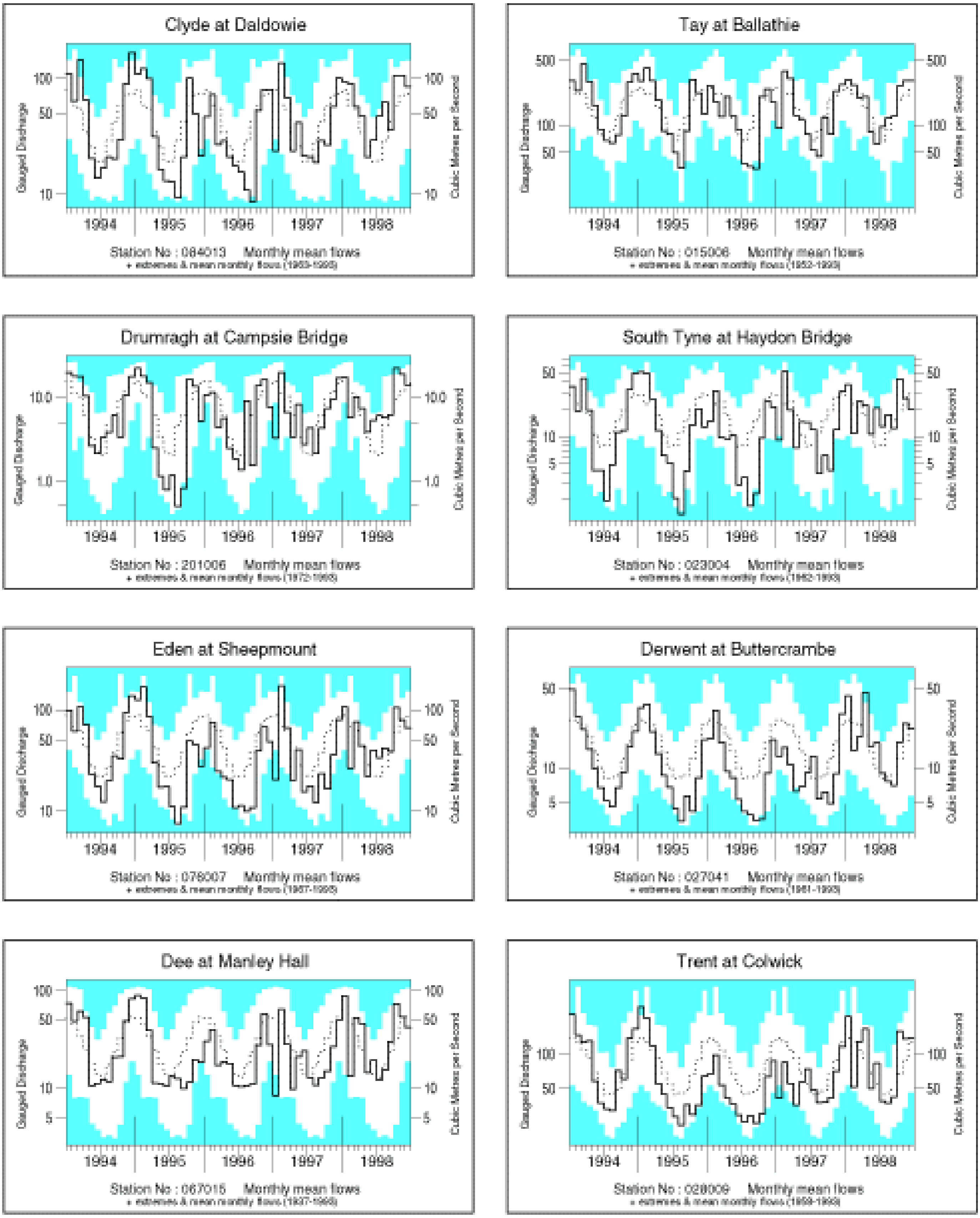


Figure 7 *(Contd.)*

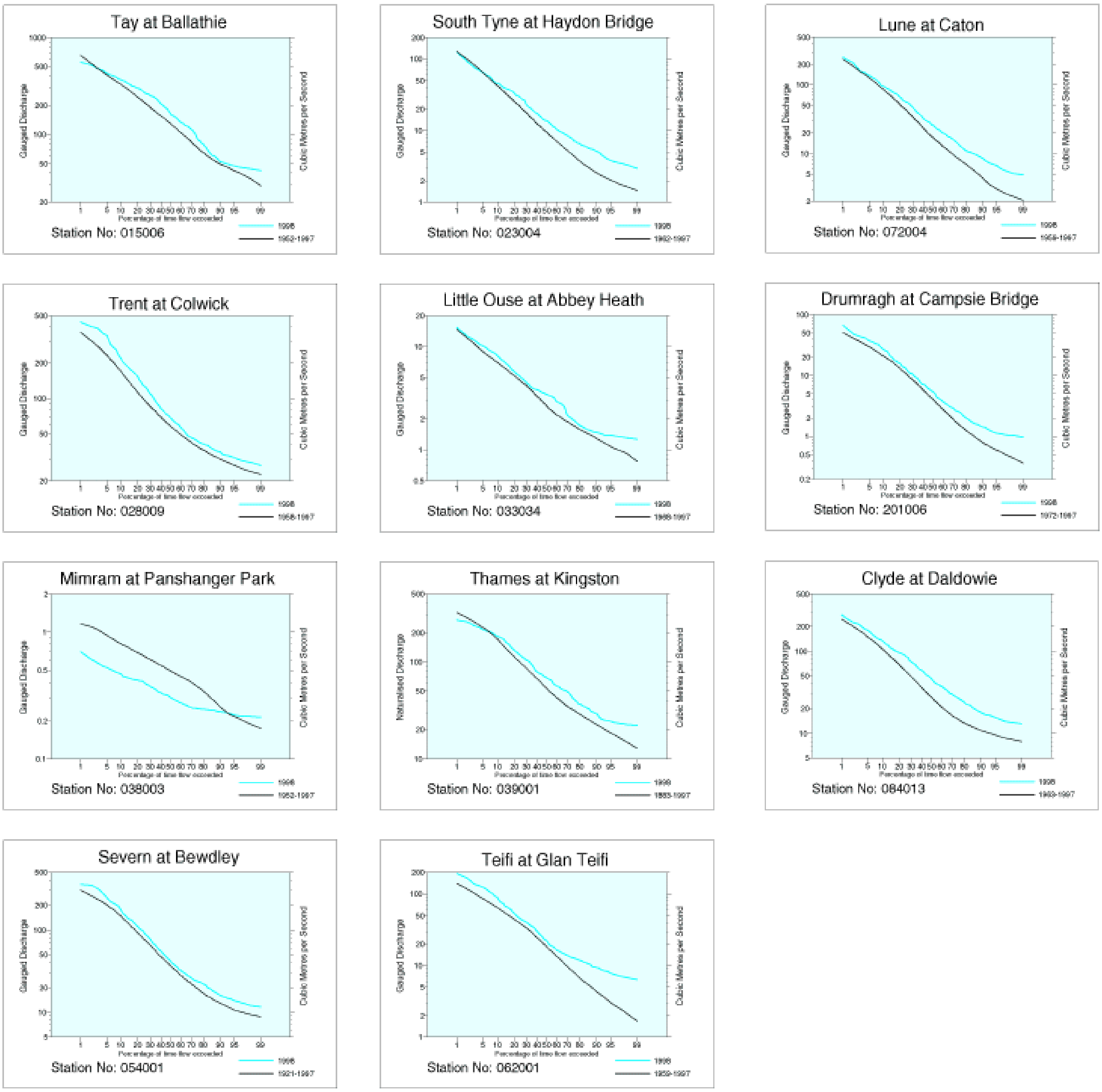


Figure 8 *Flow duration curves for 1998 (in blue) and the preceding record.*

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

Groundwater

Above average rainfall in most aquifer outcrop areas during November/December 1997 ensured that soil moisture deficits (SMDs) were eliminated in all but a few eastern districts by the beginning of 1998. The wet start to the year meant that groundwater levels were rising briskly during January in most major aquifers (see Figure 9). After over two years with levels greatly below the seasonal average, marked increases were recorded in many northern and western Permo-Triassic sandstones aquifer units. Particularly rapid rises occurred in the more responsive limestone aquifers (see map). The Chalk aquifer presented a more complex picture with exceptional rises, from a very low base, in the more westerly and northerly outcrops but levels remained depressed in the slower responding, and often deeper, wells in a zone centred on Hertfordshire and Cambridgeshire. Levels also remained low in a few eastern Permo-Triassic sandstones outcrops - notably so in parts of the Sherwood Sandstones where levels at the Morris Dancers borehole fell below any previously recorded (see Figure 9).

Infiltration was very modest in February 1998 but overall groundwater resources had improved greatly relative to a year previously. March recharge was within the normal range but the exceptional April rainfall produced infiltration totals estimated at 5-10 times the monthly average in some eastern Chalk outcrops. In such areas this late pulse of recharge generated a rise in groundwater levels at a time when the summer recessions have normally become established. Importantly, it provided impetus to the initially sluggish recovery of the water-table in the zone of maximum depression. High temperatures and low rainfall in May appeared to signal the end of the 1998/99 recharge season but the very wet June provided rare (in the east) summer infiltration - generally amounts were modest except where sustained rainfall occurred over thin soils (e.g. in parts of the North Downs).

Groundwater levels declined, following typical summer recessions, through July and August and, at the end of the summer, levels in most Limestone and Chalk index wells were close to the August average. Recoveries fell well short of this level in areas where the 1995-97 drought had most impact on groundwaters (e.g. in Hertfordshire and Cambridgeshire). At the Therfield well (near Royston), which had remained dry (for only the third time since 1922) since the early summer of 1997, levels had recovered to reach the base of the well by June 1998 but, by August, were still 10 metres below the mean for the month. Except in the South-West, late-summer levels in the Permo-Triassic sandstones were still below average but mostly well above corresponding levels in 1996 and 1997.

By late September significant infiltration had re-commenced in most western and northern areas whilst significant soil moisture deficits remained in the east. The area with minimal smds expanded rapidly in October providing the promise of a lengthy winter recharge season. Groundwater levels increased steeply in the more responsive fissured aquifers (e.g. the Carboniferous and Lincolnshire Limestones and parts of the Chalk) but the water-table response to the October infiltration pulse was delayed in many Permo-Triassic sandstones aquifer units, and in many deeper eastern Chalk wells - where the lag can be several months. Thus although typical recharge rates in November and December consolidated the improvement in overall groundwater resources, and levels in most index wells were above average at year-end, levels in some eastern aquifer units were still relatively depressed. Morris Dancers provides an extreme example - the borehole is in a forested area of the Sherwood Sandstones outcrop (which is used for public water supply) where in an average year evaporation losses leave only a modest surplus for recharge. Appreciable soil moisture deficits, even in winter, have greatly restricted the opportunity for recharge over the period since the winter of 1994/95 and substantial rainfall will be required in early 1999 to restore levels to within their normal range. Such local circumstances aside, groundwater resources at year-end were healthier than at a corresponding time in each of the preceding three years.

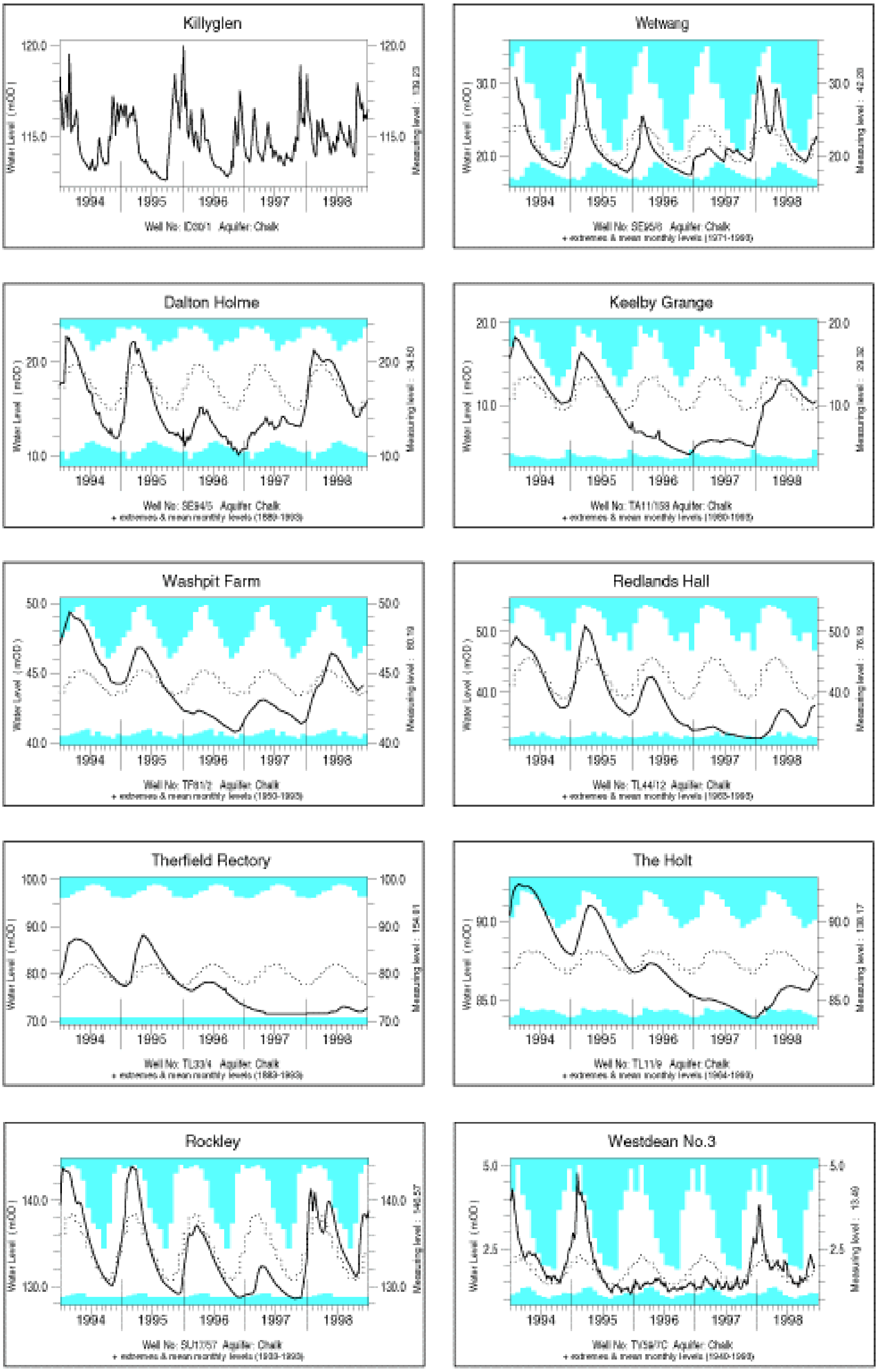
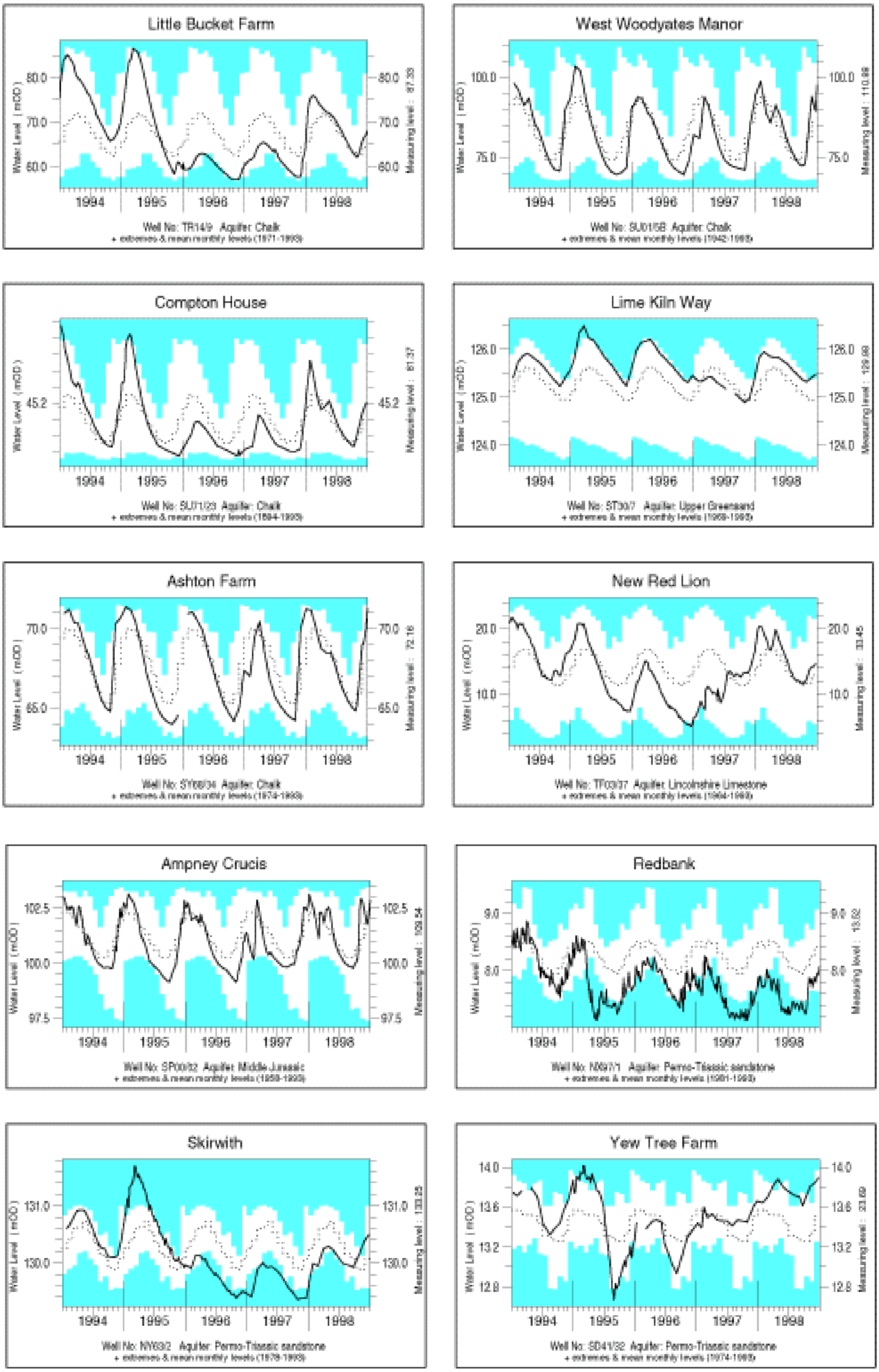


Figure 9 *Groundwater levels for selected observation sties 1994-98.*

Data sources: Environment Agency/Scottish Environment Protection Agency.



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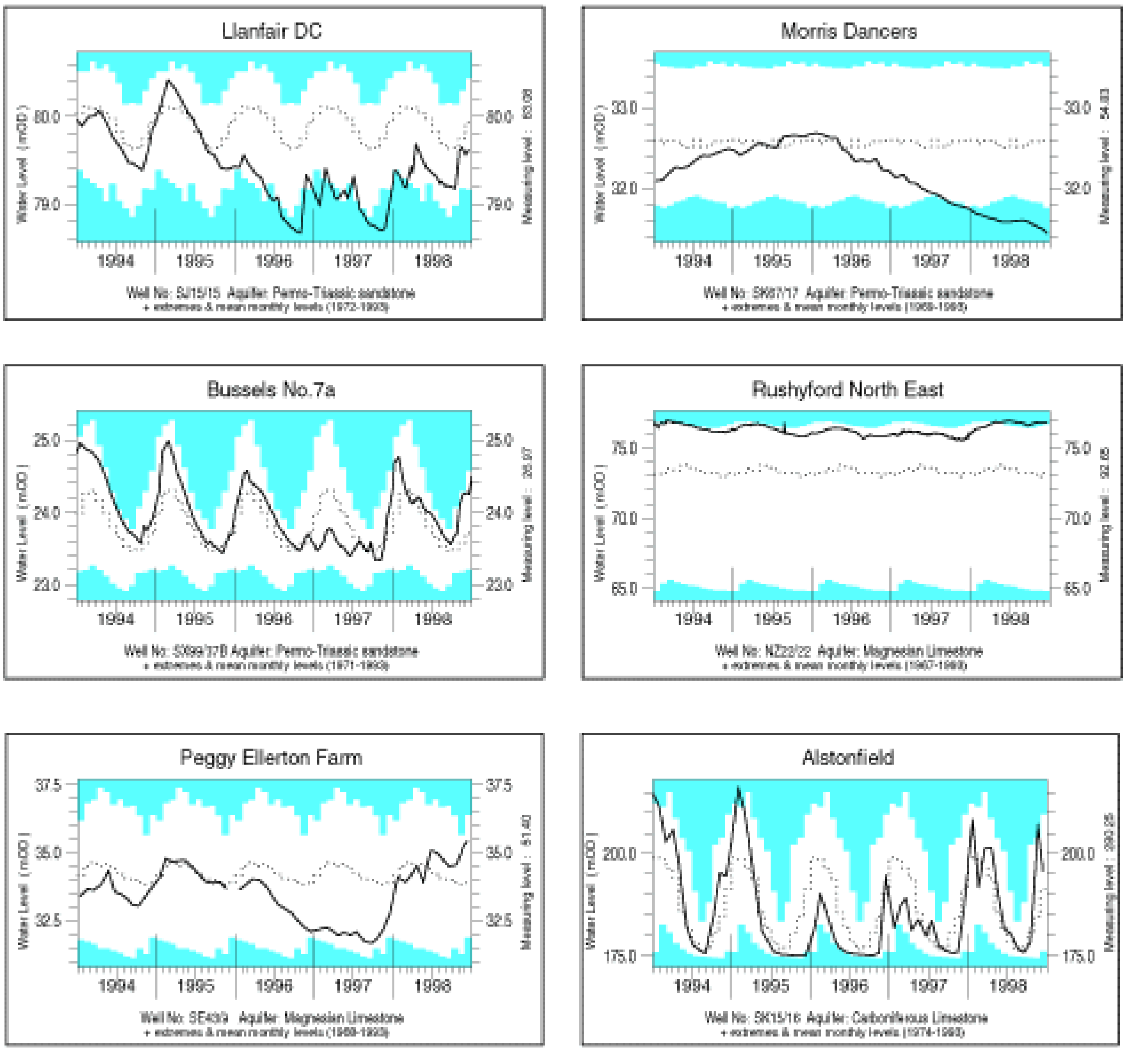

Figure 9 *(Contd.)*

Location Map

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