EA-THAMES BOX 11

GROUNDWATER FLOODING IN THE THAMES REGION WINTER 2000/01

ENVIRONMENT AGENCY

Thames Region, October 2001

GROUNDWATER FLOODING IN THE THAMES REGION
WINTER 2000/01

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Cover Picture: - Pumping out groundwater from the beer cellar, The Golden Ball Pub, Lower Assendon, Oxfordshire.

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Summary

The rainfall of winter 2000/01 and subsequent recharge into the Thames Region's aquifers exceeded all previously recorded quantities for a similar period in most areas. As a result, groundwater levels, particularly in the Chalk aquifer, rose to the highest recorded levels and by a considerable margin at many sites. Extensive groundwater flooding occurred, mainly in the upper, normally dry valleys on the dip slope of the Chalk escarpment. The return periods of the rainfall and recharge events were analysed. The groundwater level response was subject to so many variables that it could only be described as extremely unusual. This "event" acted as a natural experiment which accentuated aquifer response to a previously unobserved condition. The profile of groundwater level response on the Chalk aquifer provided an opportunity to analyse the subtle differences between in each hydrogeological province on the aquifer. This will improve the conceptual models needed for the Catchment Abstraction Management Strategies (CAMS) and groundwater modelling programme.

Because of the long response times in some areas, there is a risk of groundwater flooding in the winter of 2001/02 if there is average recharge. Various methods were used to estimate the areas which may be vulnerable in the coming Winter.

1. Introduction

The period September 2000 to May 2001 was one of the wettest in recent history. The autumn months (September to November) were particularly wet with the Thames Region as a whole receiving 205% of the long-term average for that period (CEH/BGS 2001, Figure 1). Many parts of the Thames catchment experienced several consecutive months with more than twice their monthly average rainfall and with some catchments in October having totals well in excess of three times their monthly average. This prolonged period of wet weather resulted in exceptional winter recharge into many aquifers. Incidences of groundwater flooding were reported in many groundwater catchments, particularly so in Thames Region.

Groundwater flooding (often described as 'clear water flooding') can be divided into two distinct types. The regular phenomenon of groundwater flooding, associated with river floodplains, occurs where groundwater emerges onto the floodplain from the river gravel deposits. When the gravel deposits become fully saturated, the floodplain will often flood before the river goes out of bank. This occurred in many floodplains in Thames Region during the winter of 2000/01. When rivers did subsequently flood over bank, the floodplain was already inundated by groundwater. The second type of groundwater flooding is groundwater emergence at the ground surface caused by very high groundwater levels in the major "hard" rock aquifers in the upper reaches of the tributary streams of the River Thames. This type of flooding is discussed in this report. In the winter of 2000/01 many valleys in which flow had not been observed for many decades experienced widespread and prolonged inundation.

Groundwater flooding was observed in at least 19 of the groundwater catchments of the Thames Region (Figure 2). The vast majority of these flood incidents were observed in the dip slope valleys of the Chalk escarpments (Figure 3). Groundwater flooding was observed in almost all of the unconfined Chalk catchments in the Region. Table 1 lists the Chalk catchments in which groundwater flooding was observed during winter 2000/01 in Thames Region. The unconfined Chalk catchments of the rivers Beane, Rib, Ash and Stort did not experience any substantial groundwater flooding in the upper valleys.

This report describes the rainfall event, which was the driver to the groundwater flooding and the differing responses of the Thames Region aquifers to the subsequent very high recharge. It provides some indication as to which groundwater catchments may be vulnerable to groundwater flooding during the forthcoming winter (2001/02). Groundwater catchments respond in differing ways to the same rainfall input as a result of their hydrogeological characteristics. Thus the catchments have been grouped into hydrogeological provinces here to enable generalisations to be made (Table 1).

Table 1. Catchments in which groundwater flooding occurred in 2000/01

Hydro-geological Province	Kennet Valley	South West Chilterns	Colne Valley Chilterns	North Hampshire	North Downs
Catchment	Upper Kennet	Assendon / Stonor Valley	Misbourne	Upper Loddon/ Whitewater	Wandle
	Og	Hambleden Stream	Chess	River Wey	Ravensbourne
	Aldbourne	Wye	Bulbourne		
	Lambourn		Gade		
	Pang		Ver		
			River Lee		
			Mimram		

Although the majority of incidents of groundwater flooding were restricted to the Chalk catchments of Thames Region, the Jurassic Oolitic limestone catchments of the Cotswolds, and the Lower Greensand catchments of North East Hampshire and Surrey, have been included for comparison. For each Chalk catchment the highest point at which surface flow due to groundwater emergence at ground level occurred is listed in Table 2.

Table 2. Highest point of groundwater emergence

Hydrogeological Province	Sub-catchment	Grid Reference
Kennet Valley	Upper Kennet	SU 118 787
	Og	SU 162 784
	Aldbourne	SU 257 787
	Lambourne	SU 305 820
	Shefford Valley	SU 399 797
	Winterbourne	SU 443 771
	Pang	SU 477 822
SW Chilterns	Ipsden	SU 635869
	Assendon Valley	SU 733 882
	Hambledon Valley	SU 762 914
	Wye	SU 785973
	Hughenden Valley	SU 864 967
Colne Valley Chilterns	Misbourne	SP 888 023
	Chess	SP 957 055
	Flaunden Bottom	TL 007 008
	Bulbourne	SP 954 110
	Gade	TL 003 147
	Nettleden Valley	TL 023 103
	Ver (Valleybottom)	TL 059146
	Ver (Markyate)	TL 050 183
	U. Colne (Sandridge)	TL 173 113
	U Lee	TL 060 249
	Mimram	TL 136 249
	Mimram (Kimpton)	TL 147 214
N Hampshire	Alton Wey	SU 697 397
	Wey, Lavant Strm	SU 707 338
	Lyde River	SU 668 502
	Greywell Fen	SU 703 487
	S Warnborough	SU 727 483
N Downs	Ravensbourne (Addington)	TQ 371 633
	Wandle (Whyteleaf)	TQ 358 573

For each catchment, a study was made of areal rainfall, areal percolation, river flow, and groundwater levels for the period of 1st September 2000 to 31st May 2001, where available. The restrictions on visiting rural areas imposed as a result of Foot and Mouth disease in the UK resulted in the loss of some routinely collected groundwater data and also prevented groundwater flooding being measured in some locations. Sufficient data, however, is available to fully characterise the groundwater event.

Statistical analyses of areal rainfall and areal percolation have been undertaken to give an indication of the return period of the event. Calculating return periods for groundwater levels is more problematic given the long 'memory' within the data. In effect, any single winter level is dependent on the previous summer's water levels which, in turn were dependent of the previous year. In many aquifers the dependence extends back several years. As a result of these problems, formal return periods have not been calculated but rather emphasis has been placed on identifying the response times of the Chalk aquifer in different catchments.

Thames Region's groundwater level forecasting model has also been employed to predict groundwater levels (based on current observed levels) for winter 2001/02 using 60%, 80%, 100% and 120% of average rainfall.

The methods, findings and conclusions, which include predictions of areas of likely inundation for winter 2001/02, are contained within this report.

2. Analysis of the Response Times of Thames Region Major Aquifers

2.1 Introduction

October 2000 was the wettest single month of the winter in most areas of the Thames Region with the exception of the North Downs where November was wetter. Subsequent months saw rainfall totals well in excess of the monthly long term averages, the effect of which was a continual topping up of the aquifers. Consequently, once initiated, groundwater flooding persisted for many months.

Many catchments showed several distinct peaks in both groundwater levels and in the subsequent base flows in the groundwater fed streams. The timing of both the groundwater level and river flow peaks was variable across the Thames Region. Some borehole levels peaked as early as December (For example Rockley observation borehole (OBH), SU17/57) whilst others did not peak until several months later. Water levels in those boreholes, representing the groundwater levels in the Lower Greensand, were still rising in July 2001. Figure 4 summarises the range of responses of peak river flow and peak groundwater levels for each hydrogeological province (a group of adjacent catchments with a similar groundwater response).

In each hydrogeological province a borehole and a river gauging station has been identified that typifies the province as a whole. These are listed in Table 3. Where there are several sub-catchments in a province additional river gauging stations and boreholes are shown.

Table 3. Monitoring stations used in describing river flow and groundwater level response to the winter 2000/01 rainfall event.

Hydrogeological Province	Surface Water Catchment	Gauging Station	Observation Borehole
Kennet Valley	Pang	Frilsham (2140)	Gibbet Cottages OBH (SU47/141)
	Upper Kennet	Marlborough (2210)	Avebury OBH No 2 (SU06/45)
	Kennet	Knighton (2230)	
	Lambourn	Shaw (2269)	
	Og		Rockley OBH (SU17/57)
SW Chilterns	Wye	Hedsor (2590)	
	Assendon/ Stonor Valley		Stonor Park (SU78/45A)
Colne Valley Chilterns	Gade	Croxley Green (2849)	Hollybush Farm (TL00/30)
	Upper Lee		Cole Green (TL21/87)
	Mimram	Fulling Mill (4770)	
Upper Lee Valley Tributaries (E of the Mimram)	Rib	Wadesmill (4980)	
	Stort	Stansted Mountfitchet (5106)	Berden Hall (TL42/8)
N Hampshire	Lavant Stream (Wey)	Alton (3010)	Lane End OBH (SU62/113)
N Downs	Wandle	Carshalton (4159)	Well House Inn (TQ25/13)
Cotswolds	Ampney Brook	Ampney St Peter (0470)	
	Coln		Coln St Aldwyn OBH (SP10/96)
Lower Greensand	Wey	Tilford (3040)	Frith Cottage (SU93/3)

The Figures listed in Table 4 show rainfall, percolation and river flow for the period 1st September 2000 – 31st May 2001. Groundwater levels for the monitoring stations listed in Table 3 are also included for a twelve month period starting 1st September 2000, and for the last 30 years (where available).

Table 4. List of hydrological figures for each hydrogeological province

Hydrogeological Province	Figures
Kennet Valley	7 to 13
SW Chilterns	24 and 25
NE Chilterns	32 and 33
Lee Valley	38 to 42
N Hampshire	49 and 50
N Downs	57 and 58
Cotswolds	63 and 64
Lower Greensand	67 and 68

2.2 Kennet and Pang Valleys

The locations of observed groundwater flooding and relevant monitoring sites within the Kennet and Pang valleys are shown in Figure 5. Figure 6 shows the solid and drift geology of the Kennet Valley.

River flows in response to the rainfall event peaked in the Kennet and Pang valleys between December 2000 and February 2001, as demonstrated by Kennet gauging station at Knighton (2230, Figure 7), the River Pang gauging station at Frilsham (2140, Figure 8), and the River Lambourn gauging station at Shaw (2269, Figure 9). Generally, in the large areas of open downland and arable land, groundwater level response times were as short as two to four weeks for levels to turn over from a falling trend to a rising trend in response to the start of winter recharge. Levels were then maintained throughout the rest of the winter by successive months of very high recharge. Groundwater levels peaked several times over a number of months, typically from December 2000 to March 2001. The response of groundwater levels at Gibbet Cottages (SU47/141, Figure 10) is typical of the Kennet catchment. Highest recorded groundwater levels in the last 30 years were observed in every sub-catchment.

Groundwater flooding caused numerous problems including inundation of farmland, houses and roads.

In the River Og catchment, large areas of farm land were inundated around Thames Water's Ogbourne groundwater source at SU191763 even though this was abstracting throughout the period. The Rockley observation borehole, SU17/57, is typical of the groundwater response in this area (Figure 11). Upstream of the village of Aldbourne the Water Acre valley flooded (Figures 14). In Aldourne village, groundwater surcharged sewers and storm drains and these overflowed in the streets (Figure 15). In the Lambourn valley, flooding of roads and property occurred in Upper Lambourn village. In Great Shefford, the Shefford Valley bourne flooded, closing the A338 road. (Figure 16). A new stream course was constructed by the Local Authority behind the flooded houses on the north side of the road (Figure 17) and routed to the main stream in the village. Emergence of groundwater started some 4km up valley at

SU 399 797 with much of it flowing down the main road and adjacent farm land. (Figure 18).

In the Upper Pang valley, flow started just below West Ilsley at SU 477 822, (Figures 19 and 20). The Agency's West Berkshire Groundwater Scheme abstraction borehole at Hodcott was completely inundated, (Figure 21). The floodwater bridged the power supply switching in the control building, causing the whole system to consume current, heating up the flood water in the building! More properties were flooded in East Ilsley and Hampstead Norreys. Here a new stream was dug behind Water Street, to re-route the river to avoid most of the village and alleviate flooding of properties. Many properties had to be continuously pumped out until May. In an attempt to alleviate the worst of the flooding, the Agency operated parts of the West Berkshire Groundwater Scheme boreholes in the upper Pang valley. Woodend and Compton boreholes were pumped for several weeks into the pipe lines, effectively routing some groundwater down the valley away from the flooding streams. This helped in the areas local to the sources, but on the whole most alleviation was achieved only by major ground works.

River baseflow and groundwater level responses in the upper Kennet valley above Marlborough were not typical of the rest of the Kennet Valley (Figure 12). Groundwater levels above Marlborough remained below those of the historical record and no groundwater flooding occurred. The borehole at Avebury (OBH No 2, SU06/45) typifies the observation boreholes of the Upper Kennet (Figure 13). Its level did not exceed previous wet winter levels suggesting that water can only infiltrate into the ground at a low rate, being limited by the low permeability of the Lower Chalk (discussed in section 3). A rainfall rate in excess of this infiltration rate results in additional surface runoff. The hydrograph of Marlborough gauging station (2210, Figure 12) clearly shows a response more typical of a low permeability catchment.

2.3 South West Chilterns

The locations of observed groundwater flooding, and relevant monitoring sites within the South West Chilterns are shown in Figure 22. Figure 23 shows the solid and drift geology of the South West Chilterns.

River baseflow responses in the South West Chilterns lagged behind those for the Kennet Valley generally peaking between February to April 2001. Groundwater levels reacted similarly, peaking between March and May 2001. During this period frequent visits were made to the Assendon Valley, Hambleden Valley and the Wye Valley. In the Hambledon and Wye Valleys, the point at which flow started moved up valley to a position well above those previously observed. In the Assendon Valley North West of Henley, flow started in early January 2001 at the Assendon spring (SU735 883) just below the village of Stonor. This is the known source of the ephemeral section and flows were not seen above this point although several properties, including the village pub, had flooded cellars. The stream flowed down the valley for about 1.5km before disappearing into the ground. During late January and February the river slowly extended down valley into Henley, causing flooding in scores of properties on the way (Figure 26). The under-street drainage and culverts in

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Steve

Please find enclosed 1 copy of our report on Groundwater Flooding last Winter. I've suggested to both BGS & CEH, a 1 day Seminar at which I would be prepared to make a contribution. But no feed back yet.

Vin

SJF

Henley were overwhelmed and restrictions caused groundwater level to build up in the Northfield End area, which flooded many basements and ground floor living spaces. These problems persisted until the end of June and effective alleviation was achieved only after major ground works (Figure 27) involving the rebuilding of culverts in Henley and laying of much larger diameter pipes through restrictions up to Middle Assendon. The Assendon spring and stream were still flowing as far down as Middle Assendon on September 1st 2001.
In the Hambledon Valley, flow started about 1km above Turville and flowed down the road through the village. Properties were flooded in Turville and Fingest. Bridge restrictions in the village of Hambledon caused the river to flood parts of the village for several weeks (Figure 28). Below Hambledon a new stream bed was dug on the west side of the valley to cope with the increased flow. The Marlow road was closed for several days to allow the construction of a much larger culvert to take the stream under the road to its normal confluence with the River Thames. Figure 29 shows groundwater breaking the ground surface in the upper River Wye valley.

The response to the rainfall is well typified by the gauging station record at Bourne End (Hedsor, 2590) and by the borehole record at Stonor Park (Figures 24 and 25) Record groundwater levels of (last 30 years) were recorded in the Assendon/Stonor, Hambleden Stream and the Wye catchmenst.

2.4 Colne Valley Chilterns, Upper Lee Valley and River Mimram

The locations of observed groundwater flooding and relevant monitoring sites within the Colne Valley Chilterns are shown in Figure 30. Figure 31 shows the solid and drift geology of the Colne valley Chilterns.

River baseflow responses in the Colne ValleyChilterns were similar to those in the SW Chilterns, ie they had very long response times, peaking from February to April 2001. Groundwater levels, however, peaked slightly sooner from February to March 2001. Figures 32 and 33 show typical river flow and groundwater level responses as recorded at Croxley Green gauging station (2849) and Hollybush Farm observation borehole (TL00/30). The highest ever groundwater levels in the thirty year record were observed at Hollybush Farm, which is typical of the Colne Valley Chilterns as a whole. In contrast to the Kennet Valley, most of the Colne Valley Chilterns Chalk outcrop area is covered with Clay with Flints drift deposits. The river system is one of typical Chalk open downland pattern, having dry valleys progressing down to ephemeral winterbournes. Therefore the Clay with Flints cover here does not generate a surface runoff pattern of small streams and so the drift appears to have sufficient permeability to effectively transmit recharge into the unsaturated Chalk beneath. Over much of the high Chilterns depth to mean groundwater level is very large, often over 100m. This, coupled with the Clay with Flints drift delaying but not preventing recharge, is responsible for the very long response times seen in groundwater levels. Figure 34 shows groundwater flooding in the upper Chess valley.

River hydrographs in the Clay with Flints covered sub-catchments of the Upper Lee Valley (Upper Lee to Luton and the Mimram) have similar groundwater fed profiles and response as those in the Colne Valley, as shown by Fulling Mill gauging station (4770, Figure 38). Groundwater levels also have a similar response to those in the Colne Valley (see Figure 39, Cole Green TL21/87). Figures 35, 43, 44 and 45 show examples of groundwater flooding in the upper valleys above Kimpton, and of the River Mimram above Whitwell.

2.5 Upper Lee Valley tributaries (East of River Mimram)

The locations of observed groundwater flooding and relevant monitoring sites within the Upper Lee Valley are shown in Figure 36. Figure 37 shows the solid and drift geology of the Upper Lee Valley.

River baseflows in the Upper Lee Valley tributaries (East of the River Mimram) peaked between February and April 2001. The river flow hydrograph as recorded at Wadesmill (4980) on the River Rib (Figure 40) is typical of river flow responses in the Lee Valley tributaries NE of the River Mimram. River flow here is flashy indicating a largely surface water fed rivers. A large part of the area is covered with glacial drift deposits, mainly Boulder Clay. The complex dendritic drainage pattern, shown in Figure 37, indicates that the area is essentially drained by surface runoff. This is clearly confirmed by the low base flow response of the rivers Beane, Rib, Ash and Stort. Recharge through the Boulder Clay is limited to a very low percolation rate, thus the underlying Chalk aquifer does not receive input above a certain rate regardless of the amount of rainfall. Figure 40 shows the response of the River Rib at Wadesmill which typifies the rivers in this area. The groundwater hydrographs typically have very long response times. The slow recharge into the Chalk persisted for so long that at Berden Hall observation borehole, TL42/8, Figure 41, groundwater levels reached the highest ever recorded. Groundwater flooding did not occur as extensively as it did in the Chilterns to the south west. However some instances were recorded. Figure 45 shows observation borehole TL32/7 in the unconfined Chalk in the Rib valley at Braughing overflowing due to high groundwater head. Figure 46 shows flooding in the R. Ash valley. River flow in the upper reaches of the Stort (Figure 42) as recorded at Stansted Mountfitchet (5106) is less flashy and would suggest a river fed by a greater proportion of Chalk groundwater in its upper catchment.

2.6 North Hampshire

The locations of observed groundwater flooding and relevant monitoring sites within the North Hampshire Chalk are shown in Figure 47. Figure 48 shows the solid and drift geology of North Hampshire.

Typical river flow and groundwater level responses in the North Hampshire province are shown in Figures 49 and 50. There are three river flow peaks as shown by Alton gauging station (3010) in December, February and April. Correspondingly groundwater levels remained high during this period, eg. Lane End OBH (SU62/113); December 2000/January 2001 and April/May 2001 (Figure 50). Record peak groundwater levels were recorded during winter 2000/01 in both the upper Loddon and Whitewater catchments and sub-catchments of the River Wey at Alton and Lavant Stream arm of the River Wey.

Groundwater flooding occurred on the Lavant Stream tributary of the River Wey south of Alton at Lower Farringdon. Here, the bourne stream started to flow from about 1km south of the village in an area previously lowered by flint and chalk excavation in the 19th Century for construction of the Alton to Fareham railway. This local depression became a lake estimated to be 6 Ha. in size (Figure 51). This eventually overflowed into the centre of Farringdon about 10 days before Christmas. Consequently the A32 road was closed and some adjacent properties flooded. A new housing development of fourteen houses on the low-lying Chase Field was also flooded (Figure 52) to a depth of over 1m. The flooding persisted until the end of April (Figure 53) and the A32 road was controlled by temporary traffic lights for nearly four months because of the river flowing down the road. The Chase Field properties have now been permanently abandoned. Pictures from the Village Millenium book, (Figure 54) published in 2000 show pictures of the Chase Field and the main A32 road flooded on several occasions during the 20th Century. Groundwater flooding at this location is therefore not unprecedented although the 2000/2001 event went on for much longer than earlier floods. The decision of the Planning Authority to allow the development on Chase Field has to be questioned in the light of the known history of flooding on the site. The Environment Agency Area Water Resources teams need to record these local groundwater events in order to effectively comment on future development proposals.

2.7 North Downs

The locations of observed groundwater flooding and relevant monitoring sites within the North Downs are shown in Figure 55. Figure 56 shows the solid and drift geology of the North Downs.

Similar river flow and groundwater level responses to those in North Hampshire were seen in the North Downs. The Wandle river flow hydrograph (Figure 57), as recorded at Carshalton (4159), shows peaks in December, February, and a lesser one in April. Groundwater levels typically peaked in December 2000 and then again in February/March 2001 as shown at Well House Inn (TQ25/13) in Figure 58. Groundwater levels responded more quickly to the rainfall event in the N Downs than they did in N Hampshire.

Record peak groundwater levels were recorded over the period September 2000 to May 2001 at Well House Inn (TQ25/13), which is typical of groundwater levels in the North Downs as a whole. Major urban flooding events were observed in the Whyteleaf area of the Warlingham/Caterham Valley, (Figure 59) Groundwater flooding also occurred on the Chalk dip slope "dry" valleys upstream of the River Ravensbourne at Addington and West Wickham (Figure 60). Thames Water Utilities Ltd. were asked to maintain a higher than needed pumping rate at their groundwater pumping station at Addington to help lower levels. This excess pumping was maintained through to late summer.

2.8 Cotswolds

Relevant monitoring sites within the Cotswolds are shown in Figure 61. Figure 62 shows the solid and drift geology of the Cotswolds. The main aquifers are the Great and Inferior Oolite limestones.

Although extremely high flows were recorded in the Cotswolds rivers, no incidents, which could be strictly defined as groundwater flooding, were reported. Both river flow and groundwater level response times in the oolitic limestones are very rapid (Figures 63 and 64). Very high peaks in river flow, up to 4.6 cumecs (m^3/sec) in the Ampney Brook recorded at Ampney St Peter (0470), occurred in November and December 2000. Within a few days record groundwater level peaks were recorded at Coln St Aldwyn OBH (SP10/96). This rapid response is typical of the oolitic limestone aquifers. Groundwater levels did not exceed previous levels by very much and were maintained for only a matter of days. The limestone aquifer here is very "flashy" and has the ability to rapidly transmit very large volumes of water through the high density of fissures to the streams. Consequently there were very few incidences of groundwater flooding in the locality.

2.9 Lower Greensand aquifers of North East Hampshire and Surrey

Relevant monitoring sites within the Lower Greensand Aquifers of North East Hampshire and Surrey are shown in Figure 65. Figure 66 shows the solid and drift geology of North East Hampshire and Surrey.

The aquifers lie almost exclusively in the main sub-catchments of the River Wey and part of the River Mole. No groundwater flooding was observed in these areas due to the high aquifer storage, and low permeability. Incidents of problems due to high groundwater levels were however recorded. Frith Cottage OBH (SU93/3, Figure 68) is typical Lower Greensand (LGS) groundwater level response where levels still had not peaked by July 2001. River flows as represented by Tilford gauging station (Figure 67) on the River Wey indicate that the LGS catchments behave more like surface water dominated catchments. The explanation is that groundwater flows to the river at a very steady rate because of the low permeability and high storage of the sandstone. Runoff is added to this steady hydrograph giving the spikey appearance.

3. Summary of the hydrogeological interpretation of the event

3.1 Kennet and Pang Valleys

Upper catchment areas of the Og, Aldbourne and Lambourne are largely grass covered or arable open downland and generally free of drift cover. This generates largely unimpeded recharge, resulting in groundwater level and streams flow responses of two to four weeks. The upper Kennet Valley upstream of Avebury responds more like a surface water catchment due to the low permeability of the underlying Lower Chalk.

3.2 South West Chilterns, Colne Valley Chilterns, Upper Lee Valley and River Mimram.

This large area of upland Chalk aquifer is extensively covered with Clay with Flint drift. Large areas are heavily wooded and mixed with downland on the escarpment. There are also large arable and urban areas. Groundwater level and stream response times are long; up to five months to reach peak levels and flows. The Clay with Flints acts as a low permeability aquitard but does not generate any runoff. Extensive groundwater flooding occurred in the upper winterbourne sections and normally dry valley tributaries.

3.3 Upper Lee Valley tributaries (east of River Mimram)

This area has the characteristic response of a low permeability, Glacial Boulder Clay drift covered catchment, giving rise to a high density, dendritic stream pattern. Most stream responses were rapid due to runoff from the clay. Very slow percolation through the Boulder Clay and more rapid recharge through small areas of exposed Chalk outcrop resulted in a varied but generally slow response to recharge in the Chalk aquifer resulting in few recorded incidences of groundwater flooding.

3.4 North Hampshire and the North Downs

These areas of Chalk aquifer have similar response times to the Kennet Valley Chalk, ie two to four weeks. Much of the North Downs east of Sutton is urbanised, and the rest has a very mixed vegetation cover. Patches of Clay with Flints exist over parts of the areas but not with sufficient density to produce the long response times of the Chilterns. The groundwater response was characteristic of unimpeded recharge to a Chalk escarpment aquifer.

3.5 Cotswolds Jurassic Great and Inferior Oolitic limestone aquifers

Very rapid response to recharge and rapid dissipation of groundwater head due to extremely high, semi-karstic fissure permeability. No groundwater flooding recorded.

3.6 Lower Greensand aquifers of North East Hampshire and Surrey

No indication of any groundwater flooding was reported from these areas. This is due entirely to the high storage, low permeability ratio of these aquifers resulting in very long response times. This gives the aquifers the ability to absorb huge quantities of recharge whilst releasing groundwater to streams at a slow rate.

4. Return period of the event

Statistical analyses of the winter 2000/01 rainfall event has been carried out in order to estimate return periods for areal rainfall, areal percolation and groundwater level response.

4.1 Areal rainfall

During the winter, a number of individual rain gauges recorded one day, two day and eight day totals which had estimated return periods of up to 32 years (Report on a rainfall event in Farringdon area (Hants.) October/November 2000. Met Office). The return period for the two month totals was calculated to be in excess of 200 years. These statistics are much less meaningful than those for the catchment as a whole when interpreting groundwater flooding events. Areal rainfall is estimated from a network of raingauges chosen because, when combined, they are much more representative of the whole catchment. The Agency holds a dataset of areal rainfall for all aquifer hydrological units within the Thames Region from 1920 at a daily time step. Sequences of 4, 6, 8 and 9 months starting in September 2000 generally show that this period is unprecidented in terms of rainfall totals. Return period analysis on the time series of cumulative months with fixed start dates suggests that the 2000/01 rainfall event has a return period in excess of 75 years for the Cotswolds and in excess of 100 years for all other aquifer units described here for the 9 month period starting in September. The areal rainfall datasets have a high number of extreme events in recent years which tends to reduce the estimated frequency of the 2000/01 event. Return periods calculated on the Thames Region as a whole using a much longer time series and using Tabony tables indicate that the return periods are substantially longer than those estimated here (CEH/BGS).

4.2 Areal percolation

The CEH estimates for the return period of areal recharge for catchments over southern England are in excess of 1 in 200 years (Marsh T. J. and Dale M. (2001 DRAFT) The UK Floods of 2000/01 – A Hydrometeorological Appraisal. CEH/Met Office). A more detailed analysis of catchments in Thames Region gives return periods of generally less than 1 in 200. Areal percolation is calculated for all aquifer units in Thames Region using the Soil Moisture Model (Wilby R, Greenfield B., Glenny C. (1994) A coupled synoptic hydrological model for climate change impact assessment, Journal Hydrology, 153 (1994) pp265-290). It is generally interpreted as the amount of water available, in the case of an aquifer unit, to infiltrate into the groundwater. Percolation time series have the similar problem of non-independent peaks as groundwater levels because although in most years the soil moisture deficits are eliminated, they have not normally done so by the month of September. It is therefore evident that the data consists of a degree of non-independence which is contrary to the assumptions of the return period calculation. The return periods estimated here are for a general impression only.

Recharge rates in 2000/01 were calculated to have return periods between 50 and 100 years for the 4, 6, 8 and 9 month periods starting in September with the exception of the Cotswolds where they were less than 50 years. Some estimates for the 9 month period were much greater than 100 years most notably for the Wey, North Downs and Lee Chalk.

4.3 Groundwater levels

The Stonor Park observation borehole (SU78/45A, Figure 23) weekly record was used to analyse groundwater level response to the winter 2000/01 rainfall event. Stonor was chosen for its length of record, quality of data and because of the exceptional levels attained in 2000/01. During the winter of 2000/01 groundwater levels reached their highest level ever recorded since 1961, 92.14 mAOD on 22nd April 2001. This is approximately 5m above the previously recorded peak level of 1968.

4.4 Groundwater level rise

The first evidence of recharge was seen in the borehole water levels at Stonor in late October 2000. Levels continued to rise almost without interruption until they peaked in April 2001. Recharge raised the groundwater level by 16.49m over the 2000/01 recharge season.

Given the high totals and long duration of the winter rainfall it would be fair to assume that Stonor would also have experienced record recharge. However, the absolute rise in groundwater level experienced last winter, however, was only the fourth highest on record and was well below the record year of 1992 when water levels rose by 18.95m during the recharge season. Previously recorded episodes of high recharge volumes have not led to flooding as, without exception, they have all occurred when groundwater levels have been below average summer minima. What was unusual about the 2000/01 event was that recharge started when groundwater levels were above the average for that time of year. The minimum level of summer 2000 (at 75.64m) was the seventh highest summer minimum on record.

Although record peak groundwater levels were reached, the total rise was moderated by the non-linear distribution of aquifer storativity and permeability with depth. At very high groundwater levels, the aquifer has an increased ability to both store and transmit water through the fissures in the normally unsaturated zone. The fissures become more open towards ground level as over burden pressure decreases. Thus at very high groundwater levels, it becomes increasingly difficult for a unit of recharge to achieve a linear rise in groundwater level response. This vertical non-linearity is a fundamental characteristic of chalk aquifers in the south of England (Robinson 1974) and its profile varies with both topography and location within a catchment. This is the most difficult feature to simulate when attempting to construct computer models of Chalk aquifer systems and is extensively discussed in the Major Aquifers Properties Manual. (EA/BGS 1997) Fortunately, in the past, the six highest summer minima measured at Stonor were all followed by below average recharge. Water levels rose by only 6 to 8 metres compared to an average of 9m in the total record 1961-1999 and by 16.5m in 2000/01.

It can be seen that the groundwater flooding event of winter 2000/01 in the Stonor valley is not just a result of the exceptional rainfall and recharge. The effects of the winter 2000/01 rainfall are compounded by the coincidence of the high summer minimum level caused by the cumulative effect of rainfall in the previous years. This is a consequence of the long response time of this sub-catchment (see section 3.3). The fact that groundwater levels are still high in many areas of Chalk and Lower Greensand aquifers of Thames Region highlights a risk of groundwater flooding in the winter of 2001/02 if average rainfall is experienced. The extent of this risk is discussed in Chapter 5.

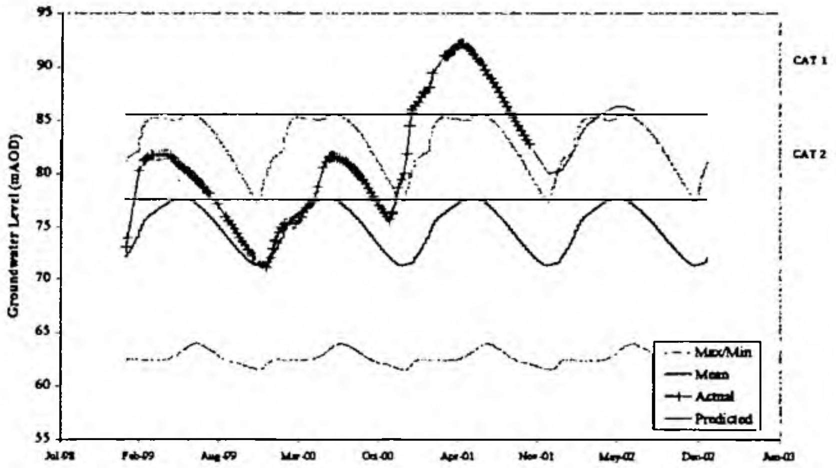
5. Catchments with potential to experience groundwater flooding in winter 2001/02

Two techniques have been used to estimate the likely groundwater levels for the winter of 2001/2. The first is based on a simple categorisation of the current groundwater levels and superimposition of average groundwater level rises. The Thames Region Groundwater Level Forecasting Model is used as the second method and provides predicted groundwater levels arising from scenario rainfall events.

5.1 Groundwater level categorisation

Predictions have been made by comparing current groundwater conditions with maximum, mean and minimum conditions (calculated using data from 01/01/75 to 31/12/99, where available). Based on this information current falling groundwater levels have been extrapolated to a 'turn-over point' where groundwater levels are estimated to start rising again. The turn-over point is based on the long term average for the data time series for an average year. The curve of mean response is added to the turn-over point to estimate likely groundwater levels for this coming winter. Figure 69 shows an example of this method for Stonor Park (SU78/45A).

Figure 69. Stonor Park (SU78/45A) Groundwater Level Categorisation



These predictive groundwater levels have subsequently been used to categorise catchments within Thames Region. There are three categories defining the vulnerability to groundwater flooding this winter (see Table 5).

Table 5. Groundwater level categorisation definitions

Category	Description	Risk of Groundwater Flooding winter (2001/02)
1	Groundwater levels above maximum winter level	High
2	Groundwater levels above average winter level	Medium
3	Groundwater levels close to average winter level	Low

Predicted groundwater levels during winter 2001/02 have led to the categorisation shown in Table 6 of catchments in Thames Region. From this analysis the areas of greatest concern with respect to groundwater flooding this winter are the South West and Colne Valley Chilterns, in particular the Assendon/Stonor valley, the Hambleden valley and the Gade catchment (see Appendix 2).

The principle limiting factor in making predictions in this way is the timing, and thus level of, the turn-over point. In order to provide as accurate a picture as possible Area Water Resources staff are keeping relevant plots (such as in Figure 69) up to date using real time data to identify the turn-over point as it happens. To facilitate this telemetry is being installed at key boreholes across the Region. In addition trigger levels, above which groundwater flooding occurred during winter 2000/01, are being calculated for key boreholes. The use of real time data can give advanced warning before groundwater levels approach trigger levels in the winter of 2001/02.

Table 6. Predicted groundwater level categorisation (winter 2001/02) for catchments in Thames Region

Hydrogeological Province	Surface Water Catchment	Observation Borehole	Category
Kennet Valley	Pang	Gibbet Cottages OBH (SU47/141)	2
	Upper Kennet	Avebury OBH No 2 (SU06/45)	2 or 3
	Aldbourne	Eastridge Farm (SU27/70)	2 or 3
	Lambourn	Bradley Wood OBH (SU47/26)	2
	Og	Rockley OBH (SU17/57)	2 or 3
SW Chilterns	Wye	Piddington (SU89/7)	2
	Assendon/Stonor Valley	Stonor Park (SU78/45A)	1
	Hambleden Stream	Bagmoor Farm (SU78/47)	2
Colne Valley Chilterns	Gade	Hollybush Farm (TL00/30)	2
	Misbourne	Village Well Lee Common (SP90/27)	2
	Chess	Wayside (SP90/56)	2
	Bulbourne	Village Well Aldbury (SP91/15)	2
	Ver	Highfield Farm (TL01/166)	2
	Upper Lee	Cole Green (TL21/87)	3
	Mimram	The Holt (TL11/9)	2
Upper Lee Valley Tributaries	Beane	Well House Bramfield (TL31/9)	2 or 3
	Ash	Church End (TL42/4)	2
	Rib	St Edmunds College (TL32/6)	2
	Stort	Berden Hall (TL42/8)	2
N Hampshire	Whitewater	Tile Barn Farm (SU74/40)	2
	Lavant Stream	Farringdon Chalk OBH (SU63/124B)	2
N Downs	Wandle	Well House Inn (TQ25/13)	2
	Ravensbourne	Addington Lodge (TQ36/35)	2
Cotswolds	Coln	Coln St Aldwyn OBH (SP10/96)	2 or 3
Lower Greensand	Wey	Frith Cottage (SU93/3)	2

5.2 Thames Region groundwater level forecasting model

A second predictive method employed was the Thames Region groundwater level forecasting model. This model generates groundwater level forecasts using a version of the rainfall-runoff model Catchmod. The model is normally used to generate river flows from rainfall. However, one of the quantities calculated within the model run is the volume of water in storage within the aquifer. This version of the model uses a relationship between volume in storage and groundwater level to generate hydrographs of groundwater level. Forecast levels are calculated by using various percentages of average monthly rainfall to estimate likely resulting groundwater levels. The forecasts should be regarded as only general indications of likely levels as actual levels will vary depending on the distribution of rainfall in time and space.

Groundwater levels have been simulated using 60, 80, 100, and 120% of average rainfall, for sites listed in Table 7 below (Figures 70 to 74).

Table 7. List of observation boreholes used with the Thames Region groundwater level forecasting model

Hydrogeological Province	Surface Water Catchment	Observation Borehole
Kennet Valley	Pang	Gibbet Cottages OBH (SU47/141)
	Og	Rockley OBH (SU17/57)
SW Chilterns	Assendon/Stonor Valley	Stonor Park (SU78/45A)
Colne Valley Chilterns	Mimram	The Holt (TL11/9)
N Downs	Wandle	Well House Inn (TQ25/13)

Taking average rainfall, the predictive levels are similar to those obtained by the 'Groundwater Level Categorisation' method as described earlier. Again the area of greatest concern with respect to groundwater flooding in winter 2001/02 is the Chilterns, as shown by the Stonor Park observation borehole (SU78/45A).

The forecasts reveal that no incidences of groundwater flooding would be expected if Thames Region receives only 60% of average rainfall during winter 2001/02. However if the Region receives 120% of average rainfall, groundwater flooding could occur in the Kennet Valley, Chilterns, and Lee Valley. If the Region receives 100% of average rainfall, only the Chilterns look likely to experience groundwater flooding during winter 2001/02.

6. Conclusions

- In the Thames Region, the rainfall event over the 9 months starting September 2000 and subsequent groundwater level response was unprecidented in a 100 year record. Actual return periods for the groundwater response have not been calculated because of the complexity of the contributing factors.
- The groundwater flooding response was largely in the upper and middle sections of the dip slope valleys of the main Chalk escarpments where there is no Glacial Boulder Clay cover.
- Groundwater flooding occurred in the upper reaches of valleys which had not seen stream flow in living memory and in ephemeral sections where the flows were so large that existing channel size, pipes and culverts were inadequate eg in Henley.
- Groundwater flooding did not start until many weeks after the rainfall event. It then persisted for many weeks after as recharge slowly raised groundwater levels.
- The flooding of property near to or by direct inundation from ephemeral groundwater fed streams assumed serious proportions in Thames Region.
- The Region's Area Water Resources Teams need to ensure that the risk of groundwater flooding, based on the knowledge gained from the 2000/01 event, is applied to the statutory planning consultation process for all applications in the areas identified by this report as liable to groundwater flooding.

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Wilby R., Greenfield B., Glenny C. (1994) A coupled synoptic hydrological model for climate change impact assessment. Journal Hydrology, 153 (1994) pp265-290.

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The physical properties of major aquifers in England and Wales. British Geological Survey and Environment Agency. (1997) Joint R&D project. Published by BGS, Keyworth.

Rainfall . . . Rainfall . . . Rainfall

Key

00% Percentage of 1961-90 average

Very wet

Substantially above average

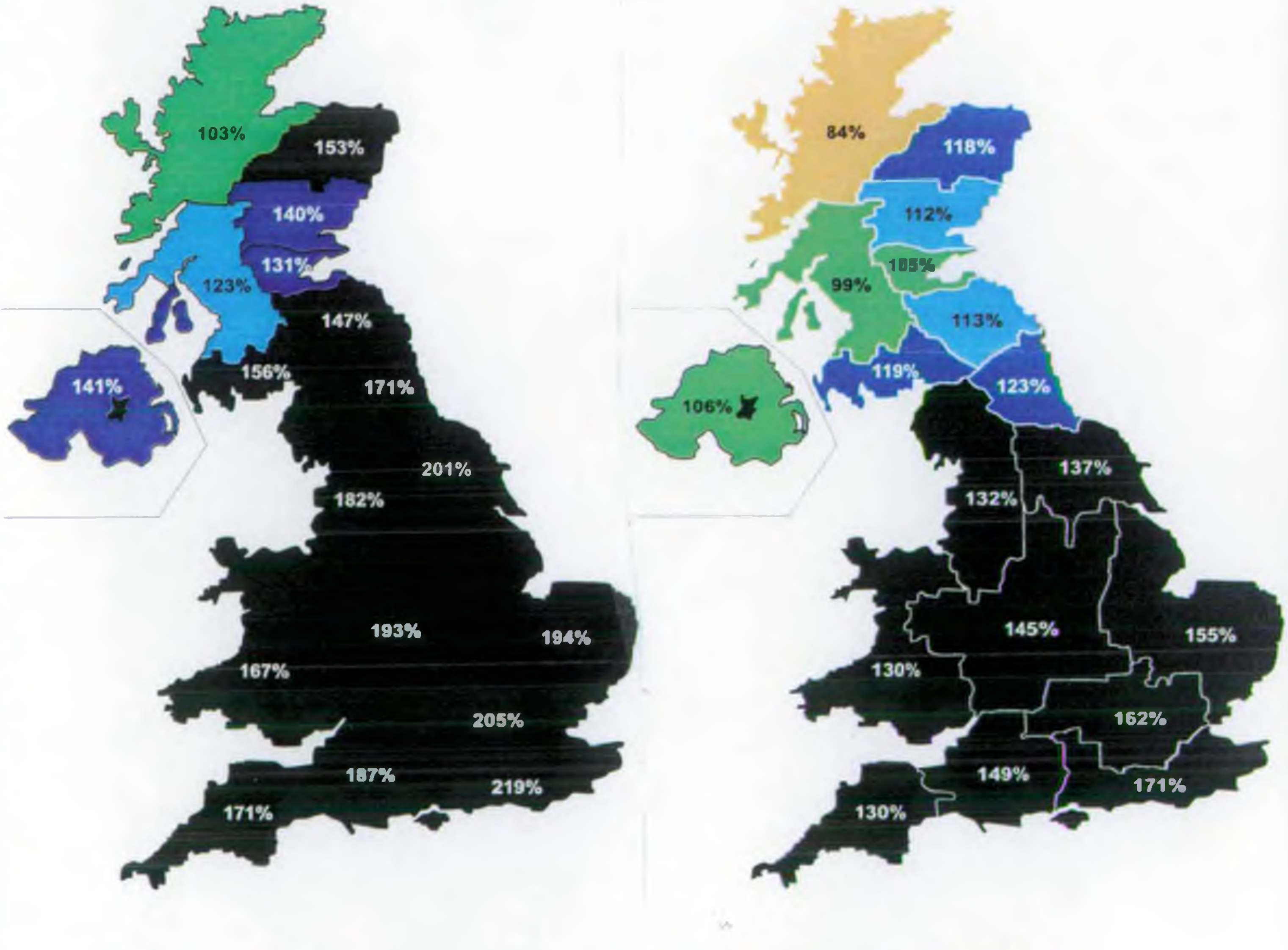
Above average

Normal range

Below average

Substantially below average

Exceptionally low rainfall



September 2000 - November 2000 **September 2000 - May 2001**

Figure 1. Rainfall intensity during winter 2000/01

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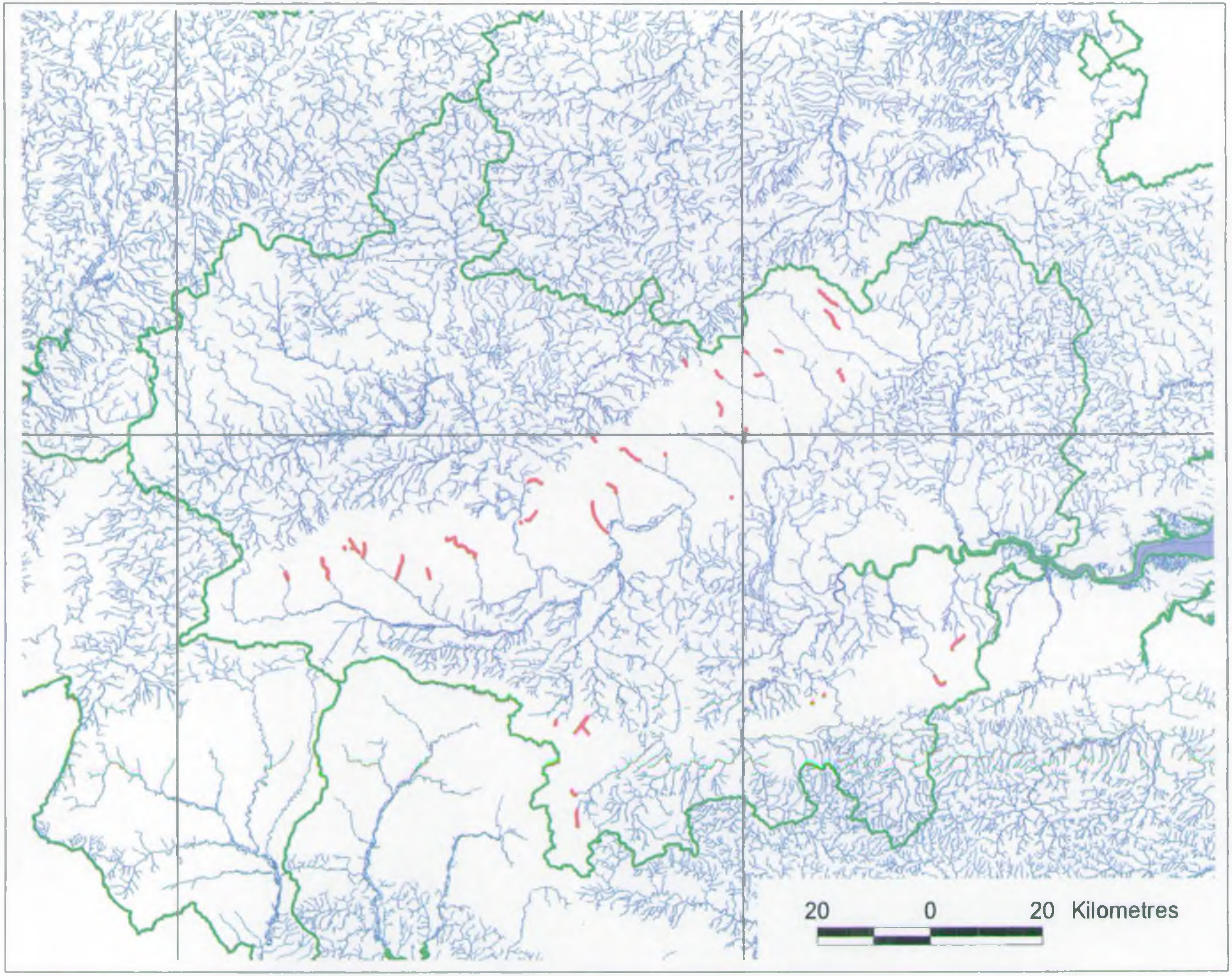


Areas of Groundwater Flooding — Rivers

Figure 2. Groundwater Flooding Observed in Thames Region Winter 2000/01

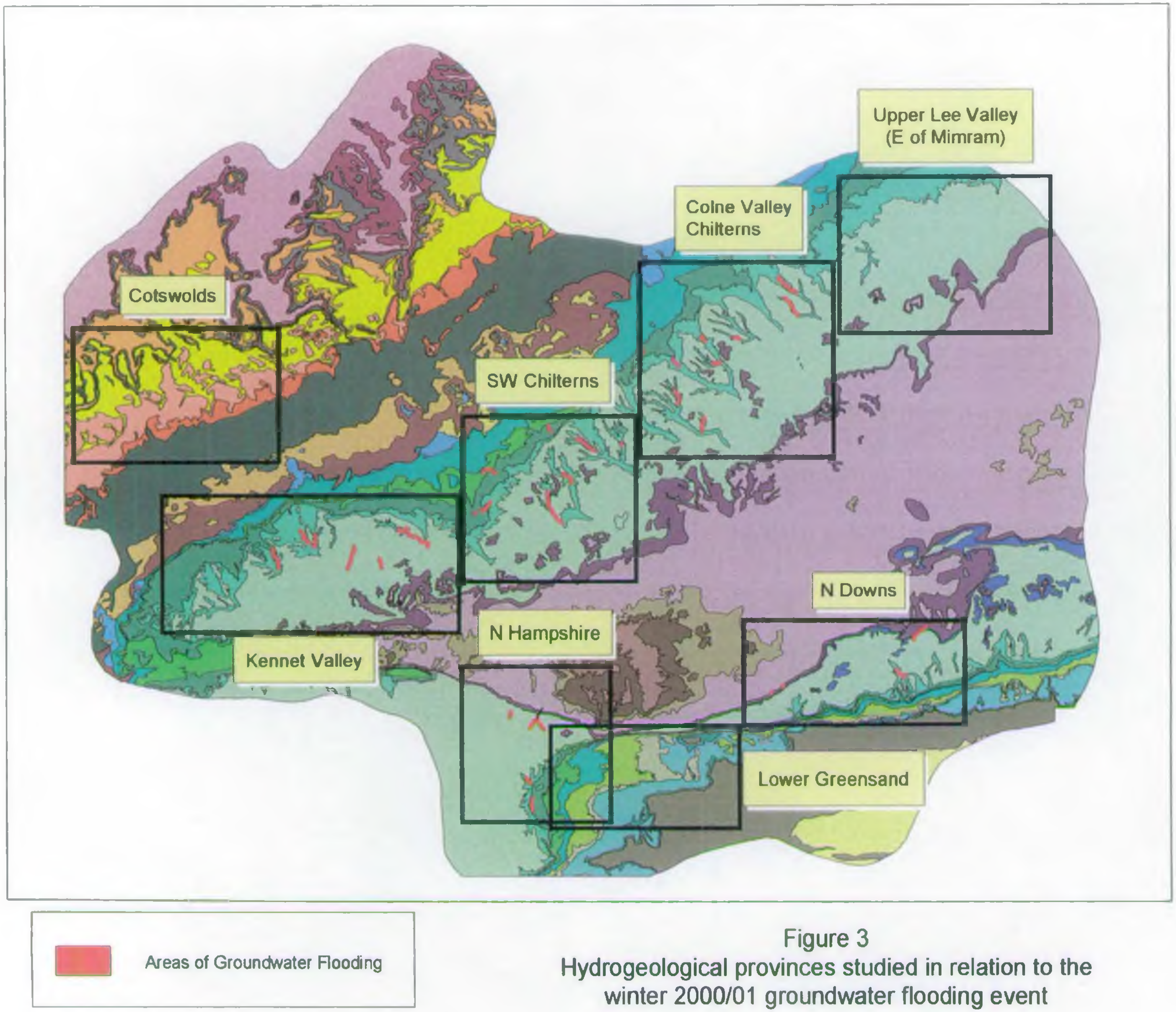


Figure 3
Hydrogeological provinces studied in relation to the winter 2000/01 groundwater flooding event

Figure 4
Peak River Flows and Groundwater Levels in Response to the October/November 2000 Rainfall Event

Hydrogeological Province	Peaks	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01
Kennet Valley	River Flow										
	Groundwater Levels										
SW Chilterns	River Flow										
	Groundwater Levels										
Colne Valley Chilterns	River Flow										
	Groundwater Levels										
Lee Valley (E of Mimram	River Flow										
	Groundwater Levels										
N Hants.	River Flow										
	Groundwater Levels										
N Downs	River Flow										
	Groundwater Levels										
Cotswolds	River Flow										
	Groundwater Levels										
Lower Greensand	River Flow										
	Groundwater Levels										*

Peak Rainfall

* GWL's still not peaked in certain bore

Figure 5. Location of observed Groundwater Flooding and Monitoring Sites, Kennet Valley

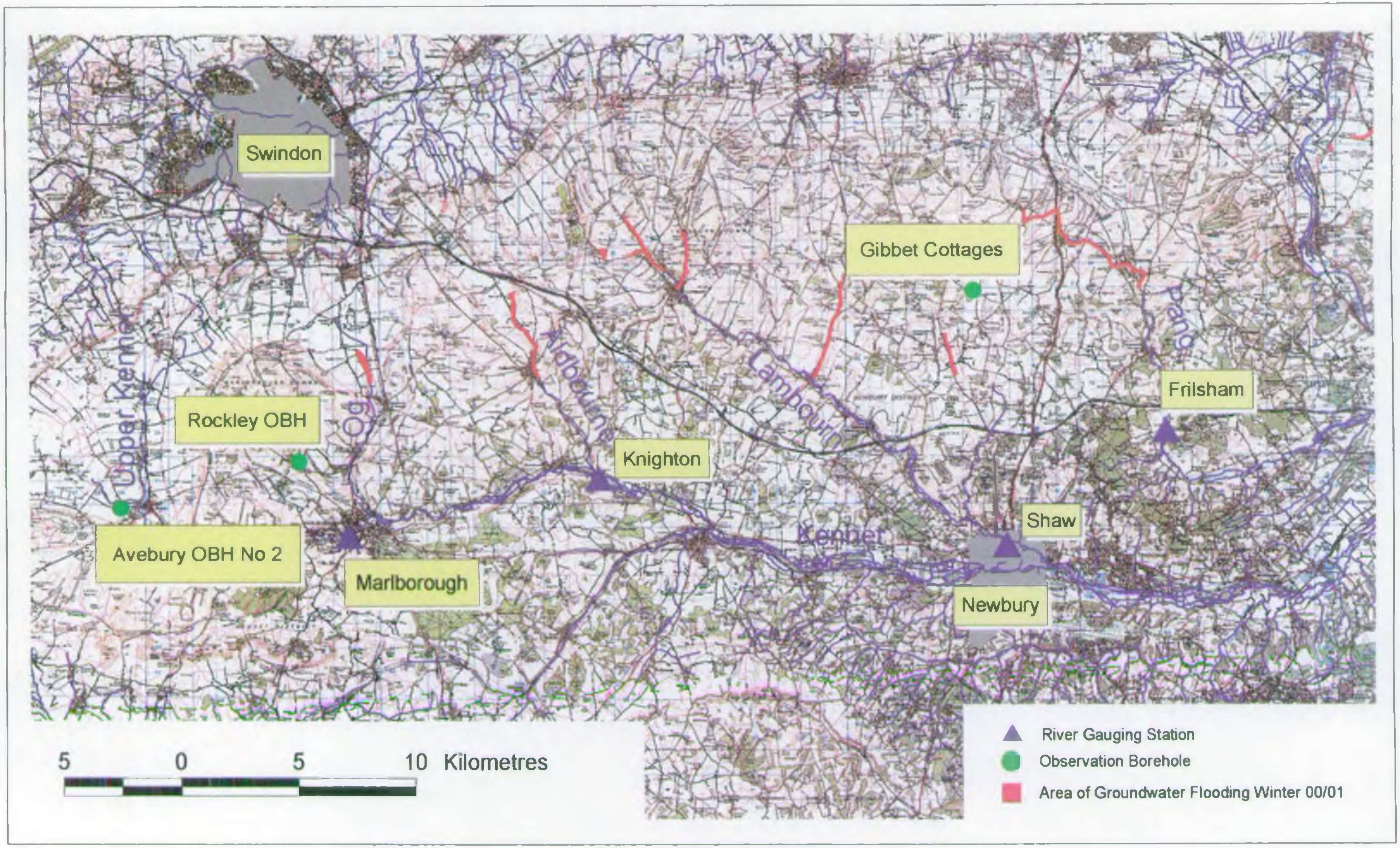
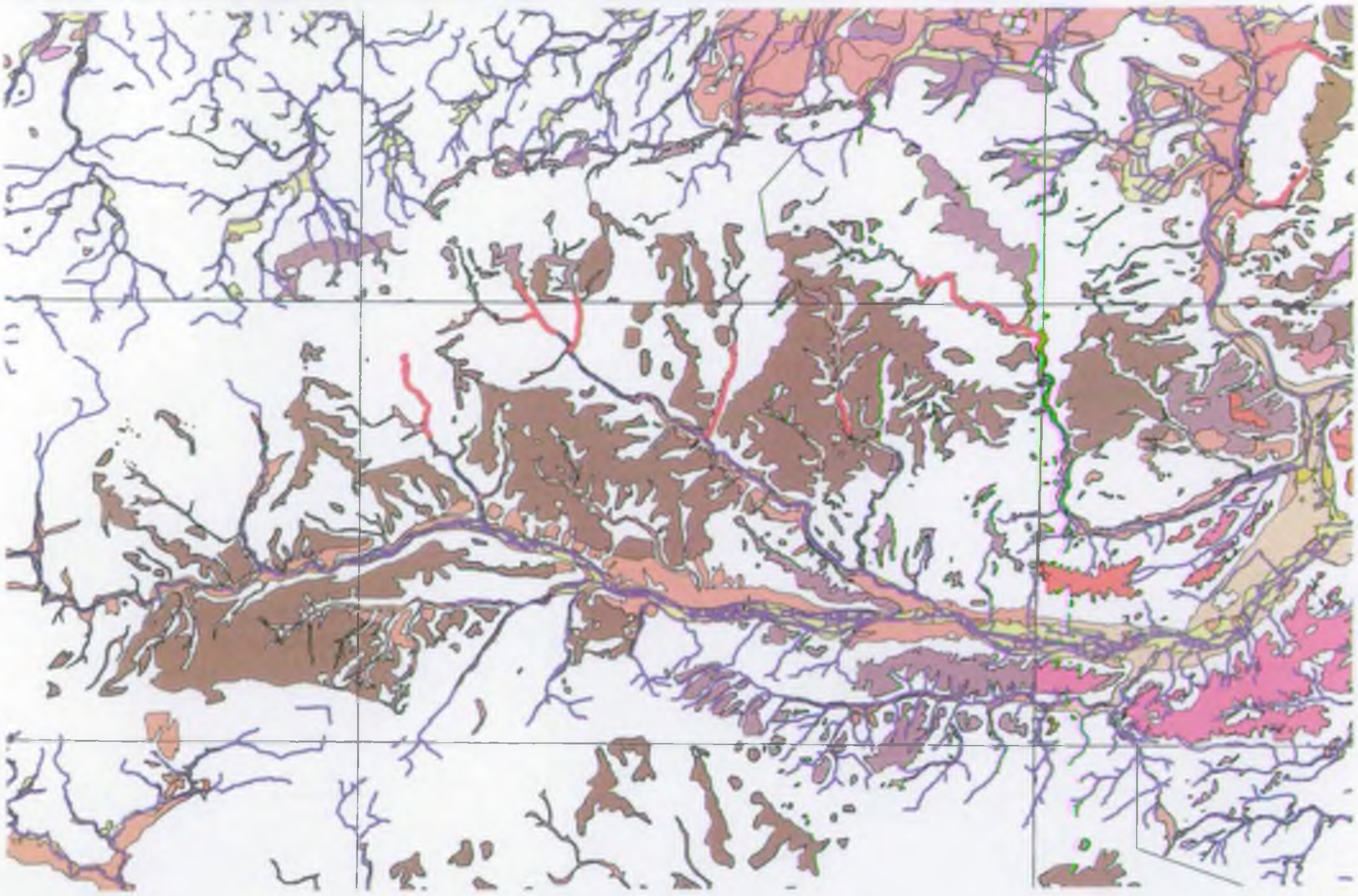
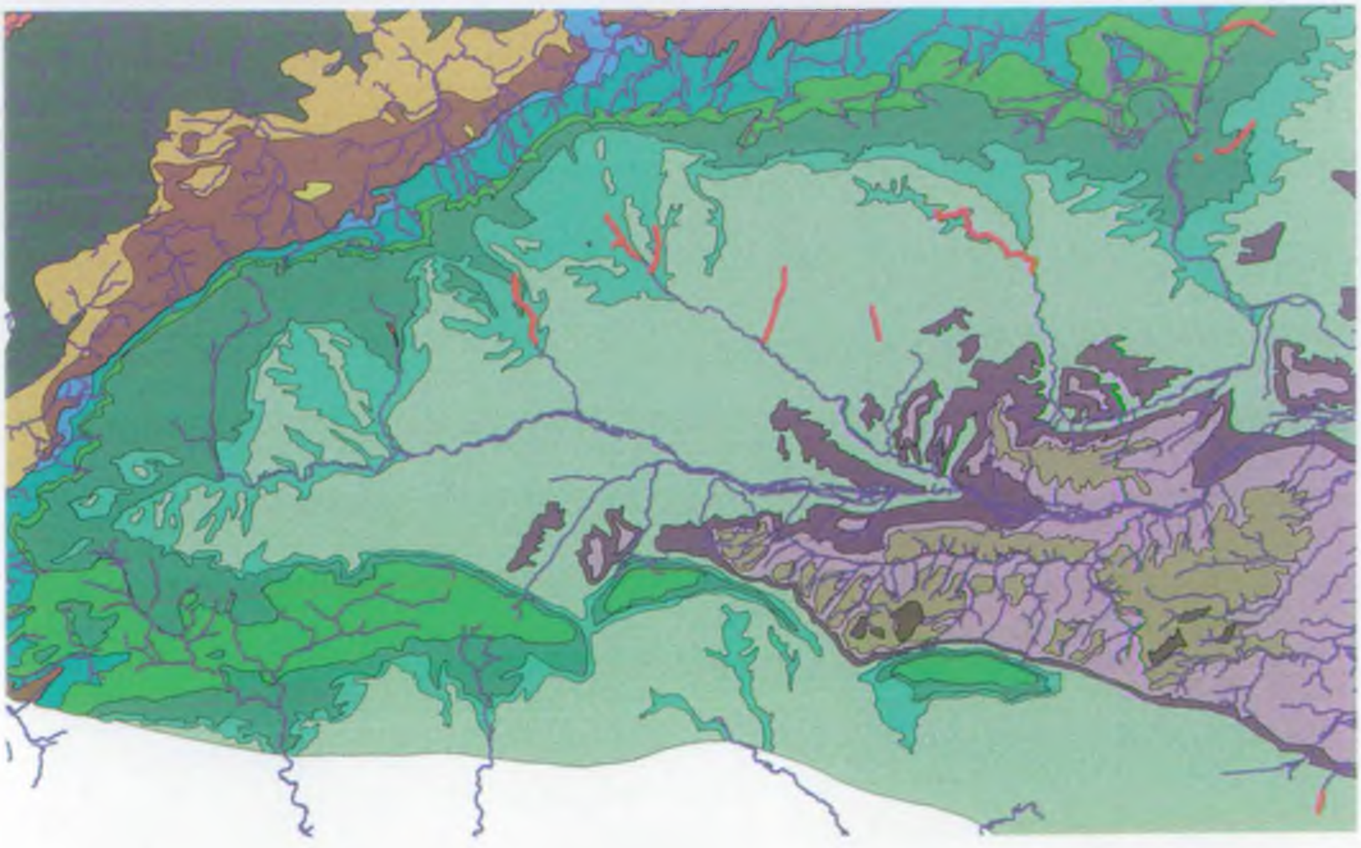


Figure 6. Solid and drift geology, Kennet Valley



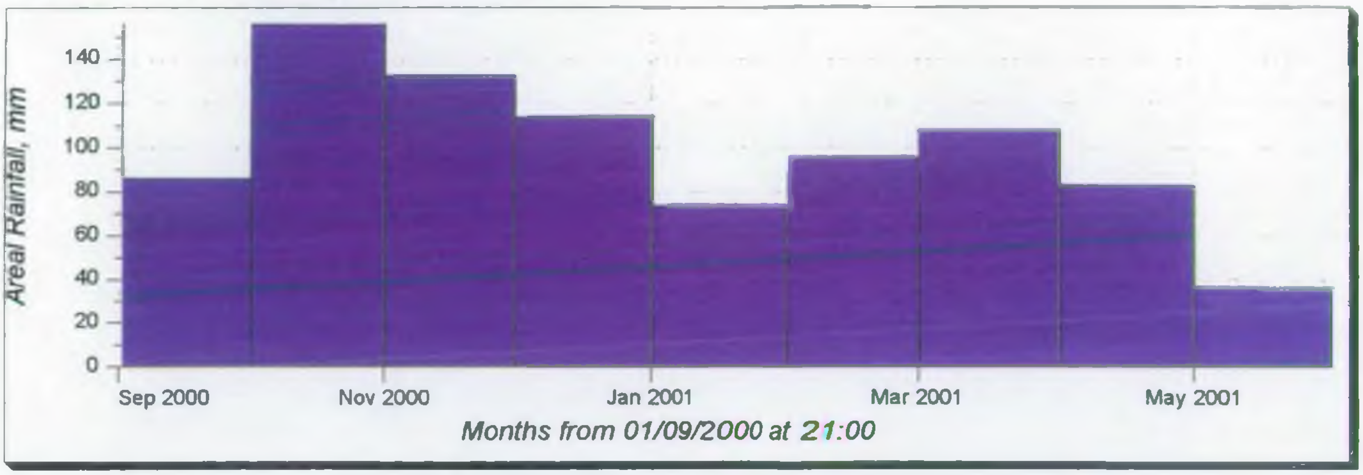
Drift Geology



Solid Geology

Figure 7 Hydrological summary for the Kennet catchment.

Berkshire Downs (6070), Areal Rainfall.



Berkshire Downs (6070), Areal Perc.

Knighton (2230), Flow.

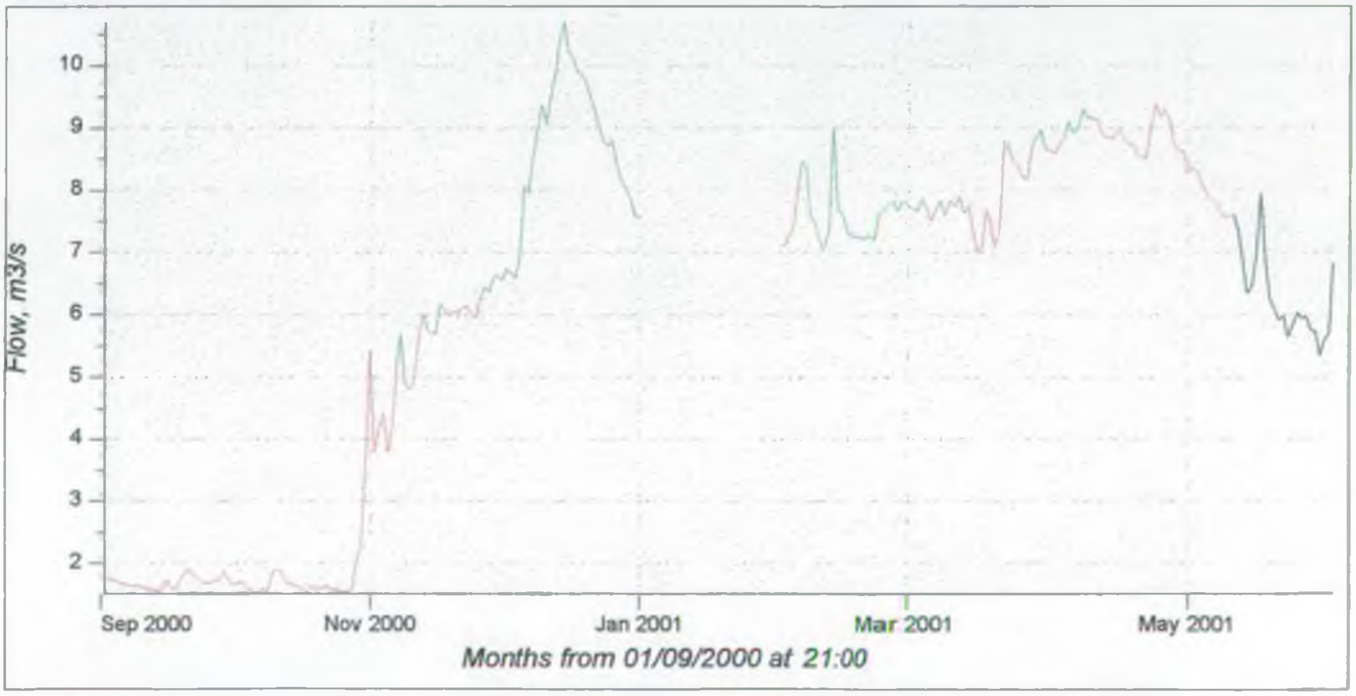
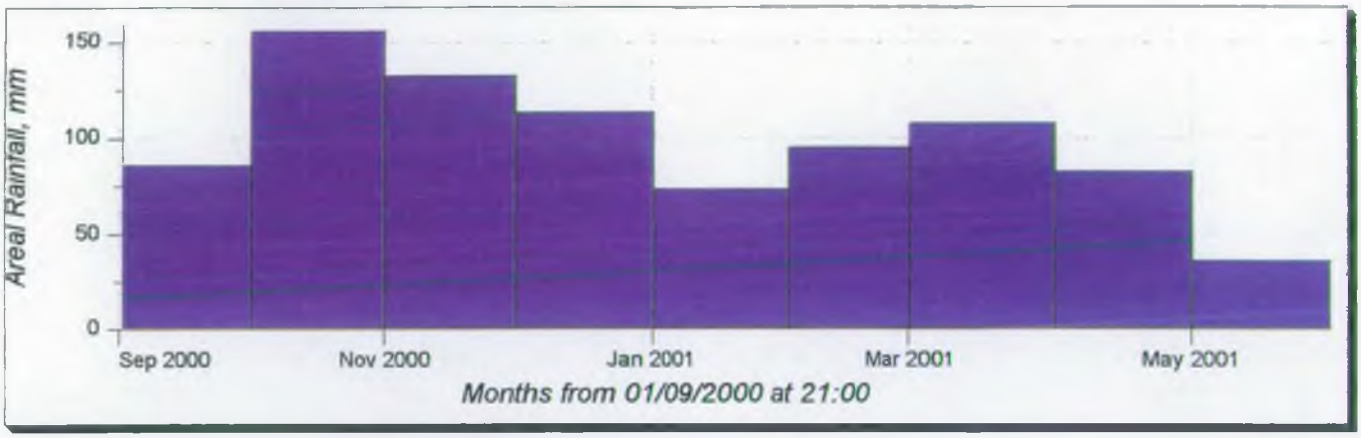
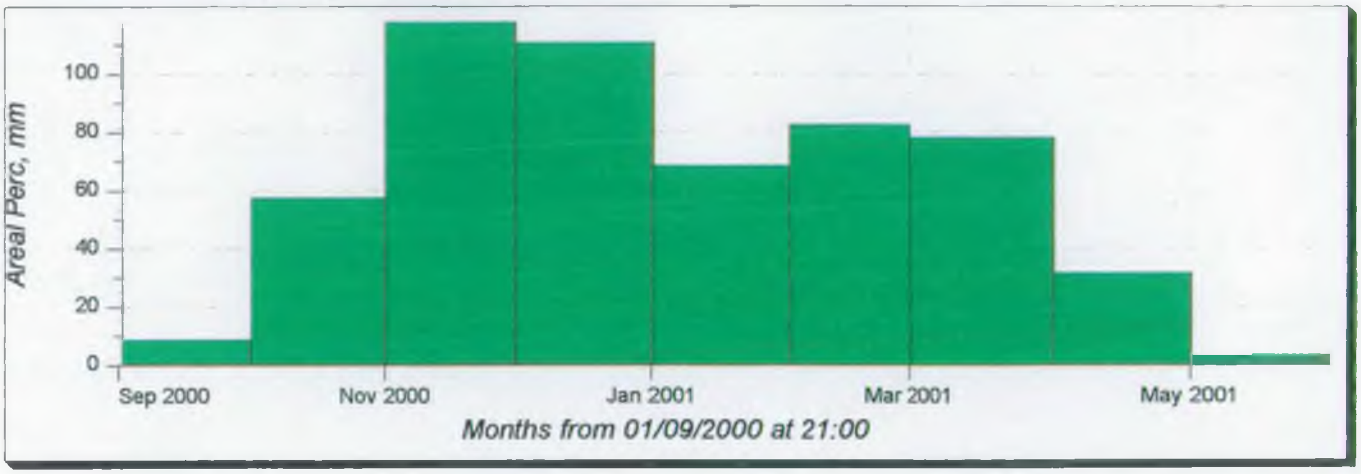


Figure 8 Hydrological summary for the Pang catchment.

Berkshire Downs (6070), Areal Rainfall.



Berkshire Downs (6070), Areal Perc.



Frilsham (2140), Flow.

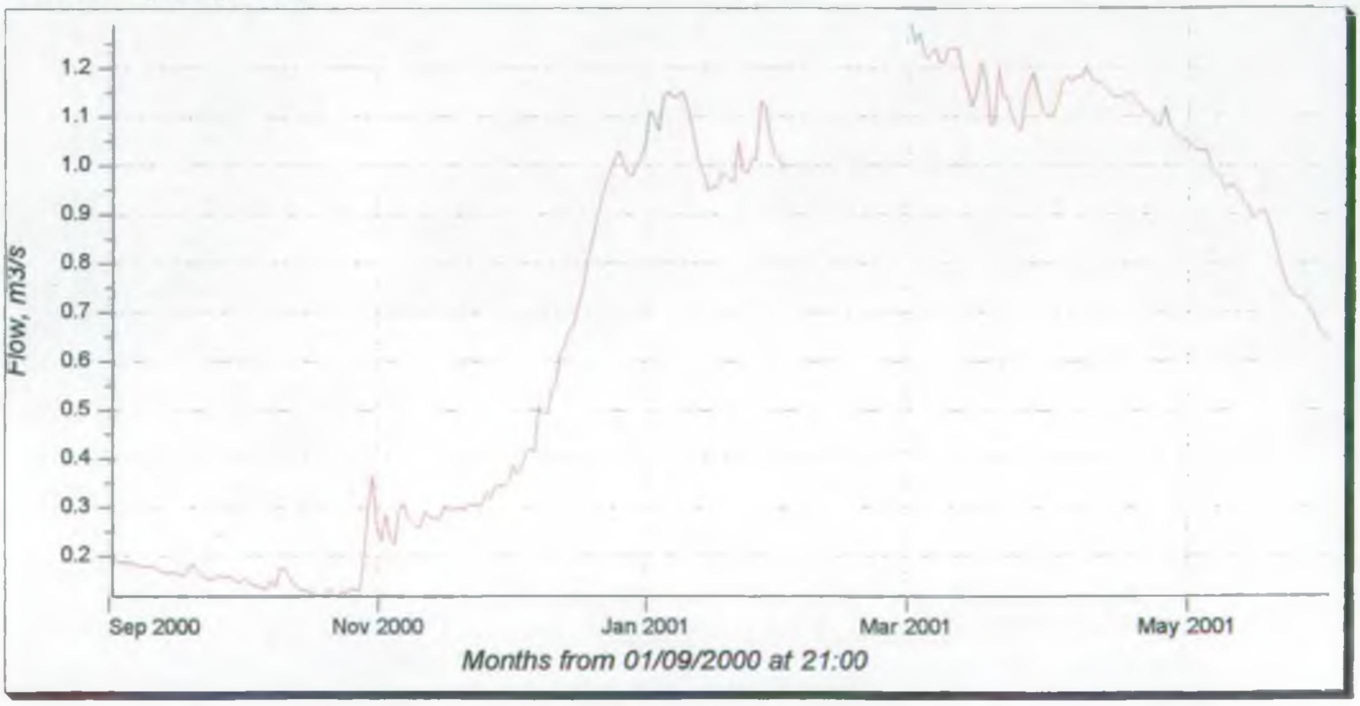
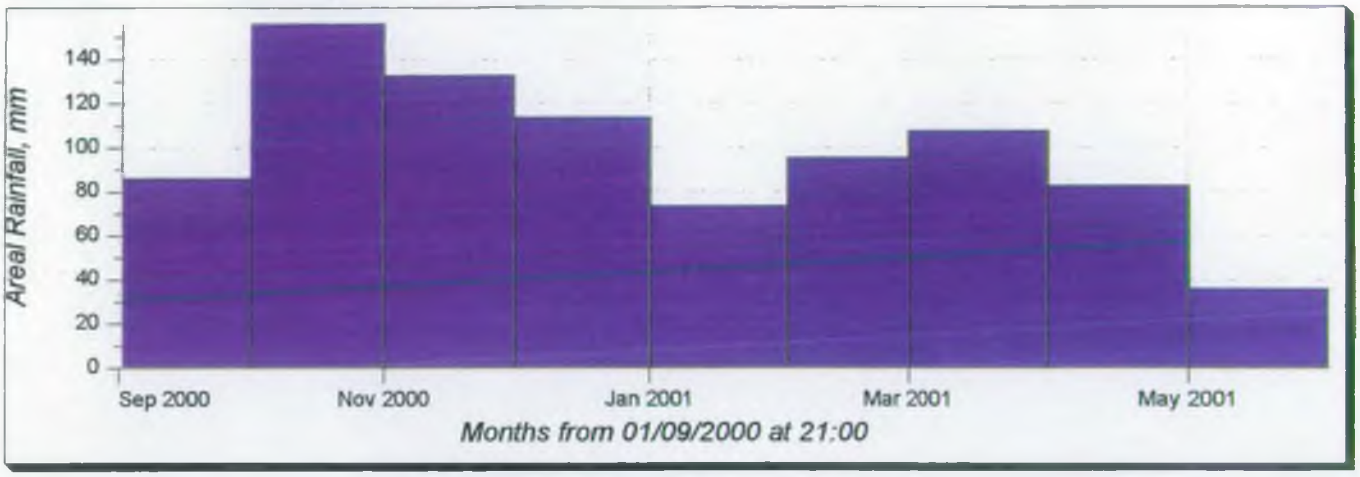
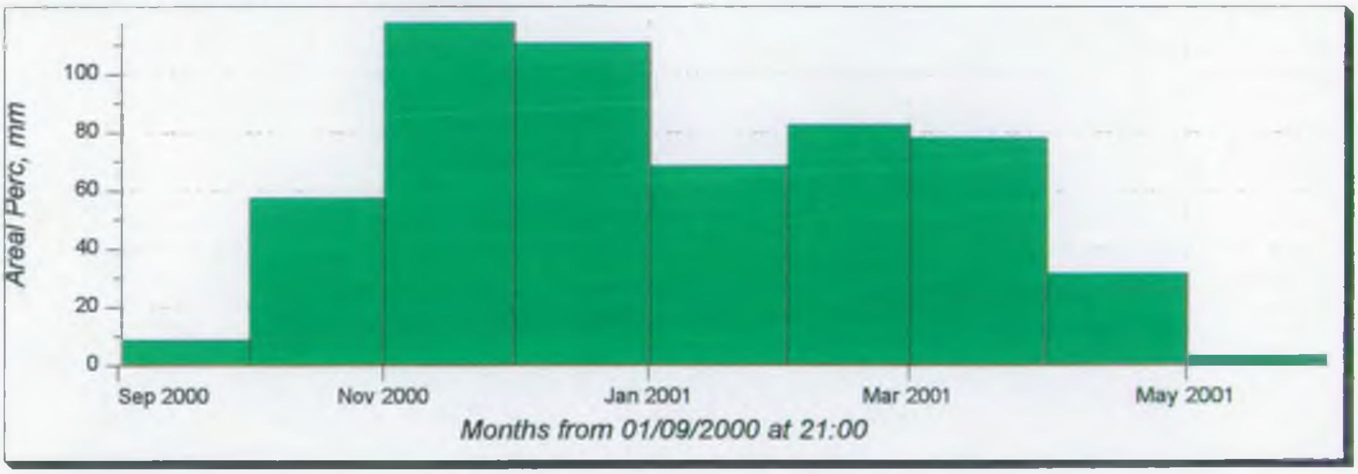


Figure 9 Hydrological summary for the Lambourn catchment.

Berkshire Downs (6070), Areal Rainfall.



Berkshire Downs (6070), Areal Perc.



Shaw (2269), Flow.

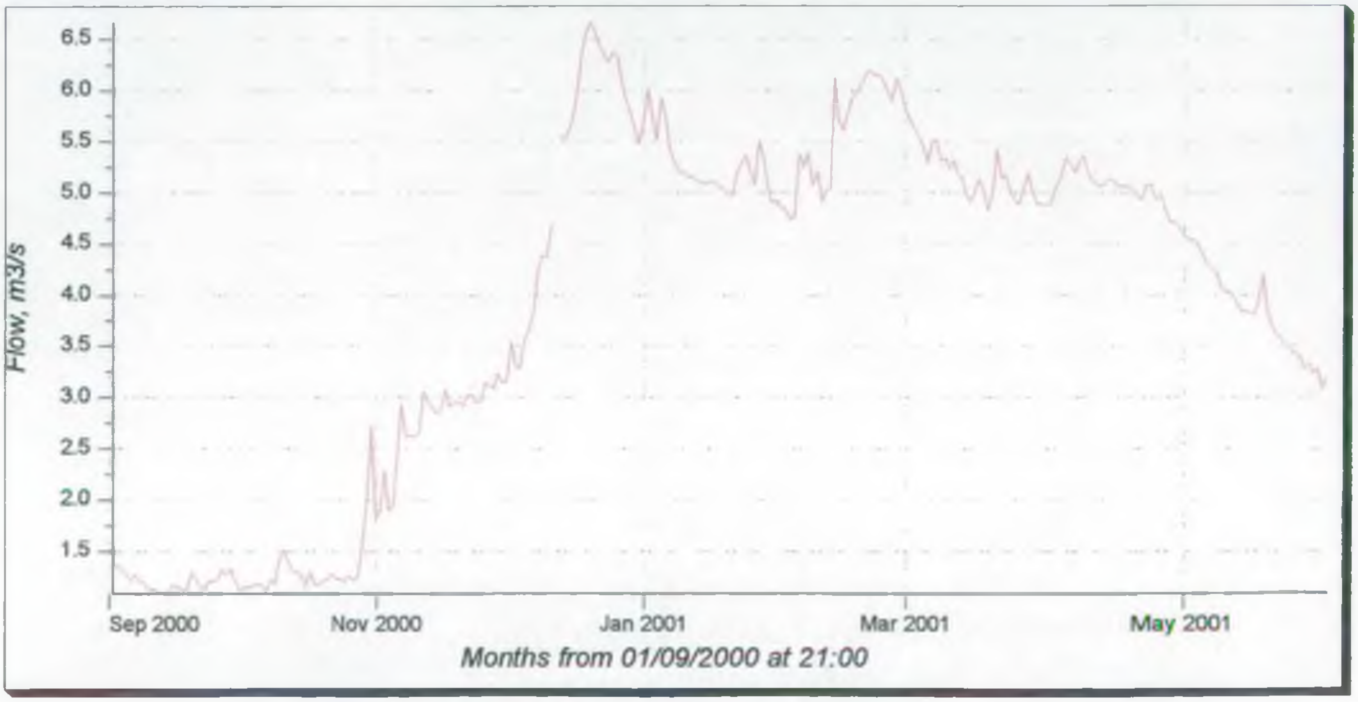
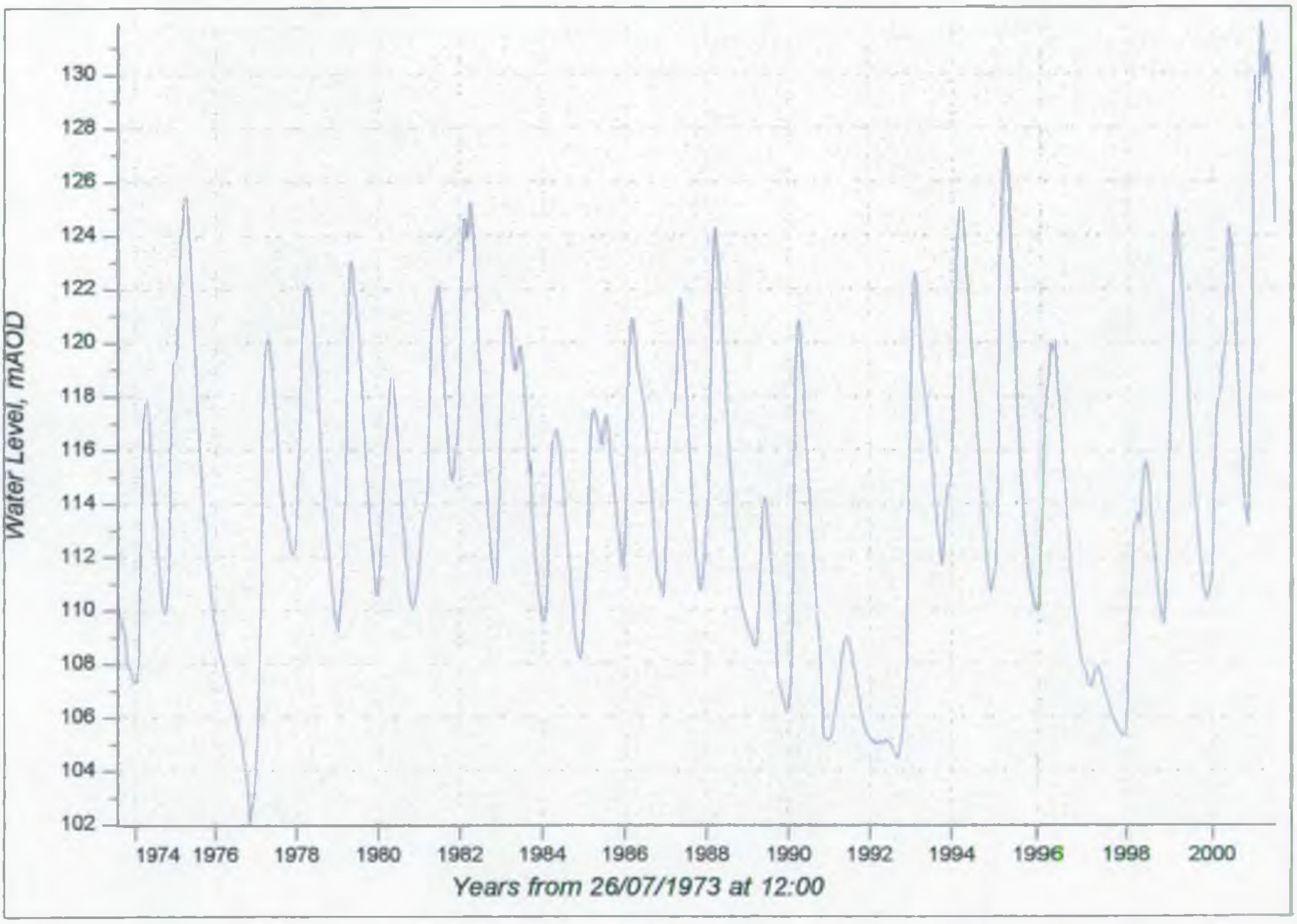


Figure 10 Gibbet Cottages OBH (SU47/141) Groundwater Levels



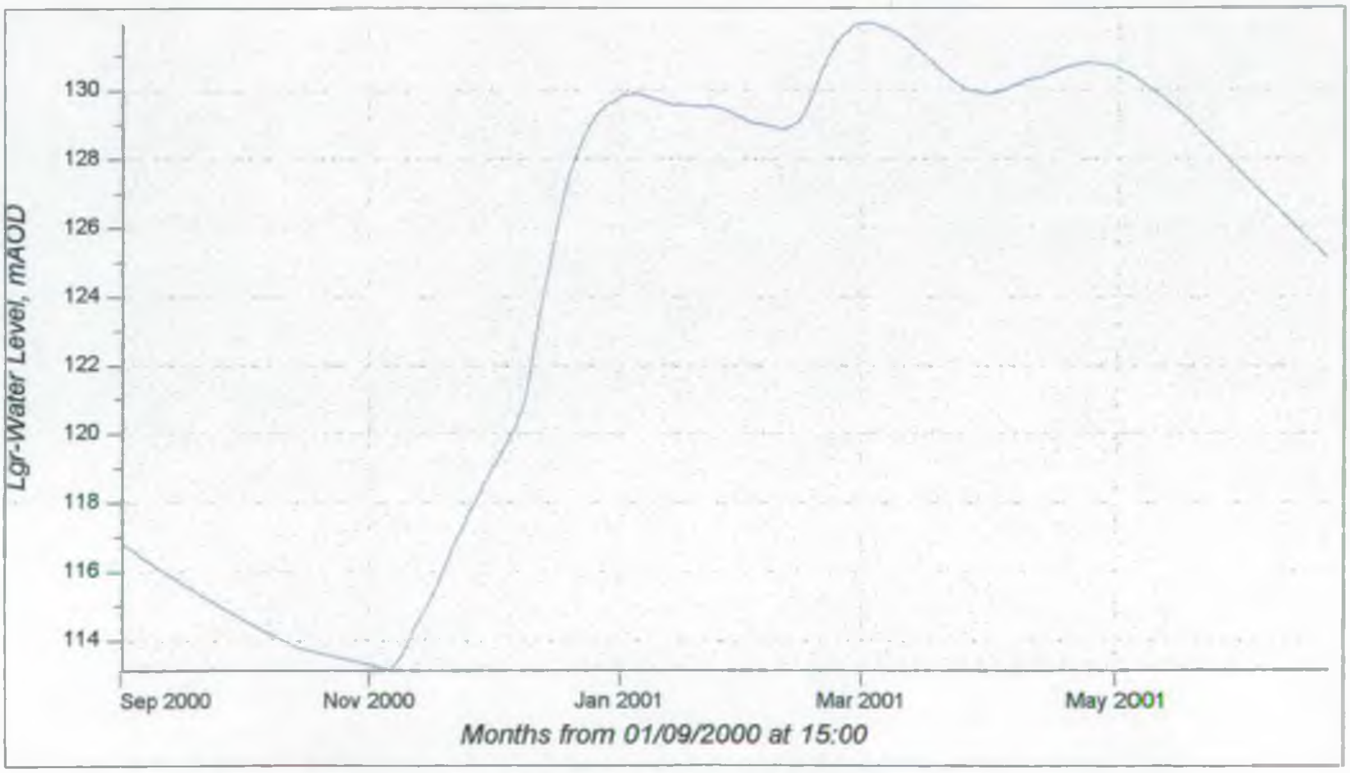
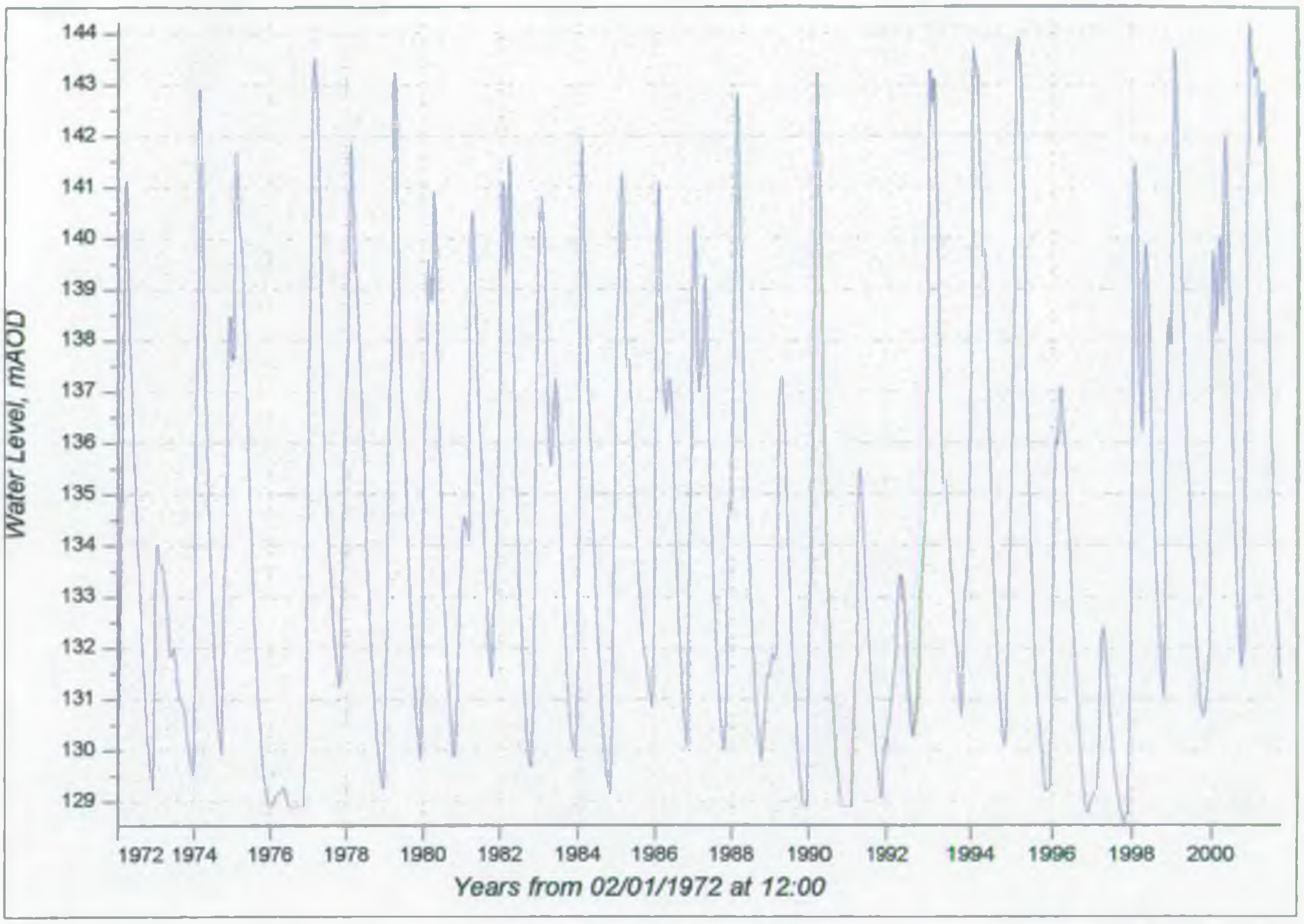


Figure 11 Rockley OBH (SU17/57) Groundwater Levels



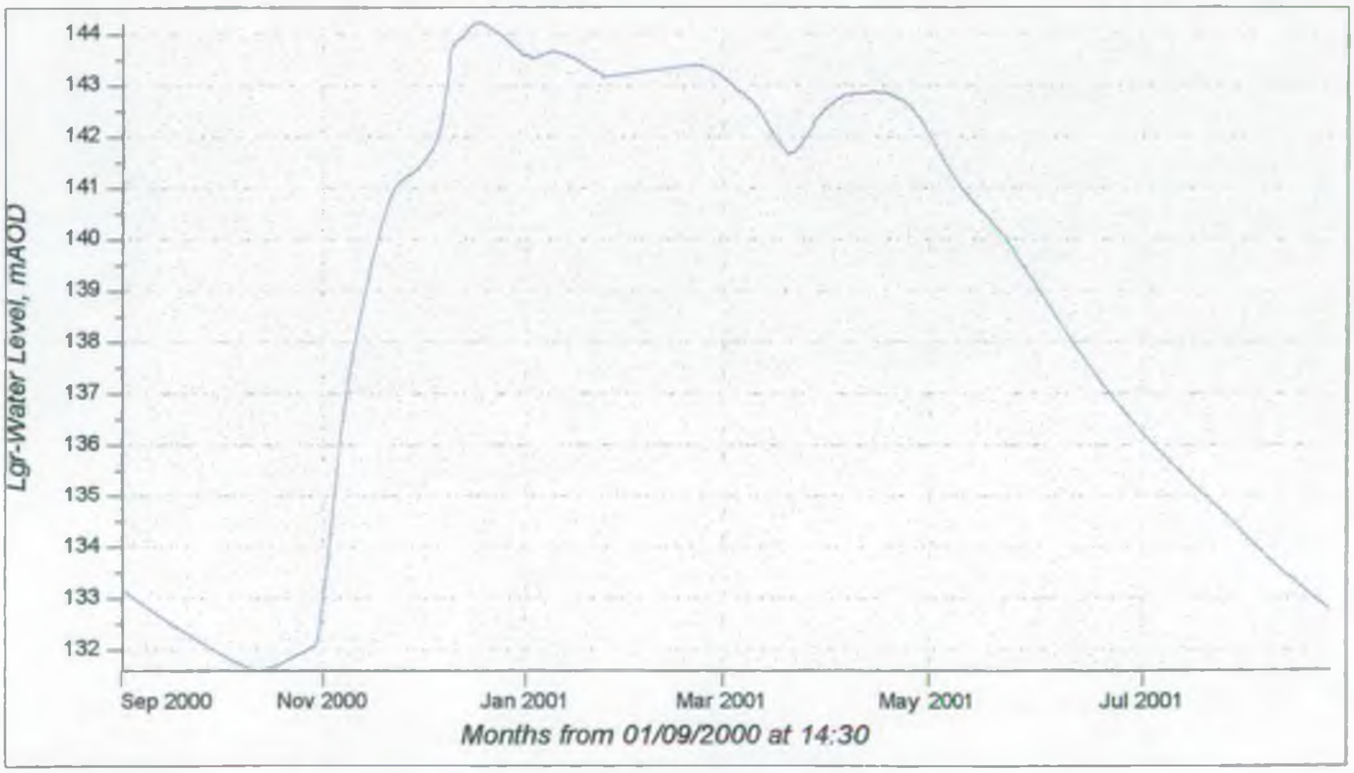
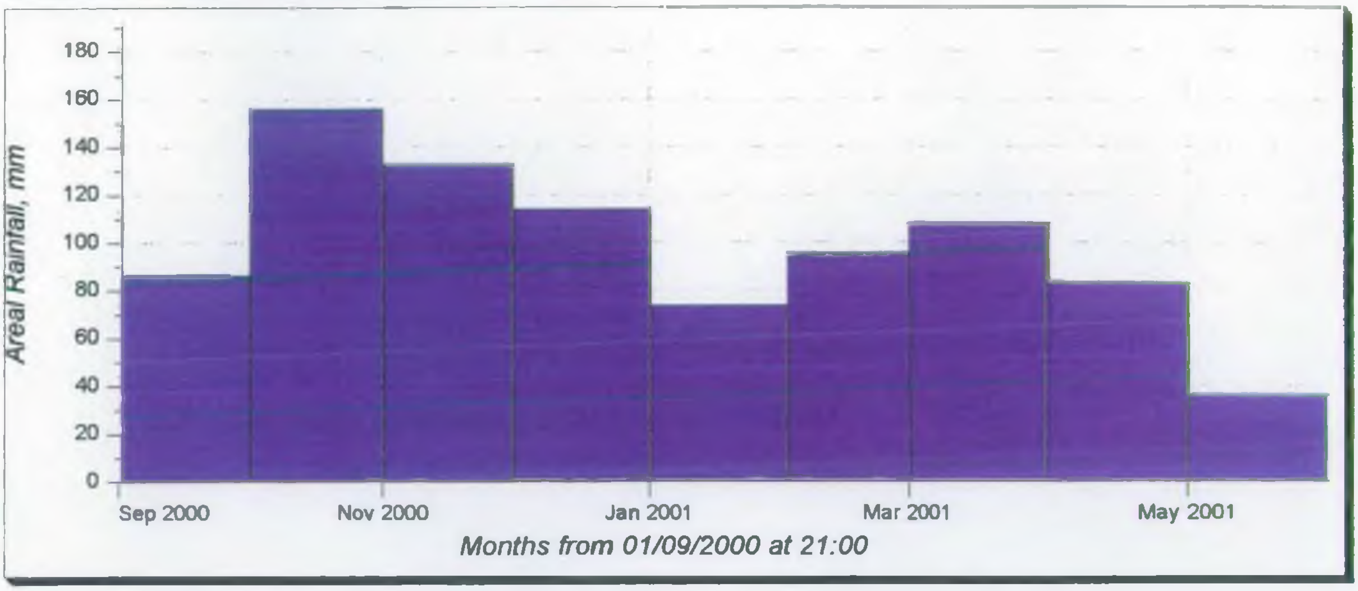
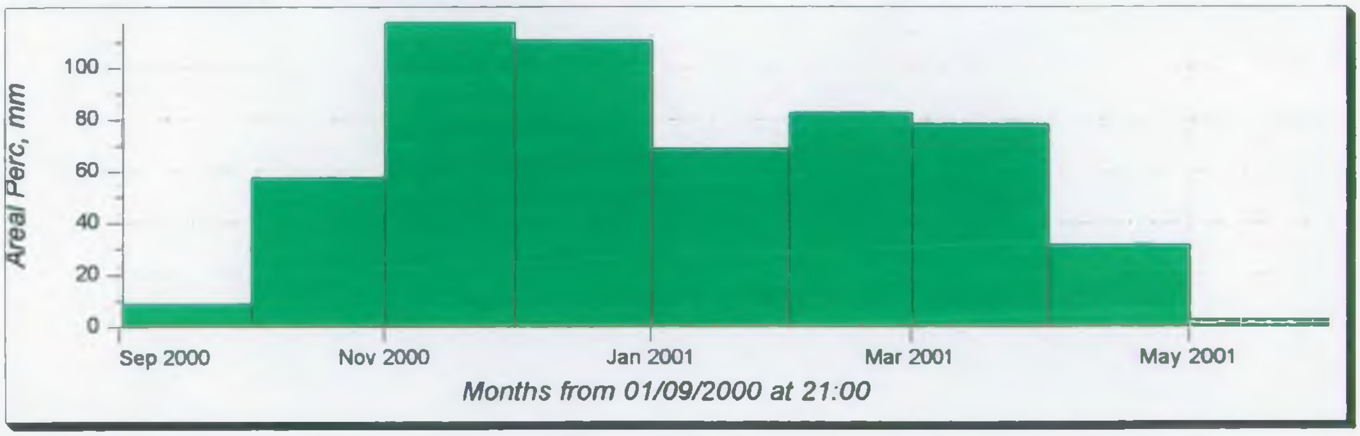


Figure 12 Hydrological summary for the Upper Kennet catchment.

Berkshire Downs (6070), Areal Rainfall.



Berkshire Downs (6070), Areal Rainfall.



Marlborough (2210), Flow.

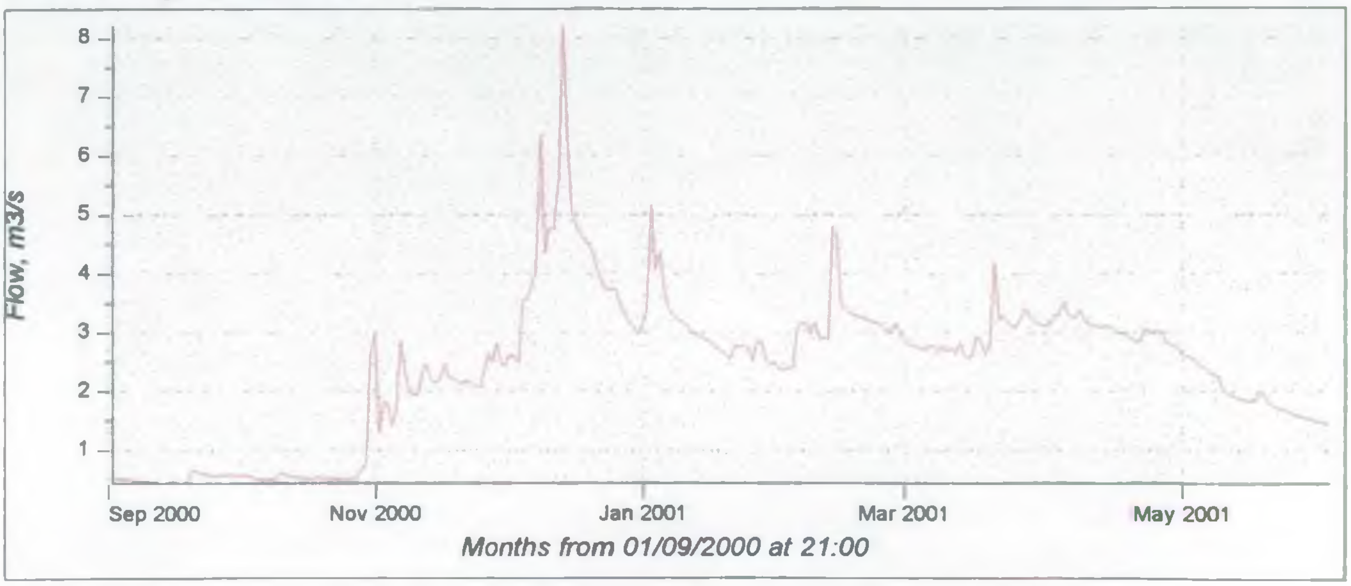
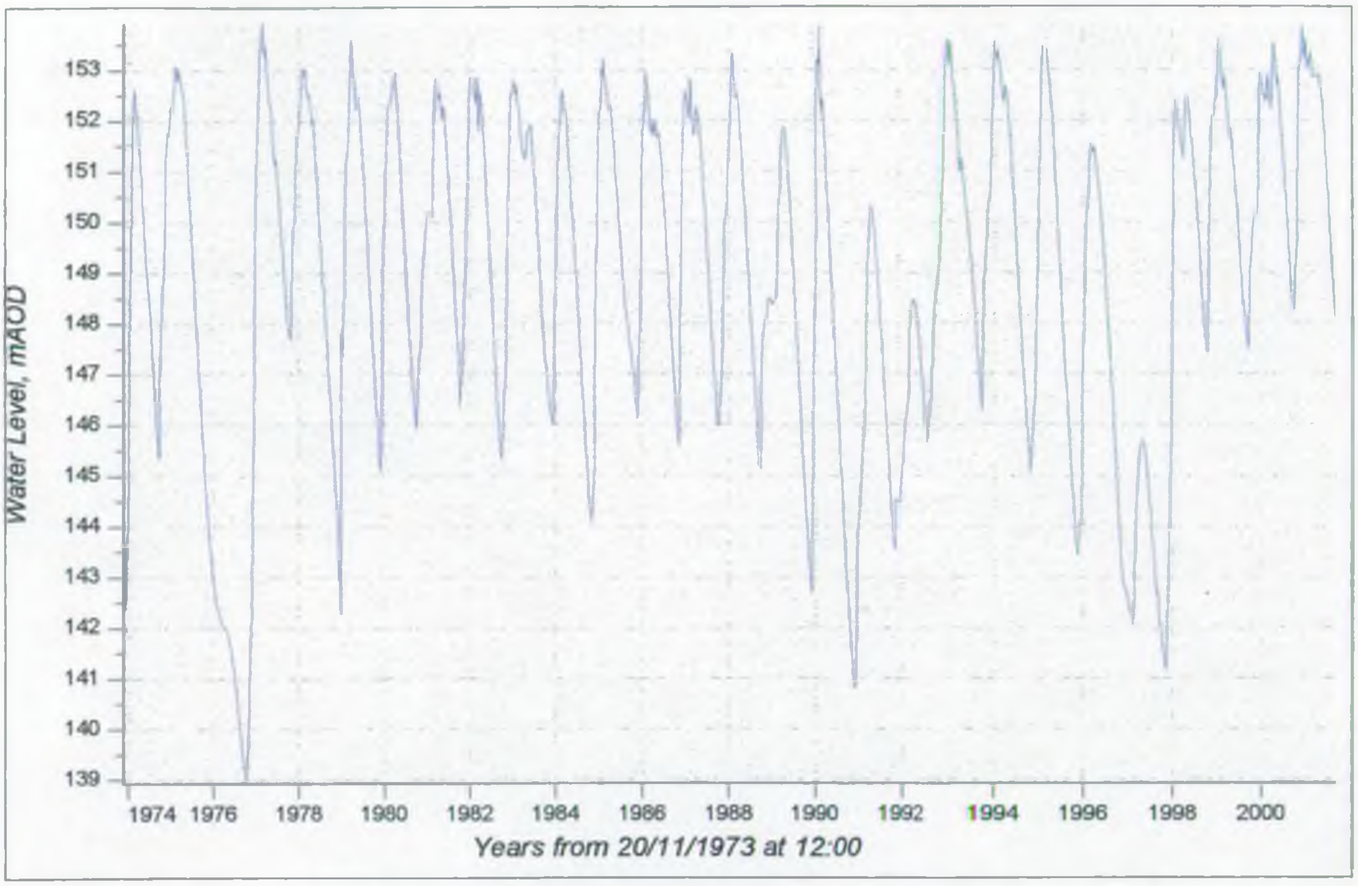


Figure 13 Avebury OBH NO 2 (SU06/45) Groundwater Levels



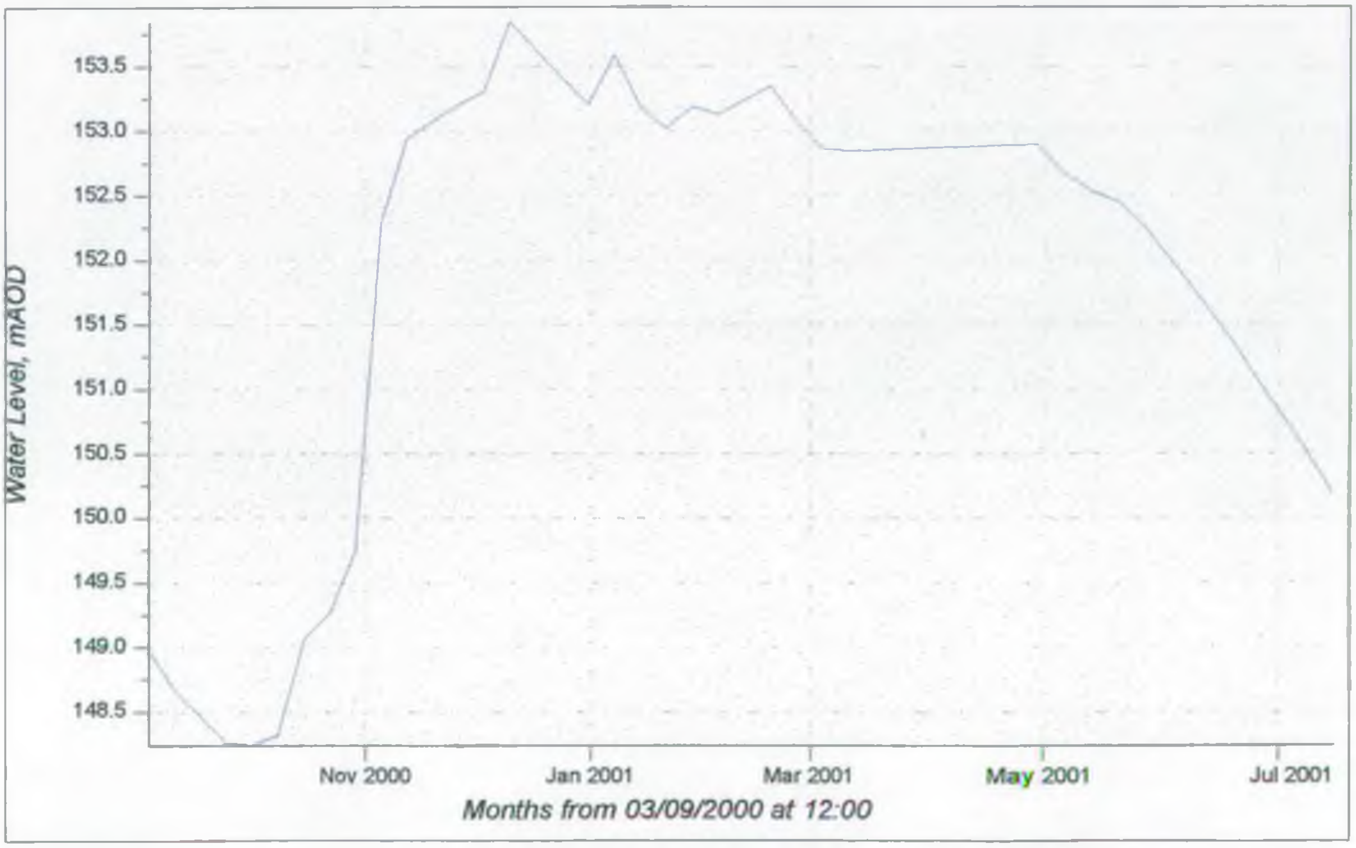


Figure 14: Flooding at Water Acre, upper Aldbourne Valley SU 258 780

Figure 15: Groundwater surcharge of drains in Aldbourne SU 264 756

Figure 16: A338, Great Shefford. SU 389 758

Figure 17: Temporary bypass stream, Great Shefford. SU 388 758

Figure 18: Trindledown Farm, A338. SU 393 772

Figure 19: Upper Pang valley groundwater flooding, Compton to E. Ilsley. ***Photo, CEH, Wallingford,***

Figure 20: Upper River Pang, looking east towards Compton. photo, CEH, Wallingford.

Figure 21: Hodcott river augmentation borehole, EA West Berks Groundwater Scheme. SU 485 819

Figure 22. Location of observed Groundwater Flooding and Monitoring Sites, SW Chilterns

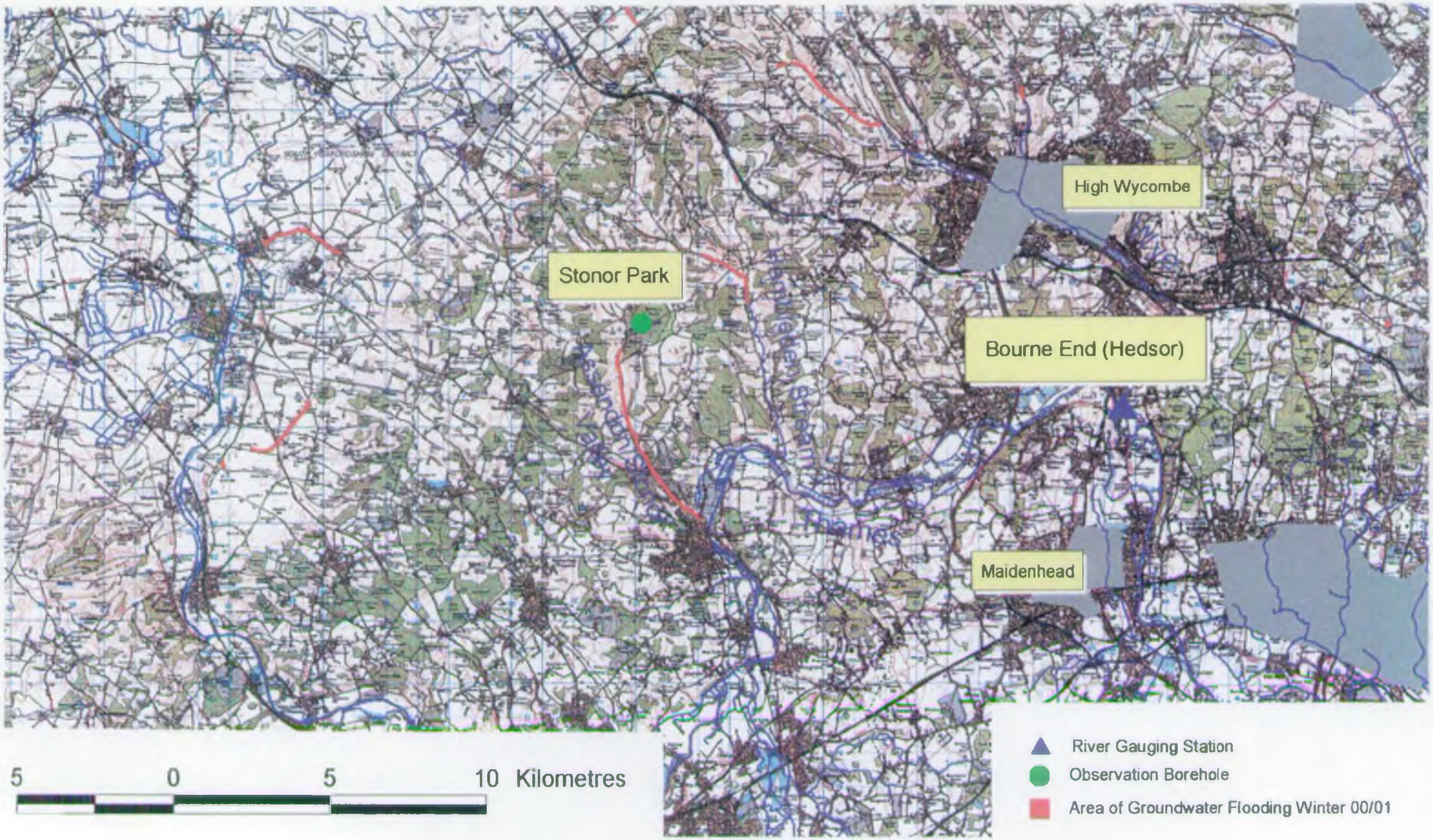
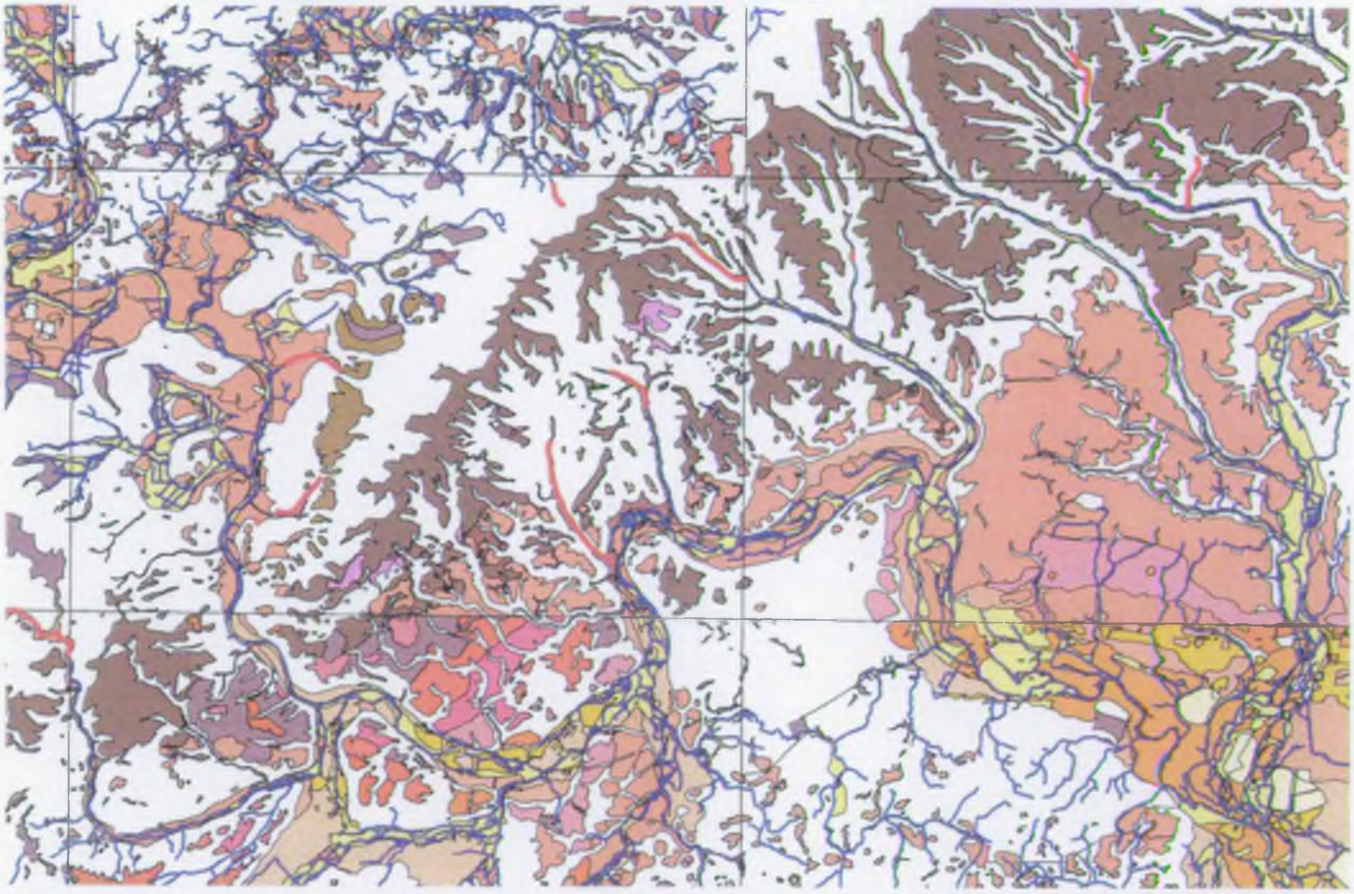
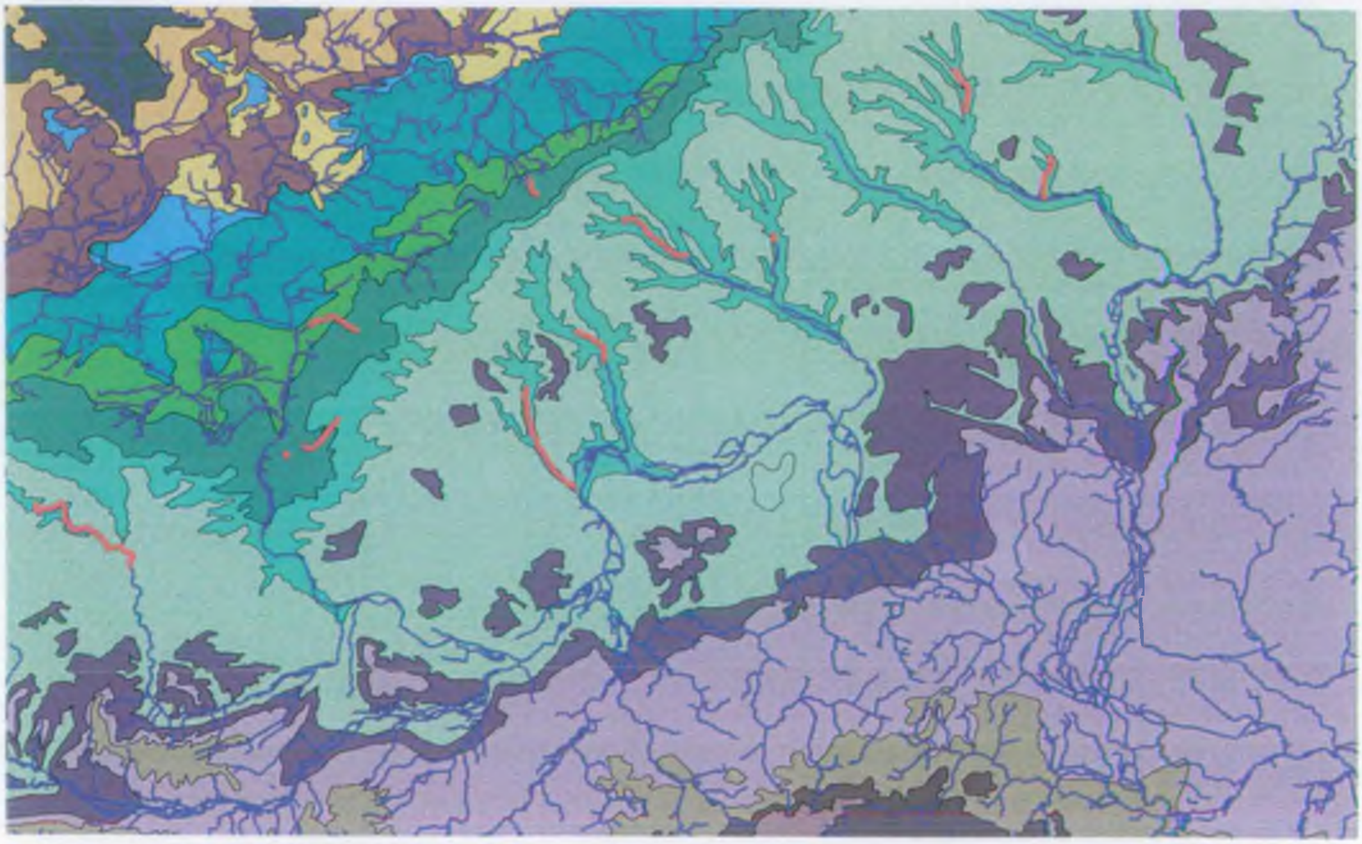


Figure 23. Solid and drift geology, SW Chilterns



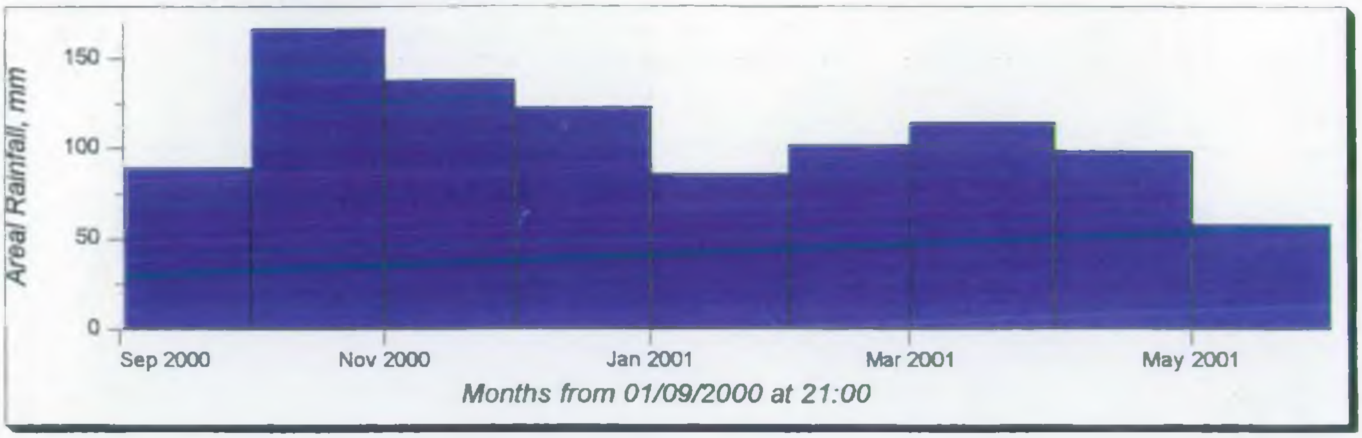
Drift Geology



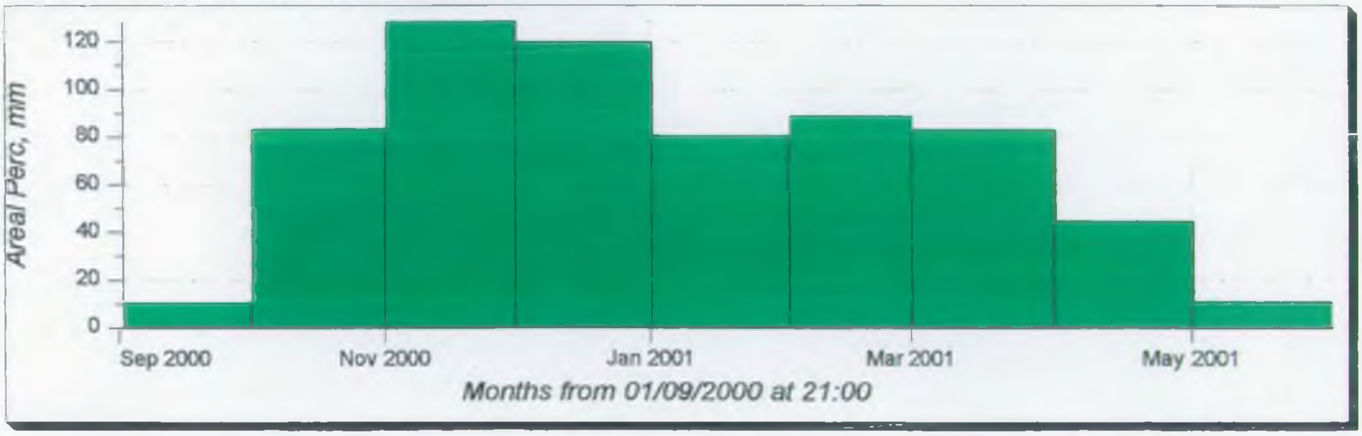
Solid Geology

Figure 24 Hydrological summary for the Wye catchment.

Chiltern-East (6140), Areal Rainfall.



Chiltern-East (6140), Areal Perc.



Bourne End (Hedsor) (2590), Flow.

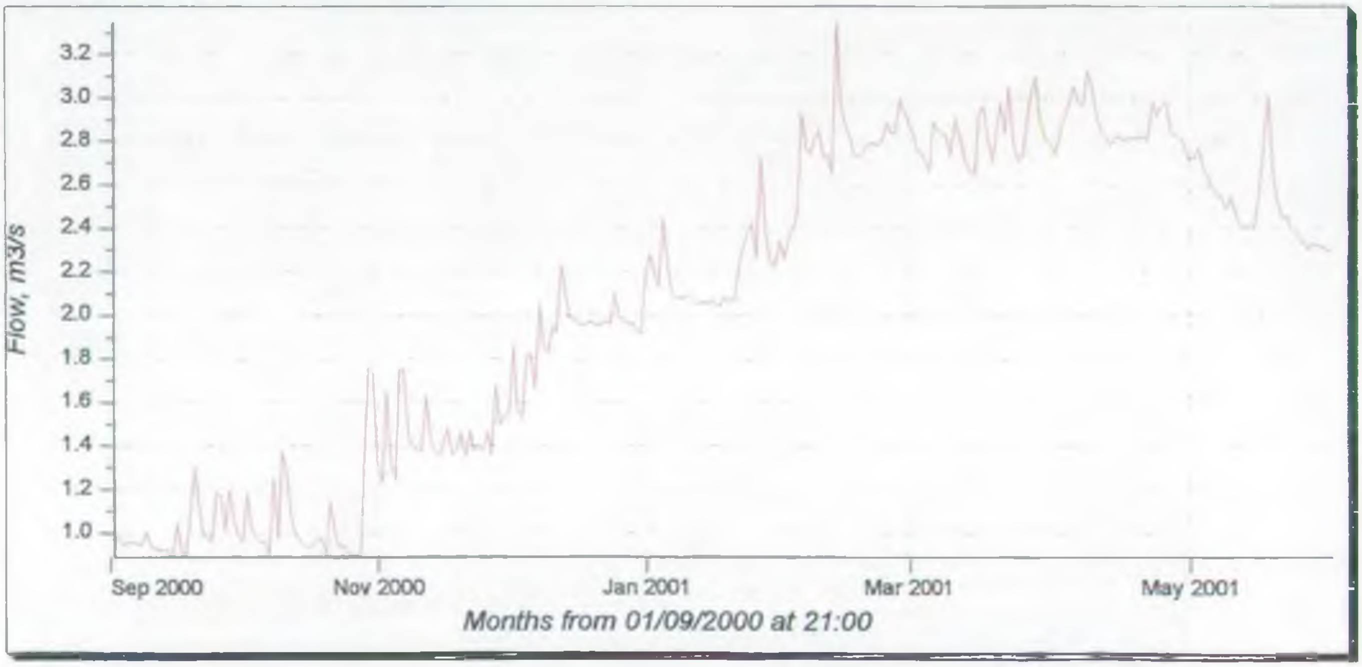
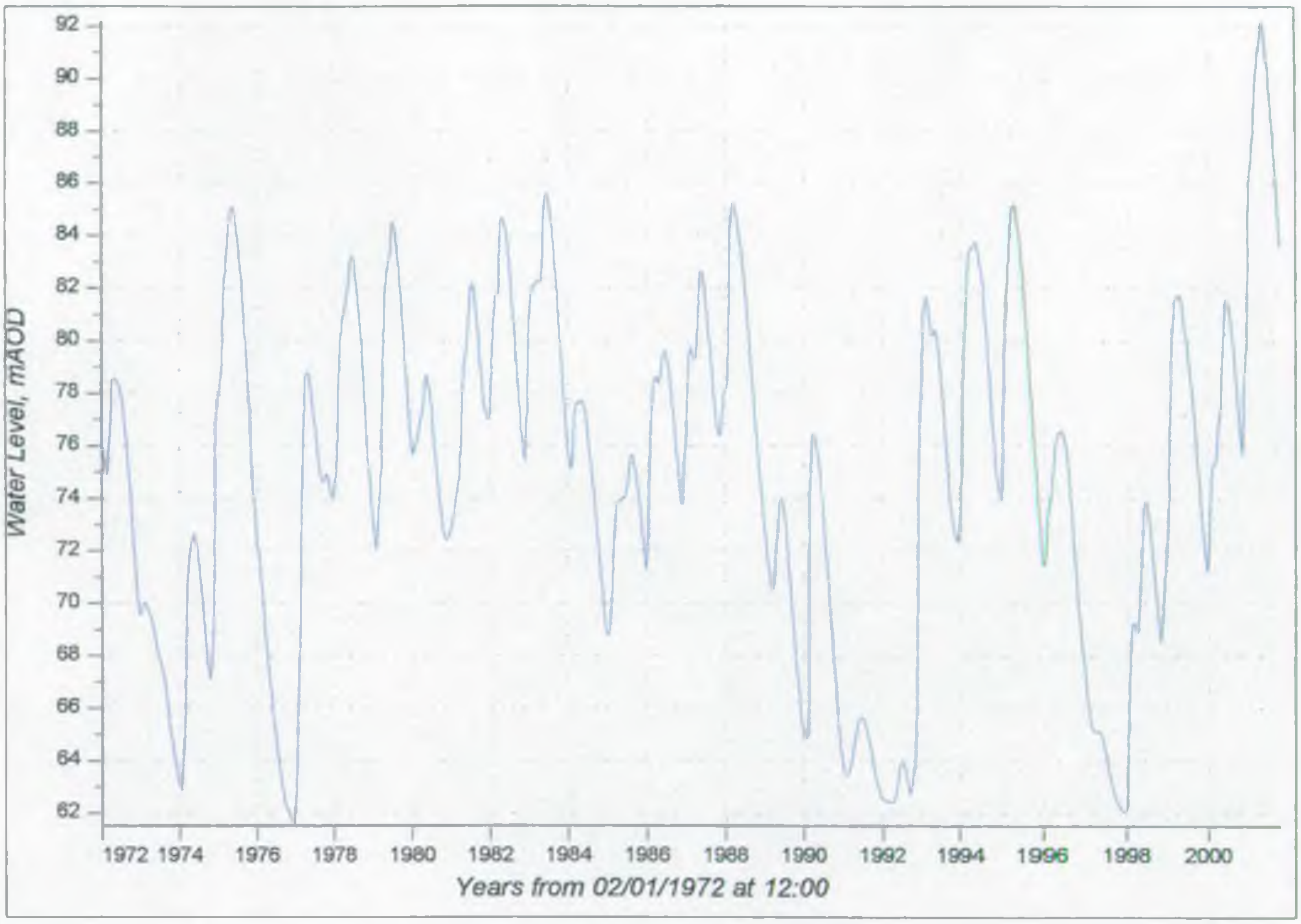


Figure 25 Stonor Park (SU78/45A) Groundwater Levels



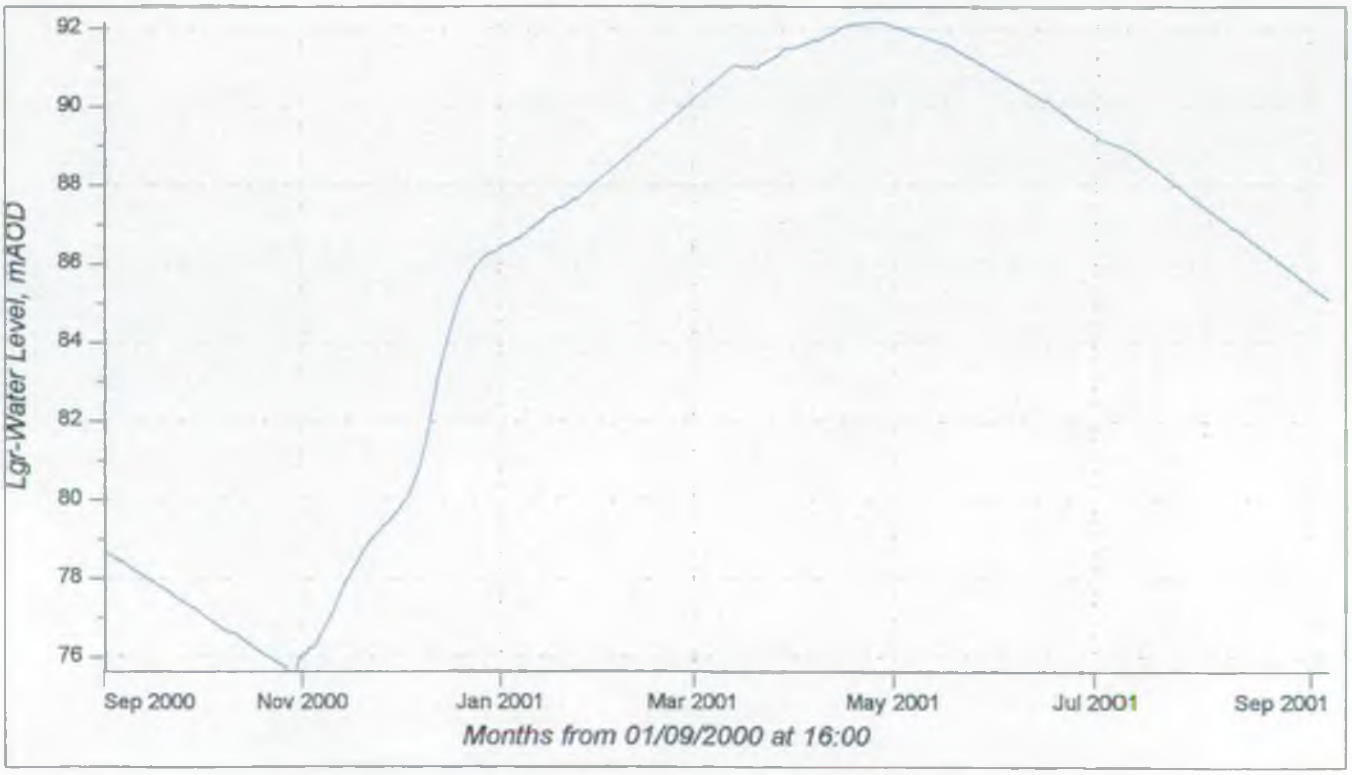


Figure 26:Lower Assendon, SU 744 847

Figure 27: Renewing culverts under the A3130 in Henley to cope with the exceptional flow, 14/04/01.

Figure 28:Hambledon village, 14/04/01

Figure 29: Groundwater breaking through the ground, upper Wye valley, SU 797 970

Figure 30. Location of observed Groundwater Flooding and Monitoring Sites, Colne Valley Chilterns

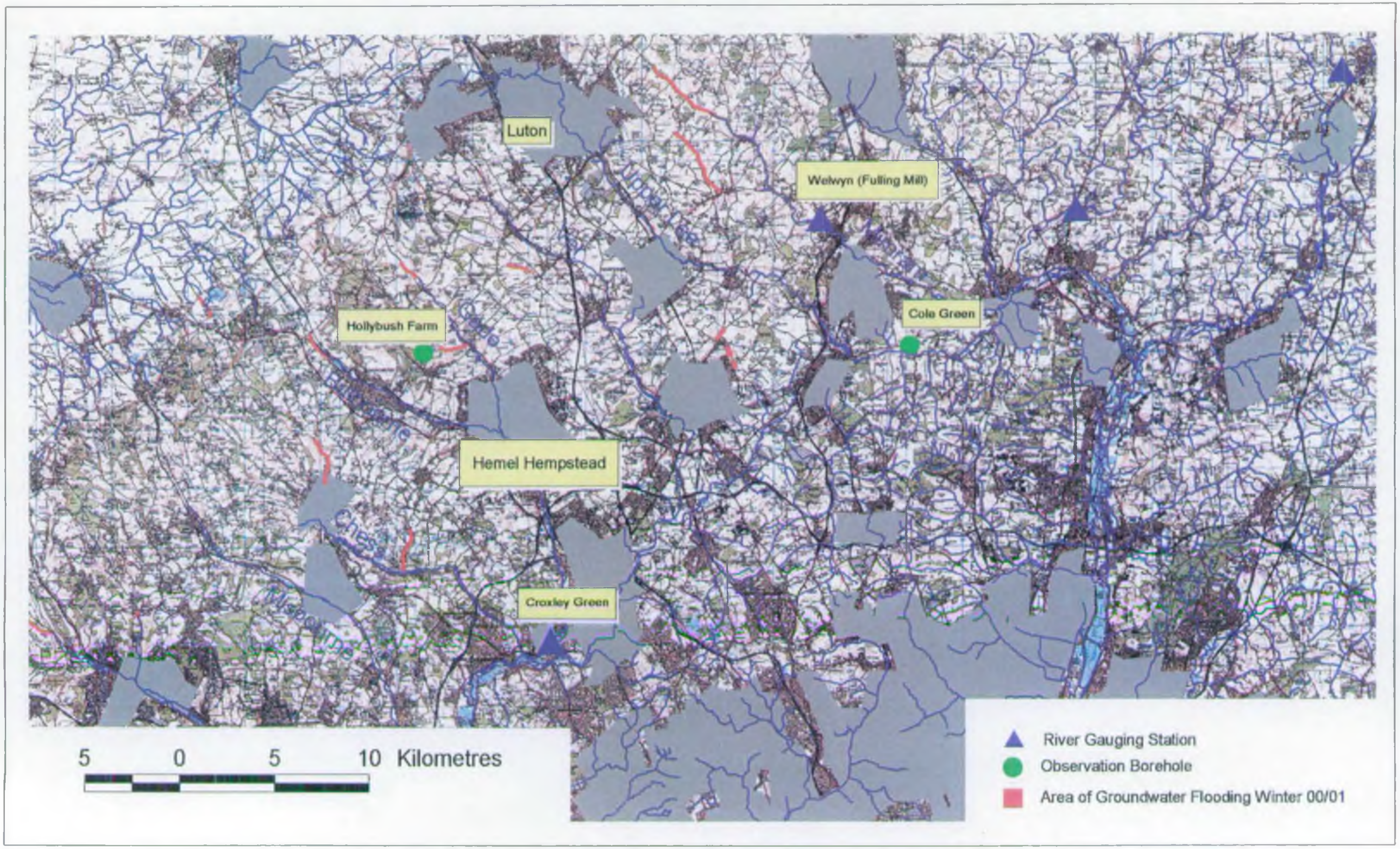
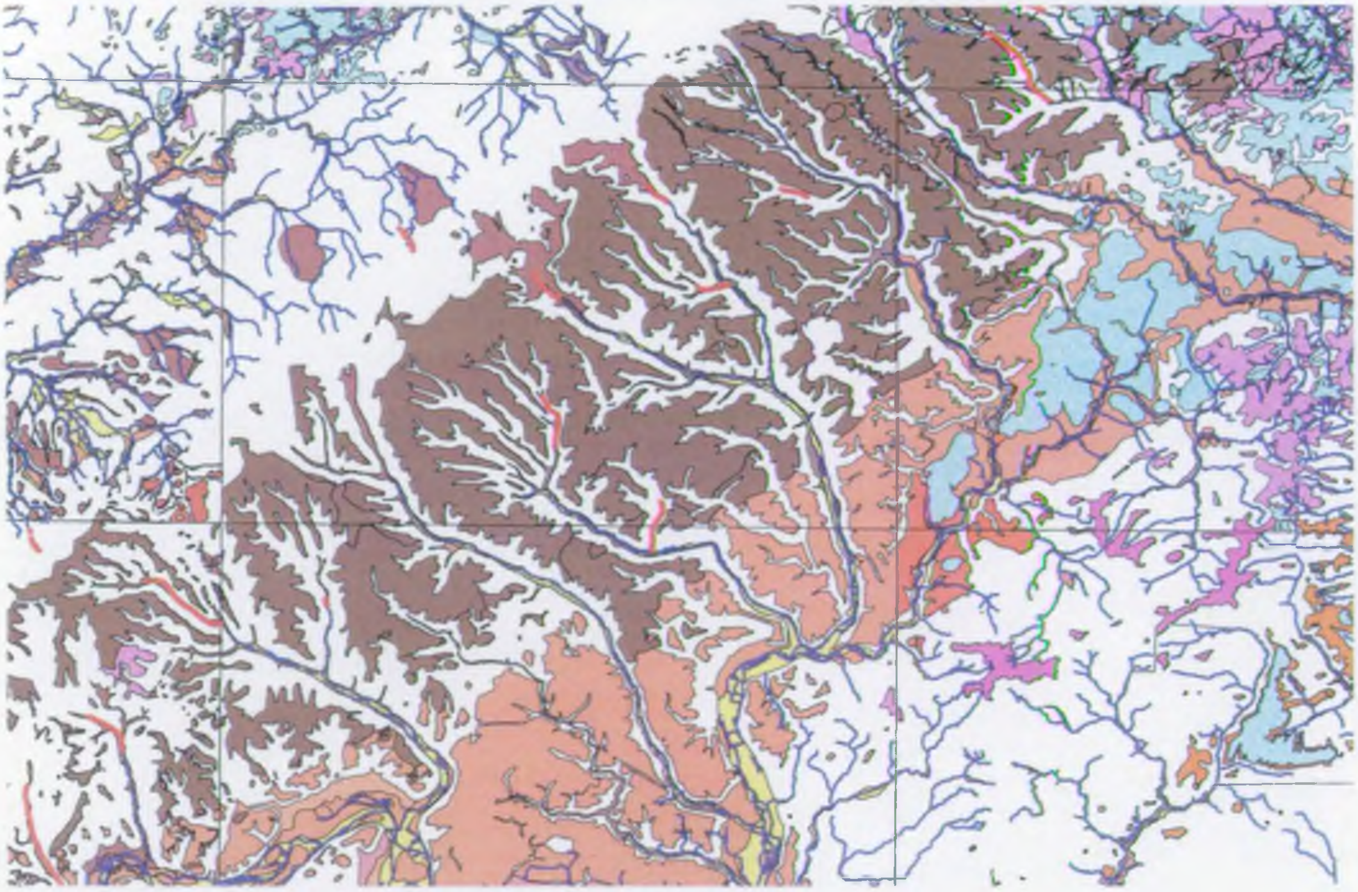
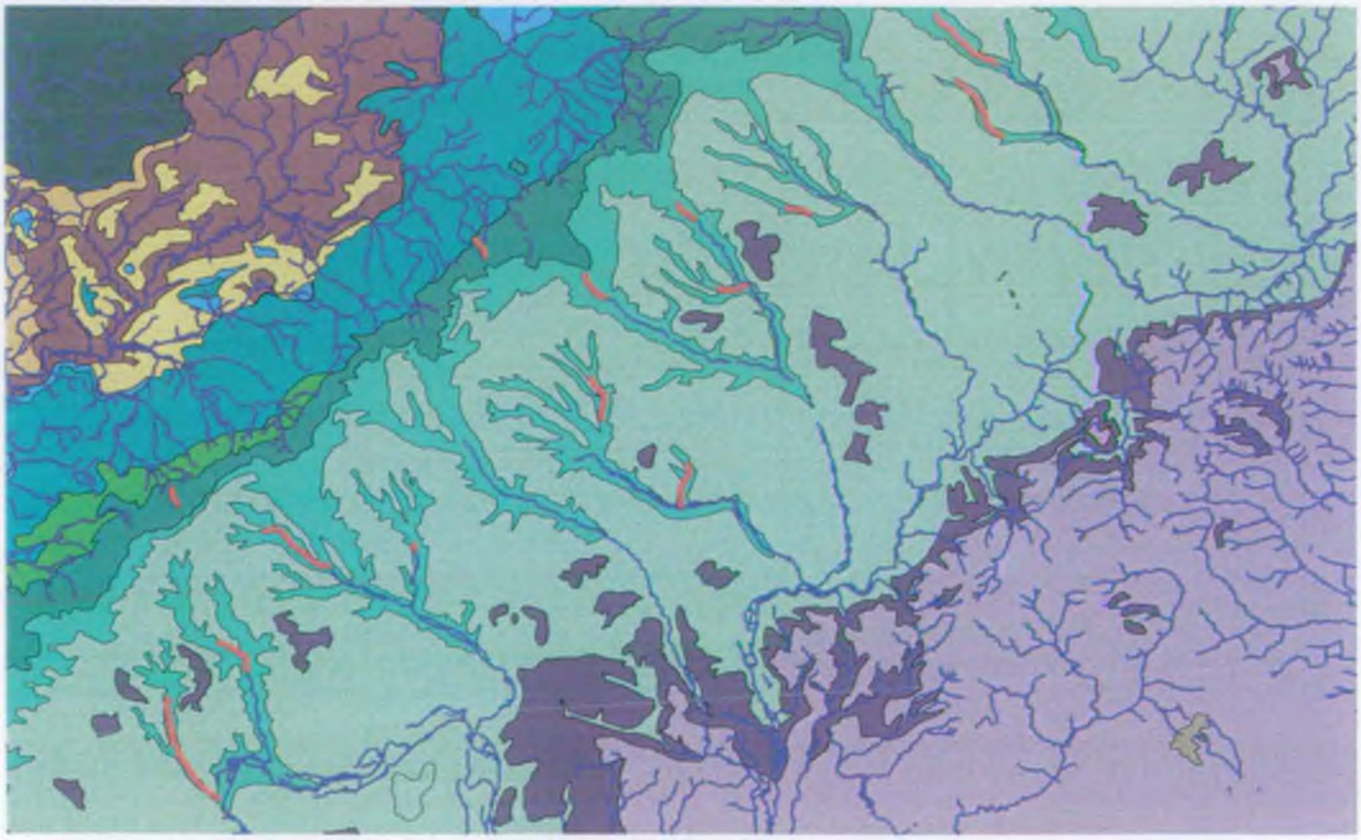


Figure 31. Solid and drift geology, Colne Valley Chilterns



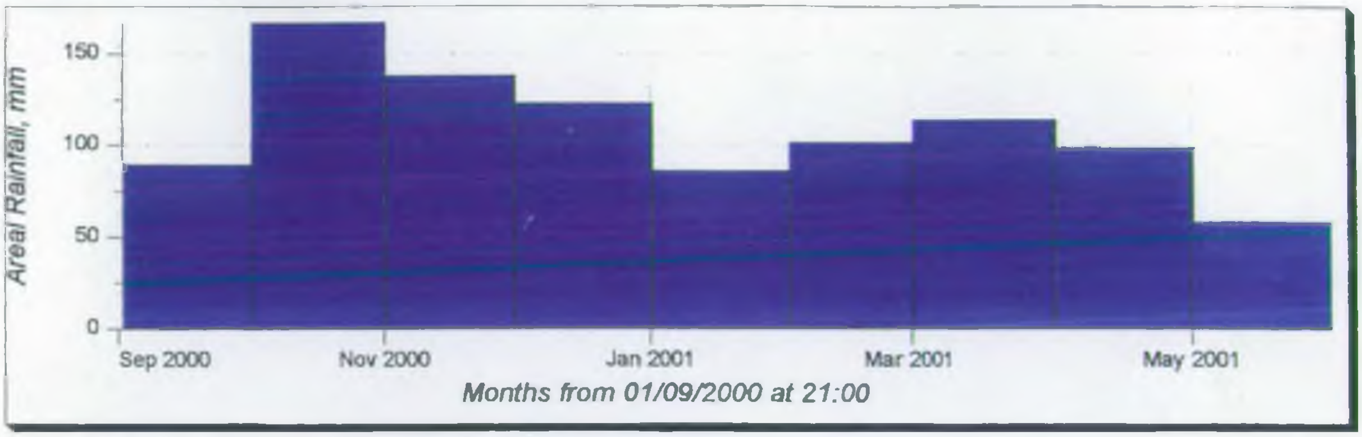
Drift Geology



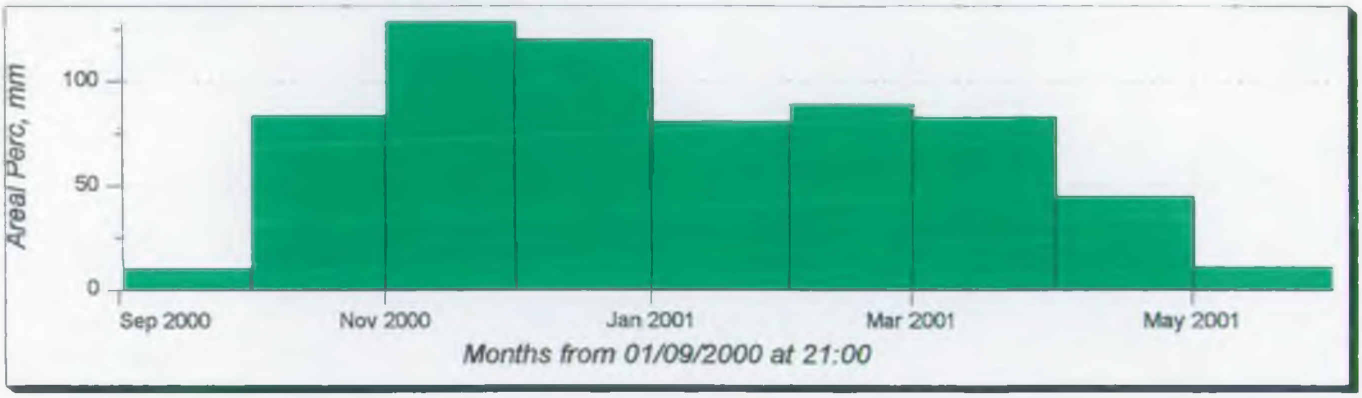
Solid Geology

Figure 32 Hydrological summary for the Gade catchment.

Chilerns-East (6140), Areal Rainfall.



Chilterns-East (6140), Areal Perc.



Croxley Green (2849), Flow.

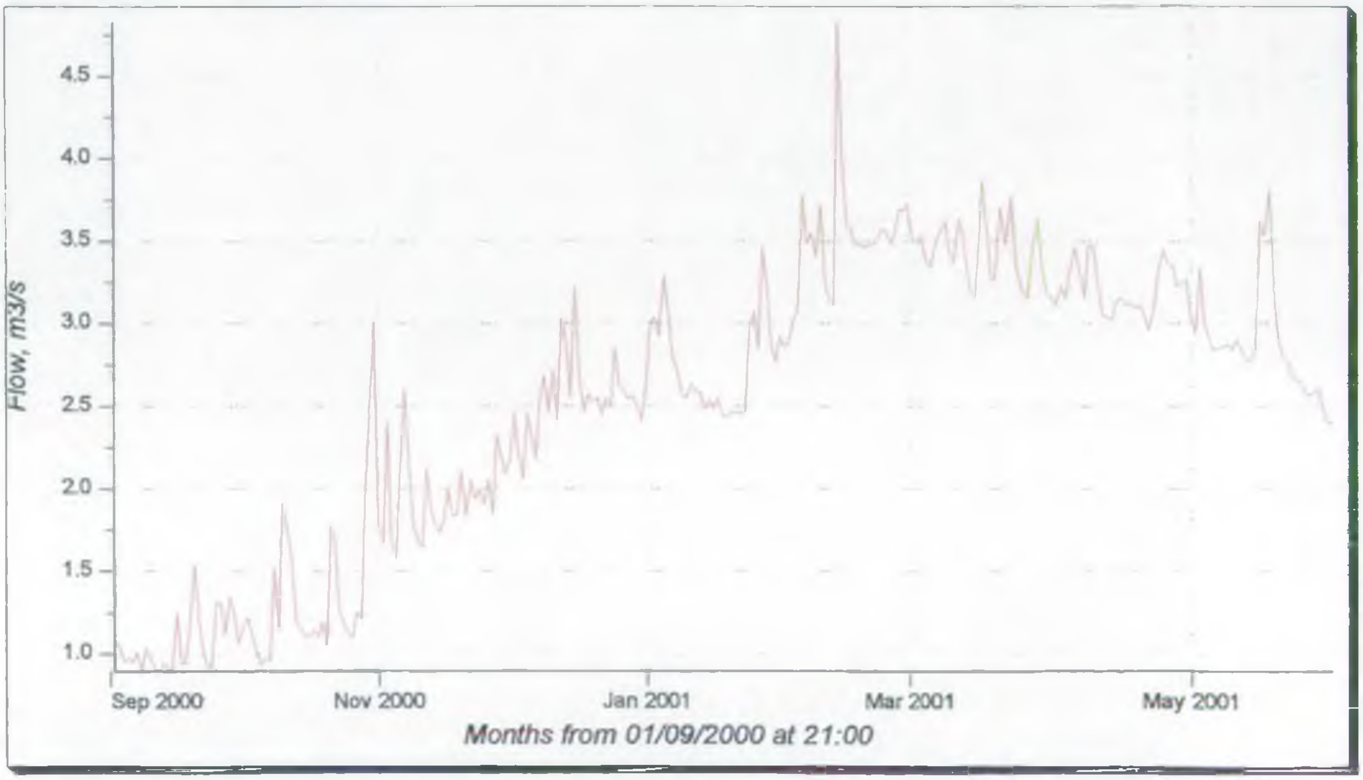
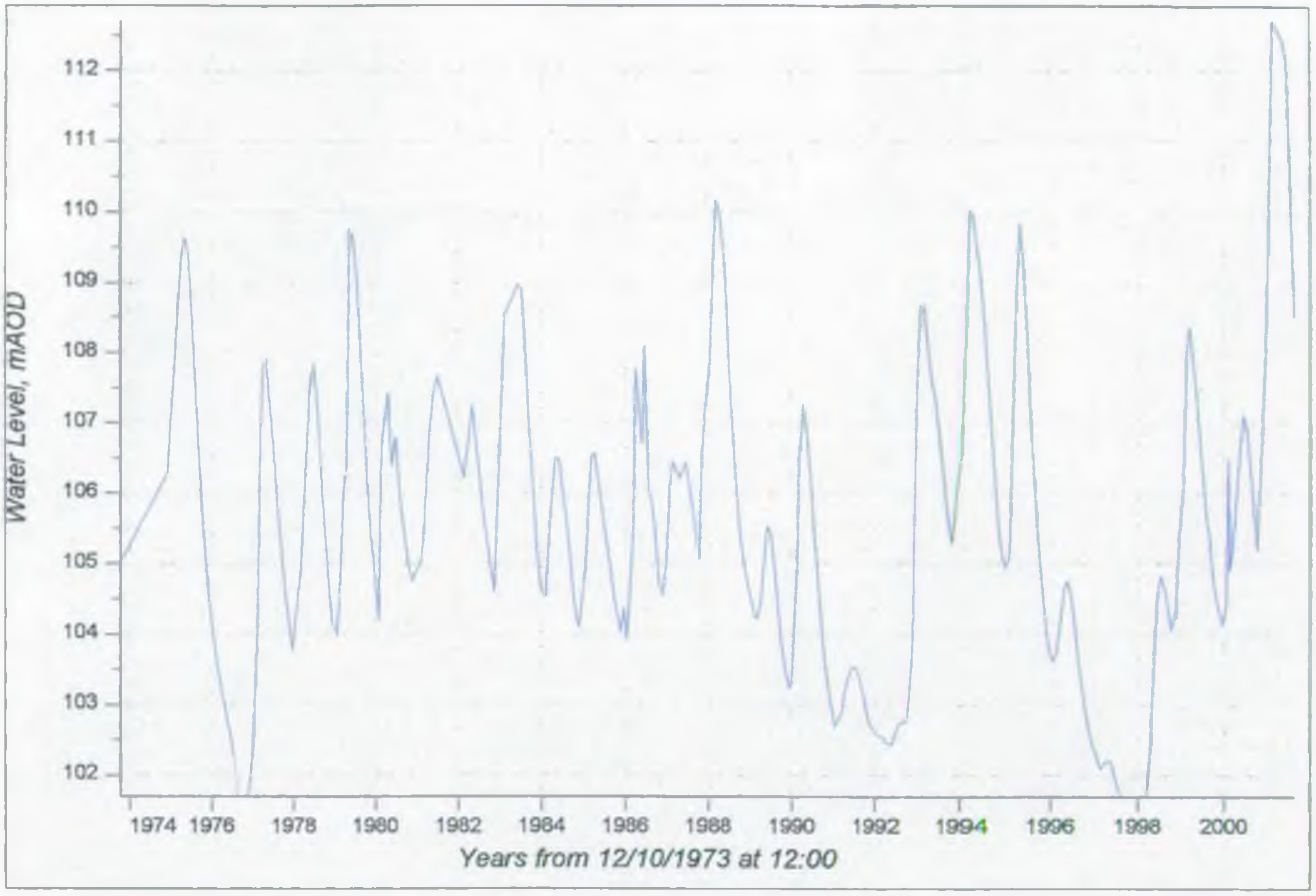


Figure 33 Hollybush Farm (TL00/30) Groundwater Levels



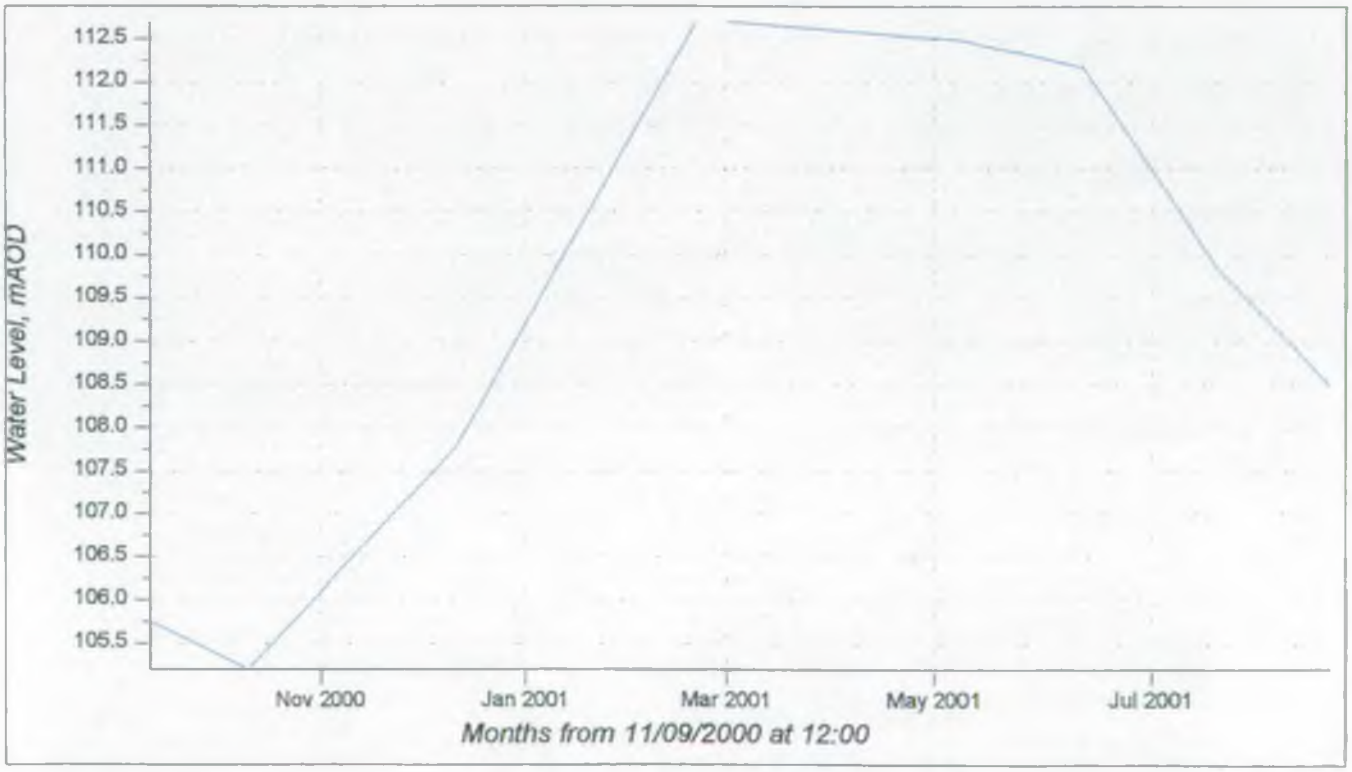


Figure 34: Groundwater, upper River Chess valley.

Figure 35: Groundwater in the upper River Mimram valley, TL 158 226

Figure 36. Location of observed Groundwater Flooding and Monitoring Sites, Upper Lee Valley tributaries

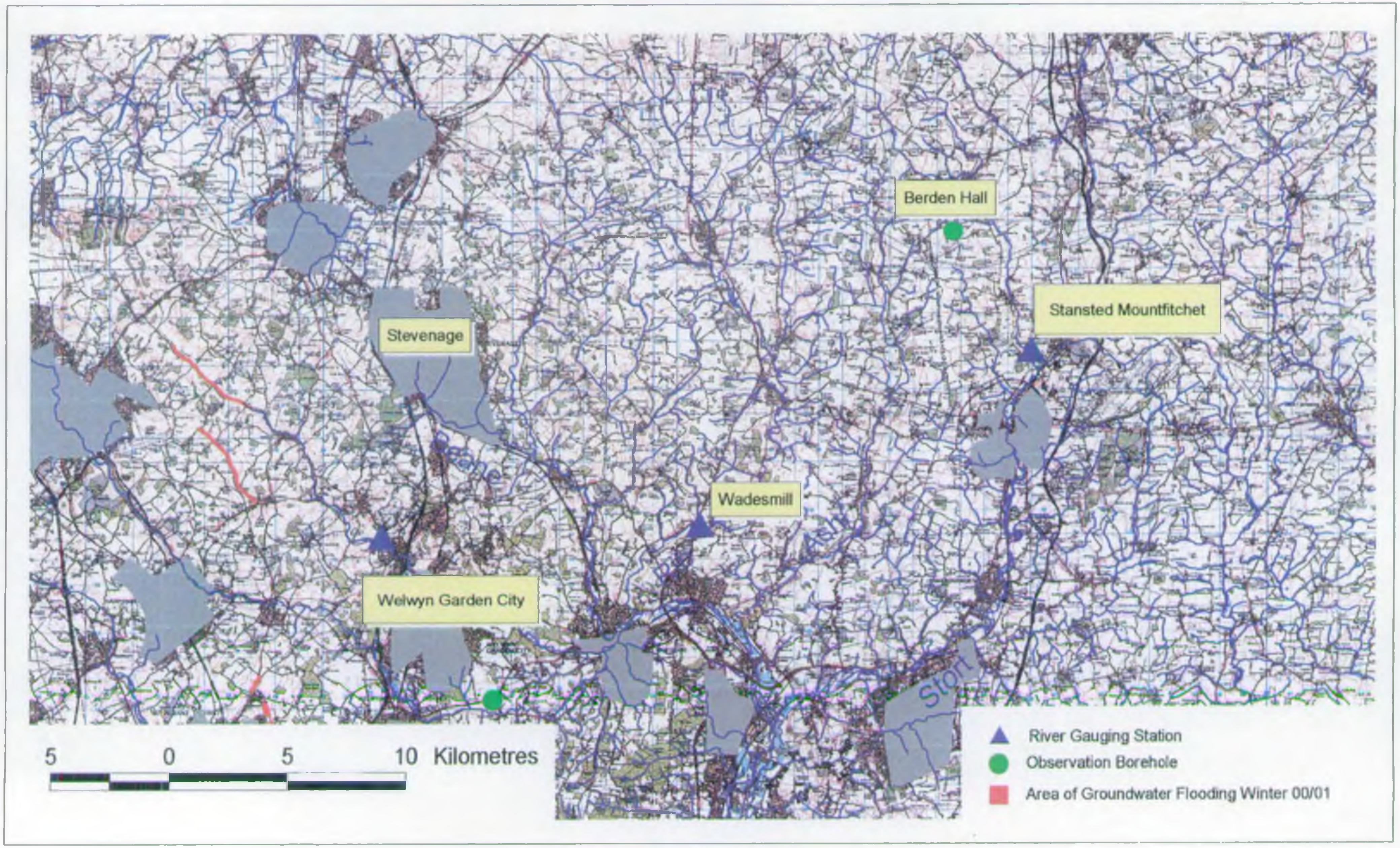
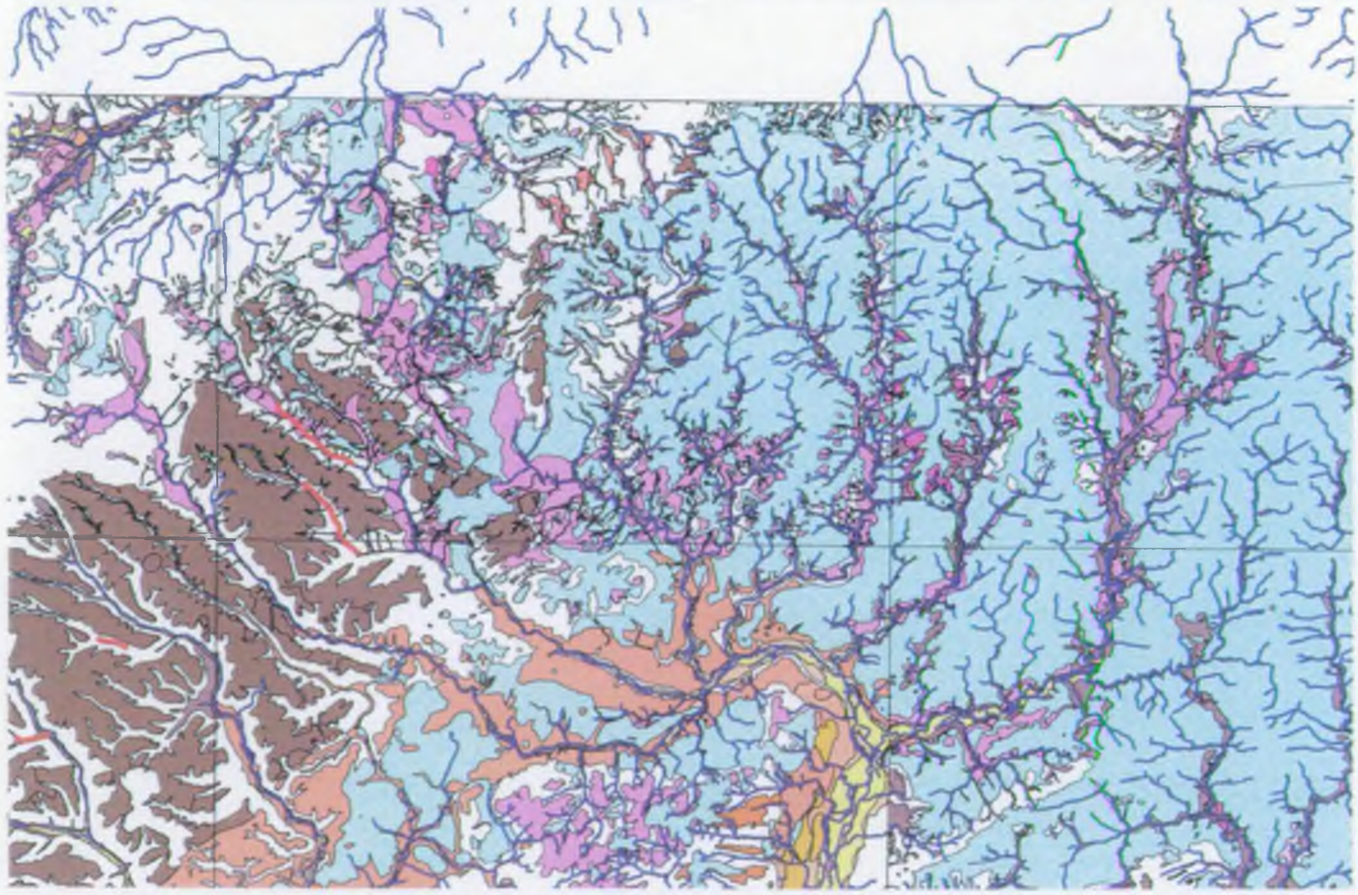
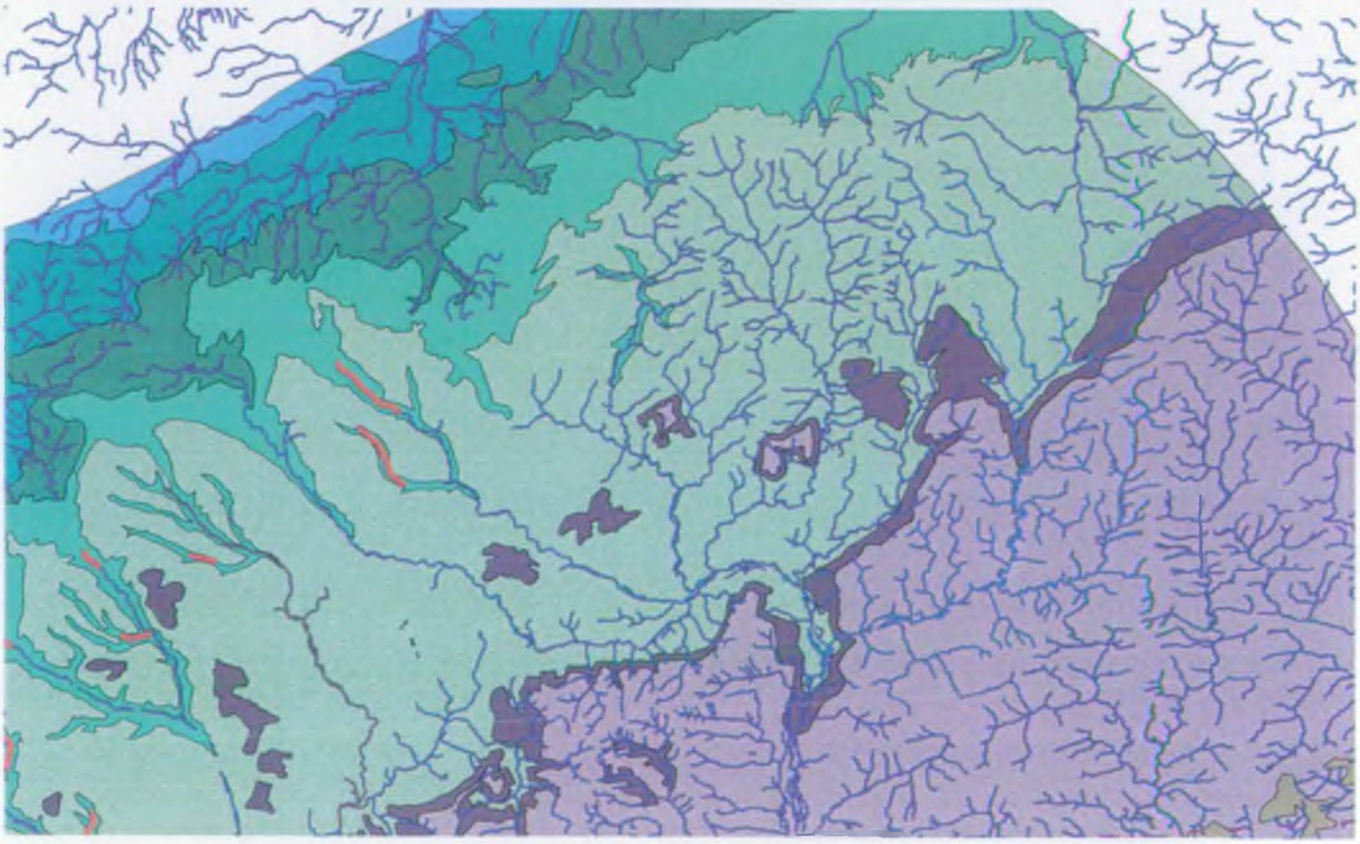


Figure 37. Solid and drift geology, Upper Lee Valley tributaries (E of Mimram)



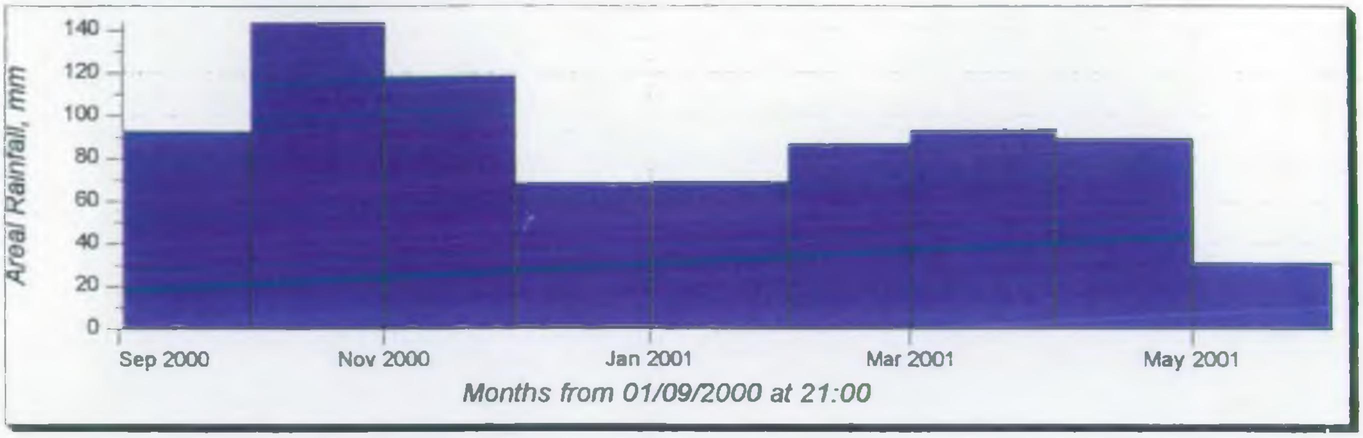
Drift Geology



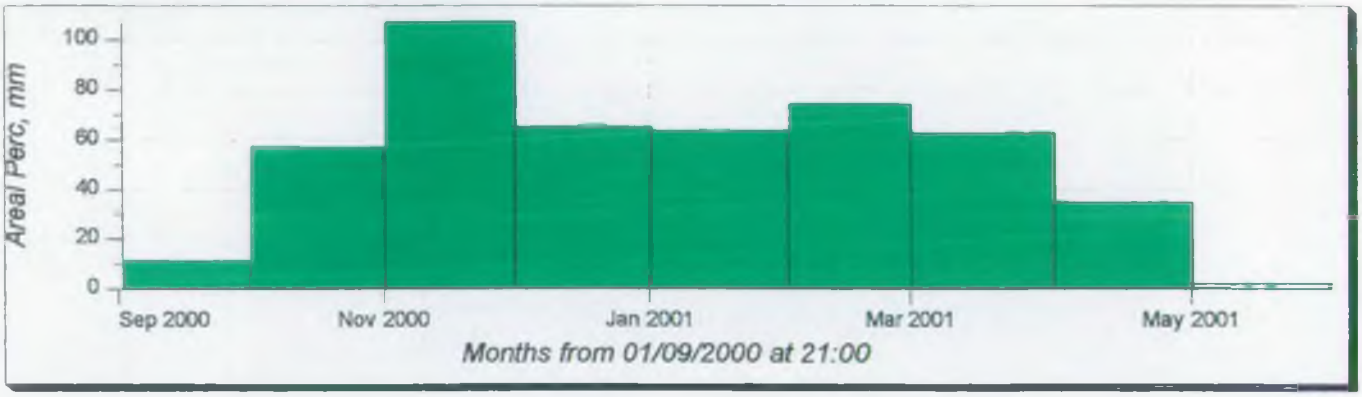
Solid Geology

Figure 38 Hydrological summary for the Mimram catchment.

Lee-Chalk (6600), Areal Rainfall.



Lee-Chalk (6600), Areal Perc.



Welwyn (Fulling Mill) (4770), Flow

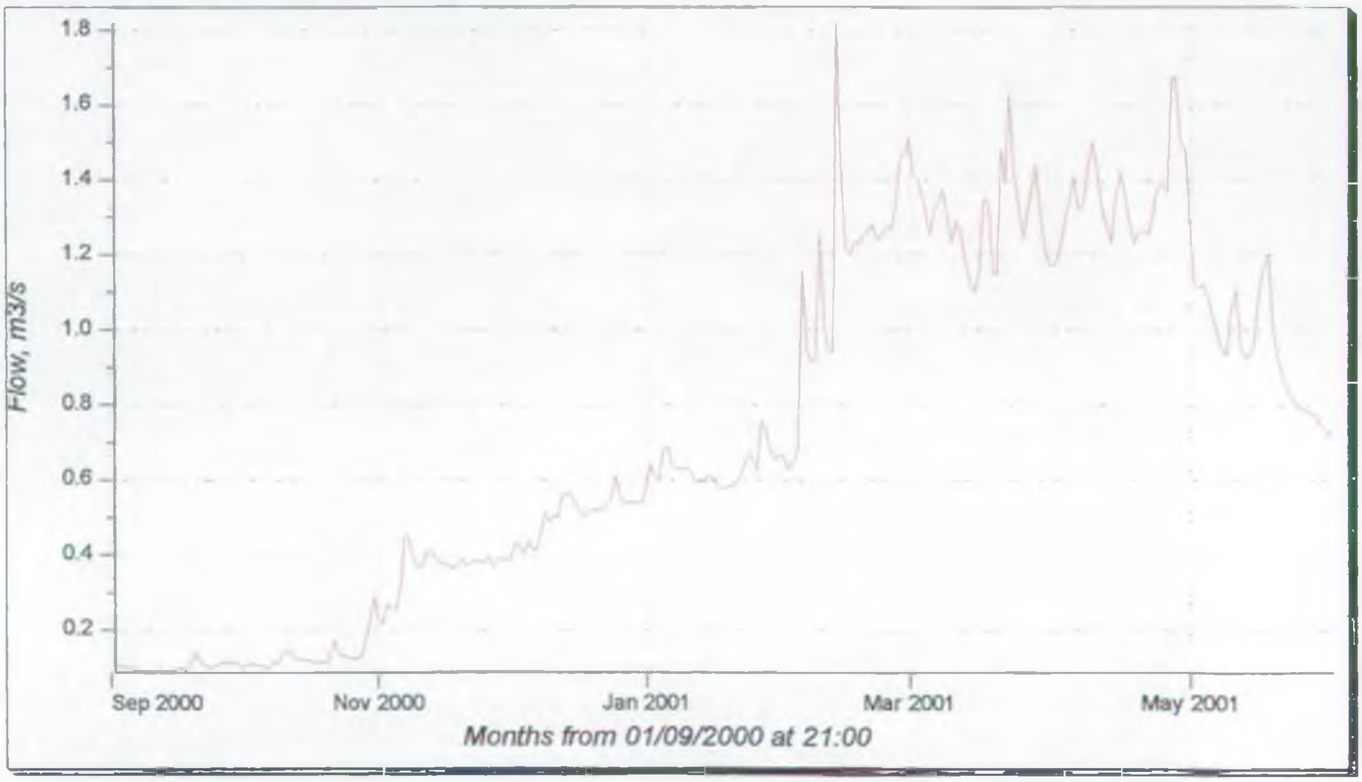


Figure 39 Cole Green (TL21/87) Groundwater Levels

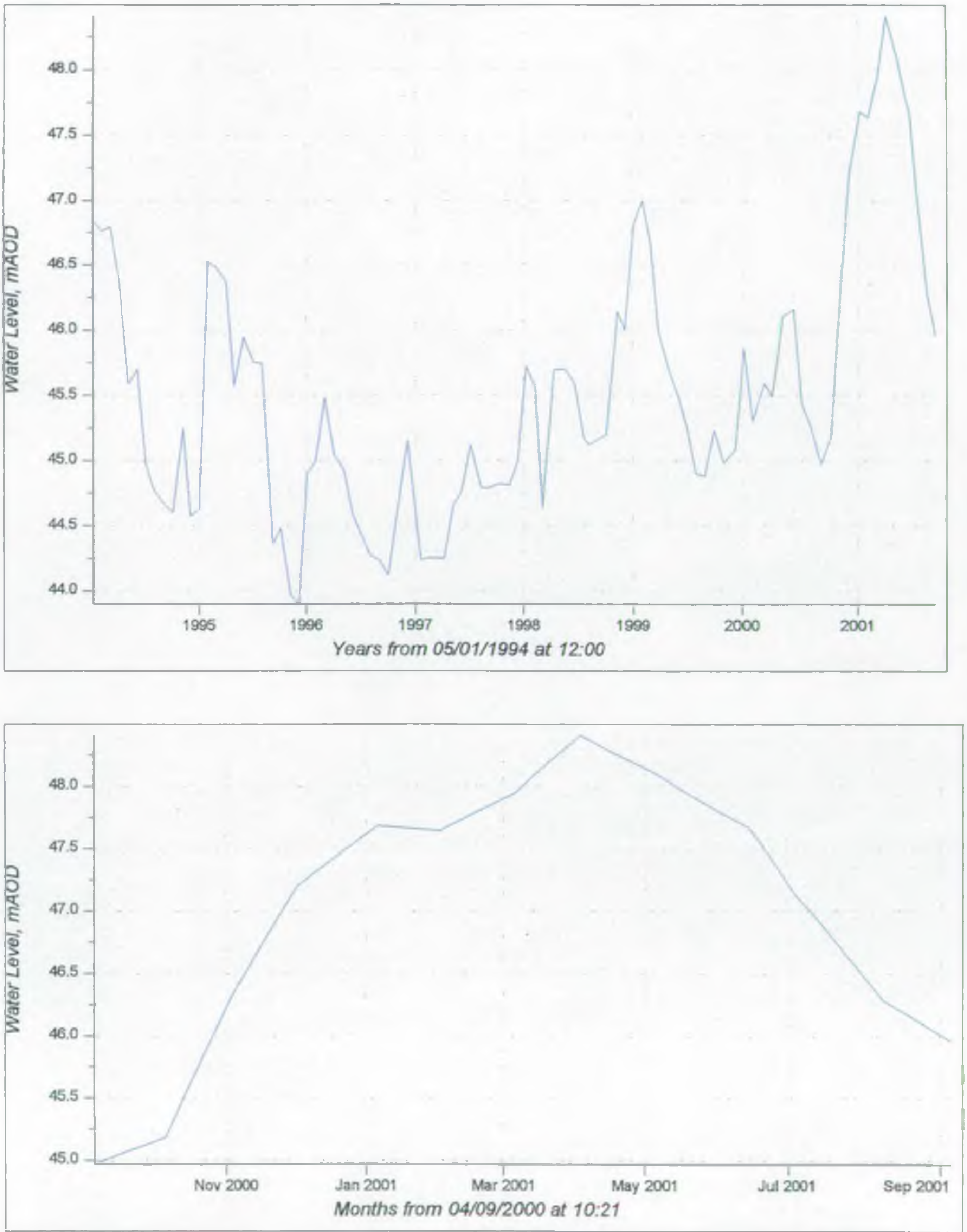
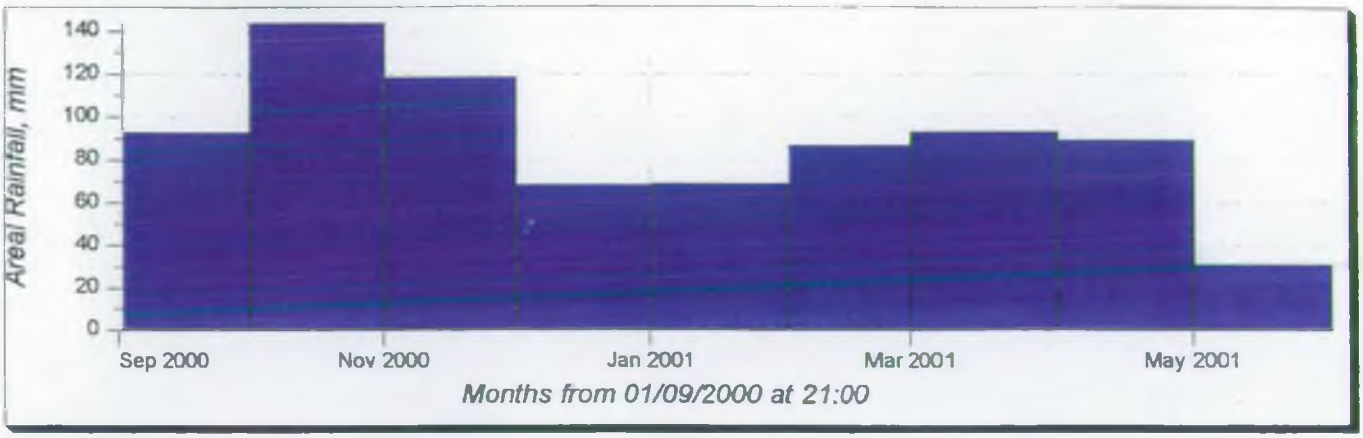
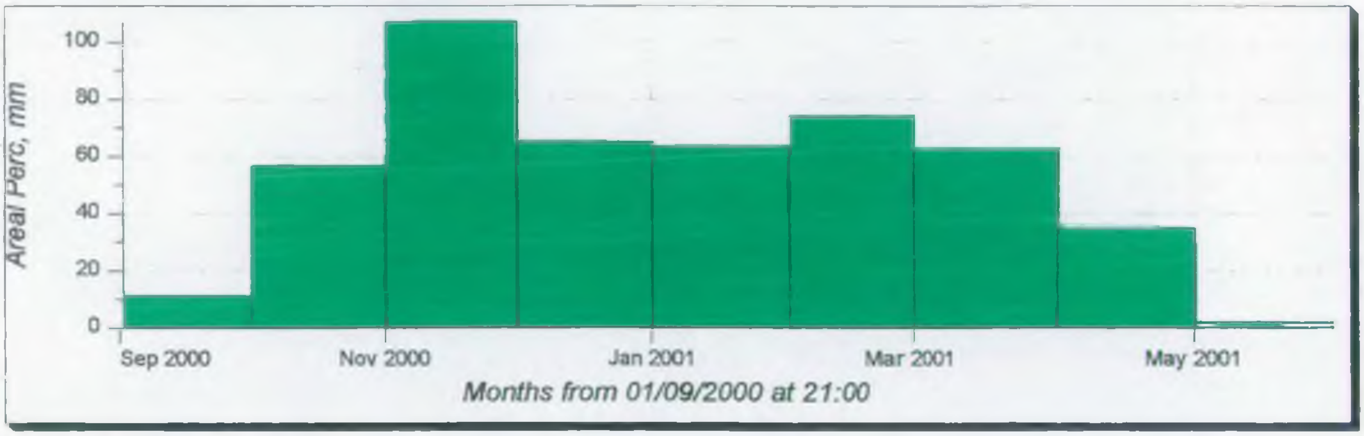


Figure 40 Hydrological summary for the Rib catchment.

Lee-Chalk (6600), Areal Rainfall.



Lee-Chalk (6600), Areal Perc.



Wadesmill (4980), Flow.

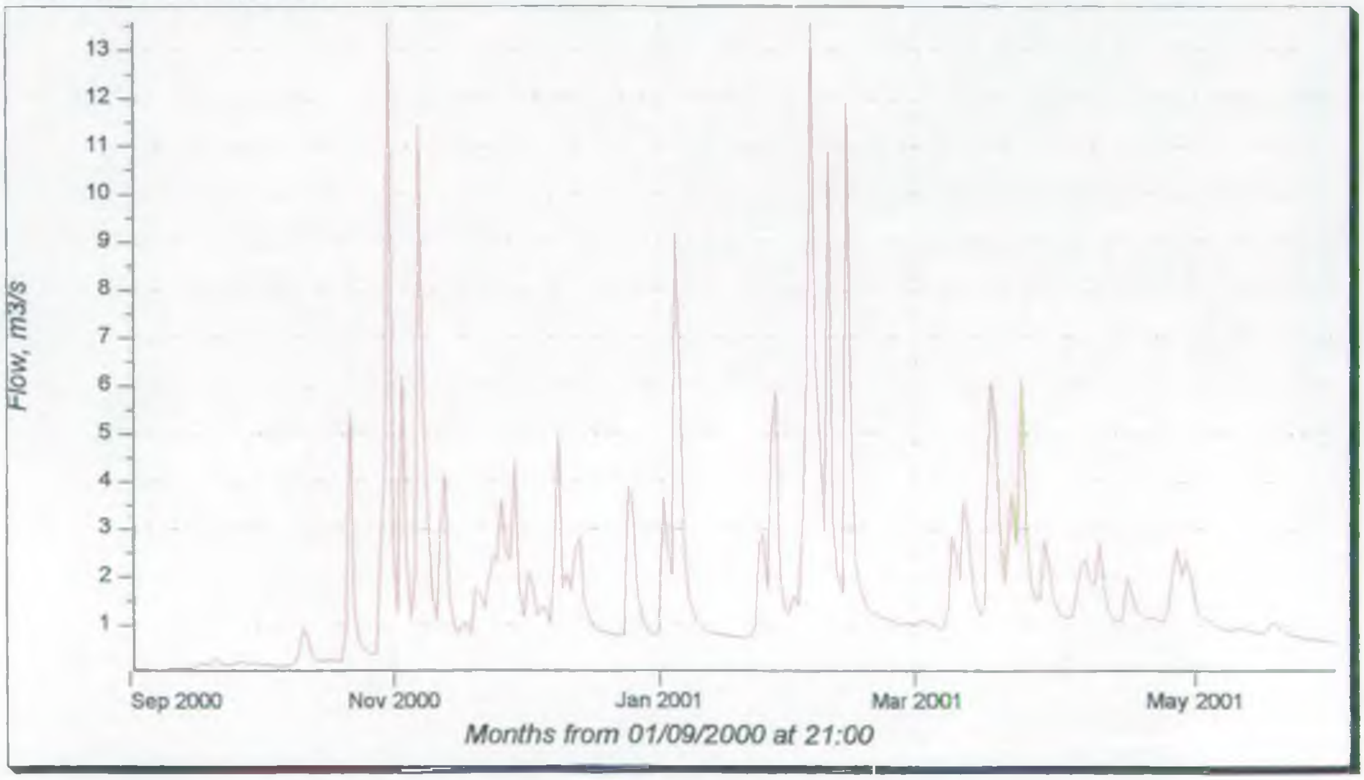
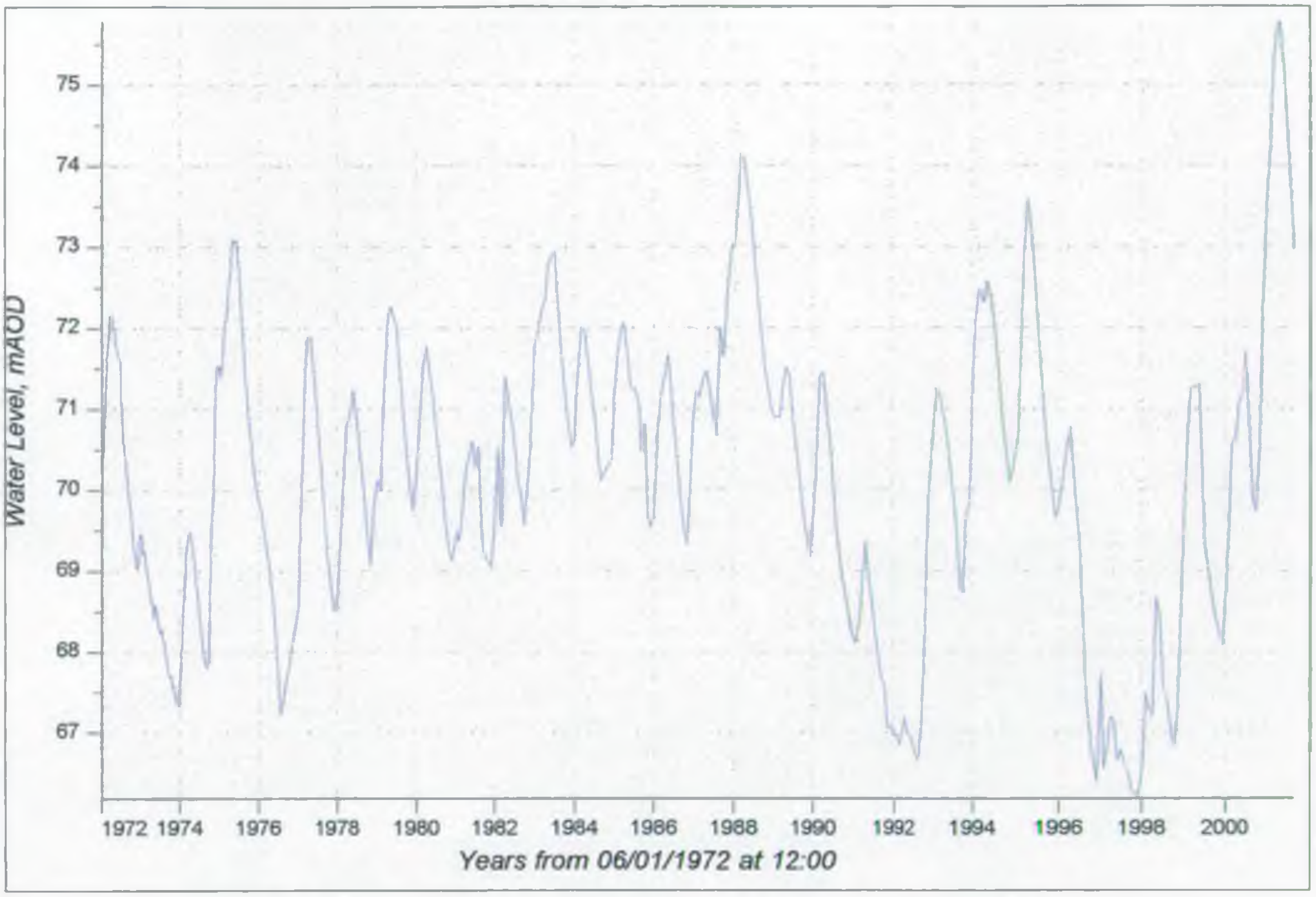


Figure 41 Berden Hall (TL42/8) Groundwater Levels



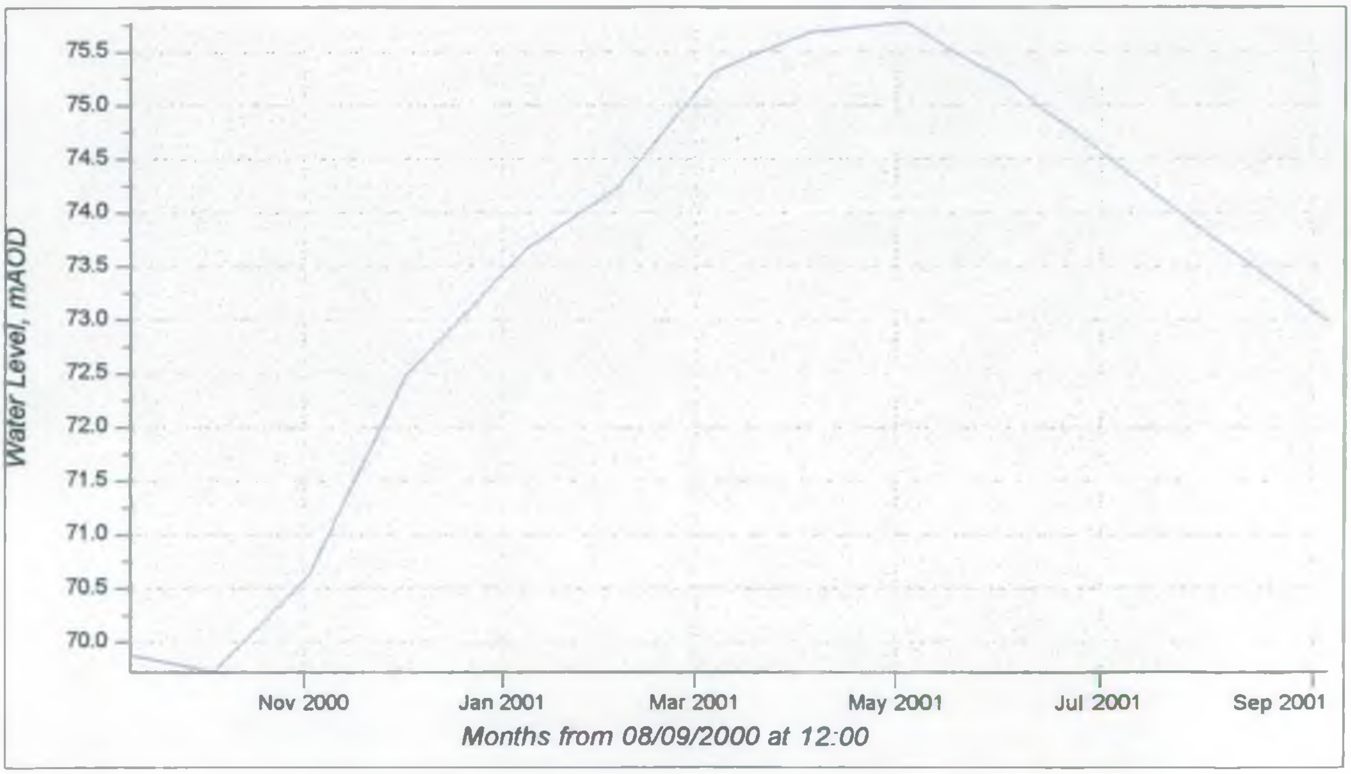
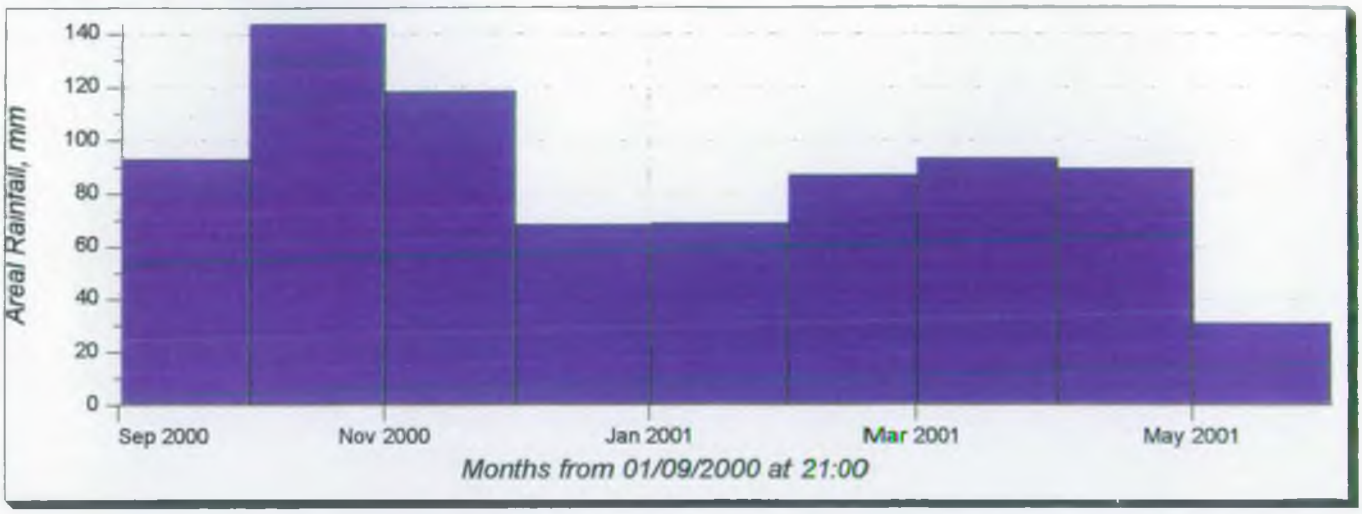
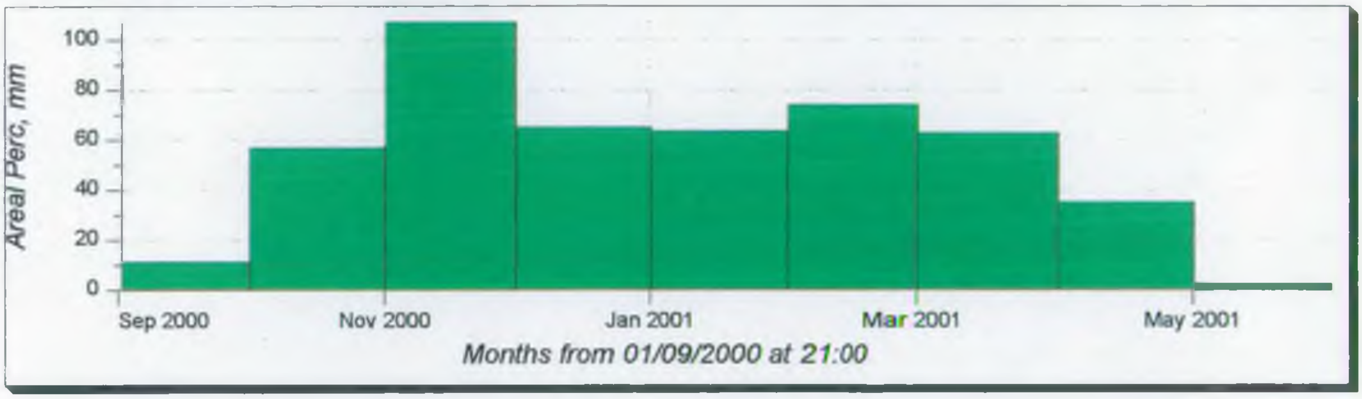


Figure 42 Hydrological summary for the Stort catchment.

Lee-Chalk (6600), Areal Rainfall.



Lee-Chalk (6600), Areal Perc.



Stansted Mountfitchet (5106), Flow.

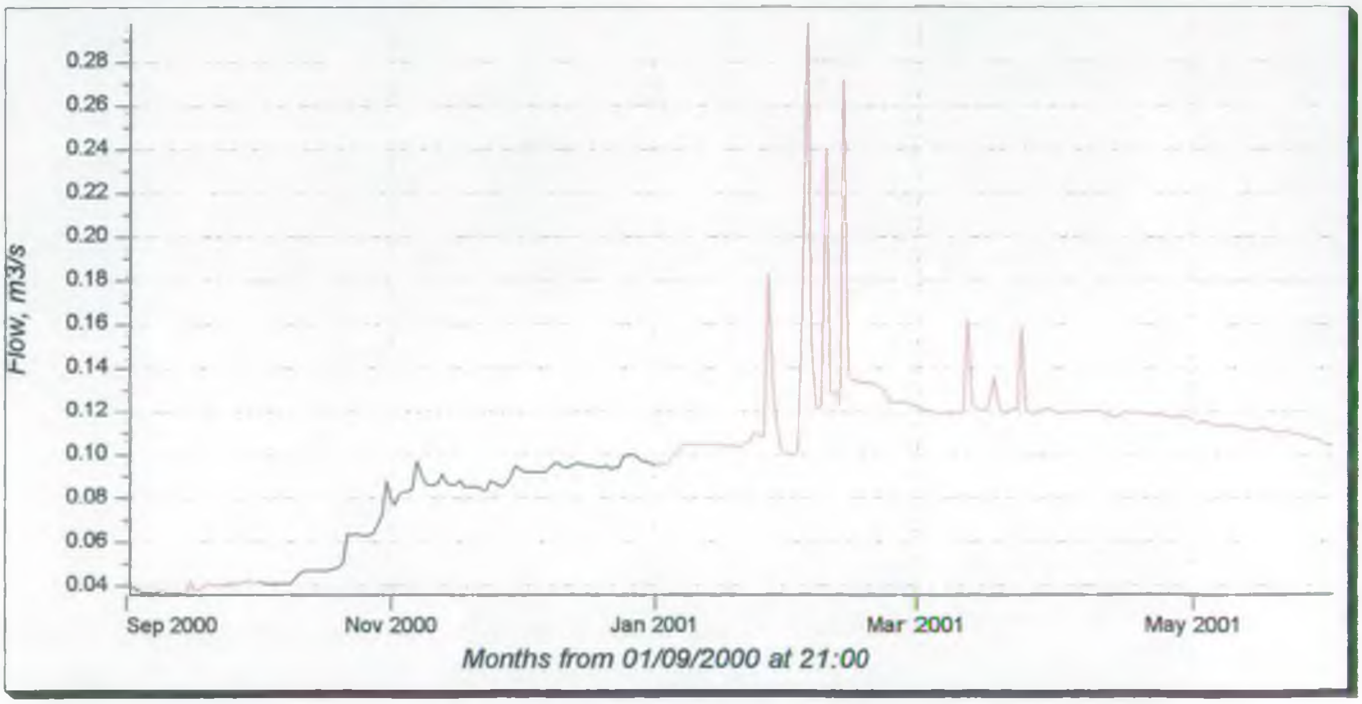


Figure 43: Groundwater flow in the valley above the village of Kimpton, Mimram catchment

Figure 44: Groundwater in the upper Mimram catchment.

Figure 45: Overflowing observation borehole, TL32/7, TL 386 247, Braughing, River Rib.

Figure 46: Groundwater in the River Ash catchment , TL 443 231.

Figure 47. Location of observed Groundwater Flooding and Monitoring Sites, N Hampshire

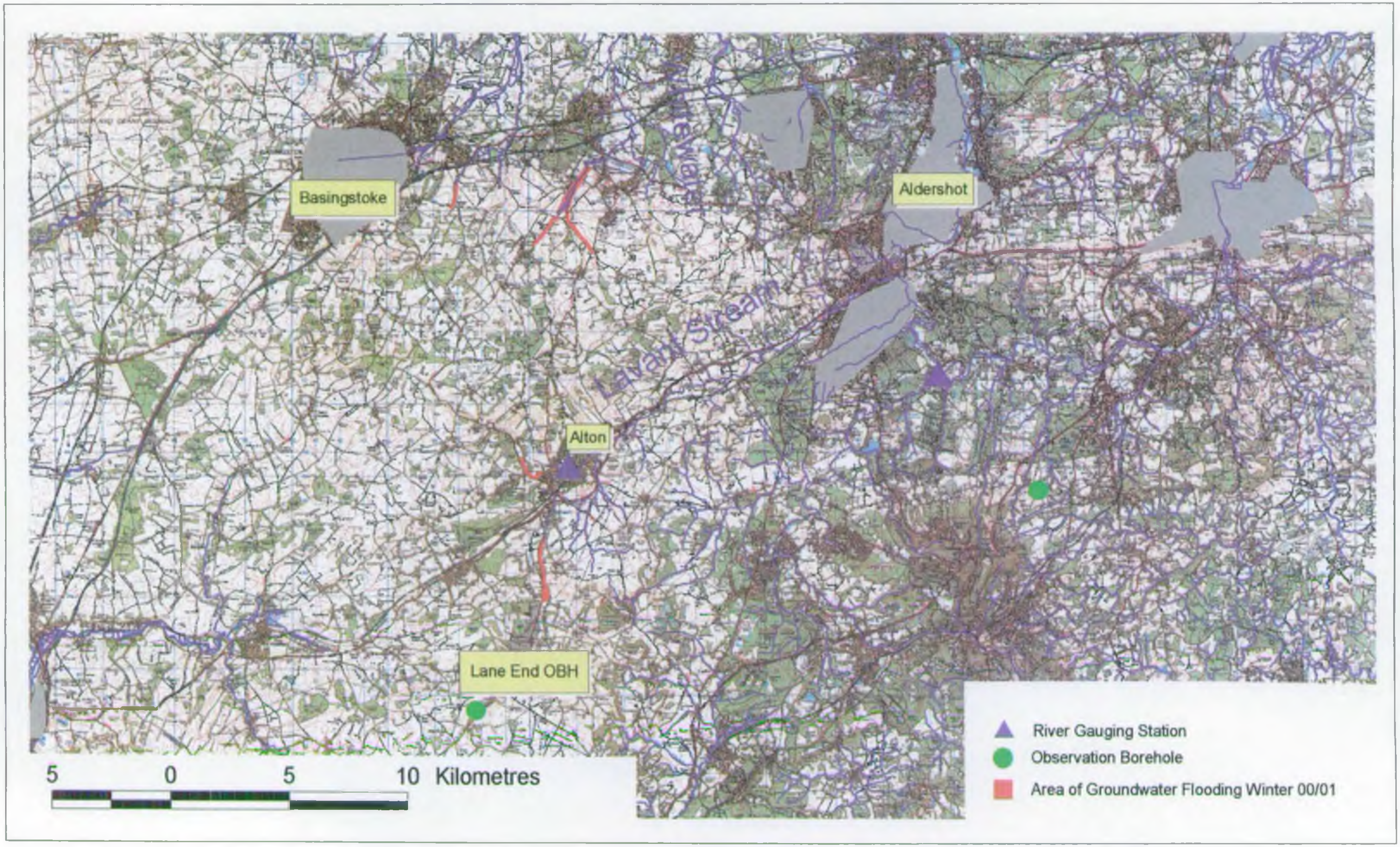
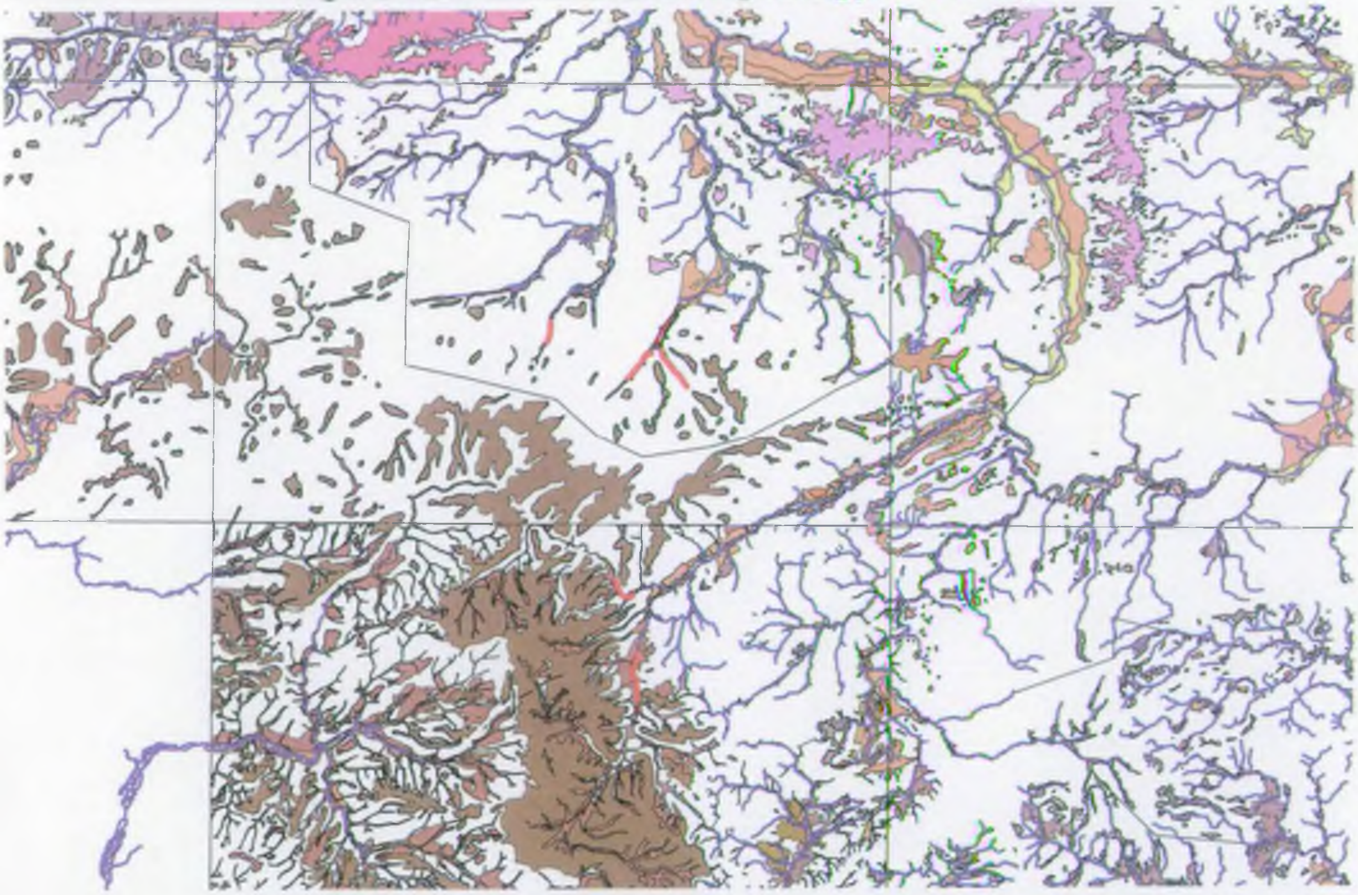
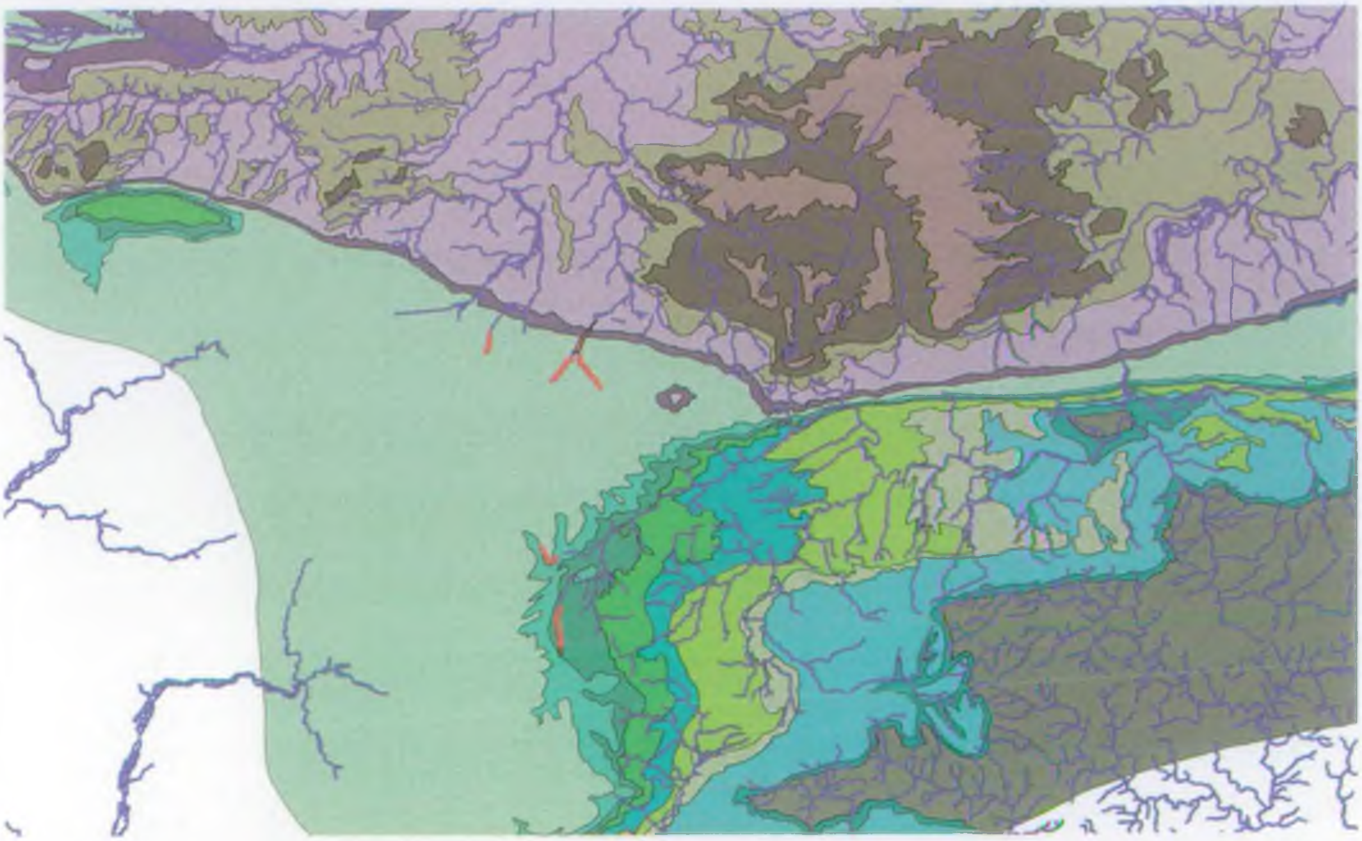


Figure 48. Solid and drift geology, N Hampshire



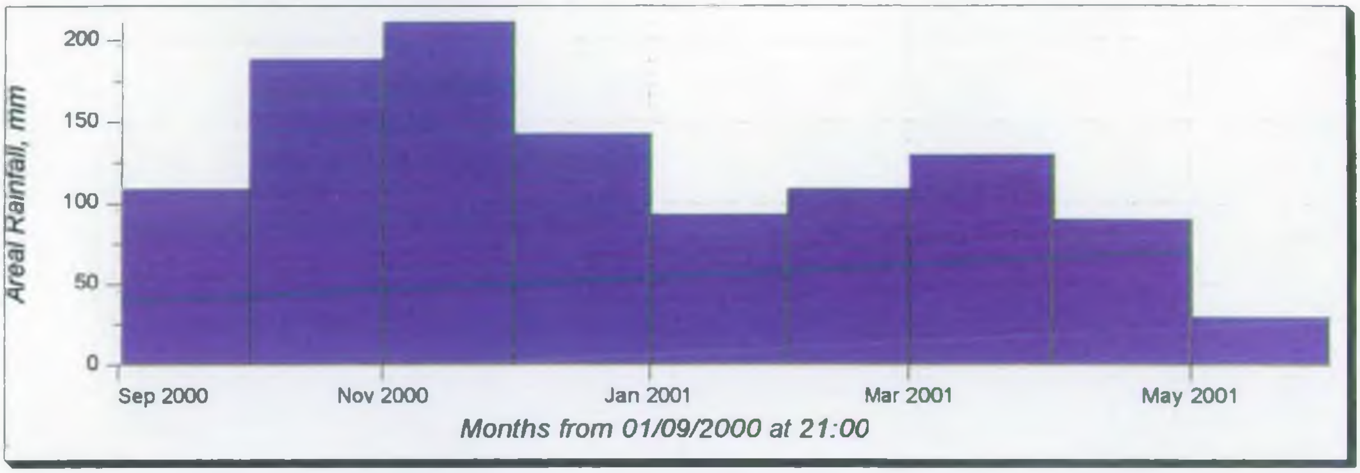
Drift Geology



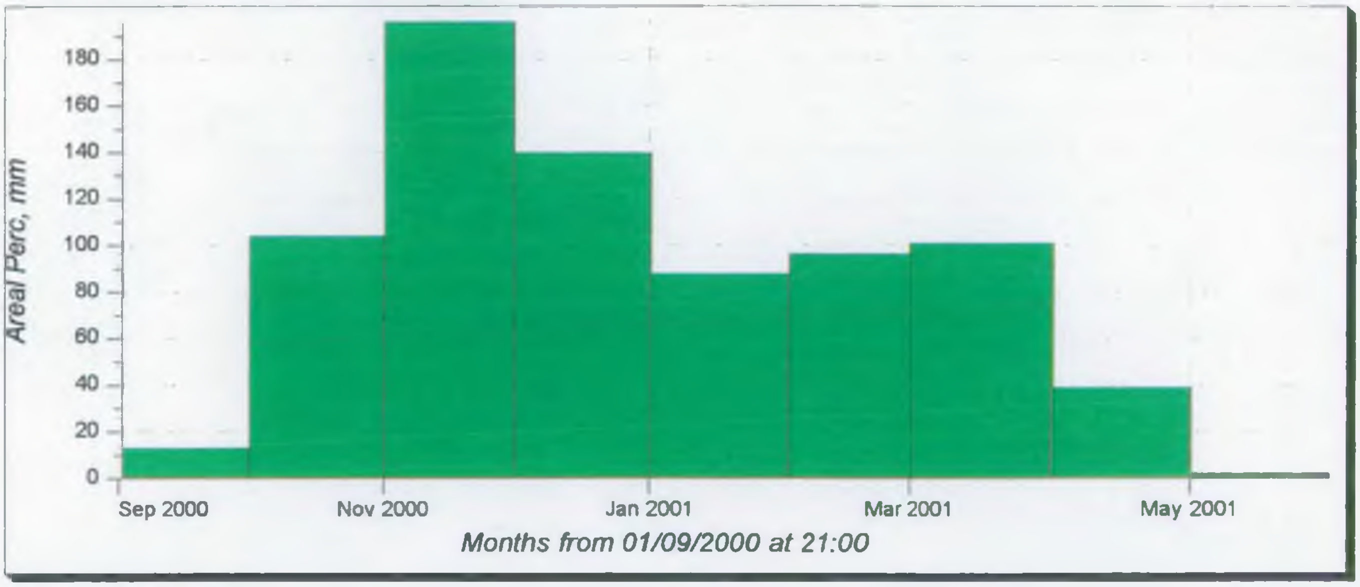
Solid Geology

Figure 49 Hydrological summary for the Lavant Stream catchment.

N.Downs-West (6162), Areal Rainfall.



N.Downs-West (6162), Areal Perc.



Alton (3010), Flow.

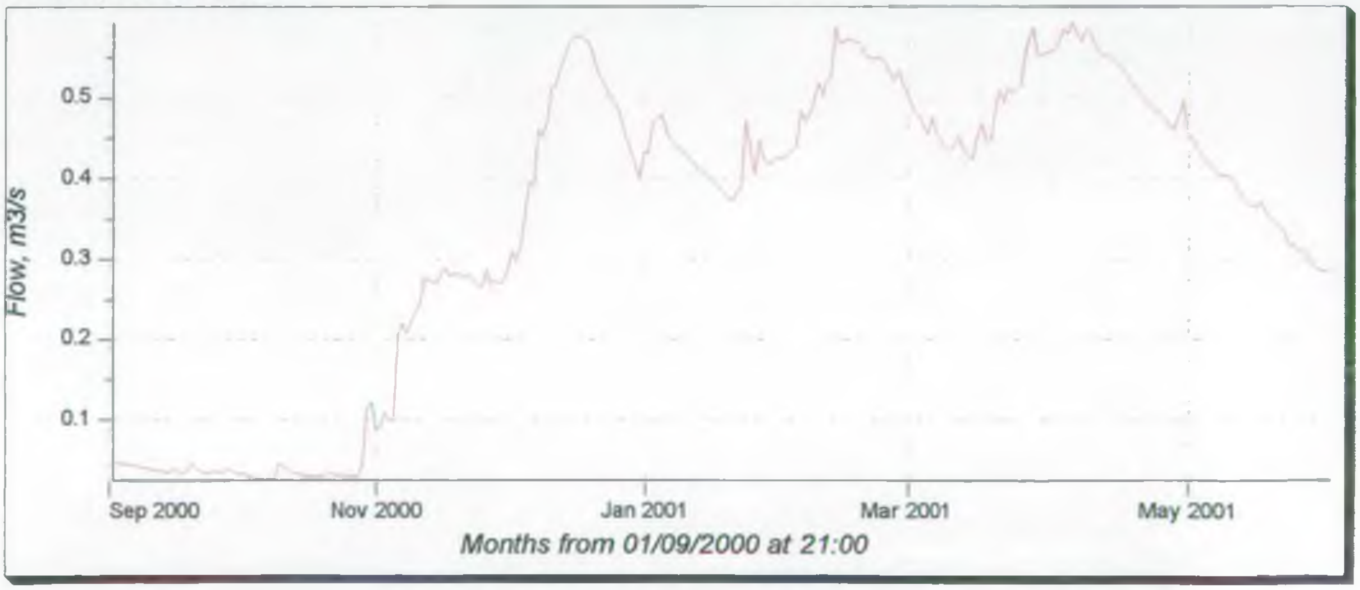


Figure 50 Lane End OBH (SU62/113) Groundwater Levels

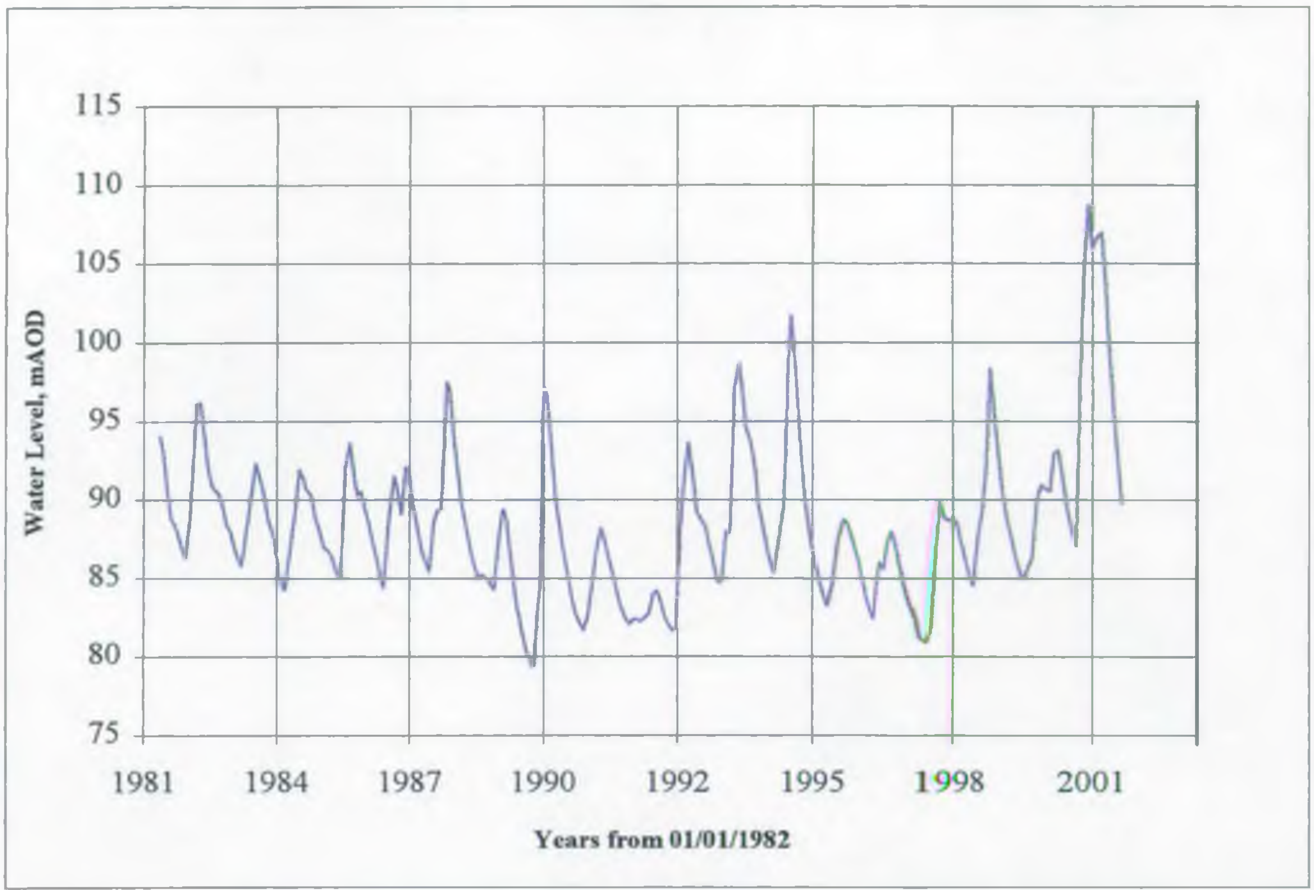


Figure 51: Groundwater lake, Lavant stream valley, above Farringdon, Hants, SU 706 344. (21/12/00)

Figure 52: Flooded properties, Chase Field, Farringdon, Lavant stream, 21/12/00

Figure 53: Chase Field properties, still flooded 8/04/01

Figure 54: Chase field, 1945 and present day - from the Farringdon Village Millenium Book.

New housing developments in Farringdon of the 20th century

Chase Field under water (left)in 1945, with visiting swans, before the new houses (below) were built

Figure 55. Location of observed Groundwater Flooding and Monitoring Sites, N Downs

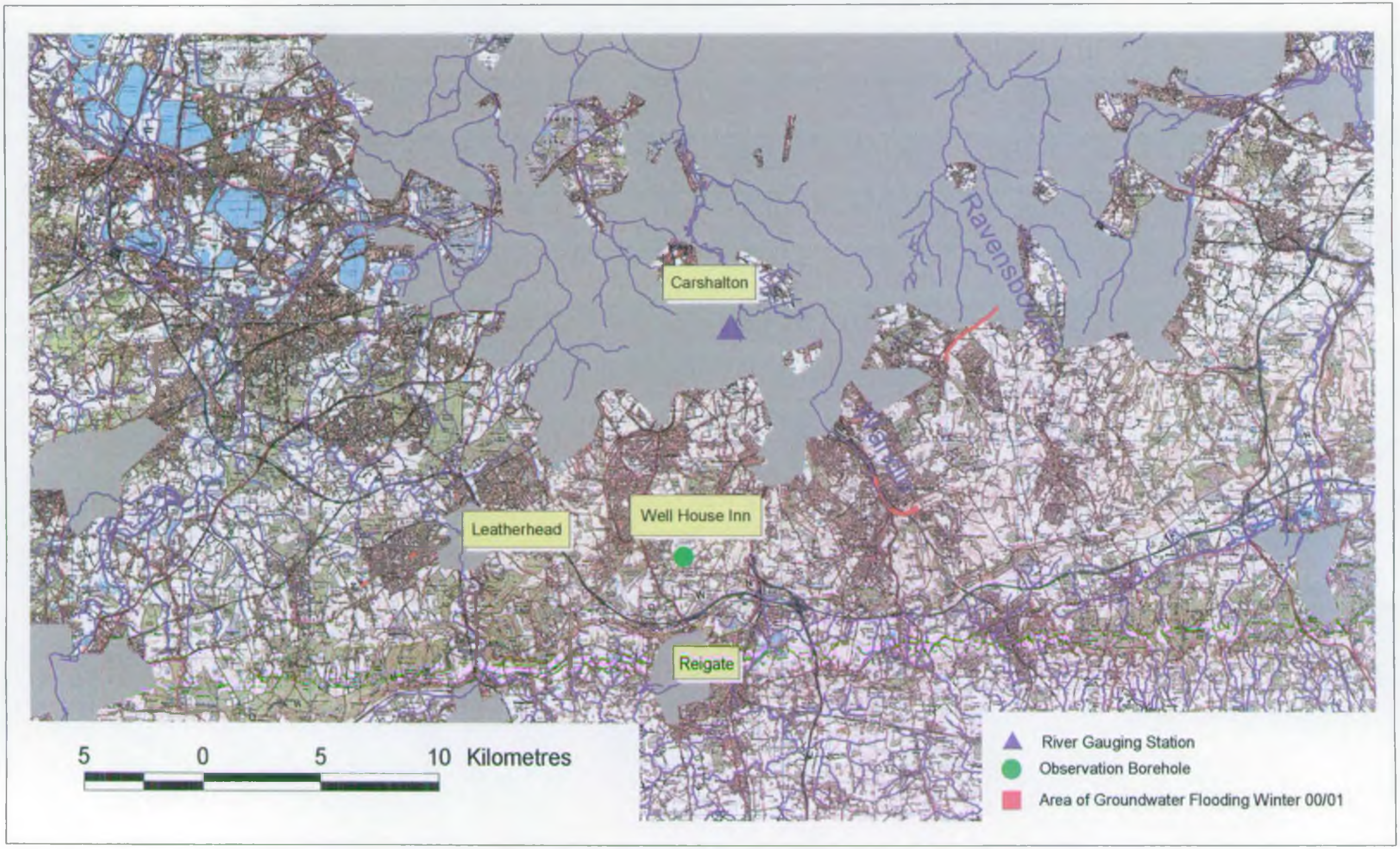
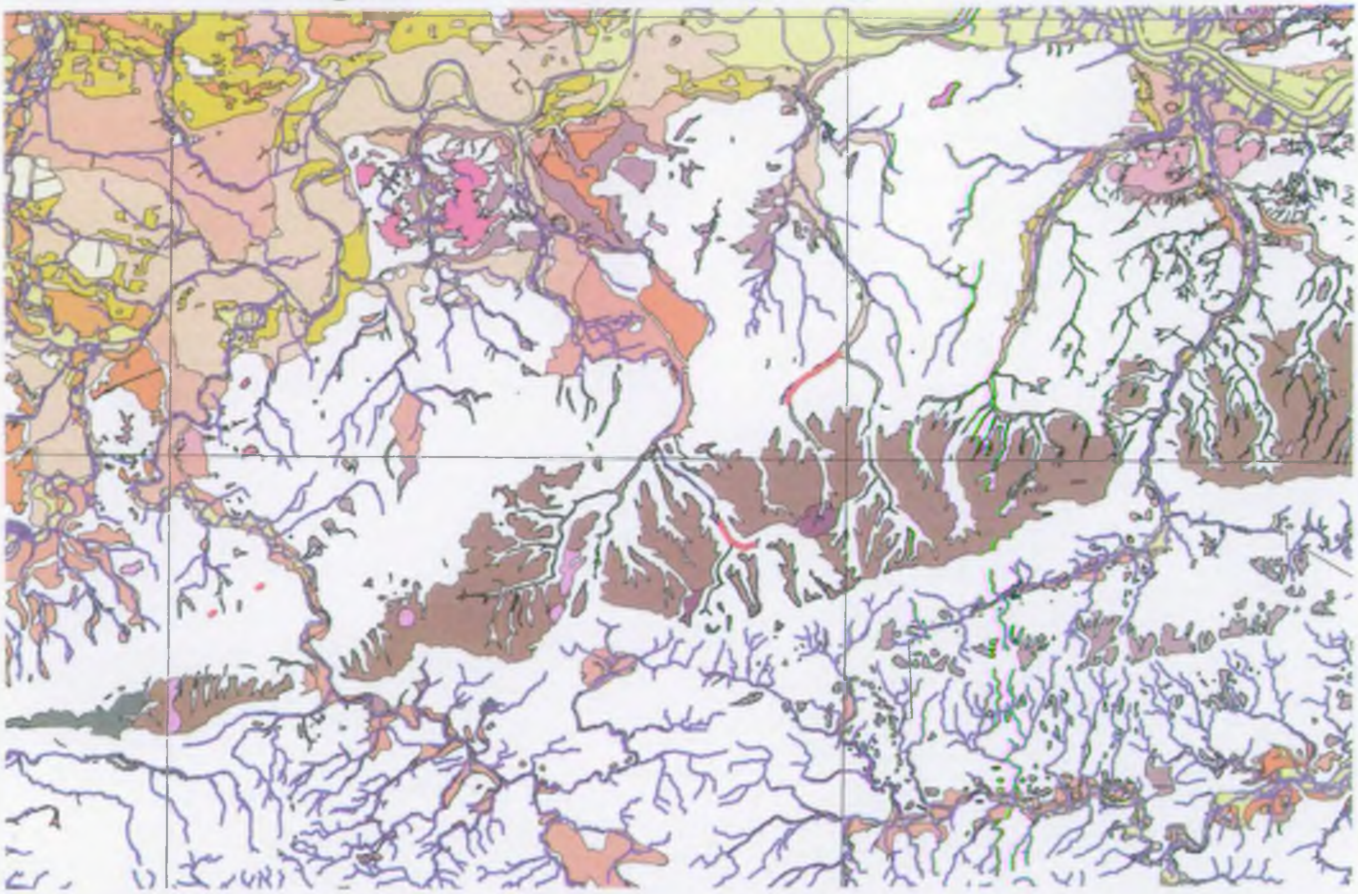
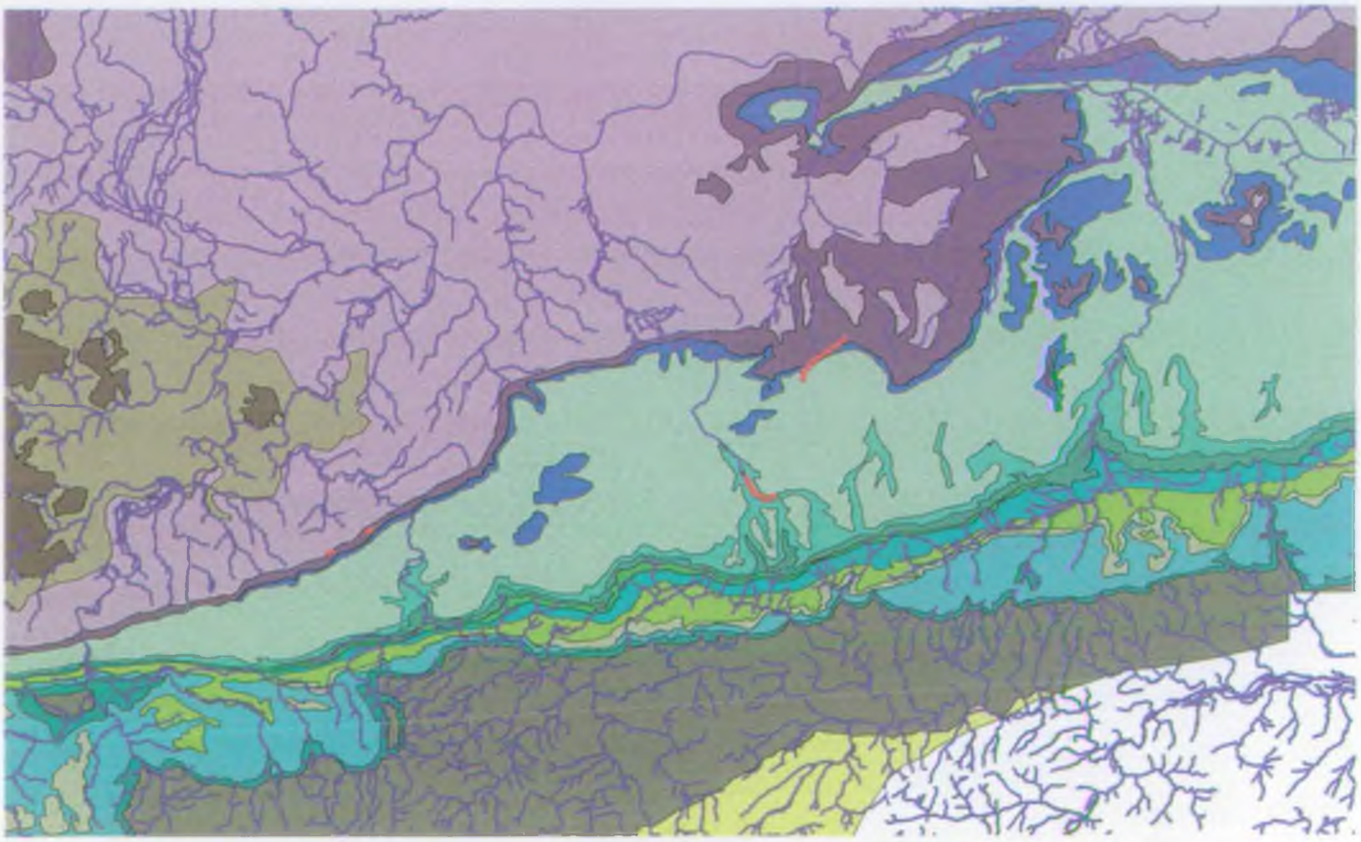


Figure 56. Solid and drift geology, N Downs



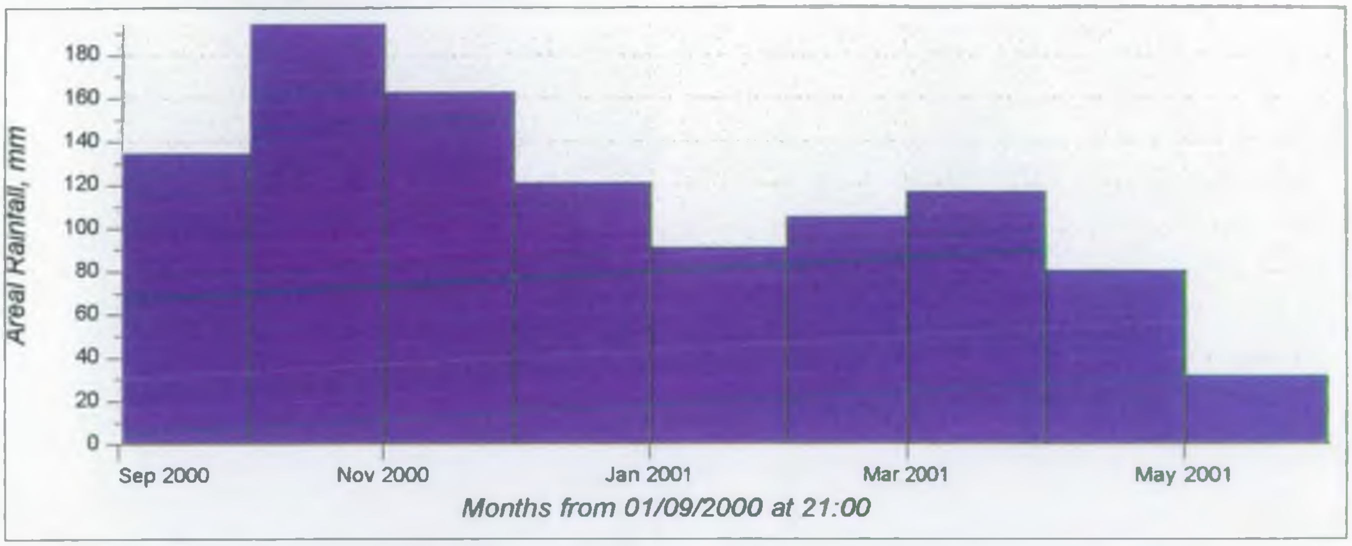
Drift Geology



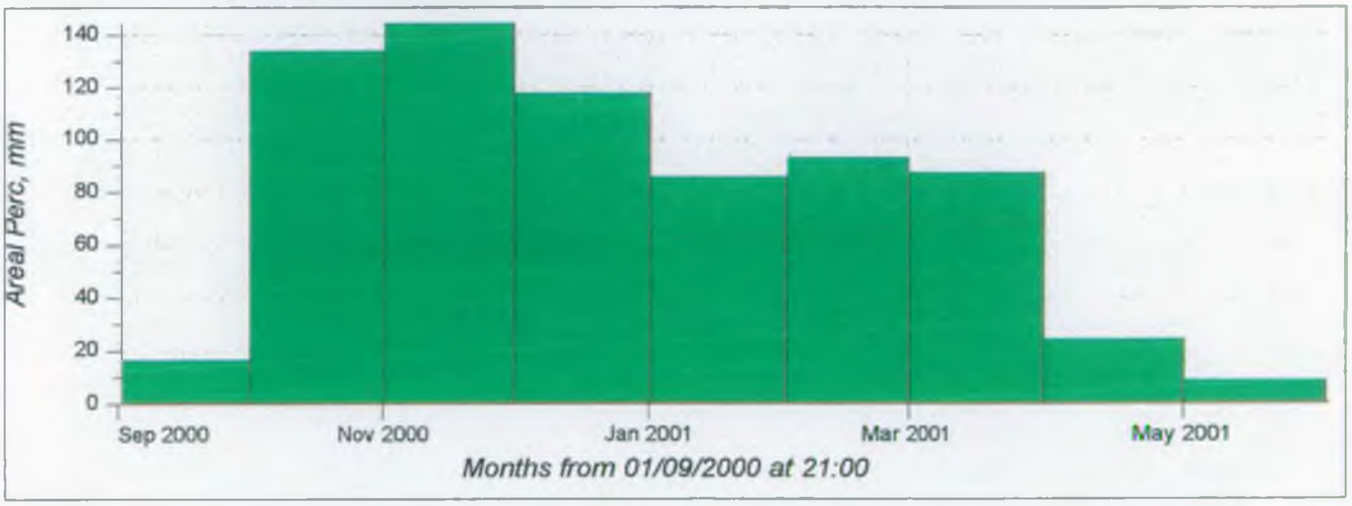
Solid Geology

Figure 57 Hydrological summary for the Wandle catchment.

N.Downs-West (6230), Areal Rainfall.



N.Downs-West (6230), Areal Perc.



Carshalton (4159), Flow.

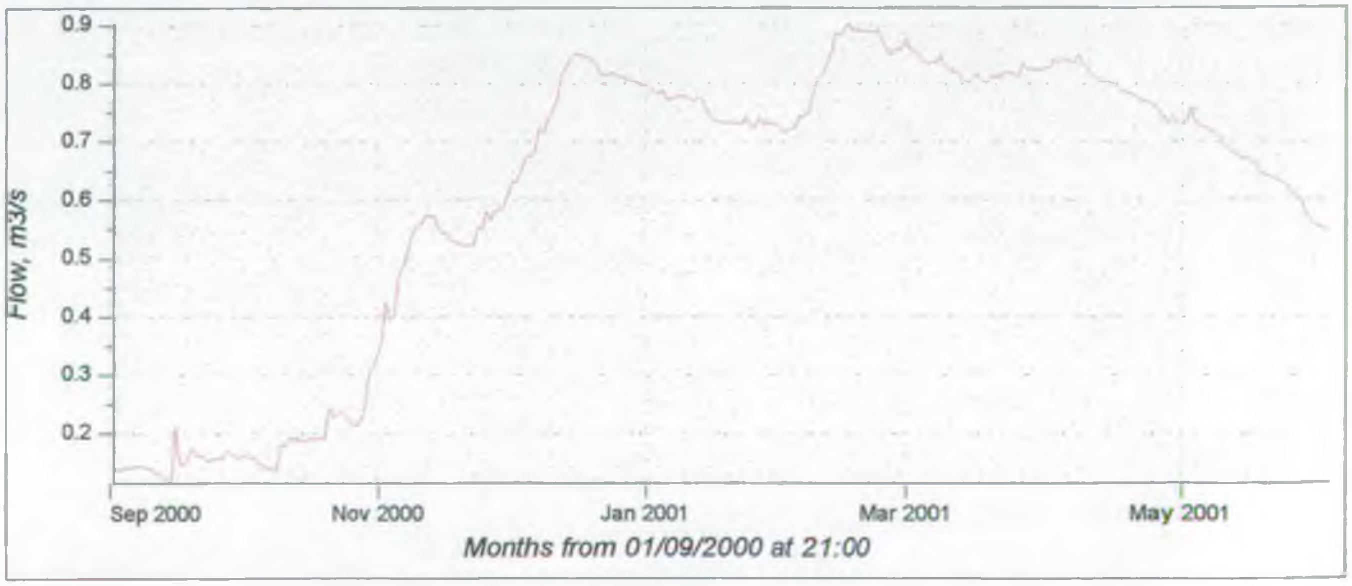
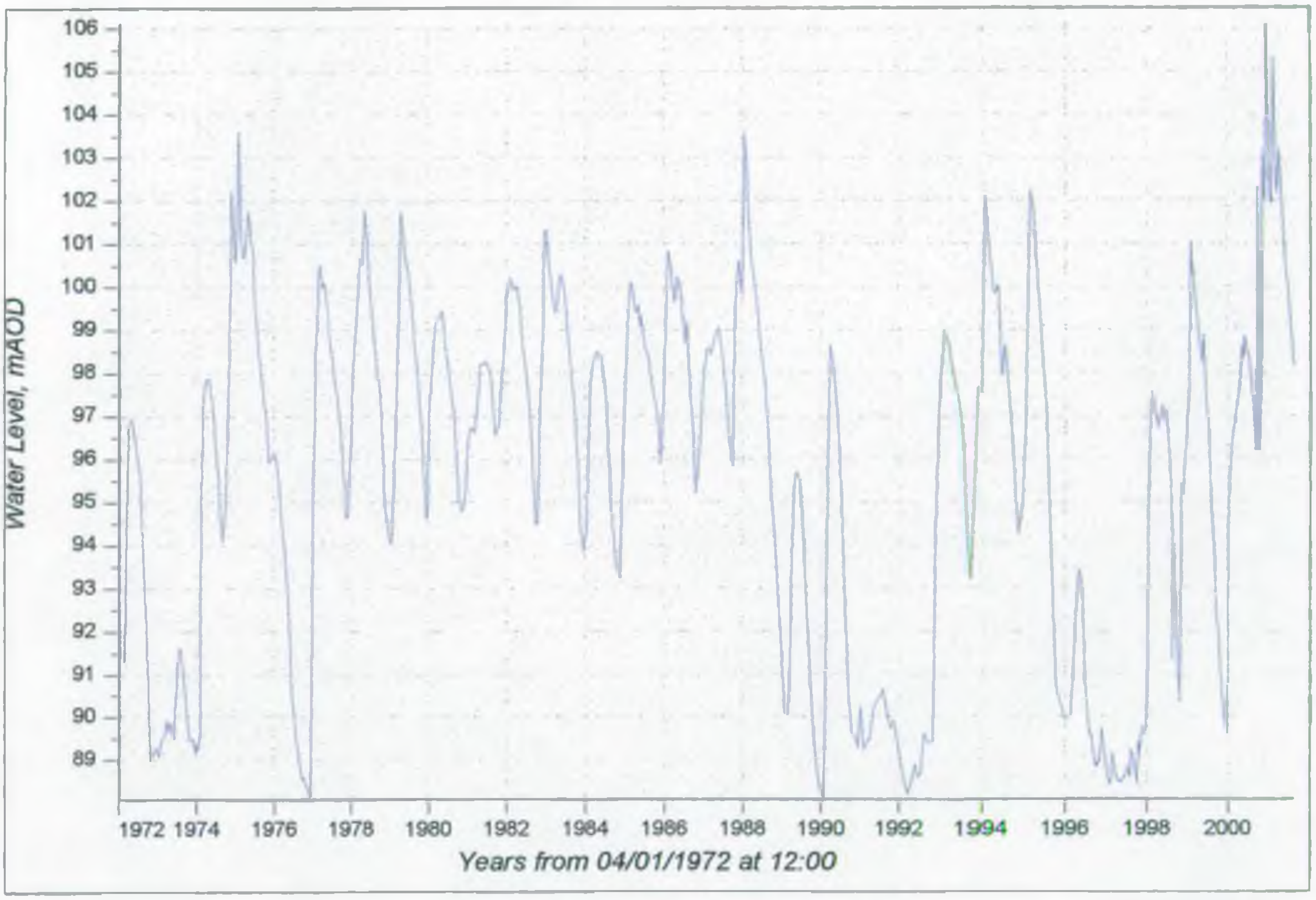


Figure 58 Well House Inn (TQ25/13) Groundwater Levels



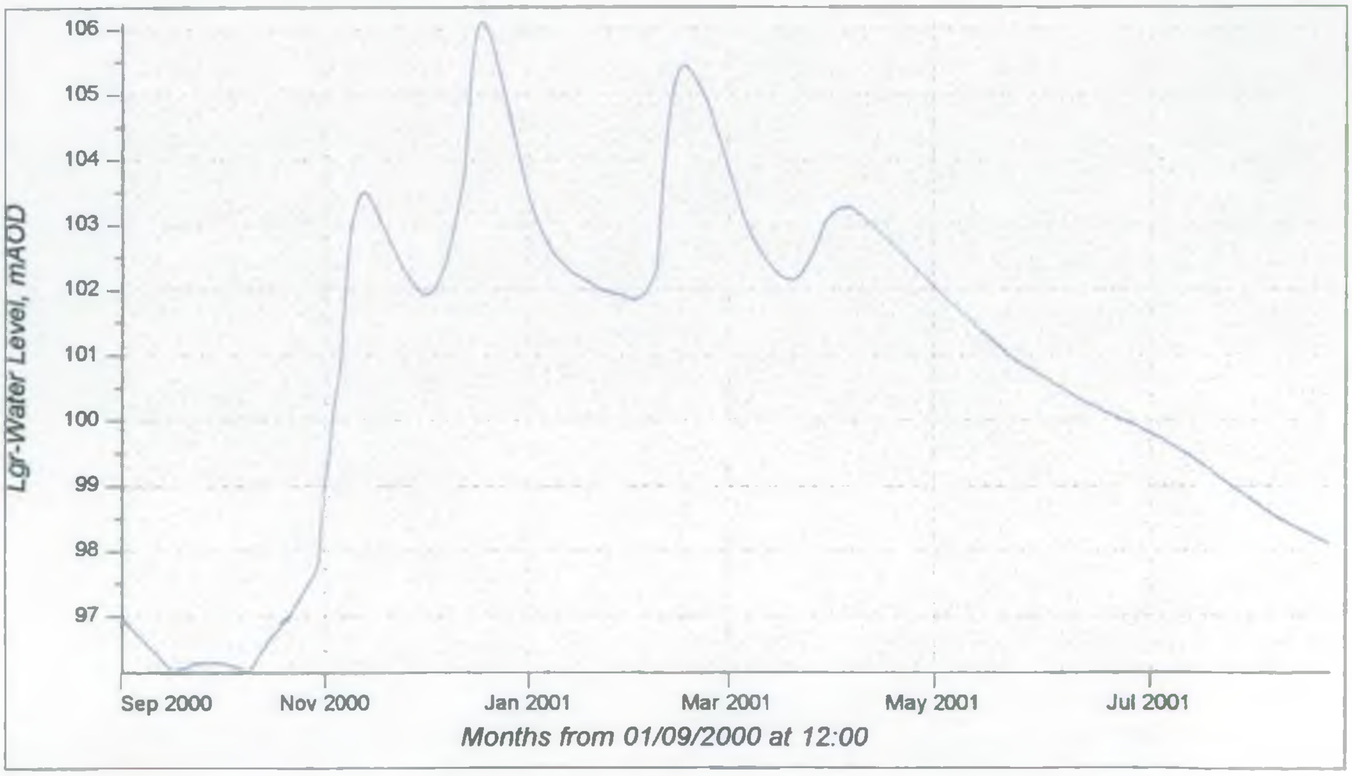


Figure 59: Whyteleaf area of Warlingham Valley TQ 339 583.

Figure 60: Groundwater at West Wickham, Upper Addington Valley, TQ 387 652

Figure 61. Location of observed Groundwater Flooding and Monitoring Sites, Cotswolds

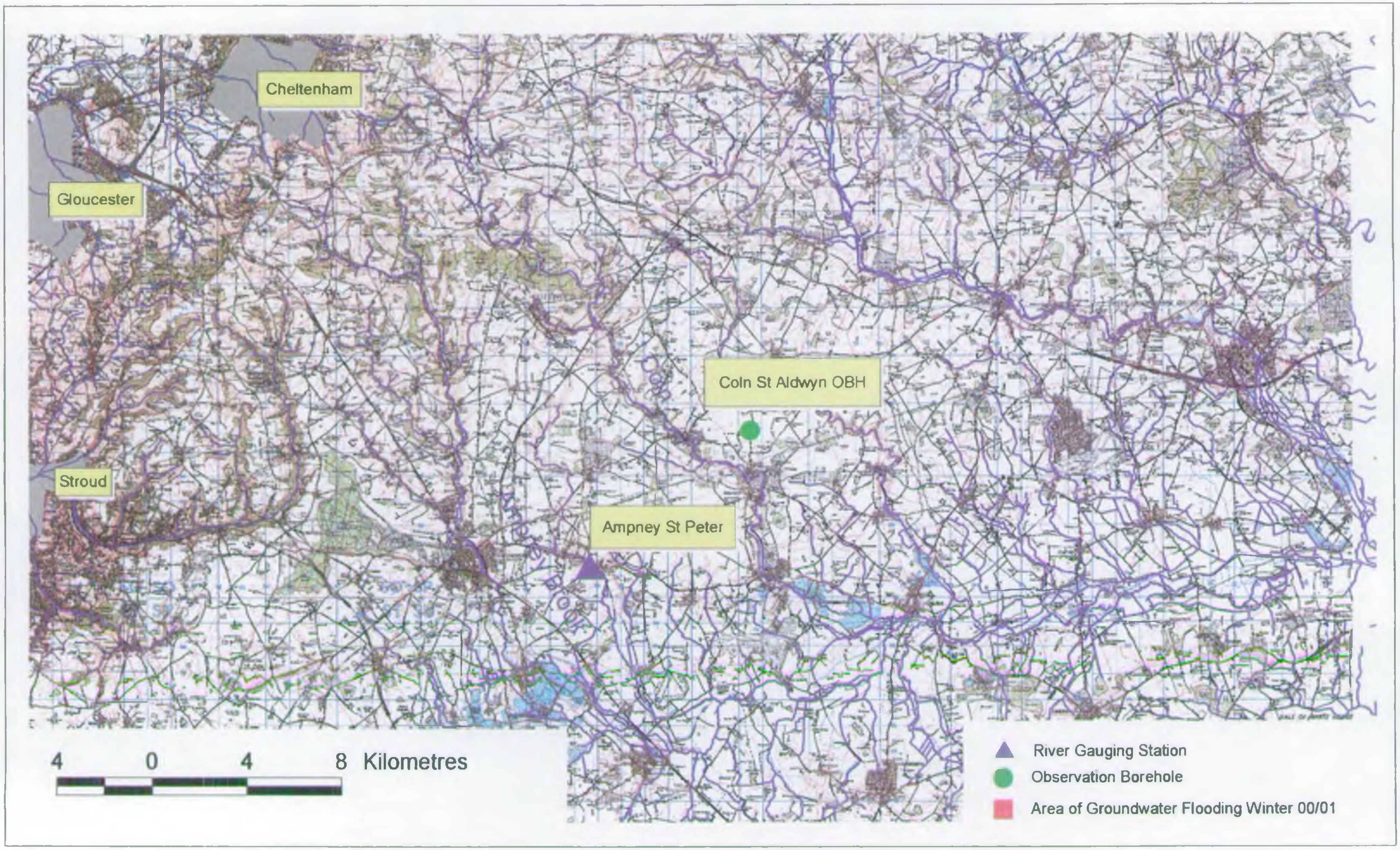
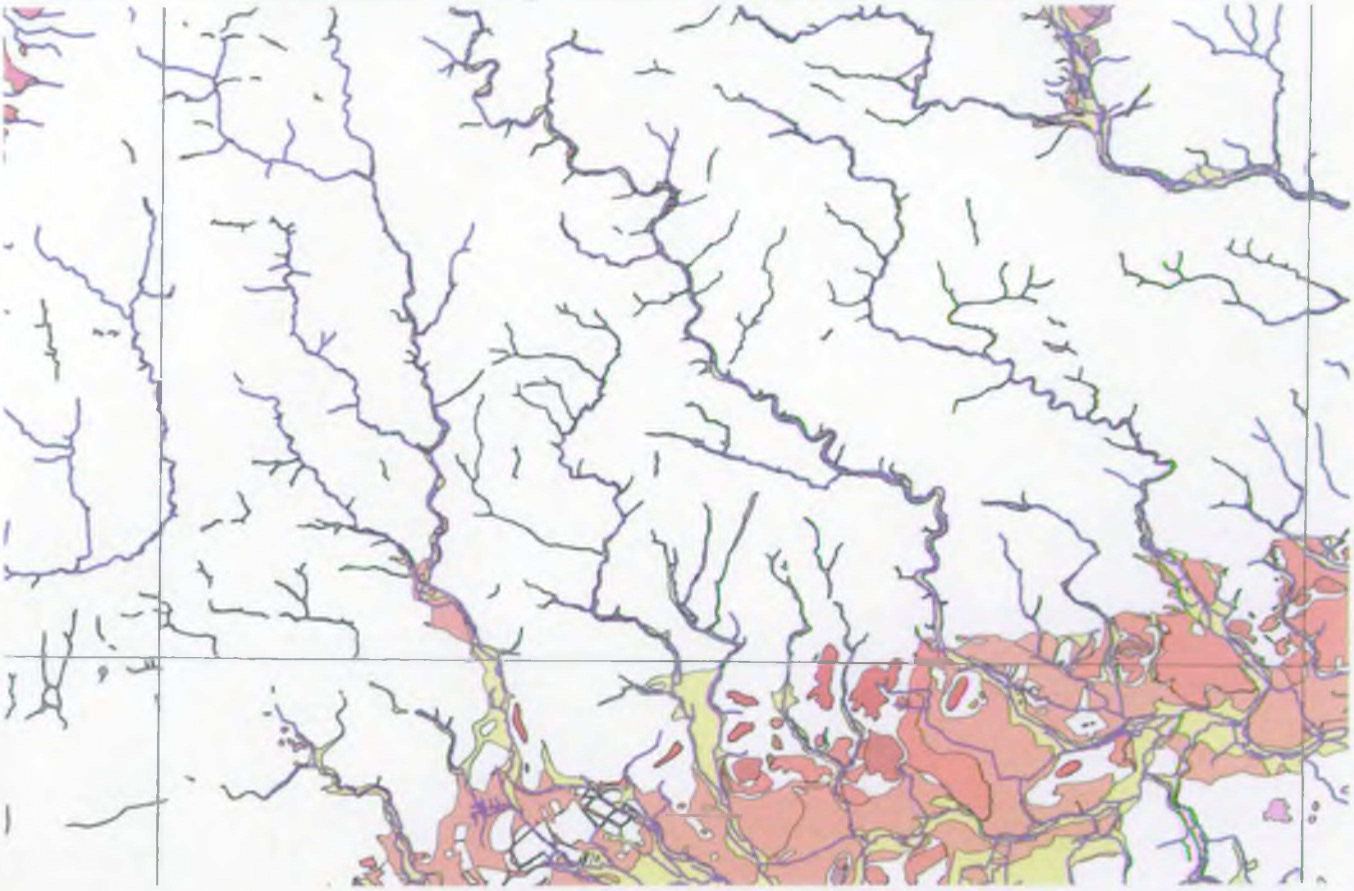
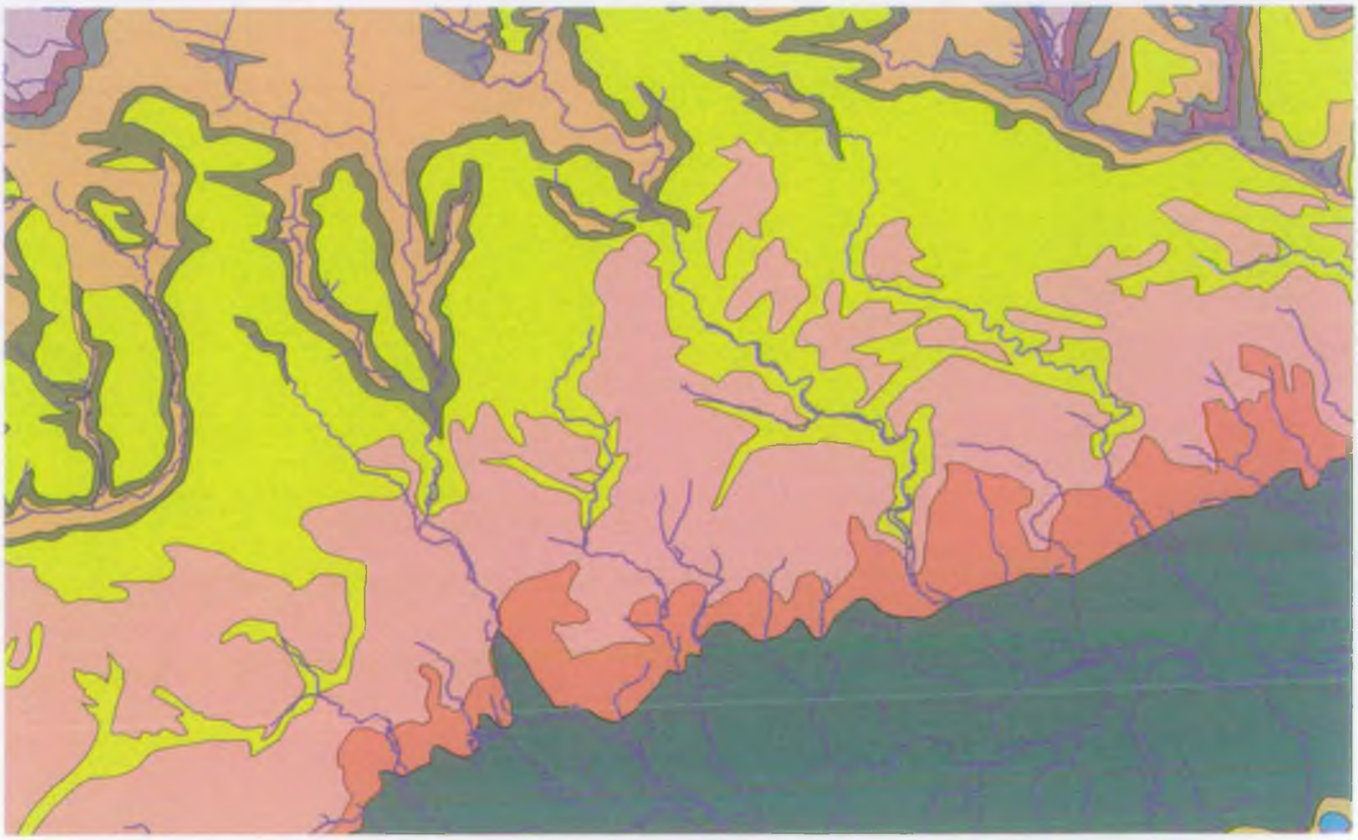


Figure 62. Solid and drift geology, Cotswolds



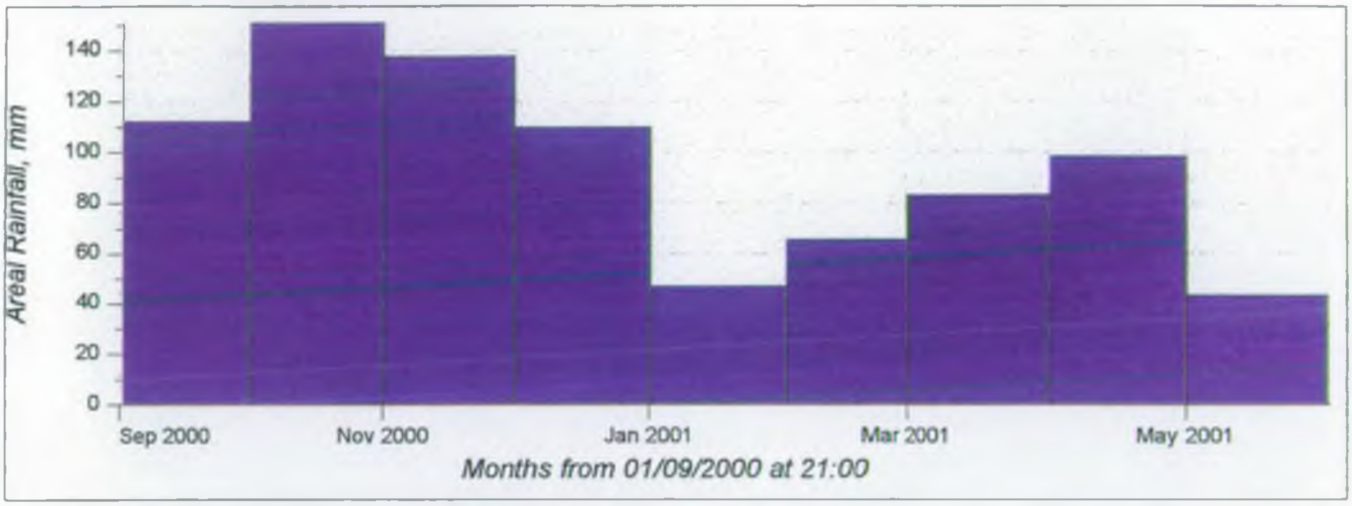
Drift Geology



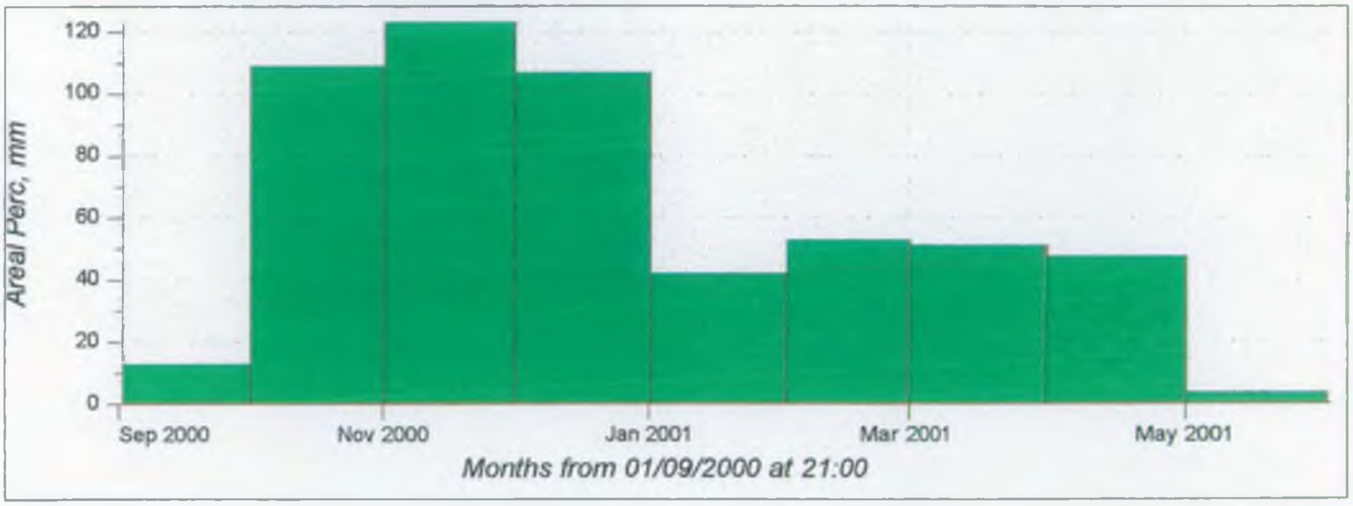
Solid Geology

Figure 63 Hydrological summary for the Ampney Brook catchment.

Cotswold-west (6190), Areal Rainfall.



Cotswold-West (6190), Areal Perc.



Ampney St Peter (0470), Flow.

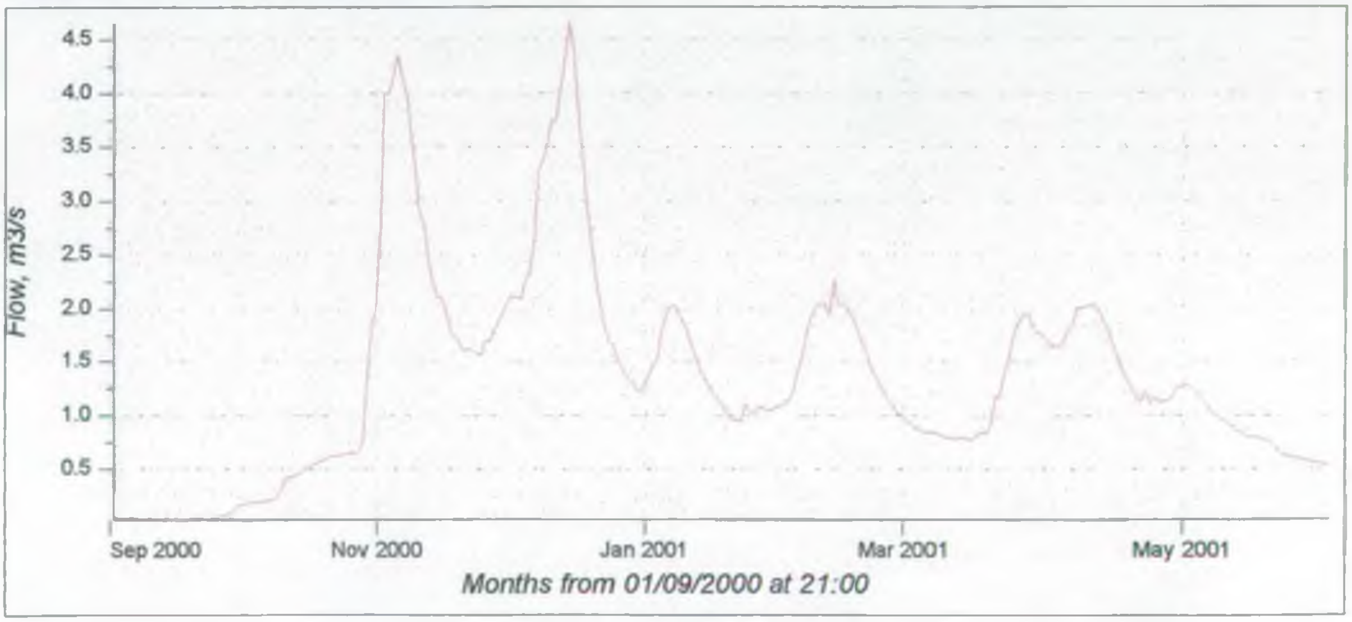
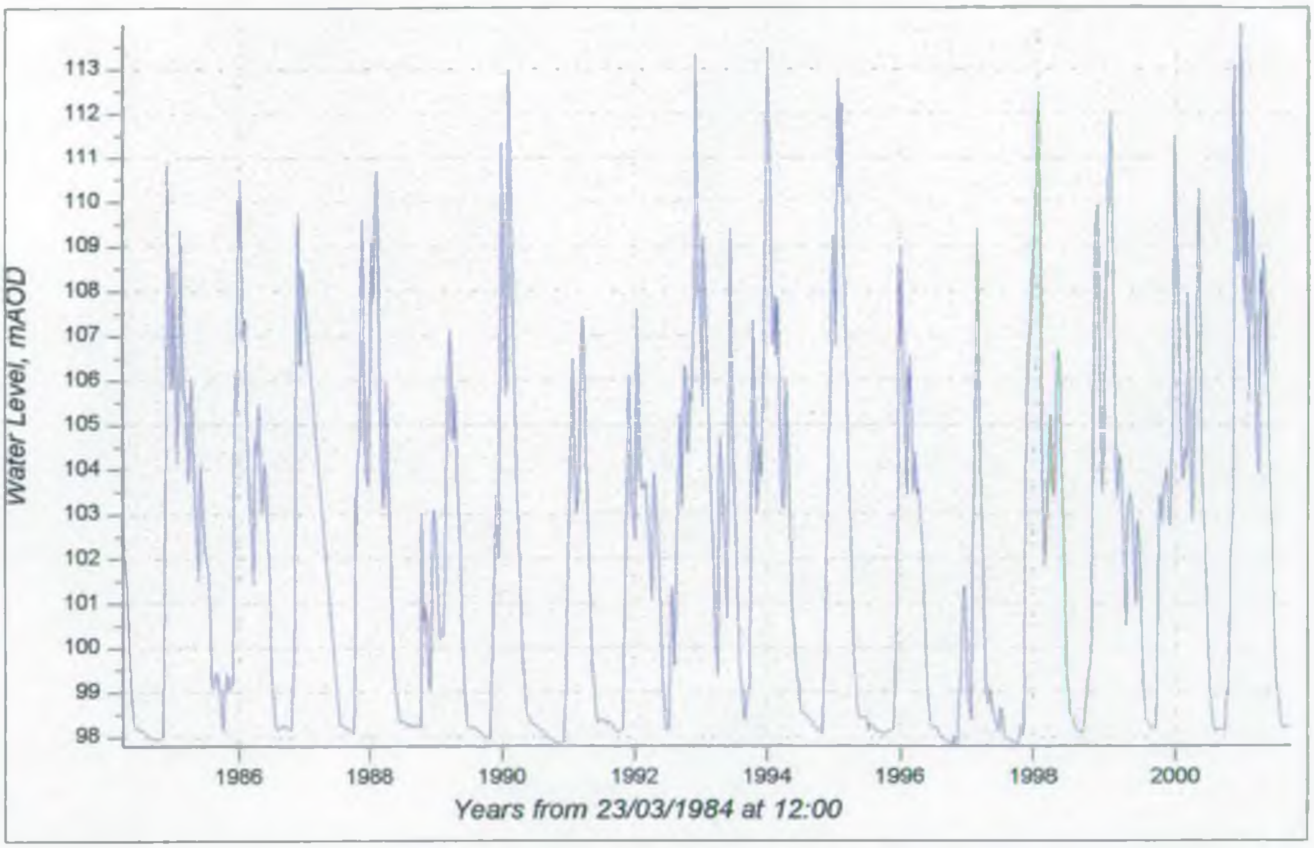


Figure 64 Coln St Aldwyn OBH (SP10/96) Groundwater Levels



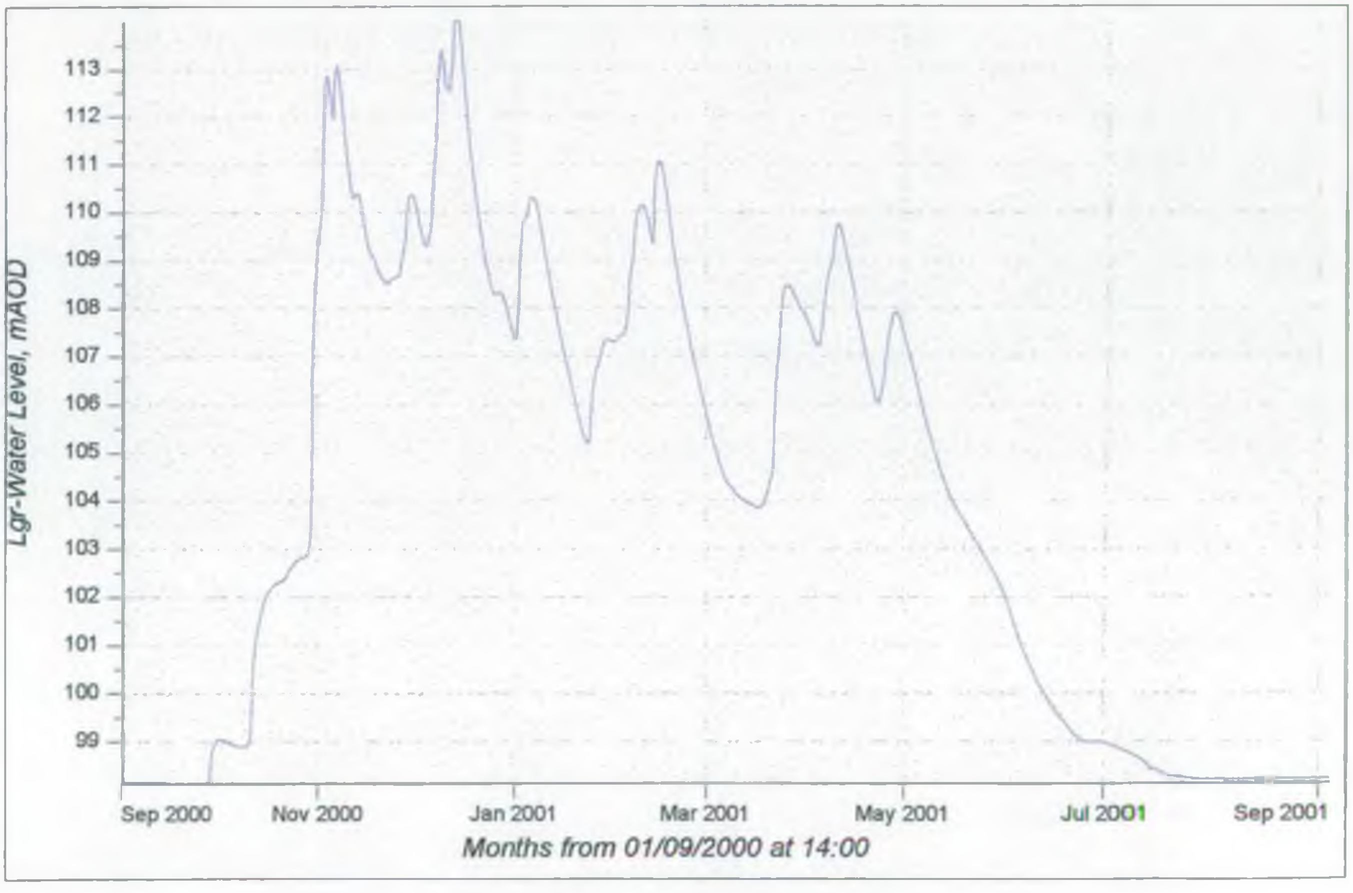


Figure 65. Location of observed Groundwater Flooding and Monitoring Sites, Lower Greensand

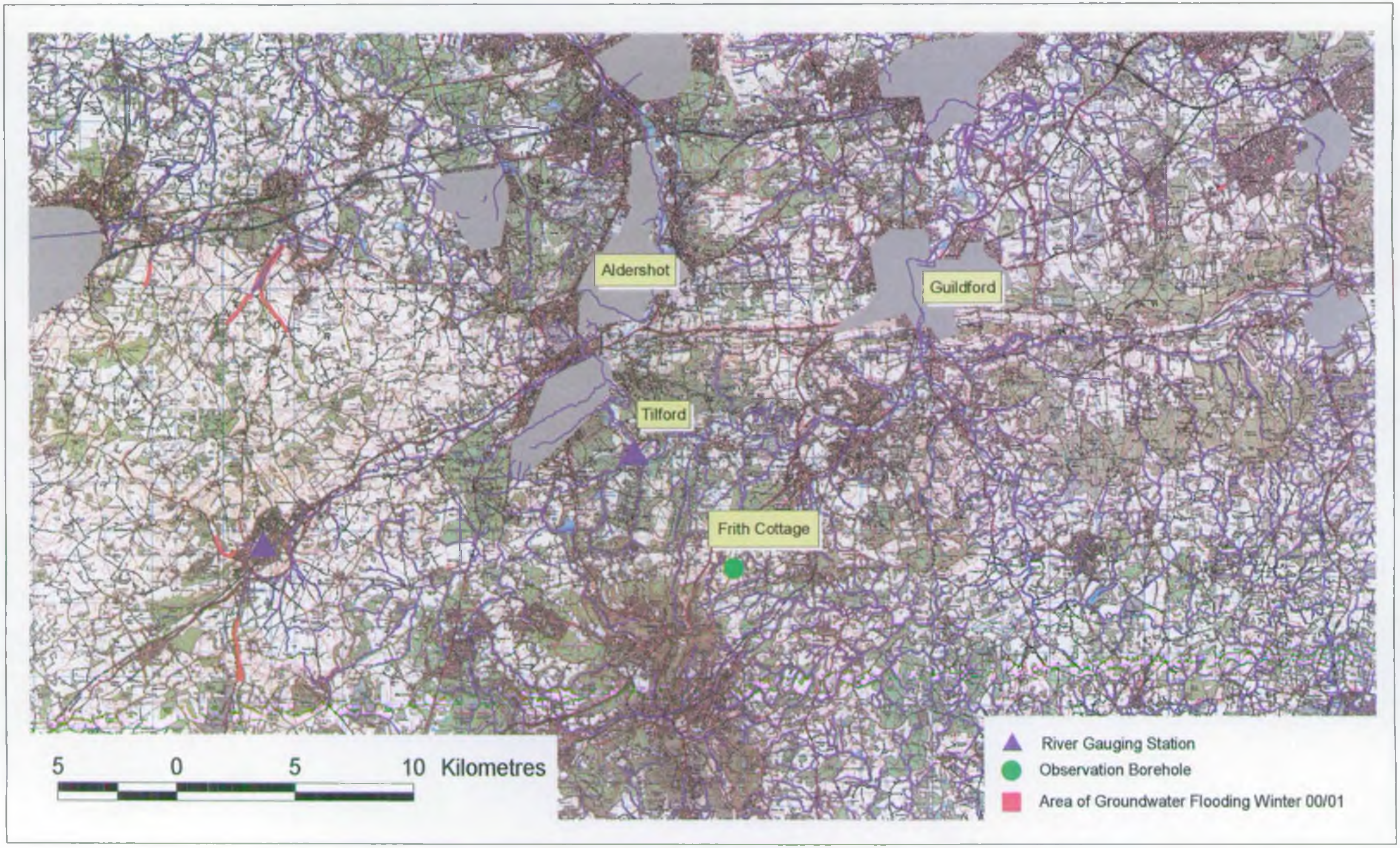
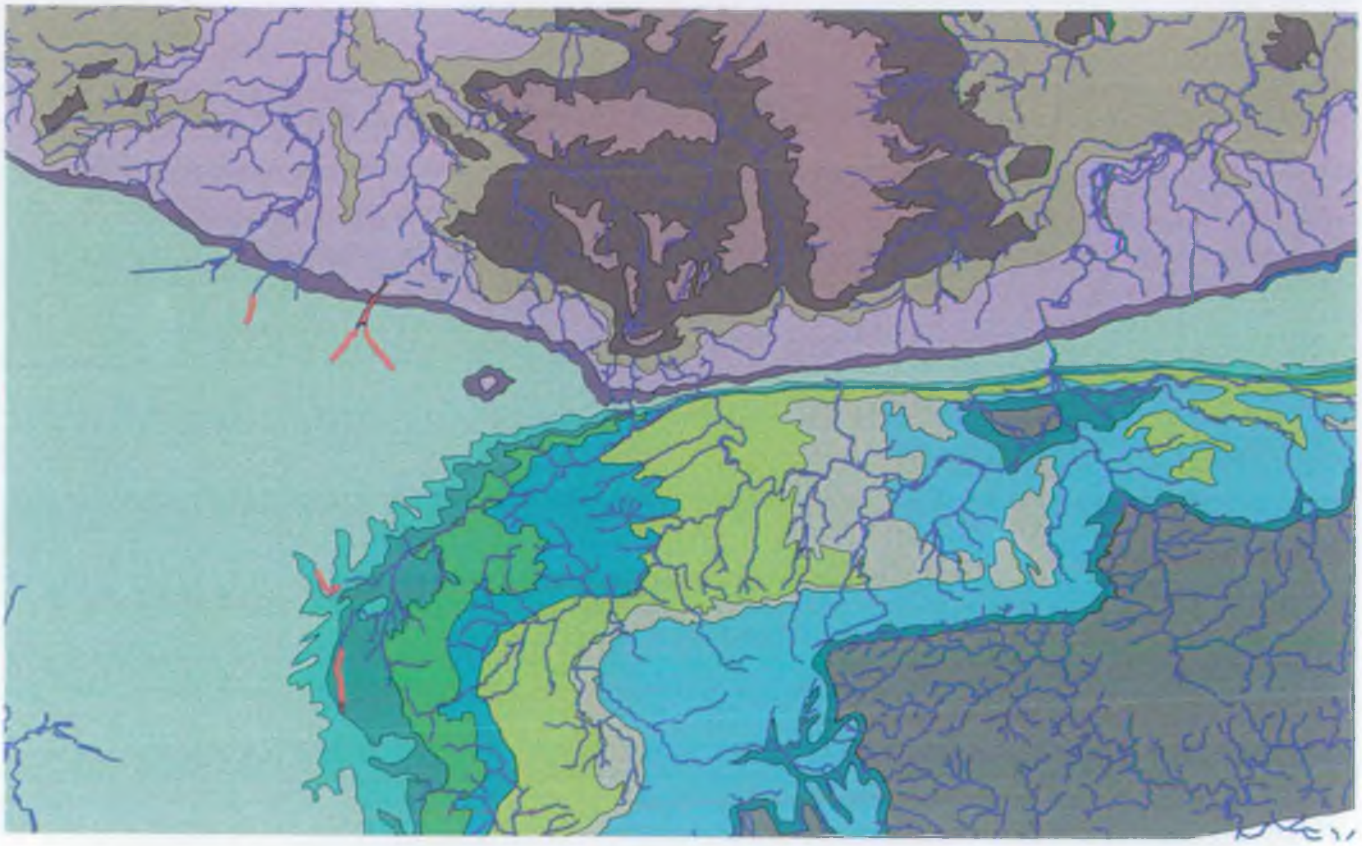


Figure 66. Solid and drift geology. Lower Greensand

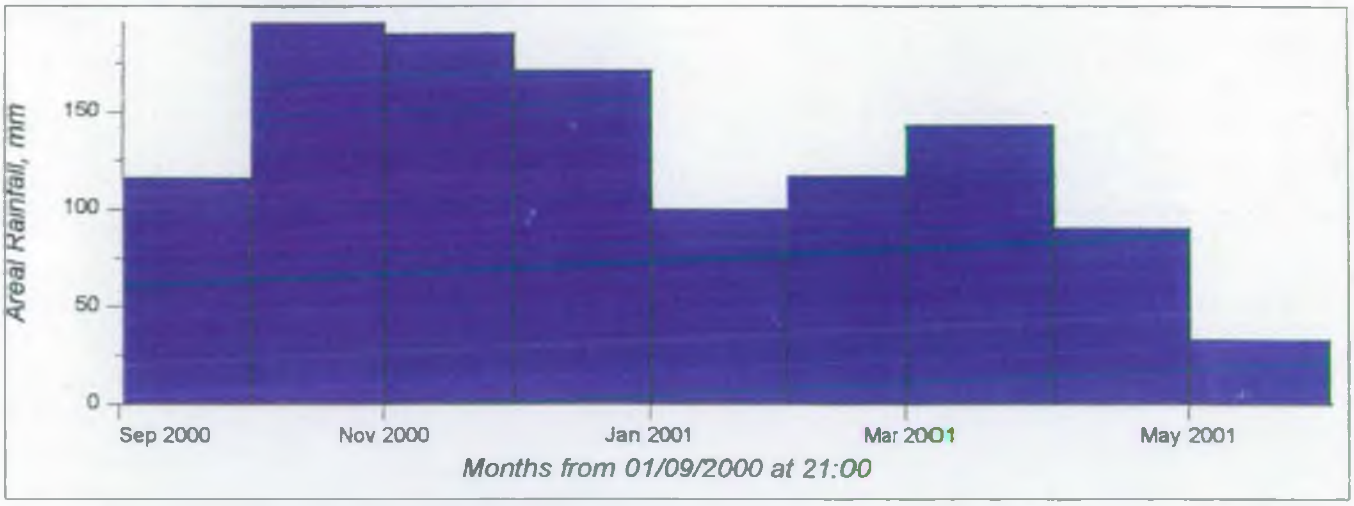
Drift Geology



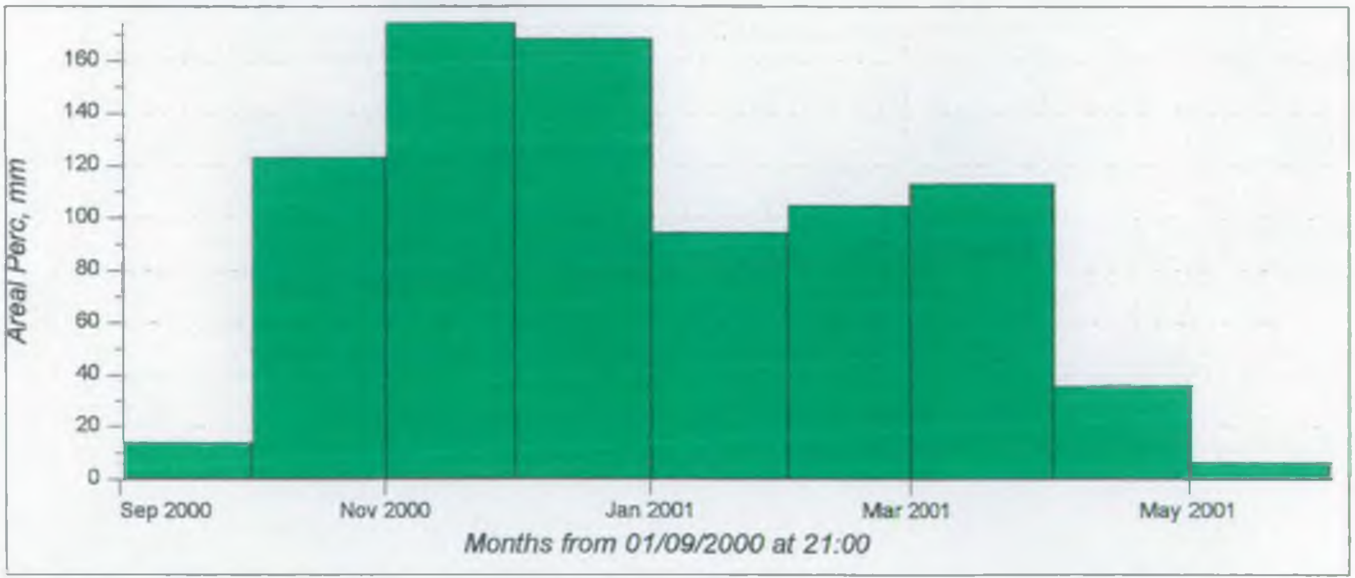
Solid Geology

Figure 67 Hydrological summary for the Wey catchment.

Wey-Greensand (6190), Areal Rainfall.



Wey-Greensand (6190), Areal Perc.



Tilford (3040), Flow.

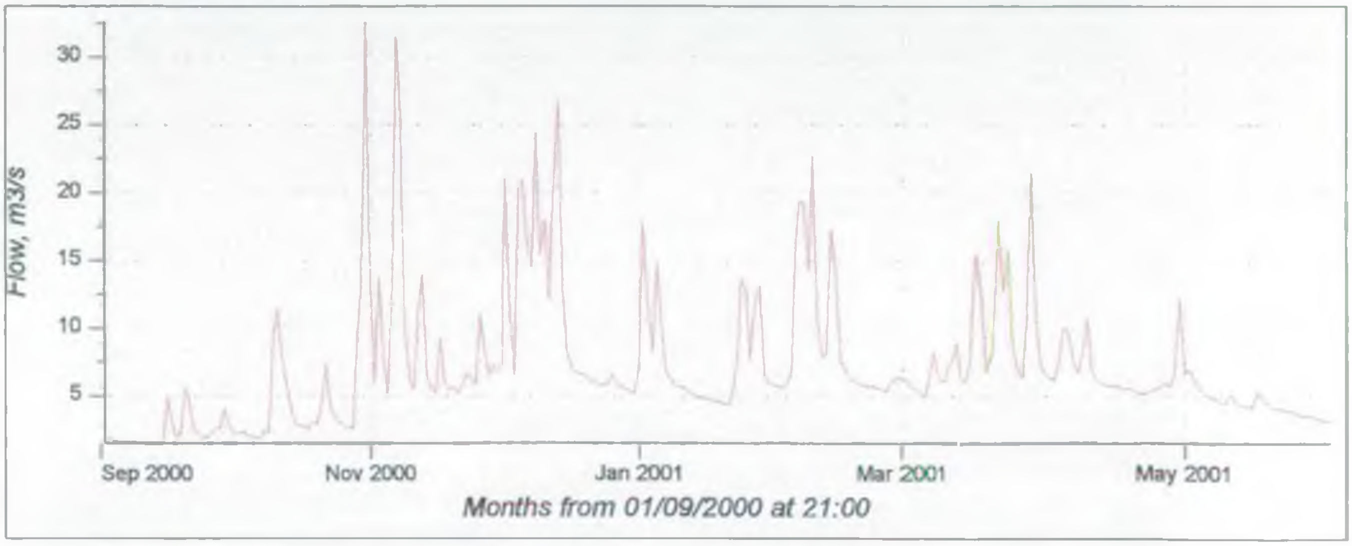
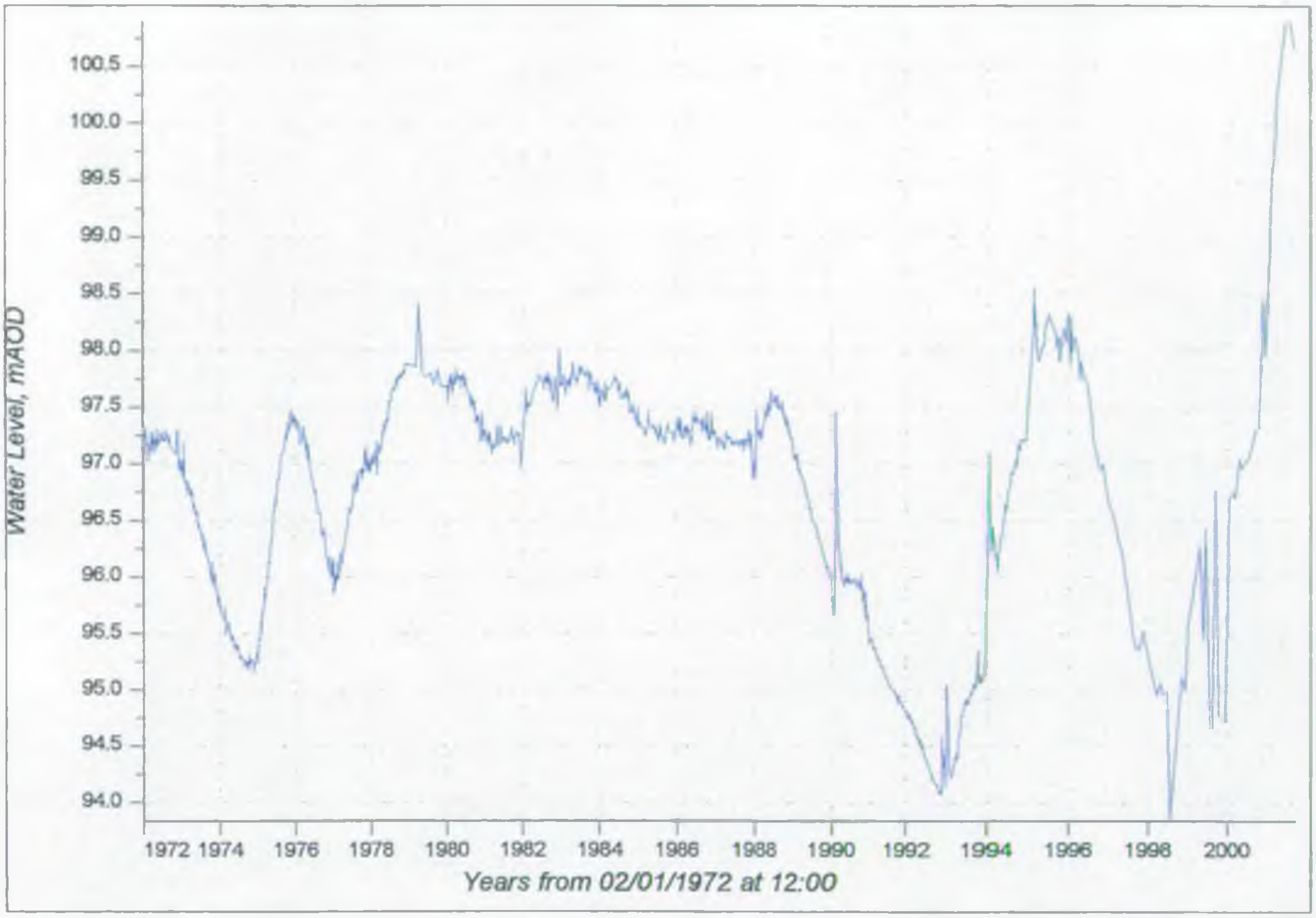


Figure 68 Frith Cottage (SU93/3) Groundwater Levels



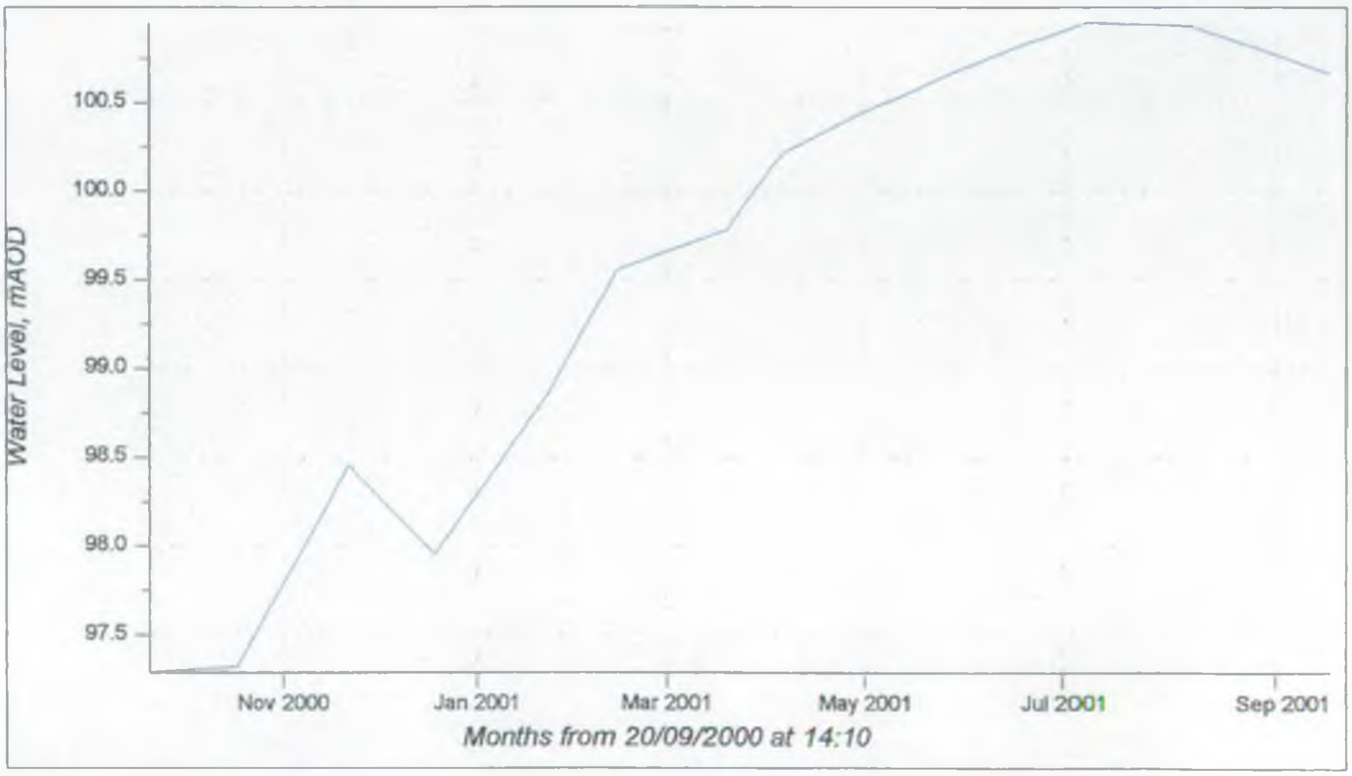
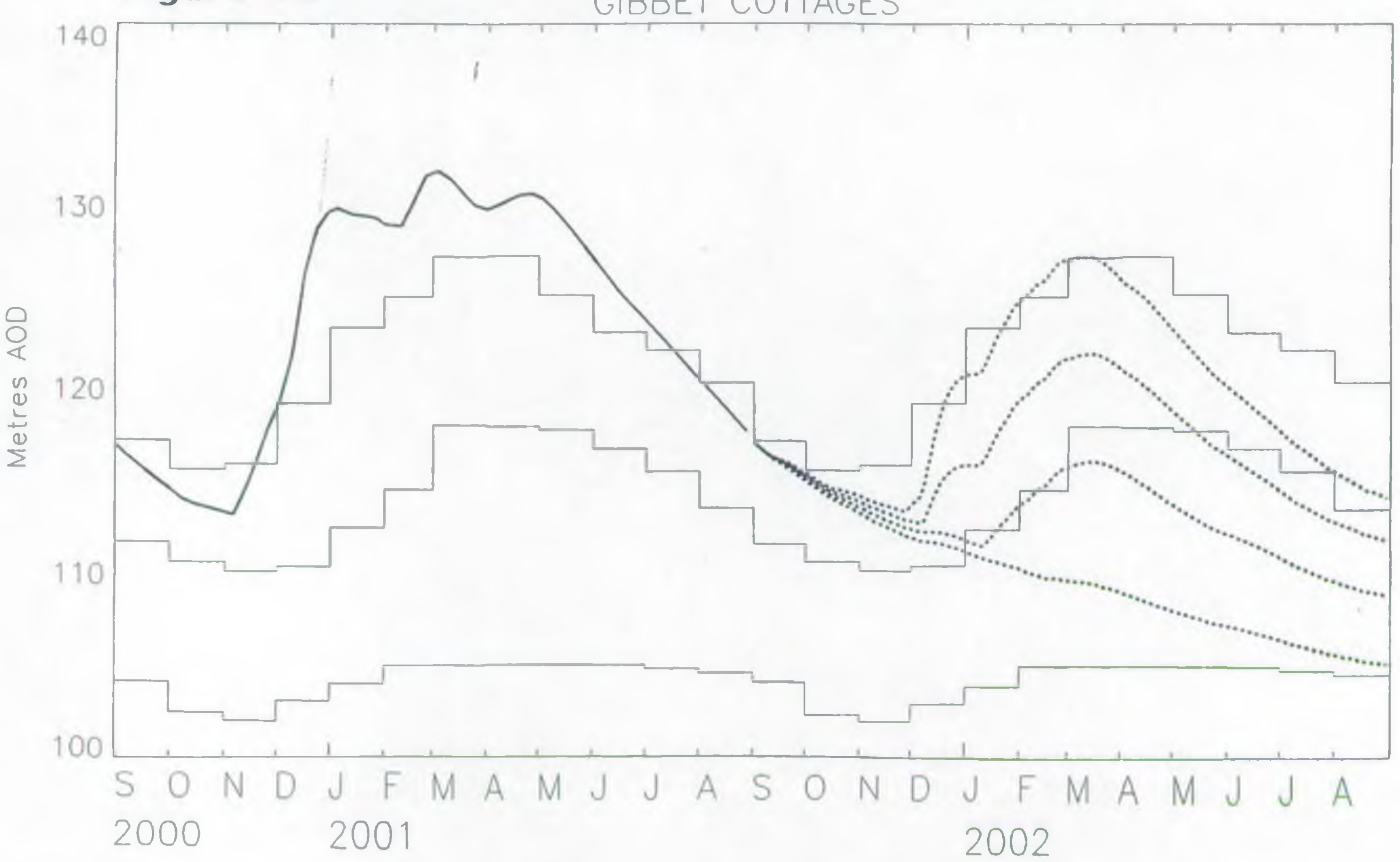


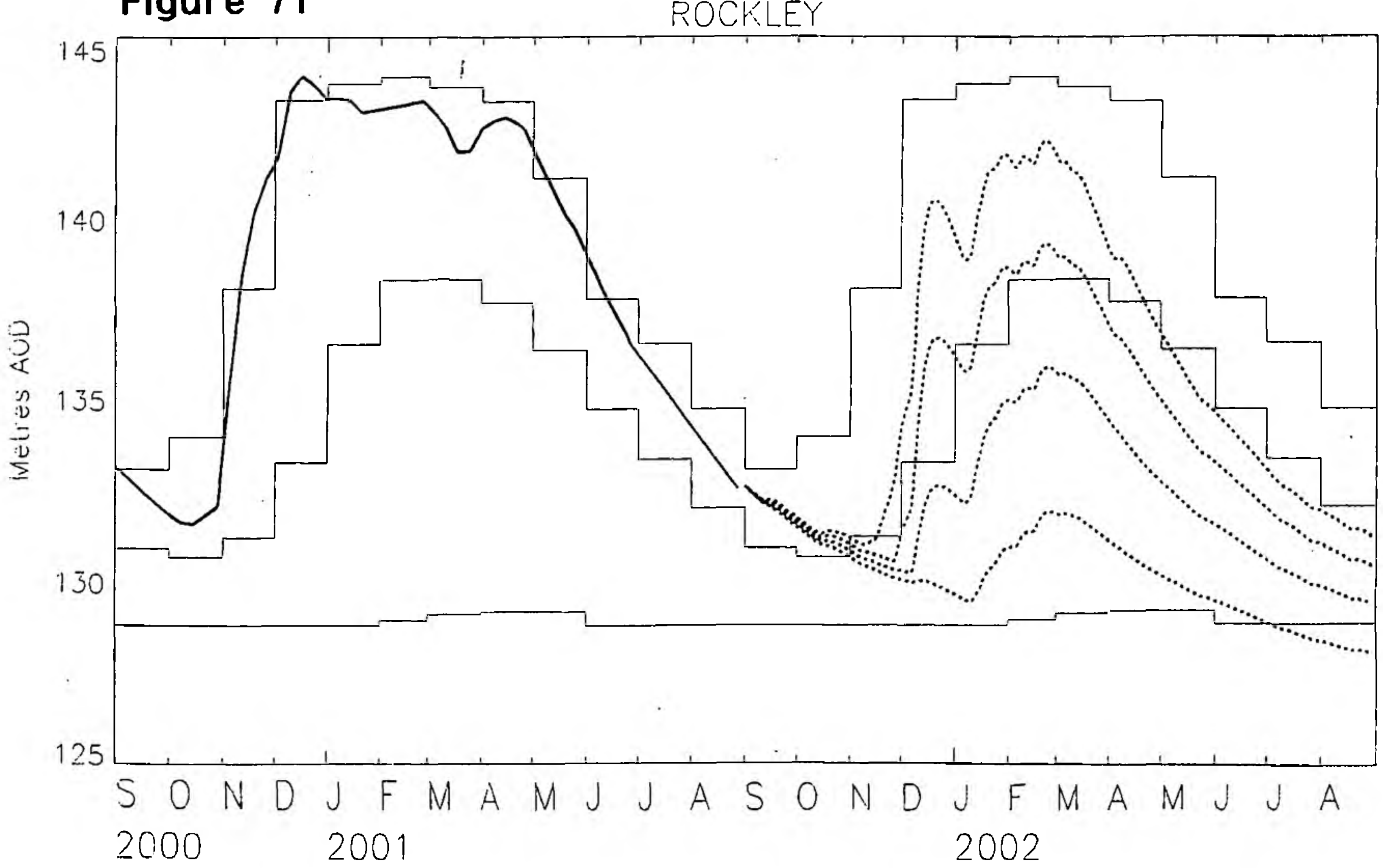
Figure 70



Groundwater Projections from 1st September 2001

Assuming 120%, 100%, 80% and 60% of Average Rainfall

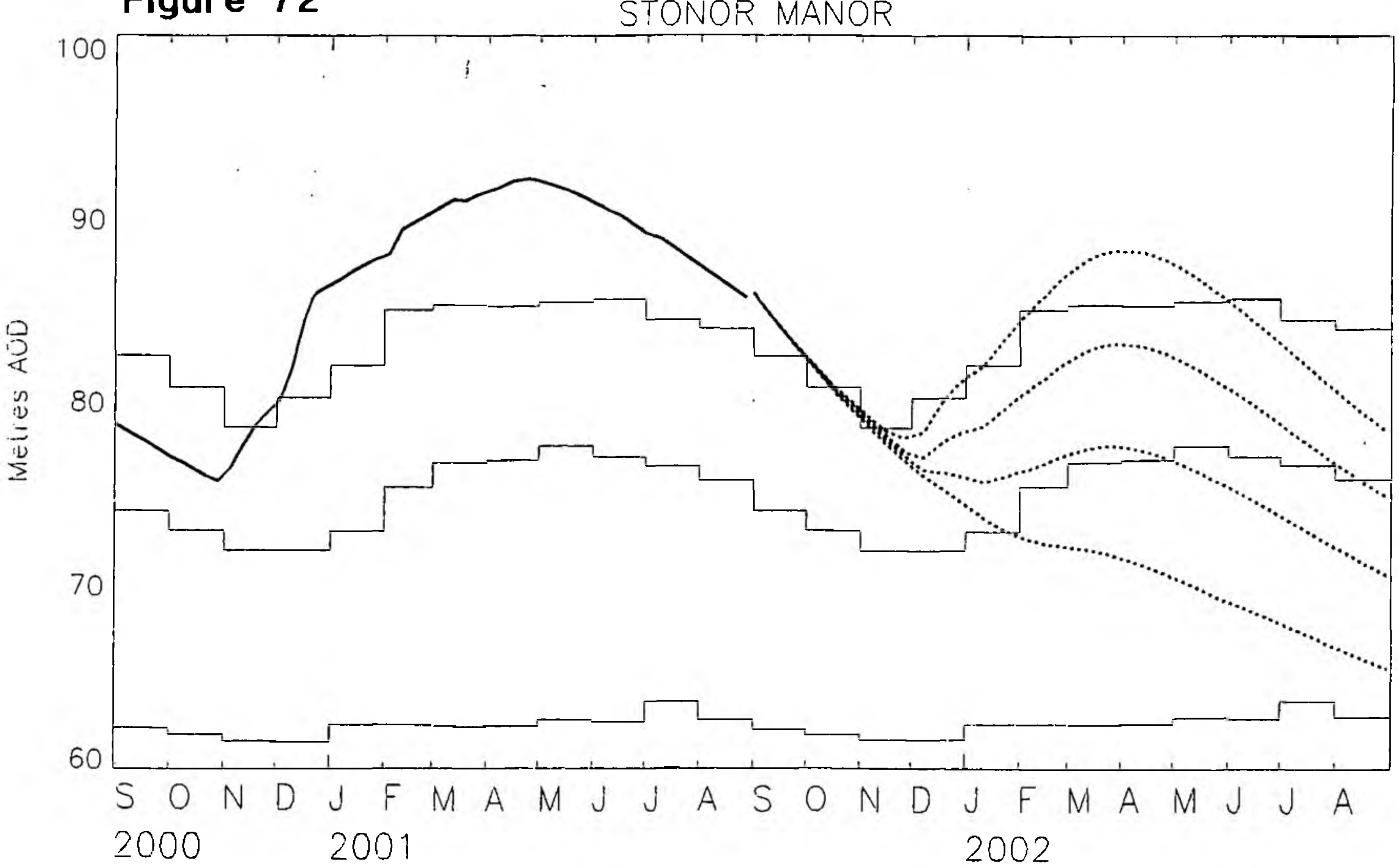
Figure 71



Groundwater Projections from 1st September 2001

Assuming 120%, 100%, 80% and 60% of Average Rainfall

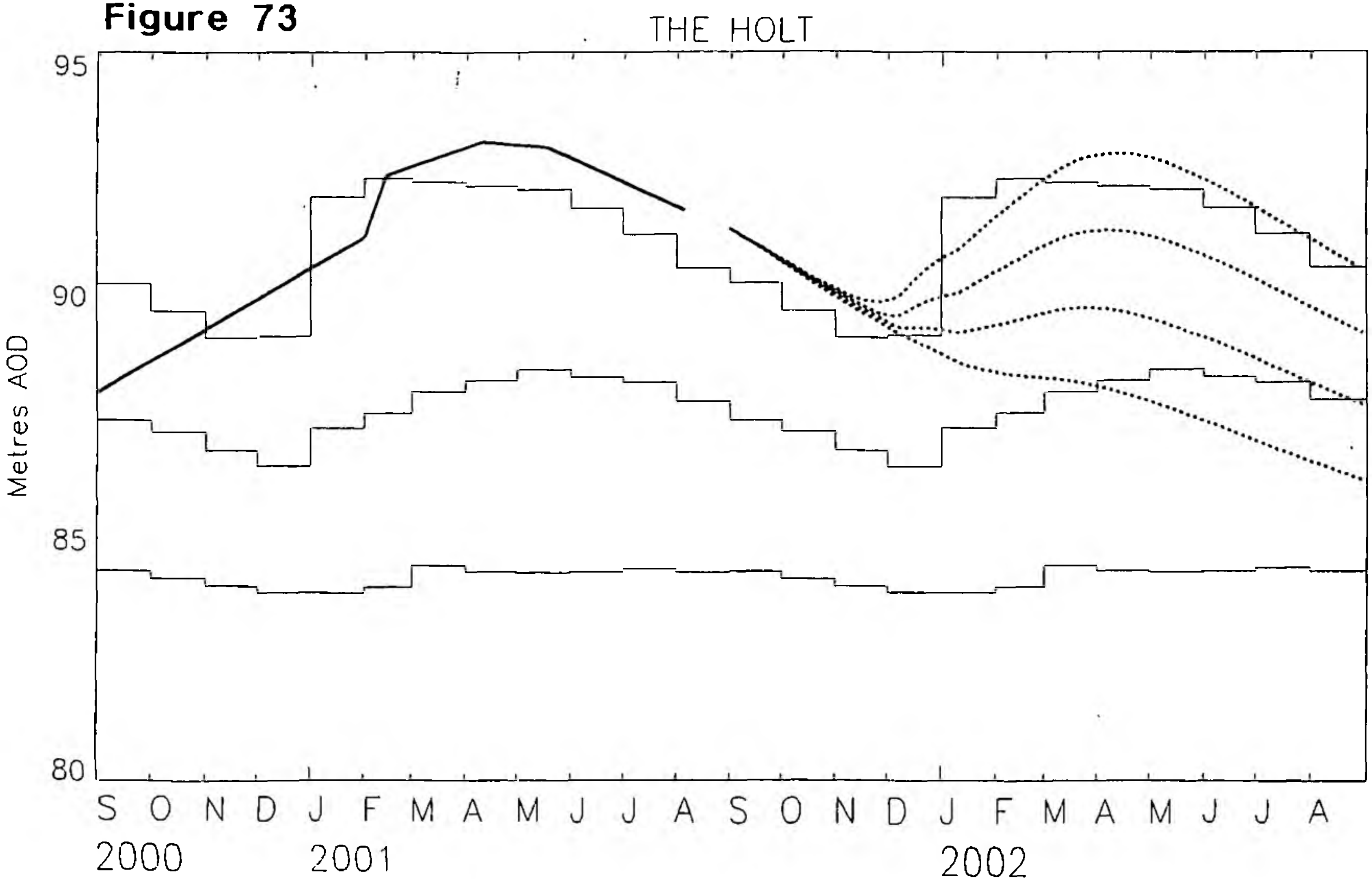
Figure 72



Groundwater Projections from 1st September 2001

Assuming 120%, 100%, 80% and 60% of Average Rainfall

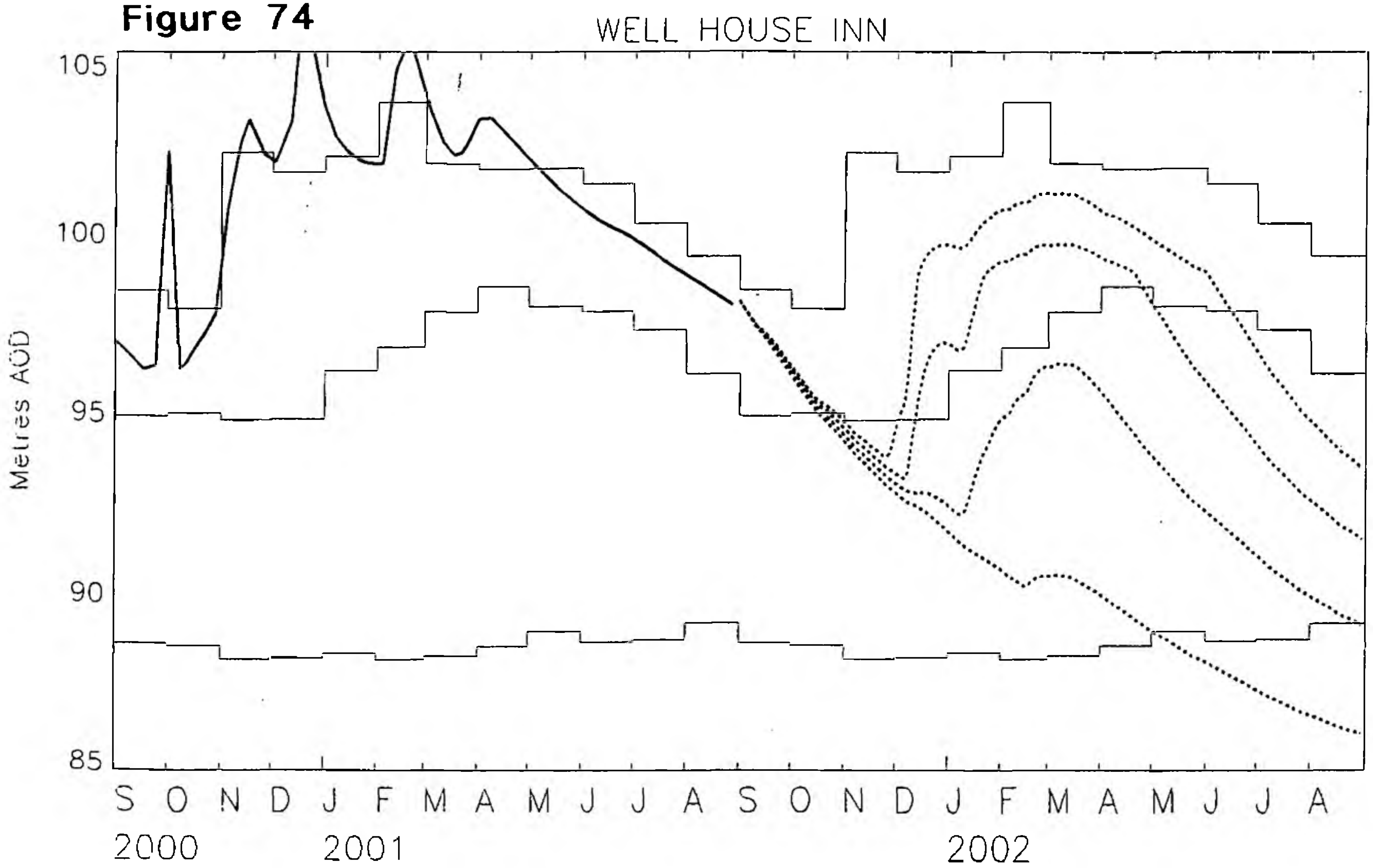
Figure 73



Groundwater Projections from 1st September 2001

Assuming 120%, 100%, 80% and 60% of Average Rainfall

Figure 74



Groundwater Projections from 1st September 2001

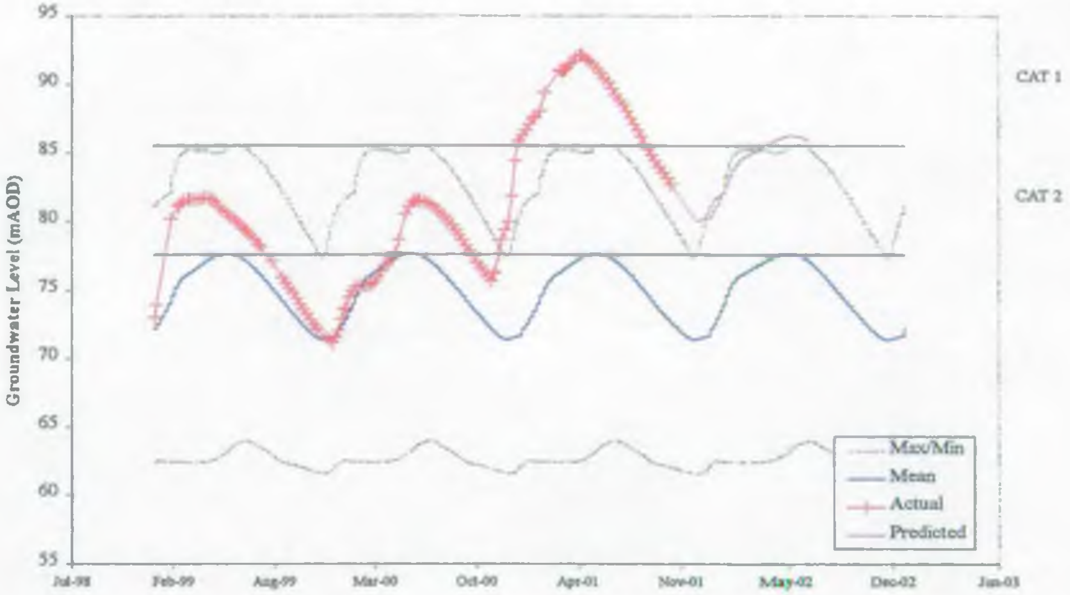
Assuming 120%, 100%, 80% and 60% of Average Rainfall

Appendix 1. List of hydrological data sources

	Areal Rainfall / Percolation		Gauging Station			Observation Borehole		
River Catchment	Name	No.	Name	No.	NGR	Name	No.	NGR
Upper Kennet	Berkshire Downs	6070	Knighton	2230	SU 294 710	Avebury OBH No 2	SU06/45	SU 0895 6980
			Marlborough	2210	SU 187 686			
Og	Berkshire Downs	6070				Rockley OBH	SU17/57	SU 1655 7174
Aldbourne	Berkshire Downs	6070				Eastridge Farm	SU27/70	SU 2995 7244
Lambourn	Berkshire Downs	6070	Shaw	2269	SU 469 682	Bradley Wood	SU47/26	SU 4342 7394
Pang	Berkshire Downs	6070	Frilsham	2140	SU 537 730	Gibbet Cottages	SU47/141	SU 4548 7887
Assendon/Stonor Valley	Chilterns-West	6130				Stonor Park	SU78/45A	SU 7419 8924
Hambleden Stream	Chilterns-West	6130				Bagmoor Farm	SU78/47	SU 7868 8902
Wye	Chilterns-West	6130	Bourne End (Hedsor)	2590	SU 896 866	Piddington	SU89/7	SU 8103 9417
Misbourne	Chilterns-East	6140				Village Well Lee Common	SP90/27	SP 9100 0410
Chess	Chilterns-East	6140				Wayside	SP90/56	SP 9474 0107
Bulbourne	Chilterns-East	6140				Village Well Aldbury	SP91/15	SP 9655 1247
Gade	Chilterns-East	6140	Croxley Green	2849	TQ 082 952	Hollybush Farm	TL00/30	TL 0142 0997
Ver	Chilterns-East	6140				Highfield Farm	TL01/166	TL 0816 1555
Upper Lee	Lee-Chalk	6600				Cole Green	TL21/87	TL 2719 1032
Mimram	Lee-Chalk	6600	Welwyn (Fulling Mill)	4770	TL 225 169	The Holt	TL11/9	TL 1696 1964
Beane	Lee-Chalk	6600				Well House Bramfield	TL31/9	TL 3018 1496

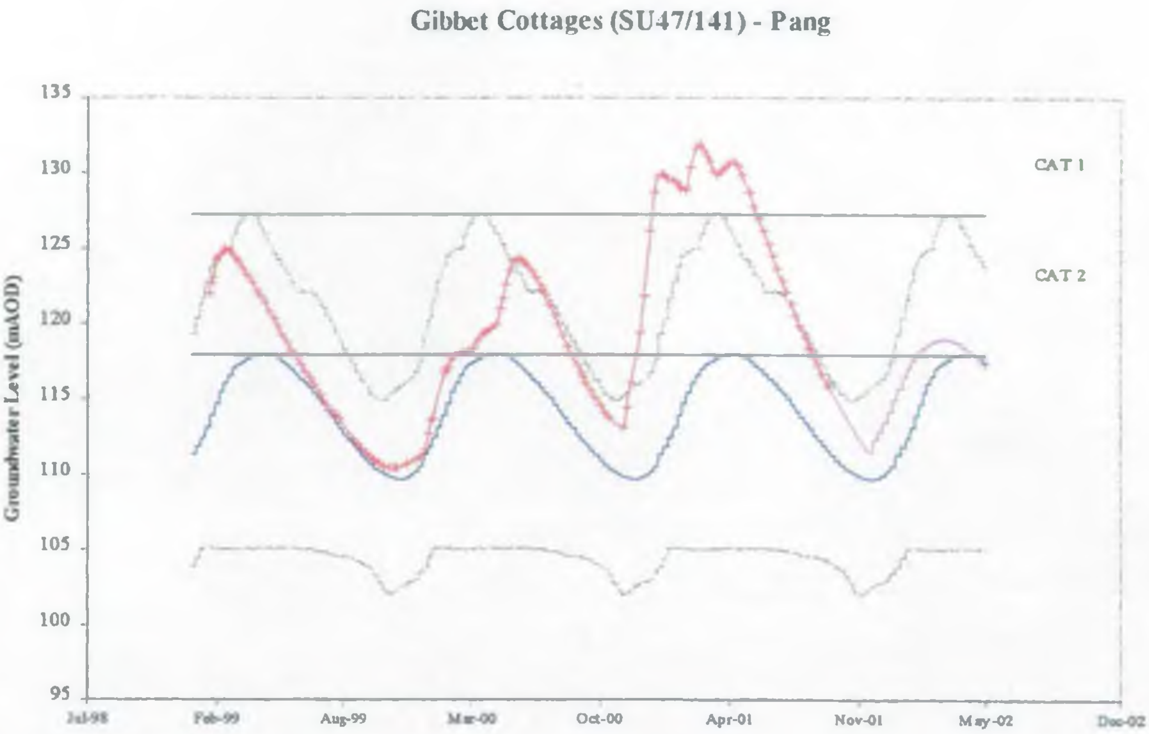
Rib	Lee-Chalk	6600	Wadesmill	4980	TL 360 174	St Edmunds College	TL32/6	TL 3747 2175
Ash	Lee-Chalk	6600				Church End	TL42/4	TL 4470 2264
Stort	Roding Catchment	6509	Stansted Mountfitchet	5106	TL 500 246	Berden Hall	TL42/8	TL 4669 2955
Whitewater	Loddon Catchment	6503				Tile Barn Farm	SU74/40	SU 7098 4781
Lavant Stream	N. Downs-West	6162	Alton	3010	SU 717 394	Lane End OBH	SU62/113	SU 6774 2935
						Farringdon Chalk OBH	SU 63/124B	SU 6988 3494
Wandle	N. Downs-West	6230	Carshalton	4159	TQ 279 647	Well House Inn	TQ25/13	TQ 2584 5524
Ravensbourne	N. Downs-West	6230				Addington Lodge	TQ36/35	TQ 3780 6230
Ampney Brook	Cotswolds-West	6010	Ampney St Peter	470	SP 077 013			
Coln						Coln St Aldwyn OBH	SP10/96	SP 1450 0688
Wey	Wey-Greensand	6190	Tilford	3040	SU 874 432	Frith Cottage	SU93/3	SU 9160 3840

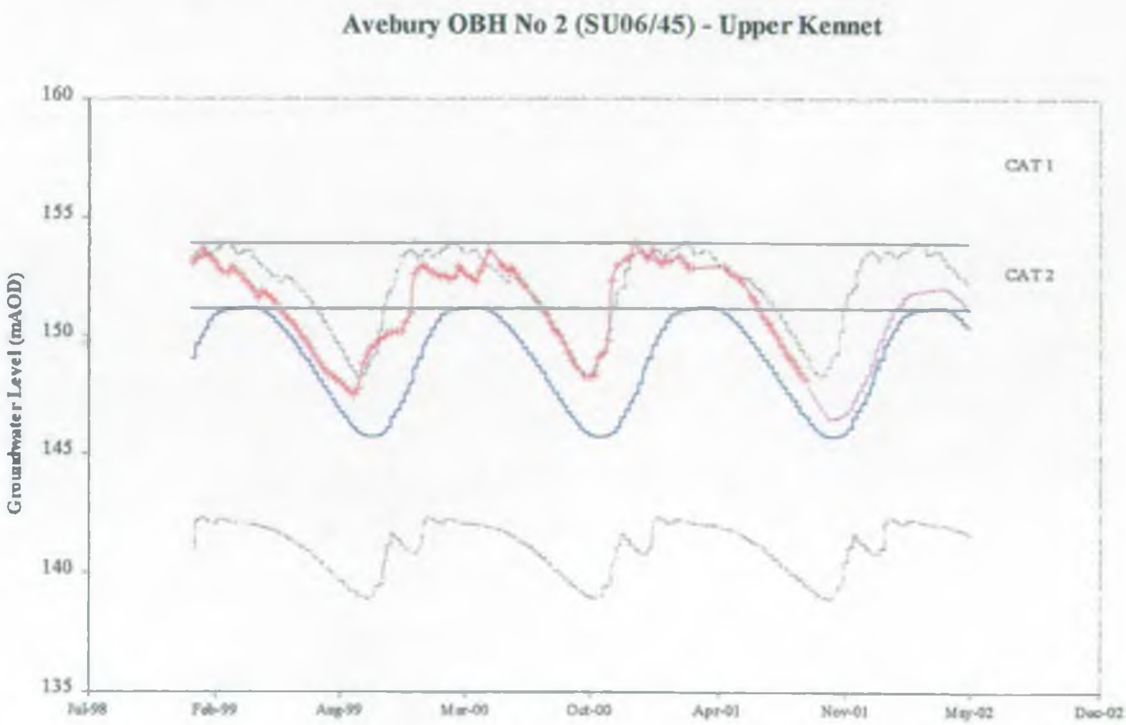
Appendix 2. Groundwater level categorisation plots



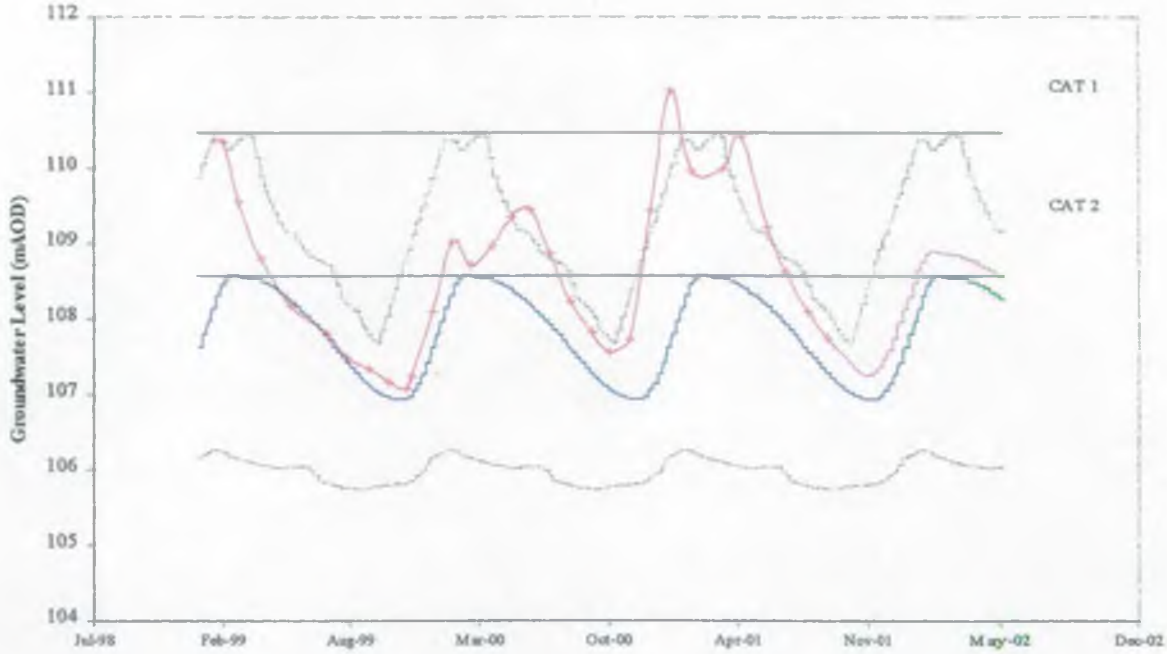
Maximum, minimum and mean groundwater levels have been calculated using the 25 year data series 1/1/1975 to 31/12/99 where available.

Kennet Valley

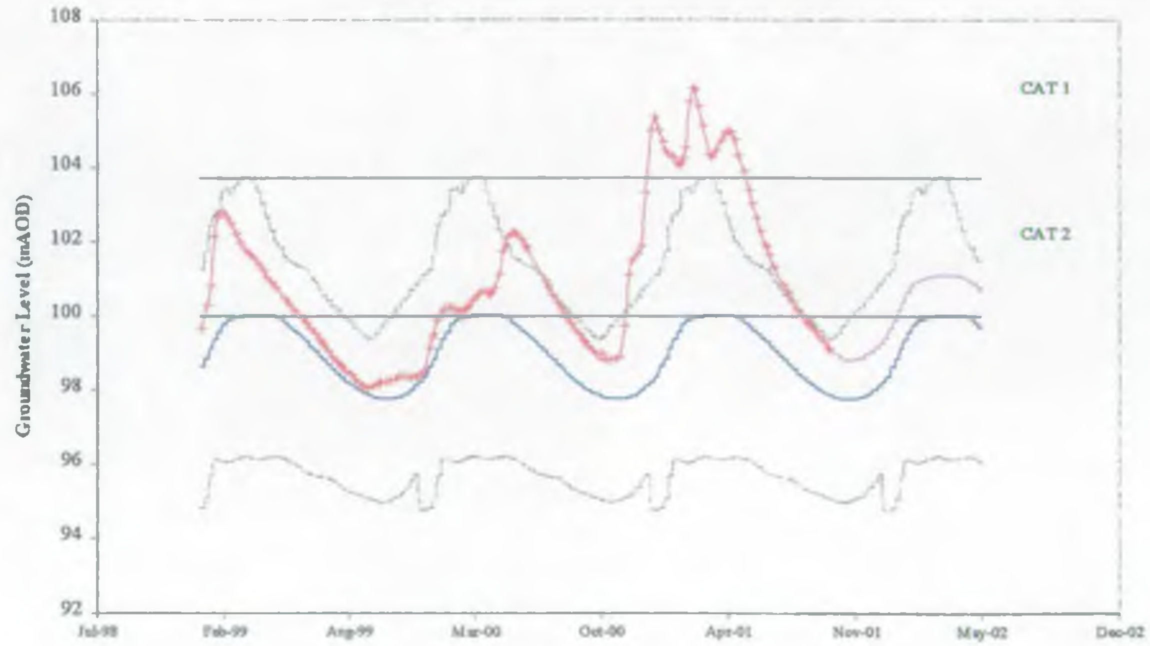


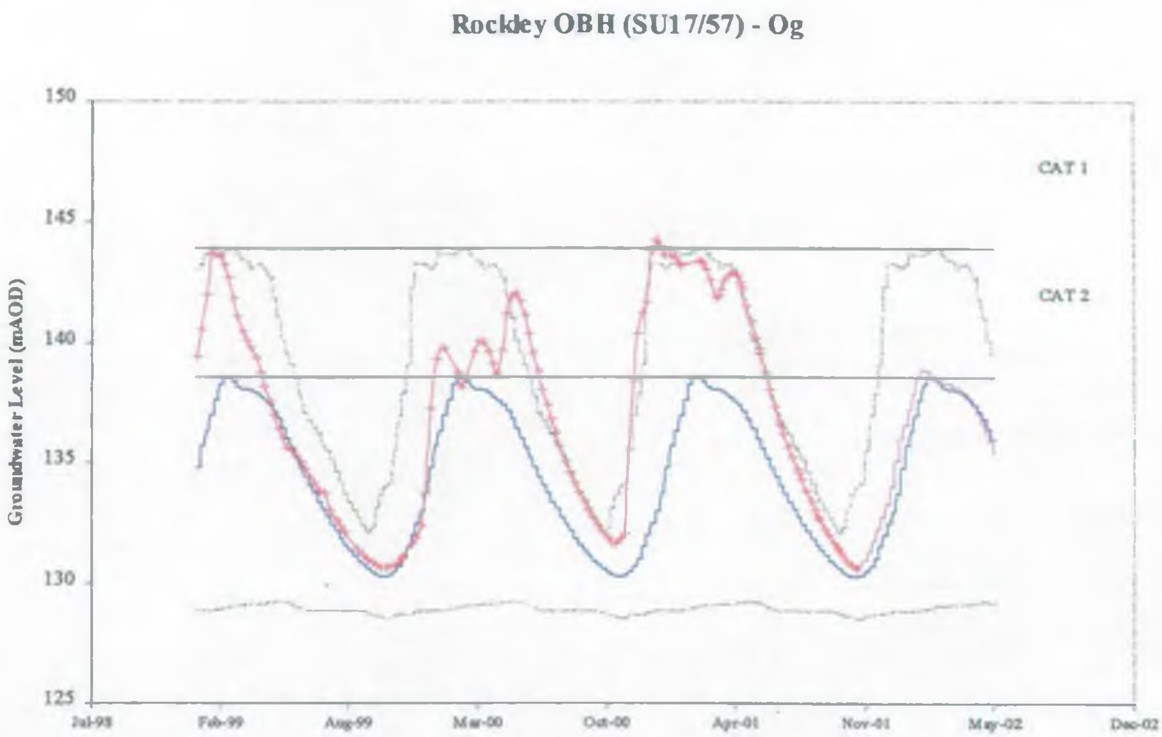


Eastridge Farm (SU27/70) - Aldbourne



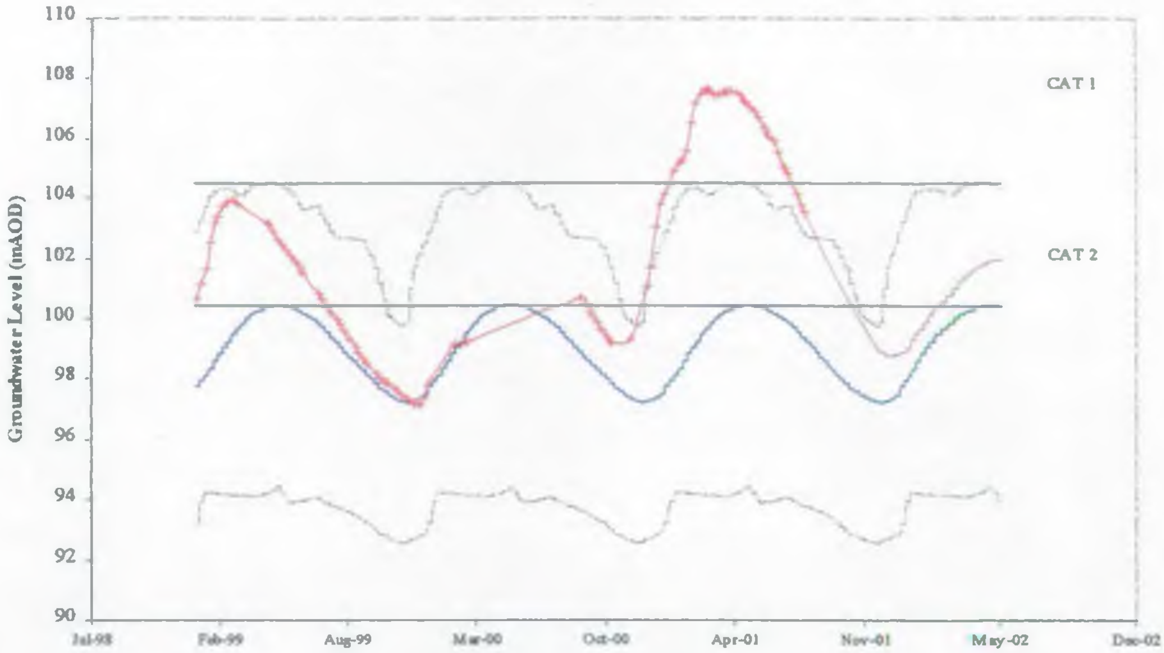
Bradley Wood OBH (SU47/26) - Lambourn



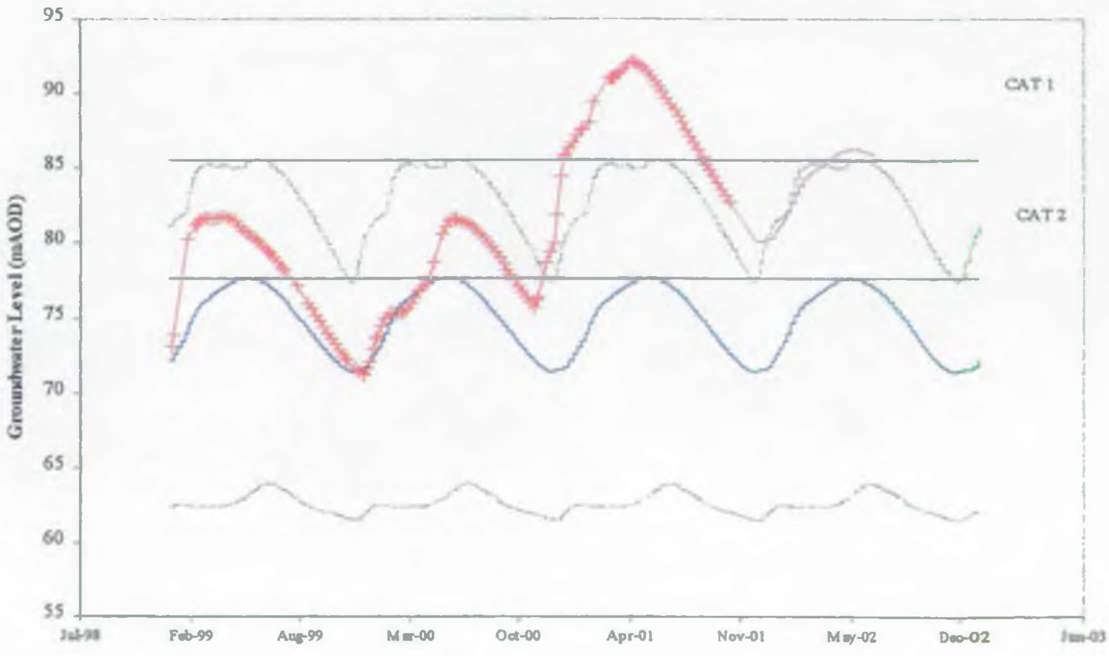

Rockley OBH (SU17/57) - Og
Groundwater Level (mAOD)
150
145
140
135
130
125
CAT 1
CAT 2
Jul-98
Feb-99
Aug-99
Mar-00
Oct-00
Apr-01
Nov-01
May-02
Dec-02

SW Chilterns

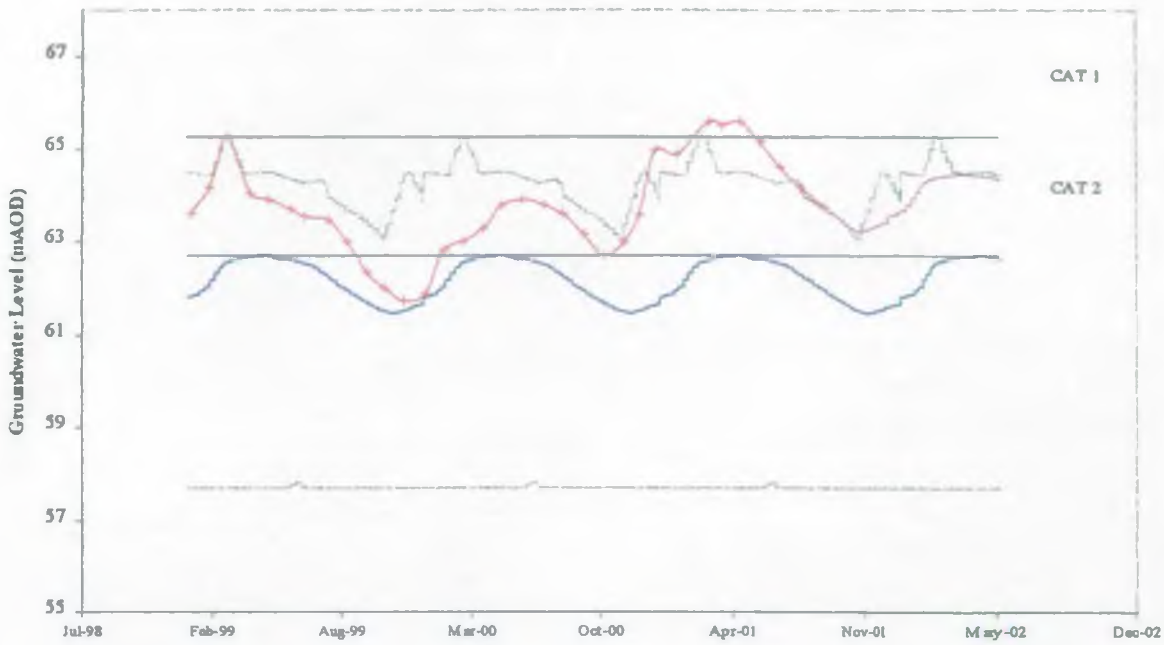
Piddington (SU89/7) - Wye



Stonor Park (SU78/45A) - Assendon/Stonor Valley

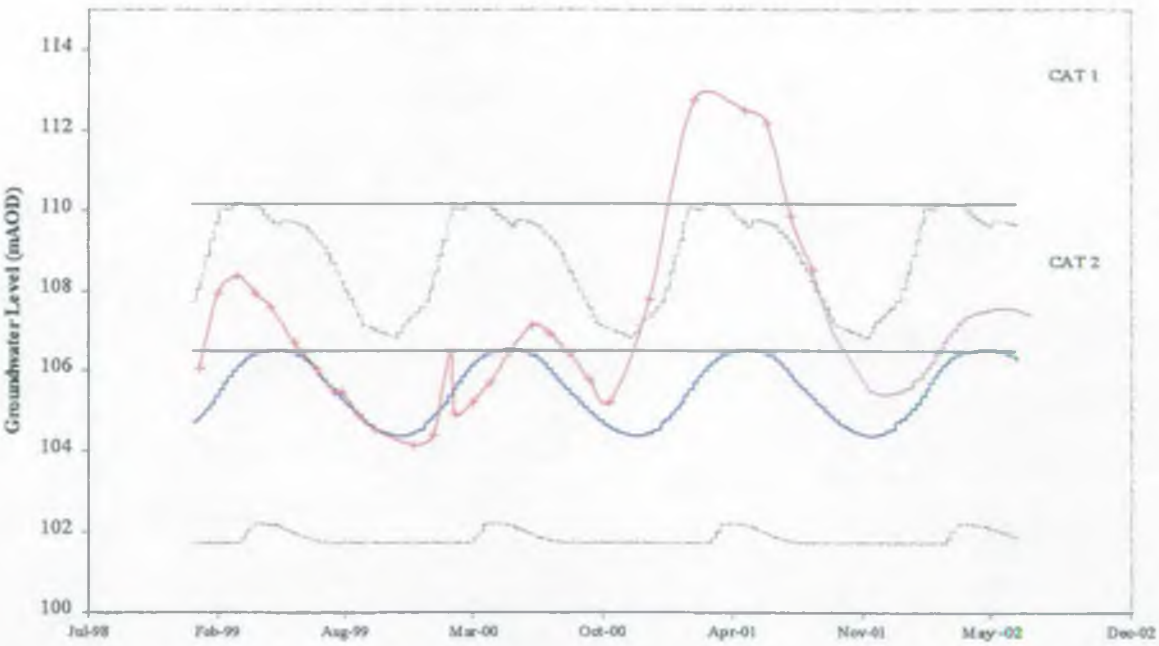


Bagmoor Farm (SU78/47) - Hambleden Stream

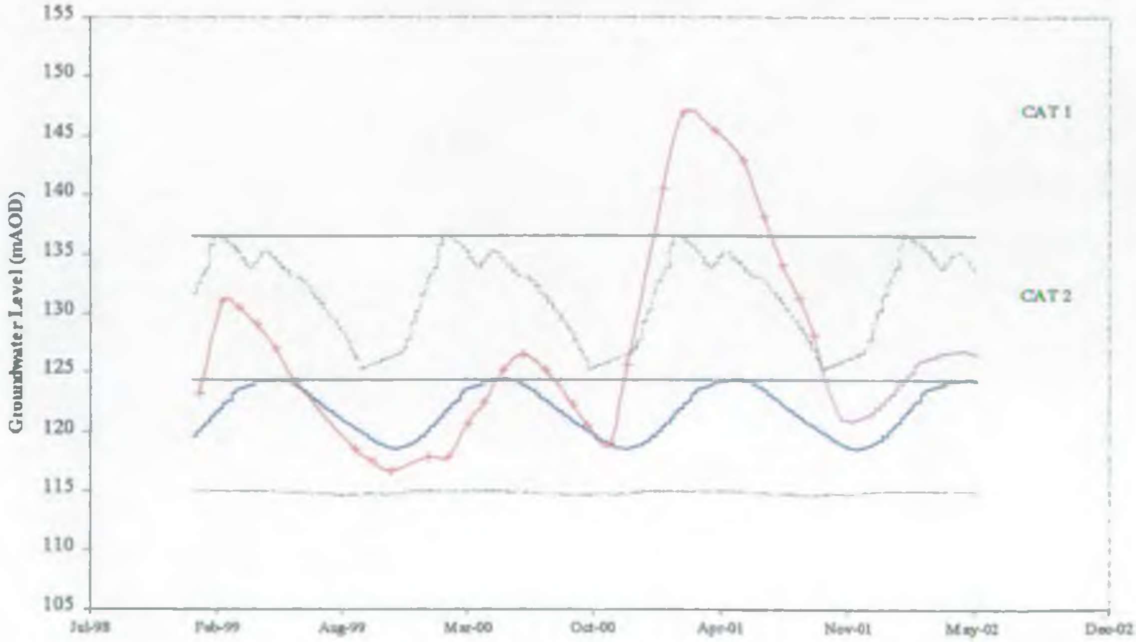


Colne Valley Chilterns

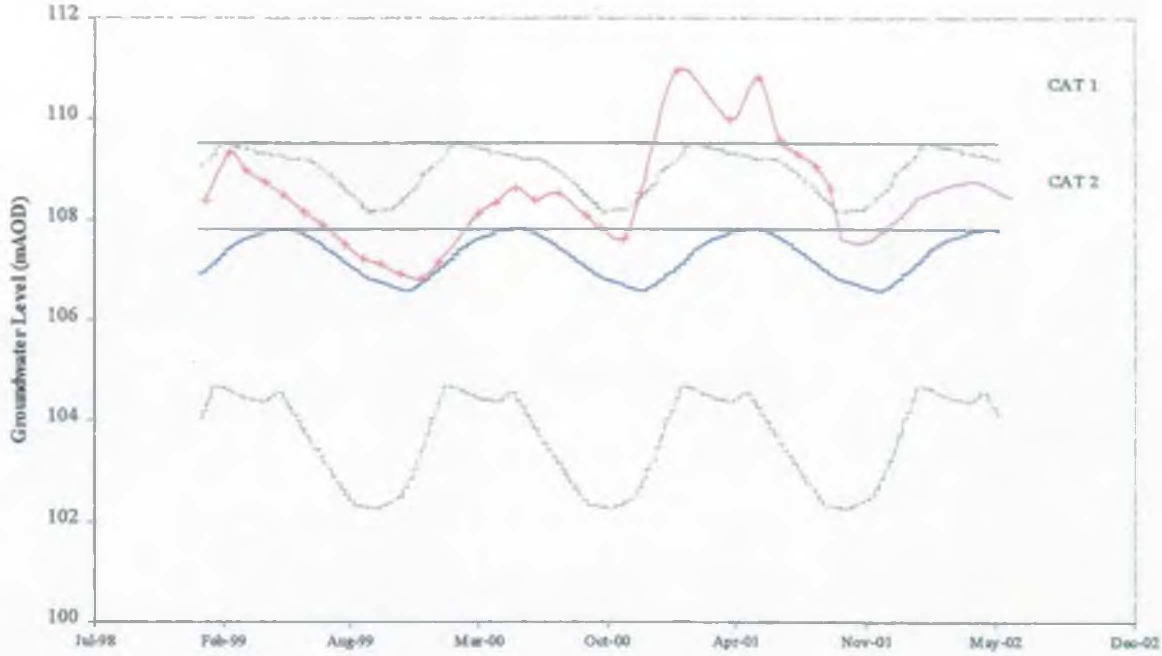
Hollybush Farm (TL00/30) - Gade



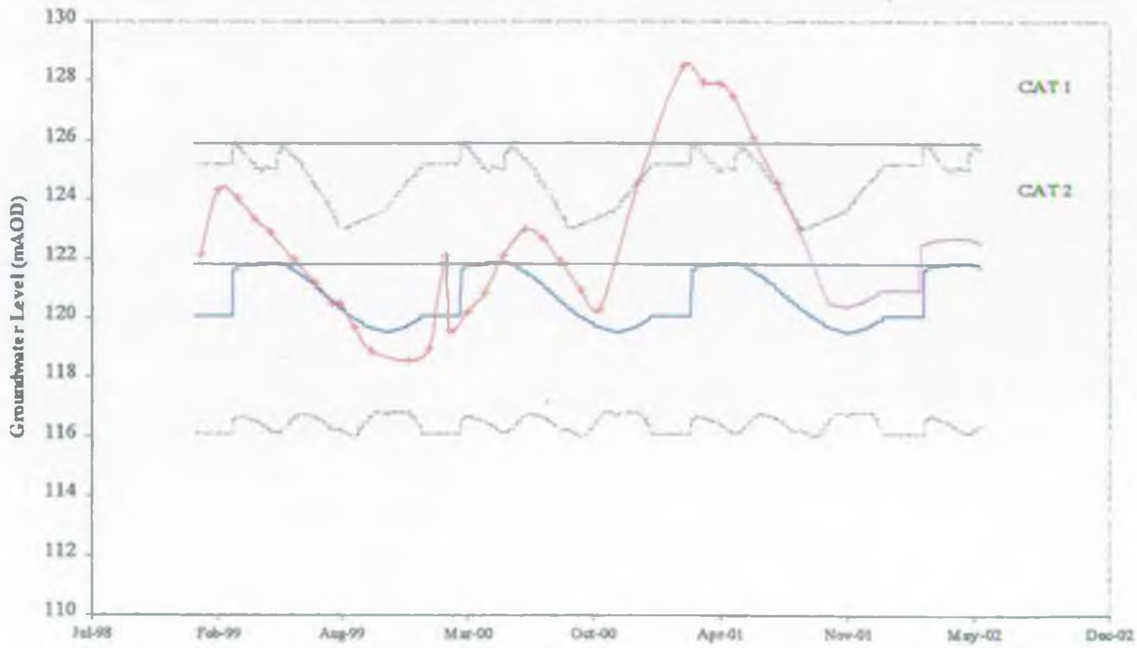
Village Well Lee Comon (SP90/27) - Misbourne



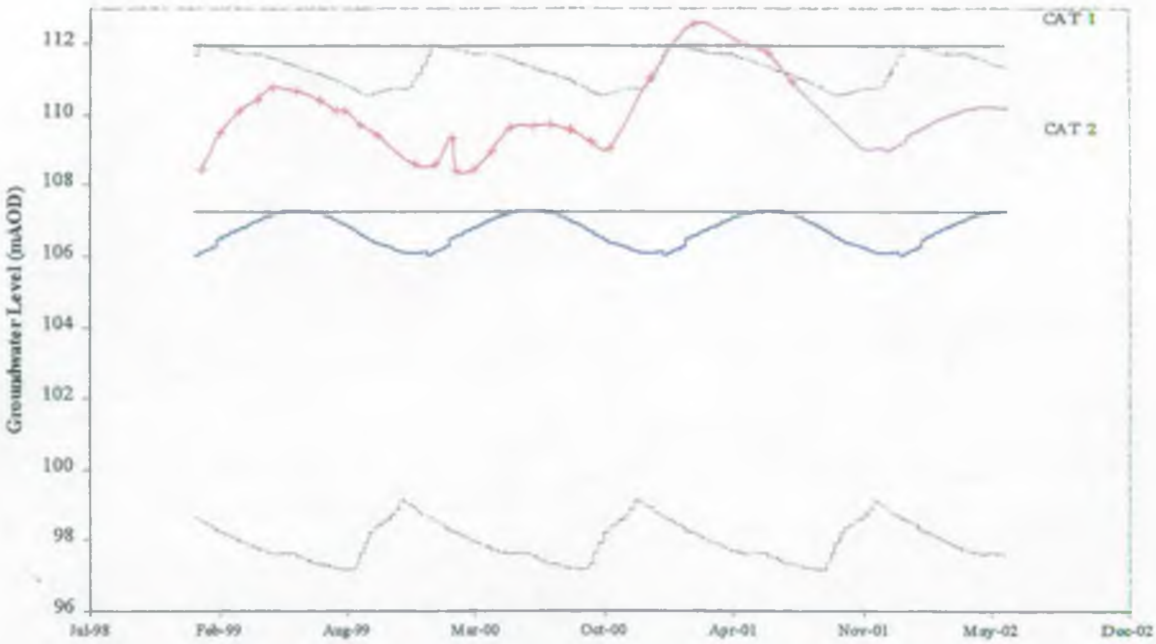
Wayside (SP90/56) - Chess



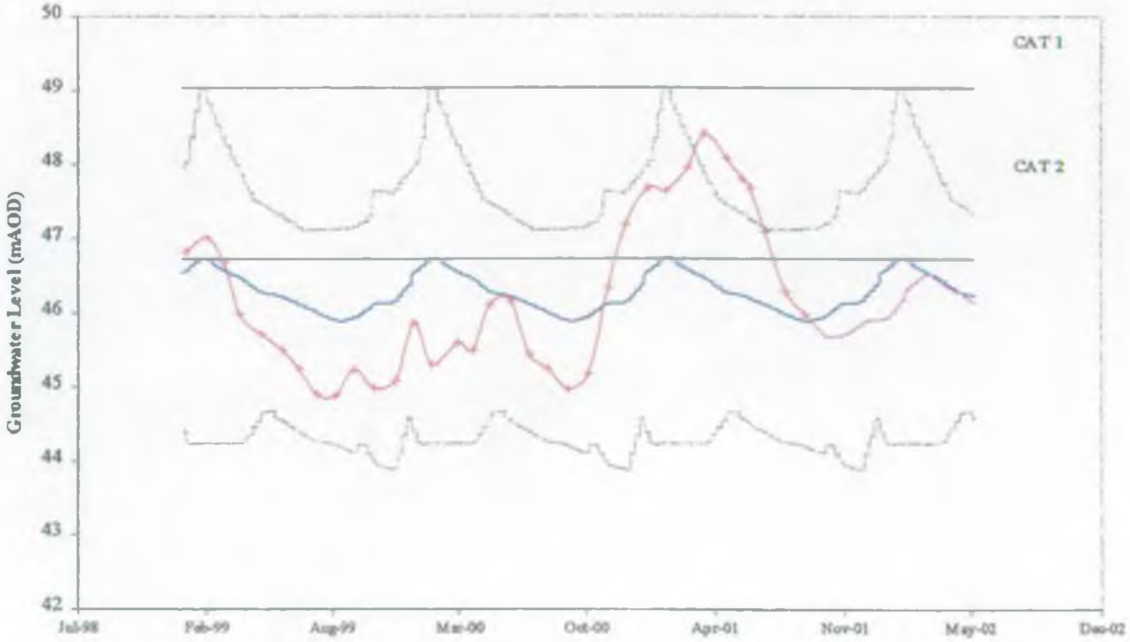
Village Well Aldbury (SP91/15) - Bulbourne



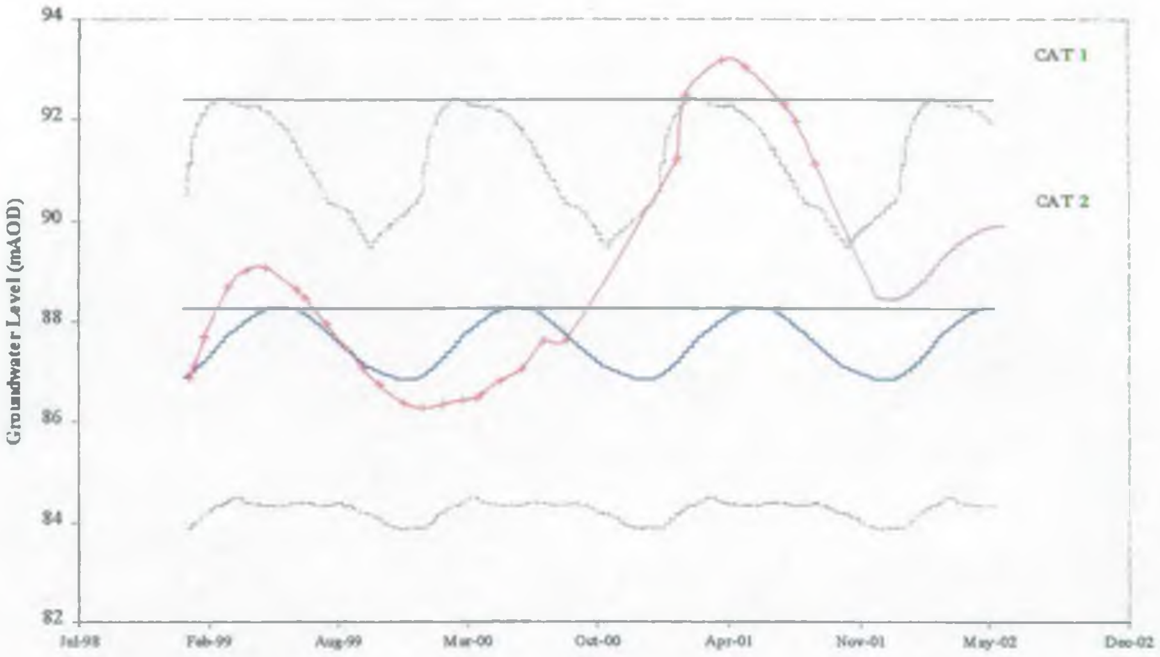
Highfield Farm (TL01/166) - Ver



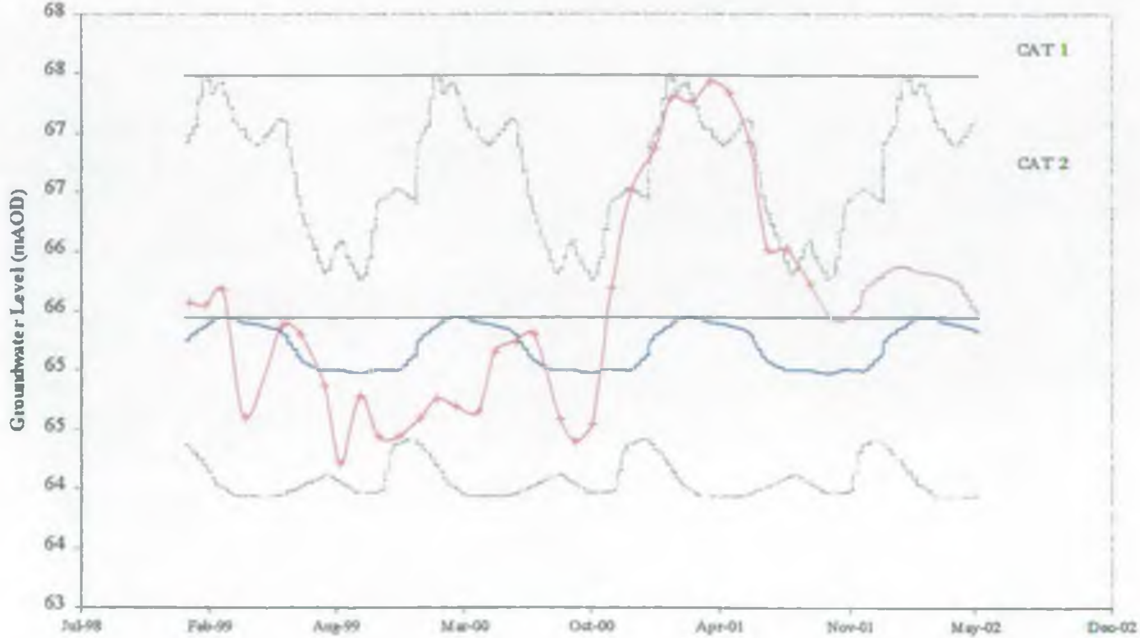
Cole Green (TL21/87) - Upper Lee



The Holt (TL11/9) - Mimram

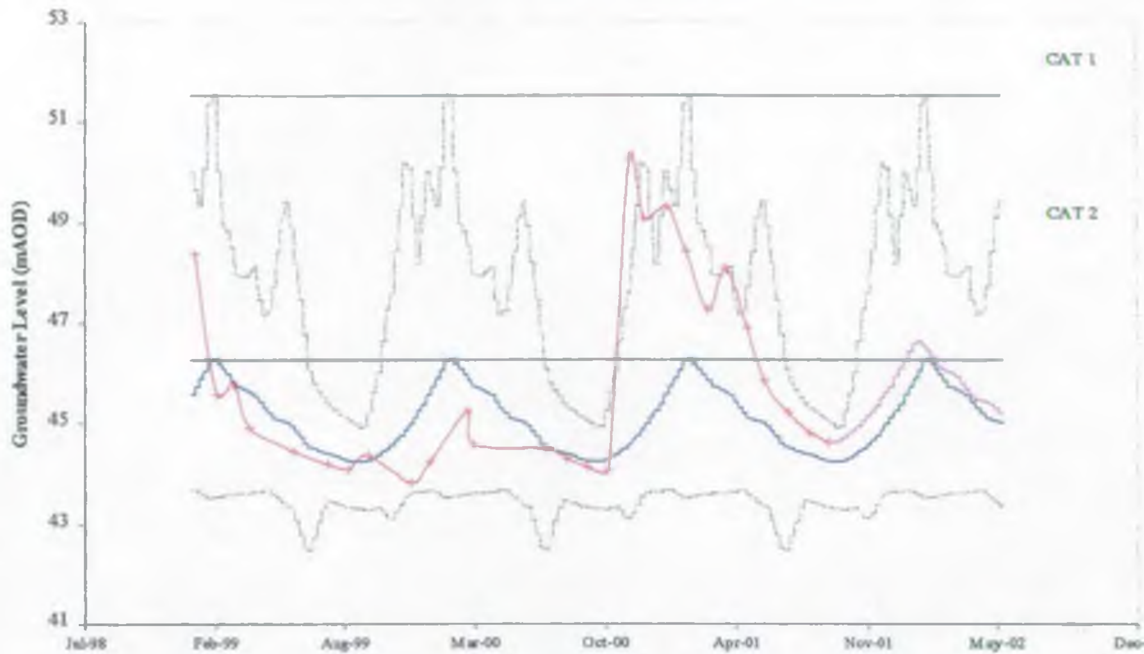


Church End (TL42/4) - Ash

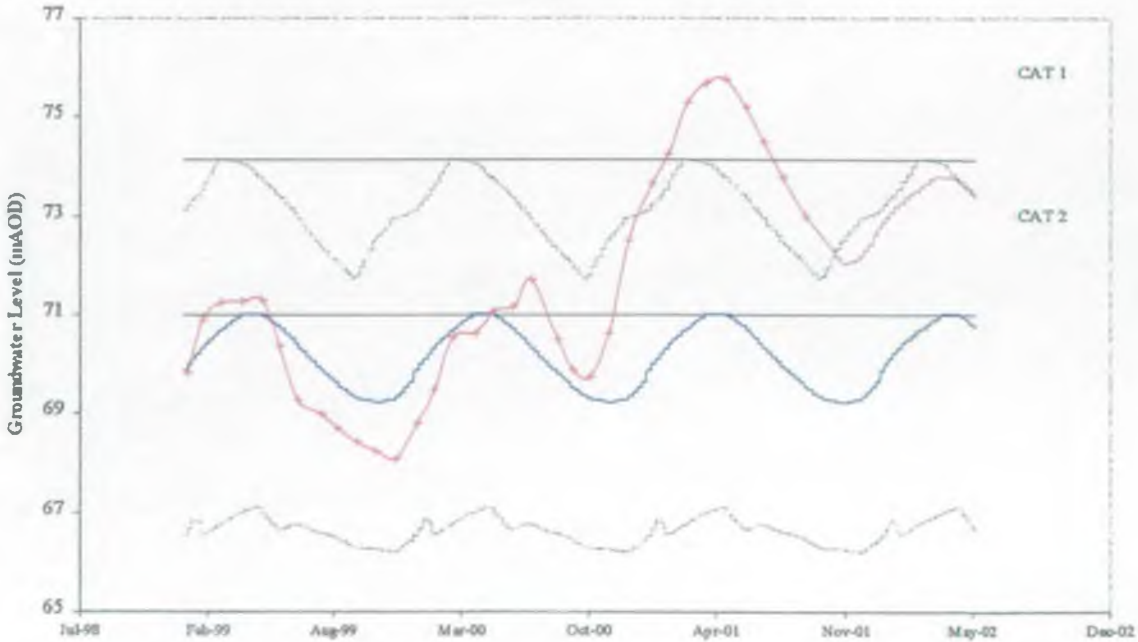


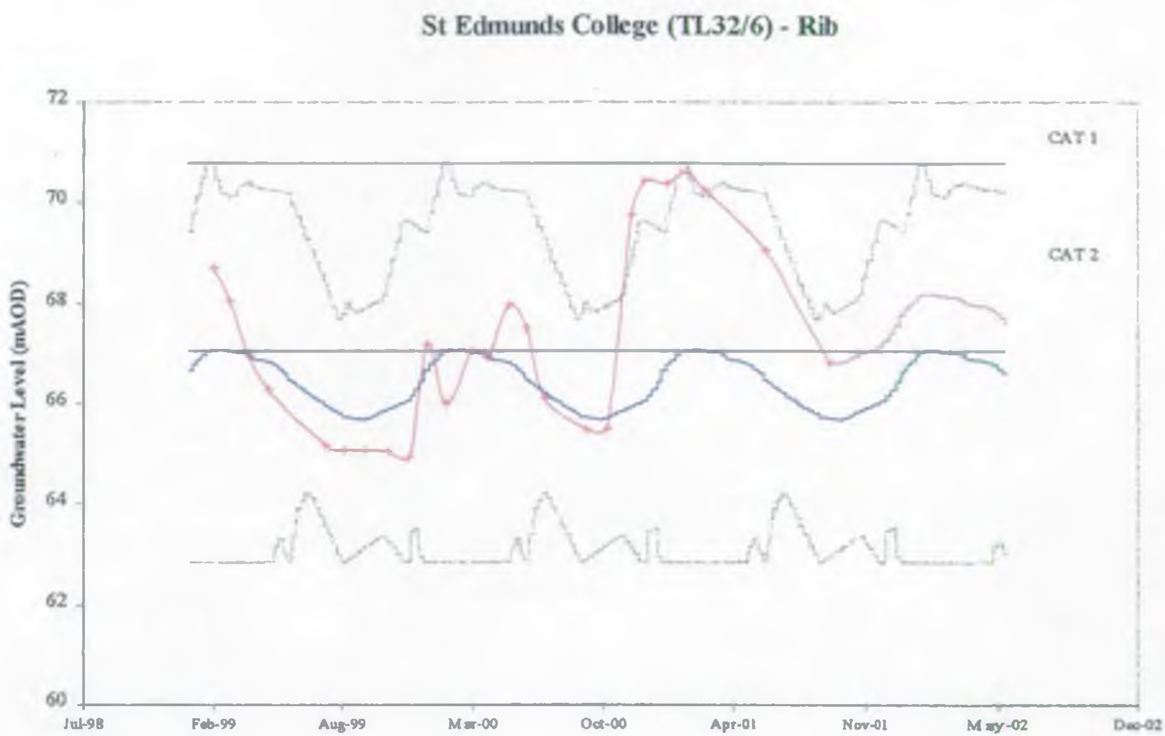
Upper Lee Tributaries

Well House Bramfield (TL31/9) - Beane



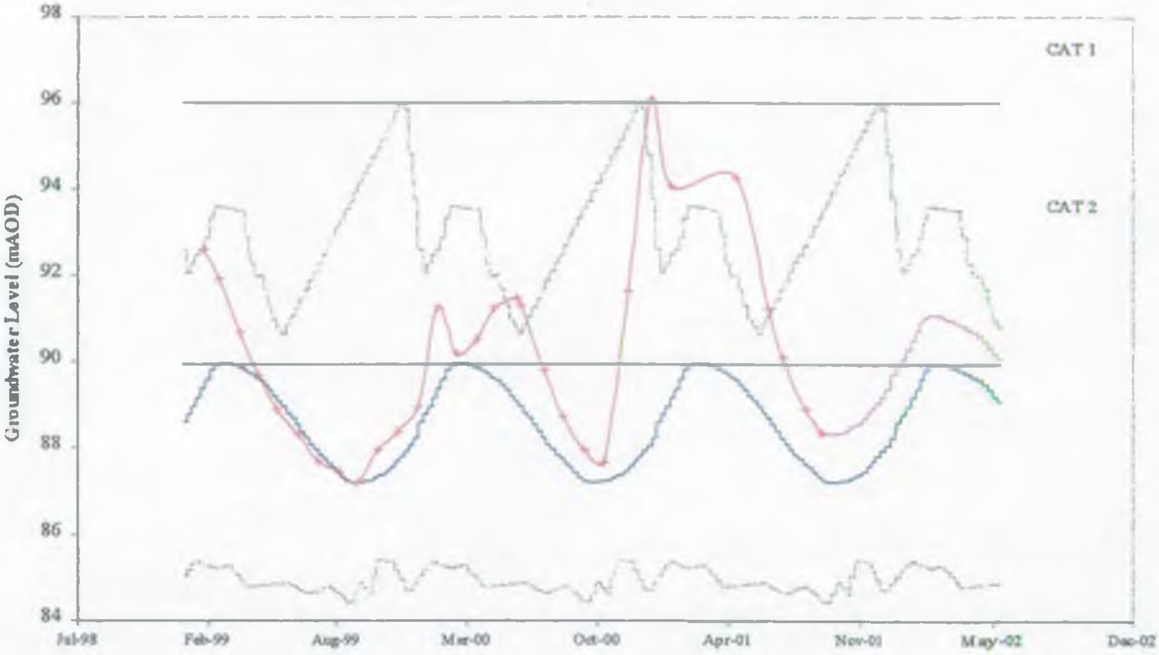
Berden Hall (TL42/8) - Stort



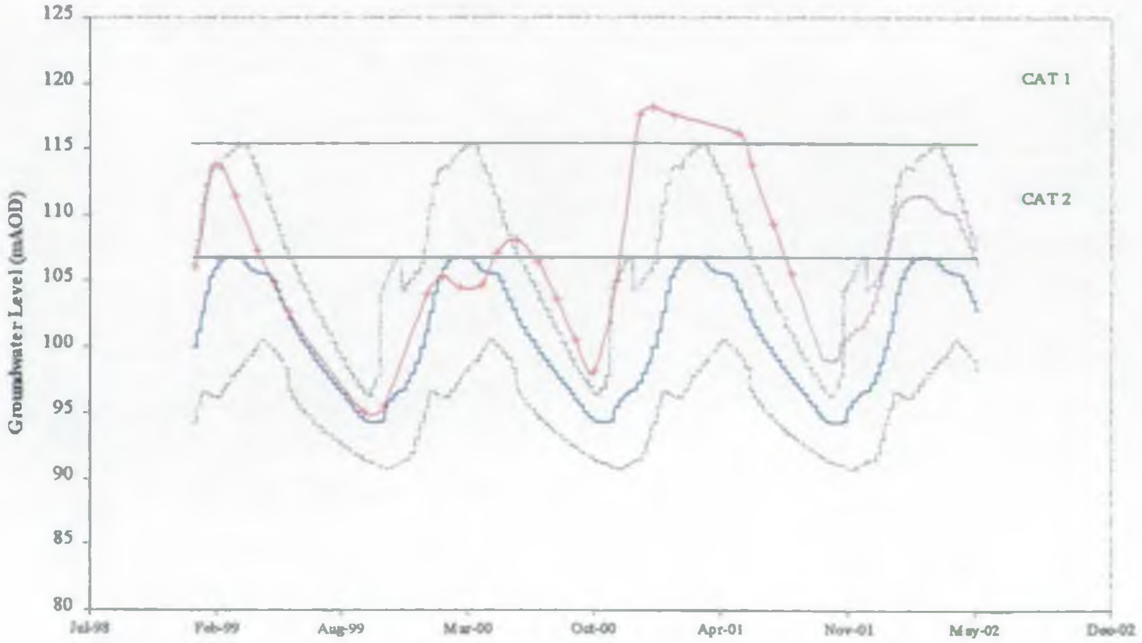

St Edmunds College (TL32/6) - Rib
Groundwater Level (mAOD)
72
70
68
66
64
62
60
CAT 1
CAT 2
Jul-98
Feb-99
Aug-99
Mar-00
Oct-00
Apr-01
Nov-01
May-02
Dec-02

N Hampshire

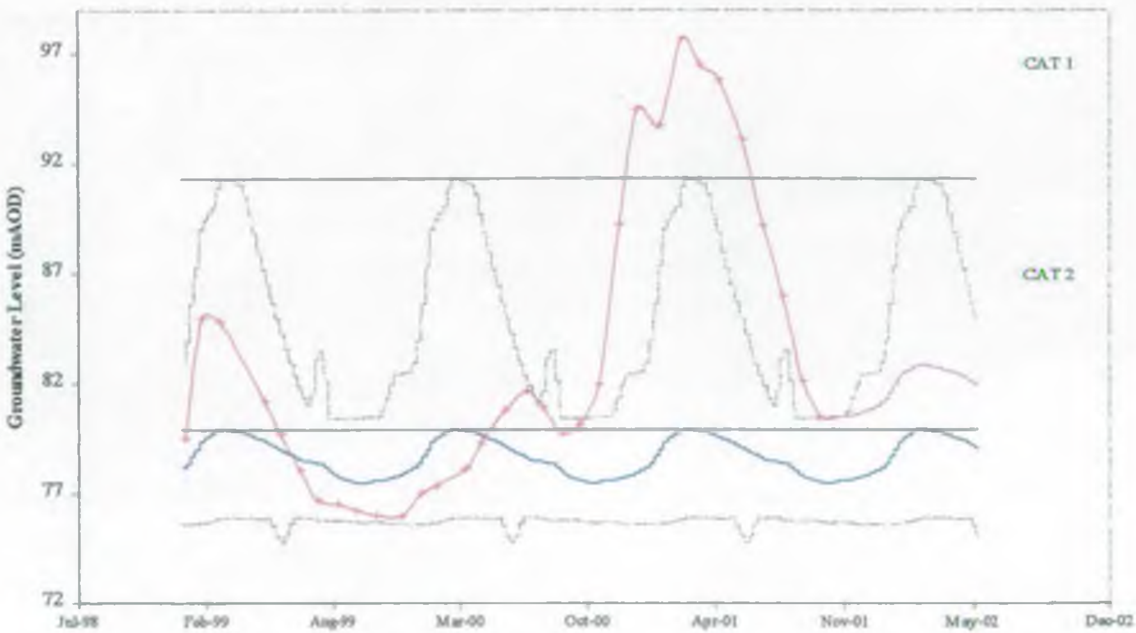
Tile Barn Farm (SU74/40) - Whitewater



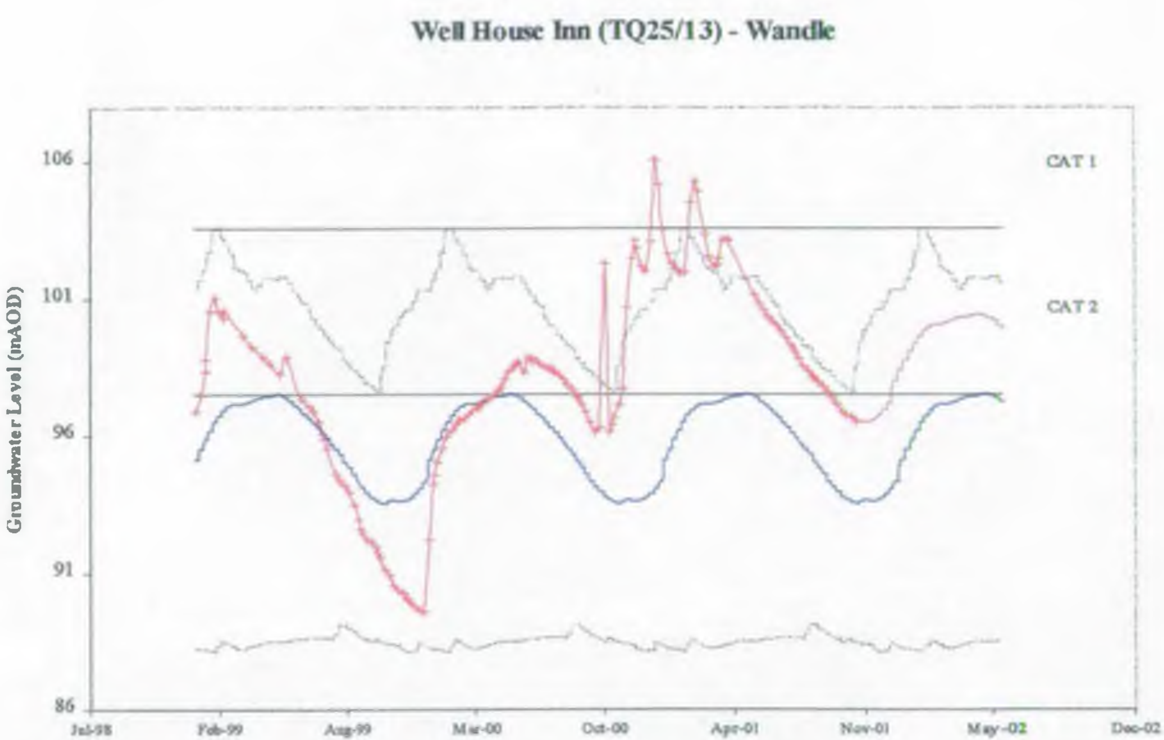
Farringdon Chalk OBH (SU63/124B) - Lavant Stream



Addington Lodge (TQ36/35) - Ravensbourne



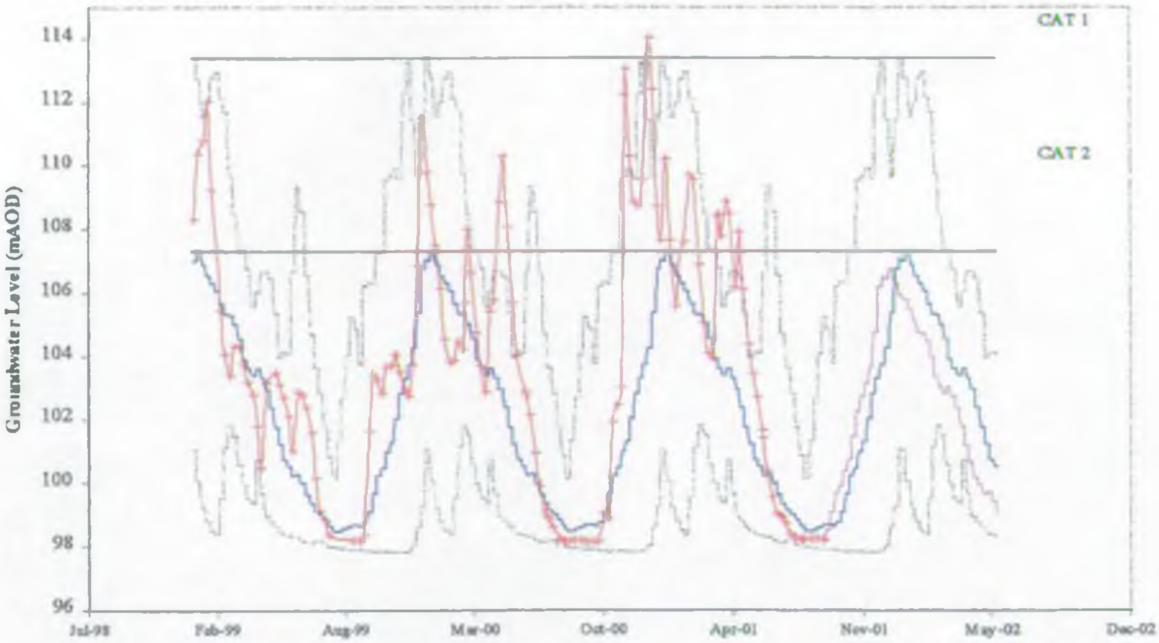
N Downs



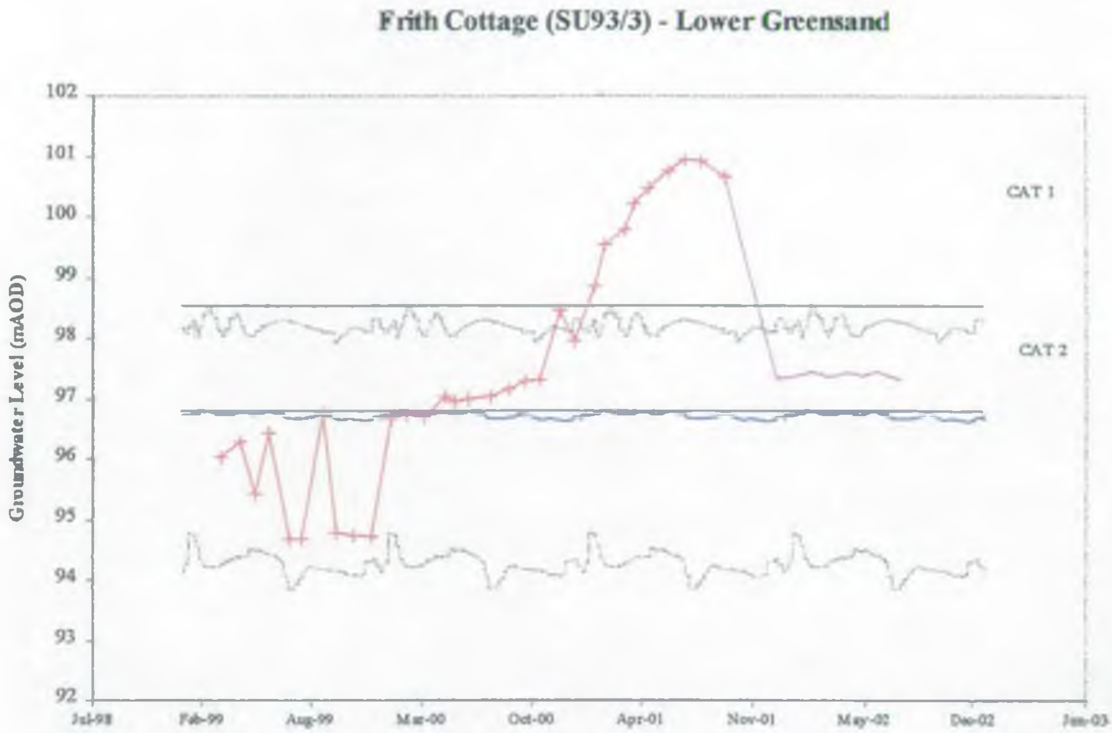
Well House Inn (TQ25/13) - Wandle
Groundwater Level (mAOD)
106
101
96
91
86
CAT 1
CAT 2
Jul-98
Feb-99
Aug-99
Mar-00
Oct-00
Apr-01
Nov-01
May-02
Dec-02

Cotswolds

Coln St Aldwyn OBH (SP10/96) - Ampney Brook



Lower Greensand



Appendix 3. Solid and drift geology legends

Solid Geology in Thames Region

- Upper Bagshot Beds
- Middle Bagshot Beds
- Lower Bagshot Beds
- London Clay
- Reading/Woolwich Beds
- Thanet Sand
- Upper Chalk
- Middle Chalk
- Lower Chalk
- Upper Greensand
- Gault
- Folkstone Beds(Lower Greensand)
- Sandgate Beds (Lower Greensand)
- Hythe Beds(Lower Greensand)
- Atherfield Clay (Lower Greensand)
- Undivided (Lower Greensand)
- Weald Clay
- Tunbridge Wells Sand
- Portland Beds
- Kimmeridge Clay
- Corallian
- Oxford Clay
- Cornbrash
- Forest Marble
- Great Oolite
- Fullers Earth Clay
- Inferior Oolite
- Upper Lias
- Middle Lias
- Lower Lias

Drift Geology in Thames Region

- ALLUVIUM
- BRICKEARTH-SILT
- VALLEY GRAVEL
- RIVER TERRACE DEPOSITS
- TERRACE GRAVEL
- HEAD
- GLACIOFLUVIAL SAND AND GRAVEL
- GLACIAL SAND & GRAVEL
- PEBBLE GRAVEL
- BOULDER CLAY
- CLAY-WITH-FLINTS