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RIVER OTTER LOW FLOW STUDY

PHASE THREE REPORT

SOUTH WEST REGION
ENVIRONMENT AGENCY

ENVIRONMENT AGENCY

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EXECUTIVE SUMMARY

This report completes the Environment Agency's River Otter Low Flow Study. It is aimed at the Rivers Sid/Otter Local Environment Action Plan Steering Group, South West Water and Wessex Water, and Environment Agency staff with a working interest in the River Otter.

The Study has identified abstraction for public water supply as a contributory factor in explaining the observed low flows in the river. Historic abstractions by South West Water from groundwater sources in the catchment downstream of Honiton are estimated to have caused a reduction in natural summer low flows of between 9 to 15 percent. Had abstraction from these sources occurred at the full licensed rate then the flow impact is estimated at between 12 to 25 percent. The largest flow impacts are estimated to occur in the estuary, downstream of Otterton.

Historic abstractions by Wessex Water from the Otterhead Lakes are estimated to have reduce natural flows in the river at Fenny Bridges by less than 3 percent. Below Fenny Bridges the historic flow impact of Otterhead Lakes abstraction is negligible. An attempt was made in the Study to estimate the flow impact caused by abstraction from the Lakes at the full licensed rate. However, the Study concludes that the prediction is a gross over-estimate.

The Study has quantified the impact of public water supply abstraction with respect to available dilution water. Water quality indicators have been calculated downstream of each of three major sewage treatment works, in the river below Fenny Bridges. The Study concludes that historic and maximum authorised abstraction would result in an insignificant water quality impact.

The Study has also assessed the impact of abstraction on the environment through analysis of various monitoring data. There is clear evidence that water quality throughout the catchment has improved since the 1980s and is comparable to the quality achieved in the 1970s. Macro-invertebrate data indicates the River Otter consistently achieves a good quality rating. In addition, a general improvement in biological quality is observed during the period 1990 to 1998. Fisheries data shows no clear trend attributable to abstraction through the period 1978 to 1998. Brown trout abundance has risen in recent years.

It has not been possible to predict the environmental impacts that may arise due to public water supply abstraction at the maximum authorised volume from the available monitoring data. This is because abstraction at the maximum rate has not occurred.

Other general environmental data shows that the River Otter is a high quality environment. The Report presents the findings of environmental surveys including information from habitat surveys undertaken by various organisations in the past. These data provide further relevant evidence beyond the routine environmental monitoring conducted by the Agency and its predecessor authorities.

The Agency can now commence the review of its approach to abstraction licensing for the River Otter. The Study recommends that the Agency discuss with South West Water the capability of full take up of their abstraction licence quantity. This is based on the uncertainty surrounding the environmental impact of the Company's groundwater abstraction at the fully authorised rate. The Study also recommends a review of the Agency's environmental monitoring programme for the River Otter.

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1. INTRODUCTION

This document concludes the River Otter Low Flow Study conducted by the Environment Agency and completes the action identified against issue 3bi ("Low Flows in the River Otter") from the Rivers Sid and Otter Catchment Management Plan Action Plan. Strategies for the completion of actions against issue 3bii ("Abstraction licensing policy in the River Otter") can now be devised, as these are dependent upon the outcome of the Study.

1.1 Audience

This report is intended for the Sid/Otter Local Environment Action Plan Steering Group, South West Water, Wessex Water and the Environment Agency.

1.2 Scope and scale of study

The Study concerns the impact of abstractions for Public Water Supply (PWS) from sources in the River Otter catchment. The particular sources examined are South West Water's boreholes in the lower catchment and Wessex Water's reservoir, Otterhead Lakes, in the upper catchment. Table 1 summarises the total current (1998) licensed abstraction in the catchment for all purposes. Details of the PWS sources examined in the Study are shown in Table 2. The impact of abstraction for purposes other than PWS is not examined in this report[1]. Where used, the term abstraction in the remainder of this report refers to the PWS sources unless otherwise stated.

The Study has examined the impact of abstractions in the River Otter at a broad scale over the period 1972 to 1998. Impacts attributable to individual sources are not derived. Instead, the Study has estimated the collective impact of abstractions. The Study period covers the years 1972 to 1998.

1.3 Assumed prior knowledge of readers

It is assumed that the reader is familiar with the River Otter catchment, its geography and the River Otter Low Flow Study (through Phases One and Two). A glossary of terms is included at the end of this document.

1. The total licensed volume of abstractions for Public Water Supply in the Otter is far in excess of the largest consumptive private water abstraction.

2. THE STUDY PROBLEM, BACKGROUND AND METHODS

2.1 The Study problem

During the last ten years various groups[2] and individuals have claimed that abstractions for PWS have caused environmental damage in the River Otter catchment. The complaints invariably refer to South West Water's (SWW) groundwater boreholes and Wessex Water Services' (WW) Otterhead Lakes abstraction. The claims specifically concern the impact abstractions have, at times, on low river flows and the resultant implications for brown trout and the effective dilution of sewage treatment works effluent.

Low flows occur naturally in the River Otter due to variations in the volume of water contributing to river flow and variations in the volume of water naturally lost from the catchment. Artificial influences, such as abstraction of water, can also cause low flows. The mechanism by which natural and artificial factors influence low river flow in the Otter catchment is detailed in Appendix Two.

The Study's central problem is to estimate the contribution of abstraction as a factor in causing low flows and to examine the evidence of subsequent environmental impact.

2.2 Background to the Study

In 1993 the River Otter Low Flow Study was begun by the National Rivers Authority (NRA) to ascertain the existence, cause and alleviation of low flows in the River Otter. The Study comprised Three Phases as follows:

- Phase One: An environmental audit of the existence, scale and location of problems;
- Phase Two: The quantification of hydrological impacts of abstraction in the catchment;
- Phase Three: The assessment of environmental implications of the hydrological impacts.

The Study has been completed by the Environment Agency, which succeeded the NRA in 1996.

2. Mainly the River Otter Association and the Otter Valley Association.

2.3 Environment Agency interim authorisation policies in the River Otter catchment

The Agency is responsible for licensing water abstraction proposals. Since the Study began the Agency has continued the NRA's policy of applying additional caution in authorising proposals in the River Otter catchment that fall within its statutory duties[3]. The Study findings will influence the future development of appropriate Agency authorisation policies for the River Otter.

2.4 Study Methods

The Study is concerned with hydrological and environmental impacts related to abstraction. Methods used in the Study to estimate these impacts are described below. The key features of the catchment as far as the Study is concerned are shown in Figure 1.

2.4.1 Methods used to estimate the hydrological impact of abstraction

In estimating hydrological (river flow) impacts the Study has had to use methods appropriate to the type of abstraction.

The hydrological impacts associated with the WW surface abstraction at Otterhead Lakes were examined in Phase Two using a flow naturalisation technique. This technique is particularly appropriate for assessing the impact of surface abstractions. Appendix Three describes the use of this technique in the Study.

In order to examine the hydrological impact of the SWW groundwater abstractions the Otter Valley Groundwater Model (OVGM) has been utilised. The model is an appropriate tool to use in relation to the borehole abstractions. This is because a major influence on flow in the catchment downstream of Fenny Bridges is the aquifer of the Otter Sandstone/Budleigh Salterton Pebble Beds. The boreholes abstract water from these rock strata. Appendix Two demonstrated that the river-aquifer interaction is the key mechanism by which natural low flows occur and through which groundwater abstraction results in river flow impacts.

The OVGM was used by the NRA in Phase Two to estimate the hydrological impacts caused by SWW borehole abstractions. Following model enhancements by the Agency, these impacts have been re-estimated in Phase Three. Details of the OVGM are included in Appendix Four.

3. The Agency has a statutory responsibility for protecting the environment from damage caused by over-abstraction. This statutory responsibility is executed through the abstraction licensing legislation. The general aim of the Agency's abstraction licensing policy is to ensure that the needs of the environment are balanced with the reasonable needs of abstractors. The Agency will not licence an abstraction that causes significant environmental damage. Such damage could include effects on the environment itself, such as fish, and the river's water quality, but also effects on existing lawful water users such as licensed abstractors. The largest abstractors in the Otter catchment are the water supply companies (South West Water and Wessex Water) who have a statutory duty to meet the water needs of their customers. The Agency must take into account this duty when balancing the needs of the abstractor with those of the environment.

2.4.2 Methods used to estimate the environmental impact of abstractions

The estimation of environmental impacts that can be attributed to abstraction was a key activity of Phase Three of the Study. The methods used are described in detail in Section Four.

2.4.3 Summary of Phase Three work

Phase Three consisted of the following work:

- Activities to improve/extend the Otter Groundwater Model (Appendix Four);
- Re-assessment of hydrological impacts caused by SWW abstraction (see Section Three);
- Assessment of environmental impact caused by abstraction (see Section Four).

During Phase Three various other assessments concerning the hydrological impact of abstractions were suggested by the Sid/Otter LEAP Steering Group. The Agency has responded fully to these suggestions both in correspondence and via presentations at LEAP Steering Group Meetings. The results of applying these methods and the Agency's assessment of their value are discussed in Appendix Seven.[4]

Section Three reports the hydrological impacts estimated in the Study.

4. It will be noted from Appendix Seven that none of the suggested approaches enables the impact of abstraction to be quantified explicitly. Instead these methods enable only qualitative or intuitive interpretations of the data. However, the Agency agreed to apply these techniques and the results show, intuitively at least, that there are no serious hydrological impacts related to abstraction in the River Otter.

3. THE HYDROLOGICAL IMPACTS CAUSED BY ABSTRACTION IN THE OTTER

This section reports the hydrological impacts of the Public Water Supply abstractions as estimated in the Study.

3.1 Estimated flow impacts caused by abstraction from Otterhead Lakes

Phase Two derived robust estimates of the hydrological impact of historic abstractions from Otterhead Lakes. These estimates were derived for flow at Fenny Bridges and Dotton gauging stations using the flow naturalisation technique. Two impacts were estimated at each site. Firstly, the average monthly flow impact was derived from the full record of recorded and naturalised flows. The month of July was found to be the month during which the peak impact occurred. Secondly, the impact of abstraction on a typical low flow index (Q_{95}) was derived from the recorded and naturalised flows. The flow impacts caused by abstraction from Otterhead Lakes at the historic rate are shown in Table 3.

Table 3

Estimated impact of historic abstraction from Otterhead Lakes

derived using flow naturalisation technique

Scenario being compared>	Natural v historic percentage difference (July river flow).	Natural v historic percentage difference (Q_{95} flow).
Site:-		
Fenny Bridges	2.5	4
Dotton	1.5	2

Phase Two concluded that estimates of the flow impact caused by abstraction at the maximum rate were of insufficient accuracy. Appendix Three explains this conclusion.

It is clear from Table 3 that historic abstraction from Otterhead Lakes results in an insignificant flow impact at Fenny Bridges and at Dotton.

3.2 Estimates of groundwater/river flow impacts caused by SWW borehole abstractions

The groundwater and river flow impacts caused by SWWS' borehole abstractions have been estimated using the Otter Valley Groundwater Model. The main concern about groundwater abstraction in the catchment has been its effect on the river downstream of Fenny Bridges.

Utilisation of the model in for this work followed the addition of several enhancements to the OVGM program and model re-calibration. Appendix Four describes these improvements and the model calibration. The Model has been used to simulate groundwater and river flows in the catchment for the period 1974 to 1995 under the three following scenarios:

- NATURAL: no abstraction from South West Water's boreholes;

- HISTORIC: abstraction from South West Water's boreholes at the actual rate that occurred during the period 1974-95;
- MAXIMUM AUTHORISED: abstraction from South West Water's boreholes at the current licensed maximum rate (including seasonal abstraction conditions).

Appendix Five describes how the model was used to provide groundwater and flow data under each of the scenarios.

3.2.1 Groundwater impacts at Alfington No. 1 caused by groundwater abstractions

Appendix Two explained that SWW borehole abstractions affect river flow through the river-aquifer interaction. The Study has been concerned with the environmental consequences of such flow variations but is also concerned with the significance of groundwater level variations at particualr "known impact" sites in the catchment. The Agency has used, therefore, the OVGM to illustrate the significance of the impact of abstractions on groundwater levels at Alfington No 1. This is a "known impact" observational borehole located 2-3 kilometres from the group of SWW boreholes at Greatwell.

The Agency has noted that a plot of observed groundwater levels at Alfington No 1 depicts a general decline in groundwater levels over the last twenty years. Figure 3 shows the modelled groundwater level under the three scenarios at Alfington No 1 for the period 1976 to 1995. Also, shown is the groundwater level as observed at Alfington No 1. This graph suggests that without abstraction the groundwater level over the period would have varied around a relatively constant value (1m range at approximately 51-52m above Ordnance Datum).

Figure 3 also shows that the observed rate (gradient) of decline in groundwater level until 1993-94 is very well mimicked by the model under the historic abstraction scenario. Notable hydrological events as depicted by the observed record are also mimicked by the model under the historic scenario. For example, the drought and recovery of 1976 can be seen in the modelled data as well as the observed data. Also simulated by the model is the recovery in groundwater levels in the years beyond 1993. The Model must achieve a reasonable fit with observed groundwater level data in order to simulate accurately the aquifer's contribution to river flow via baseflow. Appendix Five shows that a sufficiently accurate baseflow calibration has been achieved in the Otter Groundwater Model. This is the reason why the Agency concludes that the groundwater level calibration (in terms of the absolute differences between the observed and the modelled historic scenario groundwater levels) is acceptable. Appendix Five presents more details about the model calibration in terms of observation sites, simulated groundwater levels and absolute divergences from observed groundwater level.

As with river flows, groundwater levels reflect the combined effect of losses from and contributions (gains) to the groundwater system. It is apparent from the observed and modelled Alfington groundwater level data that abstraction (a loss) has caused the general long-term decline in groundwater levels. Aquifer recharge (a contributory/gain factor) at this location would appear to have a secondary, seasonal influence. Appendix Seven provides a full commentary on the Alfington No 1 groundwater level observation record, as well as other sites in the catchment. The commentary was included in the Agency's response to a request for groundwater level data from the LEAP Steering Group. It illustrates how the relative importance of abstraction and recharge as influencing factors depends, in part, on the proximity of the observation site to the abstraction point and the local geology.

The reduction in baseflow caused by SWW abstractions is the key mechanism the Agency has sought to simulate using the OVGM. It is concluded that the variations in groundwater level at Alfington No 1 are significant in terms of its likely impact on baseflows in the vicinity of Ottery St Mary. A reduction in baseflow will result in an impact on total river flow.

3.2.2 Estimated river flow impacts caused by SWW groundwater abstractions

Estimates of the impact of SWW borehole abstractions were obtained from modelled monthly flow data and modelled daily flow data obtained from the OVGM for each of the three abstraction scenarios. The period modelled is 1974 to 1995. The results from all the scenarios were compared to establish the Study's river flow impacts. The modelled flow data was obtained for two sites in the lower river:

- Dotton ; and
- A site representing the estuary.

These two sites represent the area of the lower catchment in which the largest flow impacts are thought to occur due to SWW groundwater abstractions. It will be apparent from figure 1 that a number of SWW boreholes are further south than Dotton. It is for this reason, and because groundwater flow is thought to be southerly, that the estuary site represents the impact of all of SWW's groundwater abstractions in the catchment.

The results are summarised below in terms of impact on monthly flow, summer flow and the Q_{95} flow value.

3.2.2.1 Estimated hydrological impact of SWW abstractions (modelled monthly flows)

The modelled monthly flow hydrographs under the three abstraction scenarios are depicted in Figures 4 and 5 for Dotton and the estuary respectively. These hydrographs show that historic abstraction and abstraction at the authorised maximum rate has reduced or would reduce natural flow. These figures show that there are periods when natural flow was very low. For example, in figure 4, natural flow in the estuary would have been less than 1 cubic metre per second for brief periods in 1976, 1989, 1992 and 1995.

It is also worth noting from figures 4 and 5 that the reduction in flow caused by abstraction is generally less than the range of natural low flows. For example, the highest value of late summer natural low flow at Dotton is under 2 cubic metres per second in 1988. The lowest late summer natural low flow is 0.7 cubic metres per second. However, the reduction in natural low flows (for example, in 1976 and 1992) under the historic and maximum authorised abstraction scenarios is much less than this range, being of the order of a few tenths of a cubic metre per second.

Figures 6 and 7 show the percentage difference in monthly flow between the various scenarios at Dotton and the estuary respectively. The upper graph on each figure shows the comparison between the natural and historic abstraction scenarios. The lower graph shows the difference between the natural and maximum authorised scenarios.

Table 4 below summarises the flow impacts based on modelled monthly flows under the various scenarios at Dotton and the estuary. The data is percentage difference between the flows under the two scenarios.

Table 4

Estimated percentage difference between modelled monthly flows for the three abstraction scenarios

	Dotton		Estuary	
Scenarios under comparison>>>	**Natural compared to Historic**	**Natural compared to Maximum authorised**	**Natural compared to Historic**	**Natural compared to Maximum authorised**
Mean impact (%)	6	8	10	16
Peak impact (%) Month of peak impact	18 July 1992	22 July 1992	30 July 1992	45 July 1992

3.2.2.2 Estimated impact of SWW groundwater abstraction on summer flows

As a further analysis of the modelled monthly flow data the impact of abstraction on summer flows was examined. Summer flows are taken as those flows occurring during the period July to September inclusive. Typically it is during this period when flow reaches its lowest levels. The analysis was based on deriving the flow impacts for the months July to September inclusive for each year in the period 1974 to 1995. Table 5 summarises the results of the analysis of summer flow impact:

Table 5

Estimated flow impacts (% differences)

based on modelled summer (July to September) flow data

	NATURAL COMPARED TO HISTORIC	NATURAL COMPARED TO MAXIMUM AUTHORISED	NATURAL COMPARED TO HISTORIC	NATURAL COMPARED TO MAXIMUM AUTHORISED
Average	9	12	15	25
Maximum	15	18	23	37
	Dotton		Estuary	

The summer low flow analysis shows that the average summer natural flow impact caused by historic abstractions is less than 10% at Dotton. At the other extreme, the maximum reduction in natural summer flows is 37% at the estuary caused by abstraction at the maximum authorised quantity. Caution must be used when interpreting the significance of the most extreme impact values.

3.2.2.3 Flow-duration curve under each scenario

Flow –duration curves depict on one graph the full flow regime at a location. Each daily flow value is plotted according to its value and the percentage of time that flow in the river equals or exceeds that value. The higher the exceedance value the lower the flow. A typical low flow statistic obtained from flow-duration curves is the flow exceeded 95% of the time: The so-called Q_{95} flow.

Figures 8 and 9 illustrate the flow-duration curves for Dotton and the estuary, respectively, based on modelled daily flows. The curves illustrate that the largest impacts caused by abstraction occur at times of low flow. It is only at times of low flow that a difference between the scenarios can be discerned.

Table 6 below summarises the differences between the three abstraction scenarios according to their Q_{95} value.

Table 6.

Comparison of estimated Q_{95} value (cubic metres per second)

under the three abstraction scenarios at Dotton and the estuary

with percentage differences (compared to natural) in parenthesis

Abstraction scenario>	Natural	Historic	Maximum authorised
Dotton	1.05	0.91 (13%)	0.89 (15%)
Estuary	1.12	0.88 (21%)	0.76 (32%)

As an illustration of the model's robust calibration it is worth noting that the observed Q_{95} at Dotton (0.916 cubic metres per second for the period 1962-96) is accurately mimicked by the model: The model simulates a Q_{95} at Dotton of 0.91 under the historic abstraction scenario.

3.2.2.4 Flow accretion assessment

In Phase Two the Agency produced a flow accretion graph for the River Otter using the Model. This is shown in Figure 10 and illustrates the accretion of the average Q_{95} at various locations along the main river. It is of particular use in illustrating the geographic distribution of the estimated flow impacts caused by SWW groundwater abstraction.

Although the data used in Figure 10 is from the version of the Otter Groundwater Model produced in Phase Two[5] the figure serves to complement the general impact result that the largest flow impacts are in the estuary.

Section Four reports the estimated environmental impacts caused by abstraction.

5 It may be observed that the impacts derived from the Phase Three version of the Otter Valley Groundwater Model are not dissimilar to those obtained from the Phase Two version.

4. ENVIRONMENTAL IMPACT OF ABSTRACTIONS IN THE RIVER OTTER

Section Three reported the origin and magnitude of the hydrological impacts caused by abstractions in the River Otter. This Section considers the effect that may arise as a result of abstraction; that is, the subsequent impact on environmental features. The Study has examined the impact of abstractions on three key environmental indicators in the catchment. These include the river's water quality, its macro-invertebrate population (the small animals that inhabit the river-bed) and the fish that live in its waters. This Section also presents the findings of other surveys of general environmental features in the catchment.

It is important to note that all abstractions will result in a degree of impact, but the effect may be immeasurable or insignificant. Other contributing factors could be far more significant than the effects of abstraction..

4.1 Potential environmental impacts

The Study has concluded that the major hydrological impact caused by abstraction in the River Otter is the reduction in flow in the lower river associated with SWW's groundwater abstractions. Consequently, the major environmental impacts caused by abstraction will be those associated with the decreased flow and depth of water in the lower river. A reduction in flow will directly affect the aquatic features of the river's environment as will the associated decline in water depths, velocities and wetted areas.

Section Three showed that groundwater abstraction reduces the height of the water table in the immediate vicinity of the abstraction point. Water features that form where the water table emerges above the land surface could also be affected by groundwater abstraction. However, the impact of abstractions on water features in the flood plain has not been a cause for concern in the Study. This is because there are no significant wetland features in the River Otter floodplain. For further details about the history of wetlands in the River Otter please refer to Section 4.5 below (other relevant environmental data).

The Study's environmental impact assessment covers the following potential flow-related effects:

- Deterioration in water quality;
- Reduction and/or change in macro-invertebrate population;
- Reduction and/or change in fish population.

4.2 Environmental impact assessment methodologies

The Study's environmental assessment has used two impact assessment techniques based on quantitative and qualitative approaches.

4.2.1 Quantitative environmental impact techniques

It has been possible to utilise quantitative water quality modelling techniques to provide numerical estimates of the impact of public water supply abstraction on the available water for dilution downstream of sewage treatment works.

4.2.2 Qualitative environmental impact assessment

The Study has also examined water quality, macro-invertebrate and fisheries monitoring survey data in an attempt to assess if there are causal links between public water supply abstraction and these environmental measures or features. The surveys of water quality and fisheries population cover most of the Study period (early 1970s to present). Although such a qualitative approach allows very little numerical analysis it is worthwhile because during the Study period abstraction by South West Water has reached significant volumes. For example, in the period 1989 to 1996 abstraction by the Company consistently averaged over 60 percent of the authorised maximum rate.

4.3 Quantitative water quality impact assessment

This section examines the results of the quantitative assessment of the impact of abstractions on water quality downstream of the three main sewage treatment works in the River Otter. An assessment of water quality monitoring data is presented in the Qualitative Impact Assessment section below.

4.3.1 How abstraction affects water quality

The key manner in which abstraction affects water quality is as a result of less water being available to dilute waste effluent in the river. This is known as the modified dilution effect. The greatest potential for such an effect occurs where there is a large waste discharge and when there are low flows in the river. From Section Three it will be apparent that this situation arises in the lower catchment, where the largest abstraction impact occurs, downstream of each of the following three South West Water sewage treatment works:

- Feniton;
- Ottery St. Mary; and
- Fluxton.

The location of these sewage treatment works is shown on Figure 1.

Direct discharges such as these are known as point sources of pollution. The Agency sets strict legal standards within which the discharge must operate including maximum volume of waste and its chemical composition. These standards are set by the Agency using various water quality models and analytical techniques. These models and techniques have been used in the quantitative water quality assessment.

In addition to the sewage works discharges, polluting material also enters the river from a variety of adjacent land-uses and from the atmosphere. This material is said to enter the river from diffuse sources. If the material enters the river at times of low flow then, as with the effect of the sewage discharges, there is the possibility that the river water quality could deteriorate via the modified dilution effect.

Diffuse sources can, in total, contribute a comparable mass of pollutants to that which enters the catchment via point sources. The impact of diffuse discharges is addressed in the study via the qualitative water quality assessment (the general water quality monitoring data also reflects all other pollution sources, such as the sewage treatment works).

4.3.2 Method used to derive quantitative water quality impact

In effort quantitative assessment of water quality impacts caused by abstraction the Study has utilised standard water quality models and the estimates of Q_{95} as reported in Section Three. The Agency's regular water quality monitoring data has also been used. This data is used by the Agency to classify rivers according to distinct categories of water quality (as part of the River Ecosytsem classification scheme)[6].

The method is based on the calculation of the modified dilution effect downstream of each sewage treatment works under the various abstraction scenarios. Estimates of the Q_{95} flow were obtained from the OVGM for sites in the river immediately downstream of the three sewage treatment works. These flow estimates are summarised in Table 7.

The Q_{95} values for Dotton gauging station as estimated under the maximum authorised abstraction scenario have also been utilised to derive impacts on water available for dilution. These Q_{95} values were derived in Phase Two using the flow naturalisation technique. The abstractions utilised in the assessment are all those upstream of Dotton (including SWW and WW abstractions). As previously observed, this scenario is an over-estimate of the true impact of maximum abstraction but the Agency decided to apply the estimated flow impacts in the quantitative water quality impact assessment.

The estimated Q_{95} flow impacts for each scenario were combined with water quality data via the Agency's standard water quality models. The water quality models utilise information about the composition of the effluent and the water quality of the receiving watercourse. By combining the water quality and flow data it is possible to determine the RE class of the river under the particular abstraction scenario. The RE classes obtained under each scenario were then compared to conclude whether or not a change in water quality would be likely between scenarios.

Two key indicators of water quality have been utilised to assess the RE class:

- Biological Oxygen Demand (a measure of the organic content of the water); and
- Total ammonia.

6. The Agency's water quality monitoring programme collects and describes the river's water quality on a reach by reach basis using a standard, national assessment system called the River Ecosystem (RE) classification scheme. This system categorises the river's water quality according to five distinct classes. See Appendix 6.

4.3.3 Results of the quantitative water quality assessment

Tables 9, 10 and 11 summarise the values of BOD and total ammonia under each scenario downstream of each sewage treatment works, as calculated in the Study. These impacts have been calculated based on the modelled Q_{95} value obtained from the Otter Groundwater Model at the three sites.

In Table 12 BOD and total ammonia is compared under each scenario using Q_{95} values obtained from the Phase Two flow naturalisation program (for Dotton gauging station).

The water quality statistics at each site under each scenario were then compared with the RE classification scheme standards to conclude the quantitative impact assessment. This comparison is shown in table 13.

The results in table 13 show that there is an insignificant impact on water quality downstream of the three sewage treatment works under each of the Otter Groundwater Model abstraction scenarios. Neither the historic nor the fully licensed abstraction flow impacts are predicted to cause a change in the water quality class at these sites.

Table 12 shows that there is an insignificant water quality impact at Ottery St Mary and at Fluxton caused by the estimated flow impacts under the maximum abstraction scenario for Dotton. The flow under the maximum abstraction scenario represents an estimate of the impact of all licensed abstractions upstream of Dotton. At Feniton, this flow impact is predicted to result in a decline from RE1 to RE2. However, the absolute change is marginal. In fact, this work suggests that water quality downstream of the works under natural flows would have achieved RE1 by a very small margin. Given the marginal effect on the water quality indicators, the Agency concludes that the impact of Otterhead Lakes abstraction (historic or maximum authorised) on water quality in the river below Fenny Bridges is negligible.

4.4 Qualitative environmental impact assessment

The qualitative approach poses the following question: Is there any monitoring evidence for a causal link between the observed pattern in abstraction volumes and trends in environmental features? The environmental features examined are:

- Water quality monitoring data along the main river 1975 to 1998;
- Macro-invertebrate data 1990-96;
- Fish survey data 1978-95.

4.4.1 Qualitative water quality impact assessment

In this general assessment the historic water quality monitoring data collected at sites along the main River Otter has been examined for trends and patterns. A comparison with the RE Classification standards is also included. The period examined is 1975 to 1998. To investigate trends the data has been collated into blocks of approximately five years. Three key water quality indicators (total ammonia, biological oxygen demand and dissolved oxygen) have been calculated for each period according to the standard national methodology. For example, for dissolved oxygen the data in each five year block has been ranked and the tenth percentile value selected. All available data from the main monitoring points along the river have been used to produce graphs illustrating the trends and patterns. The monitoring points are shown on Figure 1 and are listed below:

- Hoemoor Farm;
- Clapper Lane Bridge;
- Weston;
- B3176 bridge at Ottery St Mary;
- Tipton St John;
- Dotton Mill; and
- Otterton.

Clearly this qualitative method is restricted to an assessment of historic conditions – no assessment can be conducted as to the likely outcome if abstraction was at the full licensed quantity since abstraction at the maximum authorised rate has not occurred.

4.4.1.1 Results of the qualitative water quality impact assessment

Figure 11 illustrates the trend in water quality along the river for the period 1975 to 1998 in approximately five year blocks. Each water quality indicator is assessed separately, below.

a) Total ammonia

From the graphs it can be seen that all sites were achieving the RE1 class during the period 1975 to 1979. During the periods 1980 to 1984 and 1985 to 1989 the river was achieving RE2. However, by the period 1990 to 1994 most sites were achieving RE1 again and by the recent period, 1995 to 1998 all sites have achieved RE1 class.

b) Biological Oxygen Demand

The graphs show that in the period 1975 to 1979 all sites on the upper river were achieving RE1 class whilst most of the lower river was achieving RE2. During the periods 1980 to 1984 and 1985 to 1989 all sites were achieving at best the RE2 class. By the periods 1990 to 1994 and 1995 to 1998 there had been an improvement in absolute BOD level but only a couple of sites (Clapper Lane in 1990 to 1994 and Hoemoor Farm in 1995 to 1998) were achieving RE1.

c) Dissolved oxygen

The graphs for dissolved oxygen show that throughout the whole period examined all sites have achieved the RE1 class. In terms of absolute level of dissolved oxygen the highest levels have been achieved in 1975 to 1979 and 1995 to 1998.

4.4.1.2 Discussion on the results of the qualitative water quality assessment

Figure 11 shows that in recent years the River Otter's water quality has improved compared with the situation in the 1980s. In the same period abstraction has risen markedly. It would appear that there is a poor correlation between abstraction and general water quality trends.

There are two possible explanatory factors for the observed variations in water quality. Firstly, the sewage treatment works' performance may explain the observed water quality trends. The works are the main point sources of pollution in the catchment. However, records show that all the major works have performed adequately under most conditions throughout the period when water quality has been observed to have deteriorated and then improved. The alternative explanation is that diffuse sources of pollution have caused the observed pattern of water quality variation. In the River Otter, the Agency and its predecessor bodies cite the influence of pollution from dairy farming as been significant.

The River Otter is one of the most intensively farmed catchments in the country with a particular emphasis on dairy farming. Since 1945 there has been major increase in the scale and intensity of dairy farming associated with a variety of social, economic and political factors. Following the Second World War there was a marked intensification in agricultural practises nationally to meet the increased food demands. Following the United Kingdom's entry into the European Common Agriculture Policy in the early 1970s there was another period of intensification, particularly in the milk industry. The Otter Valley witnessed a sharp increase in the average number of stock per dairy farm and consequently an increase in the risk and occurrence of farm related pollution. The River Wolf tributary is a particular sub-catchment that has witnessed an increase in dairy farming during the 1970s and later. This is evidenced, in terms of the pollution effects, by the observed peak in the ammonia graph at Weston, just downstream of the Wolf confluence with the River Otter.

As a result of the obvious decline in water quality associated with farm pollution the South West Water Authority instigated extensive farm visits to ensure the risk and occurrence of pollution was minimised. The NRA continued this programme through the early 1990s and indeed the Agency is still visiting potential pollution sites to ensure risks are well managed. These efforts have clearly paid dividends as evidenced by the improvement in water quality in the River Otter through the 1990s.

4.4.2 Assessment of impact of abstraction on macro-invertebrate population

Macro-invertebrates are animals with no backbone and which can be seen with the naked eye. Aquatic macro-invertebrates include mayfly and stonefly nymphs, caddisfly larvae, snails, shrimps and worms. They form an important part of the aquatic ecosystem food-chain and in addition they are:

- Non migratory;
- Have reasonably long life cycles and, under normal circumstances, the community exists throughout the year.
- There are many families which have different responses to the physical and chemical characteristics of the river.

These factors mean that macro-invertebrates provide a useful indication of the river's biological quality and status and can be used for biological assessment.

4.4.2.1 How abstraction affects macro-invertebrates

A reduction in river flow caused by abstraction is likely to affect river flow velocity, depth, wetted area, temperature and oxygen levels as well as other changes such as increased deposition and finer particles in the riverbed. These changes may influence macro-invertebrate species composition, favouring species of ponded conditions and fine sediments.

4.4.2.2 Method of analysis of macro-invertebrate population impacts

As with the general assessment of impacts on water quality, the macro-invertebrate data has been examined qualitatively. The aim is to determine whether any changes in the macro-invertebrate population may be associated with abstraction or low flow trends.

Biological monitoring has taken place at routine sampling sites along the length of the River Otter. Macroinvertebrate samples are collected using standard Environment Agency procedures . The method employs taking a three minute kick sample and one minute search of suitable riffle sites with a standard pond net. The samples are preserved in Industrial Methylated Spirits and returned to the laboratory for sorting. Data is subjected to both internal and external quality assurances.

The data from macro-invertebrate monitoring is used to provide the biological quality assessment input to the Agency's general river quality classification system, the General Quality Assessment (GQA) scheme. Other assessments carried out by the Agency to classify rivers within the GQA scheme cover chemical, nutrient and aesthetic quality data. This part of the Study is concerned only with the biological assessment component.

As part of the GQA biological assessment monitoring the Agency collects macro-invertebrate data (to family level) at regular intervals at various locations throughout the catchment. In addition, a more detailed (to species level) set of macro-invertebrate data is collected by the Agency at a smaller number of specific sites.

For biological assessment, the macroinvertebrates are grouped into 83 families. The differing tolerances of invertebrate families allow each family to be allocated a value between 1 and 10, with the high scores indicating a reduced tolerance to pollution. An index - the Biological Monitoring Working Party (BMWP) score - can then be calculated. High final values suggest good water quality. Average Score Per Taxon (ASPT) is derived from dividing the BMWP score by the number of scoring families at each site. Again high values indicate good water quality.

By comparing ASPT and taxa found in the sample against those expected using predictions based on known information on the physical and chemical character of unstressed sites, rivers can be classified into one of six grades. RIVPACs 3+ (River Invertebrate Prediction and Classification System) is a mathematical model, used to biologically classify sites according to their macroinvertebrate fauna. This latest edition of RIVPACs, by incorporating errors, variation and biases associated with the collection of macroinvertebrate data, may be considered more robust than previous versions.

The biological quality of a river is expressed as a ratio of the actual value of the sample collected, compared with the predicted value. This ratio is termed the Ecological Quality Index and is calculated for both the number of taxa and the ASPT. An EQI of 1 or more therefore occurs when observed taxa/ASPT exceed the predicted value. The following table shows how EQI defines the biological grade of a watercourse.

ECOLOGICAL QUALITY INDEX		
Grade	**EQI for Taxa**	**EQI for ASPT**
A	0.85	1.00
B	0.70	0.90
C	0.55	0.77
D	0.45	0.65
E	0.30	0.50
F	<0.30	<0.50

The extremes, grades a and f, reflect very good and bad water quality, with the intermediate grades set between, e.g. grades b and c reflect good and fairly good water quality respectively.

It must be noted that the RIVPACS system is used mainly to compare the observed macro-invertebrate population with the population expected in the absence of pollution. The method does not explicitly account for changes in flow when calculating the expected population. However, the quality grades obtained from the GQA scheme indicate the health of the aquatic environment. These grades can be compared with the observed pattern of abstraction and low flow data over the Study period to provide a general indication of possible causal links. The period from which macro-invertebrate data is available is 1990 to 1998.

4.4.2.3 Results of the macro-invertebrate impact assessment

The results from relevant sites at and below Honiton are displayed in Table 14.

Site	Watercourse	Location	1990/ 1991	1995	1998
0413	Otter	70m u/s Clapperlane Bridge	b	b	b
0403	Otter	50m d/s bridge Weston	b	b	b
0414	Otter	150m u/s br. Fenny Bridges	c	b	b
0404	Otter	50m u/s B3176 bridge, Ottery St Mary	c	b	a
0405	Otter	200m u/s bridge, Tipton St John	c	b	a
0415	Otter	50m u/s foot bridge Dotton Mill	b	a	a
0406	Otter	25m d/s Otterton Bridge	b	a	a

TABLE 14: GQA grades for routine sites on the lower River Otter - 1990 - 1998

The family level macro-invertebrate data collected by the Agency over the period 1990-98 as part of the GQA monitoring work shows:

- The River Otter catchment generally displays good biological quality;
- Some river stretches have achieved a grade of very good biological quality and this is particularly apparent at the sites at and below Ottery St Mary (Sites 0404, 0405, 0415 and 0406); and
- Over the period the fauna has shown a general improvement in its composition and diversity.

Two sites of particular interest are site 0405 (200m u/s bridge at Tipton St John) and site 0406 (25m d/s Otterton Bridge). These are in the lower catchment, where the groundwater abstractions have a significant effect on flow. At these two particular sites, the results show a general improvement in biological water quality. At Tipton St John this improvement has resulted in an upgrading from grade c to grade a. An improvement has also occurred at Otterton Bridge with an upgrading from b to a. Biological quality at these two sites is now classified as very good, the macroinvertebrates present suggesting unstressed conditions.

There has also been more detailed monitoring to species level at several of the sites:

- Site 0412: River Otter, 45m u/s footbridge, Rawridge
- Site 0407: Wick Stream, 100m u/s farm bridge, Mill House Nursery
- Site 0403: River Otter, 50m d/s bridge, Weston
- Site 0411: River Tale. 25m d/s bridge, Taleford
- Site 0415: River Otter, 50m u/s foot bridge, Dotton Mill

Species diversity at these sites is good, including representatives from various mayfly, stonefly and caddis families. In addition the data collected has shed light on the concern voiced by the River Otter Association that during the 1980s there were relatively small numbers of *Ephemera danica* (Greendrake mayfly)and *Emphemerella ignita* (Blue Winged Olive mayfly) particularly in the middle reaches of the River Otter. Data collected for the macro-invertebrate monitoring in the 1990s shows that both species have been observed throughout the catchment. *Emphemerella ignita,* in particular, has been found to be very common throughout the catchment, including sites within the middle reaches of the river.

Over the period during which GQA assessments have been established for the River Otter there have been several severe low flow spells. Regardless of the role of abstraction in causing these low flows, no correlation with reduced macro-invertebrate diversity has been found. This suggests that the impact of low flows (and therefore abstraction) on the macro-invertebrate population is not significant.

4.4.3 Fish impact assessment

4.4.3.1 How abstraction affects fish populations

Abstraction can affect the fish population in a river mainly by the impact on flows. This can result in a reduction in water velocity, depth, wetted area and oxygen content. The outcome can be a reduction in the fisheries population as well as a change in the species composition. Within the Otter catchment there are several man-made barriers which restrict the ability of fish to migrate to spawning areas under low flows. The impact of low flows on water quality can also affect fish through physiological changes. These changes may result in acute illness and increased mortality amongst the fish population.

4.4.3.2 Key fisheries of the River Otter

The River Otter is a significant brown trout fishery. There is a small run of sea trout, and some salmon are known to enter and spawn in the tidal reaches of the river. Minor coarse fish species are widespread across the catchment.

The Agency's Fisheries Team reports the following as the predominant fisheries issues:

- decline in the indigenous brown trout populations which is widely accepted began in the 1970s as a result of deteriorating water quality;
- brown trout spawning areas made less accessible by weir construction;
- stocking with non-native brown trout;
- weirs acting as barriers to migratory fish; and
- impact of abstraction on the fishery.

External concerns in relation to the fishery of the River Otter invariably refer to a decline in the numbers of brown trout. The assessment presented here examines the brown trout population data collected by the Agency's surveys. The assessment also utilises the brown trout data as an indicator of the general status of the River Otter's fish community.

4.4.3.3 Method of analysis

The Study has examined River Otter electric-fishing survey data collected by the relevant authorities to assess the impact of abstraction. The surveys took place in 1978, 1983, 1984, 1986, 1992, 1995 and 1998.

Although it has not been possible to ascertain the potential impact on fish population of abstraction at the fully licensed rate, the surveys are always conducted during the low flow season (late summer/early autumn). Also, it is worth noting that the surveys of 1992 and 1995 were carried out at the height of particularly extreme drought conditions in the south-west (although flows in River Otter during the summer of 1995 remained relatively high).

For the purposes of this Study the survey data has been utilised to produce graphs of brown trout abundance. Abundance is measured as the number of fish per 100 square metres of river and is also described using the term "density". Survey data for two life stages of brown trout (parr and fry) has been assessed. All monitoring sites throughout the catchment, for which the Agency has historic records, have been included.

4.4.3.4 Results of the fisheries impact assessment

Figure 12 shows the overall results of the surveys during the period 1978 to 1998 as a histogram. It would appear from this graph that both the brown trout fry and parr populations have improved in recent years compared with the situation in the late 1970s and 1980s. Although the recent surveys have sampled more sites than previous surveys, the abundance of fish has increased. However, the Agency (and its predecessor authorities) has stocked many parts of the river with brown trout fry.

Typically, the stocking occurs early in the year and before the electric-fishing survey is conducted. In recent years stocking by the Agency has reduced due to concerns about the impacts on the natural population. In 1998, there was no stocking activity conducted by the Agency. Private organisations and individuals have continued to stock the river but mainly with older brown trout. The proportion of fish caught during the Agency surveys that have been privately stocked is very small.

Given these facts it would appear that the abundance of brown trout parr, whether derived from stocked or natural sources, has increased from the mid-1980s to present. Similarly, whether spawned by stocked or naturally derived fish, the data suggests that the survival rate of brown trout fry has improved in recent years. Indeed, the Agency believes that the fry observed in 1998 are mainly derived from natural recruitment.

One tributary that has never been stocked by the authorities is shown on figure 13. This graph shows brown trout abundance in the Colaton Raleigh stream. The graph shows that both brown trout fry and parr have increased in abundance in the Colaton Raleigh stream in the 1990s compared with 1983 (albeit based on an isolated survey in 1983).

The fisheries surveys data show no direct evidence of the impact of low flows associated with abstraction. In fact, the surveys have observed a brown trout population consistent with that of other South West rivers. During the Study period abstraction has risen and there have been severe dry spells. Despite these environmental pressures there has been an improvement in the brown trout population in recent years. The Agency believes that this is due to the observed improvement in water quality throughout the catchment due to changes in land-use and farming practises. There is scant evidence that the pattern of abstraction through the period can explain the variation in brown trout population.

4.5 Other relevant environmental data

This section briefly presents the findings of various environmental surveys conducted in the past in the River Otter catchment.

As part of South West Water Authority's studies of the River Otter in 1989, MRM Consultants conducted an assessment of the general environmental data from the River Otter. These data included the Phase One habitat survey of 1988, conducted by the Devon Trust for Nature Conservation, historic bird surveys (during 1977 to 1987) and a river corridor survey conducted by Nigel Holmes in 1988. In addition this Study has briefly re-examined the river corridor survey conducted in 1990.

4.5.1 Phase One Habitat survey conducted by DTNC

This survey conducted in 1988 focused on five areas in the lower catchment. Various habitat data was collected via field surveys including information on water features, the main focus of attention for Phase Three of the Study. Only one standing water feature was found in the area to the west of Ottery St Mary. More recent surveys (for example, the survey conducted by the Devon Wildlife Trust during the 1990s as part of the County Wildlife Site programme) confirm that this water feature is still present. There were no wetland sites found in the lower catchment apart from spring issues near Wiggaton, the boggy area near to the Budleigh Brook and the internationally designated wet heaths of the East Devon Pebble Beds. Both the latter features were noted as being important habitats for the Southern Damselfly. Appendix Seven suggests that abstractions for Public Water Supply have an insignificant effect on the water table in the vicinity of the East Devon Pebble Beds and thus the wet flushes.

4.5.2 Bird surveys

MRM commissioned an examination of the data obtained from various bird surveys conducted in the period 1977 to 1987 in the River Otter catchment. The surveys have occurred in the context of an apparent decline in the flooding of the estuary related to land-drainage and during the 1980s against the observed rise in abstraction. The MRM work concluded that there is a good number of wild fowl in the estuary. Also reported was the populations of riverine birds: Dippers and Grey Wagtails were noted in the lower nine kilometres of the River Otter. The MRM report cited the fact that these bird species require good water quality to support the macro-invertebrates they feed on. Overall the bird survey data shows that it is very difficult to relate changes in bird population to abstraction. Factors such as water quality are far more significant, the report concludes.

4.5.3 River corridor survey of 1988

This survey was conducted by Nigel Holmes and aimed to add to the knowledge gained during the DTNC survey. It was conducted along the whole length of the river downstream of Ottery St Mary and focused on both the channel and valley floor habitats. The survey was carried out during August of 1988 during low flow conditions. The overall conclusions were as follows:

- The river bed is very uniform being mainly coarse gravels, pebbles and cobbles and small boulders;
- Water depths are not great – there are few deep pools, maximum depth is around 0.5m;
- Artificial bank protection is evident but where natural erosion has been permitted the river forms sand cliffs which provide a habitat for sandmartins;
- Macro-flora in the river is poor – mostly water crowfoot (this is thought to be related to an unstable riverbed and a lack of fine sediments.);
- There are few emergent plants;
- Floodplain lands are of limited ecological significance (mostly high quality pasture land);
- No habitats were found in the floodplain that were dependent on the water table or inundation by the river.

The survey showed that there had been little change in features over the 1980s by comparison with previous surveys (including the DTNC survey). There was only one spring issue site at Harpford (shown on 1957 maps) which was found to have disappeared. This site is adjacent to the Harpford boreholes and the survey concluded the drying of the springs was probably caused by abstraction. However, the survey showed that the general absence of wetland sites was mainly related to land-drainage activity in the 1950s and 1960s associated with the intensification of farming.

4.5.4 River Corridor Survey of 1990

This survey was conducted for the National Rivers Authority. As part of the survey report a comparison was made with the results of the 1988 survey. The survey found that there had been very little change in habitat features since 1988. Overall, the report concluded that "the survey shows the River Otter to be of major value to wildlife, particularly as it provides continually varying habitat throughout its entire length".

4.5.5 River Habitat Surveys

In addition to the above environmental information, the Agency has undertaken River Habitat Surveys at five sites on the River Otter between 1994 and 1996. In the near future it is the Agency's intention to apply a "Habitat Quality Analysis" technique to the survey data in order to assess the physical character and quality of the river habitats at these sites. Such an approach will be most useful for future environmental monitoring and reporting for the catchment.

4.6 Phase Three environmental impact assessment: Discussion

The environmental impact assessments described above show the following:

- Quantitative assessments of the water available for dilution based on the Otter Groundwater Model flow impacts suggest that water quality downstream of the sewage treatment works in the lower river would not improve significantly had there been no groundwater abstraction by SWW. In addition, the assessments predict that water quality would not deteriorate significantly if water for public supply was abstracted at the authorised maximum rate. Similar water quality assessments based on the hydrological impacts obtained from the Flow Naturalisation technique predict that maximum authorised abstraction from all sources upstream of Dotton would cause a marginal decline in water quality. Otterhead Lakes abstraction would not cause a significant water quality impact in the river downstream of Fenny Bridges.
- Water quality monitoring data from the River Otter shows that there has been an improvement in water quality since the 1980s. This is mainly attributed to improved farm pollution risk management.
- Macro-invertebrate monitoring indicates a generally good biological rating for the River Otter. In some locations, in the lower river, the data shows the river has achieved a biological rating of "very good". Since 1990 all sites in the Study area have either maintained their historic rating or have achieved a higher quality rating.

- Fish survey data suggests an improvement in the numbers of surviving brown trout since the 1980s although many sites were artificially stocked. Those tributaries where stocking has not taken place have witnessed an increase in brown trout survival. The Agency believes this is directly related to the observed improvements in water quality.
- General environmental data shows that the River Otter provides a good quality natural environment. However, wetlands in the floodplain are almost entirely absent. The wetlands that may have existed in the last fifty years have since been removed by land-drainage practises. One isolated wet feature that still exists in the floodplain shows the signs of an impact caused by abstraction.

On balance the role of historic abstractions in influencing the environmental features of the river is concluded to be marginal. In other low flow studies conducted on rivers in the south-west, the effect of historic abstractions has been severe enough to dry the river. Consequently, the evidence of environmental impact in these rivers is much clearer. In the River Otter Low Flow Study, the hydrological impacts are not that severe and the environmental impacts are thus more difficult to discern.

The Agency's environmental monitoring data from the Combe Raleigh Stream suggest that variations in water quality are more important than abstraction in influencing the river's ecosytem. Water quality has improved in the Combe Raleigh Stream over the last ten years. Fisheries surveys show an absence of brown trout for most of the early part of this period at this location. However, the latest fish surveys show that brown trout are successfully spawning in this stream.

As far as the possible effect of abstraction at the maximum licensed rate is concerned, the Study has been able to conclude that there would be an insignificant impact on water available for dilution. This conclusion relates only to the modified dilution effect downstream of the lower river's sewage treatment works. For other elements of the environmental impact assessment it has not been possible to conclude the effect of the maximum authorised abstraction as it has not occurred. There are tentative indications, however, that the environmental impact of maximum abstraction would be marginal, as in the evidence of the historic impact of abstractions: For example, in the late 1980s and early 1990s groundwater abstraction was at its highest recorded level (60 to 70% of authorised maximum). At the same time the catchment was subject to relatively severe drought conditions but the environmental monitoring data shows no evidence of significant impact.

The hydrological impacts under the maximum abstraction scenario are estimated to be significant in the river below Ottery St Mary. These impacts are associated with South West water's groundwater abstractions. Given these estimates and the lack of full knowledge about the associated environmental impacts the Study recommends the continuation of the Agency's existing environmental monitoring programme in the catchment. In addition, the programme should be critically reviewed, in the light of this Study, to ensure it can provide the necessary environmental information at the most appropriate sites.

There is a continued need for the Agency to be cautious about the possible environmental impact of full-take up of the public water supply licences. In addition, the use of time-limits on abstraction licence applications in the River Otter catchment should be continued where relevant.

Section Five presents the Study conclusions and recommendations.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 The Study's conclusions

- The concern about the environmental impact of low flows perceived to be caused by abstractions for public water supply from the River Otter catchment has been tackled via a study consisting of three phases.

- Phase One reviewed the catchment's environmental features and concluded that the main potential for environmental impact caused by abstraction is as a result of the reduction of river flows.

- Phase Two examined the impact of public water supply abstraction on river flow using an improved, recalibrated Otter Groundwater Model and a flow naturalisation technique. The work suggests that historic abstraction from South West Water's groundwater sources have reduced river flows measurably in the lower catchment. Historic abstraction by Wessex Water from the Otterhead Lakes is estimated to reduce flow in the river at Fenny Bridges by less than 3 percent. Abstraction by both companies at the full licensed rate was predicted to result in larger flow impacts, although the technique used was found to over-estimate the impact of maximum abstraction from Otterhead Lakes.

- Phase Three has reestimated the river flow impacts caused by South West Water';s abstractions using a further improved and recalibrated version of the Otter Groundwater Model. Historic abstractions by South West Water from groundwater sources in the catchment downstream of Honiton are estimated to have caused a reduction in natural summer low flows of between 9 to 15 percent. Had abstraction from these sources occurred at the full licensed rate then the flow impact is estimated at between 12 to 25 percent. The largest flow impacts are estimated to occur in the estuary, downstream of Otterton. Phase Three has underlined that these flow impacts arise through the river-aquifer interaction.

- In Phase Three the effect of public water supply abstraction on the water available for dilution of sewage effluent has been examined through water quality modelling. The work suggests that historic abstraction has not resulted in and predicted abstraction at the full licensed rate would not result in a significant deterioration in the river's water quality.

- General environmental data collected by the Agency has also been examined in Phase Three to assess if there are causal links with historic abstraction. The water quality monitoring data suggests that in recent years, despite periods of low flow and relatively high rates of abstraction, water quality in the River Otter has improved and consistently achieves a good quality class. Similarly, the fisheries survey evidence points to a relatively healthy river environment in recent years; there is no evidence for a causal link between abstraction and fish population dynamics. The biological data collected by the Agency shows that the river has a generally good biological quality; in particular parts of the catchment the evidence suggests that the river achieves a very good biological quality.

- General surveys of other environmental features in the River Otter show no significant impact that can be attributed to historic public water supply abstraction. The surveys show the River Otter to be a high quality environment.

- Since abstraction for public water supply at the full authorised rate has not occurred there is no evidence from the Agency's survey data of the impact of abstraction at this rate on water quality, macro-invertebrates and fisheries.

5.2 The Study's recommendations

The Study suggests that the historic impact of public water supply abstractions on both the river's hydrology and environment is insignificant. The Study has identified residual uncertainty concerning the environmental impact of full take up of SWW's abstraction volume.

SWW has not made full use of its licensed resource in the Otter because such volumes are unobtainable from the existing boreholes. The ability to take more water from the same boreholes is limited by ingress of sediment at high pumping rates. It is most probable that the anticipated maximum yield for these sources is less than the maximum licensed volume.

As a precautionary approach whilst the Study has been in progress all abstraction licence applications in the Otter catchment have been subject to particular scrutiny and control. A time limit of January 13th 2000 has been applied to licences granted where there was a potential for additional adverse impact on flow regimes in problem areas of the River Otter. Whilst such uncertainty remains the Agency recommends a continuation of its abstraction licensing approach in the River Otter for the immediate future and at least until the uncertainty is satisfactorily resolved.

The following is the recommended course of action that the Agency should follow:

- Review the capability of full take up by SWW of their abstraction licence quantity from groundwater sources in the Otter Valley. Finalisation of the Company's Water Resources Plan within the AMP3 process will provide a formalised statement from the Company to both Ofwat and the Agency, and incidentally to the Secretary of State, of the anticipated yield of this group of groundwater sources. This value of forecast achievable output from the groundwater sources will operate as a guide value for the Agency as to the true potential of the licences and to the benefit of the currently licensed quantity to the Company.

- Maintain and review the Agency's environmental data monitoring programme in the catchment: water quality sampling, fisheries survey and macro-invertebrate survey.

- Review the River Otter abstraction licensing approach (including time limiting).[7]

Progress against these actions will be reported via the Otter/Sid LEAP Steering Group.

7. The DETR abstraction licensing review has recommended the introduction of a time-limit on all abstraction licences.

TABLES

Table 1: Licensed abstraction summary for the River Otter

	GROUNDWATER ABSTRACTIONS		SURFACE ABSTRACTIONS	
	No. of licences	Annual total (m^3)	No. of licences	Annual total (m^3)
Agricultural (excluding spray irrigation)	289	819145	4	634
Agricultural (fish farms)	0	0	1	1592943
Spray irrigation (agricultural)	9	91508	11	140153
Spray irrigation (other)	5	14727	1	5450
Industrial (quarrying)	1	1364	0	0
Industrial (food & drink)	5	8542	0	0
Industrial (miscellaneous)	1	2045	0	0
Private water supply	61	30078	7	20177324
Public water supply	9	13032435	3	2236706
TOTAL	**380**	**13999844**	**27**	**24152576**

Table 2: Summary of Public Water Supply abstraction licences examined in Study

Licence no.	Name of site	Type of abstraction	Annual authorised maximum abstraction (cubic metres)	Operator
14/45/01/0002	Otterhead Lakes	Surface	909091*	Wessex Water
14/45/01/0414	Greatwell borehole no 4B	Groundwater	617215	South West Water
14/45/01/0425	Kersbrook Well, Tidewell & Kersbrook Boreholes	Groundwater	795560	South West Water
14/45/01/0426	Greatwell boreholes nos 1, 2 & 3	Groundwater	1591120	South West Water
14/45/01/0478	Colaton Raleigh boreholes no 2 & 4	Groundwater	945340*	South West Water
14/45/01/0505	Greatwell borehole no 5	Groundwater	909200	South West Water
14/45/01/0518	Harpford boreholes nos 5, 6, 7, 8 & 9.	Groundwater	1716000	South West Water
14/45/01/0519	Dotton boreholes nos 1, 2, 3 & 7	Groundwater	3915000	South West Water
14/45/01/0520	Dotton boreholes nos 4 & 5	Groundwater	230000#	South West Water
14/45/01/0573	Otterton borehole no 1	Groundwater	1460000@	South West Water
14/45/01/0573	Otterton borehole no 4	Groundwater	853000#	South West Water

*Licence includes prescribed flow condition
#Licence includes a seasonal condition
@Licence includes a groundwater level condition.

Table 7
Estimated Otter Groundwater Model hydrological impacts for water quality assessment sites (cubic metres/second)

Site	Scenario	Mean flow	Q95 flow
Feniton	No abstraction	1.87	0.64
	Actual	1.87	0.64
	Maximum	1.87	0.64
Ottery	No abstraction	2.46	0.84
	Actual	2.41	0.79
	Maximum	2.40	0.78
Fluxton	No abstraction	2.69	0.91
	Actual	2.64	0.85
	Maximum	2.61	0.83

Table 8

Estimated hydrological impacts derived using the flow naturalisation technique at Dotton for water quality assessment (cubic metres/second)

Abstraction scenario	Q95 flow impact estimated at Dotton
No abstractions	1.05
Maximum authorised abstractions	0.54

Table 9

Estimated river water quality impacts at Feniton STW caused by abstractions based on hydrological impacts obtained from the Otter Groundwater Model (units are milligrams per litre)

Input Quality	BOD Mean	BOD standard deviation	Ammonia Mean	Ammonia standard deviation
Upstream	1.78	0.508	0.07	0.052
Discharge	10.04	8.219	2.49	3.045
Input flow (cumecs)	Discharge Mean	Discharge s.d.		
	0.0046	0.0005		
Results under each scenario	**BOD 90th percentile**	**Ammonia 90th percentile**	Flow mean (cumecs)	Flow Q95 (cumecs)
Model flow	**2.46**	**0.14**	1.87	0.64

Note: There is only flow result as the impact at Feniton is the same under each scenario.

Table 10

Estimated river water quality impacts at Ottery St Mary STW caused by abstractions based on hydrological impacts obtained from the Otter Groundwater Model (units are milligrams per litre)

Input Quality	BOD Mean	BOD standard deviation	Ammonia Mean	Ammonia standard deviation
Upstream	1.76	0.672	0.05	0.046
Discharge	10.22	8.866	1.51	1.307
Input flow (cumecs)	Discharge Mean	Discharge standard deviation		
	0.0123	0.0012		
Results under each scenario	**BOD 90th percentile**	**Ammonia 90th percentile**	Flow mean (cumecs)	Flow Q95 (cumecs)
No abstractions	**2.68**	**0.11**	2.46	0.84
Historic	**2.69**	**0.11**	2.41	0.79
Maximum	**2.69**	**0.11**	2.40	0.78

Table 11
Estimated river water quality impacts at Fluxton STW caused by abstractions based on hydrological impacts obtained from the Otter Groundwater Model (units are milligrams per litre)

Input Quality	BOD Mean	BOD standard deviation	Ammonia Mean	Ammonia standard deviation
Upstream	1.83	0.67	0.06	0.05
Discharge	13.33	5.820	2.17	1.524
Input flow (cumecs)	Discharge Mean	Discharge s.d.		
	0.0127	0.0013		

Results under each scenario	**BOD 90th percentile**	**Ammonia 90th percentile**	Flow mean	Flow Q95
No abstractions	**2.75**	**0.13**	2.69	0.91
Historic	**2.76**	**0.13**	2.64	0.85
Maximum	**2.76**	**0.13**	2.61	0.83

Table 12

Results of the quantitative water quality impact assessment

based on Phase Two Flow Naturalisation program hydrological impacts

STW site	Scenario	BOD 90th percentile value	RE class (BOD)	Ammonia 90th percentile	RE class (ammonia)
Feniton	Natural	2.48	RE1	0.14	RE1
	Maximum authorised	2.55	RE2	0.16	RE1
Ottery St Mary	Natural	2.69	RE2	0.11	RE1
	Maximum authorised	2.76	RE2	0.13	RE1
Fluxton	Natural	2.78	RE2	0.13	RE1
	Maximum authorised	2.84	RE2	0.15	RE1

Table 13

Results of the quantitative water quality impact assessment

based on Otter Valley Groundwater Model

Site	Abstraction scenario	Modelled BOD 90th percentile value (mg/l)	RE Class (Modelled BOD)	Modelled total ammonia 90th percentile value (mg N/l)	RE Class (Modelled total ammonia)
Feniton	(All scenarios identical flow impact)	2.46	RE1	0.14	RE1
Ottery St Mary	Natural	2.68	RE2	0.11	RE1
	Historic	2.69	RE2	0.11	RE1
	Maximum authorised	2.69	RE2	0.11	RE1
Fluxton	Natural	2.75	RE2	0.13	RE1
	Historic	2.76	RE2	0.13	RE1
	Maximum authorised	2.76	RE2	0.13	RE1

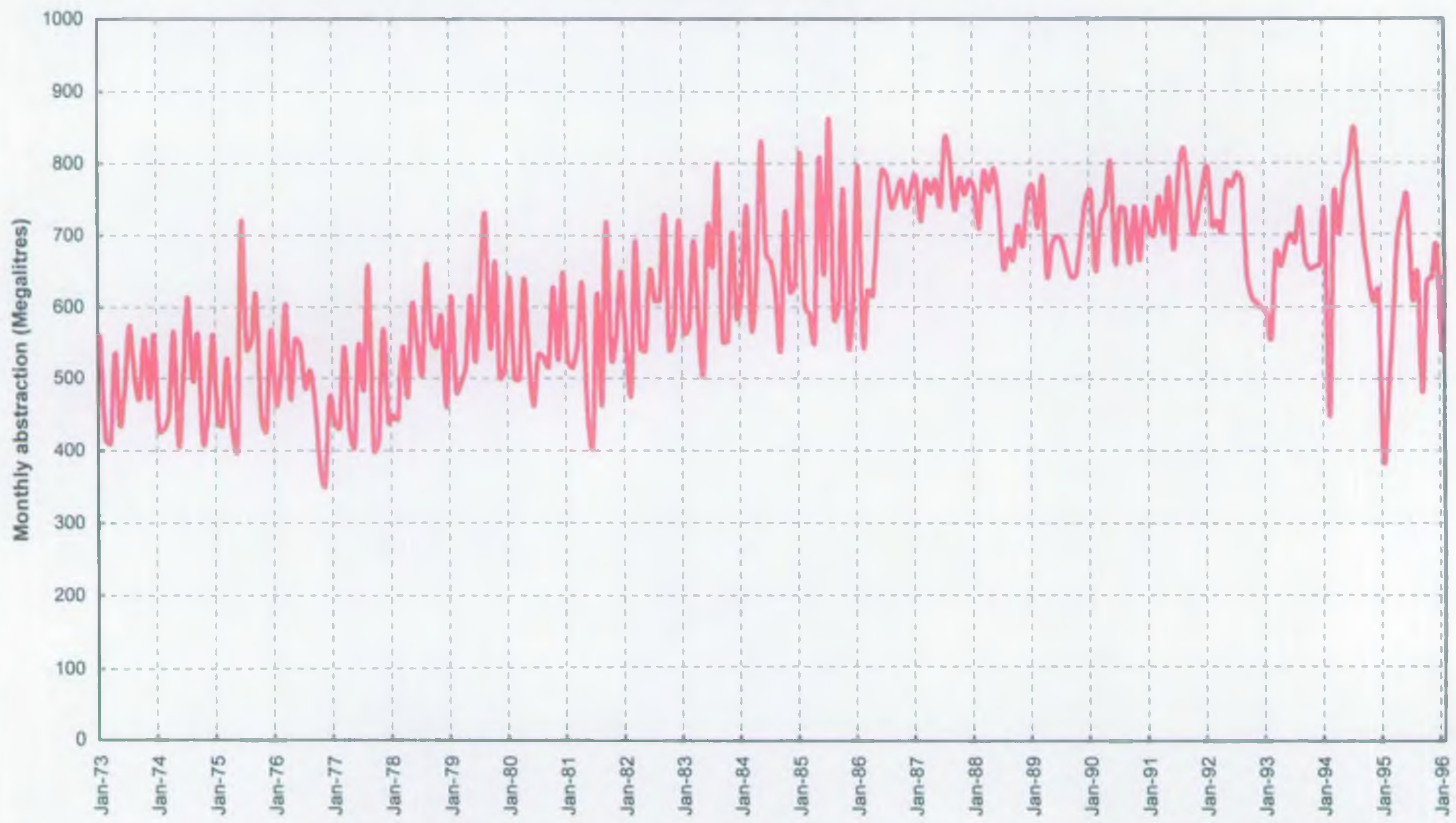
Figure 1

0 km 5

Scale

Information correct as of 1998

Figure 2: South West Water groundwater abstractions



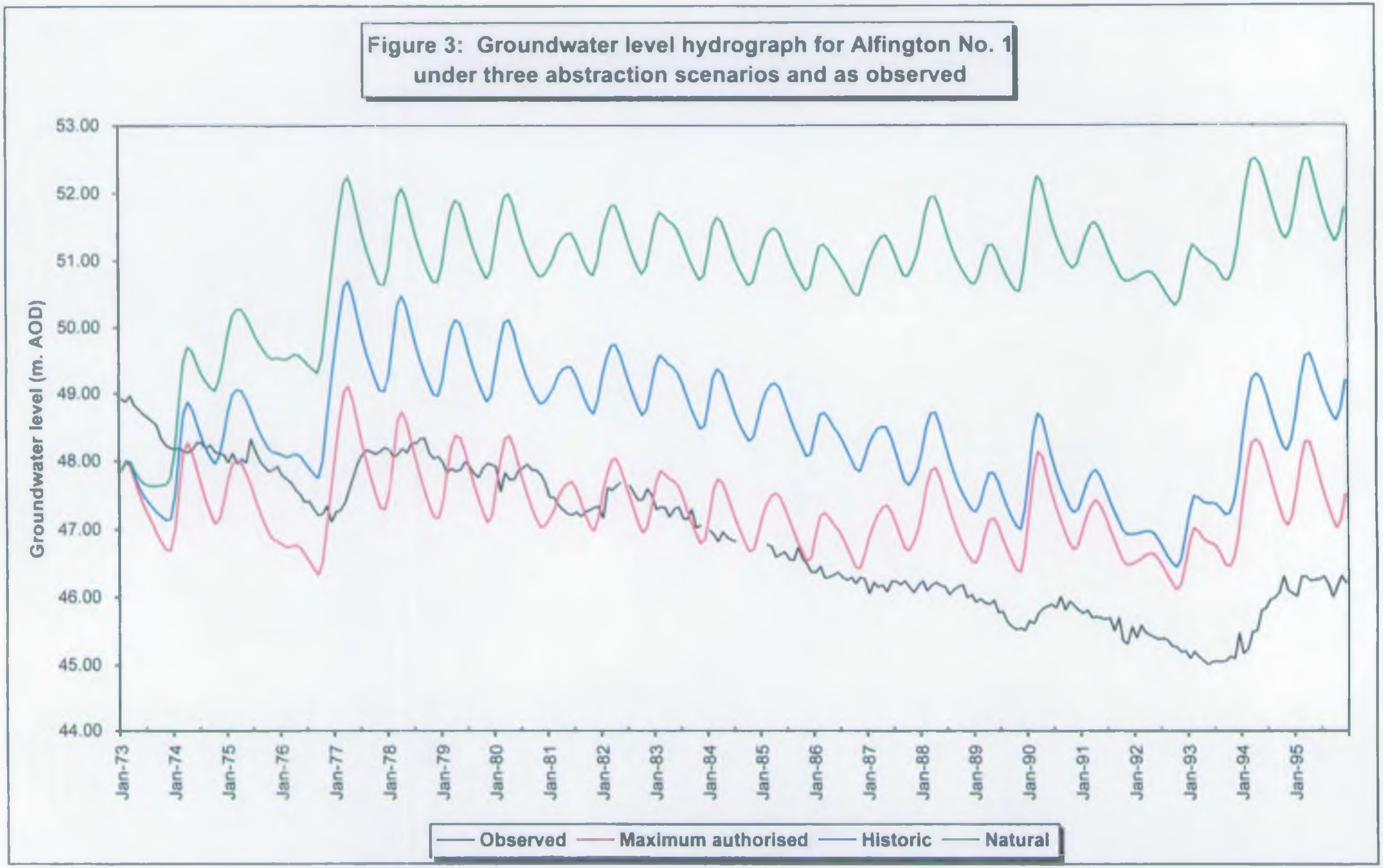
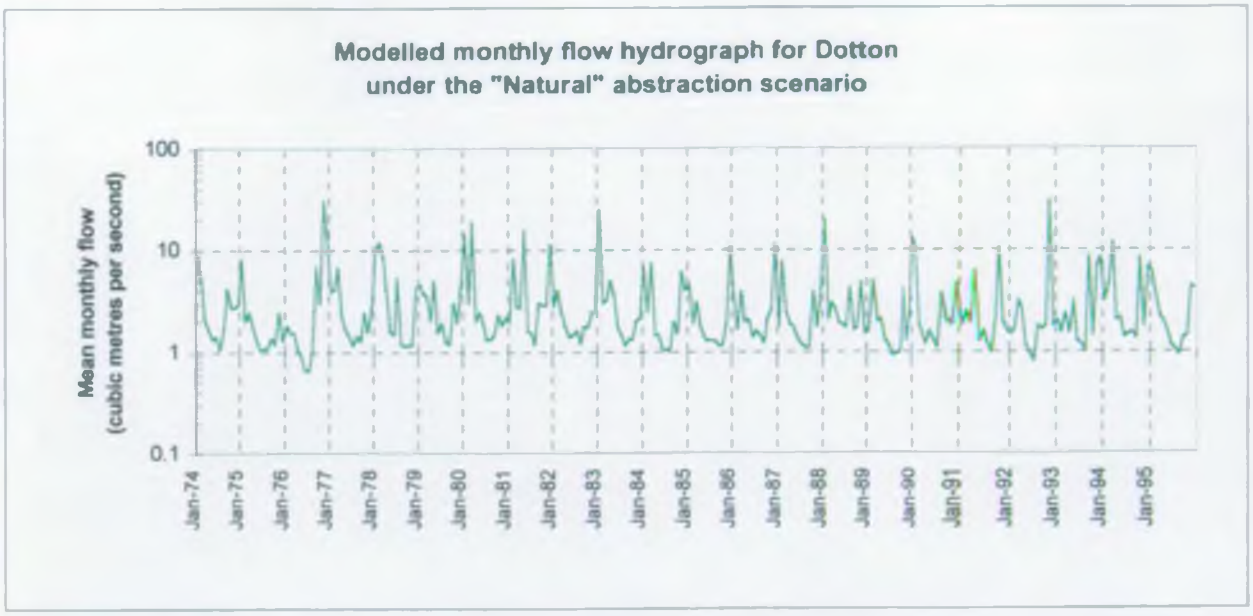
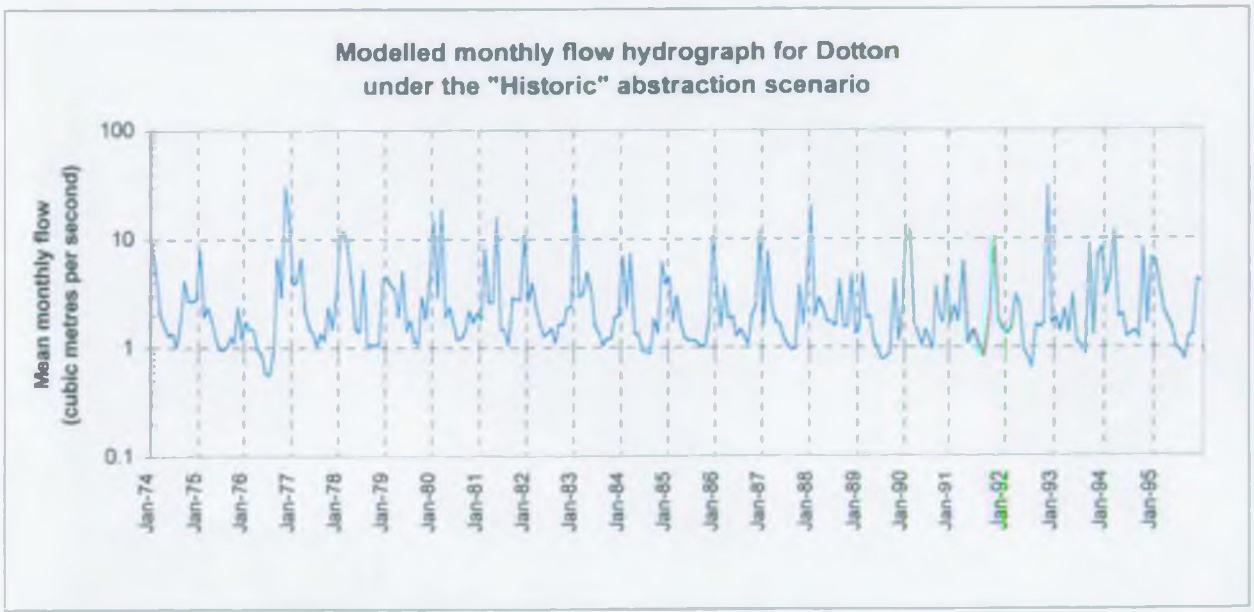


Figure 3: Groundwater level hydrograph for Alfington No. 1 under three abstraction scenarios and as observed
Groundwater level (m. AOD)
53.00
52.00
51.00
50.00
49.00
48.00
47.00
46.00
45.00
44.00
Jan-73
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Observed
Maximum authorised
Historic
Natural

Figure 4


Modelled monthly flow hydrograph for Dotton
under the "Natural" abstraction scenario
Mean monthly flow
(cubic metres per second)
100
10
1
0.1
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95


Modelled monthly flow hydrograph for Dotton
under the "Historic" abstraction scenario
Mean monthly flow
(cubic metres per second)
100
10
1
0.1
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95

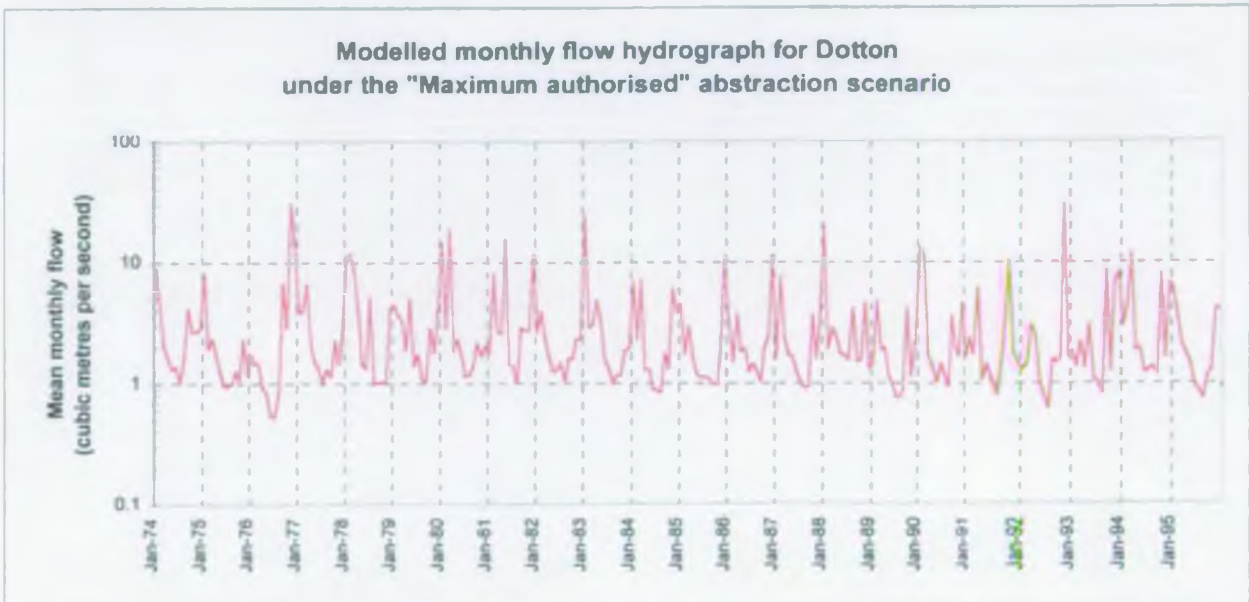
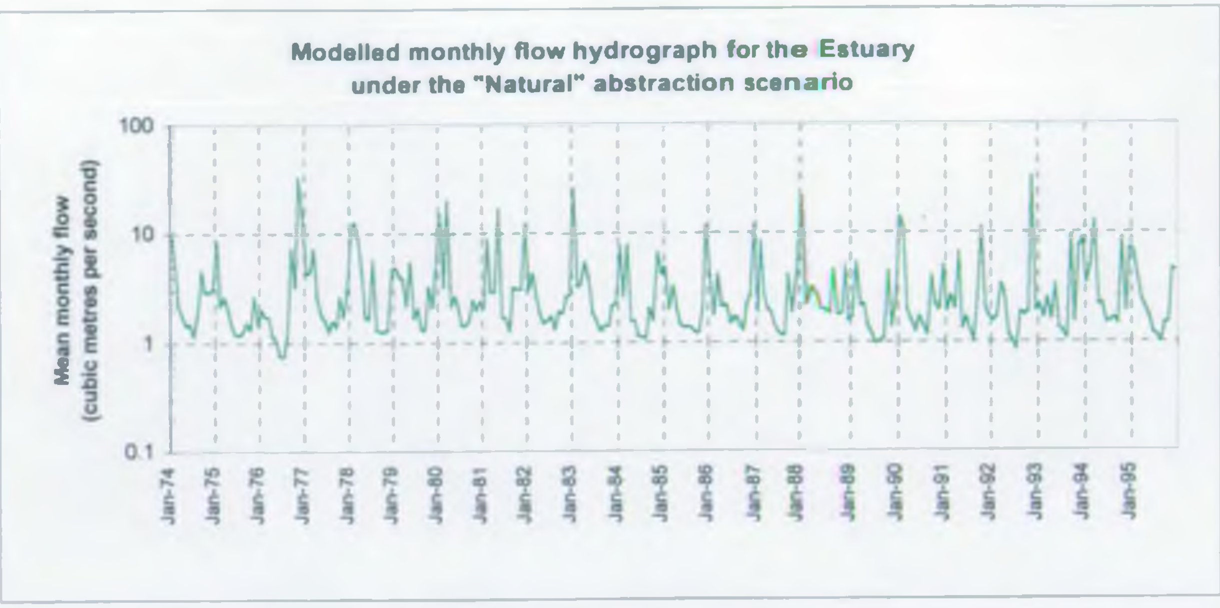
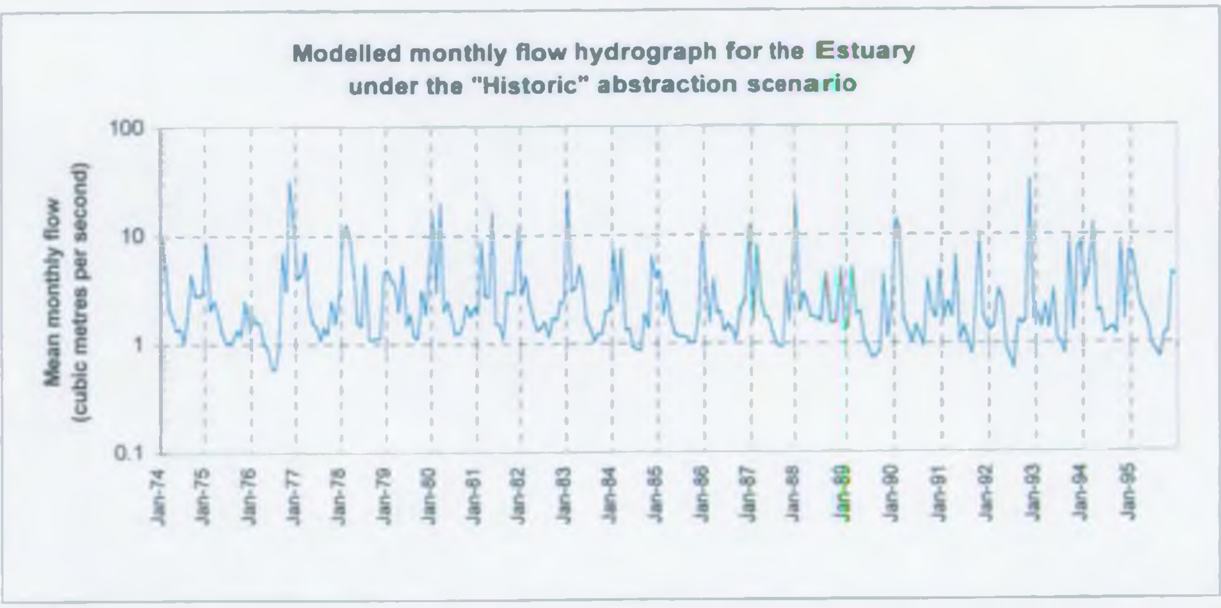

Modelled monthly flow hydrograph for Dotton
under the "Maximum authorised" abstraction scenario
Mean monthly flow
(cubic metres per second)
100
10
1
0.1
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95

Figure 5


Modelled monthly flow hydrograph for the Estuary
under the "Natural" abstraction scenario
Mean monthly flow
(cubic metres per second)
100
10
1
0.1
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95


Modelled monthly flow hydrograph for the Estuary
under the "Historic" abstraction scenario
Mean monthly flow
(cubic metres per second)
100
10
1
0.1
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95

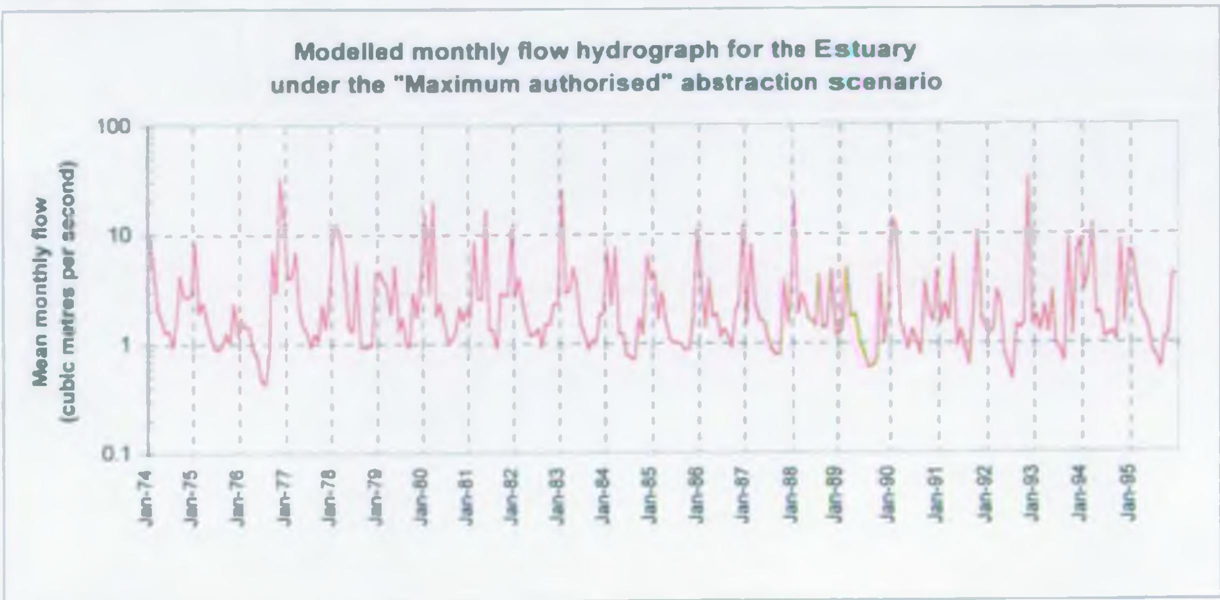
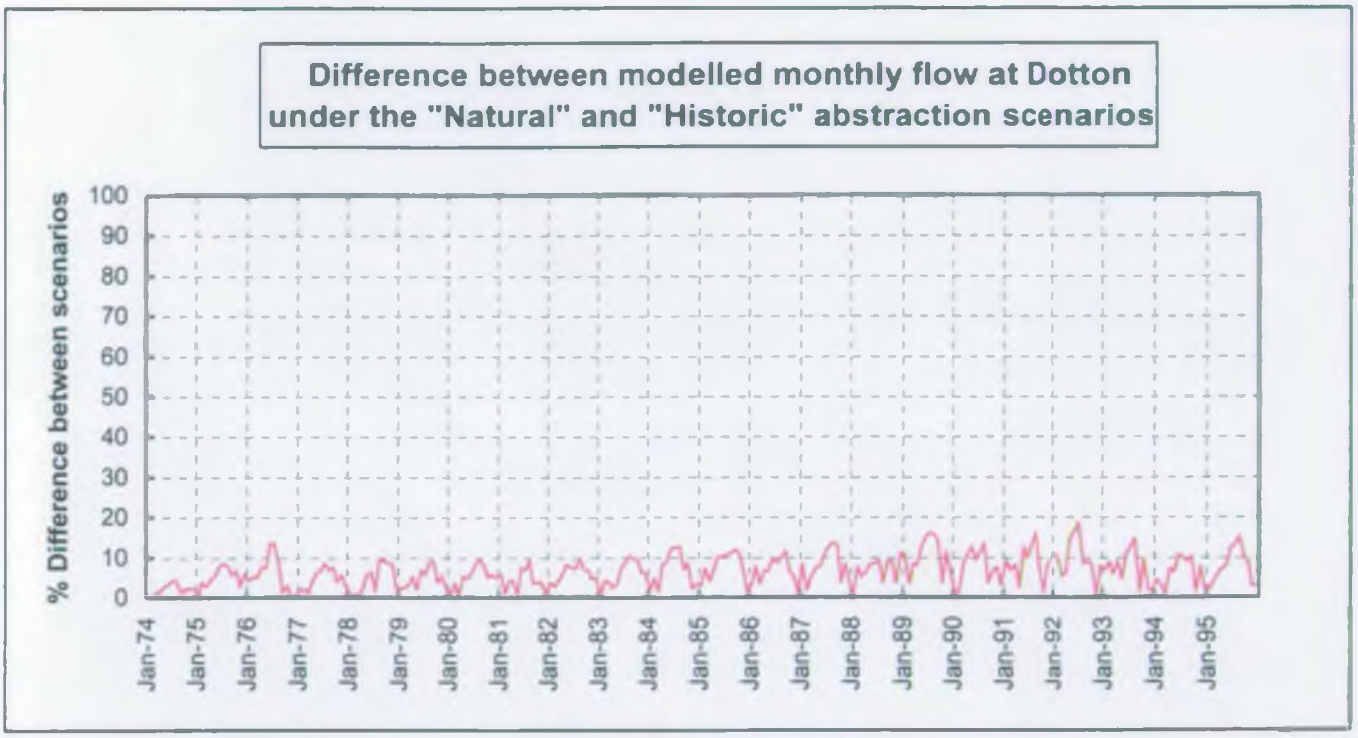
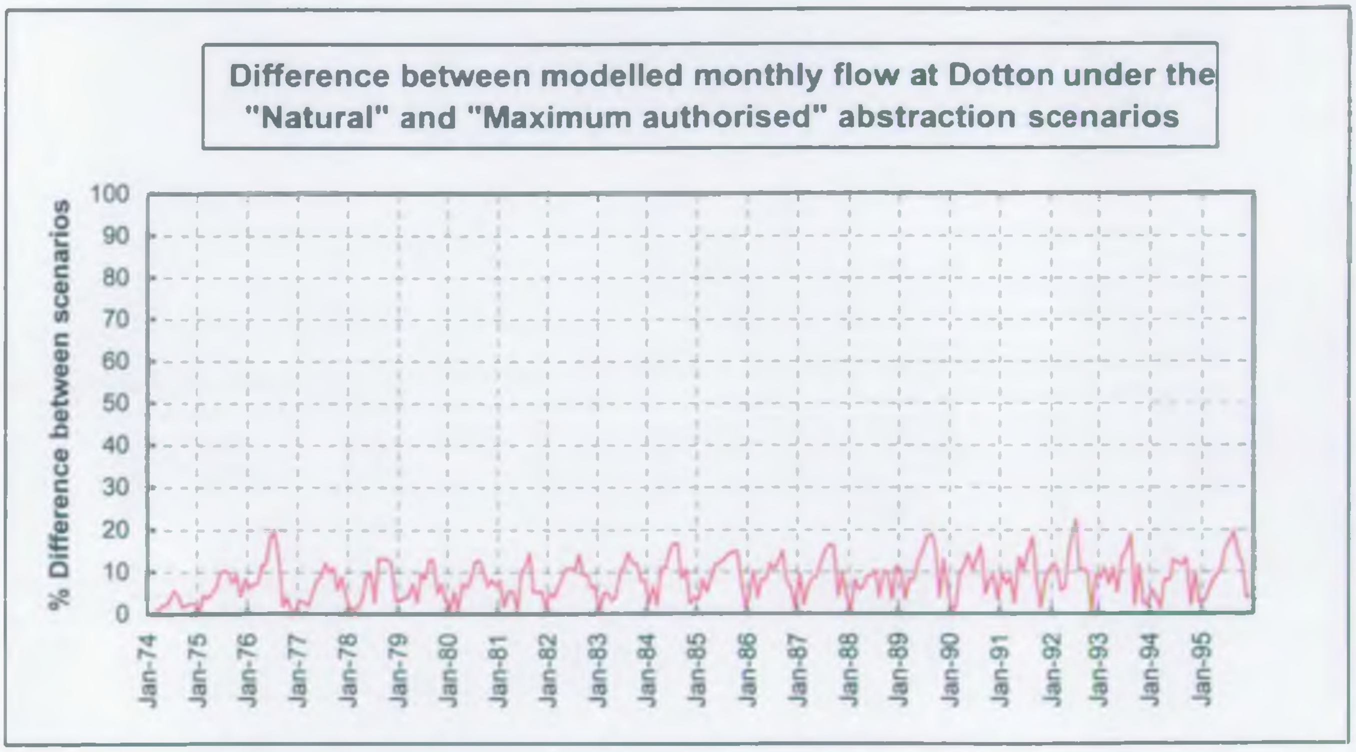

Modelled monthly flow hydrograph for the Estuary
under the "Maximum authorised" abstraction scenario
Mean monthly flow
(cubic metres per second)
100
10
1
0.1
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95

Figure 6

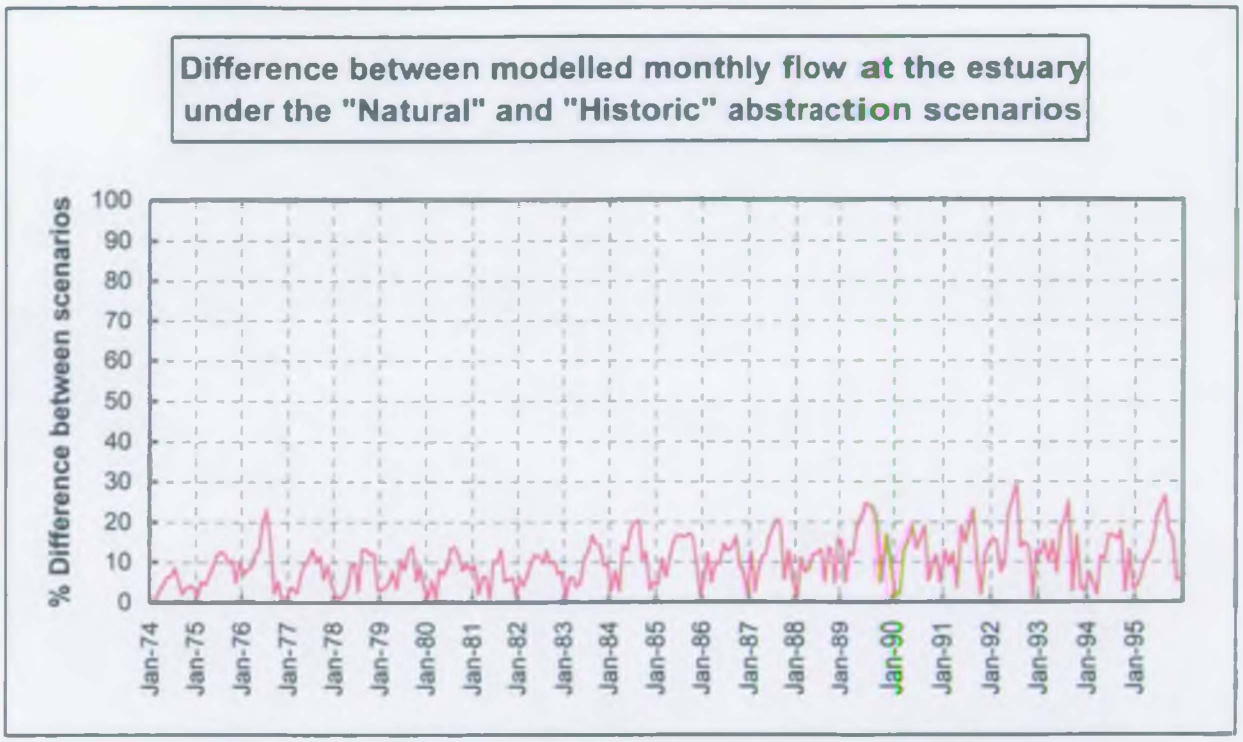


Difference between modelled monthly flow at Dotton under the "Natural" and "Historic" abstraction scenarios
% Difference between scenarios
100
90
80
70
60
50
40
30
20
10
0
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95



Difference between modelled monthly flow at Dotton under the "Natural" and "Maximum authorised" abstraction scenarios
% Difference between scenarios
100
90
80
70
60
50
40
30
20
10
0
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95

Figure 7


Difference between modelled monthly flow at the estuary under the "Natural" and "Historic" abstraction scenarios
% Difference between scenarios
100
90
80
70
60
50
40
30
20
10
0
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95

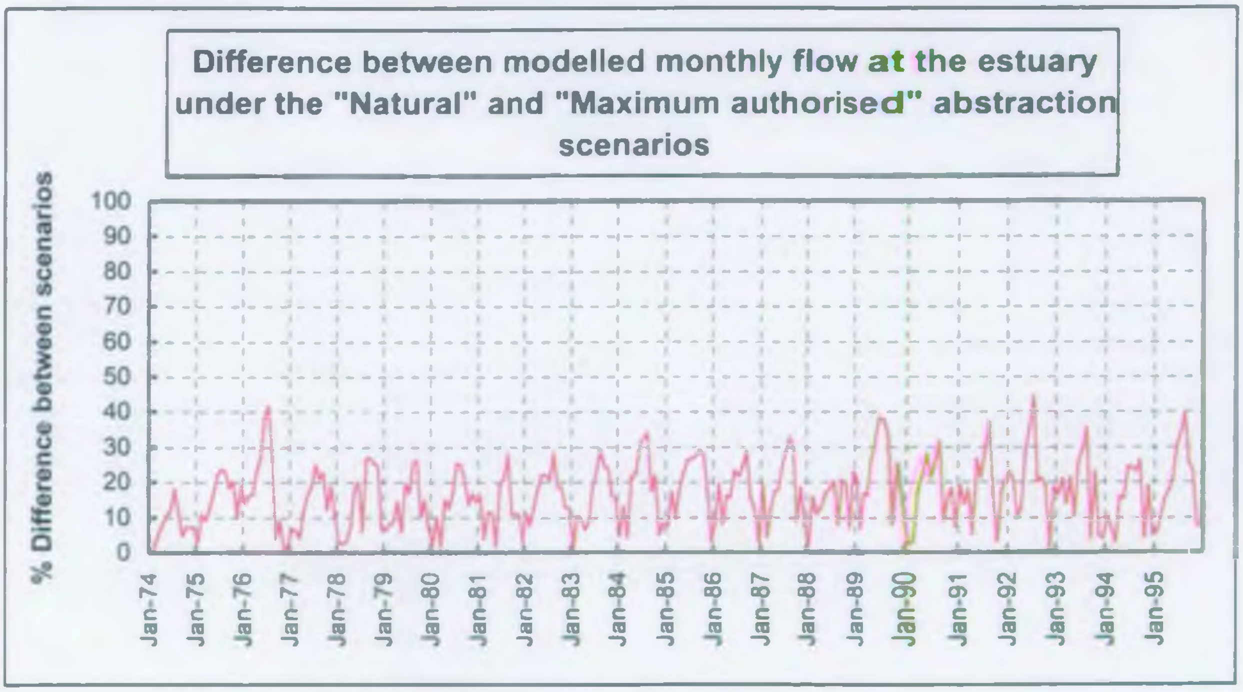

Difference between modelled monthly flow at the estuary under the "Natural" and "Maximum authorised" abstraction scenarios
% Difference between scenarios
100
90
80
70
60
50
40
30
20
10
0
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95

Figure 10: River Otter flow accretion
based on modelled Q95 1974-93
1.5
1
0.5
0
Flow (cubic metres per second)
Alfington
Feniton
Cadhay
Cotley
St Saviours
Fluxton
Tipton
Harpford
Dotton
Colaton
Estuary
0
2
4
6
8
10
12
14
16
18
20
Distance from Fenny Bridges (km)
Maximum authorised
Natural
Sites

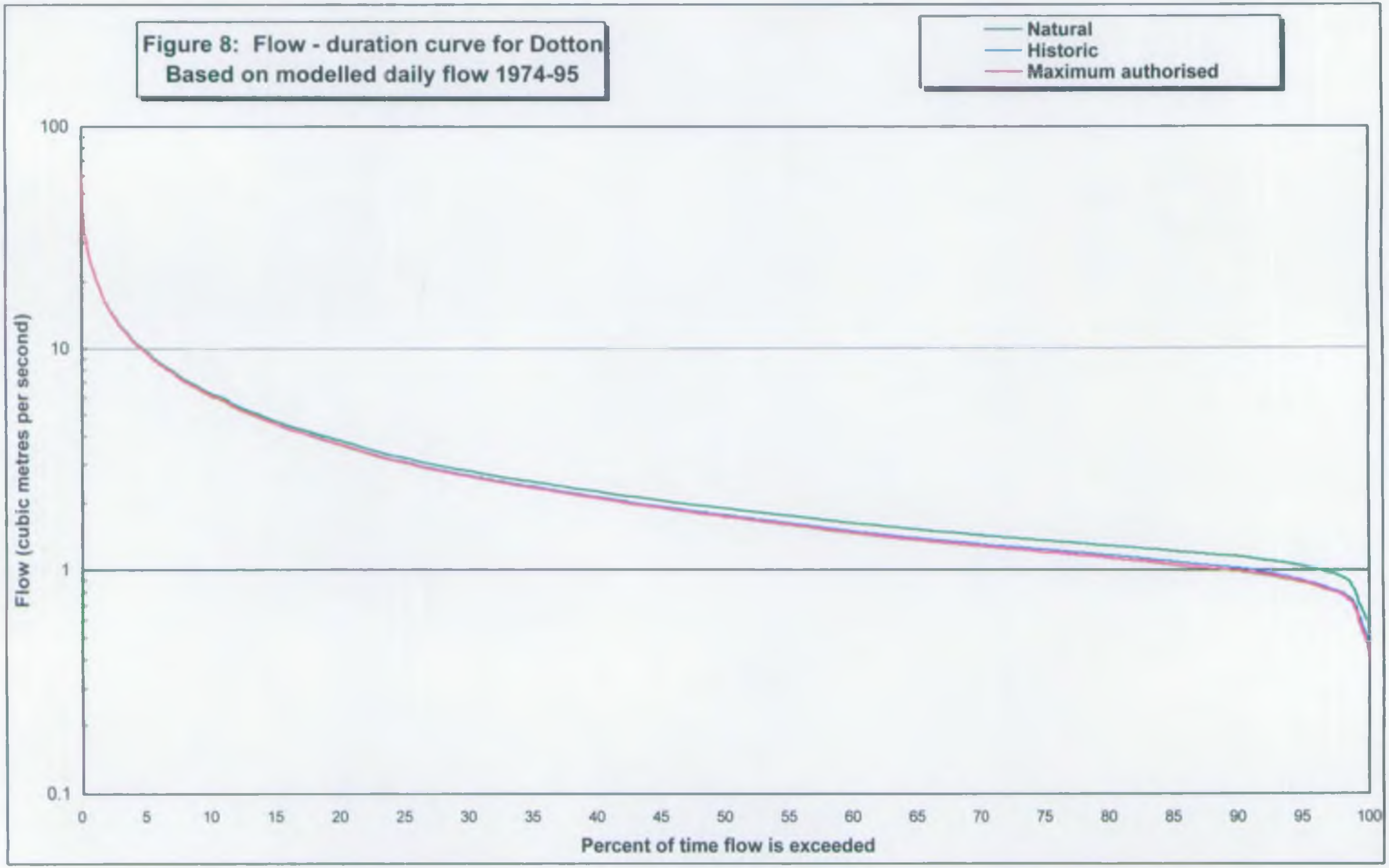


Figure 8: Flow - duration curve for Dotton
Based on modelled daily flow 1974-95
Natural
Historic
Maximum authorised
100
10
1
0.1
Flow (cubic metres per second)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Percent of time flow is exceeded

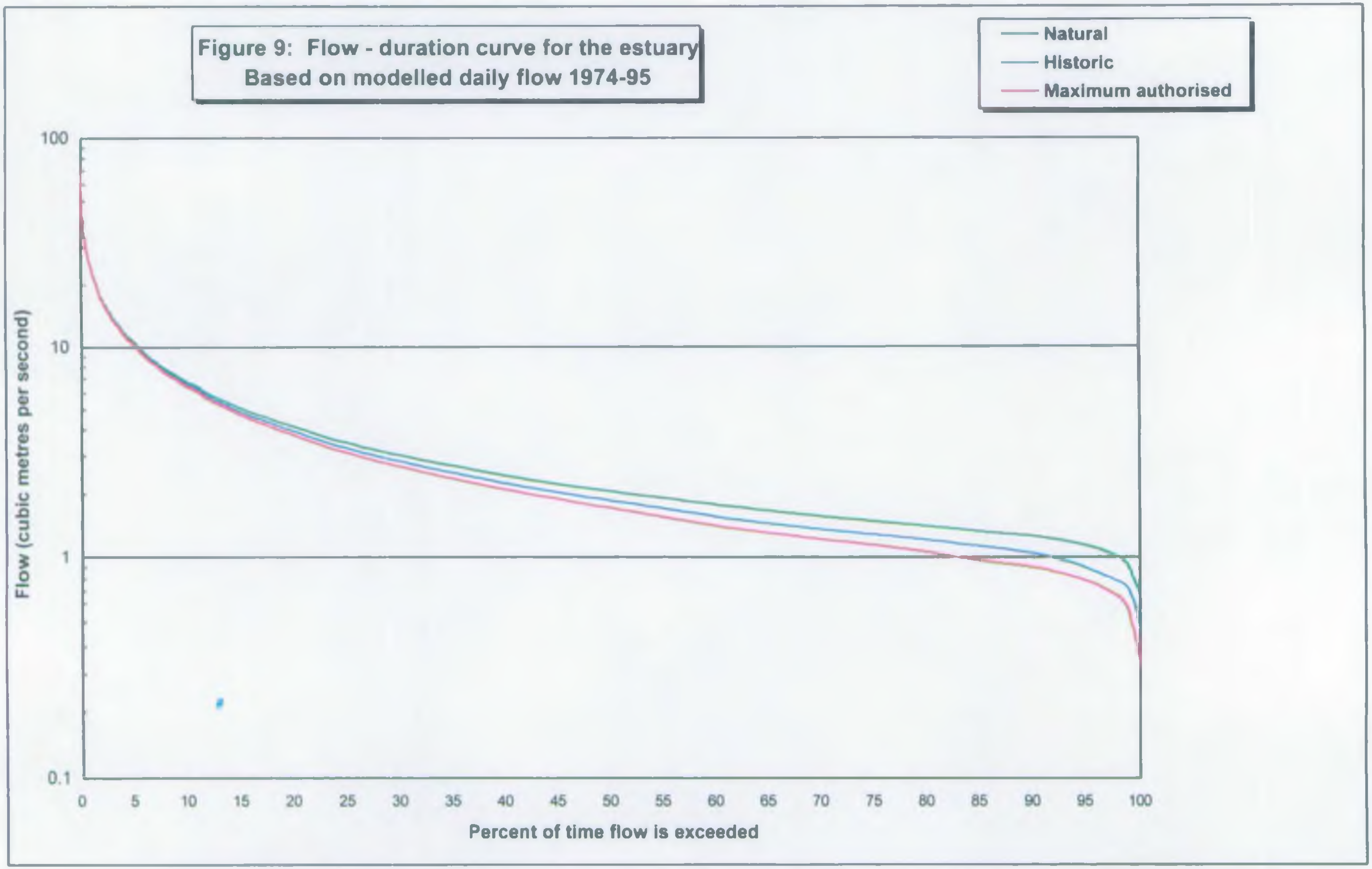
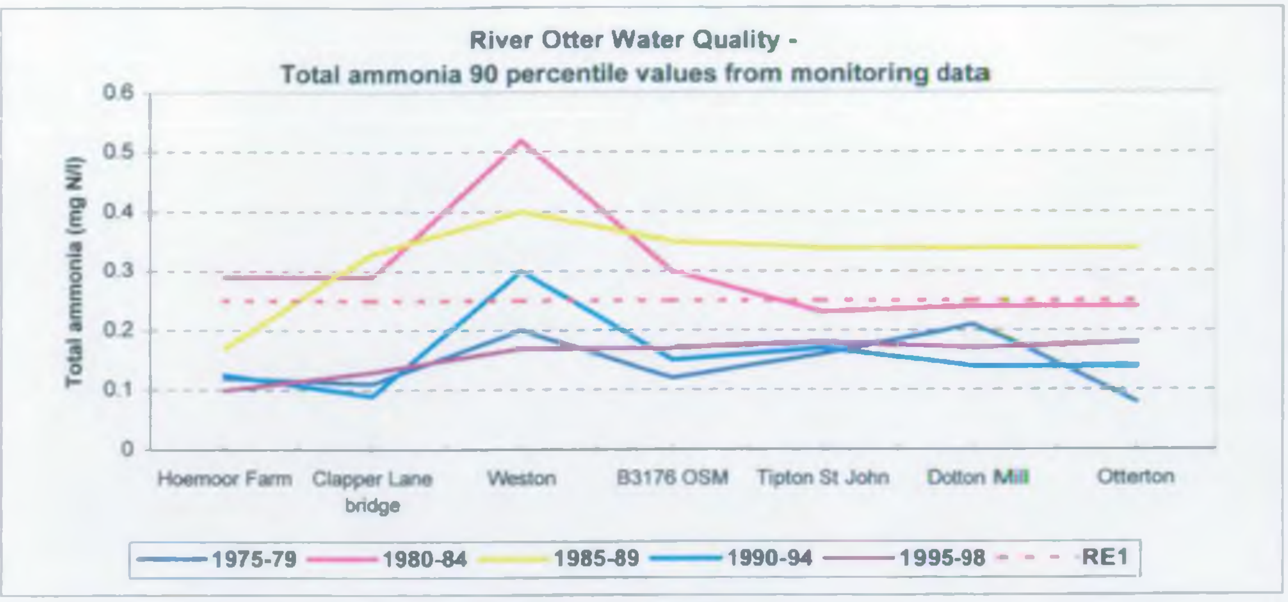
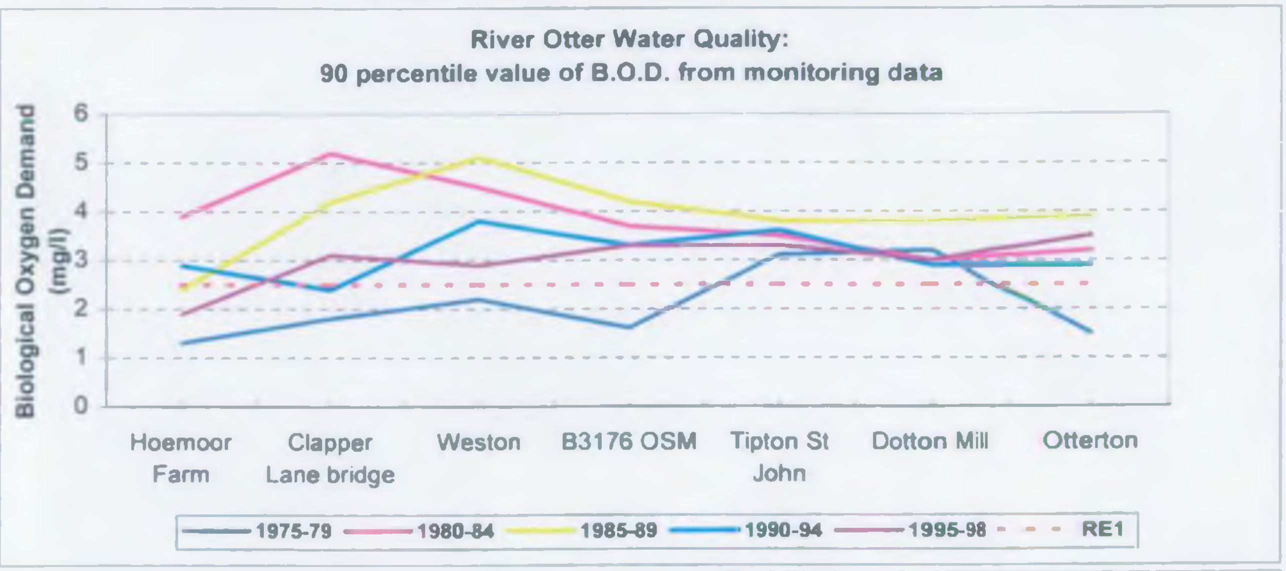


Figure 9: Flow - duration curve for the estuary
Based on modelled daily flow 1974-95
Natural
Historic
Maximum authorised
Flow (cubic metres per second)
100
10
1
0.1
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Percent of time flow is exceeded

Figure 11


River Otter Water Quality -
Total ammonia 90 percentile values from monitoring data
Total ammonia (mg N/l)
0
0.1
0.2
0.3
0.4
0.5
0.6
Hoemoor Farm
Clapper Lane bridge
Weston
B3176 OSM
Tipton St John
Dotton Mill
Otterton
1975-79
1980-84
1985-89
1990-94
1995-98
RE1


River Otter Water Quality:
90 percentile value of B.O.D. from monitoring data
Biological Oxygen Demand (mg/l)
0
1
2
3
4
5
6
Hoemoor Farm
Clapper Lane bridge
Weston
B3176 OSM
Tipton St John
Dotton Mill
Otterton
1975-79
1980-84
1985-89
1990-94
1995-98
RE1

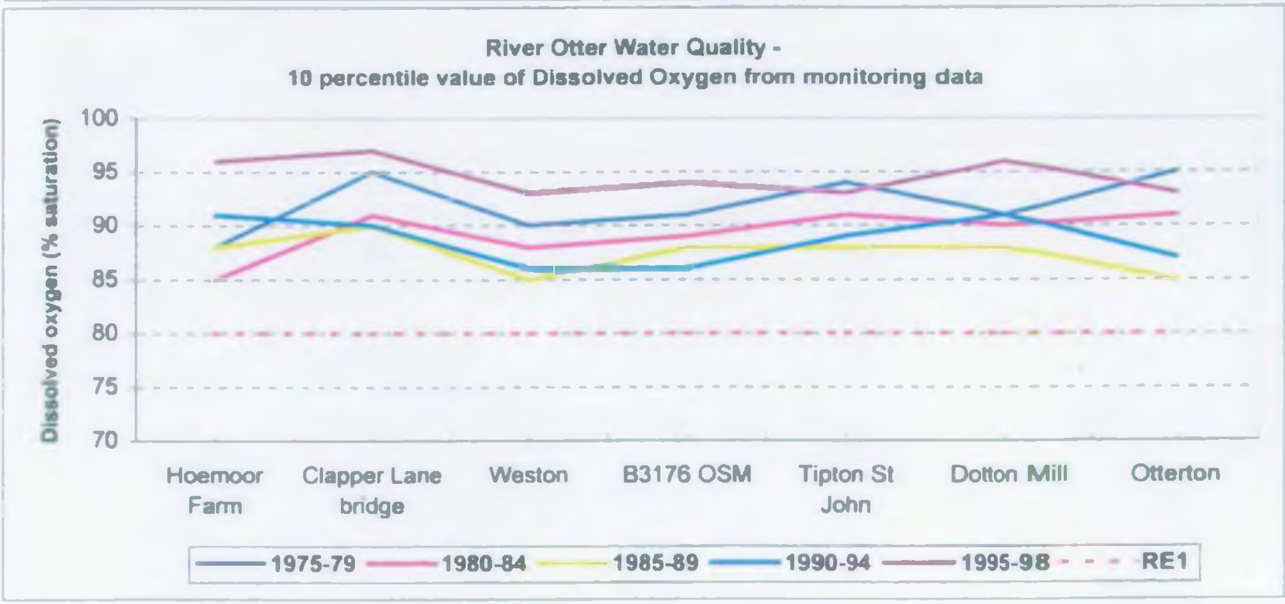
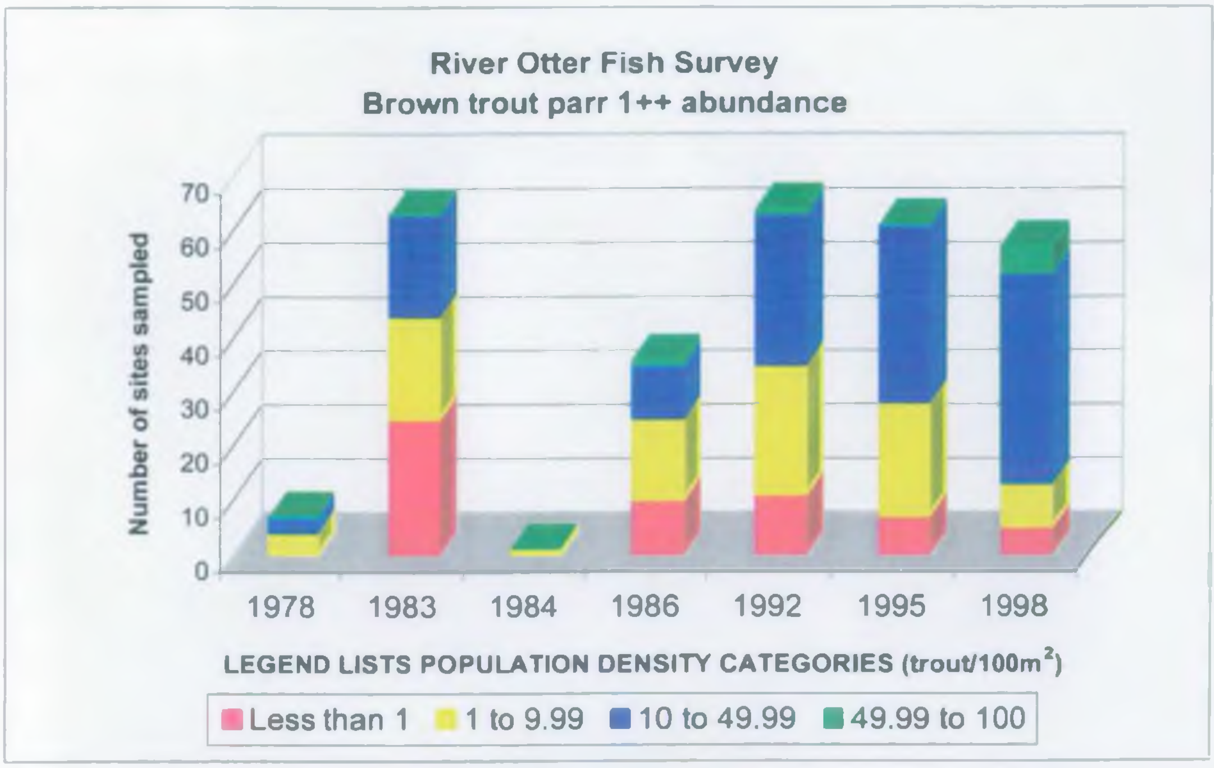

River Otter Water Quality -
10 percentile value of Dissolved Oxygen from monitoring data
Dissolved oxygen (% saturation)
70
75
80
85
90
95
100
Hoemoor Farm
Clapper Lane bridge
Weston
B3176 OSM
Tipton St John
Dotton Mill
Otterton
1975-79
1980-84
1985-89
1990-94
1995-98
RE1

Figure 12


River Otter Fish Survey
Brown trout parr 1++ abundance
Number of sites sampled
0
10
20
30
40
50
60
70
1978
1983
1984
1986
1992
1995
1998
LEGEND LISTS POPULATION DENSITY CATEGORIES (trout/100m2)
Less than 1
1 to 9.99
10 to 49.99
49.99 to 100

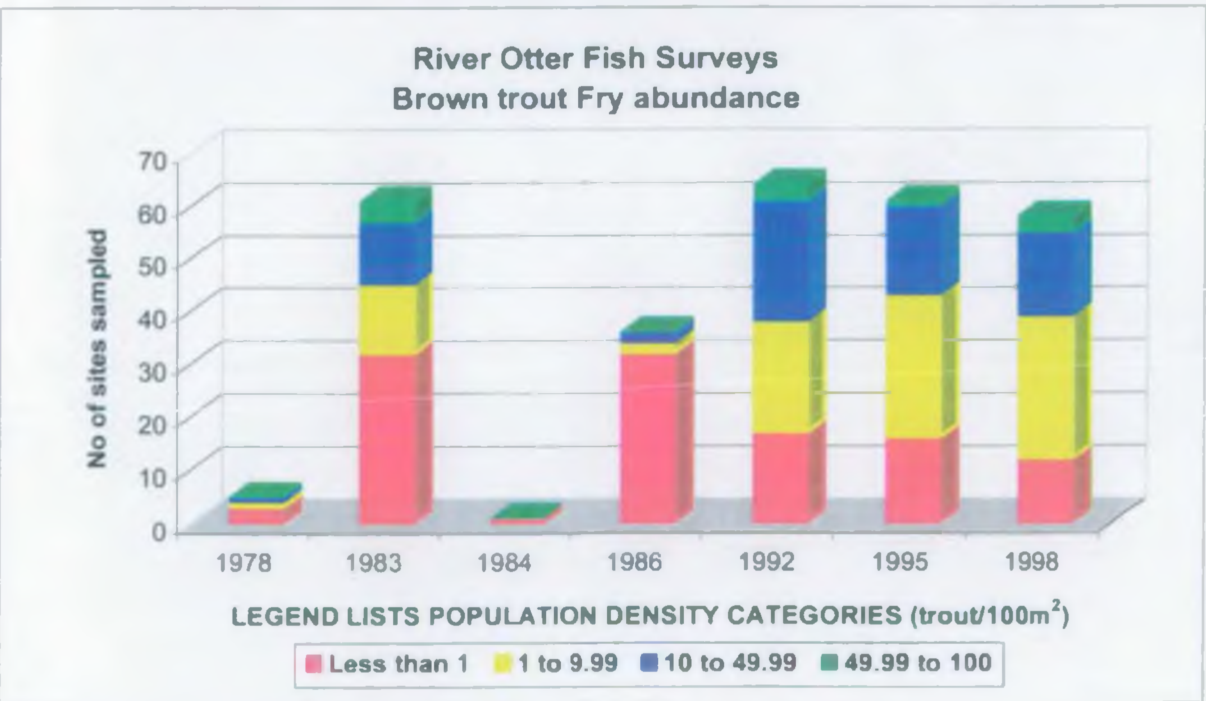
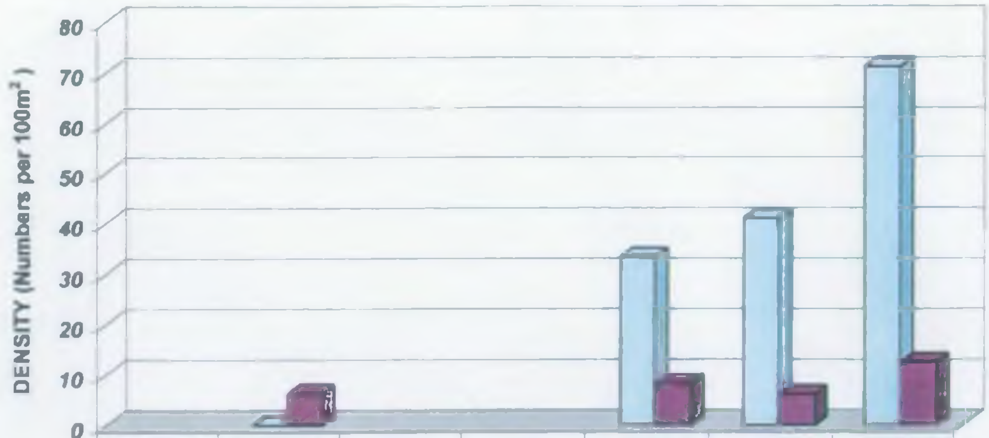

River Otter Fish Surveys
Brown trout Fry abundance
No of sites sampled
0
10
20
30
40
50
60
70
1978
1983
1984
1986
1992
1995
1998
LEGEND LISTS POPULATION DENSITY CATEGORIES (trout/100m2)
Less than 1
1 to 9.99
10 to 49.99
49.99 to 100

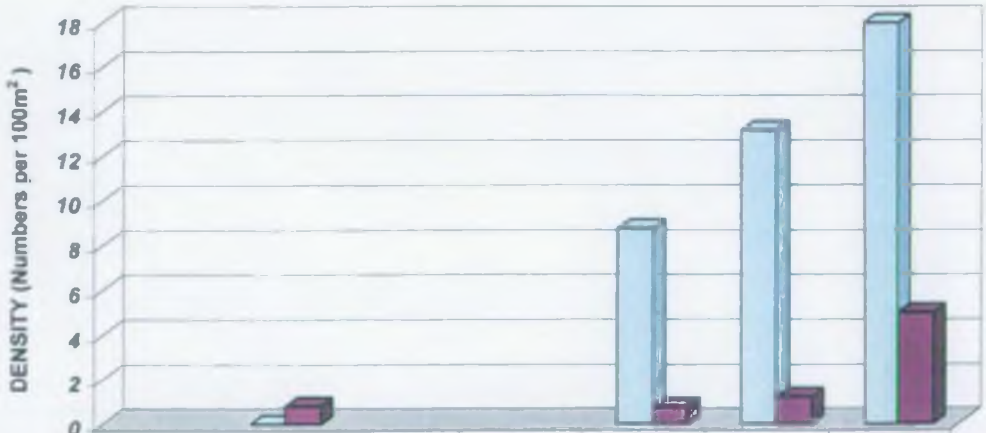
Figure 13

RIVER OTTER FISH SURVEYS
Colaton Raleigh Stream: Brown trout fry



	1978	1983	1984	1986	1992	1995	1998
Stowford		0			33.41	41.06	71.11
Pophams Farm		6.30			8.27	6.15	12.52

RIVER OTTER FISH SURVEYS
Colaton Raleigh Stream: Brown trout parr 1++



	1978	1983	1984	1986	1992	1995	1998
Stowford		0.00			8.74	13.13	17.92
Pophams Farm		0.79			0.75	1.19	4.98

Figure 1

0 km 5

Scale

Information correct as of 1998

APPENDIX ONE
References

The Study documents consist of:

- Phase One (WS Atkins Reports: Otter Low Flow Study Phase One - Four Volumes, May 1994).
- Phase Two (NRA: Otter Low Flow Study Phase One and Two Summary Report, November 1995)
- Phase Three (Environment Agency: Otter Low Flow Study Final Report, March 1998)

Other documents utilised or referred to are listed below:

- Rivers Sid/Otter, Catchment Management Plan Action Plan, Environment Agency, 1996
- South West Water Authority: Otter Valley Study (5 volumes), MRM Consultants,1989
- Water Quality Objectives: Procedures used by the National Rivers Authority for the purpose of the Surface Waters (River Ecosystem) (Classification) Regulations 1994
- Devon Area Report: River Otter Fisheries Survey 1995
- Corridor Surveys: River Otter, National Rivers Authority, 1990
- Decline of the River Otter, River Otter Association, 1992

APPENDIX TWO
The origin of low flows in the River Otter

In the River Otter, low flows naturally originate through variations in the net volume of water contributing to river flow. The contributory factors are described below. The factors vary in importance at different times of the year. The factors also vary geographically. For example, river flow in the lower half of the River Otter catchment, is greatly influenced by the presence of groundwater in the Otter Sandstone/Budleigh Salterton aquifer (see Figure One).

Factors that contribute to river flow

The following factors contribute to river flow or stream flow production:

- Direct surface run-off;
- Groundwater flow from aquifer.

Direct surface run-off

A proportion of the precipitation that falls on the catchment may flow across the land surface as direct–runoff. Direct surface run-off contributes to river flow. The proportion of precipitation that flows as surface run-off depends upon the land's permeability and the intensity of the precipitation. In the Otter catchment, surface run-off is particularly significant in the upper river.

Groundwater flow from aquifer

A proportion of the precipitation that falls on the catchment may percolate through the surface to the aquifer. Only that proportion of precipitation that does not run-off, is not evaporated or is not taken up by plants will percolate. This is known as effective precipitation. The process by which effective rainfall reaches the aquifer is known as recharge. If the resultant rise in the height of the water table in the aquifer is higher than the land surface then groundwater will emerge. This is the mechanism by which springs and wetlands emerge but the same process explains how the water table contributes to river flow: Where the water table is higher than the (permeable) river bed then it discharges water to the river.

The part of the river's flow derived from groundwater is baseflow. In the Otter, the Otter Sandstone/Budleigh Salterton Pebble Beds aquifer makes a significant contribution to river flow in the river downstream of Fenny Bridges via baseflow production. Baseflow in the river's tributaries that rise on the Upper Greensand aquifer is also notable.

Factors that reduce river flow

Factors that naturally reduce river flow include:

- river leakage
- evapo-transpiration.

River leakage

Where the river bed is permeable and the water table height is less than the river bed then river leakage can occur. This can result in a reduction in baseflow to zero at that location and an overall decline in the volume of flow in the river.

Evapo-transpiration

Water taken up by plants (transpiration) or evaporated from the surface (including directly from the river) in the catchment will result in a reduction in the volume of water in the catchment.

Seasonal effects

Variations in baseflow and groundwater level follow a typical annual pattern in the River Otter. During the winter months there is generally a greater frequency and duration of precipitation events compared with the summer. This is typical for the temperate-maritime climate zone in which the Otter is located. Water take-up by plants and evaporation is much reduced in the winter compared with the summer. The reduced evapo-transpirationand increased rainfall in the winter months results in a greater volume of aquifer recharge than in the summer months.

These natural changes in seasonal factors result in a maximum water table height in the late winter/early spring. Since groundwater flow is very slow the water table falls very slowly throughout the summer and autumn: Evapo-transpiration uses most of any rainfall that occurs in this period. In additon, little surface runoff occurs (although intense precipitation can produce significant direct run-off even in summer). The result, throughout the summer period, is a decline in the baseflow contribution to flow. Ultimately, low flows will result later on in the autumn. In this manner, it is quite natural for low flows to occur on a river such as the Otter.

Artificial influences

An artifical influence, such as abstraction of groundwater from the aquifer, can cause low flows. The abstraction reduces the local water table height, n the immediate vicinity of the abstraction point. This could cause the water table to fall below the height of the river bed if the abstraction is close enough to the watercourse. In this way baseflow is reduced. Where the river bed is permeable the water in the river can leak into the water table below. Incidentally, in the latter's case the aquifer is recharged by river water. In either case the groundwater abstraction acts to reduce the baseflow and therefore the river flow.

Lag effects

Whether derived from natural or artificial influences there is a lag between the change in water table height occurring and the effect on river flow. In the Otter the lag can be as long as several weeks as illustrated in the assessment of groundwater graphs in Appendix Seven.

APPENDIX THREE
Hydrological impact assessment: The flow naturalisation technique

This Appendix describes the use of the flow naturalisation technique to estimate abstraction impacts.

Background

The principle of flow naturalisation is as follows: The flow hydrograph reflects the combined influence of artificial and natural factors on flow. If the size of the artificial influence is known or can be accurately estimated then it can be removed from the flow data. This enables the stripped or "naturalised" flow record to be compared with the original observed hydrograph. The difference represents the influence of artificial influences.

Limitation of flow naturalisation method

The main limitation of the flow naturalisation technique is that the assessment is restricted to the site from which the original flow data is obtained. In the River Otter only two flow records covering the 1970s to 1990s are available for such analysis. These are from the gauging stations at Fenny Bridges and Dotton (the flow data collected by the Wessex Water Authority from the Upper Otter in the vicinity of the Otterhead Lakes is not available for this period).

Use of flow naturalisation in River Otter Low Flow Study

In Phase Two the NRA employed Southern Science Limited to construct a simple spreadsheet flow naturalisation model. In order to naturalise the flow records at Dotton and Fenny Bridges SSL added onto the 1972-93 recorded flow record, on a daily basis, the upstream abstractions that had taken place during that period. Similarly, effluent discharge volumes were removed from the flow record. Data from many of the smaller licences is not available and the effluent return volumes can only be estimated in most cases. It is difficult to make a full assessment. SSL took account of the effect of groundwater abstractions using the assumption that the groundwater abstraction would be directly at the expense of river flow. i.e. groundwater abstractions were treated as if the abstraction took place directly from the river. This is likely to overstate the effect of the groundwater abstraction.

SSL produced a basic 'naturalised' flow record at Fenny Bridges and at Dotton. By comparing the recorded and naturalised flows SSL defined how much natural flows had been reduced by historic abstractions.

SSL also estimated the daily volume of abstraction at the full licensed rate to calculate the daily flow record at Fenny Bridges and Dotton under maximum abstractions. The largest consumptive surface abstraction upstream of these sites is the Otterhead Lakes. The licence includes seasonal and flow-related conditions which would restrict abstraction to much less than the maximum daily volume in dry years. These conditions are linked to the observed flow at Knacker's Hole and Royston Bridge gauging stations in the uppermost reaches of the river. However, as stated above the flow data from these sites for much of the 1970s and 1980s is not available. SSL decided to assume that abstraction from the Lakes would have occurred at the maximum daily

OTTERHEAD LAKES MAXIMUM ABSTRACTION PROFILE

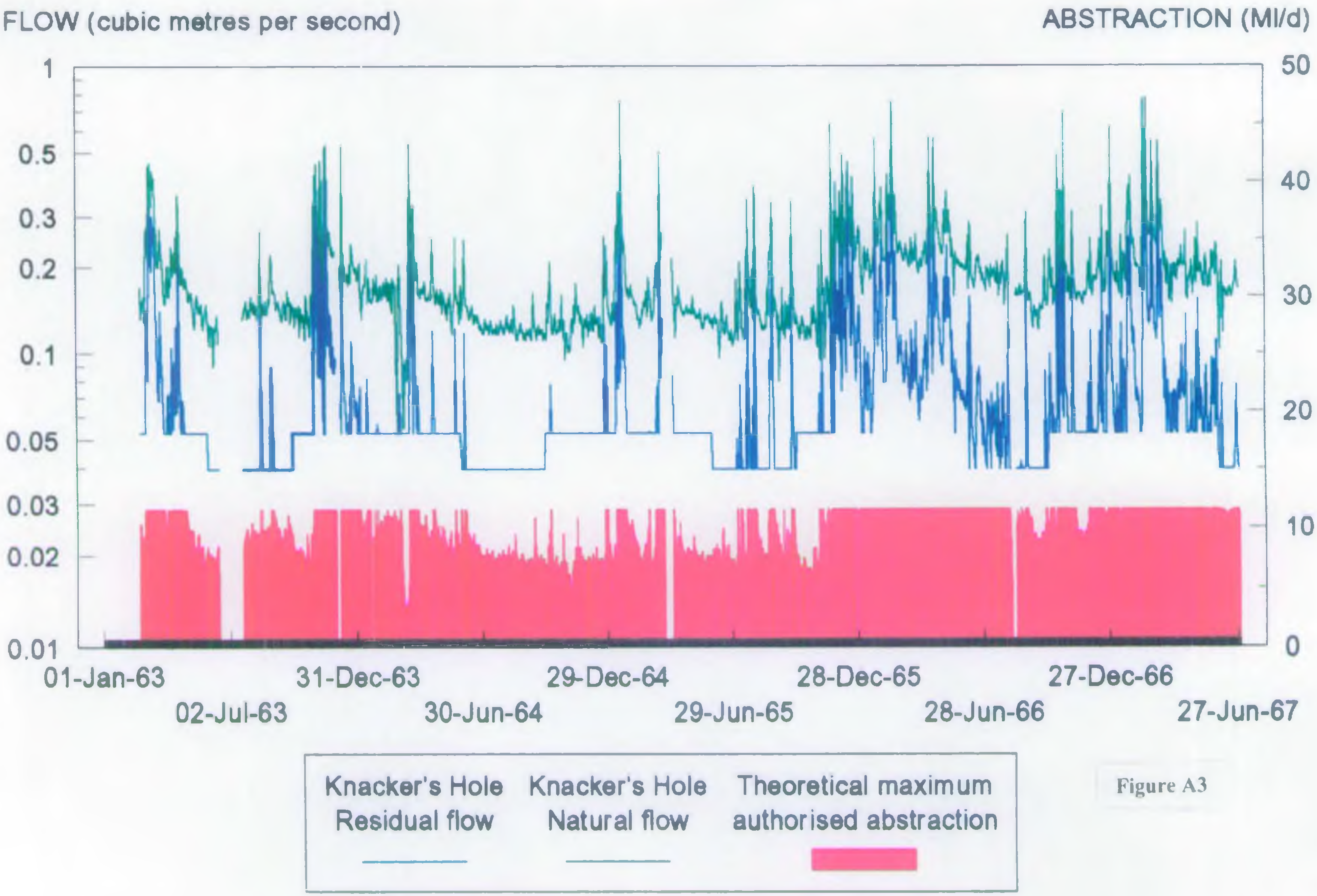


Figure A3

rate for the full period assessed (1972 to 1993) in the theoretical maximum authorised abstraction scenario.

The results of the maximum authorised abstraction scenario were excessive when compared with the results obtained for the historic scenario. Phase Two concluded, therefore, that the maximum authorised abstraction scenario flow impact results were inaccurate.

In Phase Three of the Study, the Agency undertook work to resolve the likely reduction in the permissible maximum authorised abstraction from the Otterhead Lakes associated with the licensed flow restrictions. This was achieved using 1950s and 1960s flow data from Knacker's Hole and Royston Bridge to define the maximum abstraction within the licence conditions. Figure A3 shows the permissible maximum abstraction volume from Otterhead Lakes for a period in the 1960s. The graph was produced by calculating the volume of posible abstraction given available natural river flows. Where flow conditions restrict the abstraction then the amount that can be abstracted will be reduced. This can be seen on the graph. The graph illustrates that the daily maximum as stated on the licence would not always be achievable in the 1963 to 1967 period as flow restrictions would curtail the abstraction. This contrasts with the maximum abstraction scenario as used by SSL in which the daily maximum volume was assumed to be available all year, for the whole study period.

This work shows that the full licensed flow impact for Fenny Bridges and Dotton as concluded in Phase Two is an over-estimate. For example, river flows in the 1975/76 drought would have curtailed abstraction severely. The work also shows that there is little scope for re-assessing the flow impact during the Study period (1974 to 1995) due to a lack of flow data from the gauging stations at Otterhead Lakes. Despite this over-estimate the flow impact as concluded by the flow naturalisation technique under the full licensed abstraction scenario was used in the quantitative water quality impact assessment work (see Section 4). The assessment concludes that abstraction under this scenario (including that from Otterhead Lakes) has an insignificant impact on water available for dilution.

It is worth noting that the flow impacts at Dotton concluded from the flow naturalisation carried out in Phase Two closely matched those obtained from using the groundwater model for the natural compared to historic abstraction scenario. This may seem surprising since the Groundwater Model does not include the non-Public Water Supply abstractions nor does it include the Otterhead Lakes abstraction.

However, these apparent problems are accountable:

- the Public Water Supply abstractions (which are included in the Model) are several times larger than the total volume of consumptive non-Public Water Supply abstractions;
- at Dotton, in the lower Otter, the effect of the historic Otterhead Lakes abstraction is negligible.

In fact, the only major difference between the results from the two approaches occurs under the maximum abstraction scenario. The reason for this is that the Otterhead Lakes maximum authorised abstraction scenario is overstated.

APPENDIX FOUR
Hydrological impact: The Otter Groundwater Model

The Study has utilised a computer model of the River Otter to investigate the hydrological impacts caused by South West Water's groundwater abstractions in the catchment.

Mathematical groundwater modelling

Mathematical computer-based models are potentially an extremely powerful way in which the effect of groundwater abstractions can be quantified. This is because such models permit the detailed simulation of the hydrological processes[1] that are understood to occur in the physical world. For example, the river-aquifer interaction processes can be simulated. Provided the model makes an appropriate representation of the real hydrological and hydrogeological processes occurring in the catchment and providing it is adequately calibrated then it is often the most appropriate tool available.

The availability of modern computer processing power coupled with detailed knowledge of the catchment's hydrogeology have made possible the development of the Otter Valley Groundwater Model (OVGM).

Background

The Otter Valley Groundwater Model simulates groundwater heads and river baseflows in the Triassic Sandstone aquifer of the Otter Valley in East Devon. The original model was produced for the South West Water Authority in 1989 as part of a review of water resources for East Devon. In 1993 the National Rivers Authority transferred the model to a PC version and added a user-friendly front-end. In 1995 the NRA commissioned a re-calibration exercise which resulted in an overall improvement in the model calibration. This work produced the Otter Groundwater Model Version 1.1. During this work improvements were made to the model code and suggestions for future model enhancements were identified.

In order to progress the recommended improvements the following work was undertaken by consultants, Kennedy & Donkin:

- inclusion within the model code of a shorter time-step;
- inclusion within the model code of tributary flow tracking;
- model data period update;
- further recalibration.

Model description

The Otter Groundwater Model is a two dimensional digital representation of the Triassic aquifer

1. It is vital to appreciate the mechanism by which groundwater abstractions and natural factors influence river flow (described in Appendix Two) as this explains why the Otter Groundwater Model is an appropriate hydrological impact assessment method. This appreciation will be also relevant to understanding how the model was calibrated.

and river system of the Otter catchment in south-east Devon. Operating in monthly time-steps the model simulates baseflow and groundwater heads on a nodal grid with a spacing of 250m. The model uses mathematical equations to describe the movement of water through the system. The model incorporates a definition of the the geometry of the aquifer and river system. At aquifer nodes values for permeability and storage coefficient are set. At river nodes river leakage and aquifer leakage factors are defined. In order to run the model it requires the user to input the data concerning the volume of abstraction from groundwater sources and the volume of recharge to the aquifer over the period of interest. Recharge is estimated separately from the Model but the model spatially distributes it across the catchment.

Operation of the model takes place through a Windows environment. No output analysis facilities have been set up within the model: The Agency has used the model to simulate impacts on total surface flows using software external to the model. The model takes about two hours to complete the simulation period 1973 to 1995.

The improvements made are described below:

1. Shorter time-step

The consultant shortened the model's time-step from monthly to 10 day units. This entailed program development and testing.

2. Tributary flow tracking

The consultant successfully amended the model code to include a sub-routine that tracks the volume of baseflow in the river reaches including tributaries as set up in the model. The consultant linked this tracking routine with the model's river leakage routines which allow leakage to and from the river on the basis of river leakage factors and local groundwater heads. Significantly, the consultant developed a progam routine which relates the leakage from the river to the modelled volume of baseflow in the river.

3. Model data update.

The consultant updated the model to the end of the 1995. The resultant model is termed Version 2.0.

4. Recalibration

The consultant carried out 20 recalibration runs following the completion of the model enhancements and update. These built on the 20 calibration runs that were conducted using Version 1.1 in Phase Two. Calibration of simulated output with observed or derived measurements was completed for:

- river baseflow (at Dotton gauging station); and
- groundwater levels (at 37 sites).

When comparing the baseflow data the consultant compared the modelled baseflow with the derived baseflow accretion between Fenny Bridges and Dotton. The baseflow accretion was calculated by subtracting the baseflow at Dotton from the sum of baseflow at Fairmile and Fenny Bridges. Baseflow was derived from the gauged records at these sites using the national standard method (Institute of Hydrology Baseflow Separation method). The first table at the end of this appendix shows the baseflow calibration improvements secured in the Phase Three model enhancement work.

The consultant improved the model's groundwater calibration without compromising the existing baseflow calibration. Set out in the second table at the end of this appendix is a summary of the original and final calibration 'errors' from the 1995 project and the final calibration errors achieved in Phase Three with respect to groundwater level fluctuations. A key feature that the consultant introduced was an additional zone of intermediate aquifer permeability between the 4 m/d zone in the west (representing the unconfined aquifer of the Pebble Beds) and the 0.5 m/d zone in the east (representing the confined aquifer of the Otter Sandstone) as set up in version 1.1.

For both baseflow and groundwater head calibration the following measures were used to derive an acceptable calibration:

- Graphical illustrations of modelled output against observed or derived data;
- Numerical summaries of the average errors for each site (groundwater heads only) and for the catchment overall.

In the calibration process the main aim is to simulate accurately appropriate trends and patterns in the observed data. It is also necessary to achieve an appropriate minimum absolute error. In terms of the Otter model the small baseflow errors served to indicate that the groundwater calibration was appropriate. This is because the groundwater variations influence the volume of baseflow through the river-aquifer interaction.

Run RC43 was used in the simulation work as part of the hydrological impact assessment.

Details about how the Model was used to provide the impact results are described in Appendix Five.

Run Ref.	Dotton Baseflows Q95 (m^3/day)	Q50 (m^3/day)	Q10 (m^3/day)	Divergence from Derived Q95 (%)	Q50 (%)	Q10 (%)
Derived	73306.08	123649.2	217229.7	-	-	-
rc24				1.5	-1.3	-1.6
Base run	75493.734	126007.656	216021.3985	3.0	1.9	-0.06
RC25	76613.008	125719.586	212884.7345	4.5	1.7	-0.02
RC26	76684.289	126198.609	213373.1095	4.6	2.1	-1.8
RC27	76122.797	125833.313	214424.4845	3.8	1.8	-1.3
RC28	76341.852	126514.25	214921.57	4.1	2.3	-1.1
RC29	74908.117	124841.352	214089.6875	2.2	1.0	-1.4
RC30	74371.727	124136.688	213299.9455	1.5	0.4	-1.8
RC31	74674.500	124707.367	214454.8755	1.9	0.9	-1.3
RC32	74456.695	124714.539	214725.5785	1.6	0.9	-1.2
RC33	74777.297	124576.086	214353.0155	2.0	0.7	-1.3
RC34	74984.469	124448.547	211867.883	2.3	0.6	-2.5
RC35	74388.469	124841.398	215016.086	1.5	1.0	-1.0
RC36	18900.092	36113.016	124446.375	-74.2	-70.8	-42.7
RC37	62250.73	113135.414	203818.6095	-15.1	-8.5	-6.2
RC38	76395.992	126917.594	216923.2735	4.2	2.6	-0.1
RC39	18934.848	35446.035	123441.039	-74.2	-71.3	-43.2
RC40	73283.742	123810.516	213720.758	0.0	0.1	-1.6
RC41	74429.211	124692.859	214702.1565	1.5	0.8	-1.2
RC42	73663.898	123590.086	213423.461	0.5	0	-1.8
RC43	74344.625	124432.297	212529.531	1.4	0.6	-2.2

Run Ref.	Average Water Level (m AOD)	Average Standard Deviation (m)	Average Overall Range (m)	Average Error in Mean no. of SDs	Average Std. Dev Ratio (sim:obs)
Observed	34.63	1.16	4.08		
rc24	31.14	1.1	4.92	-6.61	1.76
Base run	31.08	1.08	4.98	-5.96	1.60
RC25	31.08	1.08	4.96	-5.96	1.60
RC26	31.08	1.07	4.92	-5.96	1.59
RC27	31.08	1.07	4.95	-5.96	1.59
RC28	31.20	1.08	4.72	-5.77	1.60
RC29	31.02	1.08	4.96	-6.05	1.59
RC30	31.15	1.13	5.15	-5.77	1.65
RC31	31.08	1.10	5.04	-5.91	1.63
RC32	31.03	1.09	4.99	-6.00	1.60
RC33	31.02	1.08	4.96	-6.05	1.59
RC34	31.02	1.12	5.11	-6.01	1.62
RC35	31.07	1.10	5.01	-5.91	1.62
RC36	31.13	1.06	4.92	-5.89	1.57
RC37	31.08	1.08	4.98	-5.96	1.60
RC38	31.21	1.07	4.87	-5.75	1.55
RC39	31.08	1.08	4.98	-5.96	1.60
RC40	31.07	1.07	4.90	-5.97	1.56
RC41	31.02	1.08	4.95	-6.05	1.59
RC42	31.07	1.10	5.06	-5.93	1.59
RC43	31.18	1.06	4.64	-5.78	1.56

APPENDIX FIVE
The estimation of flow impacts using the Otter Valley Groundwater Model

The Otter Groundwater Model provides flow data for sites in the lower catchment specified by the user. This is achieved by setting up "simulation" runs using the Model. For each run the user specifies the period to be simulated and defines the scenario: For example, in the Study three sceanrios have been examined (natural or zero abstraction; historic or actual abstraction; and full licensed or maximum abstraction).

The output is river baseflow data (groundwater levels were also obtained from the same simulation run). An estimate of flow (or groundwater level) is produced for every relevant site in the catchment, each value representing a ten-day average value. Previously the Model produced values representative of one month. To obtain the monthly flow hydrographs produced in this report the ten-day values were averaged. To produce the daily values the ten-day values were broken down into daily values by correlation with the Dotton gauging station record.

As the flow output is baseflow there is a need to derive total flow data in order to conclude flow impacts. The method used was as per the Phase Two work (see Phase Two report Section 8.8).

Running simulation scenarios is very easily conducted because of the addition of the user-friendly input facility during Phase One of the Study. Processed flow data from the Model was used in a graphing and spreadsheet package to produce the graphs and data summaries, the main demand on time being the post-simulation processing.

APPENDIX SIX
Water Quality: The River Ecosystem Classification scheme

The Environment Agency uses the River Ecosystem classification scheme to categorise river water quality. The scheme is associated with the Surface Waters (River Ecosystem) (Classification) Regulations 1994, Statutory Instrument 1994 No. 1057. This Instrument enables the setting of statutory water quality objectives but is also used to describe current river quality.

The River Ecosystem scheme classifies river water according to five hierarchical classes, in order of decreasing quality: RE1, RE2, RE3, RE4 and RE5. For the key water quality criteria used in this Study the following standards must be satisfied in order to achieve the appropriate class:

Class	Dissolved oxygen % saturation 10 percentile value	Biological Oxygen Demand (mg/l) 90 percentile	Total ammonia (mg N/l) 90 percentile
RE1	80	2.5	0.25
RE2	70	4.0	0.6
RE3	60	6.0	1.3
RE4	50	8.0	2.5
RE5	20	15.0	9.0

The Regulations cover both the criteria and the methods used to derive the data for assessment of compliance purposes. This covers sample collection, analytical procedures and assessment of compliance. The methods are statistical in nature and are relatively complex. For the purposes of the Study the procedures have been followed in accordance with the Regulations and in particular the following elements have been adhered to:

- The sampling of water quality in the River Otter has been in accordance with the regulations (e.g. location, method and frequency of sampling);
- Analysis of the sample data has been in accordance with the regulations (e.g. accuracy, precision and limit of detection)
- Assessing compliance methods have been utilised in accordance with the regulations, but the purpose of assessment has been to report water quality observed (the Study does not seek to provide compliance information).

In essence the Study has determined the appropriate percentile value for each water quality determinand used in accordance with the regulations. For example, for dissolved oxygen, the sample data was utilised to derive the 10 percentile value. The result was then compared with the standard for dissolved oxygen to determine the RE class in which the site and sample period falls. As illustrated in Section Four of the main report, the Study has utilised the standards set out in the River Ecosystem scheme in various water quality assessments.

Further details of the scheme can be found in "Water Quality Objectives: Procedures used by the National Rivers Authority for the purpose of the Surface Waters (River Ecosystem) (Classification) Regulations 1994", a document available from the Environment Agency.

APPENDIX SEVEN

Hydrological impact assessment: the results of applying methods suggested by the Otter/Sid LEAP Steering Group

This Appendix considers other methods suggested at some stage of the Study to assess impacts of abstraction on river flow and groundwater level. Two approaches were recommended. Firstly, it was felt that an examination of the accretion or increase in low flows through the lower river would give a clear indication of the impact of abstraction. Similarly, the Steering Group requested groundwater level variation data, which may illustrate the impact of abstraction. Essentially, these requests reflected a view that the impact of abstraction could be examined fruitfully by observation of flow/groundwater level hydrographs.

There is some merit in examining hydrographs for the purposes of understanding seasonal trends in river flow or groundwater level. These methods are relevant when making initial considerations about the impact of abstractions. This is because the hydrographs depict measured, physical data from the catchment. This is not to say that the hydrographs truly represent the reality of river flow or groundwater level variations: There will always be an element of error in any measurement made. However, the measured data provides an estimate of the combined influence of natural and artificial factors on river flow or groundwater level. For example, a groundwater hydrograph represents the combined influence of all factors including aquifer recharge and groundwater abstractions in the local area.

However, observation of such graphs to provide unequivocal conclusions regarding the impact of potentially influencing factors is limited: The hydrographs permit an *intuitive* guess as to the relative influence of a given factor on the observed record.

The Agency duly implemented the requests for attempting the accretion plot exercise and provided groundwater level data.

Low Flow accretion assessment

During Phase Three the River Otter Association suggested an approach to demonstrate the impact of abstractions on low flows in the southern half of the catchment. The Agency carried out this assessment to illustrate that the approach gives no quantitative indication as to the contribution groundwater abstraction makes to the overall observed pattern of low flows. Indeed the approach permits no quantitative assessment of the contriubution of any other factors, such as recharge, for example.

Extracts from letters exchanged between the Agency and the River Otter Association on this matter are set out below. The accretion graph is included at the end of this section.

In the autumn of 1996 the Agency exchanged correspondence with the River Otter Association on the subject of low flow accretion. The Agency provided the Association with flow data for Fairmile, Fenny Bridges and Dotton gauging stations. The Association requested the data in order to calculate the accretion of low flows between Fenny Bridges and Dotton, having taken into account the influence of Fairmile flows. This was achieved by subtracting from the low flow data at Dotton the sum of low flows (on the same day) at Fairmile and Fenny Bridges. Expressed as a percentage of the Dotton flow this calculation gives an indication as to the increase or accretion of low flows between Fenny Bridges and Dotton.

Given that the majority of SWW's groundwater sources are located between Fenny Bridges and Dotton the assessment has some merit in terms of providing information regarding the hydrological regime in the lower River Otter catchment. However, the recorded flow data reflects both the influence of abstractions, discharges, other artificial influences and natural factors, such as effective rainfall. Clearly, the method does not enable the separate effect of natural and artificial factors to be illustrated.

Based on the production of a slightly more elaborate assessment of the low flow accretion and other data the Agency derived the graph overleaf. The Agency's graph includes the derived low flow accretion data as per the Association's method. Also plotted is:

- The equivalent depth of aquifer recharge (blue triangles);
- The equivalent "depth" of abstractions in the period examined (1978 to 1995, red squares).

The recharge and abstraction volumes have been standardised. That is, the recharge is a depth of water, directly analagous to rainfall figures. Likewise, the abstraction volume in each year has been converted to a depth equivalent by dividing by the catchment area between Fenny Bridges and Dotton (this gives an over-estimated equivalent depth since some of the abstraction points are downstream of Dotton).

The graph shows that the low flow accretion varies between about 23 to 38%. On examining the graph it is clear that the influence of aquifer recharge on the low flow accretion pattern is clearly dominant over the influence of abstractions. Abstractions represent, at most, 10% of the recharge and have not risen abruptly over the period concerned.

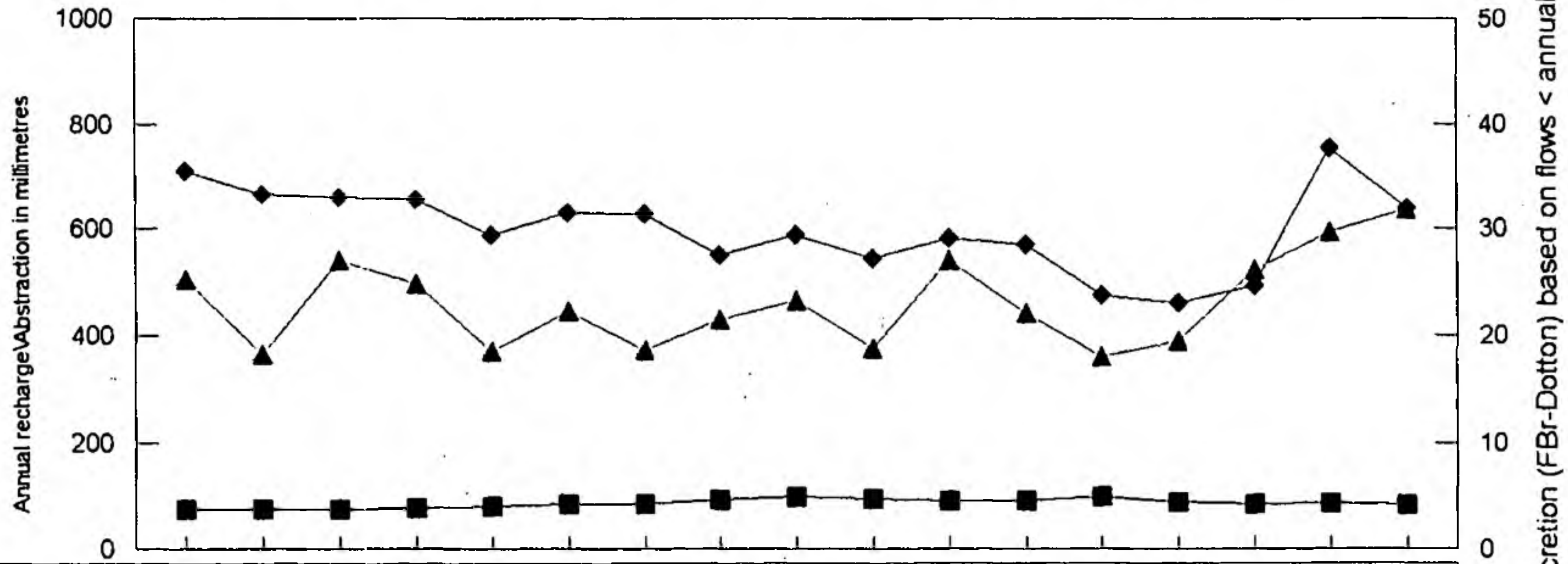
The graph has some merit in providing an insight into the hydrological processes at work: For example, the lagged nature of the influence of aquifer recharge on low flows is exemplified in the low flow accretion graph. However, the simplicity of the approach limits its usefulness. One can interpret the graph to provide theories of the processes at work but one cannot use the graph to determine, for example, by how much low flows are reduced by abstractions. There is no definition of the cause-effect link between abstraction and low flows or recharge and low flows, either on the graph or within the data. There is, therefore, no means by which the method can be applied to different scenarios. It is virtually impossible to separate the influencing factors without recourse to a model, complex or otherwise.

Groundwater level graphs

At the LEAP Steering Group meeting in June 1997 groundwater level data was requested. The request concerned groundwater levels in the Pebble Beds (in the south-west of the catchment) and groundwater levels in the Otter Sandstone (in the catchment below Fenny Bridges). The Agency provided the data as requested toegther with a full commentary. The commentary is partly reproduced below together with copies of the graphs referred to.

River Otter

Historical changes in low flow accretion, recharge and Public Water Supply abstraction



Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
■ Major GW abs.	75.6	74.1	75.5	78.0	80.3	85.4	84.1	92.3	98.8	94.2	90.2	91.7	99.0	88.2	84.2	86.1	81.8
◆ Flow accretion	35.5	33.2	33.0	32.7	29.4	31.5	31.4	27.5	29.4	27.2	29.1	28.5	23.8	23.0	24.6	37.7	31.9
▲ Recharge	430.3	291.6	465.4	418.7	291.8	360.5	288.6	337.5	367.8	282.6	450.5	349.4	261.6	301.5	439.8	507.1	554.2

Provisional data
Environment Agency December 1996

The following commentary and graphs illustrate very clearly the relative influence of natural processes and public water supply abstraction on groundwater levels in different parts of the catchment and in different geologies. In summary the graphs and notes show that:

- Where an observation well is near a public water supply borehole there is, as expected, a correlation between groundwater level and abstraction volume but very little relationship between groundwater level and recharge;
- Where an observation well is remote from a public water supply borehole there is, as expected, a correlation between groundwater level and recharge to the aquifer but none between groundwater level and abstraction;
- Abstractions from the Pebble Beds have a small radius of impact;
- Abstractions from the Otter Sandstone give rise to a large radius of impact.

Groundwater level data presented in graphs

The data is groundwater levels from various observation wells/boreholes in the areas requested presented as groundwater variation over time. To aid in the understanding/interpretation of the data it is useful to also consider recharge to and, where relevant, major abstractions (public water supply) from the aquifer. There are two graphs for each monitoring site: a graph of groundwater levels and public water supply abstraction; and a graph of groundwater levels and recharge.

Please note: The groundwater level data is taken from either automatic level monitoring equipment or from manual observations of the water level in the well/borehole. The recharge data is derived using a standard UK recharge calculation method (based on Met Office data from the catchment). The recharge represents the water that percolates through the surface, after falling as rain, to replenish the water bearing rocks or aquifer. The abstraction data is the volume of water abstracted from South West Water's various boreholes in the catchment.

All data has been averaged to give a smoothed line on the graph. This has been achieved by calculating the running average monthly value. This helps to discern trends on a seasonal, yearly and decade basis which are difficult to see when the day to day variations are displayed.

Observation sites selected

To meet the request the following sites were used:

a) Representing groundwater levels in the Pebble Beds aquifer/SW of catchment

Colaton Raleigh 2A (SY 0703-8766) - a site where there is a known abstraction impact;
Woodbury Common (SY 0533 8782) - a site where there is no abstraction impact.

b) Representing groundwater levels in the Lower catchment/Otter Sandstone aquifer

Alfington No 1 (SY 1121 9661) - a site where there is a known abstraction impact;

It is worth comparing groundwater level variations and their causes in these two aquifers as the comparison illustrates the way in which abstraction and recharge interacts with the hydrogeology in the ground to give the observed groundwater variations.

Commentary on graphs

a) Representing groundwater levels in the Pebble Beds aquifer/SW of catchment

The Colaton Raleigh 2A observation borehole is very close (less than 0.5km) to the Colaton Raleigh public water supply boreholes. Consequently one would expect the abstractions to heavily influence the observed groundwater variation at the observation borehole. Please refer to Graphs 1 and 2.

Graph 1 shows the observed groundwater levels (solid line) and the total volume of abstractions from the nearby Colaton Raleigh boreholes (dotted line) over the period 1973 to 1997. The period of higher abstractions (January 1984 to mid-1990) coincides with rather depressed groundwater levels. Within this period there have been several large but short lived reductions in the amount abstracted (e.g. in late 1986). These coincided with significant but short lived rises in groundwater level. There can be no doubt that the abstractions from the Colaton Raleigh affect the water levels in the observation borehole.

Graph 2 shows the same Colaton Raleigh 2A groundwater level record as Graph 1. Also shown on this graph is the aquifer recharge. Unlike in Graph 1 there is no clear relationship between recharge and groundwater variation. This observation re-affirms the conclusion that groundwater levels at Colaton Raleigh 2A borehole are influenced mainly by abstractions in the local area.

The Woodbury Common observation borehole is also in the Pebble Beds but is further away from the Colaton Raleigh public water supply boreholes than the Colaton Raleigh 2A observation borehole. Consequently one would not expect abstraction to influence the observed groundwater level variations at the Woodbury Common borehole. Please refer to Graphs 3 & 4.

Graph 3 shows the observed groundwater levels at Woodbury Common borehole (solid line) and the total volume of abstractions from the Colaton Raleigh boreholes (dotted line) over the period 1973 to 1997. The public water supply boreholes at Colaton Raleigh are almost 5km away. On graph 3 it is apparent that periods of high abstraction rates coincide with periods of high groundwater levels. This is quite the opposite to the pattern one would expect if abstractions affected groundwater levels. Graph 3 shows that abstractions do not influence the observed groundwater variations.

Graph 4 shows the same groundwater record at Woodbury Common (thick line) and the aquifer recharge (thinner line). There is a striking pattern illustrating a link between recharge and groundwater. As you will appreciate, when the recharge enters the land surface there is a delay of some weeks or months before it reaches the aquifer. In this way the pattern of recharge is usually mimicked in the groundwater level variation record but in a delayed fashion. For example, the recharge of the winter 1987/88 doesn't appear as a rise in groundwater levels until later. Similarly, the lack of recharge in 1990/91 results in reduced groundwater later.

Groundwater usually responds several weeks/months after recharge events.

b) Representing groundwater levels in the Lower catchment/Otter Sandstone aquifer

The Alfington No 1 borehole is in the Otter Sandstone and is close to the Greatwell group of abstraction boreholes. One would expect therefore an impact on groundwater levels caused by abstraction. Please refer to Graphs 5 & 6.

Graph 5 shows how abstraction from Greatwell increased in the mid-eighties until about 1993 when the volume abstracted declined. The groundwater level record shows an apparently related response: Levels drop during the early 80s and until about 1993 then recover. There appears to be a connection between groundwater levels and abstraction.

Graph 6 shows recharge on the Alfington No 1 groundwater graph. During the period 1988 to 1992 it is clear that abstractions were at their highest rate but beyond this they did not vary significantly from year to year. However, recharge during this period did change significantly. The recharge in 1987/88 and in 1989/90 was relatively high and indeed there can be seen small recoveries in the groundwater just after each of these events. This point illustrates the fact that recharge is influencing groundwater levels in these periods.

The role that geology plays in influencing groundwater variations in the Otter Valley

Alfington is further from the Greatwell borehole group than Colaton Raleigh observation borehole 2A is from the Colaton Raleigh borehole group. So why is there an effect at all at Alfington? The answer is due to geology:

- the Sandstone in the Greatwell area is very well cemented;
- the Sandstone in the middle and eastern part of the Otter catchment (including Greatwell) is covered (or confined) by impermeable layers of rock (and thus under increased pressure).

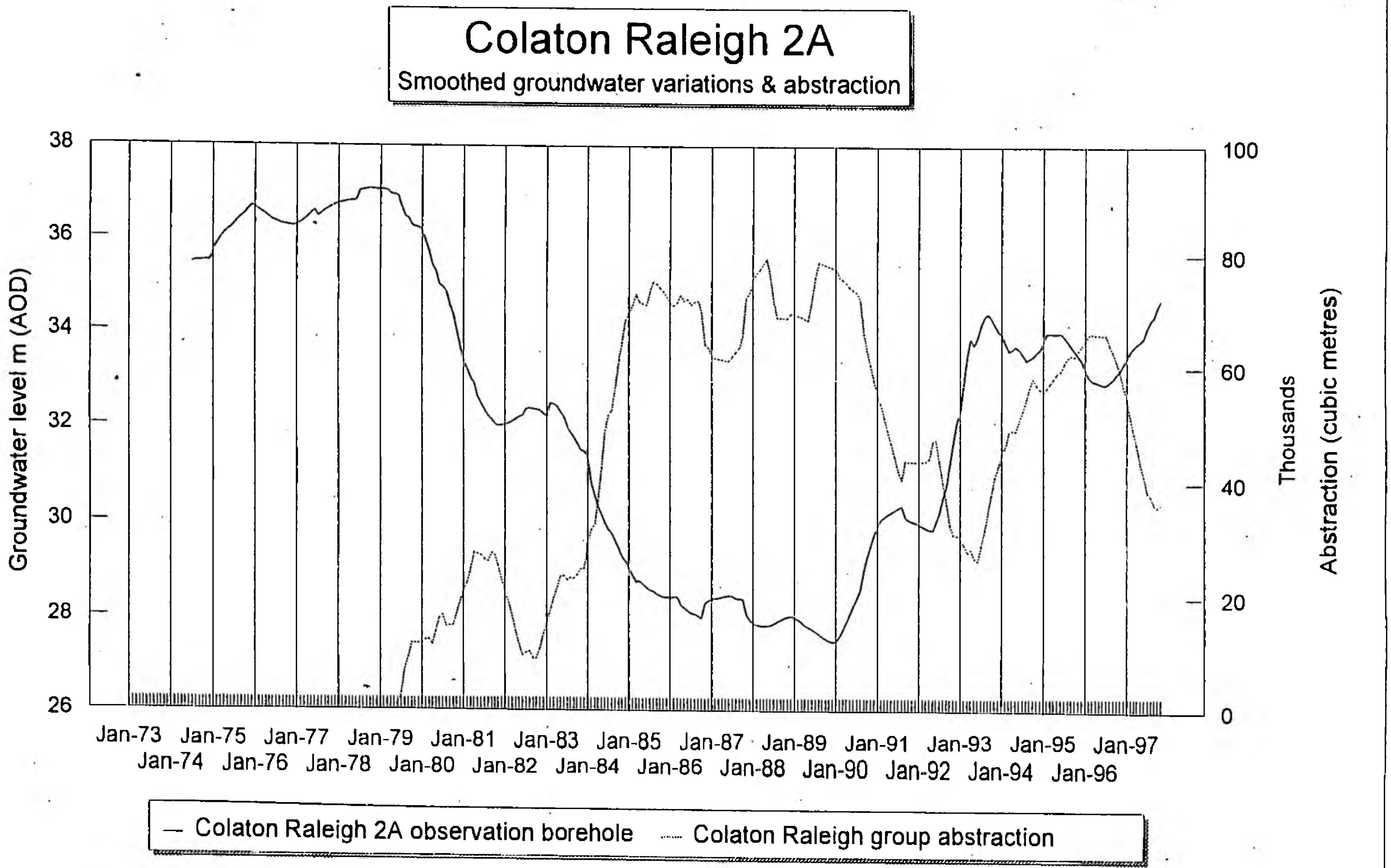
Both these factors restrict the ease with which water moves through the Sandstone aquifer. In fact the water moves with less ease through the Sandstones than in it does through the uncemented and unconfined Pebble Beds (the Pebble beds are uncemented because the percolation of acidic waters from the peaty soils of Woodbury Common dissolved the cement; the soils in the Greatwell area do not give rise to such acidic waters so the cement remains).

Because the water moves more slowly in the Sandstone the Greatwell abstractions draw water from a greater distance (eg 2-3 km) than in case of the Pebble Beds where the Colaton Raleigh abstractions draw water locally (less than 500m). The concept of "cone of depression" can be interpreted as representing the radius of a circle around an abstraction point delineating the area over which the abstraction influences groundwater levels. In a simplistic sense it can be concluded that the Greatwell group cone is larger than the Colaton Raleigh cone due to the surrounding geologies.

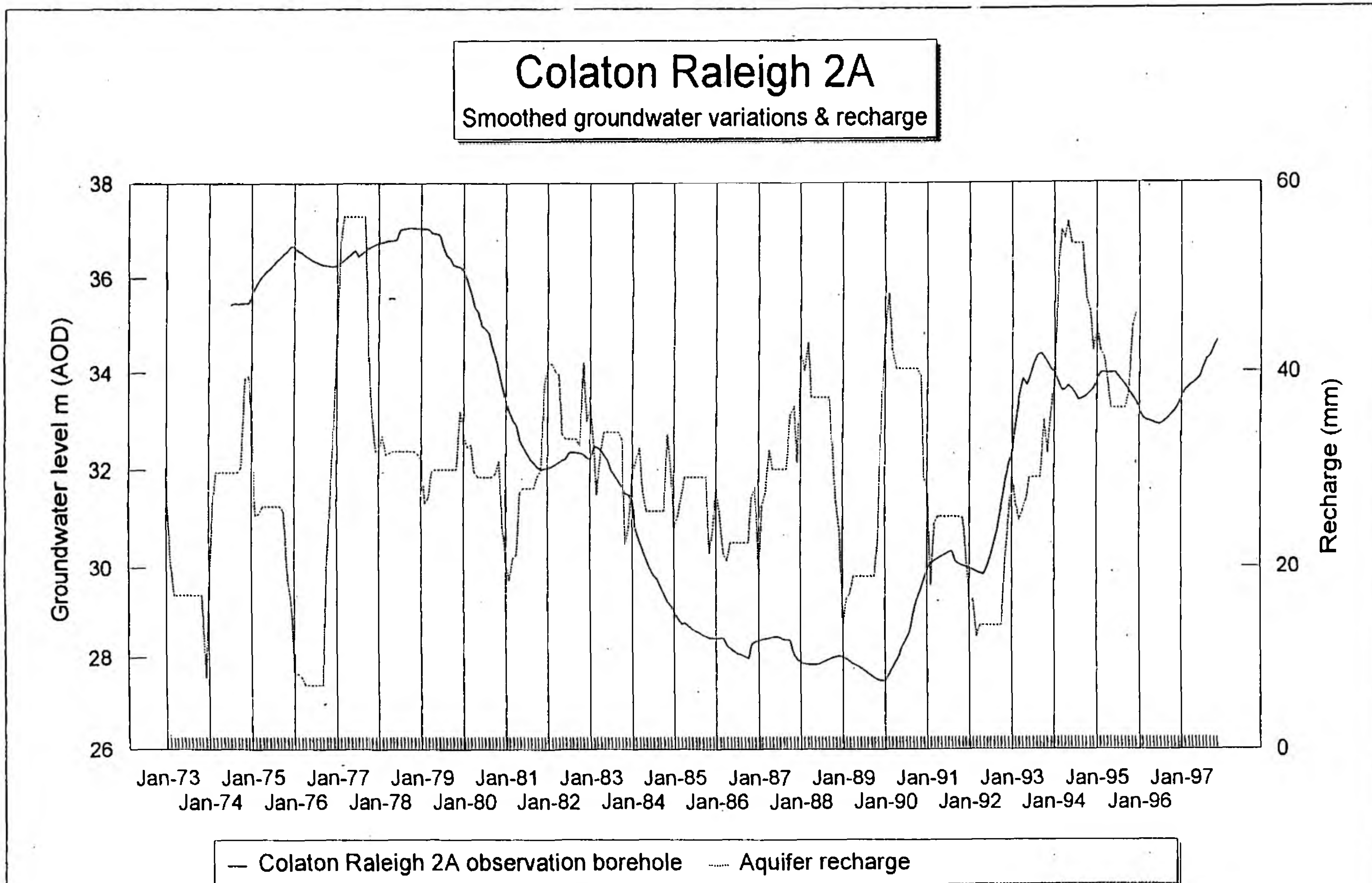
It is worth noting the significance of the reduction in groundwater levels for water resources and the environment. Groundwater levels influence flows and wetlands through the maintenance of spring flows and emergent groundwater flows to the river and surface water system. Where groundwater levels have been reduced then the flows should be expected to be depleted. The Study main report shows that flows have been depleted by historic abstractions but the hydrological and environmental evidence suggests that the flow depletion is insignificant.

Appendix Eight conclusion

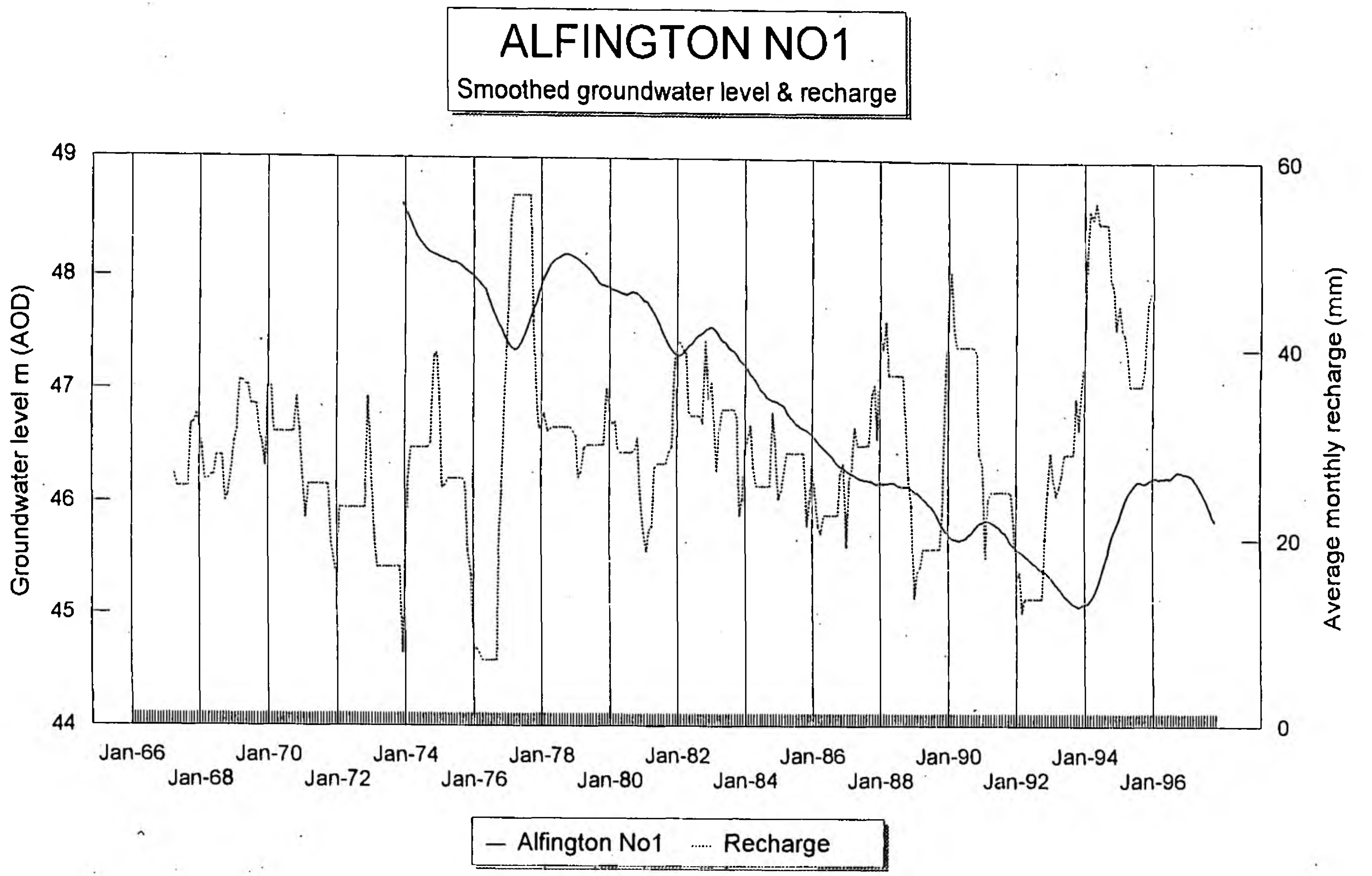
Appendix Eight has illustrated the limitations of the assessment methods suggested by the Steering Group. The limitations of these methods underline the fact that the Otter Groundwater Model is the most appropriate tool to provide quantified flow impact data in relation to SWW's borehole abstractions.



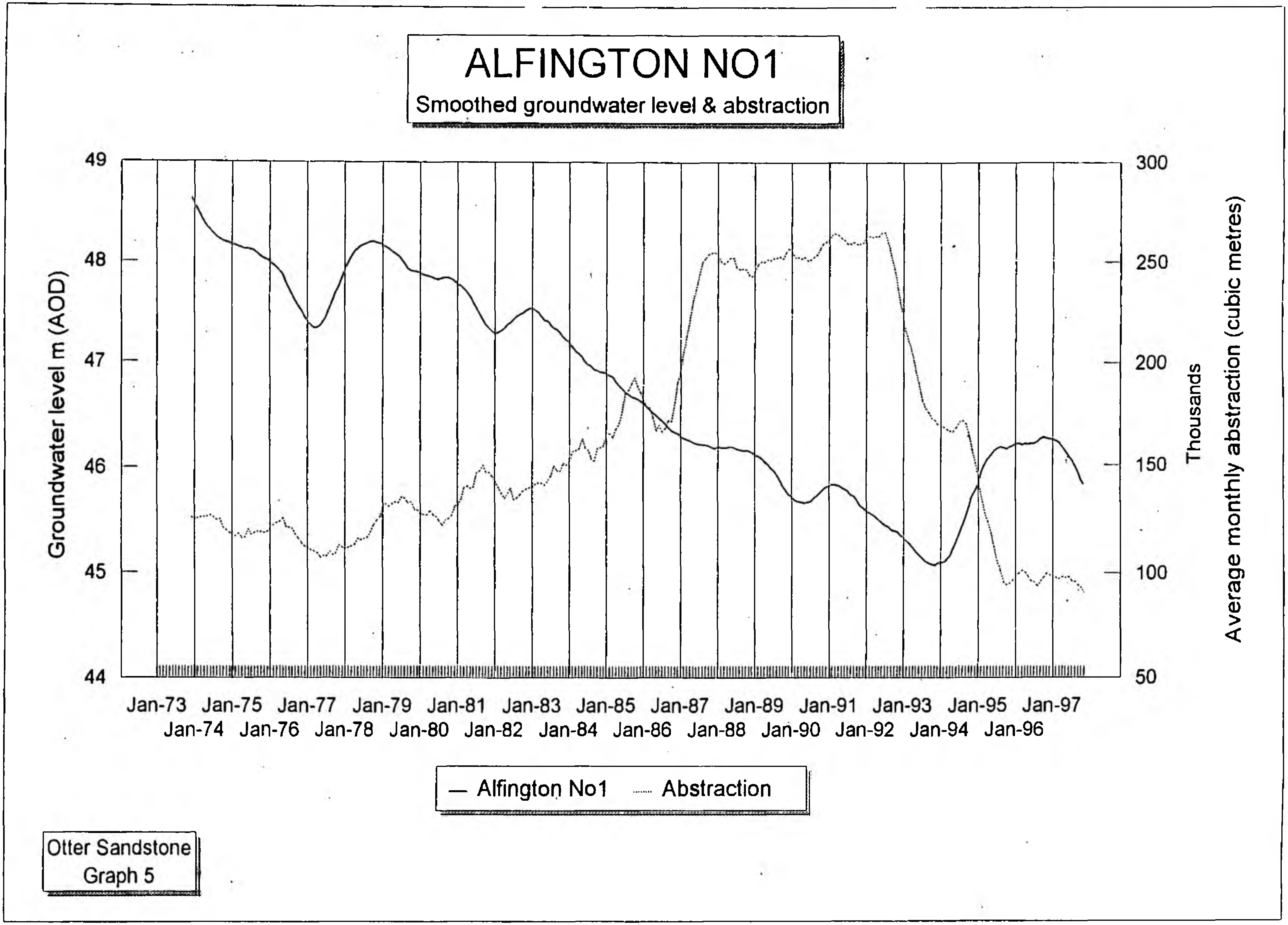
Pebble Beds
Graph 1



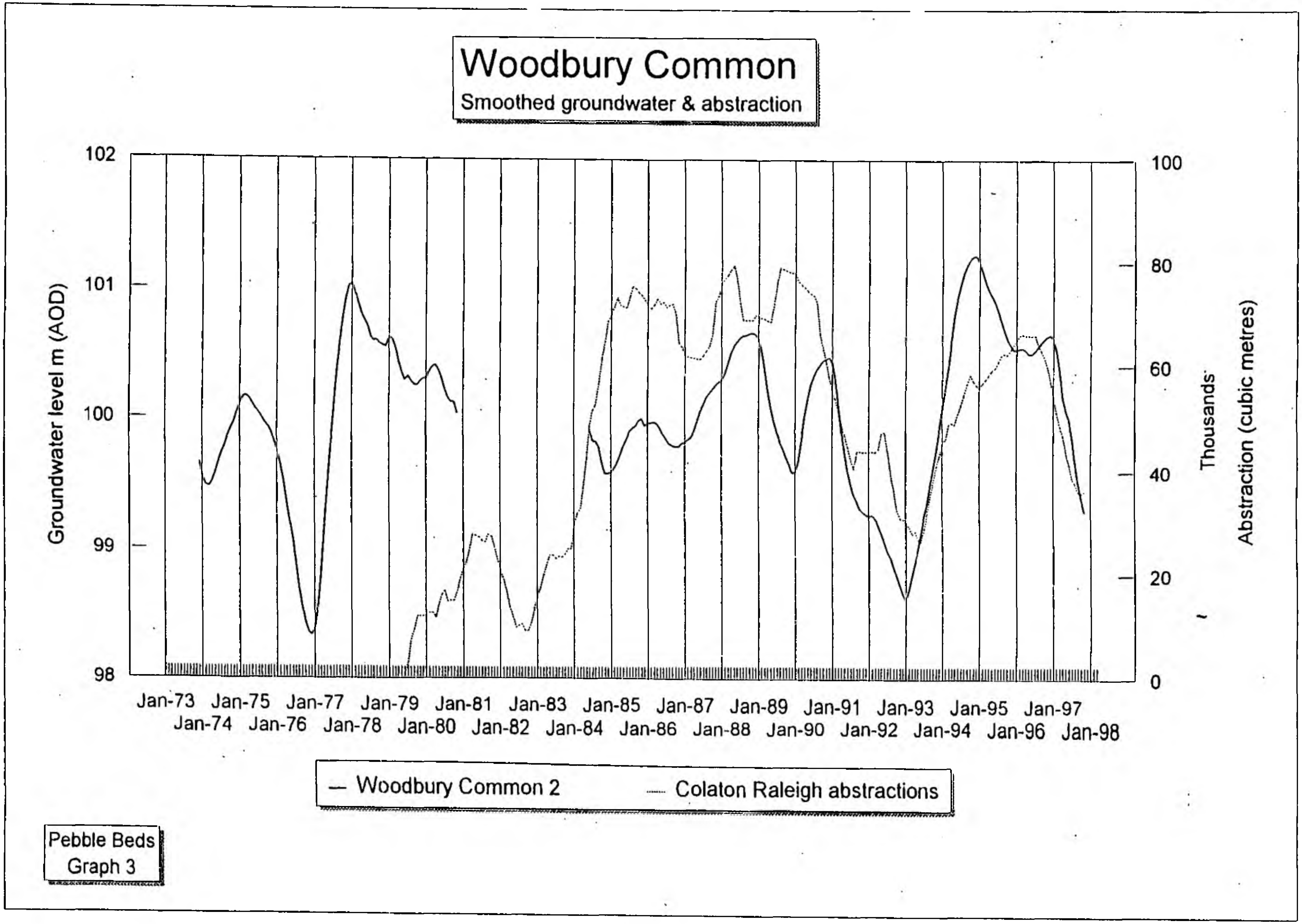
Pebble Beds
Graph 2



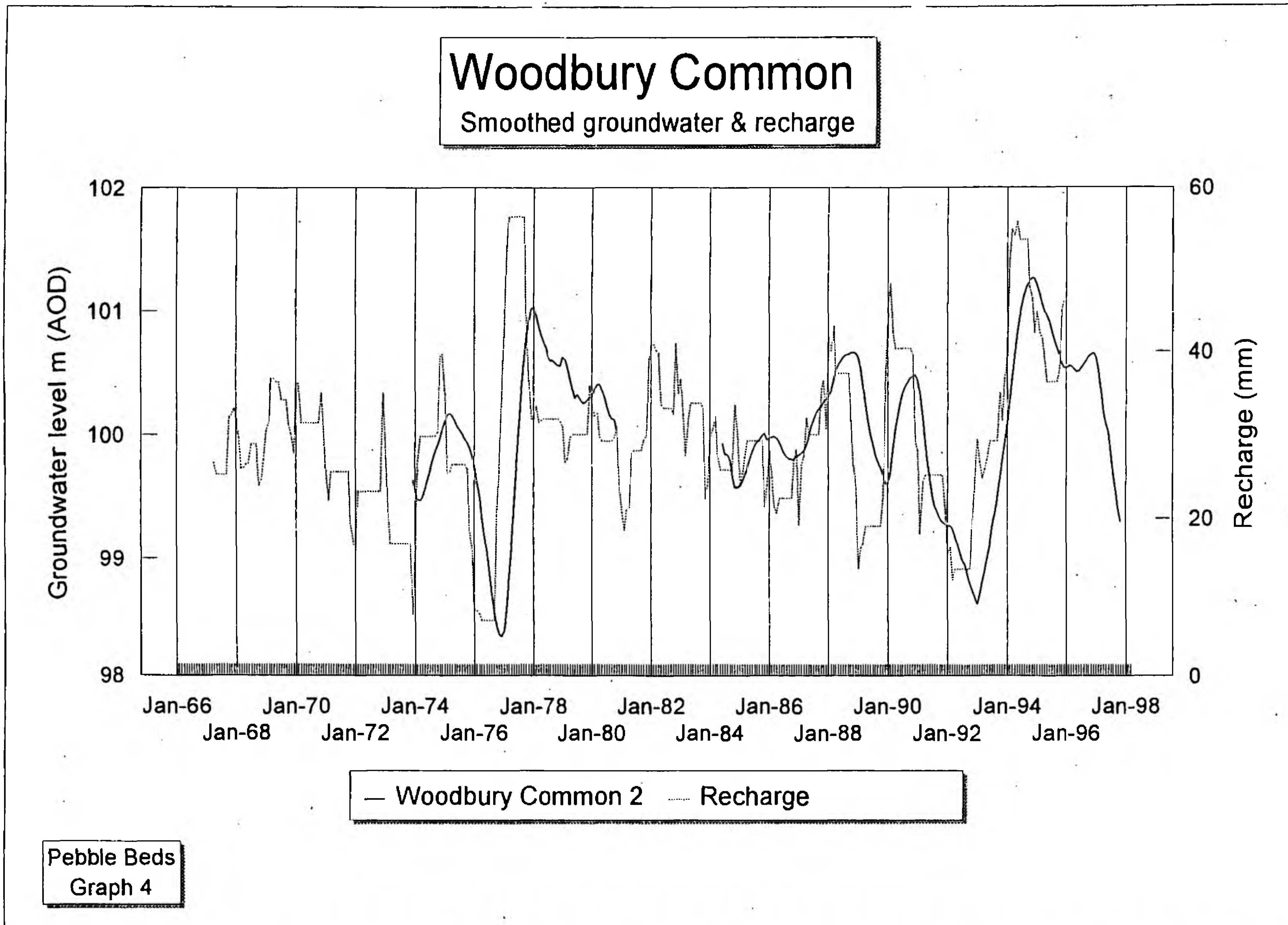
Otter Sandstone
Graph 6



ALFINGTON NO1
Smoothed groundwater level & abstraction
Groundwater level m (AOD)
49
48
47
46
45
44
300
250
200
150
100
50
Thousands
Average monthly abstraction (cubic metres)
Jan-73
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Alfington No1
Abstraction
Otter Sandstone
Graph 5



Woodbury Common
Smoothed groundwater & abstraction
Groundwater level m (AOD)
102
101
100
99
98
Thousands
Abstraction (cubic metres)
100
80
60
40
20
0
Jan-73 Jan-74 Jan-75 Jan-76 Jan-77 Jan-78 Jan-79 Jan-80 Jan-81 Jan-82 Jan-83 Jan-84 Jan-85 Jan-86 Jan-87 Jan-88 Jan-89 Jan-90 Jan-91 Jan-92 Jan-93 Jan-94 Jan-95 Jan-96 Jan-97 Jan-98
Woodbury Common 2
Colaton Raleigh abstractions
Pebble Beds
Graph 3



Woodbury Common
Smoothed groundwater & recharge
Groundwater level m (AOD)
102
101
100
99
98
Recharge (mm)
60
40
20
0
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Woodbury Common 2
Recharge
Pebble Beds
Graph 4

GLOSSARY OF TERMS

ABSTRACTION

Removal of water form surface or groundwater.

AMP

Asset Management Plan (Water Company investment plan).

AQUIFER

A sub-surface zone or formation of rock which contains exploitable resources of groundwater. Aquifers are classed as either major, minor or non-aquifers depending upon the availability of the groundwater sources.

GROUNDWATER

All the water contained in the void spaces in pervious rocks and that held within the soil, mainly derived from surface sources.

HABITAT

A certain type of location in which an organism prefers to live, and characteristic of it.

HYDROGEOLOGY

Branch of geology concerned with water within the earth's crust.

OFWAT

Office of Water Services.

PERMEABILITY

The ease at which liquids (or gases) can pass through rocks or a layer of soil.

WETLANDS

Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water (where depth at low tide does not exceed 6m).