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Environment Agency
Available Resource Methodology Assessments in Catchment Abstraction Management Strategy Trial Areas

Second Draft Report

National Groundwater and Contaminated Land Centre

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Management Strategy Trial Areas

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National Groundwater and Contaminated
Land Centre
14 February 2000

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Statement of use
This document describes the application of a framework for the assessment of acceptable abstraction impacts from an area and water resources sustainability in parallel with the Agency's existing Regional methods as part of Catchment (or 'Local') Abstraction Management Strategy (CAMS or LAMS) implementation trials.
The information within this document is for use by Environment Agency staff and others involved in managing water resources.

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Summary

This report describes the trialling and development of the Available Resource Methodology (ARM) as a Framework to guide the Environment Agency's assessment of water resources and abstraction sustainability.

The Framework starts from a description of the conceptual understanding of the area in question. It then focuses on the estimation and plotting of natural river or groundwater outflows, the artificial impacts which abstractions or discharges have on these, and on comparison with target flows established according to in-river or other environmental or down river needs. Monthly flow comparisons are made in order to represent the seasonal variation in resource availability and abstraction impacts. Wherever possible resources are defined by the natural river flow with an integrated consideration of both surface water and groundwater abstraction impacts on this resource.

For most areas the ARM Framework provides a consistent format for resource assessment which can accommodate a variety of technical approaches (as already used by Agency staff), from first approximations to more sophisticated regional models.

The ARM trials reported were carried out in parallel with other approaches used by Agency Regional teams to assess resource sustainability as part of a national trial of the Catchment Abstraction Management Strategy (CAMS) process. These Regional approaches are also described and compared with each other and with the ARM which appeared to perform well as a Framework.

Following initial trials and comparisons, further development work was carried out to improve the flexibility of the Framework and simplify the spreadsheets which can be optionally used to carry out the assessments.

Data collation requirements for the ARM do not appear to be significantly more onerous than for alternative approaches and should be reduced by other ongoing initiatives such as implementation of the National Abstraction Licensing Database, the development of national standards for flow naturalisation and the updating of microLOWFLOWS. Spreadsheet data entry and analysis of the resource balance for each of the ARM assessment areas is expected to take an experienced user between one and three days depending on how critical the balance is. More time and wider consultation may be required to establish appropriate target flows and to define and represent the initial conceptual understanding.

The ARM Framework shows promise as a consistent tool to support the CAMS process and it is recommended that it be concisely reported and reviewed nationally by the Agency for this purpose.

Glossary

TERM/ABBREVIATION	DEFINED AS:
Abstraction	Removal of water from a source of supply (surface or groundwater).
Acceptable Abstraction Impacts	The abstraction impacts which are considered acceptable given target outflows in the specified year. = Natural Outflows – Target Outflows, or = (Surplus or Deficit) + Existing Abstraction Impacts.
ARF	The analytical 'Aquifer Response Function' which can be used to derive the groundwater outflow or 'baseflow' response to recharge.
ARM Framework	Available Resource Methodology Framework.
(C)AMS or (L)AMS	(Catchment) or (Local) Abstraction Management Strategy.
Artificial Impacts	Combined impacts of consumptive abstraction and discharge on outflows from the assessment area.
Assessment Area	The area to which the assessment applies, defined in the ARM Framework according to its outflow e.g. surface catchment and associated groundwater catchment to a river gauge, or groundwater catchment to coastal discharge boundary.
BFI	Base Flow Index as defined by the Institute of Hydrology baseflow separation from a daily average river flow hydrograph.
Consumptive abstraction	Proportion of the abstracted water which is not returned to the environment close to the point of abstraction i.e. water evaporated or transferred elsewhere.
De-naturalisation	Process of converting a natural outflow to an estimated existing or scenario outflow by adding consumptive abstraction and discharge impacts.
Discharge	Release of water returned to river within the Assessment Area.
Existing Abstraction and Discharge Impacts	The amount by which all the abstractions in the area reduced natural outflows from it, taking into account the consumptiveness of the use, the location of any effluent return and any lags or smoothing between abstraction and outflow impact. Based on estimated actual abstraction rates.
Existing Outflows	The flows which actually left the Assessment Area in the specified year.
Groundwater Catchment	The area from which recharge to the aquifer would naturally discharge to a defined point of a river, or over a defined discharge boundary.
GW	Groundwater.
GWABS	Groundwater Abstraction.
Hydrological Scenario	**The hydrological scenario being used to assess resource availability. Maybe a specified year or drought return period or simulated scenario.**
IGARF	'Impact of Groundwater Abstractions on River Flows' R&D Project managed by NGCLC.
IoH	Institute of Hydrology.
Maximum % Abstraction Impact	An indicator of the maximum abstraction impacts relative to natural outflows in the specified year. $= \frac{\text{Abstraction Impact}}{\text{Natural Outflow}} \times 100$

TERM/ABBREVIATION	DEFINED AS:
Ml/d	Megalitres per day.
Natural Outflows	The flows which would naturally leave the Assessment Area in the specified year in the absence of any artificial impacts.
Naturalisation	Process of converting gauged flows to natural flows by removing consumptive abstraction and discharge impacts.
NGCLC	The Environment Agency's National Centre for Contaminated Land and Groundwater.
Q95	Flow exceeded during 95% of period over which flow data are being considered.
S	Aquifer storage.
Scenario Abstraction and Discharge Impacts	The amount by which all the abstractions in the area reduced natural outflows from it, taking into account the consumptiveness of the use, the location of any effluent return and any lags or smoothing between abstraction and outflow impact. Based on an assumed abstraction and discharge scenario (e.g. full licensed rate, deployable output etc).
Specified Year	The year chosen to assess monthly flows and target flow implications e.g. a recent drought year of a known return period.
Surface Water Catchment	The area from which runoff would naturally discharge to a defined point of a river, or over a defined boundary.
Surplus or Deficit	How much more or how much less abstraction impact is acceptable in the specified year on a monthly or annual basis. = Existing Outflows – Target Outflows. Can be expressed as a % of the Natural Outflows and summarised as annual minimum and average values.
SW	Surface Water.
SWABS	Surface Water Abstraction.
SWALP	Surface Water Abstraction Licensing Procedure.
SWDIS	Surface Water Discharges.
T	Aquifer transmissivity.
Target Outflows	The minimum outflows from the area required to protect downstream environmental objectives and protected rights e.g. in-river flow needs based on downstream abstractors or ecological criteria, or groundwater flow to prevent saline intrusion. In the ARM Framework this is expressed as 12 monthly average flows, optionally based on a defined minimum monthly flow plus a % of the natural flows above this minimum.
Trialling	Application of a proposed methodology to an Assessment Area as part of its testing and development.
Utilisation	Proportion of licensed entitlement that is actually abstracted (sometimes referred to as 'uptake').

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1. Introduction

1.1 Background to CAMS and the ARM

During July and August 1999 the Environment Agency started to trial the process for developing Catchment Abstraction Management Strategies (CAMS - initially referred to as Local Abstraction Management Strategies or LAMS) in four areas across England and Wales. CAMS will be developed within a nationally consistent framework and in consultation with the public and local stakeholders to present the Agency's vision for the sustainable management of water resources within a catchment in an open manner. An important first step within the CAMS process is to identify the water resources balance components of the area as currently managed and to determine the sustainability status of this abstraction management. Although these Agency's CAMS will be produced to a consistent format within a nationally defined framework, approaches to the calculation and presentation of the existing resource balance, and to the determination of sustainability status, currently differ between the Regions.

The Available Resource Methodology (ARM) is currently under development within the R&D programme of the Environment Agency's National Centre for Groundwater and Contaminated Land (NGCLC). The ARM is a Framework for the assessment of abstraction management sustainability. It can be implemented through a spreadsheet tool which graphically presents natural and anthropogenic components of the water resources balance for an area and which then investigates abstraction management sustainability, by calculating monthly surpluses or deficits based on target flows defined by the user. The ARM was initially intended to provide a nationally consistent framework for resource sustainability assessments in groundwater dominated areas. Preliminary development trials suggested that some elements of the ARM, in association with Agency best practice guidelines for gauged flow naturalisation, might also be applicable to gauged river catchments with relatively minor groundwater components.

The Agency therefore decided to investigate whether application of the ARM in its existing form, or following further development, might play some role in the CAMS development process. Entec were commissioned to apply the ARM within each of the four CAMS trial areas following initial consultation and data collation carried out with Agency staff. These trial areas include groundwater and surface water dominated catchments.

The results of these trials were presented in the first draft of this report in August 1999. During subsequent months, through individual consultation with Agency staff and a day long workshop, the ARM Framework and its results have been compared with the approaches adopted by the Regions to develop their own resource sustainability assessments for CAMS. Further improvements have been made to the Framework and its optional spreadsheet implementation in the light of this comparison to make it more appropriate and acceptable to a wider range of users. This Second Draft Report presents the original ARM Framework and trials (as reported in August) together with the results of its comparison with Regional approaches, an account of the subsequent improvements and conclusions regarding its applicability within the CAMS process. Recommendations for the presentation of the ARM Framework and for user guidance are also made.

1.2 Terms of Reference

The study objectives as laid out in the Terms of Reference provided by the Agency (letter reference NC/ARMAMS/sk, dated 29 June 1999) are as follows:

- To trial the ARM in parallel with Agency trials of CAMS on four pre-determined catchments in England & Wales.
- To compare and contrast the process and results of the ARM with other existing regional water resources methodologies that will be applied (by the Agency) in each of the four CAMS catchment trials.
- To report on the practical implications for future CAMS work in adopting either existing regional water resource assessment methodologies or the new ARM. Including the limitations of each approach and the respective data requirements and training needs.

The four CAMS trial areas are:

- the River Ribble catchment in North West Region (surface water dominated - including minor aquifers and part of the drift covered Fylde sandstone aquifer).
- the River Teifi catchment in Wales (surface water dominated - including minor drift aquifers only).
- the Little Ouse groundwater unit in Anglian Region (chalk groundwater dominated but with significant surface runoff from drift cover).
- the River Otter catchment in South West Region (including surface water dominated headwaters and sandstone groundwater dominated lower reaches).

The original brief was extended by the Agency's approval (letter reference NC/99/68/SK dated 17 November 1999) of Entec's proposals (letter 02019C070/RWNS/tsjm dated 5 November 1999) to carry out further development of the ARM Framework and spreadsheets with application to part of the Anglian Region trial area.

It is important to note that the emphasis throughout the trials has been to assess the appropriateness/applicability of the various methodologies and approaches, rather than to spend time ensuring that the input data streams are entirely reliable and up to date. In all the Regions collation of abstraction and other data sets has been streamlined in an attempt to mirror the inputs used for the CAMS trials and to minimise extra demands on Agency staff time.

1.3 Contents of This Second Draft Report

The work carried out to date is summarised in the following sections of this Second Draft report:

Section 2 - ARM Overview for Initial CAMS Trials
Includes a summary of the ARM Framework and spreadsheets as they stood in August 1999. Outlines how monthly surpluses and deficits are calculated and how these can be interpreted to assess abstraction sustainability. Includes a brief description of the modifications which were

made to the ARM during the initial trial process (as previously reported in the First Draft Report).

Section 3 - ARM Initial CAMS Trial Descriptions and Results
Describes how the ARM was initially applied to each of the CAMS trial areas and presents/discusses the results as sketch plans, graphical and tabulated output.

Section 4 - Comparison of the ARM Initial Trials and Regional CAMS Approaches
Briefly summarises the approaches adopted by Regional Agency staff to assess water resource sustainability as part of their own CAMS trials. Compares these with the ARM framework

Section 5 - Further Development and Trialling of the ARM Framework in Anglian Region
Describes the further changes made to the presentation of the ARM as a framework in the light of further consultation with Agency staff. Presents the modifications made to the spreadsheets to make them more flexible and simpler to use. A trial catchment from Anglian Region is presented in the revised format to illustrate these improvements.

Section 6 - Conclusions: Applicability of the ARM within the CAMS Process
Discusses the appropriateness of using the ARM framework for sustainability assessment in the CAMS process and the implications to the Agency of adopting it for this purpose in terms of its data and staff time requirements, and in the light of existing Regional practice. Section 6 also outlines the further Agency consultation which will be required to determine whether or not use of the ARM framework should be promoted in the CAMS process and suggests ways of ensuring it is effectively taken up and appropriately applied.

Section 7 - Recommendations
As with any R&D activity, the ARM framework has evolved significantly from its original conception through a process of intensive trialling and consultation. As a result, the ARM framework described in this report differs from that for which a Draft Report and User Manual were originally prepared in May 1999. Even within this Second Draft report, the framework described in Sections 5 and 6 has been improved beyond that used for the initial CAMS trials described in Sections 2 and 3. To avoid confusion there is a clear need to consolidate the research and present the ARM framework and spreadsheets in as coherent and concise a manner as possible. Section 7 briefly summarises how this should be done.

2. ARM Overview for Initial CAMS Trials

2.1 Development of the ARM to August 1999

The original evolution of the Available Resource Methodology and the rationale behind its specification are summarised in a Report, User Manual and Project Record which was circulated to all the Regions in Draft form in May 1999 as part of the National Groundwater and Contaminated Land Centre's R&D programme. Comments on this Draft were collated and drove a number of modifications to the method as it was initially applied in the CAMS trial areas, together with developments made during the trial process itself to August 1999. Developments incorporated into the version of the ARM Framework summarised in this Section and used for the trials described in Section 3 are as follows:

- increased emphasis on simple monthly plots of water resource components based on naturalisation of gauged flows to avoid dependence on rainfall - runoff modelling where possible.
- recommendation to assess long term average (LTA) monthly balances first before considering resources in specific years (e.g. drought years) to facilitate comparison between assessment areas and to simplify issues which may dominate specific years (e.g. reservoir or aquifer storage changes).
- incorporating the option of defining target river flows in terms of a monthly minimum (or 'hands-off' flow - HOF) and a percentage 'take' of natural monthly flows in excess of this minimum which it is considered acceptable to abstract. This approach is similar to that advocated by the Surface Water Abstraction Licensing Procedure (SWALP) and, by relation to the estimated natural flows during the assessment year, may be more reasonable for rivers than setting monthly targets that are fixed for all years.

It is important to note that after these initial trials further changes were made to the presentation of the Framework and to its spreadsheet implementation, as described in Section 5. Recommendations for final simplified documentation of the Framework are made in Section 6.

2.2 August 1999 ARM Framework and Spreadsheets Overview

Figure 2.1 provides an overview of the ARM which is intended to provide a framework for assessment of water resources sustainability implemented within Excel spreadsheets. All assessments start with the delineation of the assessment area - both groundwater and surface water catchments - and a simple qualitative description of the user's conceptual understanding of the specific combination of hydrological processes and artificial influences that determine the water resources issues of the area.

Thereafter the user enters average monthly flow balance components into 12 cells on the spreadsheet, including river flows into and out of the area and the impacts on these flows of surface water abstractions and discharges and groundwater abstractions. The ARM does not prescribe how this flow naturalisation or denaturalisation should be carried out but the spreadsheets provide a simple and convenient way to plot the monthly variation in resource balance and provide an understanding of the relative magnitude of the various components.

The user then sets target flows from the area which may be based on a wide range of factors and on extensive consultation. By comparison with existing outflows, the spreadsheets calculate a monthly surplus or deficit profile for the assessment year. These profiles indicate how much more of the river flow can be abstracted or the flow recovery required to meet target flows and maintain an acceptable degree of sustainability.

Several years may be assessed including a long term average and specific drought years, with the impacts of abstractions being considered either 'as licensed' (i.e. maximum potential) or as 'estimated actual'. A sustainability status can then be assigned based on interpretation of the surplus or deficit profiles derived, and their associated uncertainties.

Where possible the ARM assessment should be based around the naturalisation of gauged river flows, with an optional check against effective rainfall derived natural river flow estimates. Where no flow data exist, natural outflows are first estimated by considering effective rainfall and catchment/aquifer response characteristics, followed by de-naturalisation to estimate existing outflows. Once again the ARM does not prescribe how the rainfall-runoff modelling should be carried out although a simple analytical model to derive monthly natural outflows is provided within the spreadsheets which has been developed for groundwater dominated areas.

It is important to note that the sustainability status conclusions derived from an ARM assessment apply to the area assessed as a whole - they provide strategic ceiling values for the area to prevent progressive environmental derogation. Detailed consideration of the local impacts of abstraction on particular river reaches or wetlands etc. within the area will always remain as an essential part of licensing procedure.

The following sub-sections provide brief discussion of each element within this ARM framework as used for the trials described in Section 3 (and previously reported in August 1999).

Italicised notes indicate elements which have been the subject of subsequent development described in Section 5.

2.3 Assessment Area Delineation

The first step of any water resources assessment is to define the area for which it applies. The type of area selected and the conceptual understanding of this area ultimately governs the spreadsheet used for the assessment (see Figure 2.1) and hence considerable care is required in delineating the assessment area.

In August 1999, three types of spreadsheets were available as part of the ARM assessment framework:

- *Gauged River* **Spreadsheet.** Area defined as the surface water catchment to a river gauging station where daily flow data are available for the specified year plus the associated groundwater catchment to this point of river. Where there is more than one gauging station on a river, the assessment can be carried out either for the whole catchment upstream of a gauge, or for parts of the catchment which drain to the river reach between two gauging stations.

- *Ungauged River* **Spreadsheet.** Area defined as the surface water catchment plus associated groundwater catchment to an ungauged point of the river. If there is an upstream gauge this can be used to define river inflows for an assessment of part of the surface and groundwater catchments.

- *GW Outflow* **Spreadsheet.** Area defined as the groundwater catchment to a groundwater outflow boundary which may be the coastline, an estuary, or even a river where groundwater dominates and consideration of surface water flows and abstractions is considered unnecessary.

If the principal environmental concern is to protect river flows then the Assessment Area should naturally drain entirely to a defined point of river at which existing and target river flows are available. This approach is consistent with the Framework Directive definitions of 'groundwater bodies' or catchments which are associated with surface water catchments.

Groundwater catchments should be drawn in the light of present-day groundwater contour information but also should represent a best estimate of the *natural* (i.e. pre-abstraction) catchment. This interpretive step is important for gauged rivers as the groundwater catchment drawn will define the borehole sources which are considered to impact gauged flows.

Where possible the use of gauged river flow data is encouraged. For these CAMS trials this means that many of the assessed areas are delineated as catchments to or between flow gauging stations (e.g. trials for the Rivers Ribble, Thet, Little Ouse, Otter and Teifi).

If more than one gauging station exists the need to consider different parts of a catchment separately will depend on the level of assessment and the degree to which in-river flow needs vary down the river. For rapid regional consideration, the whole catchment to the lowest river gauge may be used. Alternatively, particular environmental flow sensitivities may warrant separate assessments for a river's headwaters, or along a particular reach over an aquifer between gauging stations (e.g. sub-area assessments of the River Otter catchment). Where a catchment is to be sub-divided in this way, flow targets should only be set once an understanding of the interdependence of each sub-catchment has been achieved.

Where there are no rivers or if groundwater flows and abstraction dominate then the assessment can be simplified to focus on groundwater outflows only (e.g. the Fylde Aquifer). In this case the Assessment Area is defined as the natural groundwater catchment to the outflow boundary, surface runoff is assumed to be lost and is not part of the resources accounted for, and river abstractions or discharges are ignored. Although relatively simple, such groundwater outflow assessments are always likely to be associated with a high degree of uncertainty, in comparison with river flow based assessments, because direct measurement or even observation of actual groundwater flows is not possible.

*Further simplification following the initial trials has reduced the spreadsheet options to two - **River** or **GW Outflow** and has ensured that river outflow assessments are always carried out for whole catchments (see Section 5).*

2.4 Conceptual Understanding

Having delineated the assessment area and selected the relevant workbook users are then required to formalise their conceptual understanding of the catchment by completing the first spreadsheet page which is common to each workbook. The aims of this sheet are to:

- delineate the Assessment Area and present a simple, qualitative conceptual understanding of its natural hydrological cycle, the relative significance of groundwater and surface water and interactions between them;
- describe the anthropogenic impacts on flows, the assumed historical shifts in water balance components and the environmental issues which are currently perceived to be most significant;
- draw a sketch plan and, if appropriate, a schematic cross-section of the Assessment Area.

2.5 Assessment Years

Headline results produced by the ARM include estimated monthly surplus/deficits and acceptable abstraction impacts for a specified assessment year. For all the CAMS study areas, assessments were carried out using input data for the following years:

- a long term average year (based on LTA flows for January, February, etc);
- a drought year (as specified by Agency staff in the Region).

For the Ribble, Otter and Teifi catchment areas a third assessment was also carried out using input data for a 'climatically typical' year.

The LTA assessments require that average monthly river flows, effective rainfall, abstractions etc. are derived over a long period of time. In order to facilitate comparison between assessments the same time period should ideally be adopted. An important factor in the choice of period is often the availability of gauged river flow data. In most of CAMS trial areas the LTA period 1980 to 1996 or 1998 was adopted because data for some gauges are not available before 1980. For the Rivers Thet and Little Ouse data from 1970 to 1992 were employed because Anglian Region's in-house CAMS trial used data collated in 1993.

Beyond the LTA assessments, the value of considering specific years lies in the possibility of comparing the impacts of licensed, actual or newly proposed abstractions and the implications of target flows against the resources available in historical droughts. Consideration of specific years also avoids the seasonal smoothing which results from the averaging required for the LTA assessments (both low and high flows become less marked). However, many of the assumptions made for the LTA assessments in terms of groundwater catchment areas and the impact of groundwater abstractions or surface reservoirs on river flows may not be valid and the interpretation of results may be less straightforward. Also, failure to achieve target flows in all drought years may not necessarily imply that the abstraction management is unsustainable – flow failure at infrequent intervals may be considered acceptable.

Following the initial trials it has been recognised that a simulated 'hydrological scenario' could be specified for assessment if this is more appropriate than the selection of a particular historical year (see Section 5).

2.6 Calculation of Monthly Surpluses or Deficits

The next stage in the ARM process is the calculation of monthly surpluses or deficits for the specified assessment year. The details of this calculation are dependent on the type of area for which the assessment is being undertaken (see Figure 2.1).

2.6.1 Gauged River Catchment Assessments

For gauged river catchments the user is required to enter gauged monthly river flows, and the estimated impacts of groundwater and surface water abstractions and surface water discharges within the assessment area on these river flows. These data are used to derive a flow series naturalised from the impacts of consumptive abstraction within the assessment area.

Following the initial trials it has been recognised that the estimated actual abstraction and discharge impacts used to naturalise gauged river flows should be entered separately from the abstraction and discharge impacts associated with the management scenario being assessed (which may, for example, be based on fully licensed or deployable output rates etc) -see Section 5.

Having estimated the naturalised river outflow from the assessment area target river flows are set. One option for this step is to use an approach comparable with the SWALP concept. The user is required to specify a minimum monthly flow (equivalent to the SWALP daily Hands Off Flow (HOF)) and a monthly % TAKE which limits how much of the naturalised flow above the monthly HOF can be abstracted. This approach protects flow variability (unless TAKE is set to 100%) and ensures that targets flows are related to flows which would be anticipated naturally for the assessment year.

The HOF and %TAKE values can be varied according to the perceived in-river flow needs of the assessment area and any downstream catchments. Determination of these target flows may therefore require an appreciation of eco-hydrological, navigational, abstraction, amenity, effluent dilution or other water quality needs. It may also requires an appreciation of river flow needs to satisfy downstream abstraction or dilution requirements. As for other calculation steps such as flow naturalisation the ARM does not prescribe how these values should be determined – it provides a framework for investigating the implications of the adopted targets in terms of the sustainability status of the area.

Following the initial trials it has been recognised that the terms 'HOF' and '%TAKE' should be avoided within the ARM as they may be confused with their use for daily flows in SWALP. The terms 'monthly minimum flow' and 'extra monthly acceptable impact %' are recommended as alternatives (see Section 5).

Comparison of the existing flow series with the target river flows enables surplus/deficits to be calculated for each month of the specified assessment year (see Figure 2.2). Throughout this spreadsheet (and the other spreadsheets) the user is expected to provide auditable references to the source of the data sets entered and to summarise any key assumptions made in external calculations. Each data set also has an associated confidence level expressed as +/- x % which is multiplied by the annual average flow to derive an indication of uncertainty which can be accumulated through the calculations and reflected in the final surplus or deficit profiles (Figure 2.2).

The final calculation step for gauged catchments is an optional comparison of naturalised gauged river flows with a natural flow series derived from effective rainfall and assumptions regarding the catchment and aquifer runoff and baseflow responses. Although not essential in the determination of the water resource balance and sustainability, this simple attempt to reconcile monthly rainfall inputs with river flow and other outputs may help to develop the user's conceptual understanding of the assessment area.

Subsequent development has replaced this 'water balance' check with a simpler, more flexible approach whereby the user can optionally compare and reconcile up to four different estimates of natural river outflow (e.g. naturalised gauge flows, regional model output, microLOWFLOWS etc) at the beginning of the calculation before selecting one to carry forward (see Section 5).

2.6.2 Ungauged River Catchment Assessments

For ungauged river catchments the first calculation step is to estimate natural monthly river flows from effective rainfall data by using external rainfall – runoff software (such as microLOWFLOWS) or using the simple analytical model (the Aquifer Response Function) provided within the spreadsheet. These flows are then de-naturalised to provide an estimate of existing river flows using surface water abstraction and discharge data and the estimated impacts of groundwater abstraction.

Target river flows are set in the same way as for gauged river assessments which in turn allow the implied surplus and deficit profile to be derived.

Subsequent development has replaced these 'Gauged' and 'Ungauged' river workbooks with a single 'River outflow' workbook. The user can also optionally split the total river flow resource into groundwater baseflow and surface runoff components although target flows and surplus/deficit profiles only apply to the total flows (see Section 5).

2.6.3 Groundwater Unit Assessments

Unlike the river flow focused assessments, Groundwater unit assessments do not consider the impacts or sustainability implications of surface water abstractions or discharges. For groundwater units the assessments start by estimating the natural groundwater outflows from the unit before considering the impacts of existing groundwater abstraction on these outflows and the target outflows required (e.g. to prevent saline intrusion).

Natural groundwater outflows can be estimated in the spreadsheet from monthly effective rainfall data by entering assumptions with regards to:

- the groundwater catchment area receiving recharge;
- the proportion of the effective rainfall which becomes recharge;

- the aquifer hydraulic properties transmissivity and storage, and the length of the boundary over which discharge is assumed to occur. These three parameters are combined in the analytical Aquifer Response Function which determines the GW outflow response to the recharge inputs.

These estimated natural outflows are then de-naturalised using groundwater abstraction data and by making further user-dependent assumptions as to the overall magnitude and timing of the impact of these abstractions on the outflows.

Target groundwater outflows are set by the user using any available information. Since groundwater outflows cannot be directly measured, outflow targets are typically a 'best guess' based on groundwater level and, in the case of coastal saline intrusion risks, water quality monitoring data. Both existing and target groundwater flows, and the monthly groundwater surplus/deficit profiles derived from these, are therefore likely to have a relatively high level of associated uncertainty.

Subsequent development has provided the user with more flexibility for the initial calculation of natural groundwater outflows (e.g. based on baseflow separation, groundwater model output or the Aquifer Response Function) (see Section 5).

2.7 ARM Outputs

Principal outputs from the ARM for gauged and ungauged river catchment spreadsheets (for any LTA or specific year assessment) are:

- stacked histogram plots of the monthly flow balance components (gauged river inflows, gauged or estimated outflows, surface water abstraction and discharges and groundwater abstraction impacts) expressed in Ml/d. This is a useful plot to illustrate the relative magnitude of the components and therefore the time and effort justified to improve understanding and management of these components. It also shows the degree to which outflows from the area are supported by inflows from any upstream catchment or by effluent discharges within it;

- the same data, excluding any gauged inflows, plotted as a stacked histogram but expressed as mm/month spread over the surface water catchment area assessed. This plot represents the amount of effective rainfall falling onto the assessment area (combined surface water and groundwater catchments) plus any extra surface water discharges within it and illustrates the extent to which this resource is committed. If plotted against a fixed scale comparison of the LTA version of this plot between gauged catchments can highlight variations in effective rainfall or in the groundwater catchment area draining to the river, as well as in the extent of anthropogenic impacts;

- the maximum monthly consumptive abstraction impact from these histograms, expressed as a percentage of the natural outflow;

- histograms comparing the target river outflows (defined by the user) with existing inflows and outflows;

- uncertainty (box and whisker) plots of the monthly surplus or deficit profile and annual summaries of this profile including minimum and average values and the average value expressed as a percentage of the estimated natural outflow.

In addition the spreadsheets calculate monthly 'acceptable abstraction impacts', defined as the difference between natural and target outflows (or derived by adding the surplus or deficit to the existing consumptive abstraction impact).

Comparable output is also generated by the ARM spreadsheet for groundwater units although the stacked histogram plots focus on groundwater outflows and abstraction impacts only. The surplus and deficit profiles also only relate to groundwater resource sustainability – surface water flows and resources are ignored.

Following the initial trials ARM spreadsheet output has been refined to more directly address the requirements of the CAMS process (see Section 5).

2.8 Interpreting Abstraction Sustainability

In the CAMS process a sustainability status is assigned to the assessment area according to the resource surplus or deficit which can be based on an interpretation of the ARM spreadsheet output described above. This status might then be summarised as a coloured area or point on a map.

In the initial CAMS trials we have not assigned a sustainability status although this could be readily achieved according to the national guidelines which we understand that the Agency is considering based on the surplus/deficit profiles illustrated in Figure 2.2 and annual summary figures described above. We understand that a fivefold classification is under consideration as follows:

- *Lightly to moderately committed*: Annual average resource surplus exceeds 30 % of the natural outflow (i.e. the total resource) from an assessment based on fully licensed abstraction rates.

- *Significantly committed*: Annual average resource surplus is between 10 % to 30 % of the natural outflow (i.e. the total resource) from an assessment based on fully licensed abstraction rates.

- *Essentially fully committed*: Annual average resource surplus exists but is less than 10 % of the natural outflow (i.e. the total resource) from an assessment based on fully licensed abstraction rates.

- *Over-committed*: Annual average resource deficit exists based on fully licensed abstraction rates but actual abstractions returns and licence utilisation data, together with monitored river flows, groundwater levels and quality observations suggest that actual abstraction is sustainable.

- *Over-developed*: Annual average resource deficit exists based on consumptive impacts of estimated actual abstractions. Assessment areas within this sustainability category may be showing some symptoms of stress (e.g. river low flows, wetland derogation, falling groundwater levels, advancing saline intrusion etc).

At this stage we are, however, uncertain as to which assessment year should be considered (drought/severe drought/LTA?) for the determination of sustainability status. It is also evident that in many cases resource deficits may exist during the summer between periods of large surplus in the winter. In the trial results presented in Section 3, no attempt has therefore been made to assign a single sustainability status to the assessment areas.

Following the initial trials it is strongly recommended that the minimum surplus or deficit % should be used as a key annual summary figure (in addition to the average described above) as this will more clearly reflect the summer condition and the sustainability of groundwater resource management (see Section 5).

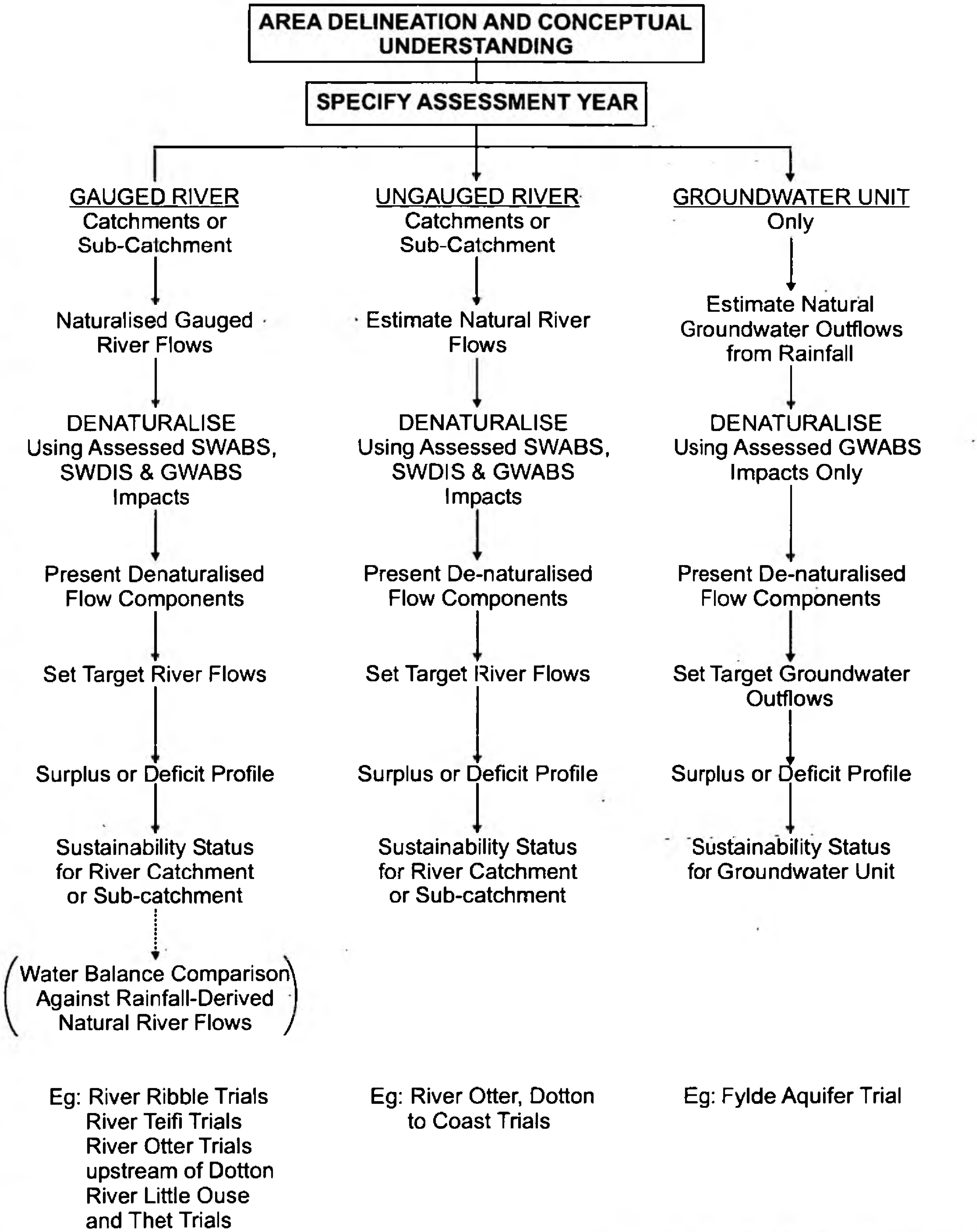

FIGURE 2.1 AUGUST 1999 ARM FRAMEWORK OVERVIEW

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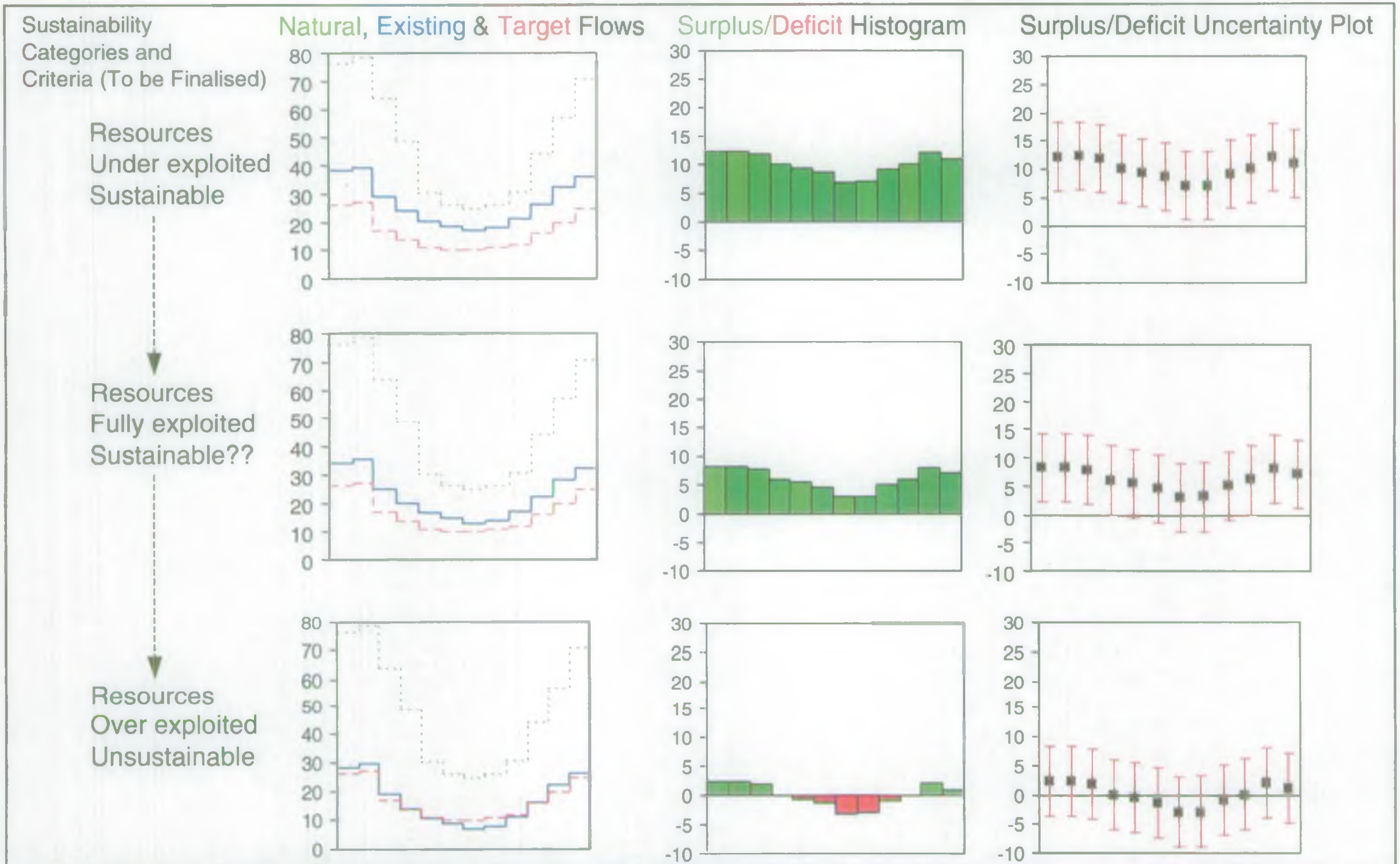

FIGURE 2.2 INTERPRETING ABSTRACTION SUSTAINABILITY STATUS

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3. ARM Initial CAMS Trial Descriptions and Results

3.1 Introduction

This Section summarises the results of the ARM assessments (based on the August 1999 version of the spreadsheets) as applied to the four CAMS trials areas. The geographic location of these trial areas are shown in Figure 3.1 along with a further three trial areas which were considered during the earlier development of the ARM framework and reported in the Draft User Manual (Ref: A Framework for Assessing Water Resource Availability and Acceptable Abstraction Impacts: Report and User Manual, National Groundwater and Contaminated Land Centre, May 1999, NC/06/01).

Further details of the ARM applications reported here are summarised in Table 3.1. The sub-division of the total CAMS trial area for the ARM assessments has been driven by discussion with Agency staff in the Regional or Area offices concerned, in line with the guidelines set out in Section 2.3. Time constraints have also meant that complete coverage of all the CAMS areas has not been possible. The River Otter catchment has, for example, been completely covered by sub-division into 4 ARM assessment areas: two gauged headwater sub-catchments (surface water dominated), a gauged central sub-area (groundwater dominated) and an ungauged coastal sub-area (groundwater dominated). Both the River Ribble and River Teifi CAMS catchments have been covered down to the lowermost gauging station and split into two ARM assessment sub-areas. The conceptual understanding of the Fylde aquifer as a largely confined unit which extends beyond the Ribble catchment has resulted in a separate, groundwater-only ARM assessment. ARM sub-area assessments of two gauged headwater catchments (the Upper Little Ouse and the Thet) have been carried out within the Little Ouse groundwater unit CAMS area.

In all cases basic data have been provided by the Agency and should be reasonably consistent with that used for the in-house CAMS. However, the level of involvement from Agency staff in the formulation of conceptual understanding, the setting of target flows or the review of results has been variable. For this reason, none of the trial spreadsheets presented should be considered as an 'Agency approved' assessment of water resource availability. It is emphasised that the credibility of the ARM results is dependent on the active involvement of staff who are familiar with the local area, particularly for the consideration of appropriate target flows, conceptual models, and licensing issues.

Hardcopies of the August 1999 format ARM spreadsheets for each of the CAMS areas referred to in this Section are provided in Appendix A.

Within this Section each ARM assessment report includes:

- a brief text summary of the delineated area and its characteristics, assessment year selection, key calculation assumptions and results;
- a sketch plan (where possible, drawn with standardised key symbols and line styles) and conceptual cross sections (as appropriate);

- two pages of headline results for each of the LTA spreadsheets which include: summary areas, inflows and outflows; the stacked histogram plots of natural and anthropogenic flow components expressed as mm/month over the assessment area (plotted to a common scale to illustrate national effective rainfall variations); monthly existing and target outflows and histograms with a summary of the rationale for target flow setting; monthly surplus or deficit profiles with associated uncertainties and annual summary as % of natural outflow; monthly acceptable abstraction impact profiles;
- a tabulated summary of monthly and annual average surplus or deficits derived from assessment spreadsheets for specific years other than the LTA.

Any key references or data sources are included on the spreadsheets themselves. The text explains the decisions taken during the ARM process but does not attempt to repeat the information presented on the spreadsheets which should be comprehensible as standalone documents. It is therefore recommended that the text be reviewed in front of a computer with a copy of the relevant spreadsheet open.

In some cases alternative scenarios based on estimated actual or licensed abstraction impacts have been considered in which case these results are also discussed in the text with the data required to investigate the scenario stored within the digital versions of the spreadsheets.

Section 4 compares each of the ARM trials with approaches adopted by the Agency's own Regional teams.

The trials for the River Thet catchment in Anglian Region (initially described in Section 3.6) were repeated following the further development of ARM framework and spreadsheets. This work is described in Section 5 with the revised format spreadsheets are included in full in Appendix B.

Table 3.1 Summary of LAMS Trial Areas and ARM Assessments

LAMS Trial Area	ARM Assessment Report Dividing Tab	ARM Assessment Report Title	ARM Assessment Areas Name	Area (sq. km.)	Assessment Type	Years Assessed	Spreadsheet Name
River Otter Catchment	1	**3.2 River Otter**	R Otter to Fenny Bridges	104	gauged river	LTA	Otfenltav1.xls
South West Region						1991 (drought)	Otfen19911.xls
						1981 (typical)	Otfen19811.xls
			R Tale to Fairmile	34	gauged river	LTA	Talfairltav.xls
						1992 (drought)	Talfair19911.xls
						1981 (typical)	Talfair19811.xls
			R Otter, Fenny Bridges to Dotton	64	gauged river	LTA	Otdotltav1.xls
						1993 (drought)	Otdot19911.xls
						1981 (typical)	Otdot19811.xls
			R Otter, Dotton to the Coast	42	ungauged river	LTA	Otcoasltav1.xls
						1994 (drought)	Otcoas19911.xls
						1981 (typical)	Otdot19811.xls
River Ribble Catchment	2	**3.3 River Ribble**	R Ribble to Arnford	204	gauged river	LTA	Ribarnltav1.xls
North West Region						1995 (drought)	Ribarn19951.xls
						1997 (typical)	Ribarn19971.xls
			R Ribble, Arnford to Samlesbury	941	gauged river	LTA	Ribsamltav1.xls
						1995 (drought)	Ribsam19951.xls
						1997 (typical)	Ribsam19971.xls
	3	**3.4 Fylde Aquifer**	Fylde Aquifer	335	groundwater outflow	LTA	Fyldltav1.xls
						1995 (drought)	Fyld19951.xls
						1997 (typical)	Fyld19971.xls
River Teifi Catchment	4	**3.5 River Teifi**	R Teifi to Llanfinghanel Bridge	448	gauged river	LTA	Llanltav1.xls
Wales						1995 (drought)	Llan19951.xls
						1997 (typical)	Llan19971.xls
			R Teifi, Llanfinghangel to Glanteifi	446	gauged river	LTA	Glanltav1.xls
						1995 (drought)	Glan19951.xls
						1997 (typical)	Glan19971.xls
Little Ouse GW Unit	5	**3.6 U. Little Ouse and Thet**	R Little Ouse to Euston	129	gauged river	LTA	Louseusltav1.xls
Anglian Region						1991 (drought)	Louseus91.xls
			R Thet to Melford Br	316	gauged river	LTA	Thetmelltav1.xls
						1991 (drought)	Thetmel91.xls

TAKEN FORM *GROUNDWATER IN THE UK 'A STRATEGIC STUDY' SS6.38 p5)*

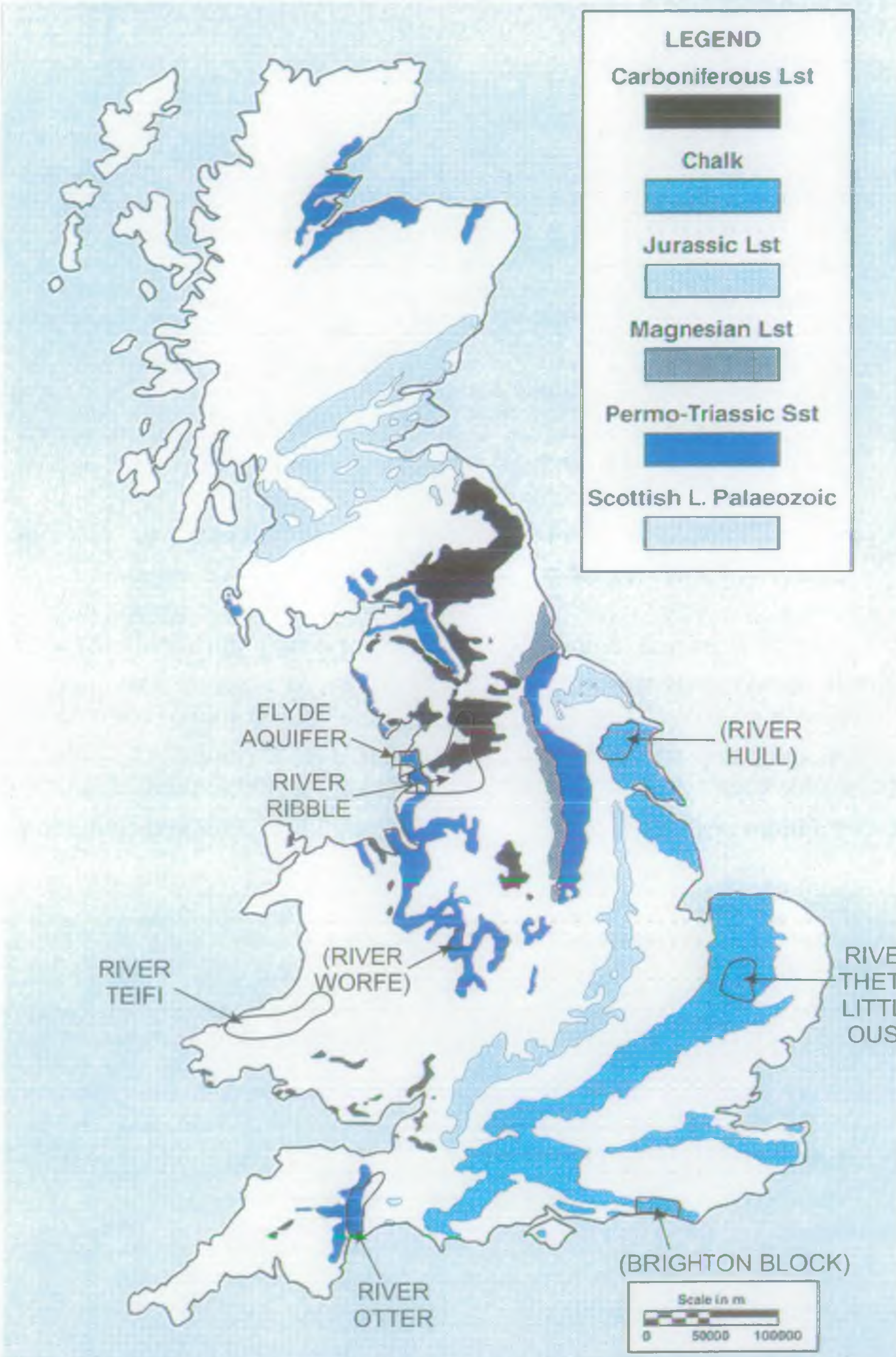

FIGURE 3.1 PRINCIPAL UK AQUIFERS AND THE LOCATION OF AMS: ARM TRIALS (AND PREVIOUS ARM TRIALS)

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3.2 River Otter Catchment Trials

3.2.1 Area Delineation, Description and Issues

Figure 3.2 shows a sketch of the River Otter surface water catchment which is the CAMS trial area in the Agency's South West Region and a conceptual cross section across the lower reaches of the river.

The River Otter flows from the Otterhead Lakes reservoir (and public water supply abstraction) over relatively impermeable geology to the Fenny Bridges gauging station where it flows onto the Otter Sandstone. Its main tributary, the River Tale joins just downstream of this gauge and is also gauged close to where it flows onto the sandstones at the Fair Mile station. The river remains on the Sandstone as it flows over a third gauging station at Dotton and onward to the sea.

Although surface water abstractions from the lower reaches of the river are relatively minor, the Otter Sandstone is an important aquifer with water abstracted for public water supply. In recent years concern has been expressed regarding the impact of these abstractions on low flows in the river, particularly in relation to trout fishing. Towards the coast the licensing control of abstractions must also take into account the potential for saline intrusion.

The Agency have recently completed a low flow study based on a distributed groundwater model and on consideration of the ecological and fisheries impacts of the abstractions. This study provides an excellent summary of the data required for the ARM assessment which have been supplemented by further data collation and discussion with the CAMS team.

For the purposes of this assessment it was decided to sub-divide the catchment into 4 parts according to the location of the river gauges. The assessment area were therefore delineated as the surface water and associated groundwater catchment to the Fenny Bridge and Fair Mile gauges, between these gauges and the Dotton gauge, and from the Dotton gauge to the coast.

3.2.2 Workbook Selection and Names

It would be possible to carry out an ARM assessment for the whole area in a single workbook based on the Ungauged River Calcs template, URIV.XLT. This would, however, overlook the opportunity to use flow gauging data from the gauging stations and to consider each of the distinctive parts of the catchment separately. The four sub-areas are assessed in the following spreadsheets (where **** is the assessment year):

Area Delineation	Excel Workbook Template Used	Completed Filename
R Tale to Fair Mile gauge	Gauged River, GRIV.XLT	TALFAIR****1.XLS
R Otter to Fenny Bridges gauge	Gauged River, GRIV.XLT	OTFEN****1.XLS
R Otter, Fair Mile and Fenny Bridges gauges to Dotton gauge	Gauged River, GRIV.XLT	OTDOT****1.XLS
R Otter, Dotton gauge to the coast	Ungauged River, URIV.XLT	OTCOAS****1.XLS

3.2.3 Assessment Years

For each of the four areas three separate assessments were carried out (as specified by the Agency) using data for the following years:

- a long term average year, LTAV(1980-1996);
- a 'drought' year, 1991;
- a climatically 'typical' year, 1981.

3.2.4 Key Assumptions

Consumptive Abstraction Impacts

Abstractions are very minor from both the River Tale and River Otter to Fenny Bridges assessment areas. Abstraction impacts have therefore been conservatively based on licensed rates as a more detailed assessment was considered unwarranted. The existence of the Otterhead Lakes reservoir has also been ignored - abstractions from it (which are small comparative to the total water balance) are assumed to have an immediate impact on the gauge. If the catchment to the reservoir was larger and the abstractions more significant, a more considered approach would be required towards the naturalisation of flows at the Fenny Bridges gauge.

Surface water abstractions are insignificant in both of the downstream sub-areas. Sewage treatment works discharges are also minor. Most of the groundwater abstracted for public water supply is transferred out of the catchment, ending up in long sea outfall discharges. The impacts of groundwater abstractions on both river flows and saline intrusion in these lower reaches are thus the crucial issues to be addressed.

Both of these lower sub-area assessments have used estimated *actual* consumptive abstractions based on returns and consumptiveness assumptions. Public water supply dominates and, although monthly abstraction aggregated for all sources may vary typically by up to 20%, total rates during the 1980s and early 1990s remained fairly steady between 19 to 25 Ml/d.

For most of the main river reaches, groundwater levels within the aquifer are considered to be above surface water levels. Borehole abstraction impacts are therefore probably largely due to a reduction in baseflow discharge to the river, rather than to losses of river water to the aquifer. Under such circumstances, and considering both the relatively small and seasonally irregular fluctuations in abstraction and the capacity of this high storage aquifer to smooth out impacts, the assumption that impacts were distributed evenly throughout the year at the average annual rate seems reasonable for the LTAV and 1981 'typical' years. Although the same assumption was also applied to the 1991 drought year, this is probably conservative as groundwater levels fell during this year indicating that at least some of the abstracted water was drawn from aquifer storage, rather than from the river.

Borehole sources were split between the two groundwater dominated sub-areas by the estimated natural groundwater catchment drawn to the Dotton gauge. Considerable uncertainty is associated with the Dotton abstraction boreholes in this respect – only one of these sources has been assumed to have an impact on the gauged flows. In 1991 actual abstractions from the aquifer upstream of Dotton amounted to 12 Ml/d (compared to a maximum combined licence rate of around 13 Ml/d). Downstream of Dotton 12 Ml/d was abstracted (compared to a licensed maximum of around 21 Ml/d).

Natural Outflows from Effective Rainfall

For the assessment area between the Dotton gauge and the coast it has been necessary to derive a natural flow response to rainfall falling within the area (using the 'Ungauged River' spreadsheet). The optional Aquifer Response Function (ARF) approach provided within the spreadsheet has been applied for this purpose. Gauged river inflows at Dotton are added in to take account of the support provided by the large headwater catchment and provide an estimate of the total natural flows leaving the area to the estuary and as groundwater discharge to the coast.

For the Otter trials, parameters for the ARF approach are relatively easily defined. The natural groundwater catchment is constrained by the limits of the aquifer outcrop. The rectangular shape of the outcrop limits the margin of interpretational error in splitting this catchment around Dotton. The length of river and coastline draining this area were measured from a map. Aquifer transmissivity and specific yield values were set at 150 m^2/d and 0.15 respectively, considered as representative by Agency staff. 10 years of antecedent monthly MORECS effective rainfall data were used to derive the natural flow responses for each assessment although, with aquifer response times calculated at around 200 - 300 days, the estimated flows are only significantly influenced by the rain which fell within the previous two years.

Target Flows

The Agency's study concluded that the recent levels of abstraction flow impacts have not resulted in unacceptable ecological or fisheries impacts. It has therefore been assumed that target flows can be based on a monthly Hands of Flow (HOF) equivalent to the historically gauged Q95 with a %TAKE of 25% of natural flows above this HOF considered acceptable by the Agency in the Region. Targets are less readily defined for the assessment area downstream of the Dotton gauge but have been based on the same principle and %TAKE, with a monthly HOF suggested by the previous modelling study.

3.2.5 Presentation and Discussion of Results

The first two pages of LTAV headline results for all four of the assessment areas follow this Section. In all cases the 3rd page which asks the user to interpret the sustainability status of the area has been omitted pending further discussion with the Agency. Table 3.2 summarises the headline results derived from all the specified years. For each year these results include:

- the natural outflow during the year derived from the assessment area (expressed as mm/a over the surface water catchment area).
- the maximum impact of existing consumptive abstractions within the assessment area expressed as a % of both the natural outflow including any inflows, and of the natural outflow excluding inflows.
- the minimum and average surplus or deficit in Ml/d and the average surplus or deficit expressed as a % of natural outflows (including any inflows).

Hardcopy versions of all the assessment spreadsheets are included in Appendix A.

Variations in effective rainfall between the upland catchment to Fenny Bridges and the lower catchments to Fair Mile and Dotton are evident from the average natural outflow values. As these are based on gauged flows divided by surface water catchment area, they are equivalent to the 'mean annual runoff' data quoted in IoH yearbooks and registers. The natural outflow apparent below the Dotton gauge to the coast is higher because the calculations are based on effective rainfall data from the 40 km by 40 km MORECS square which are probably overestimates for this low lying area.

The essentially natural water balances of the Tale and the Otter to Fenny Bridges are evident from the stacked histogram plots and the low % of maximum existing abstraction impacts (only 3% and 7% respectively for the drought year of 1991). Abstraction impacts are much higher if the resources of the two lower sub-catchments are considered in isolation (for the drought year the assumed abstraction impacts represent more than the effective rainfall to both areas - impacts are >100%). When the support from the upstream catchments is taken into account however, abstraction impacts fall to around 8 to 16 % of the natural outflows - impacts which, at existing abstraction rates, the Agency have concluded are sustainable in the recent study.

The target flows adopted are therefore designed to protect existing low flows but to allow further abstraction at higher flows. The development of further abstraction to exploit surpluses during the winter months could probably only be effectively managed through surface water licensing with flow controls linked to the Dotton gauge. Further downstream, significant summer deficits might become apparent much more frequently in the coastal area if abstraction rates from boreholes downstream of Dotton were increased to their licensed limit. It is understood that operational controls based on groundwater level monitoring are already built into some of the licences towards the coast to control the risk of saline intrusion.

Although not essential for the derivation of the main ARM outputs in gauged catchments, attempts were briefly made in all of the Otter assessments to reconcile the gauge naturalised flows with natural flows derived from rainfall and catchment runoff. The aquifer response function (ARF) model provided within the spreadsheets was used for this purpose. Comparison of the natural outflows derived for the catchment to Fenny Bridges with the naturalised gauged flows suggests that the MORECS values probably underestimate effective rainfall at higher altitudes.

The balance calculations carried out for the Fenny Bridges to Dotton assessment also suggest that the two approaches do not give the same answer. For most of the summer months, the differences lie within the estimated uncertainty of +/- 20 Ml/d. For the groundwater component of the hydrological cycle this is considered reasonable. The largest differences occur in the months of higher effective rainfall. This suggests that the simple ARF assumption that all runoff within the month would naturally flow out of the area in the same month is unreasonable. It is also possible that to naturalise the gauged flows, the impacts of steady state groundwater abstraction could be redistributed towards the wetter months to take account of aquifer storage with seasonal recharge, as suggested by the Agency's approach to naturalisation in the North East region.

Table 3.2 Summary of River Otter Catchment Trial Results

	Units	R Tale to Fairmile	R Otter to Fenny Br.	R Otter Fenny Br. to Dotton	R Otter Dotton to Coast
Natural Outflows Based On		flow gauge	flow gauge	flow gauges	gauge & MORECS
SW Catchment Area	sq. km.	34.4	104.2	63.9	42.2
LTAV (1980 - 1996)					
Annual av. nat. outflow derived from assessment area/SW catchment area	mm/a	383	632	336	428
Existing consumptive abs. impact as % nat. outflow (incl. inflow)	%	3	6	8	12
Existing consumptive abs. impact as % nat. outflow (from ass. area only)	%			79	90
Min. monthly surplus (+ve) or deficit (-ve)	Ml/d	1	3	1	-2
Annual av. surplus (+ve) or deficit (-ve)	Ml/d	6	30	39	42
Annual av. surplus (+ve) or deficit (-ve) as % nat. outflow	%	17	17	14	13
1981 ('TYPICAL' YEAR)					
Annual av. nat. outflow derived from assessment area/SW catchment area	mm/a	458	797	431	473
Existing consumptive abs. impact as % nat. outflow (incl. inflow)	%	3	6	9	12
Existing consumptive abs. impact as % nat. outflow (from ass. area only)	%			66	75
Min. monthly surplus (+ve) or deficit (-ve)	Ml/d	0	1	0	-3
Annual av. surplus (+ve) or deficit (-ve)	Ml/d	8	42	57	61
Annual av. surplus (+ve) or deficit (-ve) as % nat. outflow	%	18	19	17	16
1991 ('DROUGHT' YEAR)					
Annual av. nat. outflow derived from assessment area/SW catchment area	mm/a	339	564	256	353
Existing consumptive abs. impact as % nat. outflow (incl. inflow)	%	3	7	10	16
Existing consumptive abs. impact as % nat. outflow (from ass. area only)	%			130	121
Min. monthly surplus (+ve) or deficit (-ve)	Ml/d	0	-1	-5	-11
Annual av. surplus (+ve) or deficit (-ve)	Ml/d	5	26	29	31
Annual av. surplus (+ve) or deficit (-ve) as % nat. outflow	%	16	16	13	11

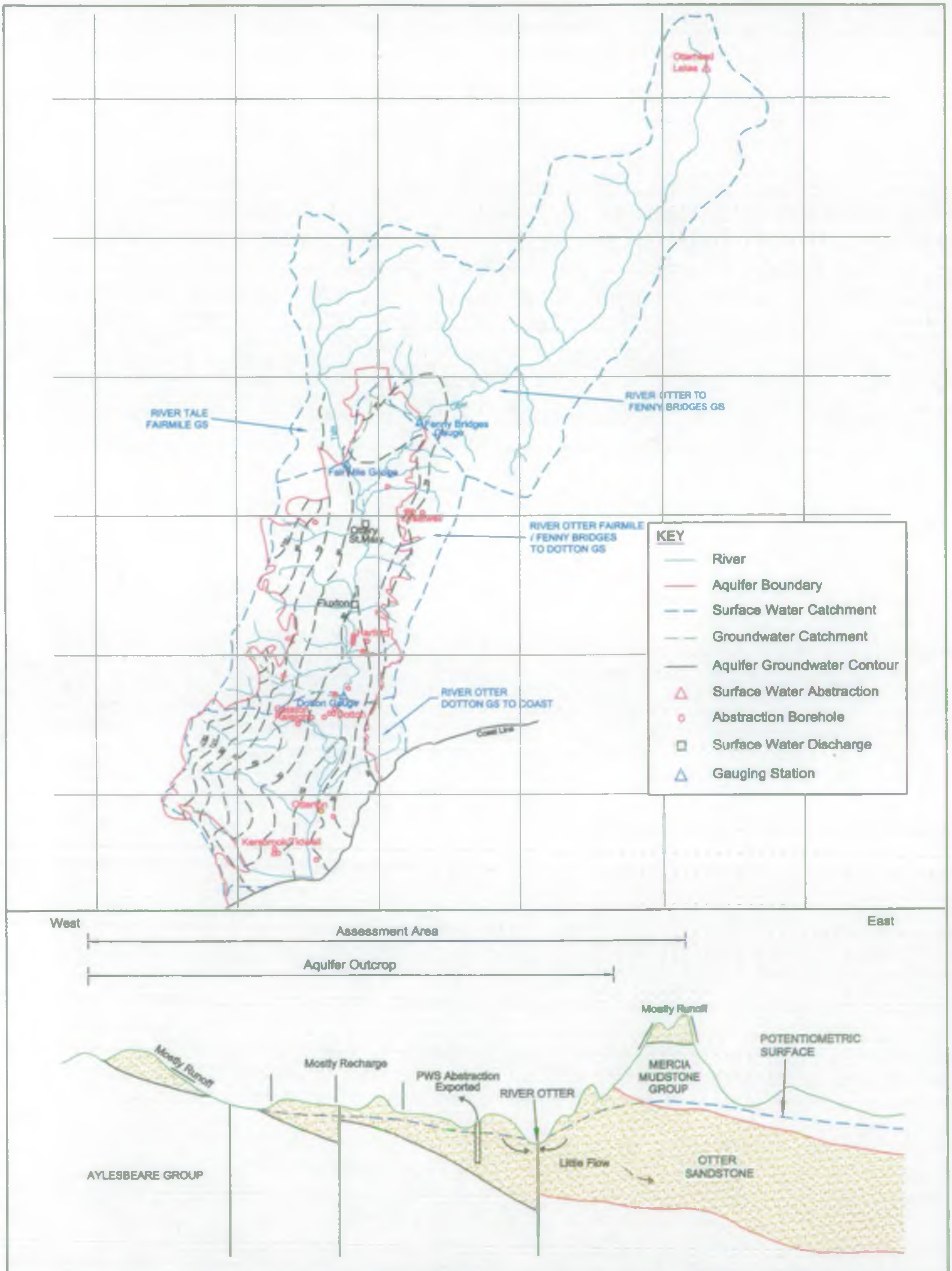


FIGURE 3.2 RIVER OTTER: ASSESSMENT AREAS SKETCH PLAN AND CROSS SECTION

Drawing No: **02019.S006** Date: **AUGUST 1999** Scale: **AS SHOWN**

Entec

ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area R Tale to Fairmile GS **ID** 0 **Ver** 1 **Rev** 0 **Date** 19/8/99

Specified Assessment Year L T Average Year (1980-1997)

1 Headline Assessment Results Summary

1.1 Annual Gauged Inflows, Gauged Outflows & Naturalised Gauged Outflows

Annual Average Gauged Inflows =	0	Ml/d
Annual Average Gauged Outflow =	36	Ml/d
Annual Average Naturalised Gauged Outflow =	36	Ml/d

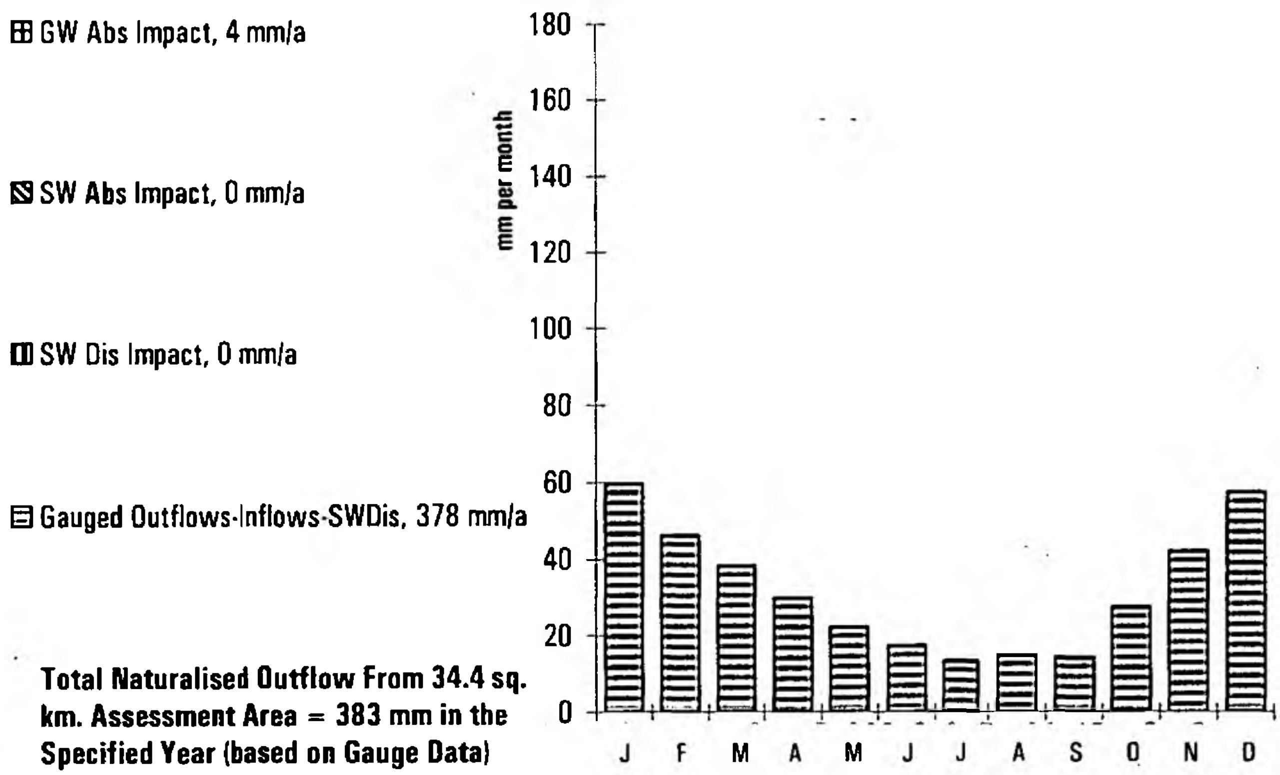
1.2 Components of Naturalised Flows Derived from the Assessment Area (i.e. Excluding Inflows) Expressed in mm Over Gauged SW Catchment

SW Catchment Area Assessed = 34.4 square kilometres

Component, Annual Total	J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 4 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
SW Abs Impact, 0 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
SW Dis Impact, 0 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
Gauged Outflows-Inflows-SWDis, 378 mm/a	59	46	38	29	22	17	13	14	14	27	42	57

Total Naturalised Outflow From 34.4 sq. km. SW Catch. Area = 383 mm in the Specified Year (based on Gauge Data)

Abs & Dis are LICENSED (NO CONTROLS) at 1999



ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

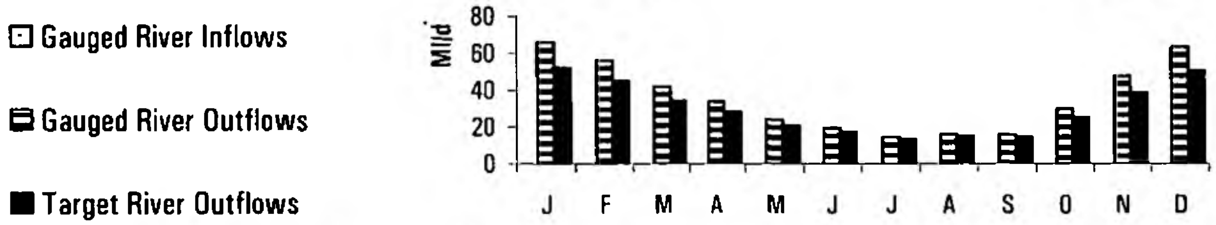
Area R Tale to Fairmile GS **ID** 0 **Ver** 1 **Rev** 0 **Date** 19/8/99

Specified Assessment Year L T Average Year (1980-1997)

1.3 Existing and Target Outflows for Specified Year, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Gauged River Inflows	0	Ml/d	0	0	0	0	0	0	0	0	0	0	0	0
Gauged River Outflows	36	Ml/d	66	56	42	34	24	19	14	16	16	30	48	63
Target River Outflows	30	Ml/d	52	45	34	28	21	17	14	15	15	25	39	50

Min. Target = 14 **Ml/d** Monthly HOF 10 Ml/d TAKE 25 % (cf Q95 10 Ml/d)



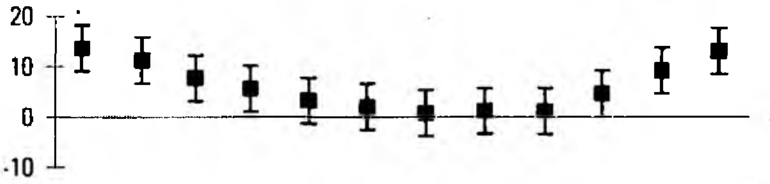
Target Flows based on: Monthly HOF = guessed Q95, TAKE = 25% of naturalised flow, (Ref. Phase 3 Report)

1.4 Surplus or Deficits for Specified Year, Ml/d

		J	F	M	A	M	J	J	A	S	O	N	D
Ann Av	6 Ml/d	14	11	8	6	3	2	1	1	1	5	9	13

Minimum 1 **Ml/d**

Uncertainty +/- 5 **Ml/d**



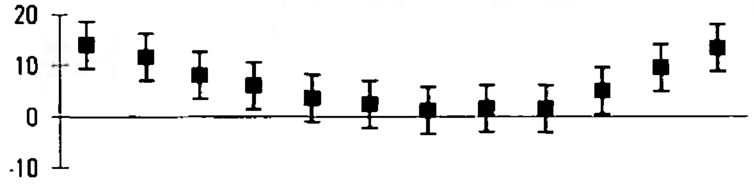
Annual Average Surplus or Deficit is 17% of the Av. Naturalised Gauged Outflow

1.5 Acceptable Abs. Impacts for Spec. Year,Given Target Outflows and Existing Inflows

			J	F	M	A	M	J	J	A	S	O	N	D
Ann Av	7 Ml/d	Ml/d	14	12	8	6	4	2	1	2	2	5	10	13

Minimum 1 **Ml/d**

Uncertainty +/- 5 **Ml/d**



	J	F	M	A	M	J	J	A	S	O	N	D
Acc. impacts/nat. gauged outflows, %	21	21	19	18	15	12	8	10	10	17	20	21

1.6a During this year, **max. existing consumptive abstraction impacts were** 3 %
of naturalised gauged river outflows in the month of Jul
(calculated from gauged river outflows + cons. abstraction impacts).

1.6b During this year, **max. existing consumptive abstraction impacts were** 3 %
of natural outflows derived from the assessment area in the month of Aug
(calculated from eff.rain. and area hydraulic response characteristics).

ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area R Otter to Fenny Bridges GS **ID** 0 **Ver** 1 **Rev** 0 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1980-1997)**

1 Headline Assessment Results Summary

1.1 Annual Gauged Inflows, Gauged Outflows & Naturalised Gauged Outflows

Annual Average Gauged Inflows =	0	Ml/d
Annual Average Gauged Outflow =	177	Ml/d
Annual Average Naturalised Gauged Outflow =	181	Ml/d

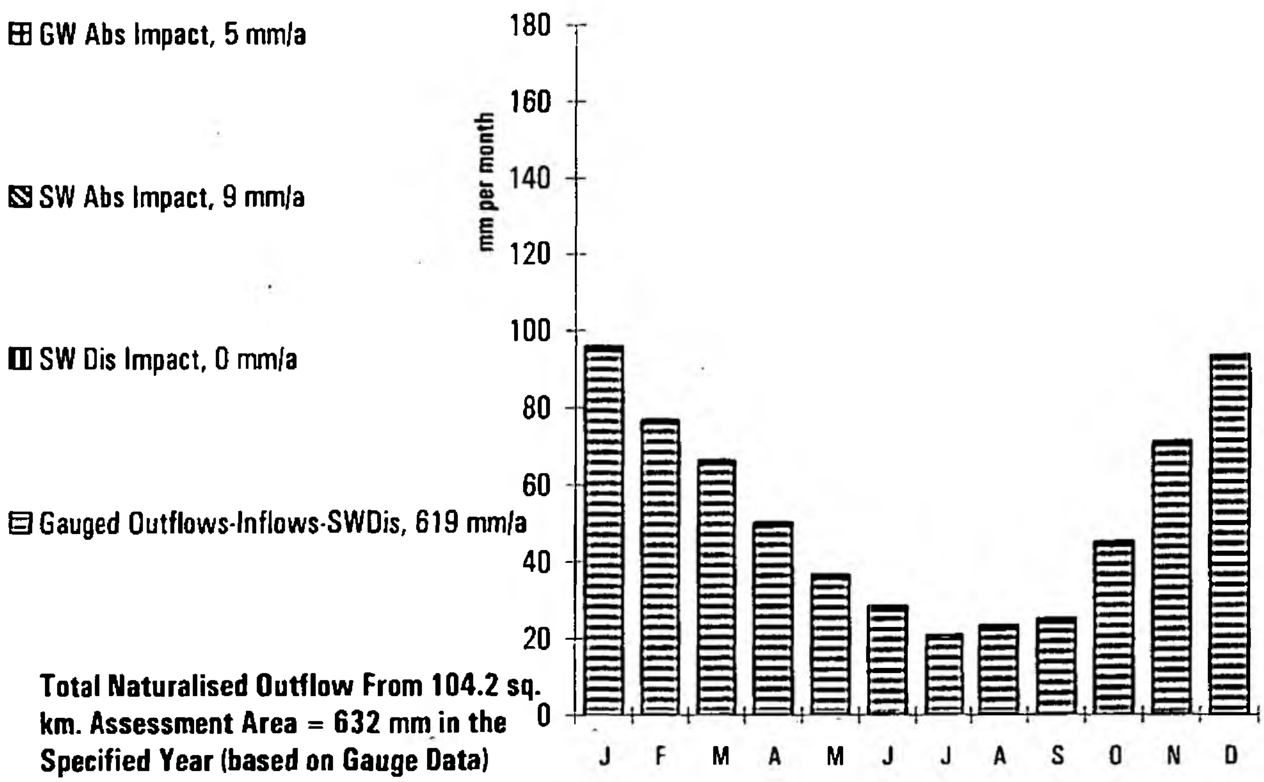
1.2 Components of Naturalised Flows Derived from the Assessment Area (i.e. Excluding Inflows) Expressed in mm Over Gauged SW Catchment

SW Catchment Area Assessed = 104.2 square kilometres

Component, Annual Total	J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 5 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
SW Abs Impact, 9 mm/a	1	1	1	1	1	1	1	1	1	1	1	1
SW Dis Impact, 0 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
Gauged Outflows-Inflows-SWDis, 619 mm/a	95	76	65	49	35	27	20	22	24	44	70	92

Total Naturalised Outflow From 104.2 sq. km. SW Catch. Area = 632 mm in the Specified Year (based on Gauge Data)

Abs & Dis are LICENSED (NO CONTROLS) at 1999



ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

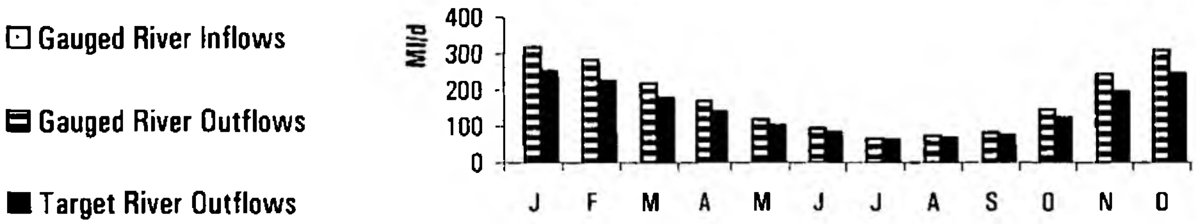
Area R Otter to Fenny Bridges GS **ID** 0 **Ver** 1 **Rev** 0 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1980-1997)**

1.3 Existing and Target Outflows for Specified Year, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Gauged River Inflows	0	Ml/d	0	0	0	0	0	0	0	0	0	0	0	0
Gauged River Outflows	177	Ml/d	318	282	219	170	119	94	66	74	83	148	243	310
Target River Outflows	146	Ml/d	252	225	178	141	103	84	63	69	76	124	196	246

Min. Target = 63 **Ml/d** Monthly HOF 43 Ml/d TAKE 25 % (cf Q95 43 Ml/d)



Target Flows based on: Monthly HOF = Q95, TAKE = 25% of naturalised flow, (Ref: Phase 3 Report)

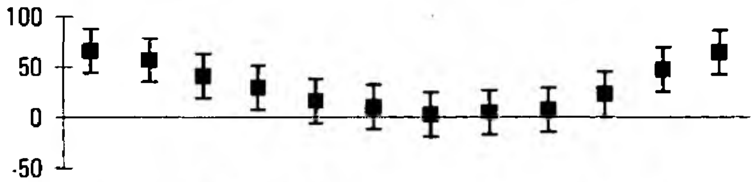
1.4 Surplus or Deficits for Specified Year, Ml/d

J	F	M	A	M	J	J	A	S	O	N	D
66	57	41	29	16	10	3	5	7	23	47	64

Ann Av 30 Ml/d

Minimum 3 Ml/d

Uncertainty +/- 22 Ml/d



Annual Average Surplus or Deficit is 17% of the Av. Naturalised Gauged Outflow

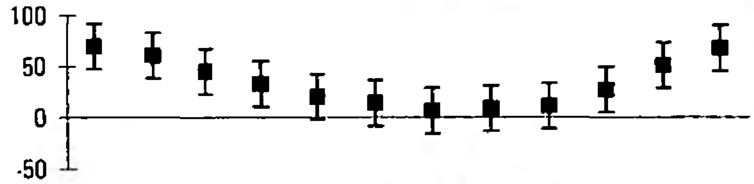
1.5 Acceptable Abs. Impacts for Spec. Year, Given Target Outflows and Existing Inflows

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	70	61	45	33	20	14	7	9	11	27	51	68

Ann Av 34 Ml/d

Minimum 7 Ml/d

Uncertainty +/- 22 Ml/d



	J	F	M	A	M	J	J	A	S	O	N	D
Acc. impacts/nat. gauged outflows, %	22	21	20	19	16	14	10	11	13	18	21	22

1.6a During this year, **max. existing consumptive abstraction impacts were** 6 %
of naturalised gauged river outflows in the month of **Jul**
(calculated from gauged river outflows + cons. abstraction impacts).

1.6b During this year, **max. existing consumptive abstraction impacts were** 6 %
of natural outflows derived from the assessment area in the month of **Aug**
(calculated from eff.rain. and area hydraulic response characteristics).

ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area R Otter Fenny Bridges to Dotton GS **ID** 0 **Ver** 1 **Rev** 0 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1980-1996)**

1 Headline Assessment Results Summary

1.1 Annual Gauged Inflows, Gauged Outflows & Naturalised Gauged Outflows

Annual Average Gauged Inflows =	212	Ml/d
Annual Average Gauged Outflow =	259	Ml/d
Annual Average Naturalised Gauged Outflow =	269	Ml/d

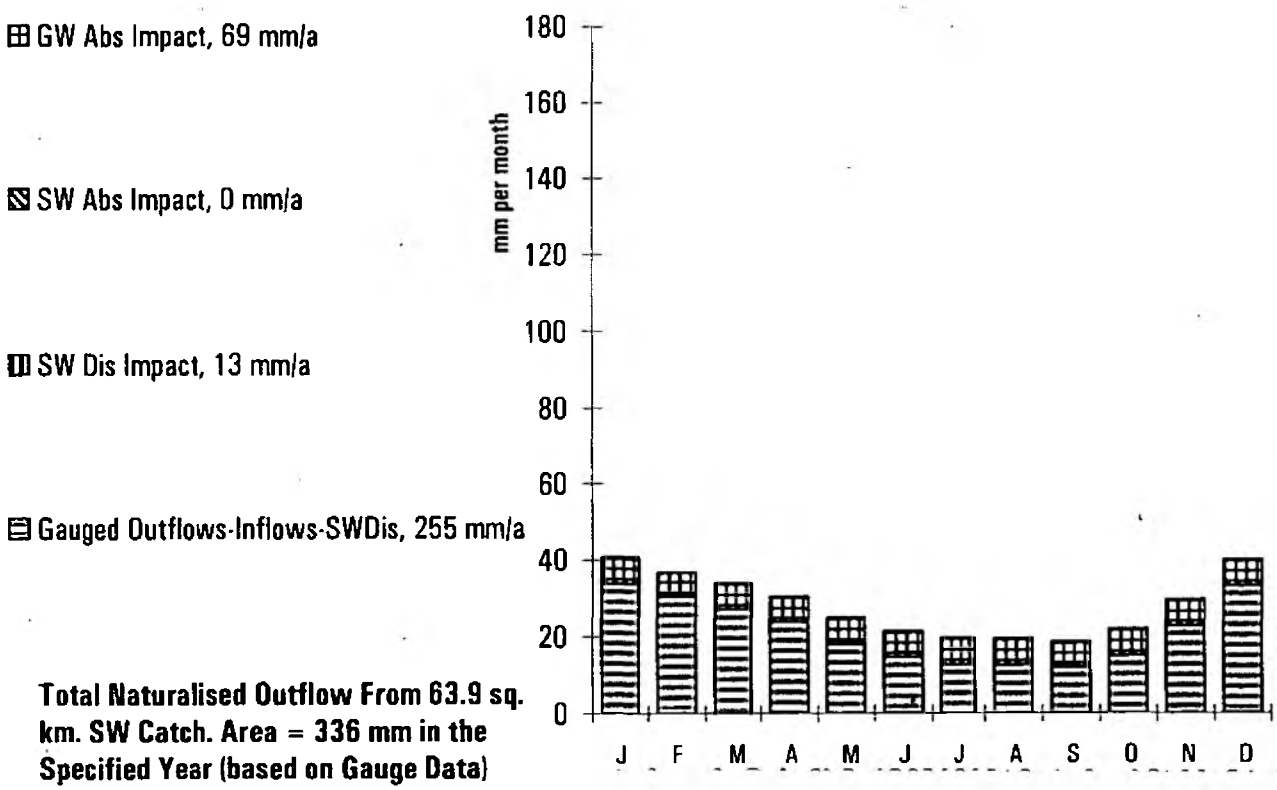
1.2 Components of Naturalised Flows Derived from the Assessment Area (i.e. Excluding Inflows) Expressed in mm Over Gauged SW Catchment

SW Catchment Area Assessed = 63.9 square kilometres

Component, Annual Total	J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 69 mm/a	6	5	6	6	6	6	6	6	6	6	6	6
SW Abs Impact, 0 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
SW Dis Impact, 13 mm/a	1	1	1	1	1	1	1	1	1	1	1	1
Gauged Outflows-Inflows-SWDis, 255 mm/a	34	30	27	24	18	15	13	13	12	15	23	33

Total Naturalised Outflow From 63.9 sq. km. SW Catch. Area = 336 mm in the Specified Year (based on Gauge Data)

Abs & Dis are ESTIMATED ACTUAL at 1999



ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

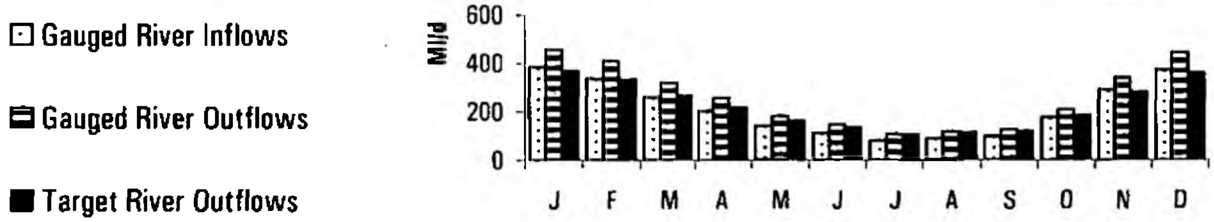
Area R Otter Fenny Bridges to Dotton GS **ID** 0 **Ver** 1 **Rev** 0 **Date** 19/8/99

Specified Assessment Year L T Average Year (1980-1996)

1.3 Existing and Target Outflows for Specified Year, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Gauged River Inflows	212	Ml/d	384	338	261	204	143	113	80	90	99	177	291	374
Gauged River Outflows	259	Ml/d	456	410	319	257	182	146	108	118	126	210	342	444
Target River Outflows	220	Ml/d	368	333	265	218	162	136	107	115	120	184	282	359

Min. Target = 107 **Ml/d** Monthly HOF 74 Ml/d TAKE 25 % (cf Q95 79 Ml/d)



Target Flows based on: Monthly HOF = min summer flow, TAKE = 25% of naturalised flow, (Ref: Phase 3 Report)

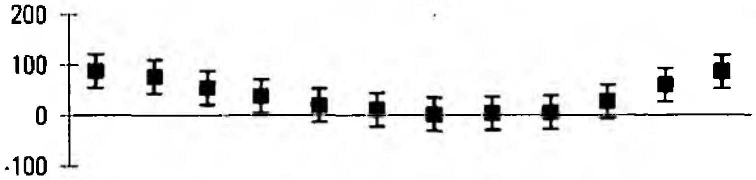
1.4 Surplus or Deficits for Specified Year, Ml/d

J	F	M	A	M	J	J	A	S	O	N	D
88	77	54	38	20	11	1	4	6	27	60	85

Ann Av 39 Ml/d

Minimum 1 Ml/d

Uncertainty +/- 33 Ml/d



Annual Average Surplus or Deficit is 14% of the Av. Naturalised Gauged Outflow

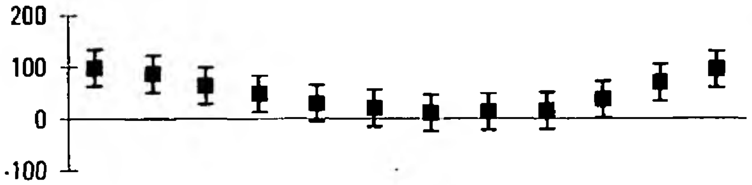
1.5 Acceptable Abs. Impacts for Spec. Year,Given Target Outflows and Existing Inflows

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	98	86	64	48	29	21	11	14	15	37	69	95

Ann Av 49 Ml/d

Minimum 11 Ml/d

Uncertainty +/- 36 Ml/d



	J	F	M	A	M	J	J	A	S	O	N	D
Acc. impacts/nat. gauged outflows, %	21	21	19	18	15	13	9	11	11	17	20	21

1.6a During this year, **max. existing consumptive abstraction impacts were** 8 % **of naturalised gauged river outflows in** the month of Jul (calculated from gauged river outflows + cons. abstraction impacts).

1.6b During this year, **max. existing consumptive abstraction impacts were** 79 % **of natural outflows derived from the assessment area in** the month of Sep (calculated from eff.rain. and area hydraulic response characteristics).

ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area R Otter Dotton GS to Coast **ID** 0 **Ver** 1 **Rev** 0 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1980-1996)**

1 Headline Assessment Results Summary

1.1 Annual Gauged Inflows, Estimated Existing Outflows & Natural Outflows

Annual Average Gauged Inflows =	259	Ml/d
Annual Average Estimated Existing Outflow =	296	Ml/d
Annual Average Estimated Natural Outflow =	313	Ml/d

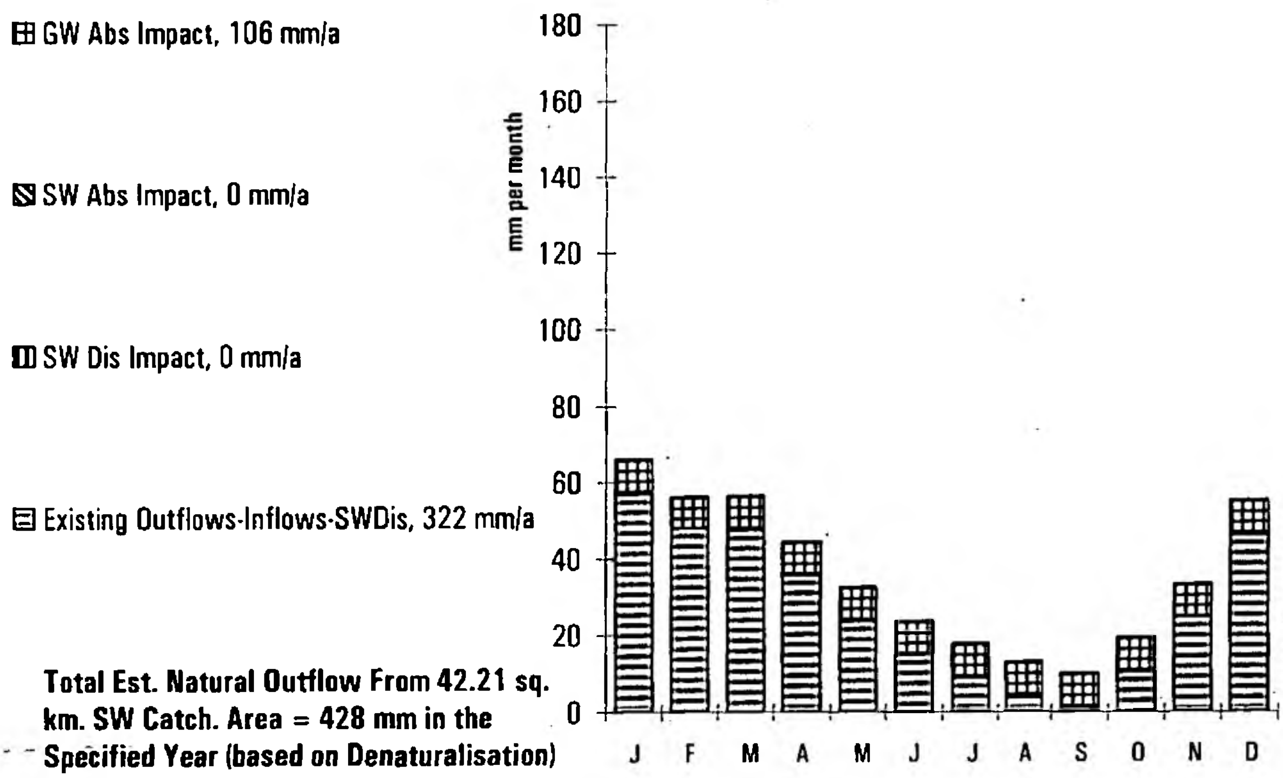
1.2 Components of Estimated Natural Flows Derived from the Assessment Area (i.e. Excluding Inflows) Expressed in mm Over SW Catchment

SW Catchment Area Assessed = 42.21 square kilometres

Component, Annual Total	J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 106 mm/a	9	8	9	9	9	9	9	9	9	9	9	9
SW Abs Impact, 0 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
SW Dis Impact, 0 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
Existing Outflows-Inflows-SWDis, 322 mm/a	57	48	48	36	24	15	9	4	1	10	25	46

Total Est. Natural Outflow From 42.21 sq. km. SW Catch. Area = 428 mm in the Specified Year (based on Denaturalisation)

Abs & Dis are ESTIMATED ACTUAL at 1999



ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

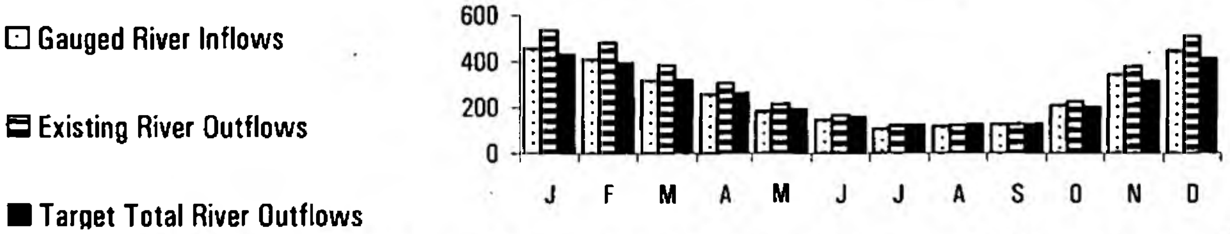
Area R Otter Dotton GS to Coast **ID** 0 **Ver** 1 **Rev** 0 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1980-1996)**

1.3 Existing and Target Outflows for Specified Year, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Gauged River Inflows	259	Ml/d	456	410	319	257	182	146	108	118	126	210	342	444
Estimated Existing River Outflows	296	Ml/d	534	483	384	307	214	167	120	124	128	224	377	507
Target River Outflows	254	Ml/d	432	394	320	262	193	157	122	125	128	200	314	412

Min. Target = 122 **Ml/d** Monthly HOF 79 Ml/d TAKE 25 % (cf Q95 79 Ml/d)



Target Flows based on: Monthly HOF = min summer flow, TAKE= 25% of naturalised flow, (Ref. Phase 3 Report)

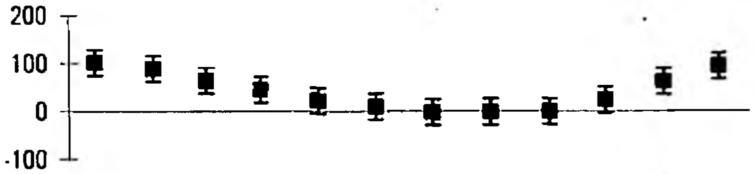
1.4 Surplus or Deficits for Specified Year, Ml/d

J	F	M	A	M	J	J	A	S	O	N	D
101	89	64	45	22	10	-2	-1	0	24	62	95

Ann Av 42 **Ml/d**

Minimum -2 **Ml/d**

Uncertainty +/- 27 **Ml/d**



Annual Average Surplus or Deficit is 13% of the Av. Natural Outflow

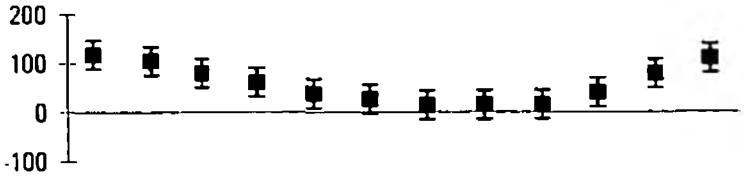
1.5 Acceptable Abs. Impacts for Spec. Year,Given Target Outflows and Existing Inflows

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	118	105	80	61	38	26	14	15	16	40	78	111

Ann Av 58 **Ml/d**

Minimum 14 **Ml/d**

Uncertainty +/- 29 **Ml/d**



	J	F	M	A	M	J	J	A	S	O	N	D
Acc. impacts/Nat. Tot. River Outflows, %	21	21	20	19	16	14	11	11	11	17	20	21

1.6a During this year, **max. existing consumptive abstraction impacts were** 90 %
of natural outflows derived from the assessment area in the month of Sep
(calculated from eff.rain. and area hydraulic response characteristics).

1.6b During this year, **max. existing consumptive abstraction impacts were** 12 %
of natural total river outflows in the month of Jul
(calculated from gauged river inflows + nat outflows from area).

3.3 River Ribble Catchment Trials

3.3.1 Area Delineation, Description and Issues

Figure 3.3 shows a sketch plan of the River Ribble surface water catchment which is the CAMS trial area in the Agency's North West Region (Hydrometric Area No 71).

For the purposes of current study two sub-areas of the Ribble catchment were delineated for assessment, namely:

- the River Ribble above Arnford gauging station;
- the River Ribble between Arnford and Samlesbury gauging stations.

The gauging station at Samlesbury is the nearest available gauging station to the Ribble Estuary and drains an area of some 1145 km^2 which represents the majority of the Ribble catchment. Few significant abstractions or discharges occur downstream of Samlesbury.

The Ribble at Arnford drains a smaller 204 km^2 headwater catchment area and is relatively undisturbed with limited abstractions and other anthropogenic influences but the ecological/amenity/etc consequences of ground and surface water abstraction may be significant.

The upper reaches of the Ribble catchment area are dominated by thick continuous sequences of karstified Carboniferous Limestone which is regarded as a minor aquifer. Around 6 km upstream of the gauging station at Arnford there is a faulted contact between the Carboniferous Limestone and the younger (Namurian) rocks of the Millstone Grit Series.

Downstream of Arnford a gentle anticlinal structure running from NE-SW across the centre of the Ribble catchment results in another wide belt of Carboniferous Limestone. This central band of limestone is younger and less karstified than the limestones in the upper part of the catchment since the sequence contains extensive interbedded sandstone and mudstone layers. Further south the limestones are overlain by a further belt of the Millstone Grit series which dips below productive coal measures (Westphalian) beneath the industrial areas of Burnley and Blackburn.

Towards the west of the catchment around Preston a faulted contact exists between the Millstone Grit to the east and the Triassic Sherwood Sandstones of the Fylde Aquifer to the west (see Section 3.4). These sandstones dip beneath Mercia Mudstones in the vicinity of the Ribble Estuary.

Much of the Ribble catchment is covered by glacial drift, principally till in the form of boulder clay. These deposits tend to be absent on higher ground and most thickly developed towards the south west of the area. Isolated areas of sand and gravel occur in the south of the catchment and peat caps are commonplace on the higher fells.

The Fylde Sherwood Sandstones represent the only major aquifer in the study area and are for the most part confined beneath a layer of thick glacial drift. The remaining geological units are all considered minor aquifers although sandstone beds which occur in the upper part of the limestone succession, the Millstone Grits and the Coal Measures, can act as significant fissure flow aquifers. Localised sources of groundwater can be found within the superficial drift deposits where the till is composed predominantly of sand and gravel type material.

Public water supply forms by far the largest consumptive use within the catchment the majority of which comes from reservoir storage and direct river intakes. Other major consumptive uses include water for industrial and agricultural use. The majority of the industrial abstractions occur in the urbanised southern parts of the catchment in the Burnley and Blackburn areas. Water for public and private water supply and agricultural use is generally drawn from boreholes and rivers in the less developed northern part of the catchment.

Current licensed abstractions total 398 Ml/d (licensed annual average) which is around 14% of the average daily flow at Samlesbury (Ref: River Ribble Catchment Management Plan Consultation Report, EA NW, March 1995) although much of the water abstracted for public water supply is returned as treated effluent within the catchment. At this level of abstraction potential low flow or water quality problems may be an important issue locally within the assessment area particularly under drought conditions.

Only a small number of groundwater and surface water abstractions take place from the catchment area upstream of Arnford. Information on returns from these abstractions for the period 1980-1998 indicates average total abstractions of around 2.3 Ml/d (similar to discharges returned to the river) compared to an average flow of 637 Ml/d in the Ribble at Arnford over the same time period. Despite this relatively low level of abstraction, concerns have been raised by the fishing community regarding perceived negative impacts on flows in the river.

3.3.2 Workbook Selection and Names

It would be possible to carry out the Assessment Framework for the whole Ribble catchment to Samlesbury. This would however overlook the opportunity to use flow gauging data from the station at Arnford to set target flows for the upper Ribble catchment. For this reason assessments have been carried out on the Ribble catchment upstream of Arnford and for the catchment between Arnford and Samlesbury. The spreadsheet type and filenames for the two areas assessed are summarised below:

Area Delineation	Excel Workbook Template Used	Filename Extension
River Ribble to Arnford	Gauged River, GRIV.XLT	RIBARN****1.XLS
River Ribble to Samlesbury	Gauged River, GRIV.XLT	RIBSAM****1.XLS

where **** is the year assessed.

3.3.3 Assessment Years

For each of the two assessment areas three separate assessments were carried out using input data for the following years:

- a long term average year, LTAV(1980-1998);
- a 'drought' year, 1995;
- a climatically 'typical' year, 1997.

3.3.4 Key Assumptions

Consumptive Abstraction Impacts

Data on actual surface and groundwater abstractions and surface water discharges from the Ribble catchment were provided by the North West Region for the period 1980-1998. Where actual returns were not available estimates have been made from licence information either on the basis of use or assuming 50% uptake of the licensed total. Further calculations were carried out by Entec in order to estimate monthly abstractions from the annual totals provided. For Spray Irrigation and Public Water Supply Abstractions demand profiles recommended in Anglian Region's best practice guidelines for flow naturalisation were used, see Table 3.3.

For all other uses monthly abstractions were distributed as outflow impacts evenly throughout the year by dividing the annual total by 12. As the stacked histogram plots indicate groundwater abstraction to be a vary small component of the water balance for both assessment areas, no attempt was made to consider a more complicated monthly profile of the impacts of this abstraction on river flows. It is important to note that, in the absence of more detailed analysis, the impacts of surface reservoir storage were also ignored as part of the gauged flow naturalisation process - surface water abstractions from reservoirs were assumed to impact gauged flows in the month of abstraction. This is clearly an over-simplistic assumption and, although possibly less significant for the LTAV assessments, further discussion with Agency hydrologists is essential to consider ways in which the effects of reservoir storage might be taken into account.

Information on consented dry weather flows from each of the sewage treatment works within the Ribble catchment was also provided by the Agency. This data was assumed to be indicative of mains water discharges from each of these works and indicates total flows of 110 Ml/d for the catchment to Samlesbury and less than 3 Ml/d for the area upstream of Arnford.

Target Flows

For the purposes of the current study target flows for both of the trial areas have been set using a method comparable to the SWALP concept. The user specifies a minimum monthly flow (equivalent to the SWALP daily Hands Off Flow (HOF)) and a monthly % TAKE which limits how much of the naturalised flow above the HOF can be abstracted. Since no HOF data were available for the Ribble catchment values of 41 and 390 ML/d have been adopted, which are equal to the gauged Q95 flows at Arnford and Samlesbury respectively (Ref: Hydrometric Register and Statistics 1991-1995, IH/BGS, 1998). A monthly TAKE of 25% of the naturalised flow above the HOF has also been assumed. For an average year this results in a minimum target flow at Arnford of 189 ML/d and 1053 ML/d at Samlesbury. At this stage there has been little opportunity to discuss the appropriateness of these monthly HOF and %TAKE with Agency staff.

3.3.5 Presentation and Discussion of Results

The first two pages of LTAV headline results for both of the assessment areas follow this Section. In both cases (as for all the First Draft trials) the 3rd page which asks the user to interpret the sustainability status of the area has been omitted pending further discussion with the Agency. Tables 3.4 and 3.5 summarise the monthly surplus and deficits derived from the assessments of specific years. Full copies and plots for all the assessments are included in Appendix A.

For the Ribble to Arnford despite the relatively low levels of existing abstraction from the catchment under long term average conditions gauged outflows during the summer are close to the defined target flows. This is a direct consequence of the target HOF and %TAKE values selected and implies that the impacts of the existing abstractions are acceptable but that there is little or no surplus for further abstraction during the summer.

The situation for the larger catchment area to Samlesbury is similar. For long term average conditions and using abstraction data based on returns results indicate little scope for further abstraction during the summer months, see Table 3.3. Indeed comparison of available returns and licensing data indicate that uptake is typically in the region of 50% of the total licensed volumes. Were each of the abstractions to draw the maximum licensed volume then results indicate significant deficits during May, June and July even under long term average conditions. Under drought conditions (1995) then abstraction of the licensed volumes is estimated to result in significant deficits from April through to December.

However for both the Arnford and Samlesbury catchments there is some potential (i.e. a surplus) for further abstraction impacts during the winter months. Since the impacts of winter groundwater abstractions may persist into the summer months, and as a result of the general lack of major aquifers in the Ribble catchment to Samlesbury, this could only be effectively managed as a surface water licence with controls based on gauged flows at Samlesbury (as advocated in SWALP).

Although not essential for the derivation of the main ARM outputs in gauged catchments, attempts were briefly made in both of the Ribble assessments to reconcile the gauge naturalised flows with natural flows derived from rainfall and catchment runoff. The aquifer response function (ARF) model provided within the spreadsheets was used for convenience although its assumptions are clearly oversimplistic for a surface water dominated catchment which includes reservoirs. In view of the lack of any water level or other evidence the groundwater catchment has been assumed to be equal to the surface water catchment area.

The lengths of rivers to Arnford and Samlesbury were taken from maps and other tabulated information included in the River Ribble Catchment Management Plan (Ref: EA March 1995). Effective rainfall data were derived from potential evapotranspiration and rainfall data (provided by the EA) using the Grindley method as MORECS data were not readily available. For all assessments 10 years of effective rainfall data were used to derive the natural flow responses.

Since the Ribble catchment area contains a number of different geological units estimating representative hydrogeological parameters for the catchment as a whole is not a straightforward process. In view of this initial guesses of transmissivity and specific yield were applied. In order to achieve a balance between the two estimates of natural flows it was necessary to adjust a number of the ARF parameters and in the majority of cases the effective rainfall totals. The values of these 'best fit' parameters differed according to the year assessed.

Thus, although it does appear possible to achieve a reasonable comparison between naturalised gauge data and rainfall derived outflow estimates, little confidence should be associated with the application of the ARF model in these catchments.

Table 3.3 Abstraction Demand Profiles (from Anglian Region Best Practice Guidelines)

Use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PWS	0.8	0.9	1.0	1.1	1.1	1.2	1.2	1.1	1.0	0.9	0.9	0.8
IA	0.0	0.0	0.0	0.0	2.4	4.0	4.0	1.6	0.0	0.9	0.0	0.0

PWS - Public Water Supply Abstraction
IA - Spray Irrigation Abstraction

Table 3.4 R Ribble to Arnford: Surplus/Deficits (Ml/d)

	LT Average Year	Estimated Actual Abstraction Drought Year (1995)	Typical Year (1997)
Jan	259	375	40
Feb	199	370	465
Mar	198	224	149
Apr	94	39	33
May	50	8	111
Jun	50	17	19
Jul	50	6	14
Aug	90	-5	13
Sep	114	13	101
Oct	206	43	113
Nov	222	66	132
Dec	264	38	294
Average (as % of naturalised flows)	150 (24%)	98 (23%)	121 (23%)

Table 3.5 R Ribble, Arnford to Samlesbury: Surplus/Deficits (Ml/d)

	Estimated Actual Abstraction			Abstractions = Licensed Totals (assuming 50% uptake)		
	LT Avg Year	Drought Year (1995)	Typical Year (1997)	LT Avg Year	Drought Year (1995)	Typical Year (1997)
Jan	1065	1895	39	923	1777	-89
Feb	672	1414	1669	502	1273	1515
Mar	701	877	527	532	737	375
Apr	279	113	53	91	-43	-117
May	87	-4	480	-95	-156	315
Jun	92	-39	22	-110	-206	-160
Jul	93	-59	-13	-102	-222	-191
Aug	258	-85	22	76	-237	-143
Sep	325	-25	293	152	-170	136
Oct	792	18	308	637	-112	168
Nov	869	100	444	709	-33	300
Dec	1072	92	1129	931	-26	1001
Average (as a % of naturalised flows)	525 (18%)	353(17%)	406(17%)	354(11%)	210(9%)	251(10%)

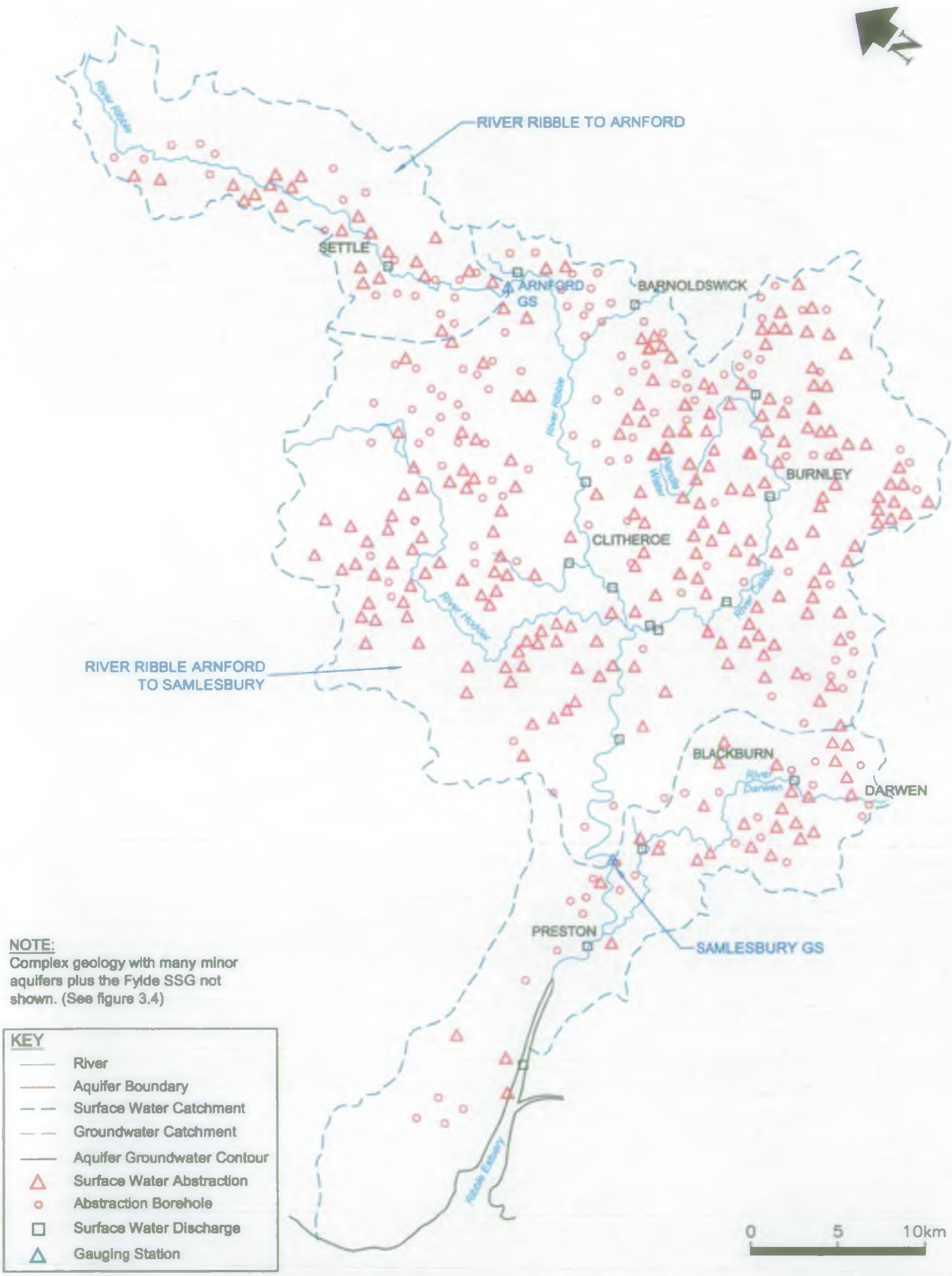


FIGURE 3.3 RIBBLE CATCHMENT AREA

Drawing No: 02019-01.S007 Date: AUGUST 1999 Scale: AS SHOWN

Entec

ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area R Ribble to Arnford GS **ID** 0 **Ver** 0 **Rev** 0 **Date** 19/8/99

Specified Assessment Year L T Average Year (1980-1998)

1 Headline Assessment Results Summary

1.1 Annual Gauged Inflows, Gauged Outflows & Naturalised Gauged Outflows

Annual Average Gauged Inflows =	0	Ml/d
Annual Average Gauged Outflow =	637	Ml/d
Annual Average Naturalised Gauged Outflow =	636	Ml/d

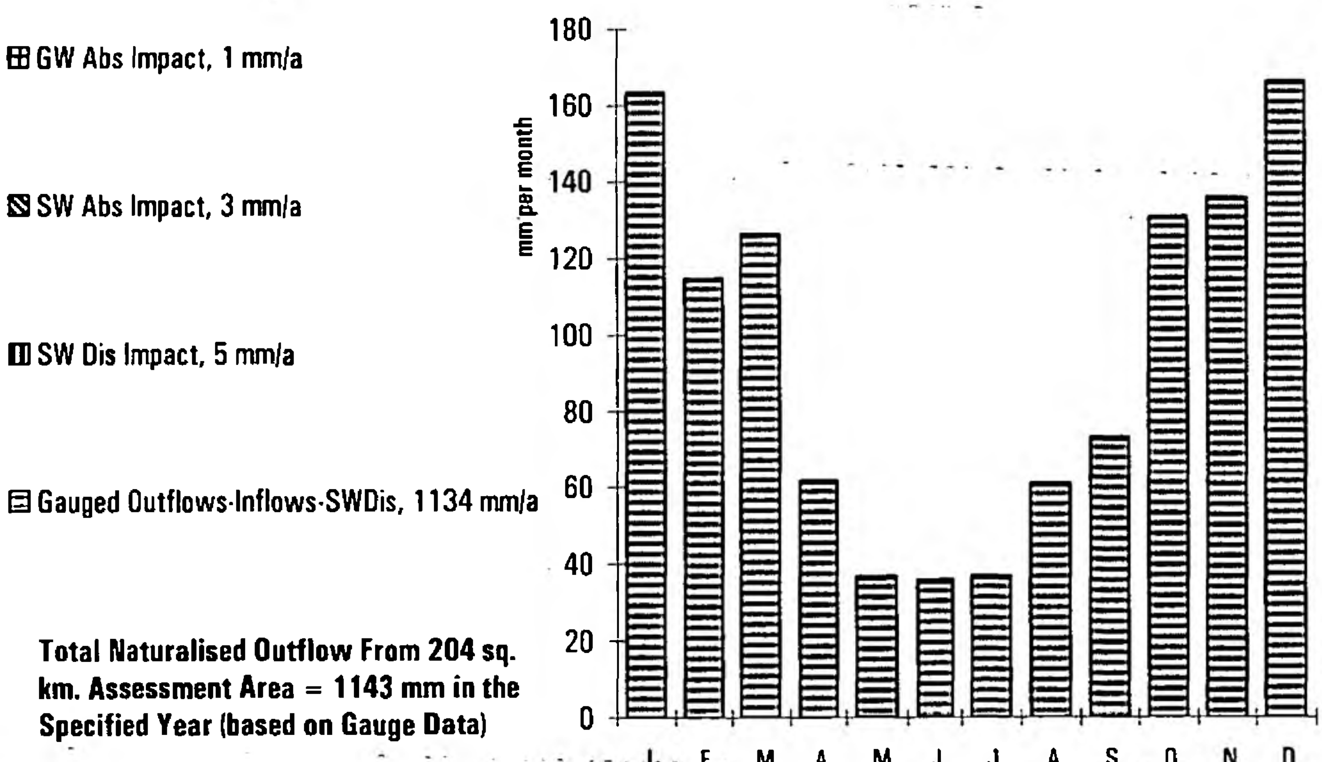
1.2 Components of Naturalised Flows Derived from the Assessment Area (i.e. Excluding Inflows) Expressed in mm Over Gauged SW Catchment

SW Catchment Area Assessed = 204 square kilometres

Component, Annual Total	J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 1 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
SW Abs Impact, 3 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
SW Dis Impact, 5 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
Gauged Outflows-Inflows-SWDis, 1134 mm/a	163	114	126	61	36	35	36	60	73	130	135	166

Total Naturalised Outflow From 204 sq. km. SW Catch. Area = 1143 mm in the Specified Year (based on Gauge Data)

Abs & Dis are ESTIMATED ACTUAL at 1980-98 av



ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

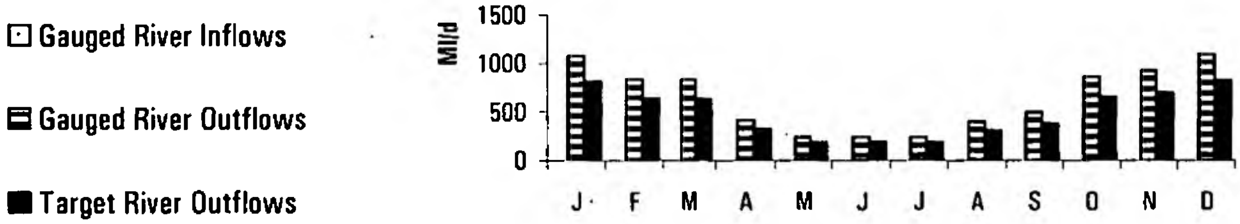
Area R Ribble to Arnford GS **ID** 0 **Ver** 0 **Rev** 0 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1980-1998)**

1.3 Existing and Target Outflows for Specified Year, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Gauged River Inflows	0	Ml/d	0	0	0	0	0	0	0	0	0	0	0	0
Gauged River Outflows	637	Ml/d	1074	834	830	417	239	241	240	399	496	860	923	1093
Target River Outflows	487	Ml/d	815	635	632	323	189	191	190	309	382	654	701	829

Min. Target = 189 **Ml/d** Monthly HOF 41 Ml/d TAKE 25 % (cf Q95 41 Ml/d)



Target Flows based on: Monthly HOF = gauged Q95, TAKE = 25% of naturalised flow

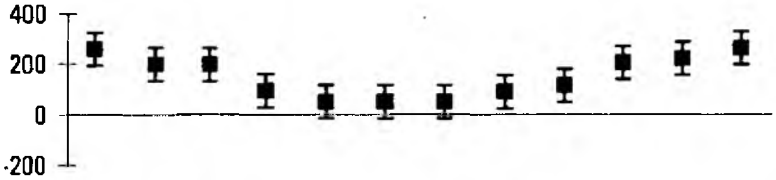
1.4 Surplus or Deficits for Specified Year, Ml/d

J	F	M	A	M	J	J	A	S	O	N	D
259	199	198	94	50	50	50	90	114	206	222	264

Ann Av 150 **Ml/d**

Minimum 50 **Ml/d**

Uncertainty +/- 66 **Ml/d**



Annual Average Surplus or Deficit is 24% of the Av. Naturalised Gauged Outflow

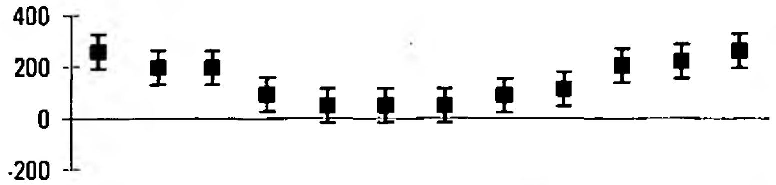
1.5 Acceptable Abs. Impacts for Spec. Year, Given Target Outflows and Existing Inflows

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	258	198	197	94	49	50	50	89	114	204	220	263

Ann Av 149 **Ml/d**

Minimum 49 **Ml/d**

Uncertainty +/- 66 **Ml/d**



	J	F	M	A	M	J	J	A	S	O	N	D
Acc. impacts/nat. gauged outflows, %	24	24	24	23	21	21	21	22	23	24	24	24

1.6a During this year, **max. existing consumptive abstraction impacts were** 0 %
of naturalised gauged river outflows in the month of Feb
(calculated from gauged river outflows + cons. abstraction impacts).

1.6b During this year, **max. existing consumptive abstraction impacts were** 0 %
of natural outflows derived from the assessment area in the month of Feb
(calculated from eff.rain. and area hydraulic response characteristics).

ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area R Ribble, Arnford to Samlesbury **ID** 0 **Ver** 0 **Rev** 0 **Date** 19/8/99

Specified Assessment Year L T Average Year (1980-1998)

1 Headline Assessment Results Summary

1.1 Annual Gauged Inflows, Gauged Outflows & Naturalised Gauged Outflows

Annual Average Gauged Inflows =	637	Ml/d
Annual Average Gauged Outflow =	2852	Ml/d
Annual Average Naturalised Gauged Outflow =	2972	Ml/d

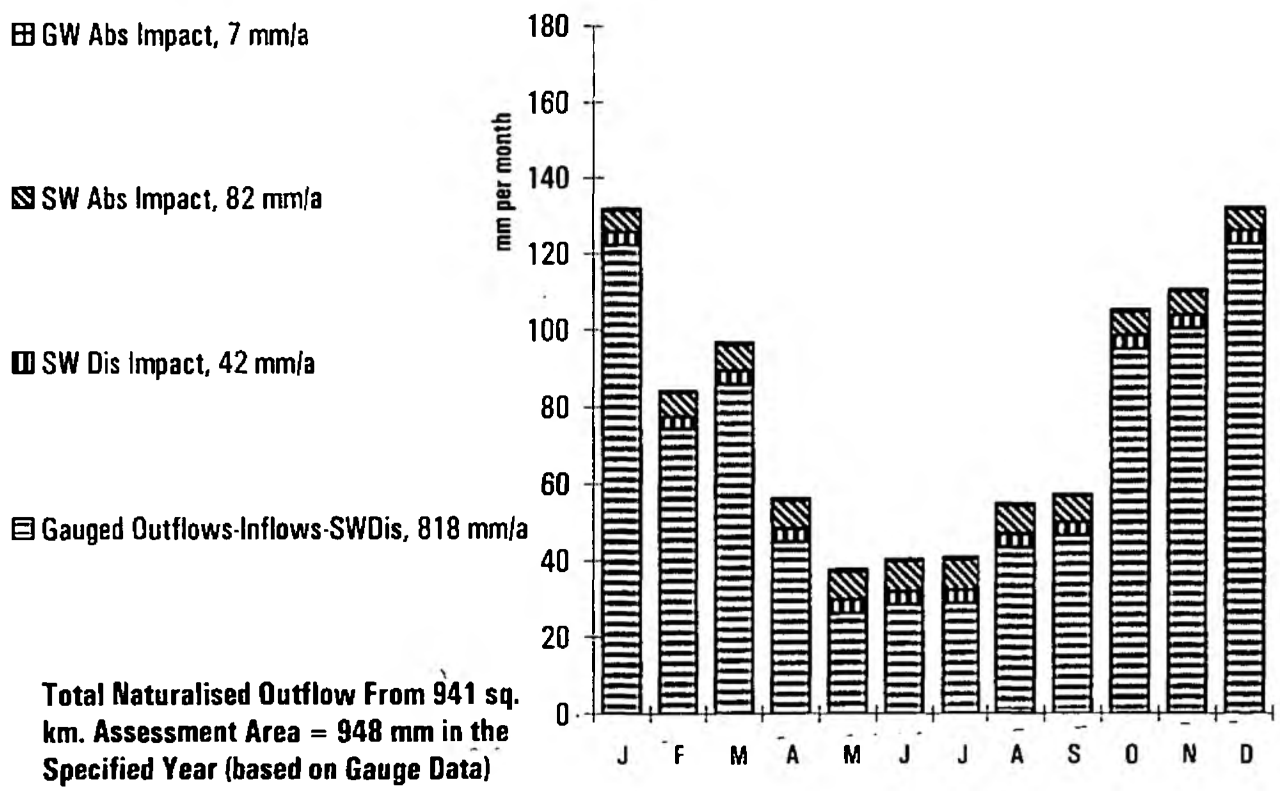
1.2 Components of Naturalised Flows Derived from the Assessment Area (i.e. Excluding Inflows) Expressed in mm Over Gauged SW Catchment

SW Catchment Area Assessed = 941 square kilometres

Component, Annual Total	J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 7 mm/a	1	1	1	1	1	1	1	1	1	1	1	1
SW Abs Impact, 82 mm/a	6	6	7	7	7	8	8	7	7	6	6	6
SW Dis Impact, 42 mm/a	4	3	4	3	4	3	4	4	3	4	3	4
Gauged Outflows-Inflows-SWDis, 818 mm/a	122	74	86	45	26	28	29	43	46	95	100	123

Total Naturalised Outflow From 941 sq. km. SW Catch. Area = 948 mm in the Specified Year (based on Gauge Data)

Abs & Dis are ESTIMATED ACTUAL at 1980-98 av



ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

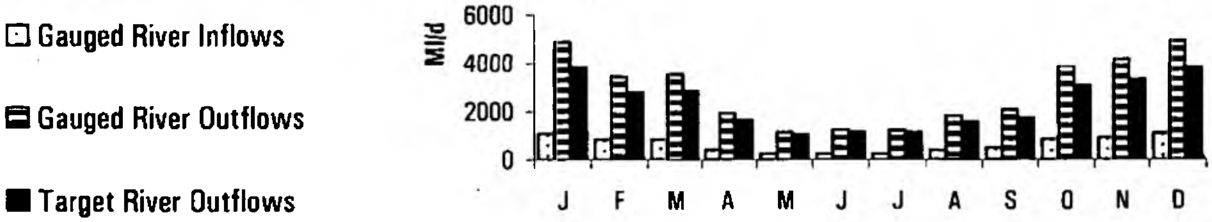
Area R Ribble, Arnford to Samlesbury **ID** 0 **Ver** 0 **Rev** 0 **Date** 19/8/99

Specified Assessment Year L T Average Year (1980-1998)

1.3 Existing and Target Outflows for Specified Year, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Gauged River Inflows	637	Ml/d	1074	834	830	417	239	241	240	399	496	860	923	1093
Gauged River Outflows	2852	Ml/d	4890	3434	3541	1929	1140	1236	1217	1822	2060	3852	4179	4919
Target River Outflows	2327	Ml/d	3825	2762	2840	1650	1053	1145	1124	1565	1735	3060	3310	3847

Min. Target = 1053 **Ml/d** Monthly HOF 390 Ml/d TAKE 25 % (cf Q95 390 Ml/d)



Target Flows based on: Monthly HOF = gauged Q95, TAKE = 25% of naturalised flow

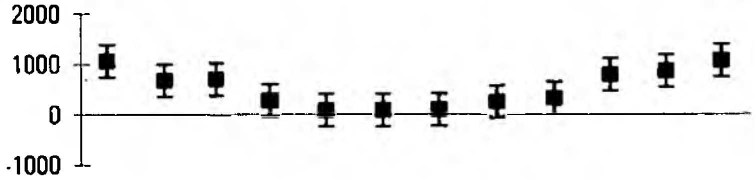
1.4 Surplus or Deficits for Specified Year, Ml/d

Ann Av 525 **Ml/d**

J	F	M	A	M	J	J	A	S	O	N	D
1065	672	701	279	87	92	93	258	325	792	869	1072

Minimum 87 **Ml/d**

Uncertainty +/- 324 **Ml/d**



Annual Average Surplus or Deficit is 18% of the Av. Naturalised Gauged Outflow

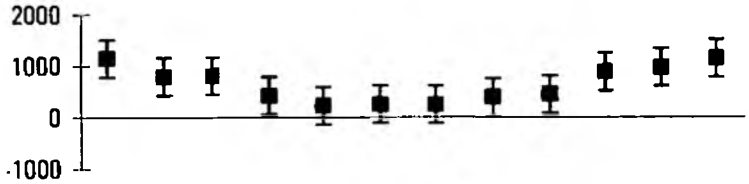
1.5 Acceptable Abs. Impacts for Spec. Year,Given Target Outflows and Existing Inflows

Ann Av 646 **Ml/d**

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	1145	791	817	420	221	252	245	392	448	890	973	1152

Minimum 221 **Ml/d**

Uncertainty +/- 368 **Ml/d**



	J	F	M	A	M	J	J	A	S	O	N	D
Acc. impacts/nat. gauged outflows, %	23	22	22	20	17	18	18	20	21	23	23	23

1.6a During this year, **max. existing consumptive abstraction impacts were** 11 % **of naturalised gauged river outflows in** the month of Jun (calculated from gauged river outflows + cons. abstraction impacts).

1.6b During this year, **max. existing consumptive abstraction impacts were** 15 % **of natural outflows derived from the assessment area in** the month of Jul (calculated from eff.rain. and area hydraulic response characteristics).

3.4 Fylde Aquifer Trial

3.4.1 Area Delineation, Description and Issues

In addition to the assessment of the two gauged river catchments to Arnford and Samlesbury a separate study of the Fylde aquifer unit has also been carried out using the Groundwater Outflow spreadsheet. This aquifer has recently been the subject of a detailed groundwater modelling exercise which indicated significant over abstraction.

Figure 3.4 shows a conceptual sketch plan and cross section of the Fylde Sherwood Sandstone aquifer which extends northwards from Preston as far as Morecombe Bay and underlies part of the Ribble and Wyre surface water catchments.

As the only major aquifer in the area the Fylde sandstones represent an important source of water for public water supply and industrial use. Data provided by the Agency indicates annual average abstractions of 33.9 Ml/d over the period 1980-1997 with demand generally much greater during summer months reflecting the use of the aquifer as part of conjunctive surface water and groundwater management at a regional level. The Permo-Triassic Sandstones of the aquifer are characterised by a series of parallel faults resulting in a Horst and Graben type structure which combined with the presence of marl layers results in what is considered to be a highly compartmentalised aquifer. However evidence from observation wells indicates that groundwater levels have typically been falling gradually since the 1970s and concerns have been raised about the potential impact on flows in the Rivers Ribble and Wyre and in relation to saline intrusion as water levels drop below the confining boulder clay layer.

Groundwater quality in the Fylde aquifer is typically good except in the vicinity of the Ribble estuary where high salinities can be encountered.

3.4.2 Workbook Selection and Names

For the most part the Fylde aquifer is overlain by a thick layer of boulder clay which acts to protect the aquifer from potential sources of pollution and limits groundwater/surface water interaction. All calculations for this sandstone unit have therefore been carried out based on the GW Outflow Calcs template, GWOUT.XLT. The basic assessment has been carried out for the block as a whole which has well defined boundaries and the simple assumption has been made that recharge is the only input to this block, with natural outflows reduced by groundwater abstraction.

Area Delineation	Excel Workbook Template Used	Filename Extension
Fylde Aquifer	GW Outflows, GWOUT.XLT	FYLD****1.XLS

where **** is the year assessed.

3.4.3 Assessment Years

In common with the approach used for the Ribble catchment three separate assessments were carried out on the Fylde aquifer using input data for the following years:

- a long term average year, LTAV (1980-1998);
- a 'drought' year, 1995;
- a climatically 'typical' year, 1997.

3.4.4 Key Assumptions

Natural Outflows from Effective Rainfall and Recharge Assumptions

The first step of the Fylde aquifer assessment was to estimate natural groundwater outflows from the block based on assumed recharge inputs using the ARF approach provided in the spreadsheet.

Recharge to the aquifer was initially calculated using data from the Fylde groundwater model on leakance through the overlying boulder clay to the sandstones (amounting to an average of 37 Ml/d). However comparison of this recharge data with plots of abstraction rates from the aquifer indicate a strong correlation between the two suggesting that leakance from the confining drift above is being induced by abstraction from the aquifer beneath. This calls into question one of the basic assumptions of the simple ARM framework - that natural recharge resources are independent of the abstraction stresses placed on them.

In order to continue with the assessment the existence of the thick drift cover was used to make the further crude assumption that the natural long term annual average recharge (40 mm/a) would be distributed evenly throughout all years in the absence of abstraction (i.e. a constant natural recharge value of 3.3 mm/month). In the absence of the previous groundwater modelling study it would also have been necessary to make assumptions concerning the long term average resource based on known abstractions and the observed groundwater level responses. However, such an approach inevitably pre-determines the outcome of the assessment on the basis of the user's perceptions of resource commitment.

Regional transmissivity and specific yield values of 200 m^2/d and 0.003 respectively were taken directly from the groundwater model. The length of boundary considered on average to drain water from the aquifer was based on information provided by the Agency which indicated two main discharge boundaries, Morecombe Bay to the north and the Ribble estuary to the south, with a combined length of 17.5 km. These parameters result in a long estimated aquifer response time of 1374 days although this has little bearing on the profile of natural groundwater outflows derived which is effectively steady state because of the assumed steady state recharge.

Consumptive Abstraction Impacts

Groundwater abstraction for public water supply and industrial use is the only significant anthropogenic impact on the water balance of the Fylde aquifer. These abstractions are treated as fully consumptive losses as all treated effluent discharges are to the sea.

Reference to water level plots for observation boreholes within the Fylde aquifer indicate a gradual long term decline in water levels. Superimposed on this gradual long term decline are summer troughs corresponding to public water supply abstractions being turned on and off to meet short term shortfalls in supply. In isolation such short term variations in abstraction will cause localised lowering of water levels in the aquifer and overlying drift without necessarily having an immediate impact on outflows from the aquifer. In assessing the long term sustainability of abstractions it has been simply assumed that aquifer storage can fully smooth the seasonality of the demands such that impacts on outflows (as recharge) are steady state averages (i.e. 34 Ml/d). Actual abstraction rates were provided by the Agency from the Fylde groundwater model for the period 1980-1997. The short term effect of increased annual abstractions during drought years such as 1995 is highlighted within the spreadsheets in terms of the estimated water table drawdown implied by the difference between the actual abstraction rate and the assumed long term steady state impact of abstractions on outflows.

Target Flows

The key factor to be considered when setting outflow protection targets for the Fylde aquifer is the volume of groundwater discharge required to prevent saline intrusion from the Ribble estuary and Morecombe Bay. Once again a steady state value of 5 Ml/d has been arbitrarily selected without detailed knowledge of the groundwater model results and has a high degree of associated uncertainty.

3.4.5 Discussion of Results

The first two pages of LTAV headline results for the Fylde assessment follow this Section. As for all the First Draft trials the 3rd page which asks the user to interpret the sustainability status of the area has been omitted pending further discussion with the Agency. Table 3.6 summarises the monthly surplus and deficits derived from the assessments which, because of the steady state assumptions adopted, are the same for all years. Full copies and plots for all the assessments are included in Appendix A.

The assumptions made throughout the assessment suggest that existing outflows are considered to be slightly below the target outflows and that a near balance situation exists between actual long term abstractions and recharge. Where annual abstractions from the aquifer exceed the long term abstraction rate of 34 Ml/d then short term declines in groundwater level are expected (Table 3.7). Existing outflows are considered to be marginally below the target outflows required to prevent saline intrusion problems from the Ribble estuary.

Annual average total licensed abstractions from the Fylde aquifer unit are around 111 Ml/d. According to the assessment assumptions such an abstraction rate is not sustainable in the long term and hence the aquifer appears to be over licensed by around 217% (see Table 3.6). In the short term were all abstractions to pump at their licensed rate for a single year then a fall in water level of around 28 m is predicted. This drop could be reversed in the longer term providing long term average abstractions remained below around 34 Ml/d.

This assessment highlights the many difficulties and uncertainties which can be encountered when attempting to quantify the water balance of a confined aquifer where recharge is controlled by the properties of the Drift and can be enhanced by abstraction, and where it is not possible to measure groundwater outflows. Although it is possible to carry out an assessment within the ARM framework (and to a nationally consistent format), the output is almost entirely pre-determined by the assumptions made by the user. Inevitably, the practical management of water resources in such a unit is heavily dependent on the observed response of water levels and quality to abstraction and may only be facilitated through more sophisticated approaches such as the groundwater model which has already been constructed.

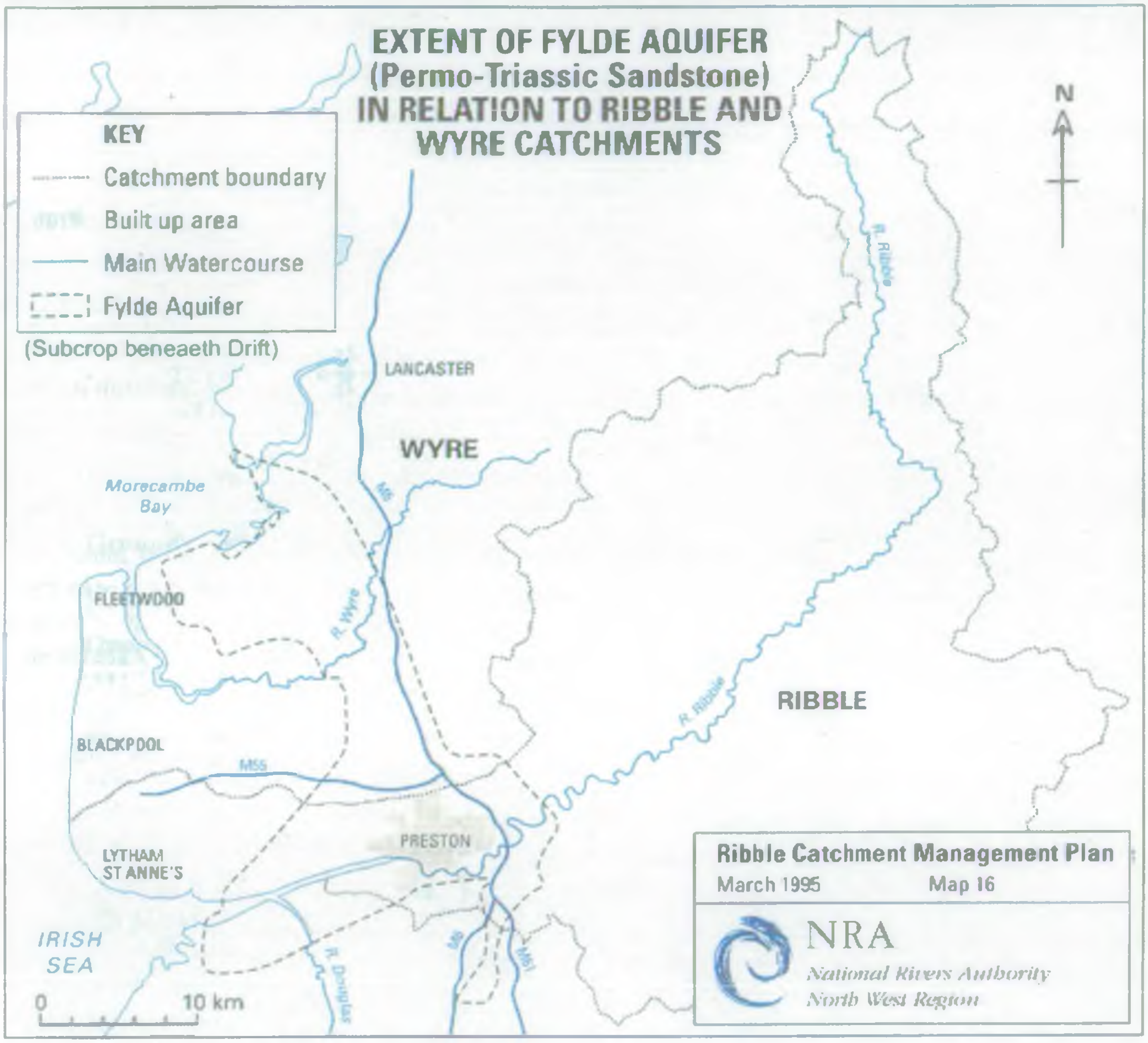
Given that the groundwater model for the Fylde does exist, it should be used as the main tool for investigating the sustainability of abstraction management.

Table 3.6 The Fylde SSG Aquifer Surplus/Deficits (Ml/d)

Month	Long Term Average Year (Abstractions = Actual)	Long Term Average Year (Abstractions = Licensed)
January	-2	-79
February	-2	-79
March	-2	-79
April	-2	-79
May	-2	-79
June	-2	-79
July	-2	-79
August	-2	-79
September	-2	-79
October	-2	-79
November	-2	-79
December	-2	-79
Average (% of natural inflows)	-2 (-6%)	-79 (-217%)

Table 3.7 The Fylde SSG Aquifer Implied Annual Water Level Rise/Fall (m)

Assessment Year	Water Levels Rise/Fall (Abstractions = Actual)
Long Term Average Year	0.03
Drought Year (1995)	-6.29
Typical Year (1997)	6.65



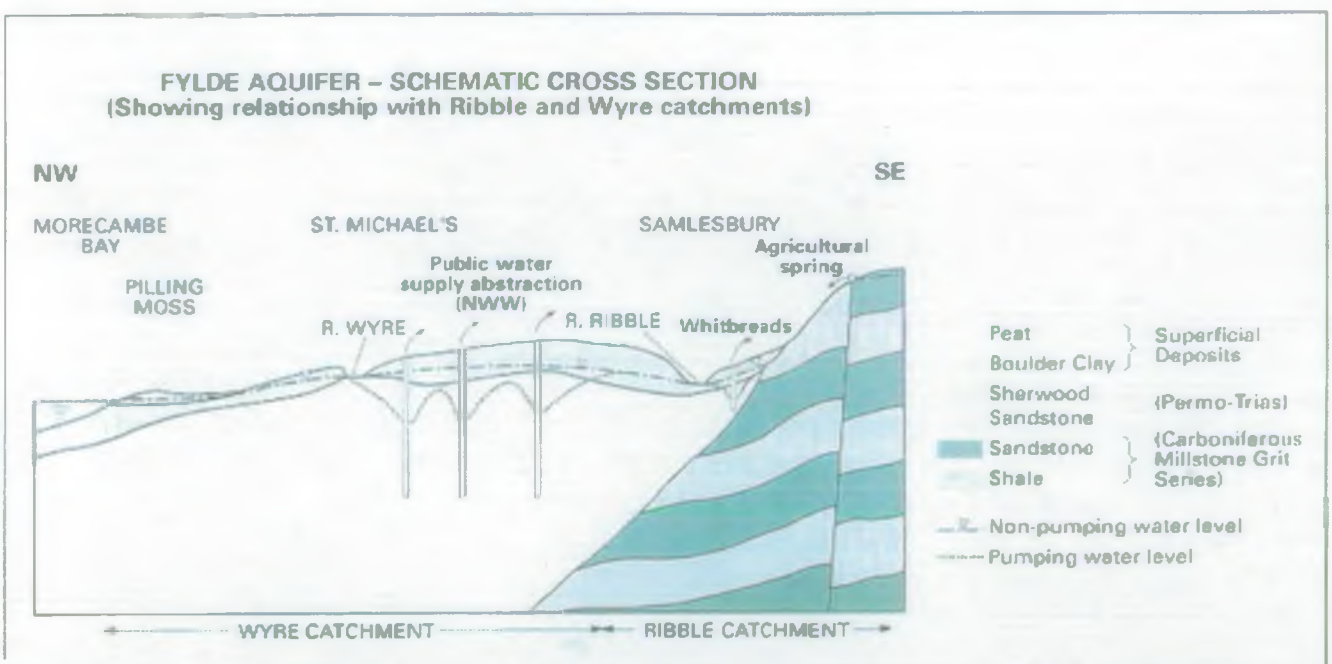


FIGURE 3.4 FYLDE AQUIFER ASSESSMENT AREA SKETCH PLAN AND CROSS SECTION

Drawing No: **02019-01.S008** Date: **AUGUST 1999** Scale: **AS SHOWN**

Entec

ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area The Fylde SSG Aquifer **ID** 0 **Ver** 0 **Rev** 0 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1980-1998)**

1 Headline Assessment Results Summary

1.1 Annual Gauged Inflows, Gauged Outflows & Naturalised Gauged Outflows

Annual Average Existing GW Outflow = 3 Ml/d
Annual Average Natural GW Outflow = 37 Ml/d

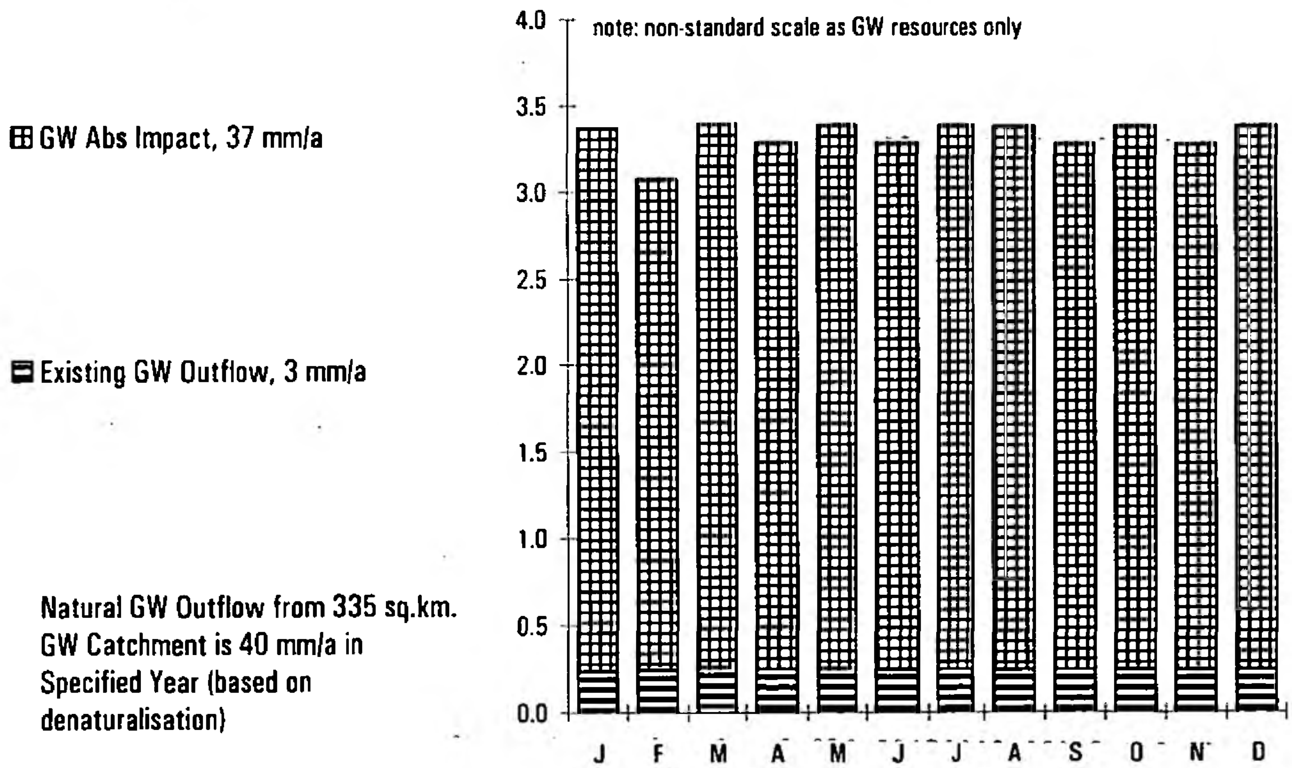
1.2 Components of Natural GW Outflow Expressed in mm Over GW Catchment

GW Catchment Area Assessed = 335 square kilometres

Component, Annual Total	J	F	M	A	M	J	J	A	S	O	N	D
Existing GW Outflow, 3 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
GW Abs Impact, 37 mm/a	3	3	3	3	3	3	3	3	3	3	3	3
Natural GW Outflow, 3 mm/a	3	3	3	3	3	3	3	3	3	3	3	3

Natural GW Outflow from 335 sq.km. GW Catchment is 40 mm/a in Specified Year (based on denaturalisation)

Abs & Dis are ESTIMATED ACTUAL at 1980-97 av



ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area The Fylde SSG Aquifer **ID** 0 **Ver** 0 **Rev** 0 **Date** 19/8/99

1.3 Existing and Target Outflows for Specified Year, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Existing GW Outflows	3	Ml/d	3	3	3	3	3	3	3	3	3	3	3	3
Target GW Outflows	5	Ml/d	5	5	5	5	5	5	5	5	5	5	5	5

Min. Target = 5 **Ml/d**

Target Flows based on: Constant GW outflow required to prevent saline intrusion

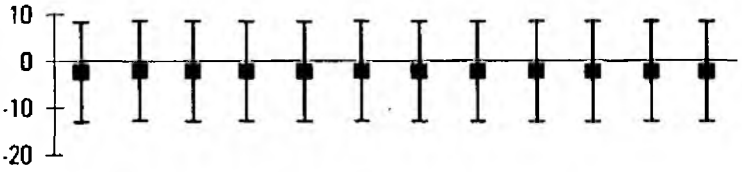
1.4 Surplus or Deficits for Specified Year, Given Target Outflows

J	F	M	A	M	J	J	A	S	O	N	D
-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2

Ann Av -2 **Ml/d**

Minimum -2 **Ml/d**

Uncertainty +/- 11 **Ml/d**



Annual Average Surplus or Deficit is -6% of the Av. Naturalised Gauged Outflow

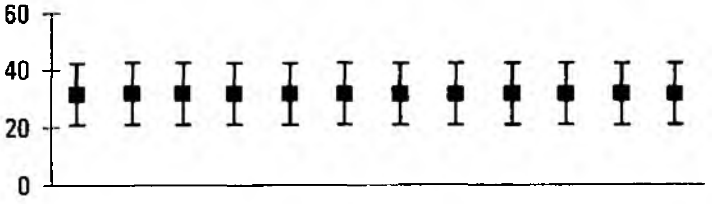
1.5 Acceptable Abs. Impacts for Spec. Year, Given Target Outflows and Existing Inflows

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	31	32	32	32	32	32	32	32	32	32	32	32

Ann Av 32 **Ml/d**

Minimum 31 **Ml/d**

Uncertainty +/- 11 **Ml/d**



Acc. impacts/natural GW outflows, %	86	86	86	86	86	86	86	86	86	86	86	86

1.6 During this year, **max. existing consumptive abstraction impacts were** 93 % **of natural outflows derived from the assessment area in** the month of **Jan** (calculated from eff.rain. and area hydraulic response characteristics).

3.5 River Teifi Catchment Trials

3.5.1 Area Delineation, Description and Issues

Figure 3.5 shows a sketch plan of the River Teifi catchment which is the CAMS trial area in west Wales (Hydrometric Area No 62).

For the purposes of the ARM assessment two sub-areas of the Teifi catchment area were delineated in consultation with Agency staff, namely:

- the upper River Teifi to Llanfihangel Bridge;
- the middle River Teifi from Llanfihangel Bridge to Glanteifi gauging station.

The gauging station at Glanteifi is the nearest available gauging station to Cardigan Bay and drains a catchment area of some 894 km^2 which represents the majority of the total 1012 km^2 Teifi catchment. The Teifi at Llanfihangel Bridge drains a smaller 448 km^2 sub-catchment area and existence of the Llanfair gauging station just downstream of the Bridge provides the opportunity to consider the upper catchment separately.

The geology of the Teifi catchment consists of Silurian and Ordovician mudstones overlain by glacial drift deposits. The drift was deposited by two different ice sheets resulting in two characteristic types of overburden. In the upper Teifi area upstream of Llanfihangel Bridge the drift was deposited by the Welsh ice sheet and contains significant fluvio-glacial sand and gravel deposits. To the south of the Llanfihangel Bridge, in the middle and lower Teifi catchment area the drift coverage is less persistent and generally contains a higher proportion of lower permeability boulder clay type material. Table 3.8 presents a summary of drift characteristics and coverage in the two assessment areas (all data supplied by EA Wales).

Land use in the rural Teifi catchment area is mainly agricultural. Groundwater and surface water abstraction volumes are relatively minor and are used predominantly for public water supply and agriculture. As a result of the low permeability of the bedrock and the overlying superficial deposits the majority of the catchment is considered a non-aquifer and is therefore licence exempt. Groundwater abstractions are only licensable in part of the upper Teifi catchment where the presence of significant sand and gravel deposits within the drift form a minor aquifer. Outside of this small area only abstractions for public water supply, hydropower or industrial use are licensable and hence there are a potentially large number of agricultural groundwater abstractions for which little or no information is available.

Information from the Teifi Local Environment Agency Plan (LEAP) (Ref: Local Environment Agency Plan, Teifi Valley, January 1999, EA Wales) indicates that public water supply forms by far the largest consumptive use within the catchment and comes from four main sources:

- The Teifi at Llechryd. A direct abstraction from the Teifi just upstream of the village of Llechryd (and immediately downstream of the Glanteifi gauging station). Total licensed volume = 19 Ml/d and 5751 Ml/a;
- Teifi Pools. A direct abstraction from the Teifi Pools in the headwaters of the Teifi catchment to the east Pontrhydfendigaid. Total licensed volume = 3300 Ml/a;

- Olwen Borehole. Groundwater abstraction from a single borehole in alluvial gravels near Lampeter. Total licensed volume = 0.4 Ml/d and 144 Ml/a;
- Pencefn. A spring source to the west of Tregaron. Total licensed volume = 0.21 Ml/d and 6 Ml/a.

The only other consumptive use of groundwater and surface water within the Teifi catchment is agricultural. Information from the LEAP indicates a total of 6 spray irrigation licences totalling 44.2 Ml/a and 56 small agricultural licenses totalling 77.6 Ml/a. In addition to these licensed abstractions EA estimates indicate around 3.2 Ml/d of unlicensed agricultural abstractions from the Teifi catchment (1.7 and 1.5 Ml/d in the upper and middle Teifi areas respectively).

Across the catchment there are also a large number of very small surface water discharges where domestic effluent is returned to the river.

Despite these low levels of abstraction, concerns have been expressed concerning perceived impacts on river flows and consequent effects on fish populations.

3.5.2 Workbook Selection and Names

It would be possible to carry out an ARM assessment for the whole Teifi catchment to the gauging station at Glanteifi. This would however overlook the opportunity to consider the upper and middle catchments separately, as these have contrasting drift characteristics. Flow gauging data from the station at Llanfair can be pro-rated according to catchment area to assess the water balance to Llanfihangel Bridge and to set target flows for the upper Teifi catchment area from which the majority of the licensed agricultural abstractions occur. For this reason assessments have been carried out for the upper Teifi to the Llanfihangel Bridge (upstream of the Llanfair gauging station) and for the middle Teifi from Llanfihangel Bridge to Glanteifi. The spreadsheet type and filenames of the two areas assessed are summarised below:

Area Delineation	Excel Workbook Template Used	Filename
Teifi to Llanfihangel Bridge	Gauged River, GRIV.XLT	LLAN****1.XLS
Teifi, Llanfihangel to Glanteifi	Gauged River, GRIV.XLT	GLAN****1.XLS

where **** is the specific year assessed.

3.5.3 Assessment Years

For each of the two assessment areas three separate assessments were carried out using input data for the following years:

- a long term average year, LTAV (1980-1998);
- a drought year, 1995;
- a climatically 'typical' year, 1997.

3.5.4 Key Assumptions

Synthesis of River Flow Series for Llanfihangel Bridge

River flows are available for the Glanteifi gauging station throughout the period of the long term average assessment but, in the absence of a gauging station at Llanfihangel Bridge it has been necessary to synthesise flows from records at the nearby Llanfair gauge.

Flow data from Llanfair are only available over an 11 year period (1971-1982). In order to produce a continuous monthly time series over the period 1980-1998 it was therefore necessary to generate a synthetic data set for this station. This was achieved by correlating flows at Llanfair and Glanteifi over the period of overlap in order to produce a regression relationship between the two data sets (see below), which enabled the Llanfair record to be extended from recorded flows at Glanteifi.

$$Y = 0.546\,X + 67.517 \qquad (\text{Adjusted } R^2 \text{ value} = 0.97)$$

Where: Y = Mean estimated monthly flow at Llanfair (Ml/d)

X = Mean recorded monthly flow at Glanteifi (Ml/d)

Flows generated using the above equation were then further adjusted by a factor of 0.82 which reflects the fact that Llanfihangel Bridge is slightly upstream of the gauging station at Llanfair. The catchment to the bridge is 448 km^2 whereas the catchment to the gauging station is 546.5 km^2 (448/546.5 = 0.82).

Consumptive Abstraction Impacts

Data on annual actual surface and groundwater abstractions and licensed totals for the Teifi catchment were provided by EA Wales for the period 1980-1998. For the purposes of the current study it has been conservatively assumed that all abstractions are operating at their annually licensed limit. Furthermore the surface water abstraction from the Teifi at Llechryd was assumed to be upstream of Glanteifi and has therefore been included in the resource balance for the middle Teifi. This abstraction is in fact just downstream of Glanteifi and therefore outside of the assessment area.

Further calculations were carried out by Entec in order to estimate monthly abstractions from the annual licensed totals for spray irrigation and public water supply abstractions based on the Anglian Region guideline demand factors (Table 3.3). For all other uses monthly abstractions were distributed evenly throughout the year by dividing the annual total by 12. Groundwater abstractions were conservatively assumed to impact on river flows during the month of pumping.

Surface water discharges from sewage treatment works within both assessment areas were calculated from information included in the Teifi LEAP showing the location of each sewage treatment works and the population served by each works. This data were converted into discharges assuming an outflow of 0.145 m^3/d/person (Ref. The Management of Water Resources in the Little Ouse Groundwater Unit, EA Anglian Region). Results indicate annual average discharges of 3.3 and 5.8 Ml/d in the upper and middle Teifi respectively.

All these conservative (and simple) flow naturalisation assumptions can be justified for the Teifi ARM assessments because anthropogenic influences are a very small part of the water balance.

Target Flows

For the purposes of the current study target flows for both of the trial areas have been set using a method comparable the SWALP concept in order to protect flow variability. The user specifies a minimum monthly flow (equivalent to the SWALP daily Hands Off Flow (HOF)) and a monthly % TAKE which limits how much of the naturalised flow above the HOF can be abstracted. Since no HOF data were available for the Teifi catchment values of 168 and 252 Ml/d have been adopted, which are the Q95 flows at Llanfihangel Bridge and Glanteifi respectively. A monthly TAKE of 25% of the naturalised flow above the HOF has also been assumed based on limited discussion with Agency staff. For the LTAV assessment this results in a minimum (summer) target flow of 308 Ml/d at Llanfihangel Bridge and 574 Ml/d at Glanteifi.

3.5.5 Discussion of Results

The first two pages of LTAV headline results for both of the assessment areas follow this Section. In both cases (as for all the First Draft trials) the 3rd page which asks the user to interpret the sustainability status of the area has been omitted pending further discussion with the Agency. Table 3.9 summarises the monthly surplus and deficits derived from the assessments of specific years. Full copies and plots for all the assessments are included in Appendix A.

For the upper Teifi catchment area estimated total licensed and unlicensed abstractions are around 10 Ml/d compared to an estimated mean annual flow at Llanfihangel Bridge of 1144 Ml/d. Results for the middle Teifi catchment demonstrate a similar pattern to those for the upper area. Abstractions total around 27 Ml/d which is around 1% of mean annual flow at Glanteifi. The stacked histogram plots for all assessed years in both areas clearly show how small anthropogenic influences are.

However, by basing target river flows on a monthly minimum HOF which is the historically gauged Q95 and a %TAKE of 25%, the user is effectively protecting the existing summer flows and indicating a potential for further abstraction (i.e. a surplus) at higher flows only. For the upper Teifi an annual average surplus of 239 Ml/d (21%) results from the LTAV assessment (Table 3.9) although, during the summer months, gauged outflows are close to the target flows. It should be noted that since a generated gauged flow series has been used for the upper Teifi catchment significant errors of up to +/- 246 Ml/d are indicated in the surplus/deficit calculations and hence the values shown in Table 3.9 should be viewed with particular caution.

For the middle Teifi the LTAV calculations indicate an average surplus of 534 Ml/d (22%) with scope for further abstraction in every month. However, particularly in drought years, gauged flows can approach or even drop below target levels during the summer months. As for the upper catchment significant errors of up to +/- 270 Ml/d are possible in the surplus/deficit results since the generated flow series for Llanfihangel Bridge represents an input to the middle Teifi area.

For both the upper and middle Teifi catchments the target flows set imply considerable potential for further abstraction impacts during the winter months. Since the impacts of winter groundwater abstractions may persist into the summer months, and as a result of the general lack of groundwater resources in the Teifi catchment, such additional abstractions could only be effectively managed by surface water licences with controls based on gauged flows at Glanteifi.

Although not essential for the derivation of the main ARM outputs in gauged catchments, attempts were briefly made in both of the Teifi assessments to reconcile the gauge naturalised flows with natural flows derived from rainfall and catchment runoff. The aquifer response function (ARF) model provided within the spreadsheets was used for convenience although its assumptions are clearly oversimplistic for a surface water dominated catchment. In view of the geology the groundwater catchment has been assumed to be equal to the surface water catchment area.

The lengths of rivers to for each assessment were provided by the Agency and were taken from 1:50 000 scale maps of the area. Effective rainfall data were also provided by the Agency in the form of MORECS data for squares 132, 133 and 144. For all assessments 10 years of effective rainfall data were used to derive the natural flow responses.

Initial estimates of hydrogeological parameters for the superficial Drift deposits (T = 150 m^2/d, S = 0.05) and the Ordovician/Silurian mudstones (T = 1 m2/d, S = 0.01) were provided by the Agency. However superficial deposits cover around 28 % of the upper Teifi catchment and approximately 12 % of the middle catchment. The ARF parameters used were therefore adjusted to reflect the general heterogeneity of the area and in order to achieve a balance between the two estimates of natural flows. In the majority of cases it was also necessary to adjust the effective rainfall series to achieve a balance. The values of these 'best fit' parameters differed according to the year assessed.

Thus, as for the Ribble, although it does appear possible to achieve a reasonable comparison between naturalised gauge data and rainfall derived outflow estimates, little confidence should be associated with the application of the ARF model in these catchments.

Table 3.8 Teifi Catchment Drift Characteristics

Drift Type	R Teifi to Llanfihangel Bridge Total Coverage (km^2)	R Teifi to Llanfihangel Bridge % of total Drift	R Teifi Llanfihangel Bridge to Glanteifi Total Coverage (km^2)	R Teifi Llanfihangel Bridge to Glanteifi % of total Drift
Fluvio-Glacial Sands & Gravels	35.5	28	14.9	28
Alluvium	16.4	13	5.8	10
Peat	13.9	1	-	-
Boulder Clay/Till	55.7	44	28.8	52
River Terrace	2.0	2	3.9	7
Alluvial Fan Material	1.2	1	1.2	2
Made Ground	0.7	0.5	0.8	1
Totals	125.5	100	55.3	100

Table 3.9 Teifi Catchment Area Calculated Surplus/Deficits (Ml/d)

	R Teifi to Llanfihangel Bridge (Abstractions = Licensed)			R Teifi Llanfihangel Bridge to Glanteifi (Abstractions = Licensed)		
	LT Avg Year	Drought Year (1995)	Typical Year (1997)	LT Avg Year	Drought Year (1995)	Typical Year (1997)
Jan	463	667	28	1005	1487	62
Feb	319	654	409	722	1463	914
Mar	321	335	157	719	750	351
Apr	197	66	22	421	150	50
May	102	30	138	202	66	308
Jun	81	23	134	165	53	301
Jul	45	-7	84	87	-15	188
Aug	81	-19	51	160	-44	114
Sep	120	-2	136	271	-5	305
Oct	319	92	178	723	203	398
Nov	434	272	617	959	608	1379
Dec	464	326	420	1036	727	938
Average (as a % of naturalised flows)	243 (21%)	201 (20%)	196 (20%)	539 (22%)	448 (21%)	438 (21%)

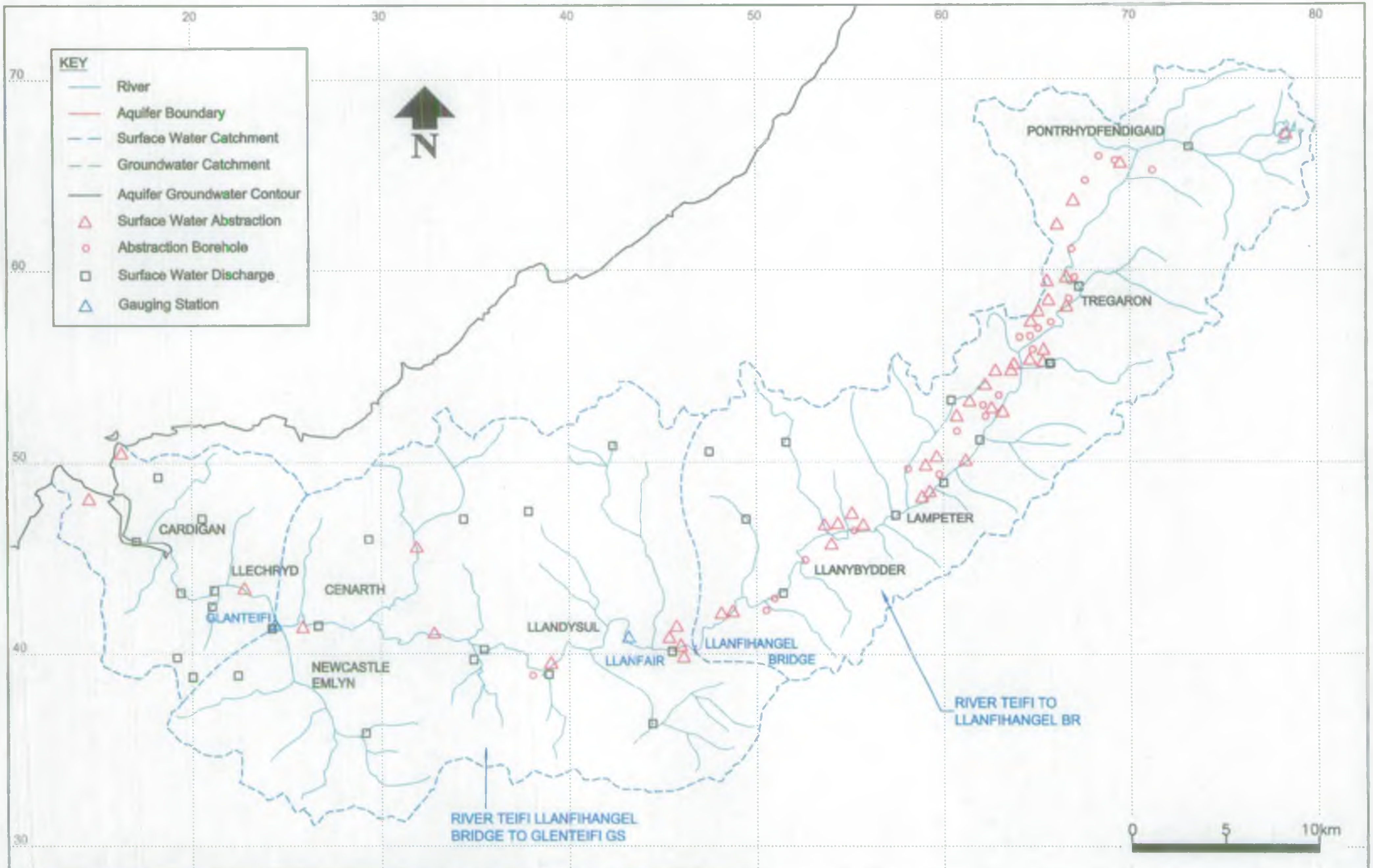


FIGURE 3.5 RIVER TEIFI ASSESSMENT AREAS SKETCH PLAN

Drawing No: 02019-01.S009 Date: AUGUST 1999 Scale: AS SHOWN

Entec

ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area R Teifi, Llanfihangel Bridge to Glanteifi **ID** 0 **Ver** 0 **Rev** 0 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1980-1998)**

1 Headline Assessment Results Summary

1.1 Annual Gauged Inflows, Gauged Outflows & Naturalised Gauged Outflows

Annual Average Gauged Inflows =	1144	Ml/d
Annual Average Gauged Outflow =	2451	Ml/d
Annual Average Naturalised Gauged Outflow =	2466	Ml/d

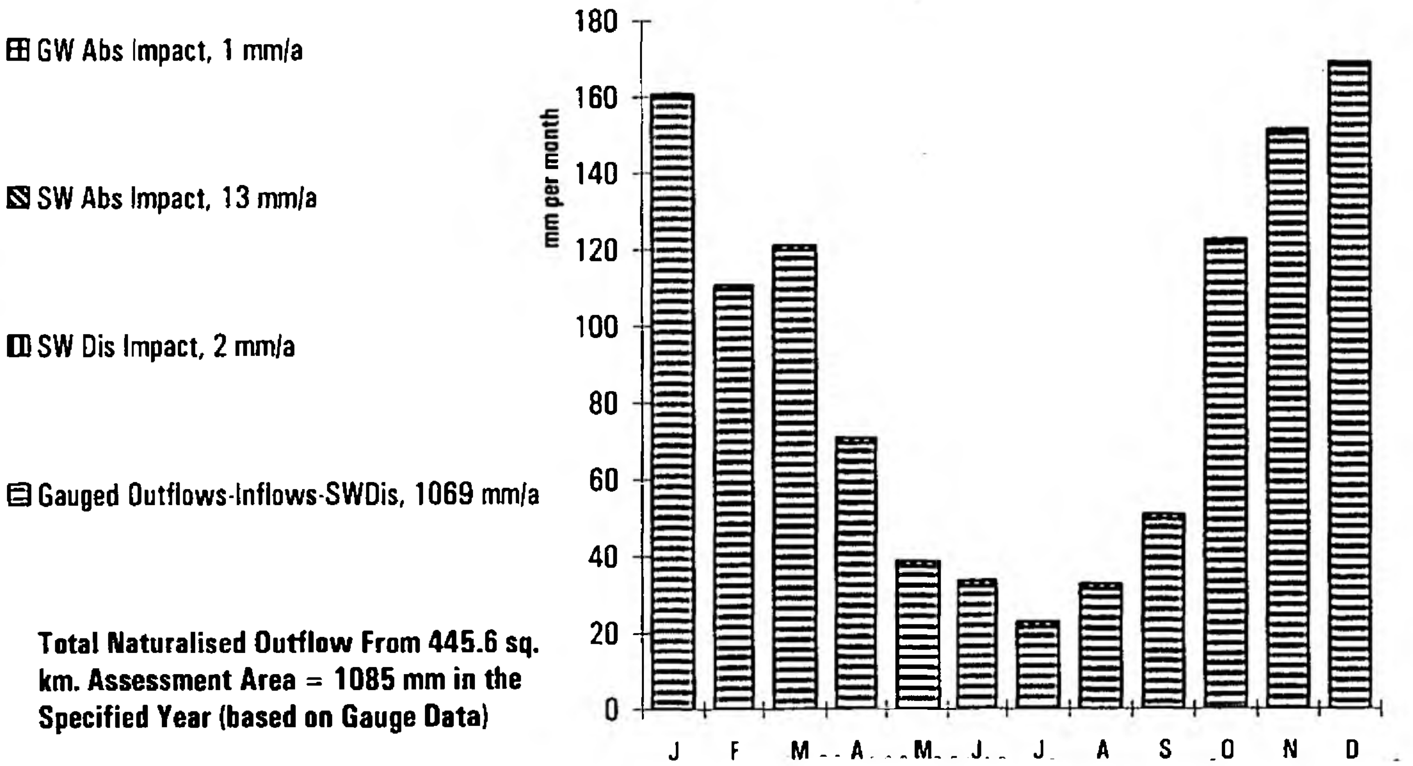
1.2 Components of Naturalised Flows Derived from the Assessment Area (i.e. Excluding Inflows) Expressed in mm Over Gauged SW Catchment

SW Catchment Area Assessed = 445.6 square kilometres

Component, Annual Total	J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 1 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
SW Abs Impact, 13 mm/a	1	1	1	1	1	1	1	1	1	1	1	1
SW Dis Impact, 2 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
Gauged Outflows-Inflows-SWDis, 1069 mm/a	160	109	120	69	37	32	21	31	49	121	150	168

Total Naturalised Outflow From 445.6 sq. km. SW Catch. Area = 1085 mm in the Specified Year (based on Gauge Data)

Abs & Dis are LICENSED (NO CONTROLS) at 1980-98 av



ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

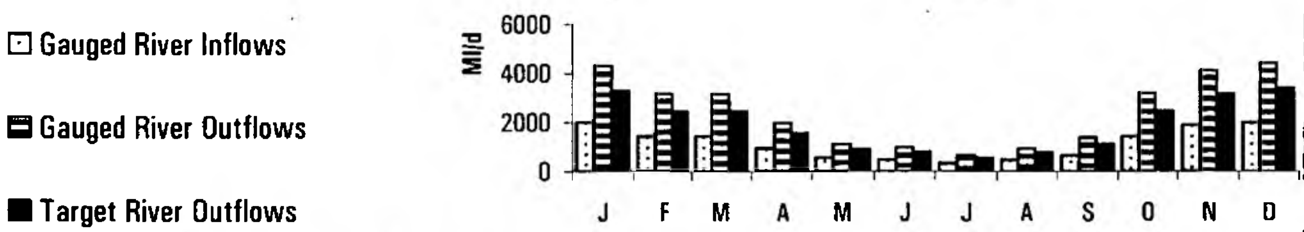
Area R Teifi, Llanfihangel Bridge to Glanteifi **ID** 0 **Ver** 0 **Rev** 0 **Date** 19/8/99

Specified Assessment Year L T Average Year (1980-1998)

1.3 Existing and Target Outflows for Specified Year, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Gauged River Inflows	1144	Ml/d	2010	1440	1447	953	572	491	347	490	643	1437	1896	2014
Gauged River Outflows	2451	Ml/d	4307	3185	3171	1986	1109	968	655	940	1380	3182	4128	4431
Target River Outflows	1913	Ml/d	3302	2462	2452	1565	907	803	568	780	1109	2459	3169	3395

Min. Target = 568 **Ml/d** Monthly HOF 252 Ml/d TAKE 25 % (cf Q95 252 Ml/d)



Target Flows based on: Monthly HOF = gauged Q95, TAKE = 25% of naturalised flow (Ref. Pers com Jean Frost)

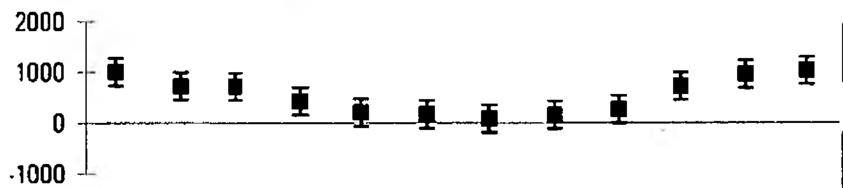
1.4 Surplus or Deficits for Specified Year, Ml/d

J	F	M	A	M	J	J	A	S	O	N	D
1005	722	719	421	202	165	87	160	271	723	959	1036

Ann Av 539 **Ml/d**

Minimum 87 **Ml/d**

Uncertainty +/- 270 **Ml/d**



Annual Average Surplus or Deficit is 22% of the Av. Naturalised Gauged Outflow

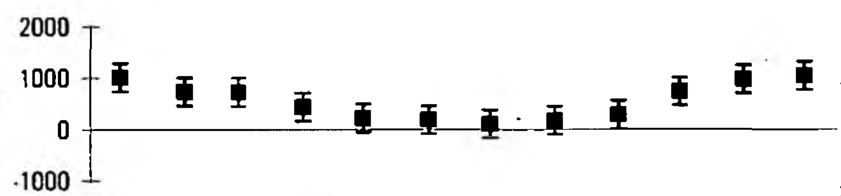
1.5 Acceptable Abs. Impacts for Spec. Year,Given Target Outflows and Existing Inflows

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	1016	737	733	438	218	184	105	176	286	736	972	1048

Ann Av 553 **Ml/d**

Minimum 105 **Ml/d**

Uncertainty +/- 274 **Ml/d**



	J	F	M	A	M	J	J	A	S	O	N	D
Acc. impacts/nat. gauged outflows, %	24	23	23	22	19	19	16	18	20	23	23	24

1.6a During this year, **max. existing consumptive abstraction impacts were** 3 % **of naturalised gauged river outflows in** the month of Jul (calculated from gauged river outflows + cons. abstraction impacts).

1.6b During this year, **max. existing consumptive abstraction impacts were** 6 % **of natural outflows derived from the assessment area in** the month of Jul (calculated from eff.rain. and area hydraulic response characteristics).

ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area R Teifi to Llanfihangel Bridge **ID** 0 **Ver** 0 **Rev** 0 **Date** 19/8/99

Specified Assessment Year L T Average Year (1980-1998)

1 Headline Assessment Results Summary

1.1 Annual Gauged Inflows, Gauged Outflows & Naturalised Gauged Outflows

Annual Average Gauged Inflows =	0	Ml/d
Annual Average Gauged Outflow =	1144	Ml/d
Annual Average Naturalised Gauged Outflow =	1151	Ml/d

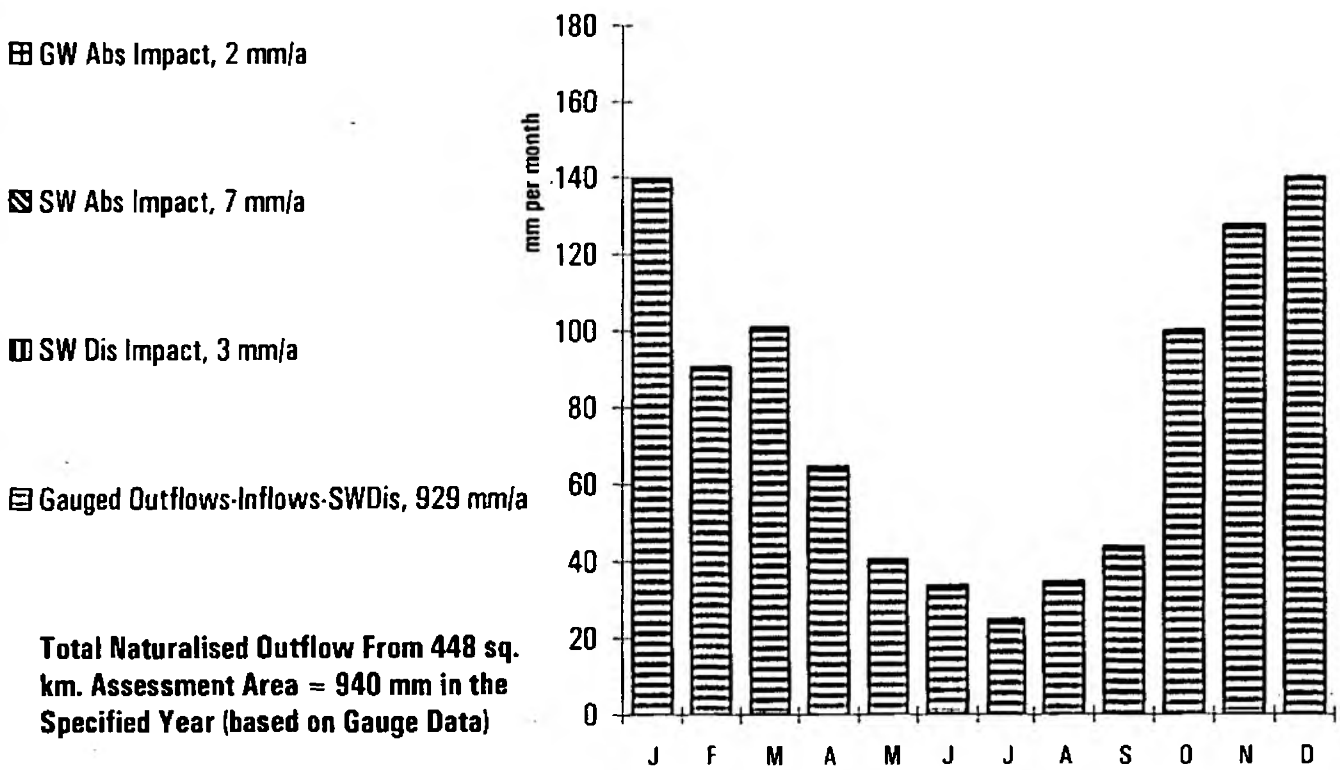
1.2 Components of Naturalised Flows Derived from the Assessment Area (i.e. Excluding Inflows) Expressed in mm Over Gauged SW Catchment

SW Catchment Area Assessed = 448 square kilometres

Component, Annual Total	J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 2 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
SW Abs Impact, 7 mm/a	0	0	1	1	1	1	1	1	1	0	0	0
SW Dis Impact, 3 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
Gauged Outflows-Inflows-SWDis, 929 mm/a	139	90	100	64	39	33	24	34	43	99	127	139

Total Naturalised Outflow From 448 sq. km. SW Catch. Area = 940 mm in the Specified Year (based on Gauge Data)

Abs & Dis are LICENSED (NO CONTROLS) at 1980-98 av



ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

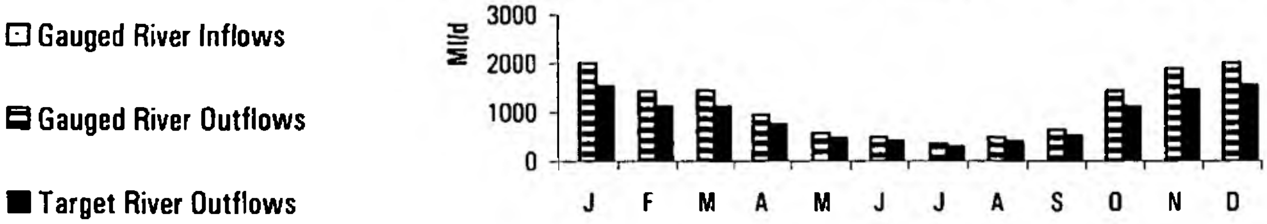
Area R Teifi to Llanfihangel Bridge **ID** 0 **Ver** 0 **Rev** 0 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1980-1998)**

1.3 Existing and Target Outflows for Specified Year, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Gauged River Inflows	0	Ml/d	0	0	0	0	0	0	0	0	0	0	0	0
Gauged River Outflows	1144	Ml/d	2010	1440	1447	953	572	491	347	490	643	1437	1896	2014
Target River Outflows	899	Ml/d	1546	1120	1126	756	470	410	302	409	523	1117	1462	1550

Min. Target = 302 **Ml/d** Monthly HOF 142 Ml/d TAKE 25 % (cf Q95 142 Ml/d)



Target Flows based on: Monthly HOF = gauged Q95, TAKE = 25% of naturalised flow, (Ref. Pers. com. Jean Frost)

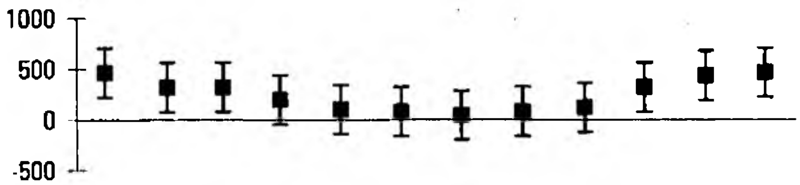
1.4 Surplus or Deficits for Specified Year, Ml/d

Ann Av 245 **Ml/d**

J	F	M	A	M	J	J	A	S	O	N	D
463	319	321	197	102	81	45	81	120	319	434	464

Minimum 45 **Ml/d**

Uncertainty +/- 243 **Ml/d**



Annual Average Surplus or Deficit is 21% of the Av. Naturalised Gauged Outflow

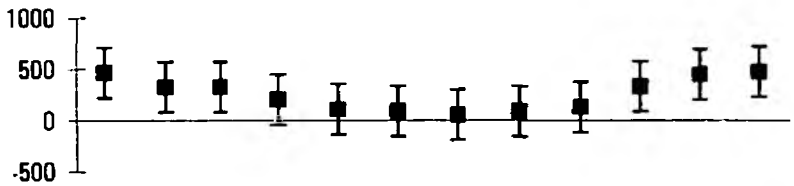
1.5 Acceptable Abs. Impacts for Spec. Year, Given Target Outflows and Existing Inflows

Ann Av 252 **Ml/d**

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	468	326	328	205	109	89	53	89	127	325	440	469

Minimum 53 **Ml/d**

Uncertainty +/- 246 **Ml/d**



	J	F	M	A	M	J	J	A	S	O	N	D
Acc. impacts/nat. gauged outflows, %	23	23	23	21	19	18	15	18	20	23	23	23

1.6a During this year, **max. existing consumptive abstraction impacts were** 2 %
of naturalised gauged river outflows in the month of **Jul**
(calculated from gauged river outflows + cons. abstraction impacts).

1.6b During this year, **max. existing consumptive abstraction impacts were** 2 %
of natural outflows derived from the assessment area in the month of **Jul**
(calculated from eff.rain. and area hydraulic response characteristics).

3.6 Rivers Upper Little Ouse and Initial Thet Catchment Trials

3.6.1 Area Delineation, Description and Issues

Figure 3.6 shows a sketch plan of the area of drift covered Chalk around the Rivers Little Ouse, Thet and Sapiston within which water resources are currently managed by the Agency as the 'Little Ouse Groundwater Unit'. This groundwater unit is the CAMS trial area in Anglian Region. It has been sub-divided by the Agency for the purposes of strategic resource assessment into four smaller groundwater sub-units:

- upper Little Ouse;
- lower Little Ouse;
- Sapiston;
- Thet.

The delineation of these sub-unit boundaries has been based on the Chalk areas around the four main river reaches. The eastern outer boundary is drawn according to the groundwater divide between the Rivers Little Ouse and Waveney which lies to the east of the surface water divide. In consultation with Agency staff it was agreed that the ARM assessments should be carried out on two gauged catchments (i.e. combined surface water and groundwater catchments) which are approximately, but not exactly equivalent to two of these sub-units:

- the upper River Little Ouse to Euston gauging station (NGR TL 892801);
- the River Thet to Melford Bridge gauging station (NGR TL 880830).

Figure 3.6 includes conceptual cross sections for both of these assessment areas drawn along lines close to the river.

River Little Ouse to Euston

The Euston gauging station is situated on the Little Ouse some 2.5 km southeast of Thetford approximately 500 m upstream of the confluence with the River Sapiston. The assessment area comprises the surface water catchment for the river above the Euston gauge and its associated groundwater catchment within the Chalk aquifer. Like the Agency's upper Little Ouse sub-unit, the groundwater catchment extends to the eastern groundwater divide in the surface water catchment of the River Waveney. The north and southwest boundaries are defined by flow lines perpendicular to groundwater contours, drawn back from the Euston gauge. The groundwater catchment can change seasonally and between years. Figure 3.6 shows catchment boundaries for an average condition and for the year 1991 which represents drought conditions.

The main aquifer in the catchment is the Chalk which crops out on valley sides in the lower reaches of the catchment, and also in areas around the upper reaches of the catchment and tributary valleys around Rickinghall and Botesdale.

The Chalk is overlain by Boulder Clay in the higher interfluve areas with pockets of glacial sand and gravel present in places along valley sides. River valley gravels are present in the River Little Ouse valley floor from Rushford to Hinderclay.

Alluvium is present in the Little Ouse valley bottom downstream of Garboldisham however the river only flows on top of these deposits in some places. The Chalk is also overlain by alluvium to the south of Rickinghall indicating the presence of former stream valleys.

Groundwater is abstracted from within the catchment primarily for public water supply and spray irrigation with some for other agricultural and industrial uses. In addition, groundwater abstraction is licensed for augmentation of river flows during times of low flows as part of the Great Ouse Groundwater Scheme (GOGWS). Only a small amount (~240 Ml/a) of surface water is abstracted in the assessment area (for spray irrigation purposes) and no significant (greater than 100 m^3/d) discharges to surface water exist apart from those associated with augmentation.

River Thet to Melford Bridge

The Melford Bridge gauging station is situated on the south eastern outskirts of Thetford some 1 km upstream of the River Thet confluence with the Little Ouse.

The assessment area comprises the surface water catchment for the river to the gauging station and its associated groundwater catchment within the Chalk aquifer. It is noted that the extent of the groundwater catchment does not coincide precisely with the surface water catchment and also that its extent varies in relation to antecedent or preceding climatic conditions. The western and southern boundaries are defined by flow lines perpendicular to groundwater contours while the northern and eastern boundaries are defined by groundwater divides. Figure 3.6 shows catchment boundaries for an average condition and for the year 1991 which represents drought conditions.

The Chalk outcrops in the lower reaches of the catchment in the River Thet valley between Thetford and East Harling. In addition drift cover over the Chalk is largely absent in the areas close to Quiddenham and Shropham as well as to the east of Harling Road.

The Chalk is overlain by Boulder Clay in the upper reaches of the catchment with pockets of glacial sands and gravels forming minor aquifers within the clay. A number of buried channels are incised into the Boulder Clay in the north of the catchment delineated by valley gravels and alluvium deposits.

The upper reaches of the main watercourses flow over Boulder Clay. In the lower reaches watercourses flow mainly on Chalk with alluvium forming the base of the River Thet between East Harling and Carling.

Groundwater is abstracted from within the catchment primarily for public water supply and spray irrigation with some for other agricultural and industrial uses. In addition, as within the upper Little Ouse, there are licensed GOGWS sources.

Approximately 1600 Ml/a of surface water is licensed for abstraction within the assessment area for spray irrigation while discharges to surface water (>100 m^3/d) amount to around 2.1 Ml/d of which 50% is effluent from sewage treatment works (ref. J Barker, D Evans 1993).

3.6.2 Workbook Selection and Names

Calculations for the two assessment areas have been saved in the following files:

Area Delineation	Excel Workbook Template Used	Filename Extension
River Little Ouse to Euston	Gauged River, GRIV.XLT	LOUSEUS****1.XLS
River Thet to Melford Br	Gauged River, GRIV.XLT	THETMEL****1.XLS

where **** is the assessment year

3.6.3 Assessment Years

Calculations have been carried out to assess the long-term average (LTAV) water resources condition using data from 1970 to 1990 and also for the specific drought year 1991. The start of the LTAV period was dependent on gauged river flow data availability and the assessments were mostly based on data from an Agency water resources report produced in 1993.

MORECS effective rainfall data show 1991 to be the driest since 1960. This year was selected to consider the impacts of abstraction and river support from the GOGWS boreholes.

3.6.4 Key Assumptions

Consumptive Abstraction Impacts
River Little Ouse to Euston

Surface water abstractions are primarily for spray irrigation purposes and licensed quantities, as they existed in 1993 for catchment no 6/33/42 have been used with Spray Irrigation Demand Factors (Regional Good Practice Guide) to estimate daily abstracted quantities. It is noted that only around 1.1 Ml/d is abstracted from surface water during the summer months for spray irrigation.

By far the largest abstractions are from the Chalk and the delineation of the groundwater catchment to the gauge, as described above, is a vital step in the naturalisation process. The groundwater catchment defines which boreholes are considered to impact flows measured at the gauge and which impact flows downstream or in other rivers.

Groundwater abstraction quantities from the Chalk have been estimated using the following:

- Public Water Supply. 1993 licence and actual abstraction data (Table 12, J Barker, 1993) has been used to determine an overall uptake factor (i.e. an estimate of the proportion of the annual licence actually pumped) of 0.43 for the Little Ouse catchment. This has been applied to a total licensed abstraction quantity of 8643 Ml/a (including 50% of the Brettenham licence which appears to straddle the groundwater divide defined between the Little Ouse and Thet catchments). In addition, further refinement of abstraction demands has been undertaken using the Public Water Supply Demand profile presented in the Regional Good Practice Guidelines.

- Spray Irrigation. A total of around 1507 Ml/a is licensed for abstraction for spray irrigation purposes (Table 11b, J Barker, 1993). The relevant demand profile presented in the Regional Good Practice Guidelines has been applied to this quantity. In addition further refinement of actual abstractions impacts from spray irrigation uses are made by applying an uptake factor of 0.6 for the long-term average condition and 0.8 for the drought condition represented by 1991.

- Other Uses. Groundwater abstractions used for other purposes are split approximately 50:50 between general agriculture (220 Ml/a) and cooling (216 Ml/a). No demand profile has been applied to these abstractions but an average uptake factor of 0.275 (Regional Good Practice Guidelines) has been used, in order to obtain an estimate of actual abstraction.

As groundwater abstraction is a significant part of the water balance, further consideration has been given to the distribution of the *impacts* of these abstractions on gauged river flows.

In the first instance a steady state (or 'fully smoothed') approach has been adopted where river flow impacts are assumed to occur at the annual average rate of 12 Ml/d and 13 Ml/d for long-term average and drought conditions respectively, for all months. This simplest impact distribution has been used when generating the hard copy assessment output which accompanies this report. It is the distribution which might be expected for an aquifer receiving steady state recharge which has sufficient storage to smooth out any seasonal variations in abstraction. Analytical approaches to the calculation of groundwater abstraction impacts (such as the Jenkins approach incorporated into microLOWFLOWS) will also predict steady state flow impacts for long term steady state abstractions.

Two alternative impact distributions, which can be considered as 'conceptual extremes' have also been provided in the spreadsheets and can be substituted into the main calculations, as follows:

- Abstractions are assumed to impact river flows in the same month as the abstraction occurs, representing boreholes close to rivers and/or in relatively high transmissivity/low storage aquifers. This impact distribution effectively considers the boreholes to be pumping water directly from the river and, because of the spray irrigation and public water supply demand profiling, implies that impacts are greater in the summer than in the winter.

- As for the other alternatives, the annual average rate of abstraction impact on river flows can be set to the annual average abstraction. This is a reasonable assumption for the LTAV assessment but is unlikely to be correct for the drought year when some or all of the abstracted water may be drawn from aquifer storage. Average flow impacts during the drought year may therefore be much lower than the average abstraction rate. Within the assessment year also, abstractions are assumed to have a greater impact on river flows during wetter months of higher flow, than during summer periods of lower flow. This approach is similar to that adopted by the Agency in North East Region and is in an attempt to take account of aquifer storage with seasonal recharge. According to this alternative, the river flow impacts are less severe in summer so that low flow recovery following abstraction cessation would also be less than at higher flows.

At this stage Entec have not attempted to consider the distribution of groundwater abstraction impacts on a source by source basis. Further discussion with the Agency CAMS team in Anglian Region would be helpful to determine which of the three alternative approaches described above is most appropriate for naturalising flows in the upper Little Ouse and Thet.

Prior to the early 1990's there were no licensed discharges to surface water to the Little Ouse upstream of the Euston gauge. However, in the drought year 1991, boreholes within the GOGWS were used to augment river flows between July and 10 October. Information from the Agency suggests that the net effect of these abstractions on the assessment area was an increase in gauged flows by volumes equivalent to 40% of the quantities abstracted from the boreholes. It is believed that the figure of 40% has been adopted by the Agency after comparing responses of river flows in augmented river reaches with simultaneous flow patterns in reaches which underwent no augmentation.

For the purpose of this assessment therefore this 40% net gain effect is represented as follows:

- groundwater abstraction rates from the GOGWS (based on 2188 Ml spread from July to 10 October) are added onto the other groundwater abstractions in the spreadsheet as fully consumptive.
- these additional GOGWS abstractions are assumed to impact river flows at a rate equal to 60% of the full abstraction rate.
- the full abstraction rates are entered as surface water discharges as all of the outfalls from the boreholes are within the same assessment area.

This approach retains the flexibility of being able to accommodate any river support abstractions which are discharged outside the area (in the same way as public water supply boreholes). It also results in an implied aquifer drawdown as the support abstractions are assumed to draw 40% from aquifer storage. However, the approach also results in the 'Nat. Outflows minus SWDis minus Inflows' series becoming negative in the stacked histogram representation of natural outflows (see Appendix A).

River Thet to Melford Bridge

Surface water abstractions in this area are also primarily for spray irrigation purposes and licensed quantities, as they existed in 1993 for catchment no 6/33/44 have been used with Spray Irrigation Demand Factors (Regional Good Practice Guide) to estimate daily abstracted quantities. It is noted that an average of around 7.7 Ml/d is abstracted from surface water during the summer months for spray irrigation.

As for the upper Little Ouse, groundwater abstractions dominate and the same process has been followed to derive an estimate of actual monthly abstractions from annually licensed totals (3752 Ml/a PWS, 1593 Ml/a SI, 370 Ml/a Ag, 801 Ml/a Ind), and then to separately investigate the possible impacts of these on river flows.

Prior to the early 1990's licensed discharges to surface water to the Thet upstream of the Melford Bridge gauge amounted to around 2.15 Ml/d. During the drought year 1991 GOGWS boreholes abstracted 11820 Ml over the period July to October. As for the upper Little Ouse this has been assumed to be associated with a 40% net flow increase and has been represented in the same manner in the 1991 spreadsheet.

Target Flows

River Little Ouse to Euston

The average gauged flows at the Euston station in 1991 ranged from 25 Ml/d in March to a minimum of 3.7 Ml/d in August. The IoH register reports a Q95 flow for the period 1948-95 to be 8 Ml/d.

The minimum target flow has been determined by the Environmental Requirement for the water and a naturalised Q95 flow of 14 Ml/d has been derived for the upper Little Ouse (J Barker, draft AMS report). For the ARM trials an additional monthly take of 50% of naturalised flows above this 'Hands off Flow' has been factored in to give a minimum target flow of 12 Ml/d which rises to up to 35 Ml/d during the winter months to protect flow variation.

River Thet to Melford Bridge

The average gauged flows at the Melford Bridge station in 1991 ranged from 149 Ml/d in March to a minimum of 55 Ml/d in July. The IoH register reports a Q95 flow for the period 1962-95 to be 42 Ml/d.

The minimum target flow has been determined by the Environmental Requirement for the water and a naturalised Q95 flow of 54 Ml/d has been derived for the River Thet (J Barker, draft AMS report?). For the ARM trials an additional monthly take of 50% of naturalised flows above this 'hands off flow' has been factored in to protect flow variation.

3.6.5 Presentation and Discussion of Results

The first two pages of LTAV headline results for both of the assessment areas follow this Section. In both cases (as for all the First Draft trials) the 3rd page which asks the user to interpret the sustainability status of the area has been omitted pending further discussion with the Agency. Table 3.10 summarises the headline results derived from all the specified years. For each year these results include:

- the natural outflow during the year derived from the assessment area (expressed as mm/a over the surface water catchment area)
- the maximum impact of existing consumptive abstractions within the assessment area expressed as a % of both the natural outflow including any inflows, and of the natural outflow excluding inflows
- the minimum and average surplus or deficit in Ml/d and the average surplus or deficit expressed as a % of natural outflows (including any inflows)

Full digital and hardcopy versions of all the assessment spreadsheets are included in Appendix A.

Annual natural outflows from the upper Little Ouse are significantly lower than from the Thet in both the LTAV and 1991 assessments. As these are based on gauged flows divided by surface water catchment area, they are equivalent to the 'mean annual runoff' data quoted in IoH yearbooks and registers. Effective rainfall variation seems unlikely to be able to account for those difference which may therefore relate to significant differences between the groundwater catchment areas draining to the gauges (i.e. there is relatively more baseflow discharge upstream of Melford Bridge than upstream of Euston). Maximum existing consumptive abstraction impacts in the Little Ouse catchment represent a much larger proportion of this natural outflow than in the Thet.

Because the assumed minimum target flows are based on a naturalised flow series estimated by the Agency, comparison with existing outflows results in summer deficits under average and drought conditions in the upper Little Ouse. Drought year deficits in the Thet catchment were more effectively reduced through the operation of the GOGWS river support abstractions. Despite these summer deficits, the assumed 50% monthly TAKE suggests the potential for further abstraction at higher flows which could probably only be effectively managed through surface water licensing with flow controls linked to the gauges.

Although not essential for the derivation of the main ARM outputs in gauged catchments, attempts were briefly made in both of these assessments to reconcile the gauge naturalised flows with natural flows derived from rainfall and catchment runoff. The aquifer response function (ARF) model provided within the spreadsheets was used to simulate to effective rainfall defined by monthly MORECS values, using:

- areas for the surface water catchment given by IoH and for groundwater catchment estimated from the sketch plan;
- an assumption that effective rainfall onto the aquifer is split between recharge and runoff according to the ratio between MORECS effective rainfall and the recharge values quoted by the Agency for each of the sub-units;
- a river length considered to drain the aquifer of 30 km (upper Little Ouse) and 40 km (Thet);
- aquifer parameters $T = 400\ m^2/d$ and $S = 0.03$ (upper Little Ouse) and $T = 500\ m^2/d$ and $S = 0.03$ (Thet);
- The LTAV comparisons result in relatively large imbalances between the natural outflows derived by the MORECS model and naturalised gauged flows. For the Little Ouse, the MORECS effective rainfall based flows exceed the gauge naturalised flows and this result is reversed in the Thet. This may indicate that the ARF assumed groundwater catchment areas are incorrect or may reflect errors in the simple assumptions used to estimate actual abstractions from licensed values as part of the gauge naturalisation process.

Table 3.10 Summary of Rivers Little Ouse and Thet Catchment Trial Results

	Units	R Little Ouse to Euston	R Thet to Melford Bridge
Natural Outflows Based On		flow gauge	flow gauge
SW Catchment Area	sq. km.	128.7	316
LTAV (1980 - 1996)			
Annual av. nat. outflow derived from assessment area/SW catchment area	mm/a	152	199
Existing maximum consumptive abs. impact as % nat. outflow (from ass. area onl)	%	43	17
Min. monthly surplus (+ve) or deficit (-ve)	Ml/d	-5	3
Annual av. surplus (+ve) or deficit (-ve)	Ml/d	7	49
Annual av. surplus (+ve) or deficit (-ve) as % nat. outflow	%	13	29
1991 ('DROUGHT' YEAR)			
Annual av. nat. outflow derived from assessment area/SW catchment area	mm/a	96	136
Existing maximum consumptive abs. impact as % nat. outflow (from ass. area onl)	%	71	20
Min. monthly surplus (+ve) or deficit (-ve)	Ml/d	-11	-2
Annual av. surplus (+ve) or deficit (-ve)	Ml/d	-4	18
Annual av. surplus (+ve) or deficit (-ve) as % nat. outflow	%	-14	21

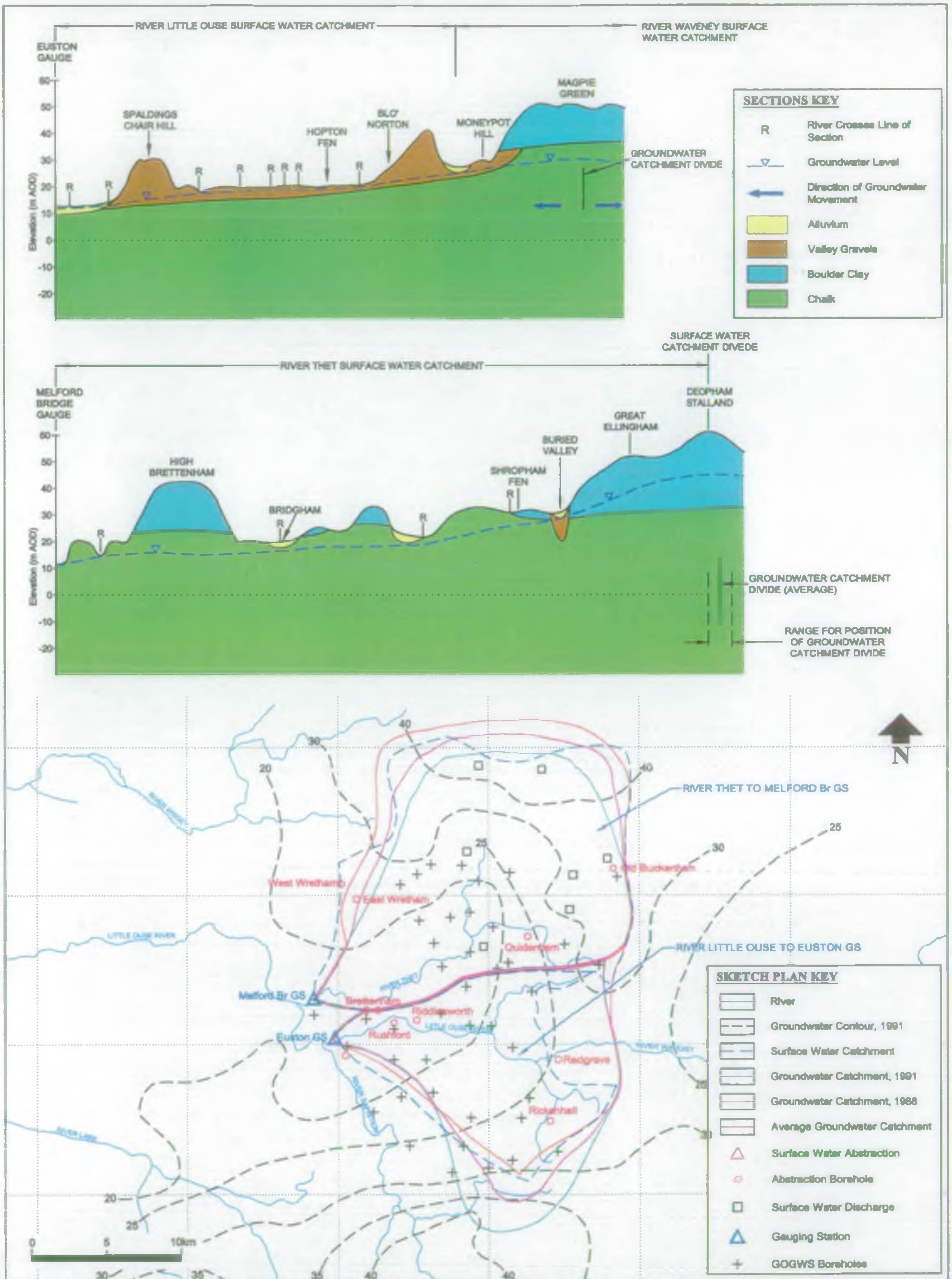


FIGURE 3.6 RIVERS LITTLE OUSE AND THET ASSESSMENT AREAS SKETCH PLAN AND CROSS SECTIONS

Drawing No: 02019-01.S010 Date: AUGUST 1999 Scale: AS SHOWN

Entec

ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area R Little Ouse to Euston GS **ID** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1970-1990)**

1 Headline Assessment Results Summary

1.1 Annual Gauged Inflows, Gauged Outflows & Naturalised Gauged Outflows

Annual Average Gauged Inflows = 0 Ml/d
Annual Average Gauged Outflow = 41 Ml/d
Annual Average Naturalised Gauged Outflow = 53 Ml/d

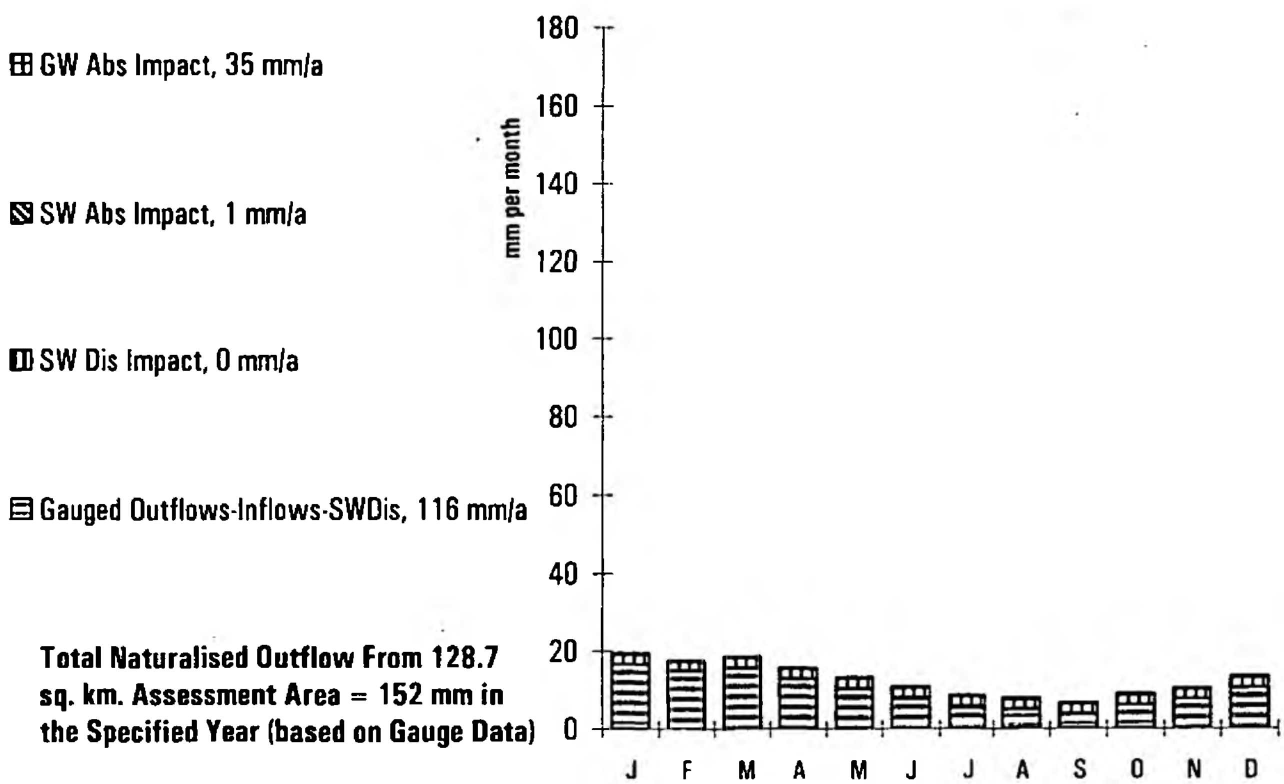
1.2 Components of Naturalised Flows Derived from the Assessment Area (i.e. Excluding Inflows) Expressed in mm Over Gauged SW Catchment

SW Catchment Area Assessed = 128.7 square kilometres

Component, Annual Total	J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 35 mm/a	3	3	3	3	3	3	3	3	3	3	3	3
SW Abs Impact, 1 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
SW Dis Impact, 0 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
Gauged Outflows-Inflows-SWDis, 116 mm/a	17	15	16	13	10	8	5	5	4	6	8	11

Total Naturalised Outflow From 128.7 sq. km. SW Catch. Area = 152 mm in the Specified Year (based on Gauge Data)

Abs & Dis are ESTIMATED ACTUAL at 1970-90 av



ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

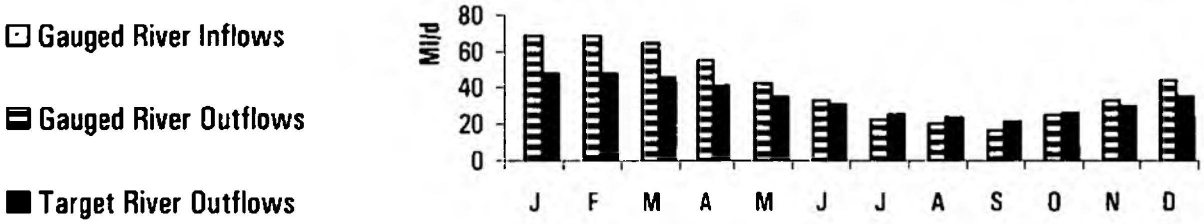
Area R Little Ouse to Euston GS **ID** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1970-1990)**

1.2 Existing and Target Outflows for Specified Year, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Gauged River Inflows	0	Ml/d	0	0	0	0	0	0	0	0	0	0	0	0
Gauged River Outflows	41	Ml/d	69	69	65	55	42	33	22	20	16	25	33	44
Target River Outflows	34	Ml/d	48	48	46	41	35	30	25	24	21	26	30	35

Min. Target = 21 **Ml/d** Monthly HOF 14 Ml/d TAKE 50 % (cf Q95 8 Ml/d)



Target Flows based on: Monthly HOF = nat Q95 (?), TAKE =50% of naturalised flow, (Ref: J Barker, draft AMS report?)

1.3 Surplus or Deficits for Specified Year, Ml/d

			J	F	M	A	M	J	J	A	S	O	N	D
Ann Av	7	Ml/d	21	21	19	14	7	2	-3	-3	-5	-1	3	9

Minimum -5 **Ml/d**

Uncertainty +/- 3 **Ml/d**

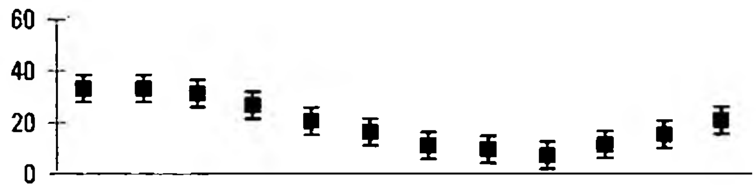
Annual Average Surplus or Deficit is **13%** of the Av. Naturalised Gauged Outflow

1.4 Acceptable Abs. Impacts for Spec. Year,Given Target Outflows and Existing Inflows

			J	F	M	A	M	J	J	A	S	O	N	D
Ann Av	20	Ml/d	33	33	31	27	20	16	11	9	7	11	15	21

Minimum 7 **Ml/d**

Uncertainty +/- 5 **Ml/d**



	J	F	M	A	M	J	J	A	S	O	N	D
Acc. impacts/nat. gauged outflows, %	41	41	41	39	37	35	30	28	25	31	34	37

1.4a During this year, **max. existing consumptive abstraction impacts were** **43** %
of naturalised gauged river outflows in the month of **Sep**
(calculated from gauged river outflows + cons. abstraction impacts).

1.4b During this year, **max. existing consumptive abstraction impacts were** **46** %
of natural outflows derived from the assessment area in the month of **Sep**
(calculated from eff.rain. and area hydraulic response characteristics).

ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

Area R Thet to Melford Bridge GS **ID** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1970-1990)**

1 Headline Assessment Results Summary

1.1 Annual Gauged Inflows, Gauged Outflows & Naturalised Gauged Outflows

Annual Average Gauged Inflows =	0	Ml/d
Annual Average Gauged Outflow =	162	Ml/d
Annual Average Naturalised Gauged Outflow =	170	Ml/d

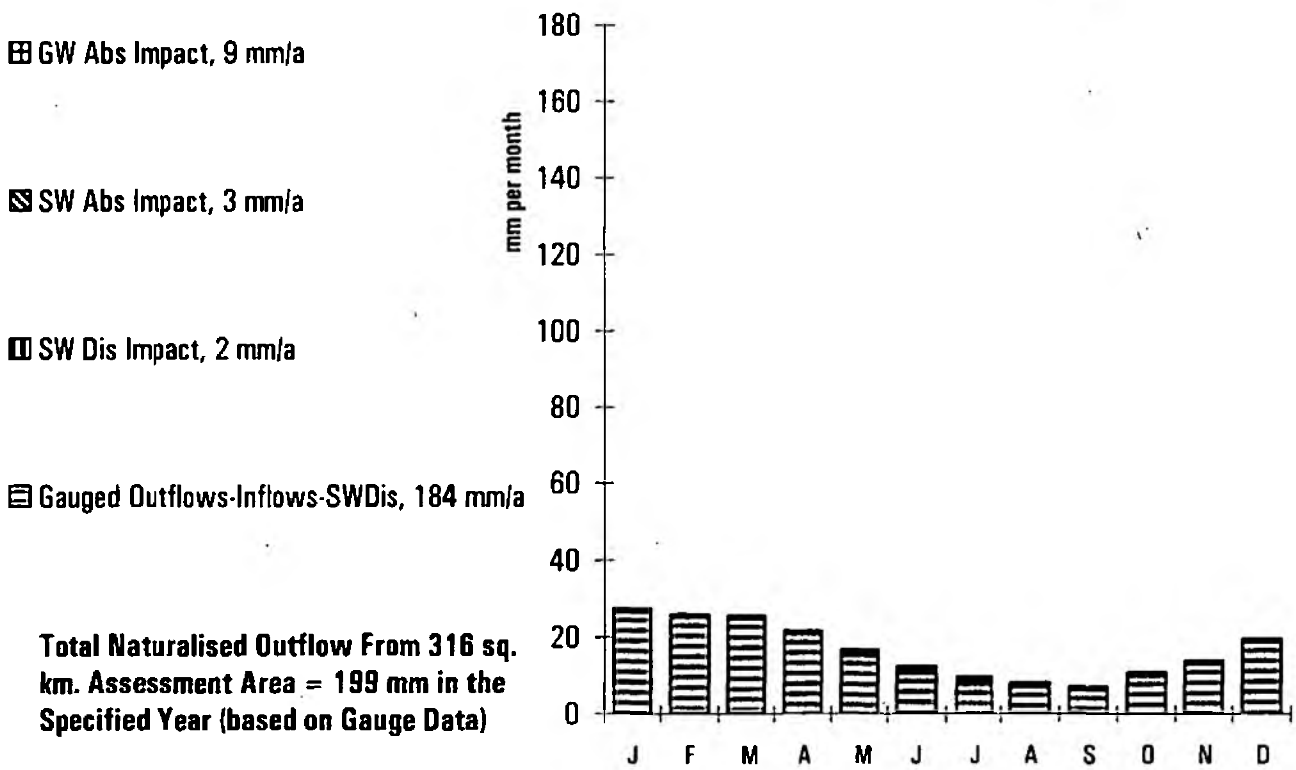
1.2 Components of Naturalised Flows Derived from the Assessment Area (i.e. Excluding Inflows) Expressed in mm Over Gauged SW Catchment

SW Catchment Area Assessed = 316 square kilometres

Component, Annual Total	J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 9 mm/a	1	1	1	1	1	1	1	1	1	1	1	1
SW Abs Impact, 3 mm/a	0	0	0	0	1	1	1	0	0	0	0	0
SW Dis Impact, 2 mm/a	0	0	0	0	0	0	0	0	0	0	0	0
Gauged Outflows-Inflows-SWDis, 184 mm/a	26	25	25	21	15	11	8	7	6	10	13	19

Total Naturalised Outflow From 316 sq. km. SW Catch. Area = 199 mm in the Specified Year (based on Gauge Data)

Abs & Dis are ESTIMATED ACTUAL at 1970-90 av



ASSESSMENT OF WATER AVAILABLE FOR ABSTRACTION

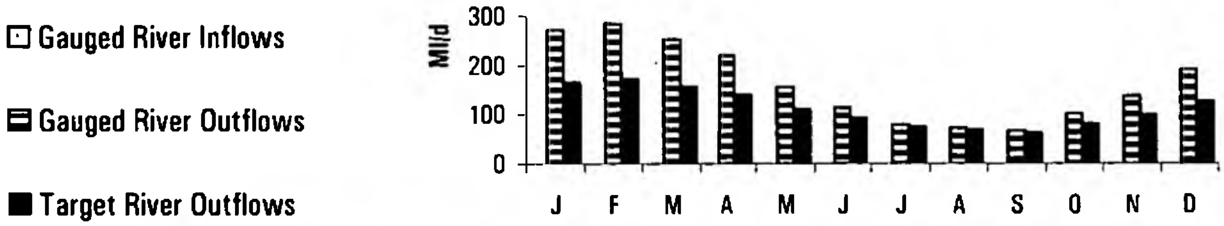
Area R Thet to Melford Bridge GS **ID** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1970-1990)**

1.2 Existing and Target Outflows for Specified Year, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Gauged River Inflows	0	Ml/d	0	0	0	0	0	0	0	0	0	0	0	0
Gauged River Outflows	162	Ml/d	272	285	253	220	156	114	79	72	67	101	137	191
Target River Outflows	112	Ml/d	166	172	157	140	111	92	75	68	63	81	99	126

Min. Target = 63 **Ml/d** Monthly HOF 54 Ml/d TAKE 50 % (cf Q95 42 Ml/d)



Target Flows based on: Monthly HOF = nat Q95?, TAKE=50% of naturalised flow, (Ref: J Barker ams draft rep?)

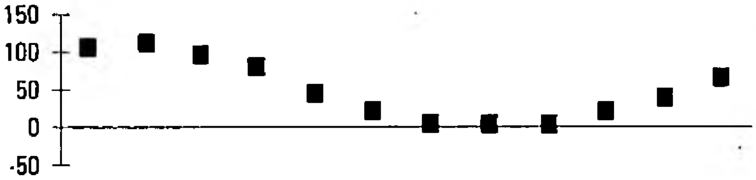
1.3 Surplus or Deficits for Specified Year, Ml/d

J	F	M	A	M	J	J	A	S	O	N	D
106	112	96	80	45	21	4	4	3	20	39	65

Ann Av 49 **Ml/d**

Minimum 3 **Ml/d**

Uncertainty +/- 11 **Ml/d**



Annual Average Surplus or Deficit is 29% of the Av. Naturalised Gauged Outflow

1.4 Acceptable Abs. Impacts for Spec. Year,Given Target Outflows and Existing Inflows

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	112	118	102	86	57	38	21	14	9	26	44	71

Ann Av 58 **Ml/d**

Minimum 9 **Ml/d**

Uncertainty +/- 13 **Ml/d**

	J	F	M	A	M	J	J	A	S	O	N	D
Acc. impacts/nat. gauged outflows, %	40	41	39	38	34	29	22	17	12	25	31	36

1.4a During this year, **max. existing consumptive abstraction impacts were** 17 %
of naturalised gauged river outflows in the month of Jul
(calculated from gauged river outflows + cons. abstraction impacts).

1.4b During this year, **max. existing consumptive abstraction impacts were** 28 %
of natural outflows derived from the assessment area in the month of Jul
(calculated from eff.rain. and area hydraulic response characteristics).

4. Comparison of ARM Initial Trials and Regional CAMS Approaches

4.1 Introduction

This Section presents brief descriptions of the approaches adopted by the Agency's four Regional teams to fulfil the requirements of the first module in the CAMS process - the determination of a sustainability status which summarises the state of water resources management for an area.

Sections 4.2 to 4.5 describe the approaches by Region according to a common format under the following headings:

- method summary;
- area delineation;
- total resource determination;
- assessment year selection;
- target flow definition;
- abstraction impact assumptions;
- sustainability status presentation;
- issues and questions raised by Regional trial team.

As for the ARM trial descriptions in Section 3 the emphasis throughout is on the methods and approaches adopted rather than on the results derived. The sustainability status results which are presented in detail within the Region's own submission to the national Abstraction Management Strategy trialling group.

Section 4.6 compares and contrasts the Regional approaches with each other and with the initial ARM trials.

4.2 South West Region Approach

4.2.1 Method Summary

The South West Region team used the Available Resource Method Spreadsheets for Gauged and Ungauged River Outflow to determine the sustainability status of water resource management for the River Otter catchment.

4.2.2 Area Delineation

The surface water catchment and associated groundwater catchment to the River Otter was divided into four sub-catchments according to the location of the flow gauging stations at Fairmile, Fenny Bridges and Dotton (as described and illustrated in Section 3.2).

4.2.3 Total Resource Determination

As in the initial ARM trial, the total resource for each of the 3 gauged sub-areas was determined by naturalising the gauged flows to remove the impacts of groundwater abstraction and surface water abstraction and discharge. This was carried out on the daily river flow series with groundwater abstractions assumed to impact 'as pumped' i.e. no allowance made for the effects of aquifer storage and seasonally variable recharge which tends to redistribute abstraction impacts on river flows towards the wetter winter months.

For the fourth, ungauged sub-catchment below the Dotton gauge, natural outflows at the estuary were taken from a previously developed hydrological model although these were also compared with flows derived from MORECS effective rainfall using the Aquifer Response Function calculations available within ARM spreadsheets.

For both gauged and ungauged areas the total resource was entered onto the spreadsheets for plotting and further calculation as a series of 12 monthly averaged natural flows for the specified assessment year.

4.2.4 Assessment Year Selection

The South West team specified the hydrological year October 1990 to September 1991 as this was considered to represent a 1 in 5 year dry year, rather than determining sustainability by analysis of a more severe but less frequent drought event. The choice of a water year (entered as Jan.91, Feb.91, Mar.91, Apr.91, May.91, Jun.91, Jul.91, Aug.91, Sep.91, Oct.90, Nov.90, Dec.90) rather than the calendar year (January to December) is possible within the August 1999 ARM spreadsheets for all purposes except for the Aquifer Response Function calculations which require that months should follow in chronological sequence.

4.2.5 Target Flow Definition

Target flows were calculated on a daily basis from the gauged naturalised or modelled natural flows during the assessment year. The target flow was defined according to the SWALP (Surface Water Abstraction Licensing Procedure) principal of protecting a minimum or 'Hands-Off-Flow' plus a variable '% Take' calculated as a fixed proportion of the natural flows exceeding this minimum. On the basis of previous studies on the River Otter and through discussion across the Agency functions the target was calculated as a minimum flow equal to the natural QN95 plus an additional 75% of the daily natural flow above this.

As for other data sets the daily target flows were averaged on a monthly basis for entry onto the ARM spreadsheets.

4.2.6 Abstraction and Discharge Impact Assumptions

The sustainability of current (i.e. 1999) licensed abstraction was assessed within the context of the 1990/91 hydrological year by considering the impacts of abstractions and discharges at their licensed 1999 rates. The assumed abstraction rates were distributed as monthly averages through the year according to the licence seasonal restrictions and also took into account any flow or groundwater level controls considered relevant to the chosen hydrological scenario.

As in gauged flow naturalisation no attempt was made to redistribute groundwater abstraction impacts on river flows towards the wetter winter months according to the effects of aquifer storage and seasonally variable recharge. As licensed abstraction is higher in the summer, this assumption can be expected to result in an overestimation of summer impacts and a conservative view of sustainability.

4.2.7 Sustainability Status Presentation

The ARM spreadsheets used present monthly surplus/deficit profiles for the assessed year for each of the sub-catchments. A single sustainability status was assigned to each area and to the total Otter catchment according to these profiles on the basis of the categories proposed in Section 2.8.

4.2.8 Issues and Questions Raised by Regional Trial Team

The main issues and questions raised by the South West team in their submission to the national group were:

- there is an initial learning curve associated with understanding the ARM framework and applying the ARM spreadsheets which should be allowed for if it is to be adopted in place of the existing Regional approaches which are more familiar to Agency teams;
- guidance is needed into the appropriate consideration of effects of groundwater (aquifer) and surface water (reservoir) storage on abstraction distribution through the year as part of flow naturalisation process;
- the trials produced credible results for the gauged sub-catchments but there were problems in the ungauged lowest reach of the Otter. These problems were considered to stem from the definition of target flows although they may also have been related to a misunderstanding concerning the calculations within the August 1999 ARM spreadsheets;
- the sub-division of river catchments for the CAMS process will influence the resulting sustainability status. Abstraction impacts may be considered acceptable when compared to natural river flows at downstream locations even though smaller headwater tributaries or reaches may be over-exploited. It is accepted that the assessment of *local* abstraction impacts should remain an essential part of any individual licence determination. It is also reasonable that Regional staff be allowed the flexibility to sub-divide catchments according to the perceived criticality of abstraction management issues. However, some national guidance on appropriate catchment sub-division would be useful.

4.3 North West Region Approach

4.3.1 Method Summary

River Ribble Trial: The sustainability assessment for the River Ribble was based on a GIS implementation of principles developed for the SWALP. W S Atkins developed a GIS database of the river system broken down into reaches with associated natural flow duration curve statistics and abstraction and discharge impacts. The application of this approach to derive a single, annual average surplus or deficit and the associated sustainability status (as proposed in Section 2.8) for the cumulative catchment to each reach is summarised in Figure 4.1. The abstraction impacts on each discrete reach were also considered (excluding upstream reaches) and monthly sustainability categories (similar to those calculated in the ARM framework) were derived for some gauged locations.

Fylde Aquifer Trial: The resources of the confined Fylde aquifer and the sustainability of groundwater abstraction from it were considered separately from the surface water catchments above it for the reasons discussed in Sections 3.1 and 3.4. The Agency's principal reference for this assessment was the recently completed groundwater modelling study of the aquifer although it is understood that attempts to apply the ARM spreadsheets to the trial (described in Section 3.4) were also reviewed during preparation of the Regional team's submission to the national group.

4.3.2 Area Delineation

River Ribble Trial: For the GIS application of SWALP the river catchment was split into 32 separate river reaches, each with its associated surface water abstractions and discharges and groundwater abstractions (understood to be delineated by the surface water catchment area?).

Fylde Aquifer Trial: The extent of the Fylde aquifer is geologically delineated by its sub-crop or outcrop area up to the coast.

4.3.3 Total Resource Determination

River Ribble Trial: The total annual resource for each reach in the GIS was defined as the flow naturally exceeded 50% of the time (QN50 - see Figure 4.1). This natural flow duration curve statistic was derived from the Agency's existing 'FES' river flow model. In addition, for some gauged catchments, resources were separately defined for each month.

Fylde Aquifer Trial: Resources available to the confined aquifer in any specified assessment year were taken from the historically 'calibrated' groundwater model based on the vertical leakage flow from the drift to the sandstones. It is important to note that the groundwater resources thus defined for a confined aquifer are partially dependant on the abstraction stress placed on it - they cannot be based on an estimate of 'natural' recharge or 'natural' throughflow.

4.3.4 Assessment Year Selection

River Ribble Trial: The GIS implemented SWALP approach is based on the long term flow duration curve statistics modelled for the river. There is therefore no need to specify a particular year or hydrological scenario for assessment.

Fylde Aquifer Trial: Consideration was given to the balance of leakage and abstraction for three separate periods based on the groundwater model simulation: a 'long term' average (1972 - 96); a 'dry' year (1995); and an 'average' year (1987).

4.3.5 Target Flow Definition

River Ribble Trial: As in South West Region the target flow was defined according to the SWALP (Surface Water Abstraction Licensing Procedure) principal of protecting a minimum or 'Hands-Off-Flow' plus a variable '% Take' calculated as a fixed proportion of the natural flows exceeding this minimum.. A minimum flow equivalent to the natural QN95 as derived from the FES model was adopted for all the reaches onto which an 'environmental allocation' of 25% of (QN50 - QN95) was added to define the target flow. The North West Region team considered the 25% Take to be more 'reasonable' (i.e. less prohibitive to resource development) as a 'benchmark' environmental allocation than that recommended by SWALP (an environmental weighting of 75% for the reaches assessed). It was recognised that as part of the real CAMS process, the basis for target flow definition could be revisited on a reach-by-reach basis.

Fylde Aquifer Trial: Beyond reviewing the groundwater outflow targets estimated to prevent saline intrusion as part of the initial ARM trials (Section 3.4) it is understood that no further attempts were made to define targets from the groundwater model. As for the definition of the total resource, the North West Region team consider that such target groundwater outflows cannot be readily calculated for a confined aquifer like the Fylde.

4.3.6 Abstraction and Discharge Impact Assumptions

River Ribble Trial: Both annually licensed abstraction rates (from the 1999 ledger) and an estimate of actual abstraction based on assumptions of license uptake were used to assess sustainability for each reach in the context of the long term QN50 total resource flow and the SWALP based target flow. The use of single annual flow and abstraction rates in this analysis effectively ignores any seasonal variations in abstraction rates or in the impacts of abstractions on flows. The consideration of monthly flows at some of the gauged sites did allow representation of the seasonal variation in abstraction sustainability. It is understood that in flow de-naturalisation for this monthly groundwater abstractions were assumed to impact 'as they pump' which appears to be a justifiable approach given their relatively minor impact on river flows across most of the Ribble (see Section 3.3).

Fylde Aquifer Trial: Abstractions from the Fylde aquifer are used conjunctive with surface water resources so that actual pumping rates vary seasonally and from year to year with higher rates of abstraction during drier periods when surface water sources are stressed. The impacts of abstractions on groundwater outflow, saline intrusion and overlying Drift groundwater levels are complex and cast doubt on the value of applying simple water balance or analytical approaches (Section 3.4). The North West Region team therefore consider that the calibrated groundwater model is the most credible tool for determining abstraction impacts and sustainability, confirmed in the field by ongoing monitoring. No model runs were carried out specifically for these CAMS trials but the Agency's team relied on the conclusion of the recently reported model development study that the aquifer is overcommitted.

4.3.7 Sustainability Status Presentation

River Ribble Trial: North West Region submitted two maps of the River Ribble and its tributaries with each of the reaches included in the GIS coloured according to the sustainability status derived (see Section 2.8). On the first map colours represents the cumulative sustainability status of all upstream reaches, on the second they relate to each discrete reach.

Fylde Aquifer Trial: A third map shows the sustainability of groundwater abstraction as a separate resource. This map simply differentiates the subcrop of Fylde aquifer (considered to be 'Overcommitted') from the minor aquifers which underlie the remainder of the Ribble and surrounding surface catchments (considered to have the potential for further abstraction subject to local impact assessment).

4.3.8 Issues and Questions Raised by Regional Trial Team

The main issues and questions raised by the North West team in their submission to the national group were:

- flow naturalisation guidelines are required to provide some consistency towards estimation of actual abstractions and discharges their impacts on river flows, particularly for groundwater abstractions, and on the appropriate consideration of surface reservoirs and conjunctive use schemes;
- some national consistency within the flow units and terminology used in CAMS would be helpful;
- the GIS implementation of SWALP seemed to be effective and useful although there are significant costs associated with establishing such a system;
- the environmental weightings recommended by SWALP (i.e. for the reaches assessed, the protection of 75% of flows over the QN95) seem too prohibitive. As the establishment of target flows has a key bearing on the sustainability status which results, there should be some review across the Agency of the most appropriate and consistent approach to setting targets. In some cases it may be reasonable to base targets around the existing Q95 flow, rather than on the estimated natural QN95;
- presentation of sustainability status by colouring entire reaches of the river system is potentially misleading as the assessment relates to the outflow point of the reach only. Upstream of this point the situation will vary according to the specific locations of abstractions and discharges. Presentation of sustainability status as coloured map areas (either groundwater 'units' or surface water catchments) may be similarly misleading with regards to local resource stresses.

4.4 Wales Region Approach

4.4.1 Method Summary

Following initial attempts using the Anglian Region groundwater resource methodology, the Wales team used an assessment of 12 monthly flows, impacts and targets to determine the sustainability status of water resource management for the River Teifi catchment for submission to the national trialling group. This approach was very similar to the steps in the ARM framework but was implemented on the team's own spreadsheets.

4.4.2 Area Delineation

Assessment area defined as the surface catchment to the River Teifi (groundwater catchment assumed to be the same) split into 3 sub-catchments according to the location of gauging stations and Drift geology (see Section 3.5.1).

4.4.3 Total Resource Determination

Knowing that abstractions and discharges generally have a very small impact on river flows, Agency's team made the pragmatic assumption that the natural resource could be closely approximated by the gauged (i.e. impacted) river flows out of each area. This is a conservative approach as abstraction impacts will represent a greater proportion of this gauged flow than of the natural flow. For each area the resource was therefore defined as a profile of 12 average monthly gauged flows for the assessment years.

4.4.4 Assessment Year Selection

Three assessment years were considered:

- a long term averaged year taking data from the 1961 to 1998;
- a 'dry' year 1995;
- a 'dry' year 1996.

4.4.5 Target Flow Definition

As in South West and North West Region target flows were defined according to the SWALP (Surface Water Abstraction Licensing Procedure) principal of protecting a minimum or 'Hands-Off-Flow' plus a variable '% Take' calculated as a fixed proportion of the natural flows exceeding this minimum. For the Teifi, the minimum flow was based on the gauged Q95, combined with an environmental allocation of 75% of the gauged flows above this, as suggested by a SWALP-type evaluation of the river needs. Target flows were defined from gauged flows on a daily basis and then averaged to monthly values for the years assessed,

4.4.6 Abstraction and Discharge Impact Assumptions

Licensed abstractions were assumed to be operating at their full annual rates and these were combined with conservative estimates of the unlicensed sources within the catchments. No consideration was given to the existence of the small reservoirs within the catchment or to possible seasonal variations in the magnitude of groundwater abstraction impacts. These simplifying assumptions can be justified because artificial influences are relatively very small.

4.4.7 Sustainability Status Presentation

Monthly surplus or deficit flow histograms were presented for each sub-catchment and the total catchment for each year assessed. These plots are like those generated by the ARM spreadsheets without the associated uncertainty bars.

4.4.8 Issues and Questions Raised by Regional Trial Team

The main issues and questions raised by the Wales team in their submission to the national group were:

- guidelines on gauged flow naturalisation options should allow for pragmatic simplifying assumptions (e.g. assuming reservoirs are fixtures, assuming gauged flows are 'natural') if these can be justified;
- comparison of MORECS effective rainfall values for the Teifi show these to be around 30% lower than the equivalent mean annual runoff measured by the river flow gauges. MORECS effective rainfall could not be used to reliably predict natural flows;
- Natural Q95 and mean flows derived from microLOWFLOWS v 1 for the Teifi are around 10 to 15% greater than gauged flows;
- there is a need for guidance and consistency with regards to the appropriate choice of assessment year. Should drought severity and return period be based on an analysis of rainfall, MORECS effective rainfall, or river flows?

4.5 Anglian Region Approach

4.5.1 Method Summary

The Anglian Region team used a previous assessment carried out according to the Region's own groundwater resource methodology to determine the sustainability status of groundwater resource management for the Little Ouse Groundwater Unit for submission to the national trialling group. The Anglian Methodology is summarised in Figure 4.2 and focuses on an assessment of reliable groundwater recharge, minimum river baseflow needs and groundwater abstractions. Summer surface water abstractions and discharges are also considered insofar as they affect the river's requirements for natural groundwater baseflow support. The trial catchment of the Little Ouse also includes a number of river support boreholes operated as part of the Great Ouse Groundwater Scheme to artificially support low flows during droughts.

The elements of the Methodology described below are drawn from the Region's report to the national trialling group. It is understood that in applying the Methodology, experienced staff may consider a variety of approaches to each element of the calculation drawing on MORECS effective rainfall, microLOWFLOWS output and gauged river flow statistics to improve confidence in the conclusions derived. It is also recognised that the Agency has embarked on a strategy to develop water resources models including an integrated groundwater and surface water flow across Anglian Region which will be available to assess the sustainability of abstraction impacts in future.

4.5.2 Area Delineation

The existing Little Ouse Groundwater Unit and its four sub-units (described in Section 3.6) were delineated for assessment. These sub-units relate to the catchments of the rivers Thet, Upper Little Ouse, Sapiston and Lower Little Ouse but are not delineated according to the surface water or groundwater catchments to specified points on these rivers.

4.5.3 Total Resource Determination

The Anglian Methodology calculates a total or 'gross' groundwater resource on the basis of an estimate of the long term average infiltration of effective rainfall to groundwater (which may vary according to the presence and nature of Drift cover) multiplied by the area of the unit. This calculation of recharge inflow resource is distinct from outflow defined assessments but is based on research into the relationships between rainfall and river baseflows across the Region.

As the average recharge or 'gross' resource is not reliably available in dry years or summer months, the Methodology reduces it by 20% to derive the 'Available Groundwater Resource'.

4.5.4 Assessment Year Selection

The Anglian Methodology does not consider any specific historical year - it compares a resource based on 80% of 'average' recharge with summer river baseflow needs and groundwater abstractions.

4.5.5 Target Flow Definition

The Environmental Requirement for water (equivalent to groundwater outflow targets) are based primarily on minimum natural river flow requirements. In practice these are based on the naturalised QN95 for the river in each sub unit derived from a calibrated river flow model (in other areas the requirement may include groundwater discharge support for wetlands or to prevent saline intrusion). The existence of any upstream summer surface water abstractions (e.g. for spray irrigation) or discharges is taken into account when determining how much of this natural QN95 depends on groundwater baseflow. The Agency also protects low flows during drought by active management of the Great Ouse Groundwater Scheme river support boreholes.

There is no consideration of winter river flows in the Anglian Methodology. The allocation to higher river flows of the 20% of gross resource considered 'unreliable' and any surface runoff entering the river directly is implicit within the Methodology so higher flow targets to protect seasonal variation (as advocated by SWALP) are not explicitly defined.

4.5.6 Abstraction and Discharge Impact Assumptions

Annually licensed groundwater abstraction rates and the Environmental Requirement for natural baseflow support are subtracted from the Available Groundwater Resource to derive the groundwater surplus or deficit for the unit. The consumptiveness of the licence use is taken into account (e.g. spray irrigation is fully consumptive whereas fish farming or cooling are not) but abstractions for the river support scheme (which is only used in droughts) are not included. As the Methodology derives a single surplus or deficit figure, any seasonal variations in the impacts of groundwater abstractions are ignored.

Within the groundwater Methodology, consideration of direct abstractions or discharges from the river is limited to the summer licensed spray irrigation or consented discharge impacts on minimum natural flows.

4.5.7 Sustainability Status Presentation

Annual groundwater surplus or deficits expressed as a percentage of the Gross Resource are presented for each sub-unit and for the Little Ouse Groundwater Unit as a whole and allow a status to be assigned according to the proposals in Section 2.8.

4.5.8 Issues and Questions Raised by Regional Trial Team

The main issues and questions raised by the Anglian team in their submission to the national group were:

- how should groundwater unit resource assessments be related to surface water CAMS assessments?
- is it appropriate to calculate reliably available groundwater resources based on 80% of the average recharge and compare these with natural river baseflow targets?
- can the sustainability of intermittent river support abstractions such as the Great Ouse Groundwater Scheme or other conjunctive use schemes be appropriately assessed without a calibrated groundwater flow model?
- should the sustainability status for each sub-unit be presented separately, or only for the whole?

4.6 Comparison of the Initial ARM Trials with Regional Approaches

The use of common headings summarising the key elements of each Region's approach facilitates comparison between them and with the initial ARM trials described in Section 3. The discussion below considers the similarities between the approaches before highlighting the key differences.

The approaches adopted in South West Region and Wales are both very similar to the ARM framework. They all define the total resource as the 12 average monthly natural river flows for a specified assessment year or years. This resource is not separated into groundwater and surface water components. The impacts of surface and groundwater abstractions and of surface water discharges on the natural river flows are estimated on a monthly basis in a process of de-naturalisation. Target flows are set according to the SWALP principle as the sum of a defined minimum plus a fixed percentage of natural flow above this minimum and sustainability is assessed from a monthly surplus or deficit profile calculated by subtracting target flows from de-naturalised flows.

The surplus or deficit profile indicates how much more abstraction impact on river flows would be acceptable or by how much the impact should be reduced. This commonly varies seasonally with large surpluses in the winter and smaller surpluses or deficits in summer. Unless there is groundwater in a highly transmissive, low storage karstic aquifer where abstraction impacts on river flows are close to the pumping rate it is probable that winter surpluses can only be effectively licensed as surface water abstractions with river flow controls.

Adopting a monthly flow approach allows any perceived seasonal variation in the impact of groundwater abstractions (due to aquifer storage and the seasonal or year to year variation in recharge) to be represented if these abstractions are significant enough to warrant such treatment.

The problem of how to consistently select an appropriate historical year or hydrological scenario for monthly consideration is common to these monthly approaches. However, in the same way, the ability to illustrate how severely impacted resources might have been in a recent drought if a particular abstraction and discharge scenario had applied could be viewed as a strength.

North West Region's GIS application of a simplified version of SWALP for the River Ribble also based both the resource and target flows on estimates of natural river outflows (in a similar way to the ARM framework and the Wales and South West trials). For the GIS trials however these estimates were summarised as single flow duration statistics (e.g. the resource as QN50 rather than Qmean) based on the long term daily flow rather than considering impacts on the whole flow duration curve. As such the single surplus or deficit figure derived tends to only reflect the 'average' condition. The decision to consider monthly flow variations for some gauged sites on the Ribble may have been made partly in recognition that the 'average' approach might not conservatively represent the most stressed lower flows.

The separate consideration of groundwater resources alone for the Fylde is in sharp contrast to the integrated surface water – groundwater assessments carried out by all the teams for the Teifi (runoff dominated), Otter (significant baseflow) and Ribble (mixed). This decision appears entirely reasonable given the poor surface water connections to this confined aquifer as does the conclusion that a calibrated groundwater model provides the only appropriate tool for investigating long term sustainability of abstraction from it as part of a conjunctive use scheme. Natural groundwater resources, target outflows and abstraction impacts all elude simple approximation in such an aquifer.

The Anglian Groundwater Resource Methodology has served the Region successfully as a practical and simple tool for the management of groundwater resources for many years. However, a recharge based definition of gross resource may be difficult to compare with the other, river outflow focussed approaches to resource calculation applied elsewhere and also with targets derived from gauged, naturalised or modelled river outflows. Like the North West Region's GIS approach to the Ribble, a single surplus or deficit percentage is quoted in the Anglian submission which is not specific to any particular year, but these figures are not comparable. The figures for the Ribble represent an 'average annual' surplus or deficit derived from a total river flow based resource and target whereas for the Little Ouse, the surplus or deficit percentages relate to the more stressed summer groundwater balance only, expressed as a percentage of long term average recharge.

The ongoing development programme of regional groundwater models across Anglian Region is in recognition that, as for the Fylde, such models provide the most appropriate tool for considering resources, river flow naturalisation and abstraction sustainability where the exploitation of groundwater resources is significant. When these models are in place they should be used both as part of the CAMS process and for more local impact assessment.

In the meantime (i.e. before such models are available), if CAMS require river outflow focussed assessments which can be used to investigate and represent seasonal variations in the abstraction stresses and the resource balance in a manner which integrates surface water and groundwater flows, it appears that the two candidate approaches are:

- a monthly flow consideration for specified historic years or hydrological scenarios, as advocated by the ARM framework and applied by 3 of the Agency's Regional teams;
- a flow duration curve approach, as advocated by SWALP which considers abstraction impacts on the whole curve (i.e. which allows high and low flow impacts to differ) rather than simply the QN50 or Qmean.

From all the Agency team comments it is clear however that the adoption of a common approach or framework for the CAMS sustainability calculations is not itself a guarantee of comparability or consistency. Wider awareness of guidelines covering each of the main elements (i.e. hydrological scenario or year selection, flow naturalisation assumptions, abstraction scenario assumptions, interpretation and representation of surplus or deficits) would be useful. Local consultation, within the Agency and with catchment stakeholders, will also be essential to achieve a defensible consensus on appropriate target flows.

The information and arguments summarised in this Section were presented and discussed at a workshop with representatives from the Agency's Regional and National trialling teams. Although there was not universal agreement with the arguments made, a clear consensus emerged to recommend that the ARM framework should be further considered and that the spreadsheets be improved and developed in the light of Agency comments with a further trial in Anglian Region. This work is described in the next Section.

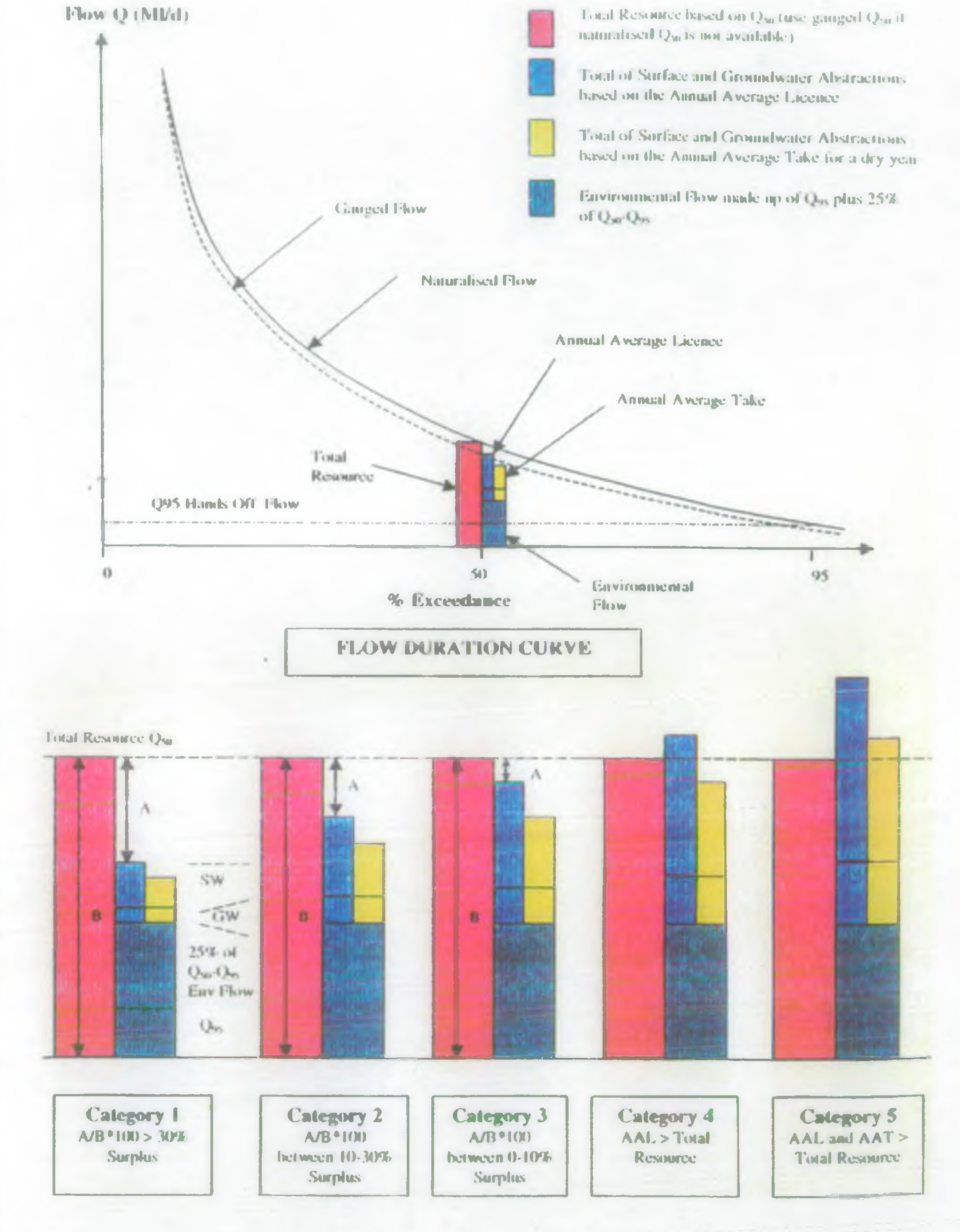


FIGURE 4.1 SCHEMATIC OF FLOW DURATION CURVE METHODOLOGY USED BY NORTH WEST REGION

Drawing No: 02701.-01.S011 Date: JANUARY 2000 Scale: NTS

Entec

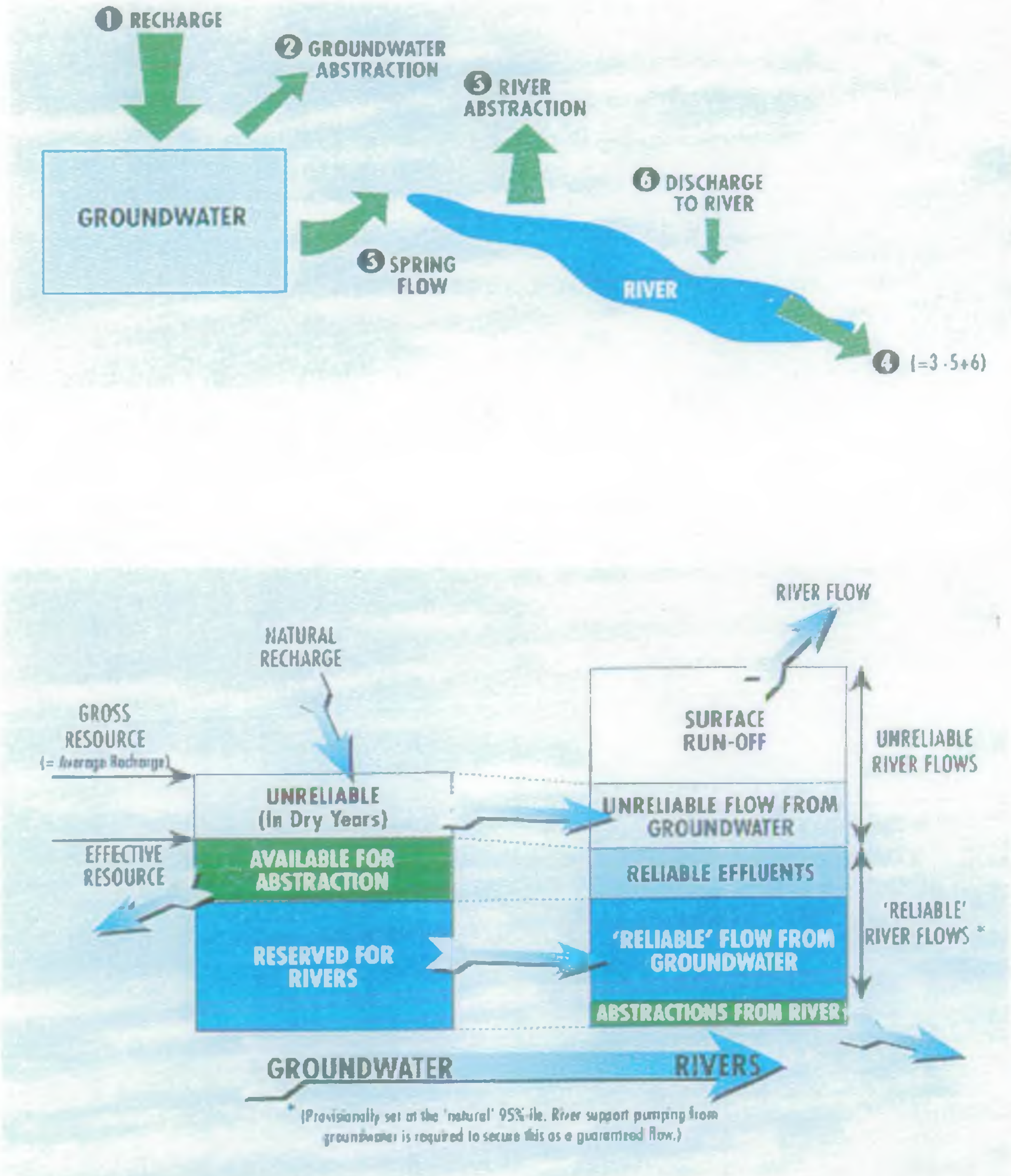


FIGURE 4.2 SCHEMATIC OF ANGLIAN REGION BELOW GROUNDWATER RESOURCE METHODOLOGY

Drawing No: 02701.-01.S012 Date: JANUARY 2000 Scale: NTS

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5. Further Development and Trialling of the ARM Framework in Anglian Region

5.1 The Need for Further Development

Delegates to the CAMS trial workshop agreed that further consideration and development of the monthly Available Resource Methodology was justified in order to:

- present the ARM more clearly as a simplified *Framework* defining the main elements of a resource sustainability assessment but allowing users flexibility as to how these elements are achieved;
- revise, update and simplify the ARM spreadsheets to provide a more flexible tool for assessments within the Framework, if people want to use them;
- to discuss this further work with the Anglian Region team and to repeat trials on the River Thet using the revised Framework and spreadsheets.

This Section describes the results of these tasks.

5.2 The ARM as a Framework

Figure 5.1 shows an overview of the revised and simplified ARM Framework which supersedes that shown in Figure 2.1. This Framework defines the basic elements of a monthly resource sustainability assessment which should satisfy the CAMS requirement. The requirement to produce monthly plots which focus either on river or groundwater outflows remains, as does the need to record a qualitative description of the conceptual understanding at the outset.

The main changes made are:

- if appropriate, a simulated hydrological scenario can be specified for assessment in place of an historical year;
- the distinction between gauged and ungauged river assessments has been removed. The first step of the calculation is to determine and plot natural river flows in any appropriate way (e.g. gauged flow naturalisation, microLOWFLOWS, groundwater model output etc.). The choice of a gauged location is still favoured as it should reduce assessment uncertainties, may play a key role in surface water abstraction license conditions, and offers the chance of comparing actual flows with targets;
- as part of a river outflow assessment, groundwater baseflows and recharge can be optionally separated from the total flow resource at an early stage;
- the artificial impacts on flows being assessed (which are likely to be related to the present-day license ledger) are termed the 'scenario' impacts to clearly

differentiate them from impacts which may have used to naturalise gauged flows in an historical year;

- the optional 'water balance' comparison of gauge naturalised and rainfall derived natural flows previously included at the end of the framework for gauged rivers has been removed. Comparisons of different natural flow estimates can optionally be made at the start of the calculations if required, where they may more usefully highlight uncertainties in the understanding of the system.

It is recommended that this Framework should be presented in a short summary report together with key diagrams (such as Figure 2.2) but separately from the ARM spreadsheet user manual. Agency trial teams at the workshop considered that the application of the ARM as a Framework rather than as a spreadsheet would be more appropriate and acceptable.

5.3 Spreadsheet Revisions and Sustainability Output Presentation

Spreadsheet revisions have been made in order to:

- **correct mistakes** within the August 1999 versions (e.g. these wrongly assumed that the abstraction impacts used for gauge flow naturalisation are the same as those being considered for the sustainability assessment);

- **simplify the river assessments** so that flow naturalisation and targets always relate to the resources of the entire catchment upstream of the assessed outflow point, whilst maintaining the option to present the resources and abstraction impacts for any discrete reach separately if required. This is done by assessing the total catchment targets, scenario flows and impacts first and then subtracting the scenario flows and impacts for any catchments to be excluded upstream of the reach being considered;

- **reflect the more flexible nature of the Framework** proposed above. The gauged flow naturalisation and Aquifer Response Function calculations have been separated out from the main spreadsheet as optional derivations of natural river flow. The user can optionally specify and compare up to 4 different estimates of natural flows (e.g. including microLOWFLOWS or groundwater model output) before selecting one of these to carry forward into the assessment;

- allow for the **optional inclusion of a separated baseflow resource** which can be compared to groundwater abstraction impacts if specified. This allows for a separate definition of groundwater resources based on baseflows which should be more readily comparable with previous assessments using the Anglian Region Methodology;

- **tailor presentation** of calculation results more closely **to the requirements of the CAMS** process. The monthly surplus or deficit plot can be readily used to derive both the annual average % of total resource figure referred to in the currently proposed status classification (see Section 2.8) but also allow the more critical summer month impacts and surplus or deficit % to be stated. The Anglian Region team are concerned that this summer status should be clearly stated as it more closely reflects the sustainability of groundwater abstraction management previously derived by their own Methodology. The accumulation of data uncertainties through the calculations and the resulting representation as error bars on the monthly surplus or deficit profile allow these uncertainties to be taken into account in the final allocation of a sustainability status.

Figure 5.2 shows an example of how ARM spreadsheet results might be presented for the long term average CAMS assessments of the River Ribble to Arnford and Samlesbury gauging stations. The plots have been taken from the Conclusions sheet of the Excel Workbook for each revised assessment and include histogram summaries of monthly natural, scenario and target flows, and the surplus or deficit profile with uncertainty bars. Key figures such as the average and minimum surplus have also been abstracted expressed both as Ml/d and as a percentage of the natural flow in the year and month respectively. These are useful for the interpretation of sustainability status when viewed alongside other, specific year assessments. No attempt should been made to colour the rivers according to this status as it only applies to the outflow point at each gauging station - the calculations combine the impacts of all upstream artificial influences and take no account of their location on the river.

It is recognised that the revised spreadsheets have been developed significantly beyond the versions for which a draft user manual was prepared in May 1999. It is therefore recommended that an updated and simplified Manual for spreadsheet users be produced which can accompany the short summary report on the framework itself. This can be taken for further internal review in the Agency and, if approved, could be rolled out to appropriate staff in the Regions as part of a structured training programme.

5.4 Revised Spreadsheet Application to the Thet Catchment

The changes to the ARM Framework and spreadsheets described above were made in discussion with Anglian Region staff and the trials for the River Thet to Melford Bridge were repeated on the revised spreadsheets. The conceptual description of the study area, assessed years (long term average, and 1991 with the Great Ouse Groundwater Scheme in operation), abstraction impact and target flow assumptions were all as described for the initial trials in Section 3.6 but the simpler spreadsheet format and the inclusion of the optional baseflow separation early in the calculation make it more readily comparable with the Anglian Methodology.

The revised spreadsheets for both years are included in Appendix B with the headline results in the 'Conclusions and QA' sheets presented first, followed by the main 'River Outflow Calcs' sheet and the optional supporting gauge naturalisation and aquifer response function sheets. The paragraphs below are a commentary the 'River Outflow Calcs' sheet for the 1970 to 1990 long term average assessment (filename: 'thetmelltav2.xls').

Steps 1 and 2: The surface water catchment area of the Thet to Melford Bridge is 316 km^2, as assessed by the ARM, is close to the 316 km^2 area of Anglian's Thet sub-groundwater unit. The long term average period selected should not be used by itself to derive sustainability as summer low flows and winter peaks are smoothed out but it is more closely comparable with the Anglian Methodology calculations than the consideration of the 1991 drought year.

Step 3: In addition to the gauged flow naturalisation and effective rainfall based calculations of natural river flows which are presented on the accompanying optional sheets, two other synthetic natural flow estimates have been manually entered to illustrate how output from microLOWFLOWS or a groundwater model might be taken into the assessment. If available, flows from the river flow model used by Anglian Region to determine natural QN95 protection targets could have been entered at this stage. All four estimates are plotted and can be compared and revised before one (in this example that based on gauge flow naturalisation) is taken forward.

Step 4: The option of separately specifying a natural baseflow has been taken with three alternative estimates provided and plotted. Two of these (the baseflow separation and the groundwater model output) have been synthesised and manually entered for illustrative purposes only. The third estimate is taken from the effective rainfall based aquifer response function calculations on the supporting spreadsheet. This is very close to the Anglian Methodology derived groundwater resource (66 Ml/d ARM average cf. 64 Ml/d Anglian Gross Resource, 51 Ml/d ARM minimum cf. 51 Ml/d Anglian reliably Available Resource) and has been taken forward for later comparison with groundwater abstraction impacts.

Step 5 and 6: There are some differences in the basic artificial impact data used for the ARM and Anglian assessments. Surface water abstraction licenses used in the ARM assessment have been profiled according to Anglian Region guidelines but suggest summer month impacts around 10 Ml/d as compared to the 3 Ml/d used in the Region's own CAMS submission. There is a discrepancy between the groundwater abstractions. In the ARM example groundwater abstraction varies seasonally with a summer (spray irrigation) peak of 17 Ml/d, but the impact of this abstraction cycle on river flows is assumed to be evenly distributed throughout the year at an average rate around 8 Ml/d. This compares with the 13 Ml/d impact assumed in the Region's submission. Finally, the Agency's submission assumes effluent returns of 4.5 Ml/d compared to the ARM value of 2 Ml/d. These combine to result in a differences between the net consumptive abstraction impact in the Agency's submission (12 Ml/d) and that derived by ARM (Step 5.5 - average 9 Ml/d, summer around 16 Ml/d).

Step 7: The minimum monthly flow of 54 Ml/d in the ARM assessment was taken directly from the natural QN95 specified for protection according to the river flow model in the Agency's submission (even though this is greater than the 51 Ml/d quoted by the Agency as being reliably available from groundwater). Monthly variability in the ARM target was allowed by assuming that it is acceptable to abstract 50% of natural flows above this minimum. The Anglian Methodology makes no equivalent allowance although it implicitly assumes that winter flows will be assured by the 'unreliable' groundwater flows and runoff (Figure 4.2).

Step 8: The surplus or deficit profile resulting from the ARM assessment suggests a very small minimum surplus of 3 Ml/d in September with an associated error bar of +/- 18 Ml/d. The Anglian Methodology deficit of around 14 Ml/d for the summer groundwater balance should be close to this minimum value and does fall within the uncertainty interval i.e. the ARM assessment would not justify a change to the Agency's policy of no further groundwater licenses in the Unit. This is encouraging. Apart from the differences in artificial impact assumptions described above, the discrepancy in final surplus or deficit estimates is probably mostly due to the ARM choice of defining total resources according to naturalised gauged outflows rather than estimated recharge inflows. It is important to note however that the mean annual surplus of 29 % from the ARM assessment would be misleading as a summary of sustainability for groundwater unless accompanied by the seasonal profile and minimum 4 % value.

Steps 9 to 12: These steps provide further plots 'for information' of acceptable abstraction impacts, of scenario outflow composition as Ml/d and as mm over the surface water catchment, and of baseflow minus groundwater abstraction impacts.

All of the main plots and results from the 'River Flow Calcs' Sheet are summarised on the 'Conclusions and QA' sheet.

The results of this comparison are encouraging and suggest that although there are significant differences in the two approaches, certain key stages of the calculations are comparable. The final conclusions are also similar - no further groundwater licenses should be considered in the assessed catchment as they are likely to place further unacceptable stress on summer flows but further surface water abstractions with seasonal and/or flow restrictions tied into the Melford gauge can be considered subject to local impact assessments.

A brief review of the 1991 ARM spreadsheets for the River Thet in Appendix B shows how the impacts of the river support scheme can be taken into account (see Section 3.6). It also illustrates how the use of the support boreholes was largely successful in maintaining river low flows around the target levels even though the natural flows would have been much lower (the artificial impacts 'scenario' considered in this example was based on the actual use of the scheme in 1991).

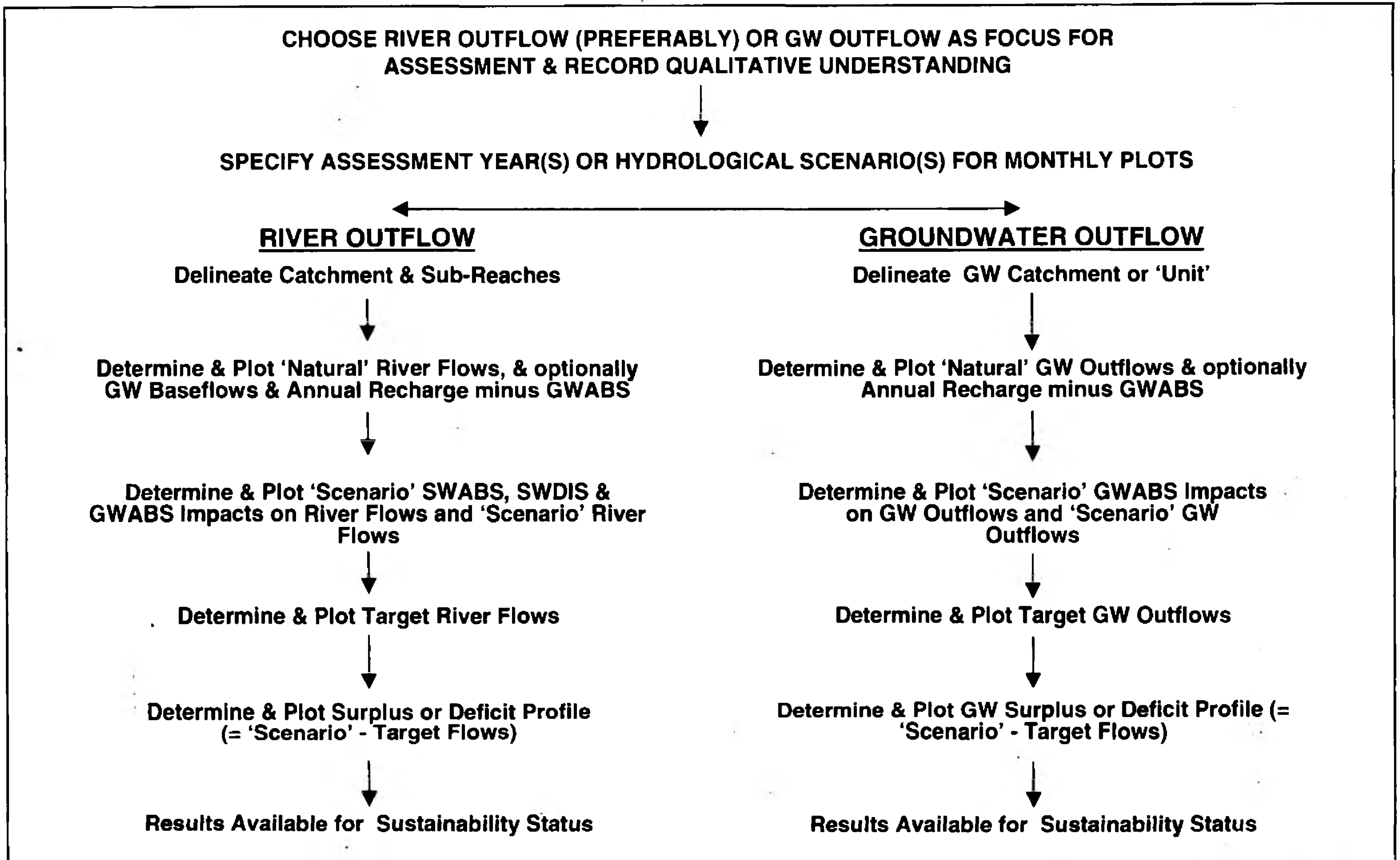

FIGURE 5.1 REVISED ARM FRAMEWORK OVERVIEW

Drawing No : 02019-01.S013 | Date: JANUARY 2000 | Scale: N/A

Entec

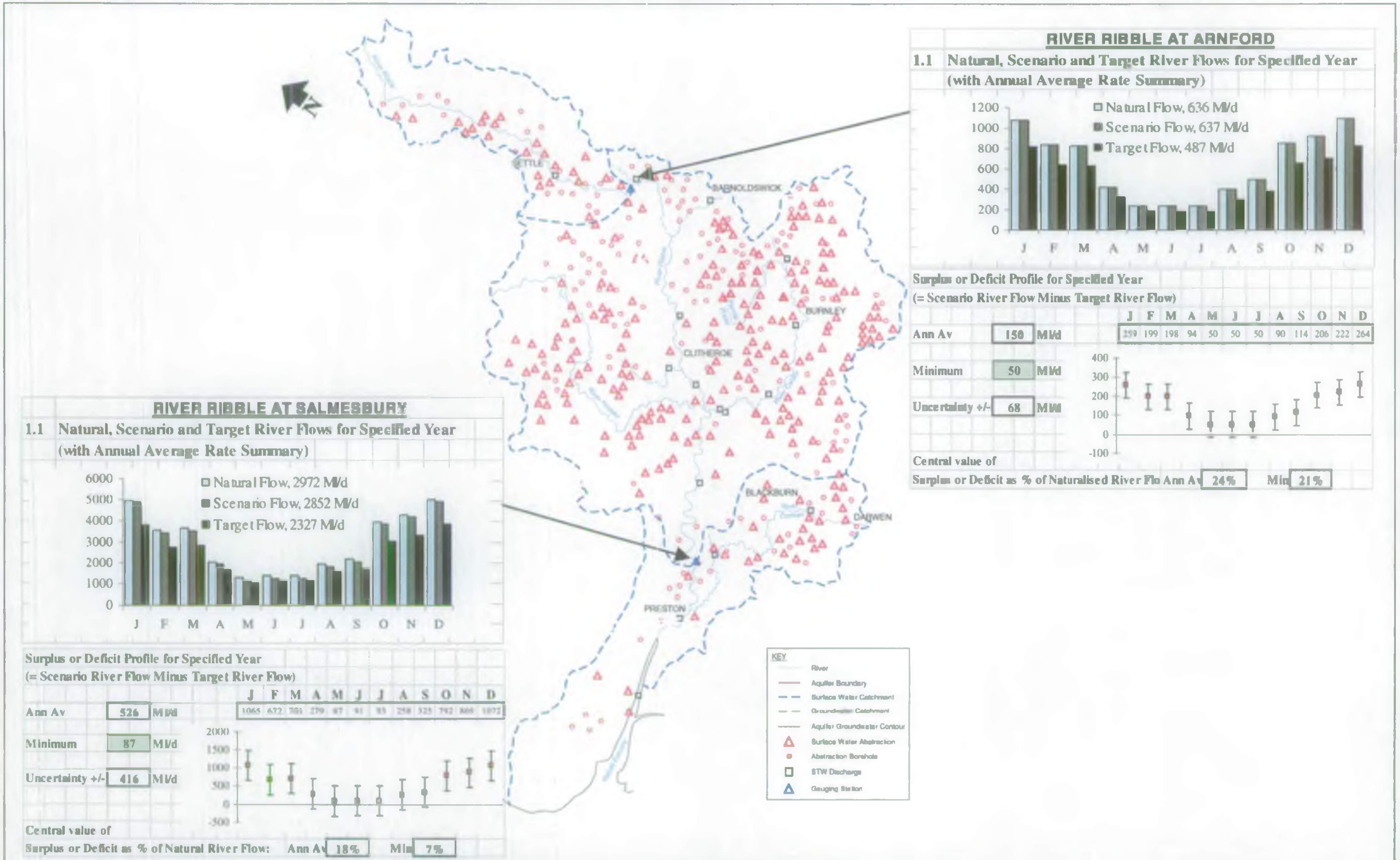

FIGURE 5.2 POSSIBLE PRESENTATION OF ARM RESULTS FOR CAMS (Ribble Catchment Example)

Drawing No : 02019-01.S014a Date: MARCH 2000 Scale: AS SHOWN

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6. Conclusions: Applicability of the ARM Framework Within the CAMS Process

The findings of the trial comparisons and further development reported in Sections 2 to 5 are encouraging with regards to the applicability of the ARM for sustainability assessments within the CAMS programme. Adopting the ARM as a Framework should not in itself require any more Agency staff time than would otherwise be required for resource calculations (beyond an initial training requirement) as it merely sets out a recommended order of procedures which should themselves be subject to Agency best practice guidelines. As a Framework the ARM can accommodate a variety of techniques for each of the calculation steps, including all of those currently in use in the Regions, but it also provides a consistent focus of assessment on river outflow impacts which are likely to be the principal aspect of management concern. Furthermore, the recommended reporting style (monthly outflow and surplus or deficit plots), if consistently adopted across the Agency, could arguably save time and effort when compiling regional and national reports.

The ARM spreadsheets are clearly able to combine and present monthly variations in existing water resource balance components, to compare these between areas, and to investigate the implications of target flows in terms of the sustainability status of abstraction management. The representation of natural and artificial flow components as stacked histograms and the simple consideration of the possible uncertainties associated with each component should help to prioritise abstraction management interventions or further investigations.

The trials reported show that the ARM is widely (but not universally) applicable to both surface water and groundwater dominated catchments. Where possible assessments should be focussed on gauged catchments, with groundwater and surface water flows and abstraction impacts considered together and compared against target flows which can be measured. However, the absence of a gauging station does not prohibit the application of the ARM as it can accommodate a variety of approaches to natural flow and impact estimation (microLOWFLOWS, surface water models, groundwater models etc.). Similarly the ARM can be applied to groundwater resources separately where this is justified (e.g. confined or coastal aquifers where interaction with rivers is limited) although, as with most other approaches, its conclusions in such areas should be viewed with extreme caution. Application of the ARM is most problematic for confined aquifers where the recharge 'resource' is partly dependent on the abstraction stress, and target outflows are unmeasurable. In such areas the basic premise of a natural outflow reduced by abstraction falls down and the ARM spreadsheets may only offer a consistent reporting format for more sophisticated assessment based on groundwater flow modelling.

The assessments may be most effectively carried out by the Agency staff who know the area. Data requirements do not appear to be significantly more onerous than the resource assessment approaches already in use in the Regions although estimates of actual abstraction impacts are required where these differ from licensed rates and are a key part of the balance. Data collation time should be reduced by other ongoing initiatives such as implementation of the National Abstraction Licensing Database, the development of national standards for flow naturalisation and the updating of microLOWFLOWS. Spreadsheet data entry and analysis of the resource balance for each of the ARM assessment areas in the LTAV and one specific year is expected to take an experienced user between one and three days depending on how critical the balance is. More time and wider consultation may be required to establish appropriate target flows (including consideration of downstream needs), and to define and represent the initial conceptual understanding.

ARM assessments are most straightforward and are probably associated with the least uncertainty when focussed on reliably gauged river flows. This has implications with regards to the preferred delineation of assessment areas as the combined (but not necessarily coincident) surface and natural groundwater catchment to a river gauge or between two river gauges. In groundwater dominated areas the Agency's existing groundwater management units may not be defined in this way so that trial results may not be directly comparable with current resource estimates. The sub-division of a catchment into sub-areas for ARM assessment also requires careful consideration and may be based on either perceived changes in the characteristics of the catchment or in the environmental sensitivity of river flows. The size of the catchments assessed in these trials varies considerably although this may be justified by differences between the current levels of abstraction stress and environmental concern. The additional representation in the spreadsheets of monthly flow balances as mm/month (by dividing by the surface catchment area) facilitates resource comparison regardless of catchment size across the country. It also enables easier comparison with resource estimates initially derived from effective rainfall or recharge calculations (such as the Anglian Methodology).

The key issues to ensure consistency in gauged river assessments are firstly that these flows are naturalised according to nationally accepted Agency guidelines and secondly that the target flows can be justified through the consultative process both between internal Agency functions and with interested parties and the public.

The most problematic elements of the naturalisation process are likely to be the estimation of the impacts of groundwater abstraction, surface reservoirs and river support boreholes on river flows. However the effort invested in resolving these issues can be considered pragmatically in the light of their significance to the overall water balance. Conservative assumptions based on licensed groundwater rates can be readily applied to the Teifi catchment whereas the timing of groundwater abstraction impacts is much more critical to the Anglian and South West Region trial areas (a criticality demonstrated by efforts to construct and use groundwater flow models in both cases).

The surplus and deficit profiles which are a key output from the ARM process are critically dependent on the target flows. As for flow naturalisation, the ARM does not prescribe how these should be set - this has been the subject of extensive previous research (e.g. SWALP) and intensive current debate. The option of defining targets on the basis of a minimum flow and an acceptable abstraction % of natural flows above this minimum may be helpful to ensure that the targets are 'reasonable' for any specified assessment year.

Whilst the presentation of the average surplus or deficit from the profile as a percentage of the total resource is helpful for comparative purposes and to inform the interpretation of sustainability status proposed in Section 2.8, it is also essential to quote the minimum surplus as this more closely reflects the groundwater resource position.

As with other approaches, application of the ARM to assessment areas with ungauged river outflows or unmeasurable groundwater outflows is likely to be less reliable and more involved, particularly for drift covered aquifers like the Fylde. Where groundwater system behaviour becomes significantly non-linear or where surface water runoff processes, reservoirs or river support boreholes are important, the optional ARF approach to estimate natural outflows from effective rainfall inputs provided within the spreadsheets may be of limited value. Alternative rainfall-runoff approaches (e.g. microLOWFLOWS) should always be considered but more intensive (and costly) distributed modelling may be required to adequately assess such areas, if warranted by a critical sustainability status. Target groundwater outflows will also be difficult to determine and should be associated with large uncertainties. In such areas practical abstraction management should lean strongly towards the precautionary principle with particular dependence on time limited licences and controls based on groundwater level or quality monitoring.

Before taking application of the ARM Framework or spreadsheets further some key issues remain to be addressed:

- is the monthly flow approach for a specified year or scenario preferable to a flow duration curve based approach such as SWALP?
- how can the change in the approach to resource assessment which would be apparent to stakeholders and the public be made, and are the suggested formats for presentation of sustainability appropriate in the light of previous Agency practice?
- how can consistency in the choice of assessment years or scenarios be achieved across the Regions?
- are the proposed approaches to the incorporation of river augmentation schemes such as in Anglian Region appropriate and how should the existence of surface water reservoirs be best accommodated?
- who should be the main users of the Framework and the spreadsheets?
- can the terminology of the ARM Framework and the spreadsheets be simplified to make it more readily user friendly and more readily accessible to non-specialist personnel?

As such we conclude that the ARM Framework and associated spreadsheets warrant further scrutiny by a national Agency group. This group should include both surface water and groundwater specialists with experience in alternative approaches such as SWALP, microLOWFLOWS, and the Anglian Groundwater Methodology, and in approaches to estimating the impact of groundwater abstractions on river flows.

7. Recommendations

In summary Entec recommend:

- that the Available Resource Methodology (ARM) be concisely reported as a flexible Framework for the Agency to use as a basis for assessments of water resources and abstraction sustainability;
- that a concise User Manual be prepared to accompany the ARM spreadsheets;
- that these documents and previous Project Reports and Records detailing the development of the Framework, its trials and comparisons with other approaches should be considered by an appropriate national Agency group to determine whether the ARM Framework be adopted to support the CAMS process;
- that, if adopted, the ARM Framework be rolled out to appropriate Agency staff across the Regions in a structured manner with training;
- that, in order to make subsequent ARM assessments more consistent across the country, the Agency should progress a common approach towards, and establish best practice in: definitions and terminology; flow naturalisation (including IGARF); setting target flows or river flow objectives; appropriate selection of assessment years; translation of surplus or deficit profiles into a sustainability status; presentation formats for CAMS documents.

Appendix A
Hardcopies of August 1999 ARM Spreadsheets for Initial CAMS Area Trials

196 Pages
(Note: These are as included in the first draft report. They are not copied in this Second Draft).

Appendix B
Hardcopies of Revised ARM Spreadsheets for River Thet Trials

31 Pages

Entec

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet at Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev** 1 **Date** 19/8/99

Conceptual Understanding

1 **Area Definition, Boundaries and Surface Drainage**

Draw on the attached sheet, a simple sketch plan of the Area, with features traced from a map.
Show/label the following features (as relevant): Area boundaries, SW catchment boundaries, GW contours & catchment boundaries **as you think they were before abstraction,** geol. boundaries, the coast, rivers flowing in and out, gauging station locations, names of surrounding assessment areas, location of major SW discharges and SW and GW abstractions, key wetland features, urban areas etc

2 **Geology of the Area and Schematic Cross Section** Bedrock Drift

Main geological formation: Chalk Type: Y or (tick)

Is this an aquifer - is GW a significant part of the hydrological cycle? (Y/N) Y (if N, go to **5**)

Underlying solid geology in Area: Chalk

Overlying solid or drift geology in Area: Approx 50% area overlain by boulder clay

If appropriate: Draw on the attached sheet a schematic geological cross section(s) through the area.

3 **Groundwater Recharge and Interaction between Groundwater and Surface Water**

Aquifer Condition: Confined Unconfined Mixed y

if confined, by what? confined by boulder clay in places toward east of area

Recharge:	Relevant processes (please tick):	Direct recharge:	Y
		Stream/river leakage/runoff-recharge:	Y
		'Urban' leakage:	N
		Drift 'recharge reduction & smoothing':	Y

Recharge occurs over: All the area: Part of the Area: Y

If only part, which part: Less through boulder clay overburden

Aquifer Response to Recharge (in words):	year	season	month	week	day
please tick according to your conceptual feel:			y		

Groundwater - River Interaction:	poorly connected	well connected
please tick according to your conceptual feel:		Y
	baseflow independent	baseflow dependent
river flows are now:		Y
	baseflow independent	baseflow dependent
'naturally' rivers were:		Y

If appropriate: Mark recharge and discharge areas and 'losing/gaining' river reaches on the conceptual sketch plan. Add GW-SW concepts to sketched cross section(s)

4 **Hydrogeological Boundaries and Groundwater Flow**

Are there significant groundwater flows into or out of the Area: Yes: No: N

show on sketch plan & section and describe Possibly some flow to Thet or Sapiston

Are there hydrogeological flow barriers or Transmissivity variations: Yes: Y No:

show on sketch plan & section and describe Chalk has very variable T

Does water quality constrain abstraction (eg saline intrusion etc): Yes: No: N

show on sketch plan & section and describe

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet at Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev** 1 **Date** 19/8/99

5 Observed Hydrological Trends and Environmental Concerns

5.1 Perceived Trends from 'Natural' to 1970	falling	steady	rising	mixed	comment/data source
Groundwater levels:					No Data
River flows:					No Data
GW abstraction:					No Data
SW abstraction:					No Data

5.2 Trends Evident from 1970 to Present	falling	steady	rising	mixed	
Groundwater levels:					No Data
River flows:	Y				Table 2. L/O WRM, 19!
GW abstraction:			Y		Returns
SW abstraction:			Y		Returns

5.3 Relative Magnitude of Current Anthropogenic Influences
Please rank by magnitude SW discharges, GW abstraction and SW abstraction

GW abs > SW dis > SW abs

5.4 Water Resources Environmental Concerns

Please summarise river flows Y wetlands Y salinity other

Please explain: Perceived low flow problems in rivers and falling regional groundwater levels.
Causing derogation to Wetlands

6 Previous Studies and Reason for this Assessment

Please List: 1993 Little Ouse Water Resources report by Julie Barker - this area similar to sub-unit A
1998 Ely-Ouse Environmental Overview (data behind 1999 Ely Ouse LEAP)

Please explain why you are carrying out this assessment now:
As part of the ARM : AMS trial

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet at Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev** 1 **Date** 19/8/99

Conceptual sketch plan (hand sketch or import as windows metafile)

see Figure 3.6, main report

Assessment Area is SW and GW catcment of R Thet to Melford Br GS

Schematic conceptual sketch cross-section(s) (hand sketch or import as windows metafile)

END OF SHEET

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet at Melford Bridge GS **ID** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1970-1990)**

1 Results Summary for the Total Catchment to the Outflow Point

1.1 Natural, Scenario and Target River Flows for Specified Year (with Annual Average Rate Summary)

☐ Natural Flow, 170 Ml/d

⊟ Scenario Flow, 161 Ml/d

■ Target Flow, 112 Ml/d

Target Flows based on: Monthly Minimum of nat QN95 plus 50% of naturalised flow above this

1.2 Scenario Artificial Impacts (with Annual Average Rate Summary)

Abs & Dis Scenario: Licensed 1993 Rates (No Restrictions)

⊞ GW Abstraction Impact, 8 Ml/d

▧ SW Abstraction Impact, 3 Ml/d

◫ SW Discharge Impact, -2 Ml/d

Net Abstraction Impact, 9 Ml/d

Maximum net abstraction impact for total catchment based on
Max. (net abs impact/natural river flow from total catchment) = 17 % in **Jul**

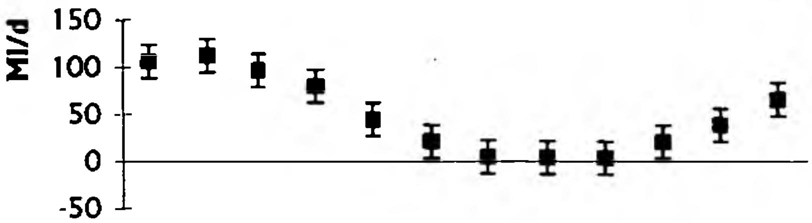
1.3 Surplus or Deficit Profile for Specified Year (= Scenario River Flow Minus Target River Flow)

Ann Av 49 Ml/d

J	F	M	A	M	J	J	A	S	O	N	D
106	112	97	80	45	21	5	4	3	21	39	66

Minimum 3 Ml/d

Uncertainty +/- 18 Ml/d



Central value of
Surplus or Deficit as % of Natural River Flow: **Ann Av** 29% **Min** 5%

1.4 Interpreted Sustainability Status of Resource Management at Outflow Point

Sustainability Status Category:

Comments :

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet at Melford Bridge GS **ID** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1970-1990)**

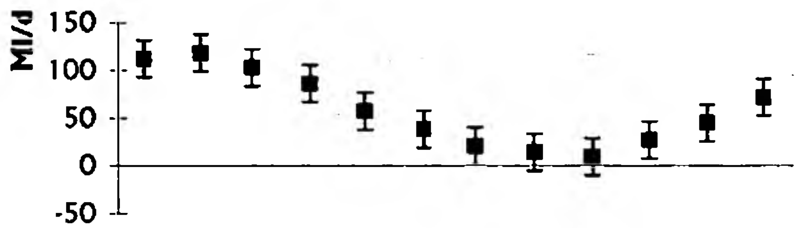
1.5 Acceptable Net Abstraction Impacts Profile for Specified Year (= Natural Flow Minus Target Flow)

Ann Av 58 Ml/d

Minimum 9 Ml/d

Uncertainty +/- 19 Ml/d

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	112	118	102	86	57	38	21	14	9	27	45	71



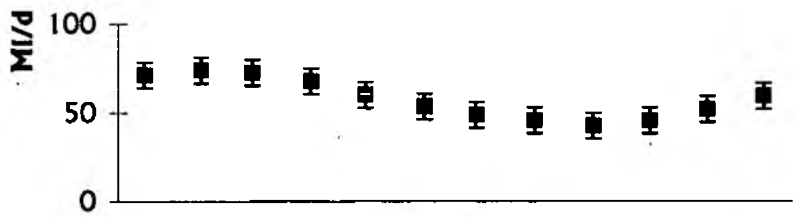
1.6 Natural Baseflow Minus Locally Consumptive Groundwater Abstraction Impact if baseflow (i.e. groundwater resource) has been separately defined

Ann Av 58 Ml/d

Minimum 43 Ml/d

Uncertainty +/- 7 Ml/d

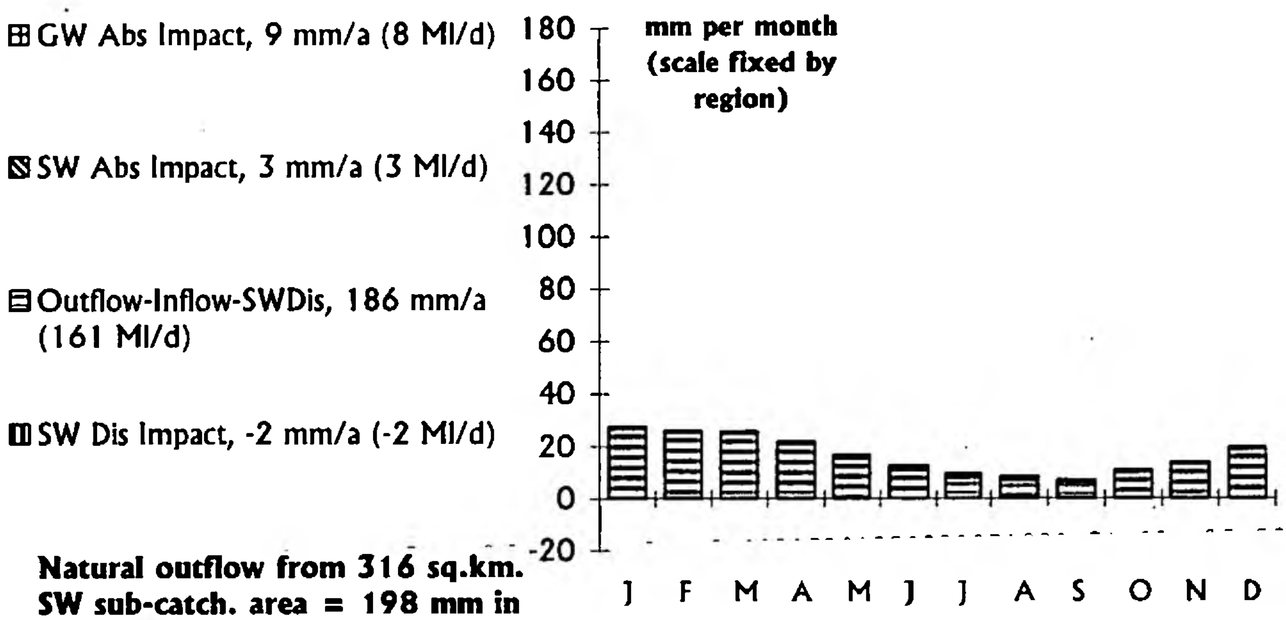
	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	71	74	73	68	60	54	49	46	43	46	52	59



2 Outflow Components (Optionally Excluding Upstream Sub Catchments)

Upstream Catchments Excluded 0

Flow Components Derived from the Sub Catchment
Expressed in mm/month Over Gauged Surface Water Sub-Catchment Area
(with Annual Average Rate Summaries in mm/a and Ml/d)



Natural outflow from 316 sq.km. SW sub-catch. area = 198 mm in

Maximum net abstraction impact for this sub-catchment area only (exluding upstream catchmen

Max. (sub-catchment net abs impact/sub-catchment nat outflow) = 17 % in Jul

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet at Melford Bridge GS **ID** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Specified Assessment Year **L T Average Year (1970-1990)**

3 Interpreted Management Action Required

Note: this section may be based on consideration of other years in other spreadsheets

3.1 Potential for Further Development

Potential for additional steady state net abstraction impacts Ml/d (zero if none)

Potential for additional winter-only net abstraction impacts Ml/d (zero if none)

(river flow controlled SW abstraction in winter)

3.2 Target For Abstraction Impact Reduction

Overall target for reduction of abstraction impacts: Ml/d during

3.3 Proposals for Augmentation or Mitigation to meet Flow Targets

NOTE: Each licence application or reduction assessed on a case by case basis considering: proximity to rivers/wetlands, consumptiveness/point of return, seasonality etc

4 QA Authorisation and Version Control

4.1 Acceptable Impact Assessment Review and Authorisation

Version: **1** Assessed by: **G Coombs** sign

Reviewed by (hydrogeologist & hydrologist): **R Soley & J Bloggs** sign

Authorised by **J Bloggs** sign

Assessment based on: Agency framework: Detailed model#: Other#:

other study/calculation/report reference:

Any need/plans to reassess resource soon?:

target date	method
01/01/00	**AMS the real thing**

4.2 Abstraction Ledger Update Control

Ledger rev. no: **0** Updated on: By:

In connection with licence numbers:

END OF SHEET

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet at Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

Assessment for Areas which Drain to a River Outflow

1.0 Surface Water Catchment Area

Surface catchment area to river outflow point assessed = 316 sq. km. Based on: ih hydrometric register, 91-95

2.0 Year or Hydrological Scenario of Assessment

The year specified for this assessment is L T Average Year (1970-1990) Basis for selection of this year ltav comparison

3.0 Natural River Flows in Specified Year to Define the Total Water Resource

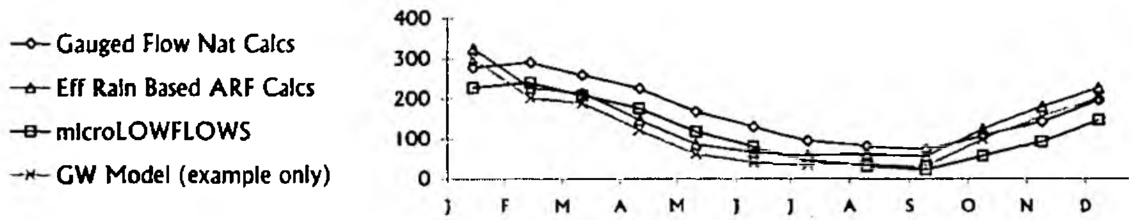
Enter the monthly averaged natural river flows for the assessment year, and an associated % possible error, based on one or more of the following:

a. Gauged Flow Naturalisation *(use the 'Gauge Nat Calcs' sheet or overtype based on Agency national guidelines)*,
b. Effective Rainfall Based Aquifer Response Function Calculations *(use the 'Eff Rain Based ARF Calcs (Riv)' sheet)*
c. MicroLOWFLOWS for average year flows *(please reference calculation)*
d. An Alternative Method e.g. Standard Hydrological Approaches, River or Groundwater Flow Model *(please reference method & calculations)*

Compare these different estimates, adjust them if required, then select one to carry forward as the total water resource profile for the year.

	Method and Calculation Reference	Select One type 'x'		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	% Err.
a.	*Gauge Nat Calcs* Results	x	Ml/d	170	72	278	290	259	226	168	130	96	82	72	107	143	197	6.1
b.	*Eff Rain Based ARF Calcs (Riv)* Results		Ml/d	148	56	325	228	215	147	87	66	58	62	56	124	181	228	10
c.	MicroLOWFLOWS ref: Example only for plot		Ml/d	120	22	228	240	209	176	118	80	46	32	22	57	93	147	
d.	GW Model (example only) ref: Example only for plot		Ml/d	123	31	300	203	190	122	62	41	33	37	31	99	156	203	

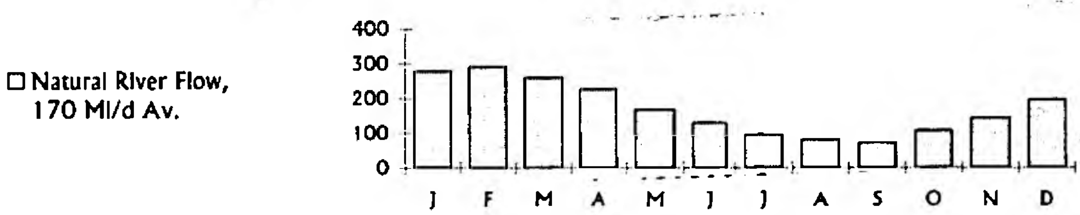
(Monthly Av. Natural River Flow in Specified Year, Ml/d)



Selected Method	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Natural River Flow, 170 M: Gauged Flow Nat Calcs	169.99	72.363	277.77	290.4	258.96	225.88	167.88	129.94	95.508	82.046	72.363	107.06	143.28	196.99	10

(Selected Natural River Flow in Specified Year, Ml/d)

Annual Equivalent **Effective Rainfall** over SW Catchment is 196 mm/a



4.0 Natural River Baseflows in Specified Year to Define the Groundwater Resource (optional)

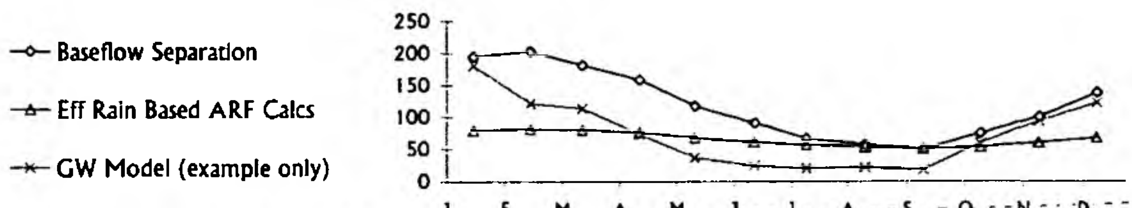
If a separate estimate of groundwater resources is required, enter the monthly averaged natural river baseflows, based on one or more of the following:

a. Baseflow Separation of Total Flow Hydrograph *(please reference method & calculations)*
b. Effective Rainfall Based Aquifer Response Function Calculations *(use the 'Eff Rain Based ARF Calcs (Riv)' sheet)*
c. An Alternative Method e.g. Standard Hydrological Approaches, River or Groundwater Flow Model *(please reference method & calculations)*

Compare these different estimates and, considering the natural river flow selected, select one to carry forward as the groundwater resource profile.

	Method and Calculation Reference	Select One type 'x'		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	% Err.
a.	Baseflow Separation ref: E.g. 70% nat tot flow		Ml/d	119	51	194	203	181	158	118	91	67	57	51	75	100	138	15
b.	*Eff Rain Based ARF Calcs (Riv)* Results	x	Ml/d	66	51	79	82	80	76	68	61	57	54	51	54	60	67	10
c.	GW Model (example only) ref: example for plot only		Ml/d	74	18	180	122	114	73	37	24	20	22	18	60	94	122	15

(Monthly Av. Natural River Baseflow in Specified Year, Ml/d)



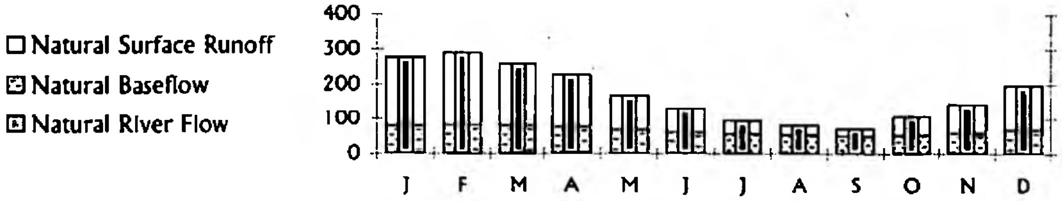
AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet at Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

Selected Natural Baseflow in Specified Year, Ml/d

Selected Method	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Eff Rain Based ARF Calcs	66	51	79.203	81.744	80.454	75.703	67.981	61.471	56.749	53.63	50.827	53.595	60.014	67.307	6.56
Implied Surface Runoff Flow	104	22	198.57	208.66	178.51	150.17	99.902	68.467	38.759	28.416	21.536	53.469	83.263	129.68	

Annual Equivalent **Recharge** over SW Catchment is 76 mm/a



5.0 Impacts of Consumptive Abstraction and Discharges Scenario on River Flows in Specified Year

Abstraction rates should be locally consumptive (i.e. excluding any water *locally* returned to the catchment).
Public water supply abstractions should be considered as fully consumptive because sewage treatment works or transfer discharges are accounted for separately. Surface water abstractions and discharges are assumed to impact on river outflows as they pump. Groundwater abstraction impacts on the river are entered separately as they may differ from the pumped profile because of groundwater storage changes.
In this scenario the pumping rates used to derive the impacts of SWabs/GWabs/SWdis are based on (please describe Assumed Abstraction Scenario) (e.g.full licensed 1999 rates/deployable output/actual 1999 rates) **Licensed 1993 Rates (No Restrictions)**

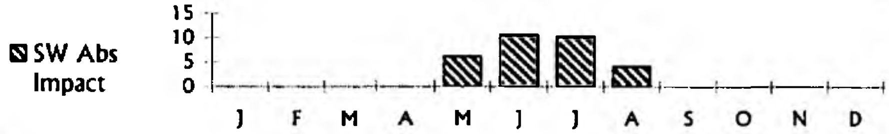
5.1 Scenario Surface Water Abstraction Impacts on River Flows in Specified Year

Year 1993 licenced Calcs in: natcalsLTA.xls - spray irrigation licenses profiled as per Anglian naturalisation guidelines

Data compilation & calculation imply level of confidence in this data set is +/- 10 %

Consumptive SW Abs Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
3	Ml/d	0	0	0	0	6	11	10	4	0	0	0	0	0



5.2 Scenario Groundwater Abstraction Impacts on River Flows in Specified Year

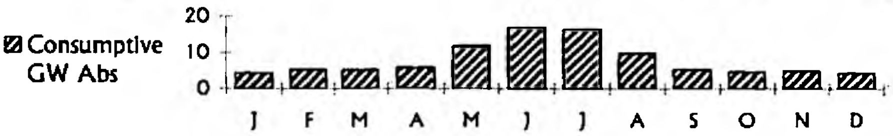
5.2 a. Scenario Groundwater Abstraction in the Month of Pumping

Year est actual Calcs in: natcalsLTA.xls - 1993 licenced flow ignoring GOGWS * demand profile * uptake factor

Data compilation & calculation imply av. level of confidence in this data set is +/- 10 %

Consumptive GW Abstraction, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
8	Ml/d	4	5	5	6	12	17	16	10	5	5	5	4	1



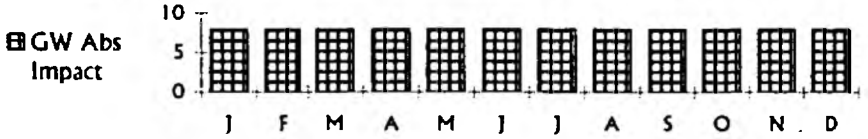
5.2 b. Scenario Groundwater Abstraction Impacts on River Flows in Specified Year

Impact Calcs Assumptions & reference: assuming fully smoothed steady state impacts (as IGARF or Jenkins)

Data compilation & calculation imply av. level of confidence in this data set is +/- 15 %

Consumptive GW Abs Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
8	Ml/d	8	8	8	8	8	8	8	8	8	8	8	8	1



5.3 Scenario Surface Water Discharges Impacts on River Flows in Specified Year

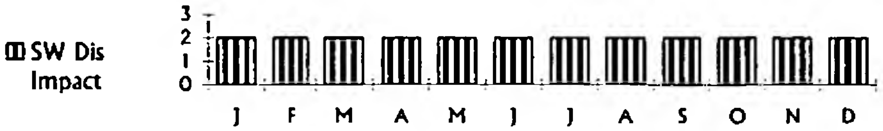
Include all sewage treatment works discharges or river support discharges to the river upstream of the gauge. Base discharge rate on est. DWFs

Year 1993 Calcs in: Taken from J.Barker report for 1993

Data compilation & calculation imply av. level of confidence in this data set is +/- 20 %

SW Dis Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
2	Ml/d	2	2	2	2	2	2	2	2	2	2	2	2	0



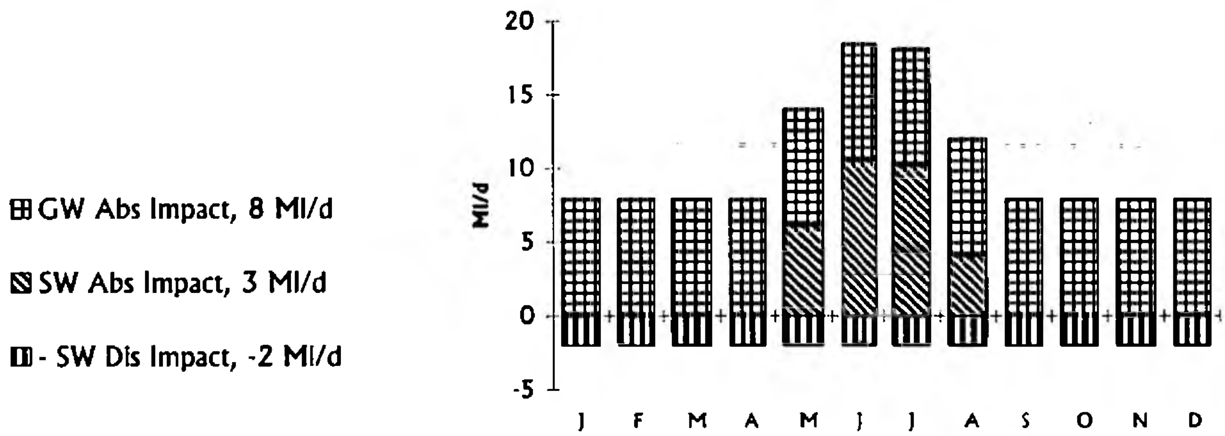
AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet at Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

5.4 Summary of Scenario Abstraction and Discharges Impacts on River Flows in Specified Year

GW Abs, SW Abs & SW Dis Impacts on River Flows, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 8 Ml/d	8	Ml/d	8	8	8	8	8	8	8	8	8	8	8	8
SW Abs Impact, 3 Ml/d	3	Ml/d	0	0	0	0	6	11	10	4	0	0	0	0
- SW Dis Impact, -2 Ml/d	-2	Ml/d	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2



5.5 Scenario Net Consumptive Artificial Impacts in Specified Year

Net Abs Impact = SW+GWAbs Impacts - SWDis Impact, Ml/d
= step 5.1 + step 5.2b - step 5.3

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Net Abs Impact, 9 Ml/d	9	Ml/d	6	6	6	6	12	16	16	10	6	6	6	6	2
Net Abs Impact/Natural River Flow, %	7	%	2	2	2	3	7	13	17	12	8	6	4	3	

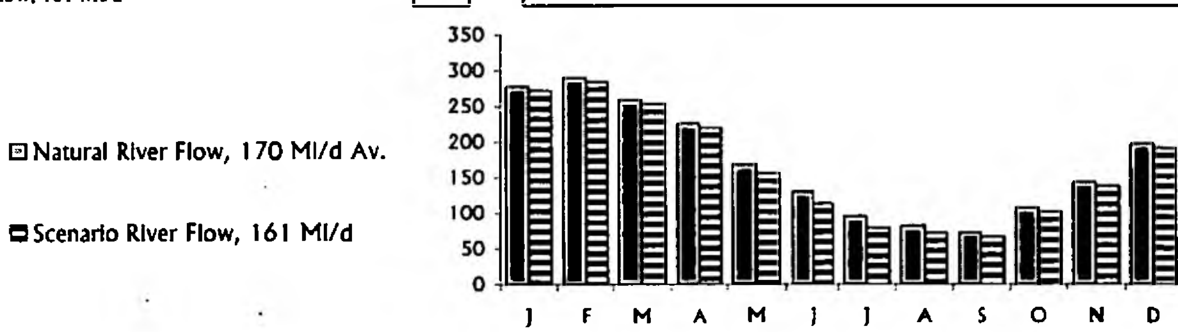
Maximum Percentage Impact = 17 %

In the month of Jul

6.0 River Flows for this Artificial Impact Scenario in Specified Year

Scenario River Flow = Natural Flow - Net Abs Impact, Ml/d
= step 3 - step 5.5

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Scenario River Flow, 161 Ml/d	161	Ml/d	272	284	253	220	156	113	79	72	66	101	137	191	12



AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet at Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

7.0 Setting Target River Outflows for Specified Year

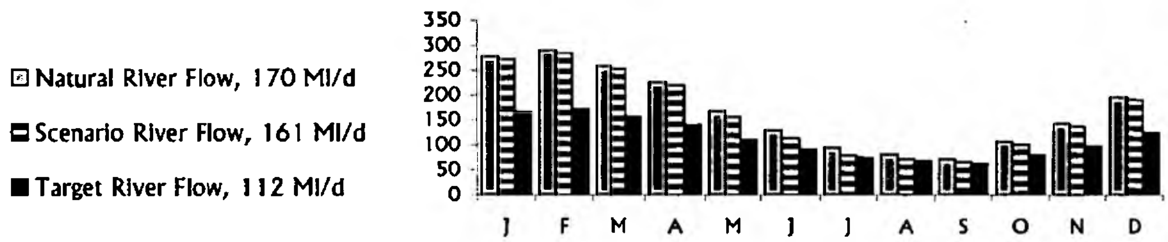
Target flows based on (summarise): Monthly Minimum of nat QN95 plus 50% of naturalised flow above this

Calc/Authorisation Ref: **J.Barker AMS Draft Report**

Natural, Scenario & Target Total River Flows, Ml/d

		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	
Natural River Flow, 170 Ml/d		170	72.363	277.77	290.4	258.96	225.88	167.88	129.94	95.508	82.046	72.363	107.06	143.28	196.99	
Scenario River Flow, 161 Ml/d		161	66.444	272	284	253	220	156	113	79	72	66	101	137	191	
Monthly Minimum Flow, Qmin		54	54	54	54	54	54	54	54	54	54	54	54	54	54	Ml/d
% Acceptable Abs. Impact of QNat over QMin	50 %	58	9.1814	112	118	102	86	57	38	21	14	9	27	45	71	Err+/-
Target River Flow, 112 Ml/d	Confidence: +/- 10 %	112	63	166	172	156	140	111	92	75	68	63	81	99	125	5

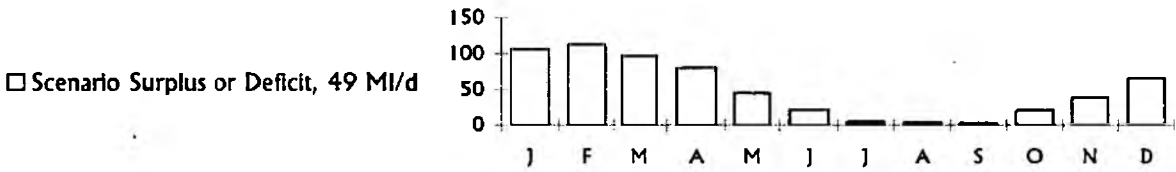
Compare with Q95 = 42 Ml/d Reported Elsewhere in
Ref: ih yearbook gauge Q95, 1962-95



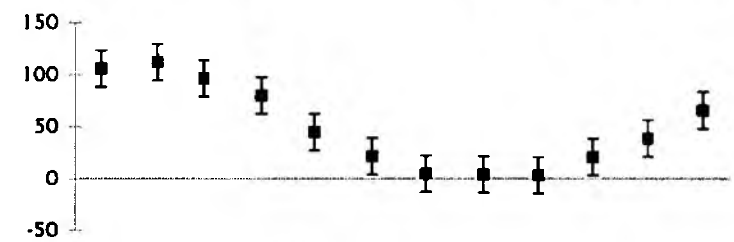
8.0 Scenario Surplus or Deficit for Specified Year, Given Target River Outflows

Surplus or Deficit = Scenario - Target River Flow Ml/d

	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Scenario Surplus or Deficit, 49 Ml/d	49	3.263	106	112	97	80	45	21	5	4	3	21	39	66	18
Surplus or Deficit as % of Natural River Flow	29		38	39	37	35	27	17	5	5	5	19	27	33	



Same surplus/deficit plot with
combined error bar of +/- 18 Ml/d



Over the Whole Year,

Annual Average Surplus or Deficit = **29%**

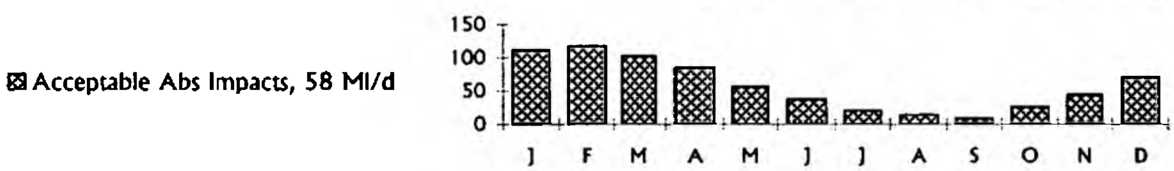
Annual Average Naturalised Gauged Flow and minimum = **5%**

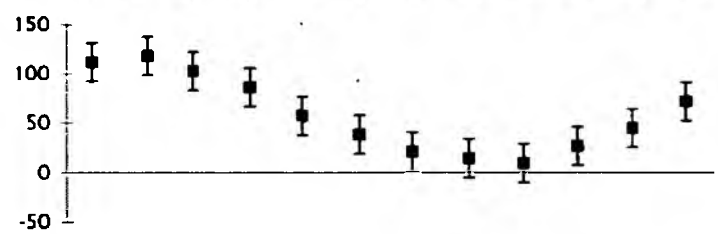
9.0 Acceptable Abstraction Impacts for Specified Year Given Target River Flows

Defined as the total acceptable abstraction impact on outflows. This is simply calculated either by adding the scenario surplus or deficit to the scenario net consumptive abstraction impacts or by subtracting target from natural flows (Dependent only on natural and target flows, not on the abstraction scenario assessed)

Acceptable Abstraction Impacts for Specified Year, Ml/d

	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Acceptable Abs Impacts, 58 Ml/d	58	9.1814	112	118	102	86	57	38	21	14	9	27	45	71	19





Same surplus/deficit plot with
combined error bar of +/- 19 Ml/d

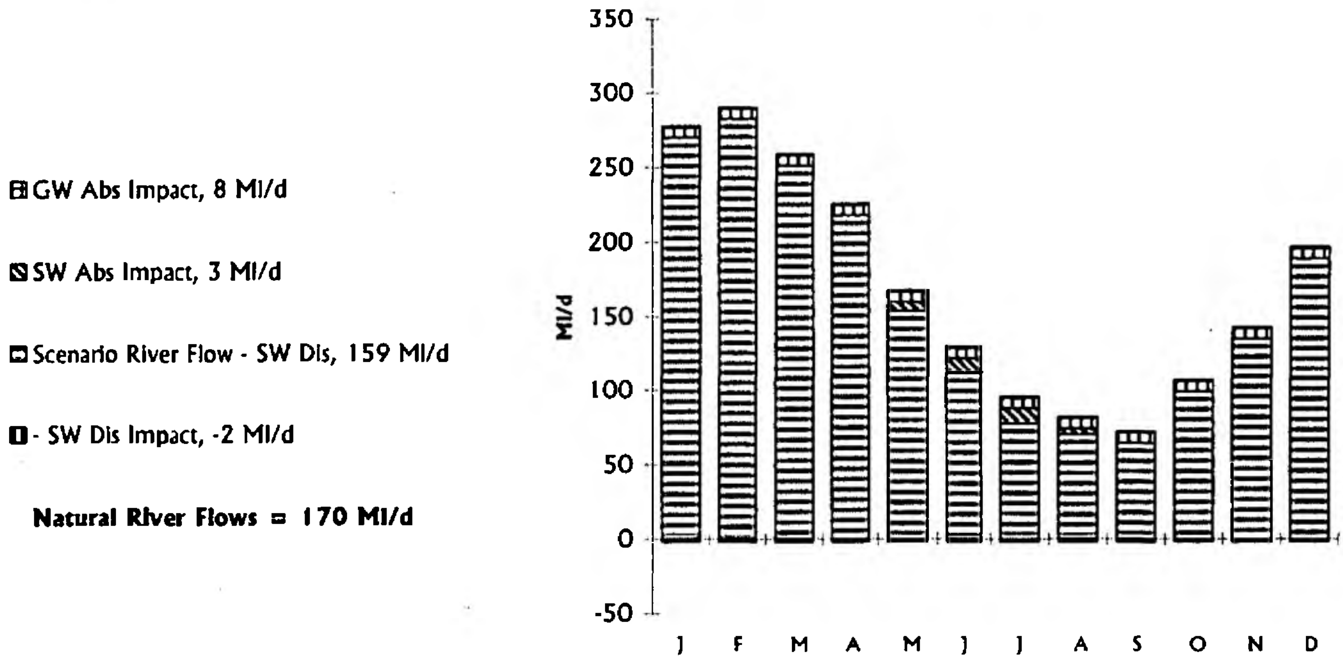
AVAILABLE RESOURCE METHODOLOGY (ARM)

Area	R Thet at Melford Bridge GS	ID	?	Version	1	Ledger Rev.	1	Date	19/8/99

10 Scenario Outflow Composition from Total Catchment in Specified Year

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Scenario River Flow, 161 Ml/d	161	Ml/d	272	284	253	220	156	113	79	72	66	101	137	191
GW Abs Impact, 8 Ml/d	8	Ml/d	8	8	8	8	8	8	8	8	8	8	8	8
SW Abs Impact, 3 Ml/d	3	Ml/d	0	0	0	0	6	11	10	4	0	0	0	0
- SW Dis Impact, -2 Ml/d	-2	Ml/d	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
Scenario River Flow - SW Dis, 159 Ml/d	159	Ml/d	270	282	251	218	154	111	77	70	64	99	135	189
Natural River Flows = 170 Ml/d	170	Ml/d	Surface water catchment area =				316	sq km						

Licensed 1993 Rates (No Restrictions)

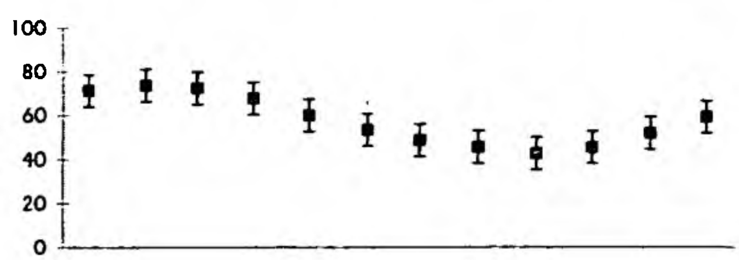


11 Natural Baseflow (Groundwater Resource) Minus Consumptive GW Abstraction Impact in Specified Year
Only plotted if a baseflow has been specified at step 4.

Natural Baseflow - Consumptive GW Abs. Impacts, Ml/d
= step 4 - step 5.3b

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Baseflow - GW Abs Impact, 58 Ml/d	58	Ml/d	71	74	73	68	60	54	49	46	43	46	52	59	7

Same Baseflow - GWAbs Impacts plot with combined error bar of +/- 7 Ml/d



AVAILABLE RESOURCE METHODOLOGY (ARM)

Area	R Thet at Melford Bridge GS	ID	?	Version	1	Ledger Rev.	1	Date	19/8/99

12 Scenario Outflow Composition from Sub-Catchment in Specified Year, as mm/month over Sub- Catchment Area

This plot expresses the scenario outflow components as mm per month over the surface water catchment area.
The step 10 values from upstream assessment areas can be combined and pasted below in order to plot the outflows from the lower sub-catchment only. If no values are pasted in, the plot represents the entire catchment assessed.

Identify the upstream catchments to be excluded from the plot: Catchments Excluded:

Combine Step 10 values from these assessments and paste below.

Scenario Outflow Values (Step 10) from Upstream Catchs, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Scenario River Flow, 0 Ml/d	0	Ml/d												
GW Abs Impact, 0 Ml/d	0	Ml/d												
SW Abs Impact, 0 Ml/d	0	Ml/d												
- SW Dis Impact, 0 Ml/d	0	Ml/d												

Combined Upstream SW catchment areas = sq km

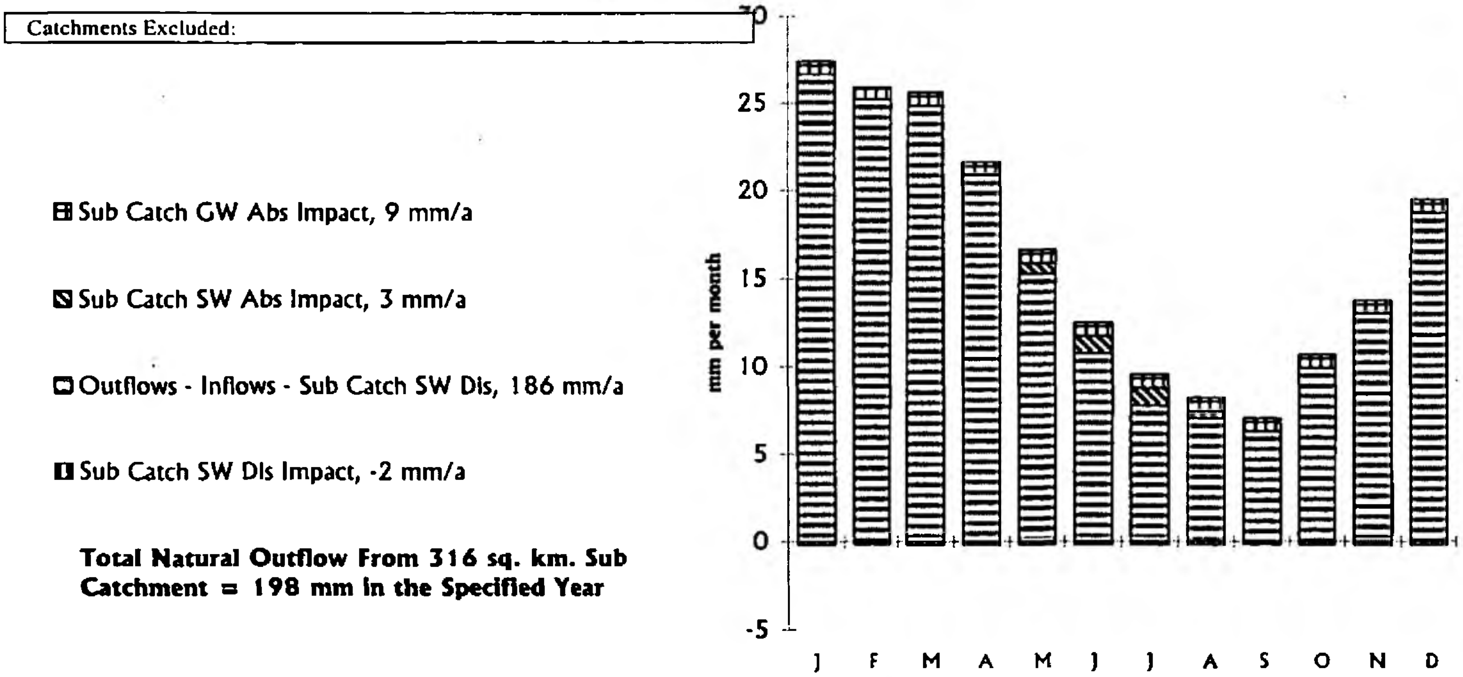
Surface Water Sub-Catchment Area for this plot 316 sq. km.

Components of Nat. Outflow as mm/month over SW sub catch.

	Ann Tot		J	F	M	A	M	J	J	A	S	O	N	D
Sub Catch GW Abs Impact, 9 mm/a	9	mm/a	1	1	1	1	1	1	1	1	1	1	1	1
Sub Catch SW Abs Impact, 3 mm/a	3	mm/a	0	0	0	0	1	1	1	0	0	0	0	0
Sub Catch SW Dis Impact, -2 mm/a	-2	mm/a	0	0	0	0	0	0	0	0	0	0	0	0
Outflows - Inflows - Sub Catch SW Dis, 186 mm/a	186	mm/a	27	25	25	21	15	11	8	7	6	10	13	19

Total Natural Outflow From 316 sq. km. Sub Catchment = 198 mm in the Specified Year

Licensed 1993 Rates (No Restrictions)



	J	F	M	A	M	J	J	A	S	O	N	D
% (net abs impact for sub-catchment)/(nat outflow from sub-catchment) =	2	2	2	3	7	13	17	12	8	5	4	3

Maximum net abstraction impact for this sub-catchment area only (exluding upstream catchments)

Max. (sub-catchment net abs impact/sub-catchment nat outflow) = 17 % in Jul

END OF SHEET

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area: R Thet at Melford Bridge GS | ID: ? | Version: 1 | Ledger Rev.: 1 | Date: 19/8/99

GAUGED FLOW NATURALISATION SHEET *(OPTIONAL)*

1.0 Year of Assessment

The year specified for this assessment is: L T Average Year (1970-1990) | Basis for selection of this year: ltav comparison

(these are specified in the 'River Outflow Calcs' sheet)

2.0 Gauged River Flows in Specified Year

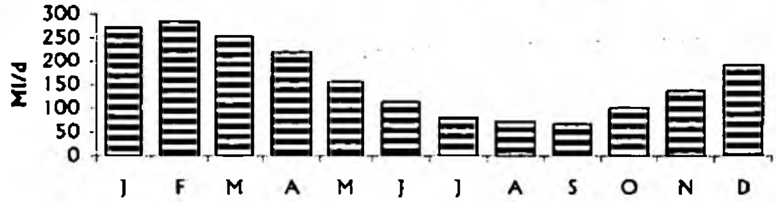
Enter the monthly averaged gauged river flows for the assessment year

Gauged River Flow in Specified Year, Ml/d

Gauging Station Name	Data Ref	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Melford Br (av.1970-90)	thet-mel.xls	162	Ml/d	272	285	253	220	156	114	79	72	67	101	137	191

Data compilation & calculation imply level of confidence in this data set is +/- 5 %

i.e. error bar assumed to be +/- 8 Ml/d



3.0 Gauged Flow Naturalisation: Removing Impacts of Consumptive Abstraction and Discharges on River Flows in Specified Year

The flow rates used to derive the impacts of SWabs, GWabs & SWdis should be based on best estimate of actual abstraction or discharge during the specified year. Abstraction rates should be locally consumptive (i.e. excluding any water *locally* returned to the catchment) Public water supply abstractions should be considered as fully consumptive because sewage treatment works or transfer discharges are accounted for separately. Surface water abstractions and discharges are assumed to impact on river outflows as they pump. Groundwater abstraction impacts on the river are entered separately as they may differ from the pumped profile because of groundwater storage changes.

3.1 Surface Water Abstraction Impacts on River Flows in Specified Year

Assumptions and Calculations Ref: natcalsLTA.xls - spray irrigation licenses profiled as per Anglian naturalisation guidelines

Consumptive SW Abs Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
3	Ml/d	0	0	0	0	6	11	10	4	0	0	0	0

Data compilation & calculation imply level of confidence in this data set is +/- 10 %

i.e. error bar assumed to be +/- 0 Ml/d

3.2 Groundwater Abstraction Impacts on River Flows in Specified Year

3.2 a. Groundwater Abstraction in the Month of Pumping

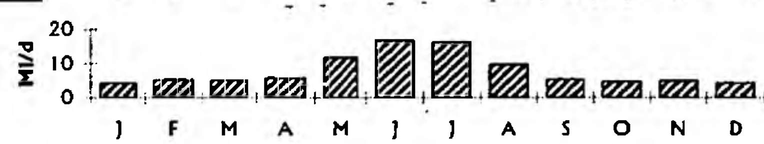
Assumptions and Calculations Ref: natcalsLTA.xls - 1993 licenced flow ignoring GOGWS * demand profile * uptake factor

Consumptive GW Abs, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
8	Ml/d	4	5	5	6	12	17	16	10	5	5	5	4

Data compilation & calculation imply av. level of confidence in this data set is +/- 10 %

i.e. error bar assumed to be +/- 0.8 Ml/d



3.2 b. Groundwater Abstraction Impacts on River Flows in Specified Year

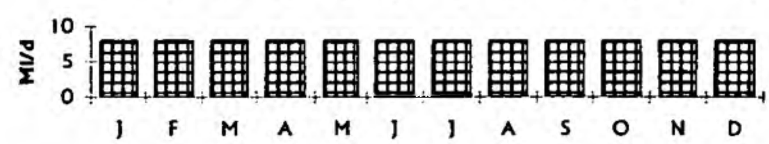
Impact Calcs Assumptions & reference: assuming fully smoothed steady state impacts (as IGARF or Jenkins)

Consumptive GW Abs Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
8	Ml/d	8	8	8	8	8	8	8	8	8	8	8	8

Data compilation & calculation imply av. level of confidence in this data set is +/- 20 %

i.e. error bar assumed to be +/- 1.6 Ml/d



3.3 Surface Water Discharges Impacts on River Flows in Specified Year

Include all sewage treatment works or river support discharges to the river upstream of the gauge. Base estimated dry weather flows.

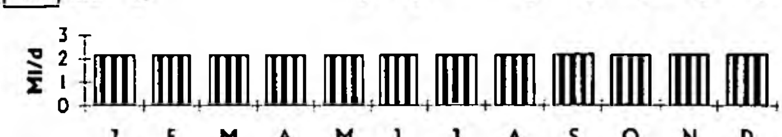
Assumptions and Calculations Ref: taken from j barker report for 1993

SW Dis Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
2.2	Ml/d	2	2	2	2	2	2	2	2	2	2	2	2

Data compilation & calculation imply av. level of confidence in this data set is +/- 20 %

i.e. error bar assumed to be +/- 0 Ml/d



AVAILABLE RESOURCE METHODOLOGY (ARM)

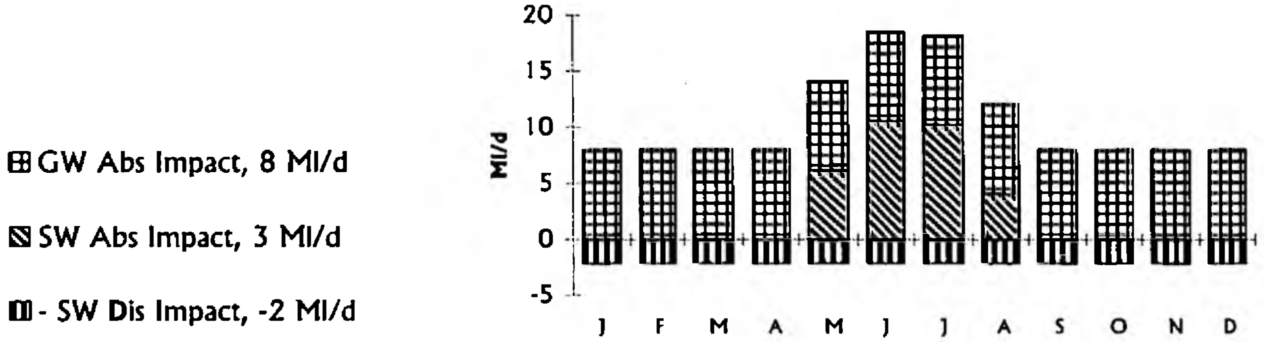
Area R Thet at Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

GAUGED FLOW NATURALISATION SHEET *(OPTIONAL)*

3.4 Summary of Abstraction and Discharges Impacts on River Flows in Specified Year

GW Abs, SW Abs & SW Dis Impacts on River Flows, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 8 Ml/d	8	Ml/d	8	8	8	8	8	8	8	8	8	8	8	8
SW Abs Impact, 3 Ml/d	3	Ml/d	0	0	0	0	6	11	10	4	0	0	0	0
- SW Dis Impact, -2 Ml/d	-2	Ml/d	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2

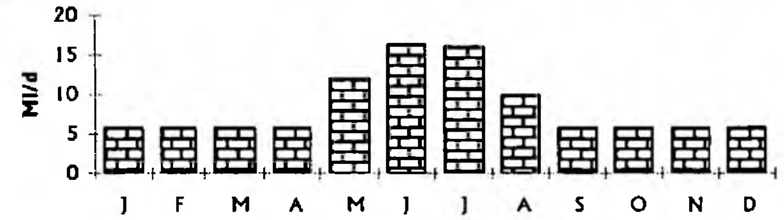


3.5 Calculated Net Consumptive Abstraction & Discharge Impacts in Specified Year

Combined error bar is +/- 2.3 Ml/d

Net Abs Impacts = SW+GW Abs Impacts - SW Dis Impacts, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
8.5	Ml/d	6	6	6	6	12	16	16	10	6	6	6	6



3.6 Result: Calculated Naturalised River Flows in Specified Year

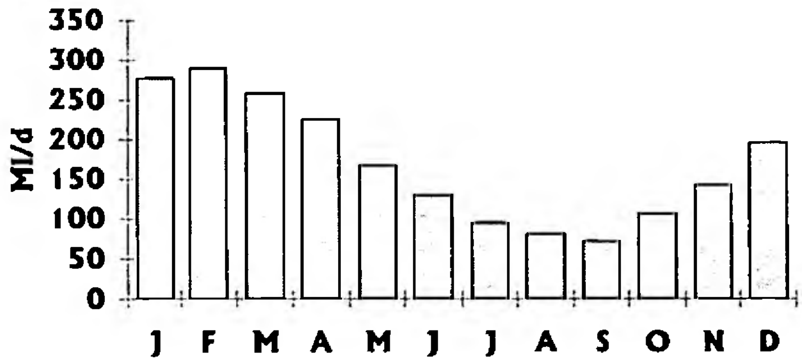
Combined error bar is +/- 10.4 Ml/d

i.e. combined error bar is +/- 6 % Av Nat Flow

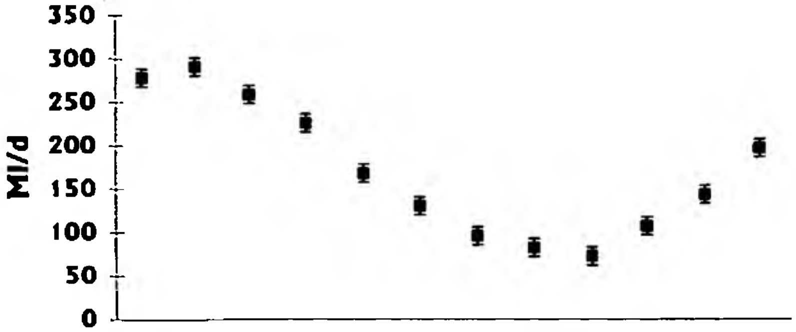
(these Naturalised Flows are passed back to the 'River Outflow Calcs' sheet)

Naturalised Flow = Gauged Flows + Net Abs Impacts, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
170	Ml/d	278	290	259	226	168	130	96	82	72	107	143	197



Same Naturalised Flow Plot with Error Bars



AVAILABLE RESOURCE METHODOLOGY (ARM)

Area: R Thet at Melford Bridge GS | ID: ? | Version: 1 | Ledger Rev.: 1 | Date: 19/8/99

GAUGED FLOW NATURALISATION SHEET *(OPTIONAL)*

4.0 **Naturalised River Flow Composition in Specified Year, as mm/month over Surface Catchment Area**

(For information only - equivalent of IoH 'gauged runoff' - not carried forward in calculations)

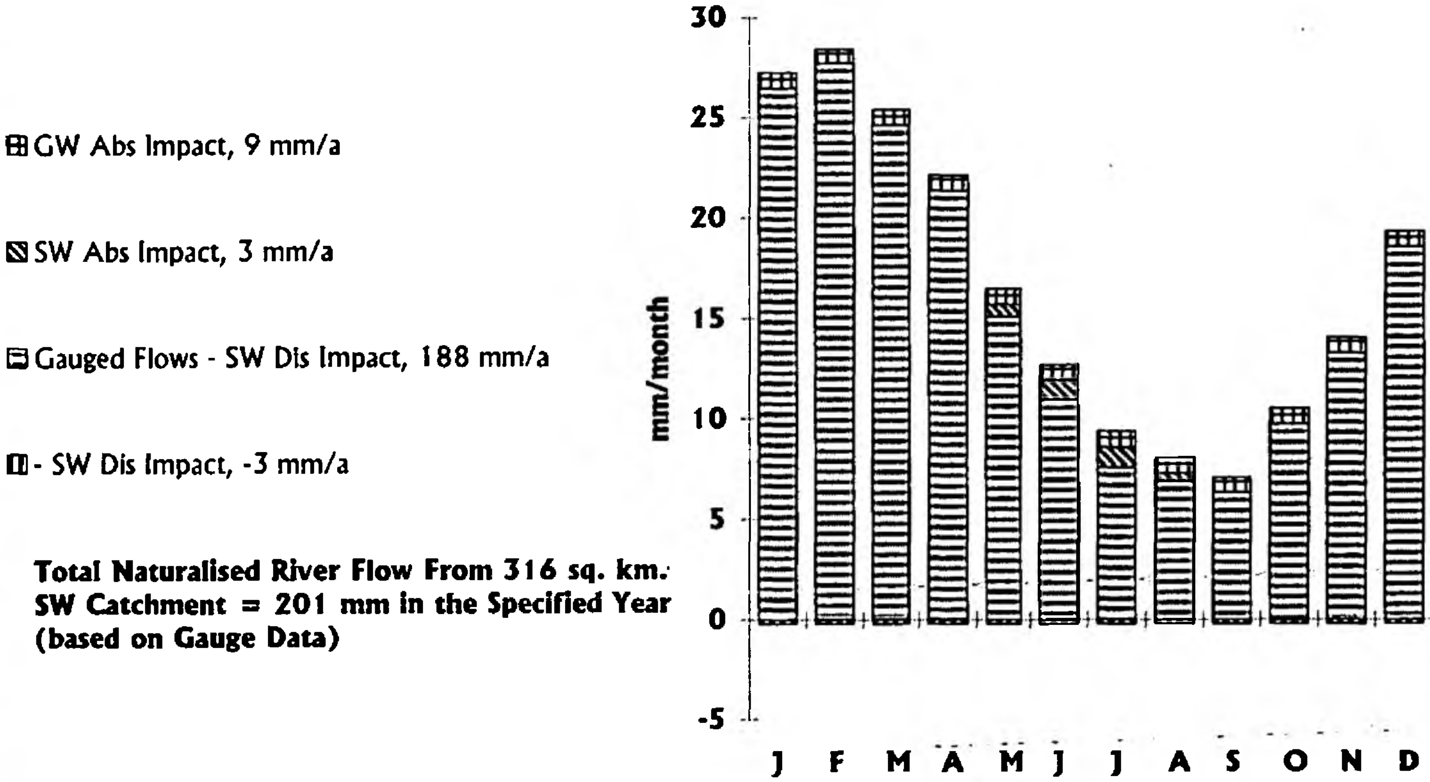
Surface Water Catchment to River Gauge in sq. km. = 316 Ref: ih hydrometric register, 91-95

(area from which runoff enters the river above the gauge) *(these are specified in the 'River Outflow Calcs' sheet)*

Components of Naturalised Outflow as mm/month over SW catch.

	Ann Tot		J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 9 mm/a	9	mm/a	1	1	1	1	1	1	1	1	1	1	1	1
SW Abs Impact, 3 mm/a	3	mm/a	0	0	0	0	1	1	1	0	0	0	0	0
- SW Dis Impact, -3 mm/a	-3	mm/a	0	0	0	0	0	0	0	0	0	0	0	0
Gauged Flows - SW Dis Impact, 188 mm/a	188	mm/a	26	28	25	21	15	11	8	7	6	10	13	19

Total Naturalised River Flow From 316 sq. km. SW Catchment = 201 mm in the Specified Year (based on Gauge Data)



END OF SHEET

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet at Melford Bridge GS **ID** 7 **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

NATURAL RIVER FLOWS DERIVED FROM EFFECTIVE RAINFALL USING THE AQUIFER RESPONSE FUNCTION *(OPTIONAL)*

These calculations derive natural river flows from effective rainfall, assumptions of water routing and catchment characteristics using the Aquifer Response Function. Results are compared with other flow estimates (e.g. based on gauge flow naturalisation) in the 'River Outflow Calcs' sheet.

Calculations consider:

a. flows in a year of 'average' rainfall, then

b. flows for the specified assessment yr.

1 Year of Assessment

The year specified for this assessment is L T Average Year (1970-1990) Basis for selection of this year: ltav comparison

(these are specified in the 'River Outflow Calcs' sheet)

2 a. Natural River Flows in an 'Average' Year Based on the Aquifer Response Function (ARF)

Areas	sq km	**Based on:**
Surface Water Catchment to River Gauge in Assessment Area	316	ih hydrometric register, 91-95
(area from which runoff enters the river above the gauge) *(these are specified in the 'River Outflow Calcs' sheet)*		
Aquifer Area within the Surface Water Catchment	316	assume all area receives recharge
(area from which runoff enters the river upstream of the gauge and recharge enters the aquifer)		
Groundwater Catchment to River Gauge	316	sw c.area (approx) under avg. conditions
(aquifer area from which recharge would naturally discharge as baseflow to the river upstream of the gauge)		

Long Term Annual Average Hydrologically Effective Rainfall	mm/a	**Based on:**
Average Annual Total Hydrologically Effective Rainfall	173.1	morecs sq 130 average 1970-90

Assumptions Splitting Hydrologically Effective Rainfall into Runoff and Recharge — **Based on:**

Aquifer recharge as % of effective rainfall: 44 % — J. Barker & calcs in sq130-mo.xls

(so Aquifer runoff = 56 %)

Calculated Long Term Annual Average Runoff and Recharge

Calculated Ann. Av. Recharge draining to river = 65.9 Ml/d = recharge % * eff rainfall * GW catch area

(equivalent to 76 mm/a over the GW catchment area)

Calculated Ann. Av. Runoff draining to river = 83.9 Ml/d

=eff rainfall*(SW catch area - aquifer area in SW catch) + eff rainfall*aquifer runoff %*aquifer area in SW catch

Total Ann. Av. Eff. Rain draining to river = 149.9 Ml/d =recharge input plus runoff input

(equivalent to 173 mm/a over the SW catchment area)

Calculated Average Distribution of Runoff and Recharge

Based on: Av = 1.00

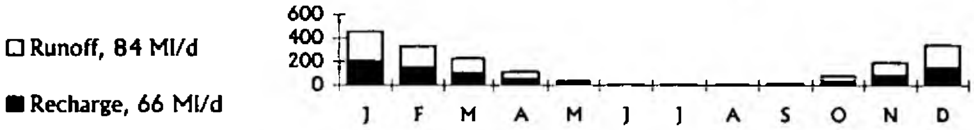
Default values = typical MORECS square Eff. Rain. factors: 1.00

Av. Monthly Factors of Av. Ann. Rech & Runoff Rates

J	F	M	A	M	J	J	A	S	O	N	D
3.04	2.22	1.53	0.74	0.22	0.04	0.03	0.02	0.10	0.53	1.31	2.29

Average Runoff and Recharge, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Runoff, 84 Ml/d	84	Ml/d	255	186	128	62	18	3	3	1	9	44	110	192
Recharge, 66 Ml/d	66	Ml/d	201	146	101	49	14	2	2	1	7	35	86	151



Aquifer Characteristics Controlling Natural River Flow Response to Recharge — **Based on:**

Recharge % which becomes river flow in the same month: 0 % — No karstic response

Aquifer Characteristics Controlling Natural Baseflow from Remaining Recharge

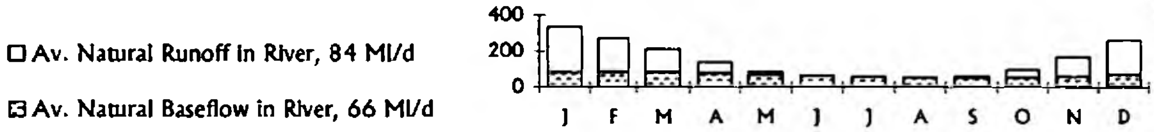
Total length of rivers draining GW catchment	30	km	measured length of upper l Ouse
Average Storage (Specific Yield)	0.03	no units	guess from Redgrave
Average Transmissivity	500	m2/d	guess from Redgrave

Aquifer Response Time = 1664.27 days

Calculated Average Natural Runoff and Baseflow in the River

Average Natural Runoff and Baseflow in River, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Av. Natural Runoff in River, 84 Ml/d	84	Ml/d	255	186	128	62	18	3	3	1	9	44	110	192
Av. Natural Baseflow in River, 66 Ml/d	66	Ml/d	80	84	82	76	68	61	57	53	51	52	57	68



Average Natural Total River Flow = Runoff + Baseflow, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Av. Natural Total Flow in River, 150 Ml/d	150	Ml/d	336	271	210	138	86	64	60	55	60	96	167	260

Min. Natural Total Flow in an Av. Year = 54.6 Ml/d

2 b. Natural River Flows derived from Hydrologically Effective Rainfall in the Specified Assessment Year and Preceding Nine Years

Hydrologically Effective Rainfall (HER) Data Entry
Enter 10 yrs of monthly HER values, yr 10 being that specified for assessment, in column DI from Row 24 down
Data Source: Morecs square 130 ltav1970-90

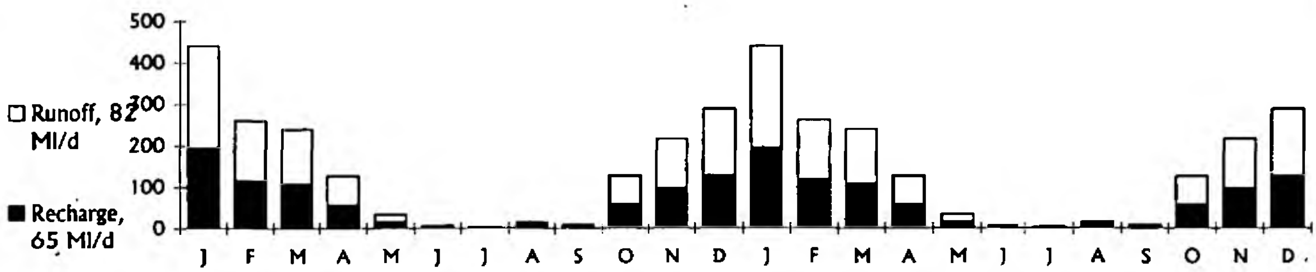
Hydrologically Effective Rainfall for Preceding & Specified Year, mm/month

	Preceding Year												Specified Assessment Year												Yr
10 Yr Av	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	Tot
173 mm/a	43	26	24	12	3	1	0	1	1	12	21	28	43	26	24	12	3	1	0	1	1	12	21	28	173 mm/a

Calculated Runoff and Recharge for Preceding & Specified Year, Ml/d

	Preceding Year												Specified Assessment Year												Yr
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	Av
Runoff, 82 Ml/d	246	146	134	71	19	4	2	8	5	71	121	161	246	146	134	71	19	4	2	8	5	71	121	161	82
Recharge, 65 Ml/d	193	115	105	56	15	3	1	7	4	56	95	127	193	115	105	56	15	3	1	7	4	56	95	127	65

Ml/d

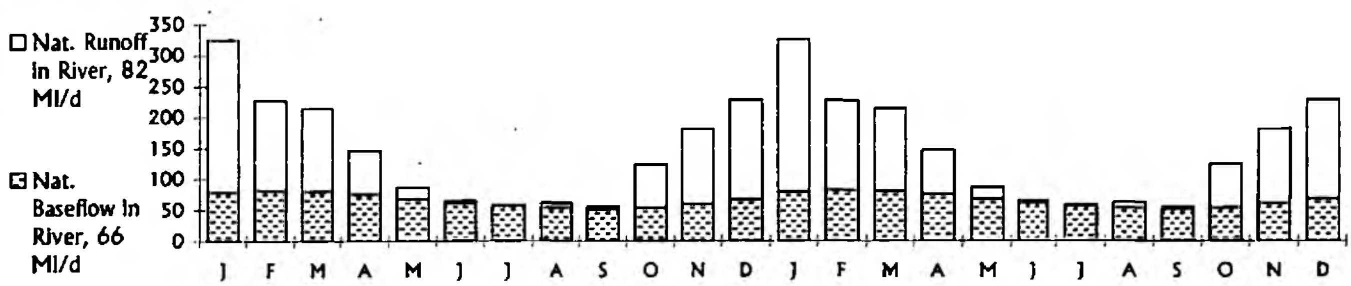


Data compilation & calculation imply av. level of confidence in this recharge is +/- 10 % i.e. error bar assumed to be +/- 6 Ml/d

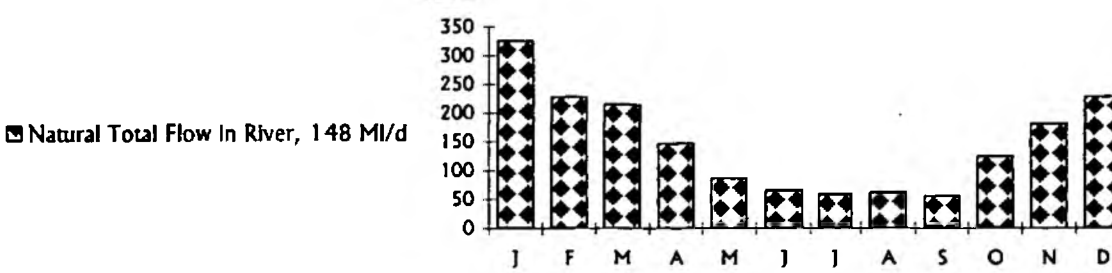
Calculated Natural Runoff and Baseflow in River for Preceding & Specified Year, Ml/d

	Preceding Year												Specified Assessment Year												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	Av.
Nat. Runoff in River, 82	246	146	134	71	19	4	2	8	5	71	121	161	246	146	134	71	19	4	2	8	5	71	121	161	82
Nat. Baseflow in River,	79	81	80	75	68	61	57	53	51	53	60	67	79	82	80	76	68	61	57	54	51	54	60	67	66

Ml/d



		Specified Assessment Year											
		Natural Total River Flow = Runoff + Baseflow, Ml/d											
	Ann Av	J	F	M	A	M	J	J	A	S	O	N	D
Natural Total Flow in River, 148 Ml/d	148 Ml/d	325	228	215	147	87	66	58	62	56	124	181	228



Minimum Natural Total Flow in this Year = 55.8 **Ml/d**

(these Natural Flow Estimates are passed back to the 'River Outflow Calcs' sheet)

Data compilation & calculation imply av. level of confidence in this total flow is +/- 10 % i.e. error bar assumed to be +/- 15 Ml/d

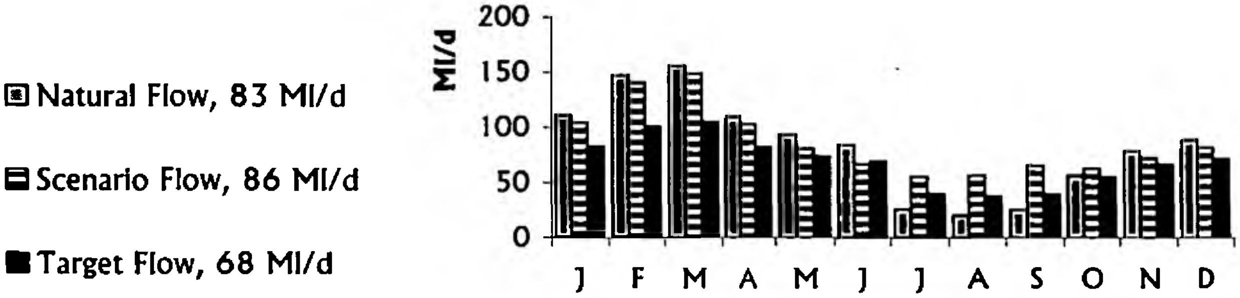
AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet to Melford Bridge GS **ID** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Specified Assessment Year **Drought condition 1991**

1 Results Summary for the Total Catchment to the Outflow Point

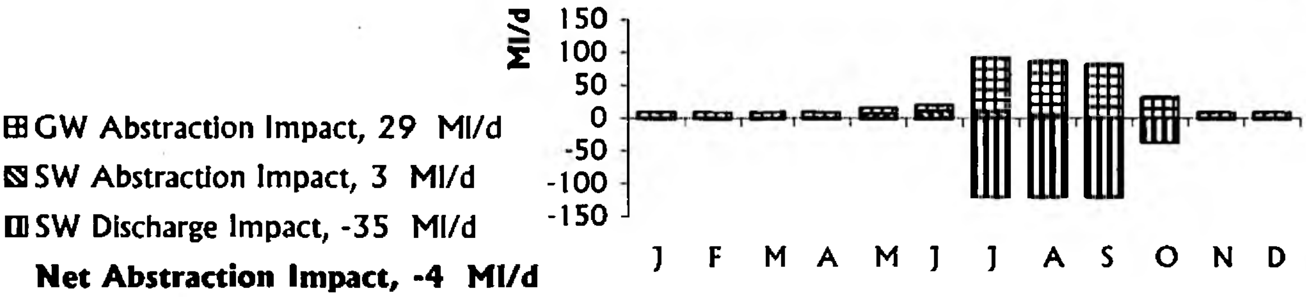
1.1 Natural, Scenario and Target River Flows for Specified Year (with Annual Average Rate Summary)



Target Flows based on Monthly Minimum of nat QN95 plus 50% of naturalised flow above this

1.2 Scenario Artificial Impacts (with Annual Average Rate Summary)

Abs & Dis Scenario: Licensed 1993 Rates (No Restrictions)



Maximum net abstraction impact for total catchment based on
Max. (net abs impact/natural river flow from total catchment) = 20 % in Jun

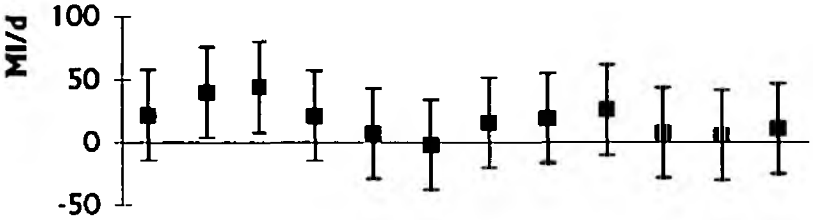
1.3 Surplus or Deficit Profile for Specified Year (= Scenario River Flow Minus Target River Flow)

	J	F	M	A	M	J	J	A	S	O	N	D
	22	40	44	21	7	-2	15	19	26	8	6	11

Ann Av 18 Ml/d

Minimum -2 Ml/d

Uncertainty +/- 36 Ml/d



Central value of
Surplus or Deficit as % of Natural River Flow: Ann Av 22% Min -3%

1.4 Interpreted Sustainability Status of Resource Management at Outflow Point

Sustainability Status Category:

Comments :

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet to Melford Bridge GS **ID** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Specified Assessment Year **Drought condition 1991**

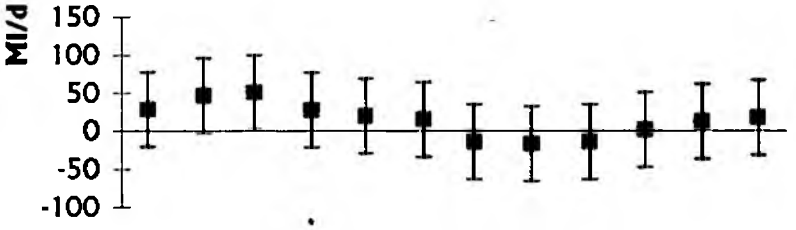
1.5 Acceptable Net Abstraction Impacts Profile for Specified Year (= Natural Flow Minus Target Flow)

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	28	47	51	28	20	15	-14	-17	-14	1	12	17

Ann Av 14 Ml/d

Minimum -17 Ml/d

Uncertainty +/- 49 Ml/d



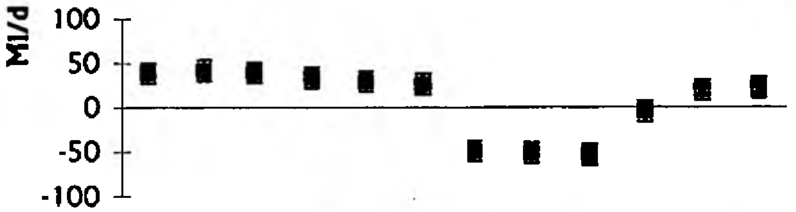
1.6 Natural Baseflow Minus Locally Consumptive Groundwater Abstraction Impact if baseflow (i.e. groundwater resource) has been separately defined

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	38	41	40	33	29	26	-49	-51	-53	-4	19	22

Ann Av 7 Ml/d

Minimum -53 Ml/d

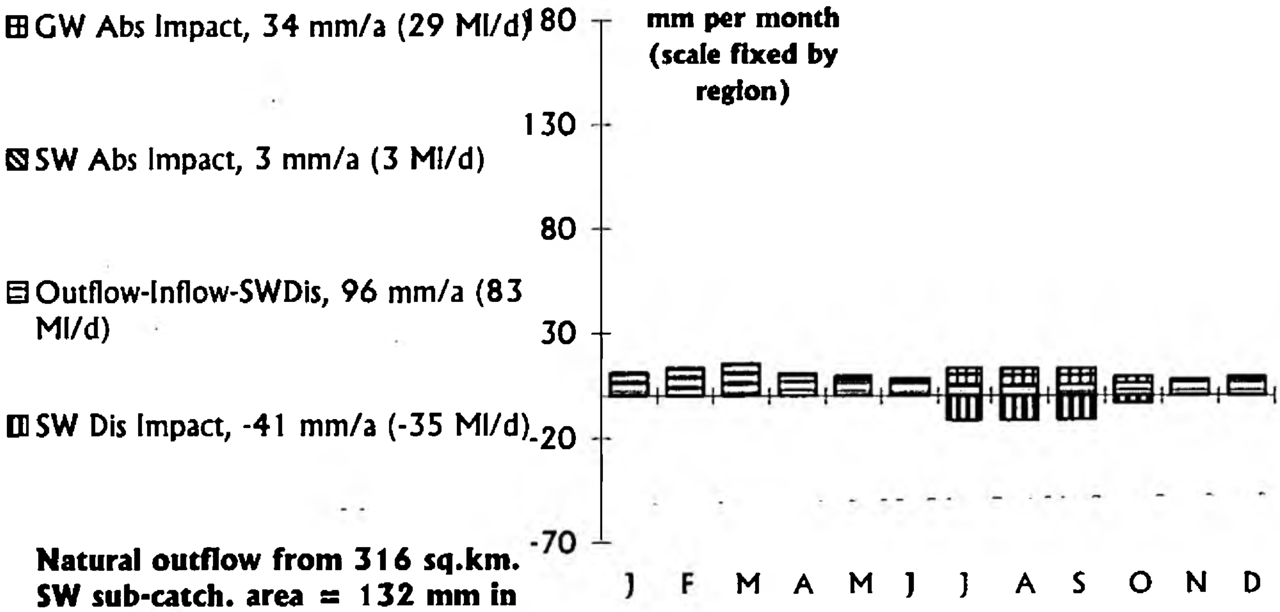
Uncertainty +/- 12 Ml/d



2 Outflow Components (Optionally Excluding Upstream Sub Catchments)

Upstream Catchments Excluded 0

Flow Components Derived from the Sub Catchment
Expressed in mm/month Over Gauged Surface Water Sub-Catchment Area
(with Annual Average Rate Summaries in mm/a and Ml/d)



Natural outflow from 316 sq.km. SW sub-catch. area = 132 mm in

Maximum net abstraction impact for this sub-catchment area only (exluding upstream catchmen

Max. (sub-catchment net abs impact/sub-catchment nat outflow) = 20 % in Jun

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet to Melford Bridge GS **ID** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Specified Assessment Year **Drought condition 1991**

3 Interpreted Management Action Required

Note: this section may be based on consideration of other years in other spreadsheets

3.1 Potential for Further Development

Potential for additional steady state net abstraction impacts Ml/d (zero if none)

Potential for additional winter-only net abstraction impacts Ml/d (zero if none)
(river flow controlled SW abstraction in winter)

3.2 Target For Abstraction Impact Reduction

Overall target for reduction of abstraction impacts: Ml/d during

3.3 Proposals for Augmentation or Mitigation to meet Flow Targets

NOTE: Each licence application or reduction assessed on a case by case basis considering: proximity to rivers/wetlands, consumptiveness/point of return, seasonality etc

4 QA Authorisation and Version Control

4.1 Acceptable Impact Assessment Review and Authorisation

Version: **1** Assessed by: **G Coombs** sign

Reviewed by (hydrogeologist & hydrologist): **R Soley & J Bloggs** sign

Authorised by **J Bloggs** sign

Assessment based on: Agency framework: Detailed model#: Other#:

other study/calculation/report reference:

Any need/plans to reassess resource soon?:

target date	method
01/01/00	**AMS the real thing**

4.2 Abstraction Ledger Update Control

Ledger rev. no: **0** Updated on: By:

In connection with licence numbers:

END OF SHEET

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet to Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

Assessment for Areas which Drain to a River Outflow

1.0 Surface Water Catchment Area

Surface catchment area to river outflow point assessed = 316 sq. km. Based on: ih hydrometric register, 91-95

2.0 Year or Hydrological Scenario of Assessment

The year specified for this assessment is Drought condition 1991 Basis for selection of this year stressed resources & GOGWS

3.0 Natural River Flows in Specified Year to Define the Total Water Resource

Enter the monthly averaged natural river flows for the assessment year, and an associated % possible error, based on one or more of the following:

a. Gauged Flow Naturalisation *(use the 'Gauge Nat Calcs' sheet or overtype based on Agency national guidelines)*,
b. Effective Rainfall Based Aquifer Response Function Calculations *(use the 'Eff Rain Based ARF Calcs (Riv)' sheet)*
c. MicroLOWFLOWS for average year flows *(please reference calculation)*
d. An Alternative Method e.g. Standard Hydrological Approaches, River or Groundwater Flow Model *(please reference method & calculations)*

Compare these different estimates, adjust them if required, then select one to carry forward as the total water resource profile for the year.

	Method and Calculation Reference	Select One type 'x'		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	% Err.
a.	*Gauge Nat Calcs* Results	x	Ml/d	83	21	111	147	156	109	93	84	26	21	26	56	79	88	21.1
b.	*Eff Rain Based ARF Calcs (Riv)* Results		Ml/d	68	28	172	151	111	43	39	35	32	30	29	28	57	89	15
c.	MicroLOWFLOWS ref: none available		Ml/d	0	0													
d.	GW Model (eg only) ref: e.g. for plot only		Ml/d	43	3	147	126	86	18	14	10	7	5	4	3	32	64	

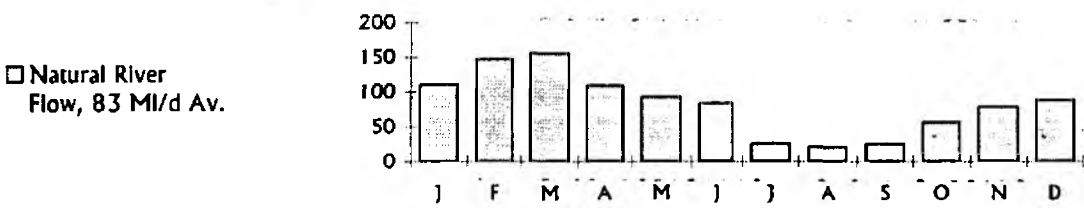
(Monthly Av. Natural River Flow in Specified Year, Ml/d)

Selected Method

	Selected Method	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Natural River Flow, 83 Ml/d	Gauged Flow Nat Calcs	82.572	20.687	110.85	147.08	155.62	109.32	93.373	84.055	25.779	20.687	25.697	56.448	78.702	88.451	17

(Selected Natural River Flow in Specified Year, Ml/d)

Annual Equivalent **Effective Rainfall** over SW Catchment is 95 mm/a



4.0 Natural River Baseflows in Specified Year to Define the Groundwater Resource (optional)

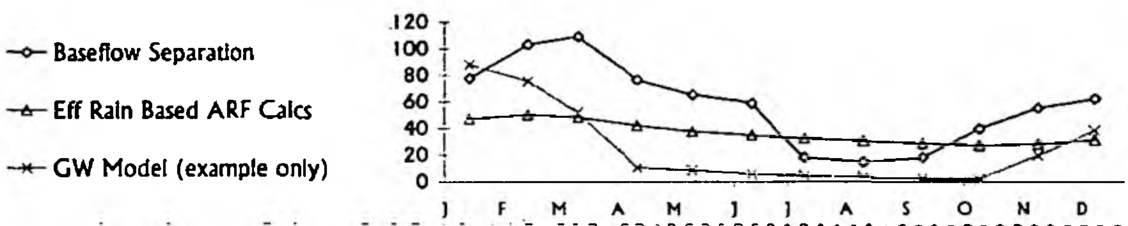
If a separate estimate of groundwater resources is required, enter the monthly averaged natural river baseflows, based on one or more of the following:

a. Baseflow Separation of Total Flow Hydrograph *(please reference method & calculations)*
b. Effective Rainfall Based Aquifer Response Function Calculations *(use the 'Eff Rain Based ARF Calcs (Riv)' sheet)*
c. An Alternative Method e.g. Standard Hydrological Approaches, River or Groundwater Flow Model *(please reference method & calculations)*

Compare these different estimates and, considering the natural river flow selected, select one to carry forward as the groundwater resource profile.

	Method and Calculation Reference	Select One type 'x'		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	% Err.
a.	Baseflow Separation ref: E.g. 70% nat tot flow		Ml/d	58	14	78	103	109	77	65	59	18	14	18	40	55	62	15
b.	*Eff Rain Based ARF Calcs (Riv)* Results	x	Ml/d	36	27	47	50	48	42	38	35	32	30	29	27	28	31	15
c.	GW Model (example only) ref: example for plot only		Ml/d	26	2	88	75	52	11	9	6	4	3	2	2	19	38	15

(Monthly Av. Natural River Baseflow in Specified Year, Ml/d)



AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet to Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

Selected Natural Baseflow in Specified Year, Ml/d

Selected Method	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Eff Rain Based ARF Calcs	36	27	47.161	50.264	48.406	42.15	37.66	34.684	32.322	30.308	28.567	27.09	28.021	30.883	5.46
Implied Surface Runoff Flow	46	-10	63.684	96.814	107.21	67.169	55.713	49.371	-6.543	-9.621	-2.871	29.358	50.681	57.568	

Annual Equivalent **Recharge** over SW Catchment is 42 mm/a

5.0 Impacts of Consumptive Abstraction and Discharges Scenario on River Flows in Specified Year

Abstraction rates should be locally consumptive (i.e. excluding any water *locally* returned to the catchment).
Public water supply abstractions should be considered as fully consumptive because sewage treatment works or transfer discharges are accounted for separately. Surface water abstractions and discharges are assumed to impact on river outflows as they pump. Groundwater abstraction impacts on the river are entered separately as they may differ from the pumped profile because of groundwater storage changes.
In this scenario the pumping rates used to derive the impacts of SWabs/GWabs/SWdis are based on (please describe Assumed Abstraction Scenario) (e.g.full licensed 1999 rates/deployable output/actual 1999 rates) **Licensed 1993 Rates (No Restrictions)**

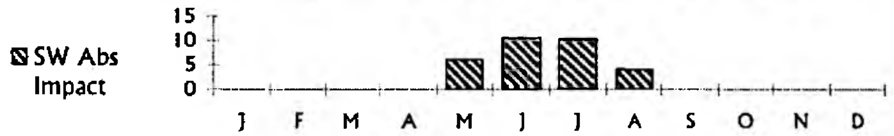
5.1 Scenario Surface Water Abstraction Impacts on River Flows in Specified Year

Year 1993 licenced Calcs in: natcals91.xls - spray irrigation licenses profiled as per Anglian naturalisation guidelines

Data compilation & calculation imply level of confidence in this data set is +/- 10 %

Consumptive SW Abs Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
3	Ml/d	0	0	0	0	6	11	10	4	0	0	0	0	0



5.2 Scenario Groundwater Abstraction Impacts on River Flows in Specified Year

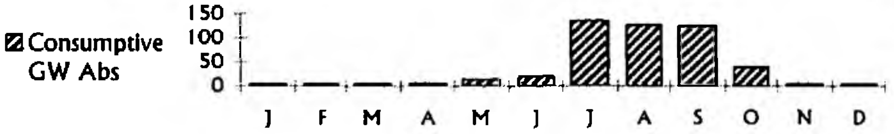
5.2 a. Scenario Groundwater Abstraction in the Month of Pumping

Year est actual Calcs in: natcals91.xls - 1993 licenced flow*demand profile*drought uptake factor + 100% GOGWS abstraction

Data compilation & calculation imply av. level of confidence in this data set is +/- 15 %

Consumptive GW Abstraction, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
41	Ml/d	4	5	5	6	14	20	135	127	125	39	5	4	6



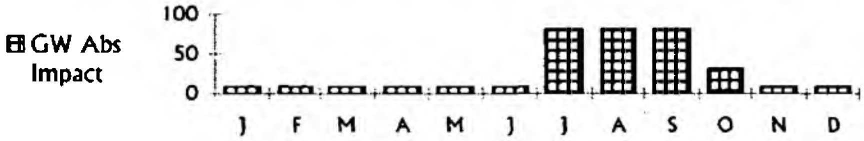
5.2 b. Scenario Groundwater Abstraction Impacts on River Flows in Specified Year

Impact Calcs Assumptions & reference: assume fully smoothed impacts of all long term est abs + 60 % GOGWS abstraction

Data compilation & calculation imply av. level of confidence in this data set is +/- 20 %

Consumptive GW Abs Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
29	Ml/d	9	9	9	9	9	9	82	82	82	32	9	9	6



5.3 Scenario Surface Water Discharges Impacts on River Flows in Specified Year

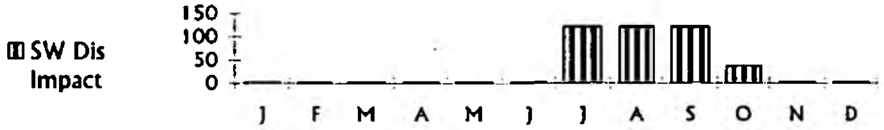
Include all sewage treatment works discharges or river support discharges to the river upstream of the gauge. Base discharge rate on est. DWFs

Year 1991 est actual Calcs in: GOGWS July - 10 Oct (as 100 % abstracted) (natcals91.xls)

Data compilation & calculation imply av. level of confidence in this data set is +/- 20 %

SW Dis Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
35	Ml/d	2	2	2	2	2	2	122	122	122	38	2	2	7



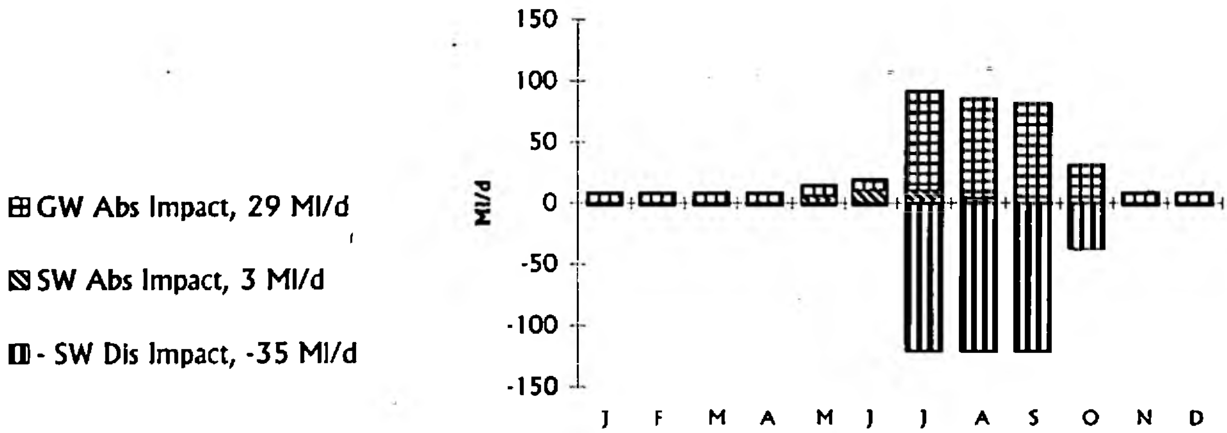
AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet to Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

5.4 Summary of Scenario Abstraction and Discharges Impacts on River Flows in Specified Year

GW Abs, SW Abs & SW Dis Impacts on River Flows, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 29 Ml/d	29	Ml/d	9	9	9	9	9	9	82	82	82	32	9	9
SW Abs Impact, 3 Ml/d	3	Ml/d	0	0	0	0	6	11	10	4	0	0	0	0
- SW Dis Impact, -35 Ml/d	-35	Ml/d	-2	-2	-2	-2	-2	-2	-122	-122	-122	-38	-2	-2



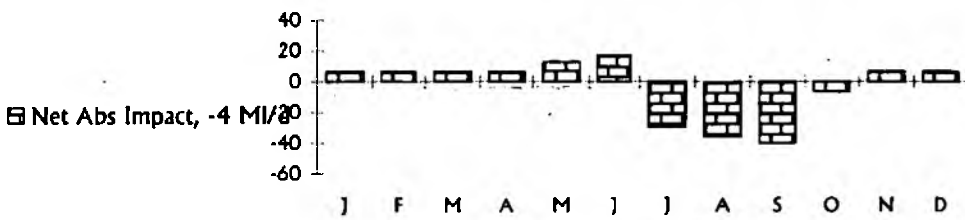
5.5 Scenario Net Consumptive Artificial Impacts in Specified Year

Net Abs Impact = SW+GWAbs Impacts - SWDis Impact, Ml/d
= step 5.1 + step 5.2b - step 5.3

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Net Abs Impact, -4 Ml/d	-4	Ml/d	7	7	7	7	13	17	-30	-36	-40	-6	7	7	13
Net Abs Impact/Natural River Flow, %	-32	%	6	5	4	6	14	20	-115	-173	-155	-11	8	8	

Maximum Percentage Impact = 20 %

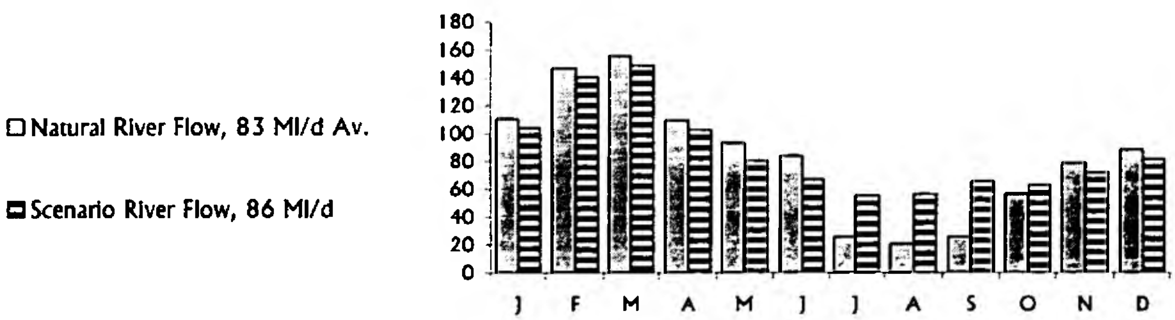
In the month of Jun



6.0 River Flows for this Artificial Impact Scenario in Specified Year

Scenario River Flow = Natural Flow - Net Abs Impact, Ml/d
= step 3 - step 5.5

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Scenario River Flow, 86 Ml/d	86	Ml/d	104	140	149	103	81	67	55	56	66	63	72	82	31



AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet to Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

7.0 Setting Target River Outflows for Specified Year

Target flows based on (summarise): Monthly Minimum of nat QN95 plus 50% of naturalised flow above this

Calc/Authorisation Ref: J.Barker AMS Draft Report

Natural, Scenario & Target Total River Flows, Ml/d

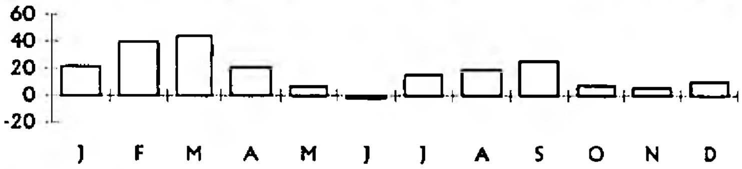
	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	
Natural River Flow, 83 Ml/d	83	20.687	110.85	147.08	155.62	109.32	93.373	84.055	25.779	20.687	25.697	56.448	78.702	88.451	
Scenario River Flow, 86 Ml/d	86	55.377	104	140	149	103	81	67	55	56	66	63	72	82	
Monthly Minimum Flow, Qmin	54	54	54	54	54	54	54	54	54	54	54	54	54	54	Ml/d
% Acceptable Abs. Impact of QNat over 50 %	14	-16.66	28	47	51	28	20	15	-14	-17	-14	1	12	17	Err+/-
Target River Flow, 68 Ml/d Confidence: +/- 10 %	68	37	82	101	105	82	74	69	40	37	40	55	66	71	5

Compare with Q95 = 42 Ml/d Reported Elsewhere in
Ref: ih yearbook gauge Q95, 1962-95

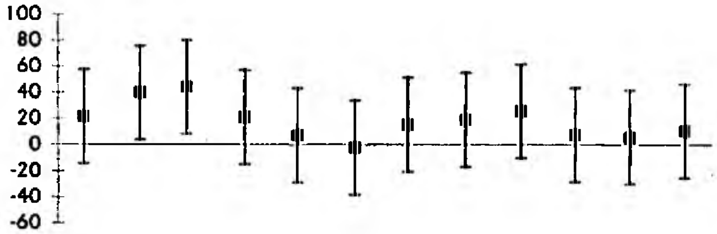
8.0 Scenario Surplus or Deficit for Specified Year, Given Target River Outflows

Surplus or Deficit = Scenario - Target River Flow Ml/d

	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Scenario Surplus or Deficit, 18 Ml/d	18	-2.182	22	40	44	21	7	-2	15	19	26	8	6	11	36
Surplus or Deficit as % of Natural River Flow	22		20	27	28	19	7	-3	60	92	100	13	7	12	



Same surplus/deficit plot with combined error bar of +/- 36 Ml/d



Over the Whole Year,

Annual Average Surplus or Deficit = **22%**

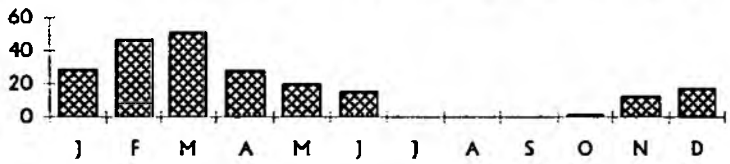
Annual Average Naturalised Gauged Flow and minimum = **-3%**

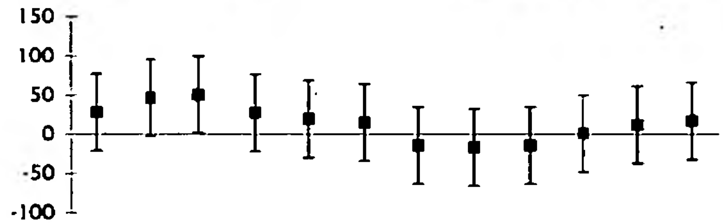
9.0 Acceptable Abstraction Impacts for Specified Year Given Target River Flows

Defined as the total acceptable abstraction impact on outflows. This is simply calculated either by adding the scenario surplus or deficit to the scenario net consumptive abstraction impacts or by subtracting target from natural flows (Dependent only on natural and target flows, not on the abstraction scenario assessed)

Acceptable Abstraction Impacts for Specified Year, Ml/d

	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Acceptable Abs Impacts, 14 Ml/d	14	-16.66	28	47	51	28	20	15	-14	-17	-14	1	12	17	49





Same surplus/deficit plot with combined error bar of +/- 49 Ml/d

AVAILABLE RESOURCE METHODOLOGY (ARM)

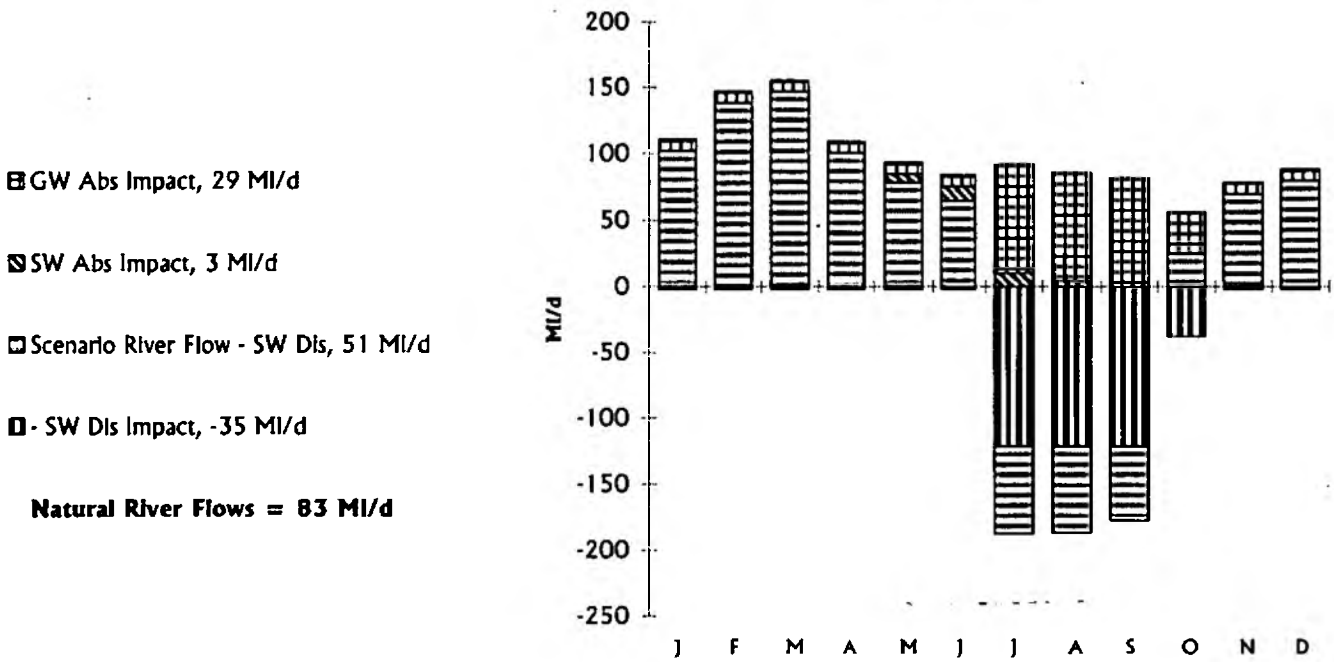
Area R Thet to Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

10 Scenario Outflow Composition from Total Catchment in Specified Year

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Scenario River Flow, 86 Ml/d	86	Ml/d	104	140	149	103	81	67	55	56	66	63	72	82
GW Abs Impact, 29 Ml/d	29	Ml/d	9	9	9	9	9	9	82	82	82	32	9	9
SW Abs Impact, 3 Ml/d	3	Ml/d	0	0	0	0	6	11	10	4	0	0	0	0
- SW Dis Impact, -35 Ml/d	-35	Ml/d	-2	-2	-2	-2	-2	-2	-122	-122	-122	-38	-2	-2
Scenario River Flow - SW Dis, 51 Ml/d	51	Ml/d	102	138	147	101	78	65	-66	-65	-56	25	70	80
Natural River Flows = 83 Ml/d	83	Ml/d												

Surface water catchment area = 316 sq km

Licensed 1993 Rates (No Restrictions)

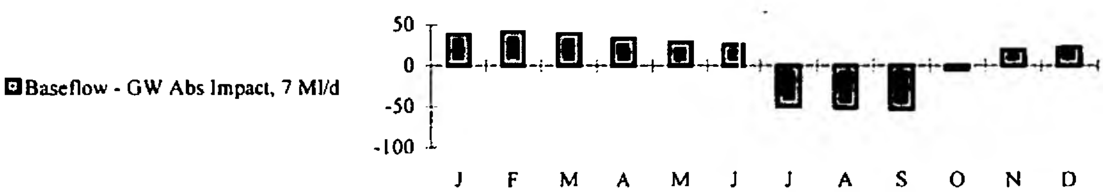


11 Natural Baseflow (Groundwater Resource) Minus Consumptive GW Abstraction Impact in Specified Year

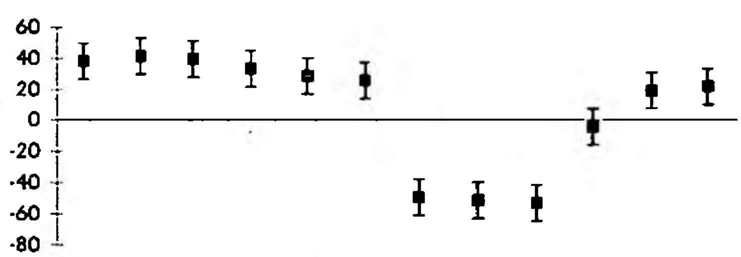
Only plotted if a baseflow has been specified at step 4.

Natural Baseflow - Consumptive GW Abs. Impacts, Ml/d
= step 4 - step 5.3b

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Baseflow - GW Abs Impact, 7 Ml/d	7	Ml/d	38	41	40	33	29	26	-49	-51	-53	-4	19	22	12



Same Baseflow - GWAbs plot with combined error bar of +/- 12 Ml/d



AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet to Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

12 **Scenario Outflow Composition from Sub-Catchment in Specified Year, as mm/month over Sub- Catchment Area**
This plot expresses the scenario outflow components as mm per month over the surface water catchment area.
The step 10 values from upstream assessment areas can be combined and pasted below in order to plot the outflows from the lower sub-catchment only. If no values are pasted in, the plot represents the entire catchment assessed.
Identify the upstream catchments to be excluded from the plot: Catchments Excluded:

Combine Step 10 values from these assessments and paste below.
Scenario Outflow Values (Step 10) from Upstream Catchs, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Scenario River Flow, 0 Ml/d	0	Ml/d												
GW Abs Impact, 0 Ml/d	0	Ml/d												
SW Abs Impact, 0 Ml/d	0	Ml/d												
- SW Dis Impact, 0 Ml/d	0	Ml/d												

Combined Upstream SW catchment areas = sq km

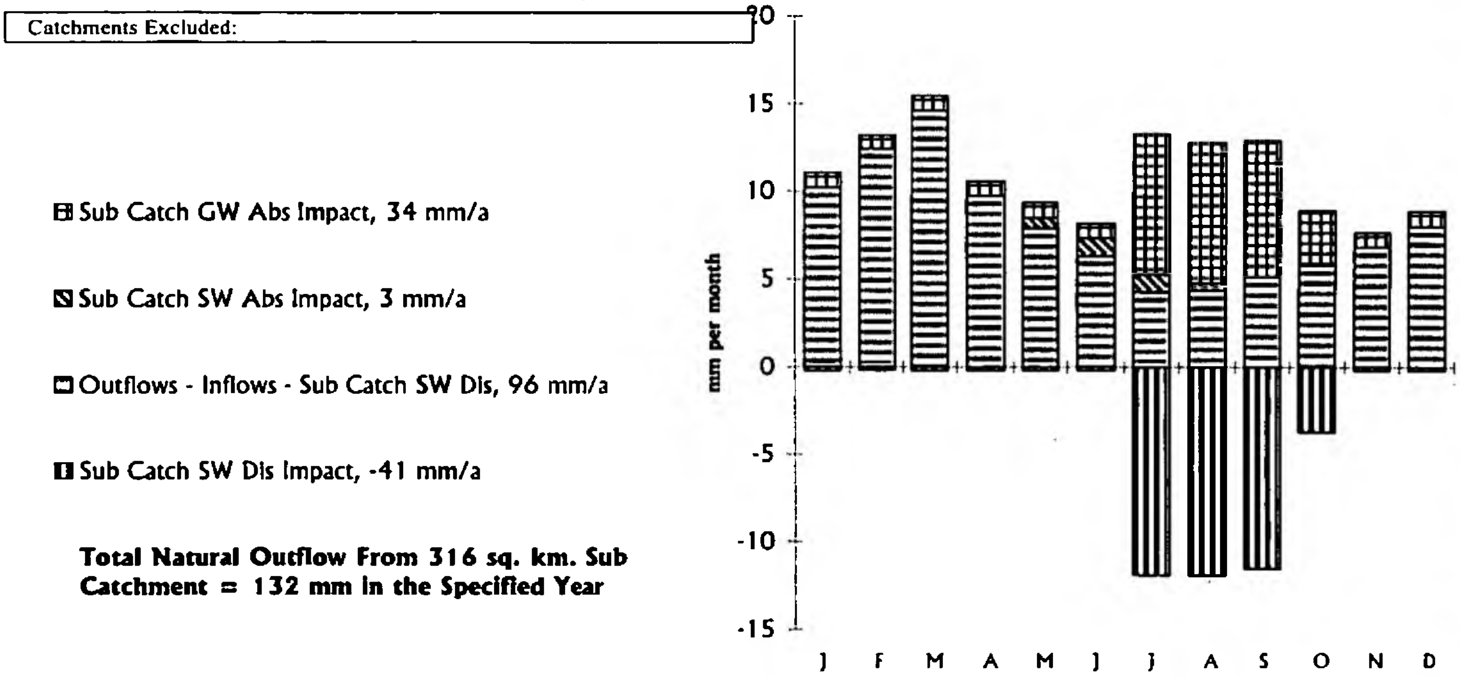
Surface Water Sub-Catchment Area for this plot 316 sq. km.

Components of Nat. Outflow as mm/month over SW sub catch.

	Ann Tot		J	F	M	A	M	J	J	A	S	O	N	D
Sub Catch GW Abs Impact, 34 mm/a	34	mm/a	1	1	1	1	1	1	8	8	8	3	1	1
Sub Catch SW Abs Impact, 3 mm/a	3	mm/a	0	0	0	0	1	1	1	0	0	0	0	0
Sub Catch SW Dis Impact, -41 mm/a	-41	mm/a	0	0	0	0	0	0	-12	-12	-12	-4	0	0
Outflows - Inflows - Sub Catch SW Dis, 96 mm/a	96	mm/a	10	12	15	10	8	6	4	4	5	6	7	8

Total Natural Outflow From 316 sq. km. Sub Catchment = 132 mm in the Specified Year

Licensed 1993 Rates (No Restrictions)



	J	F	M	A	M	J	J	A	S	O	N	D
% (net abs impact for sub-catchment)/(nat outflow from sub-catchment) =	6	4	4	6	13	20	-22	-27	-29	-7	8	7

Maximum net abstraction impact for this sub-catchment area only (exluding upstream catchments)
Max. (sub-catchment net abs impact/sub-catchment nat outflow) = 20 % in **Jun**

END OF SHEET

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet to Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

GAUGED FLOW NATURALISATION SHEET *(OPTIONAL)*

1.0 Year of Assessment

The year specified for this assessment is: Drought condition 1991 — Basis for selection of this year: stressed resources & GOGWS

(these are specified in the 'River Outflow Calcs' sheet)

2.0 Gauged River Flows in Specified Year

Enter the monthly averaged gauged river flows for the assessment year

Gauged River Flow in Specified Year, Ml/d

Gauging Station Name	Data Ref	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Melford Br (1991)	thet-mel.xls	86	Ml/d	104	140	149	103	81	67	55	56	66	63	72	82

Data compilation & calculation imply level of confidence in this data set is +/- 5 %

i.e. error bar assumed to be +/- 4 Ml/d

3.0 Gauged Flow Naturalisation: Removing Impacts of Consumptive Abstraction and Discharges on River Flows in Specified Year

The flow rates used to derive the impacts of SWabs, GWabs & SWdis should be based on best estimate of actual abstraction or discharge during the specified year. Abstraction rates should be locally consumptive (i.e. excluding any water *locally* returned to the catchment) Public water supply abstractions should be considered as fully consumptive because sewage treatment works or transfer discharges are accounted for separately. Surface water abstractions and discharges are assumed to impact on river outflows as they pump. Groundwater abstraction impacts on the river are entered separately as they may differ from the pumped profile because of groundwater storage changes.

3.1 Surface Water Abstraction Impacts on River Flows in Specified Year

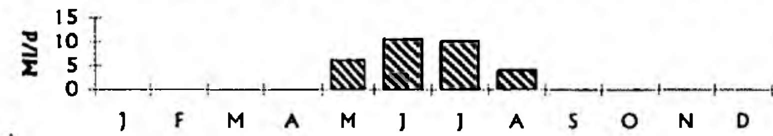
Assumptions and Calculations Ref: natcals91.xls - spray irrigation licenses profiled as per Anglian naturalisation guidelines

Consumptive SW Abs Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
3	Ml/d	0	0	0	0	6	11	10	4	0	0	0	0

Data compilation & calculation imply level of confidence in this data set is +/- 10 %

i.e. error bar assumed to be +/- 0 Ml/d



3.2 Groundwater Abstraction Impacts on River Flows in Specified Year

3.2 a. Groundwater Abstraction in the Month of Pumping

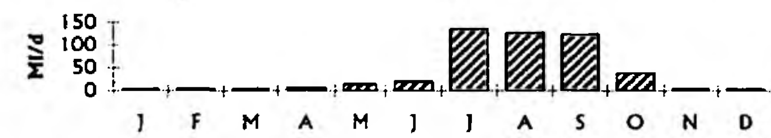
Assumptions and Calculations Ref: natcals91.xls - 1993 licenced flow*demand profile*drought uptake factor + 100% GOGWS abstraction

Consumptive GW Abs, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
41	Ml/d	4	5	5	6	14	20	135	127	125	39	5	4

Data compilation & calculation imply av. level of confidence in this data set is +/- 15 %

i.e. error bar assumed to be +/- 6.2 Ml/d



3.2 b. Groundwater Abstraction Impacts on River Flows in Specified Year

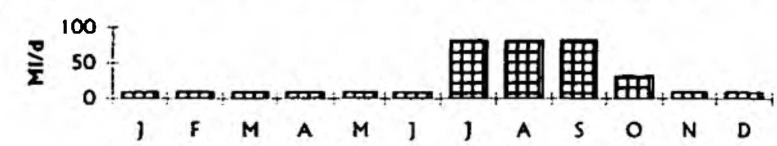
Impact Calcs Assumptions & reference: assume fully smoothed impacts of all long term est abs + 60 % GOGWS abstraction

Consumptive GW Abs Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
29	Ml/d	9	9	9	9	9	9	82	82	82	32	9	9

Data compilation & calculation imply av. level of confidence in this data set is +/- 20 %

i.e. error bar assumed to be +/- 5.8 Ml/d



3.3 Surface Water Discharges Impacts on River Flows in Specified Year

Include all sewage treatment works or river support discharges to the river upstream of the gauge. Base estimated dry weather flows.

Assumptions and Calculations Ref: GOGWS July - 10 Oct (as 100 % abstracted) (natcals91.xls)

SW Dis Impacts on River Flows, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
35.3	Ml/d	2	2	2	2	2	2	122	122	122	38	2	2

Data compilation & calculation imply av. level of confidence in this data set is +/- 20 %

i.e. error bar assumed to be +/- 7 Ml/d

AVAILABLE RESOURCE METHODOLOGY (ARM)

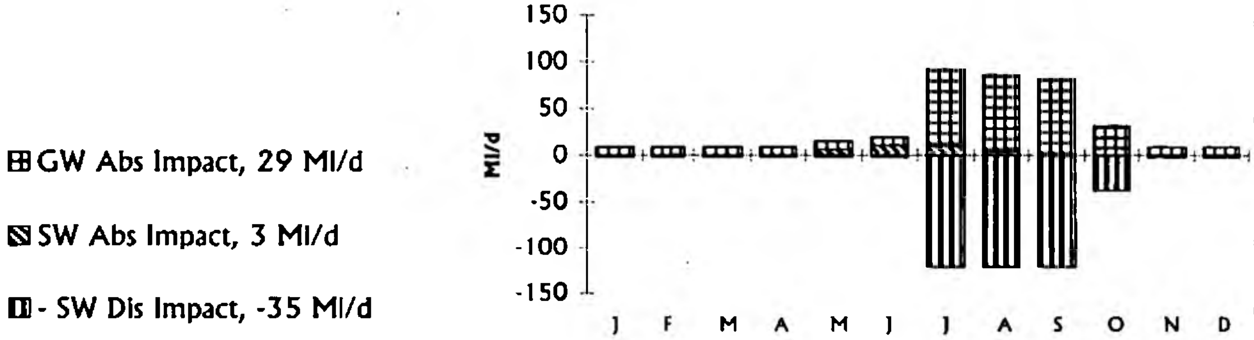
Area: R Thet to Melford Bridge GS | ID: ? | Version: 1 | Ledger Rev.: 1 | Date: 19/8/99

GAUGED FLOW NATURALISATION SHEET *(OPTIONAL)*

3.4 Summary of Abstraction and Discharges Impacts on River Flows in Specified Year

GW Abs, SW Abs & SW Dis Impacts on River Flows, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 29 Ml/d	29	Ml/d	9	9	9	9	9	9	82	82	82	32	9	9
SW Abs Impact, 3 Ml/d	3	Ml/d	0	0	0	0	6	11	10	4	0	0	0	0
- SW Dis Impact, -35 Ml/d	-35	Ml/d	-2	-2	-2	-2	-2	-2	-122	-122	-122	-38	-2	-2



3.5 Calculated Net Consumptive Abstraction & Discharge Impacts in Specified Year

Combined error bar is +/- 13.1 Ml/d

Net Abs Impacts = SW+GW Abs Impacts - SW Dis Impacts, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
-3.6	Ml/d	7	7	7	7	13	17	-30	-36	-40	-6	7	7

3.6 Result: Calculated Naturalised River Flows in Specified Year

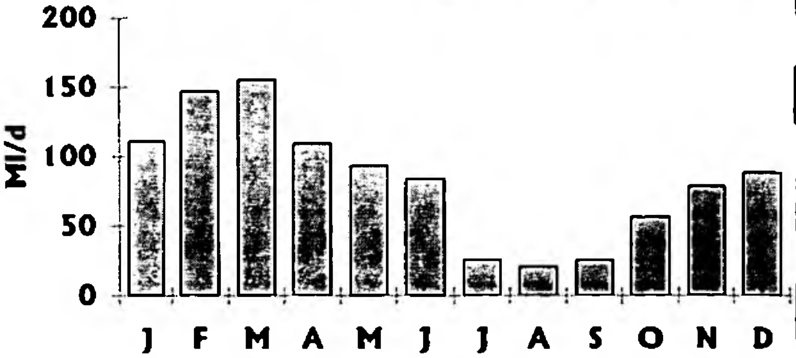
Combined error bar is +/- 17.4 Ml/d

i.e. combined error bar is +/- 21 % Av Nat Flow

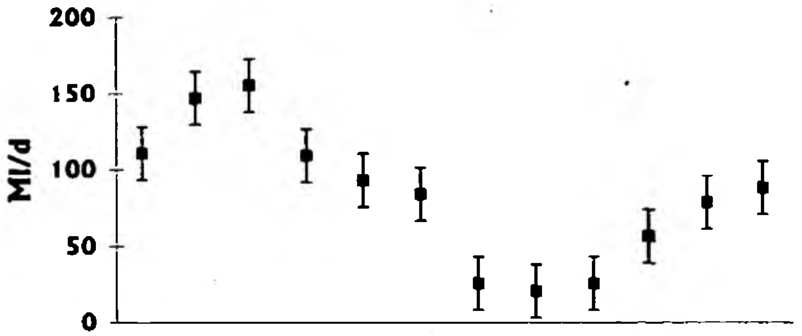
(these Naturalised Flows are passed back to the 'River Outflow Calcs' sheet)

Naturalised Flow = Gauged Flows + Net Abs Impacts, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
83	Ml/d	111	147	156	109	93	84	26	21	26	56	79	88



Same Naturalised Flow Plot with Error Bars



AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet to Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

GAUGED FLOW NATURALISATION SHEET *(OPTIONAL)*

4.0 Naturalised River Flow Composition in Specified Year, as mm/month over Surface Catchment Area

(For information only - equivalent of IoH 'gauged runoff' - not carried forward in calculations)

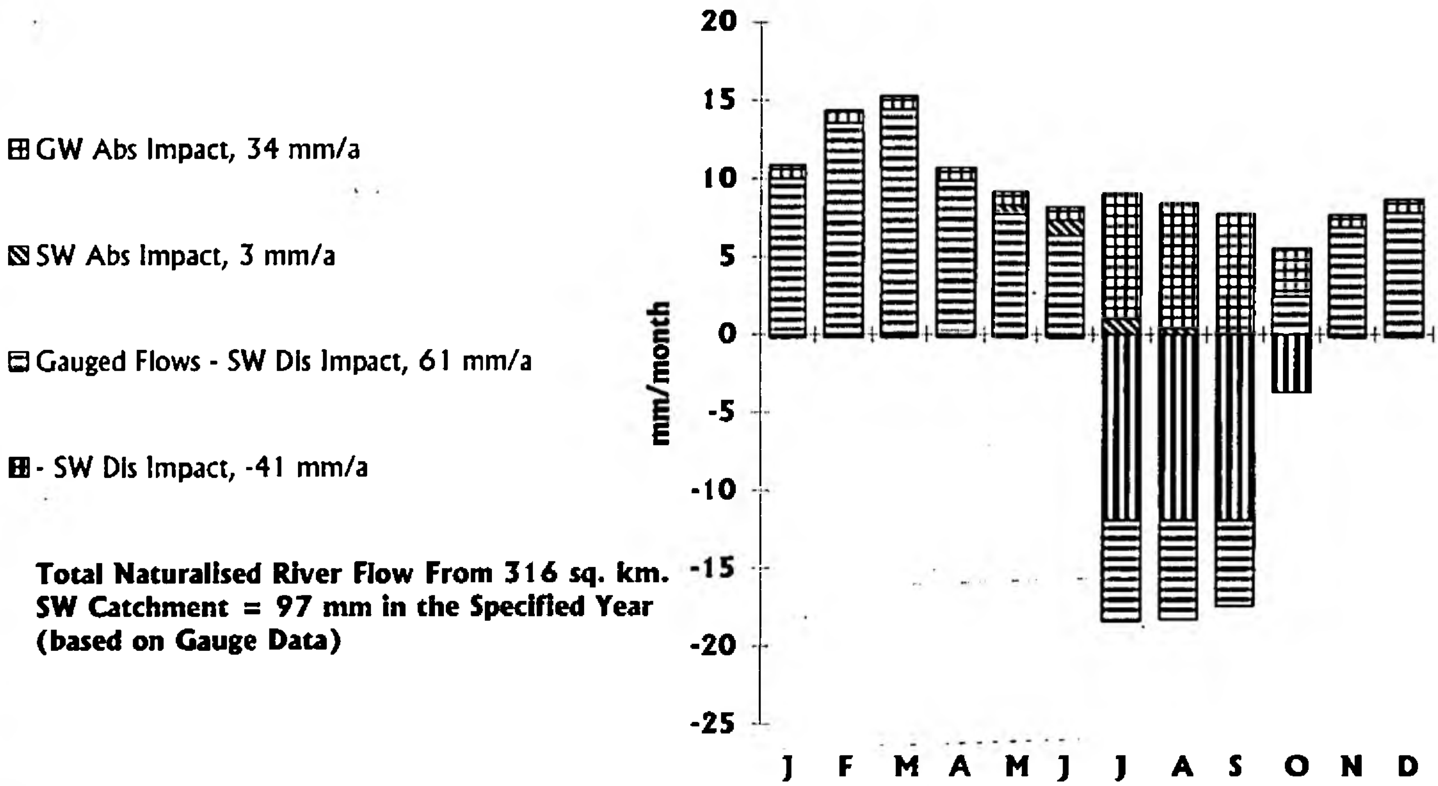
Surface Water Catchment to River Gauge in sq. km. = 316 Ref: ih hydrometric register, 91-95

(area from which runoff enters the river above the gauge) *(these are specified in the 'River Outflow Calcs' sheet)*

Components of Naturalised Outflow as mm/month over SW catch.

	Ann Tot		J	F	M	A	M	J	J	A	S	O	N	D
GW Abs Impact, 34 mm/a	34	mm/a	1	1	1	1	1	1	8	8	8	3	1	1
SW Abs Impact, 3 mm/a	3	mm/a	0	0	0	0	1	1	1	0	0	0	0	0
- SW Dis Impact, -41 mm/a	-41	mm/a	0	0	0	0	0	0	-12	-12	-12	-4	0	0
Gauged Flows - SW Dis Impact, 61 mm/a	61	mm/a	10	14	14	10	8	6	-6	-6	-5	2	7	8

Total Naturalised River Flow From 316 sq. km. SW Catchment = 97 mm in the Specified Year (based on Gauge Data)



END OF SHEET

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area R Thet to Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

NATURAL RIVER FLOWS DERIVED FROM EFFECTIVE RAINFALL USING THE AQUIFER RESPONSE FUNCTION *(OPTIONAL)*

These calculations derive natural river flows from effective rainfall, assumptions of water routing and catchment characteristics using the Aquifer Response Function. Results are compared with other flow estimates (e.g. based on gauge flow naturalisation) in the 'River Outflow Calcs' sheet.

Calculations consider:

a. flows in a year of 'average' rainfall, then
b. flows for the specified assessment yr.

1 Year of Assessment

The year specified for this assessment is: Drought condition 1991 — Basis for selection of this year: stressed resources & GOGWS

(these are specified in the 'River Outflow Calcs' sheet)

2 a. Natural River Flows in an 'Average' Year Based on the Aquifer Response Function (ARF)

Areas	**sq km**	**Based on:**
Surface Water Catchment to River Gauge in Assessment Area	316	ih hydrometric register, 91-95
(area from which runoff enters the river above the gauge) *(these are specified in the 'River Outflow Calcs' sheet)*		
Aquifer Area within the Surface Water Catchment	316	assume all area receives recharge
(area from which runoff enters the river upstream of the gauge and recharge enters the aquifer)		
Groundwater Catchment to River Gauge	296	sw catch area - ~20sq km for drought condition
(aquifer area from which recharge would naturally discharge as baseflow to the river upstream of the gauge)		

Long Term Annual Average Hydrologically Effective Rainfall	**mm/a**	**Based on:**
Average Annual Total Hydrologically Effective Rainfall	173.1	morecs sq 130 average 1970-90

Assumptions Splitting Hydrologically Effective Rainfall into Runoff and Recharge — **Based on:**

Aquifer recharge as % of effective rainfall: 44 % — J. Barker & calcs in sq130-mo.xls

(so Aquifer runoff = 56 %)

Calculated Long Term Annual Average Runoff and Recharge

Calculated Ann. Av. Recharge draining to river = **61.8** Ml/d = recharge % * eff rainfall * GW catch area

(equivalent to 76 mm/a over the GW catchment area)

Calculated Ann. Av. Runoff draining to river = **83.9** Ml/d

=eff rainfall*(SW catch area - aquifer area in SW catch) + eff rainfall*aquifer runoff %*aquifer area in SW catch

Total Ann. Av. Eff. Rain draining to river = **145.7** Ml/d =recharge input plus runoff input

(equivalent to 168 mm/a over the SW catchment area)

Calculated Average Distribution of Runoff and Recharge

Based on: Av = 1.00

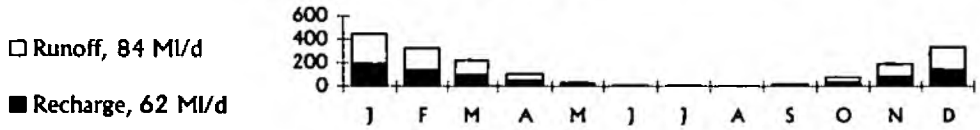
Default values = typical MORECS square Eff. Rain. factors: 1.00

Av. Monthly Factors of Av. Ann. Rech & Runoff Rates

J	F	M	A	M	J	J	A	S	O	N	D
3.04	2.22	1.53	0.74	0.22	0.04	0.03	0.02	0.10	0.53	1.31	2.29

Average Runoff and Recharge, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Runoff, 84 Ml/d	84	Ml/d	255	186	128	62	18	3	3	1	9	44	110	192
Recharge, 62 Ml/d	62	Ml/d	188	137	94	46	13	2	2	1	6	33	81	141



Aquifer Characteristics Controlling Natural River Flow Response to Recharge — **Based on:**

Recharge % which becomes river flow in the same month: 0 % — No karstic response

Aquifer Characteristics Controlling Natural Baseflow from Remaining Recharge

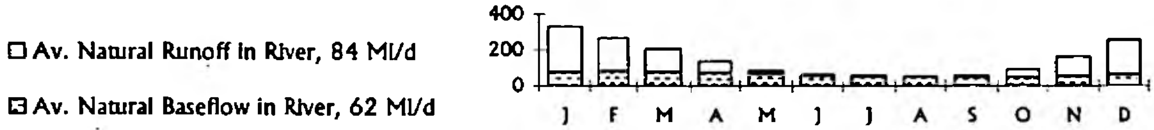
Total length of rivers draining GW catchment	30	km	measured length of upper l Ouse
Average Storage (Specific Yield)	0.03	no units	guess from Redgrave
Average Transmissivity	500	m2/d	guess from Redgrave

Aquifer Response Time = 1460.27 days

Calculated Average Natural Runoff and Baseflow in the River

Average Natural Runoff and Baseflow in River, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Av. Natural Runoff in River, 84 Ml/d	84	Ml/d	255	186	128	62	18	3	3	1	9	44	110	192
Av. Natural Baseflow in River, 62 Ml/d	62	Ml/d	76	80	78	72	64	57	53	49	47	48	53	64



Average Natural Total River Flow = Runoff + Baseflow, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Av. Natural Total Flow in River, 146 Ml/d	146	Ml/d	332	267	206	134	82	60	56	51	56	92	163	256

Min. Natural Total Flow in an Av. Year = 50.6 Ml/d

2 b. Natural River Flows derived from Hydrologically Effective Rainfall in the Specified Assessment Year and Preceding Nine Years

Hydrologically Effective Rainfall (HER) Data Entry

Enter 10 yrs of monthly HER values, yr 10 being that specified for assessment, in column DI from Row 24 down

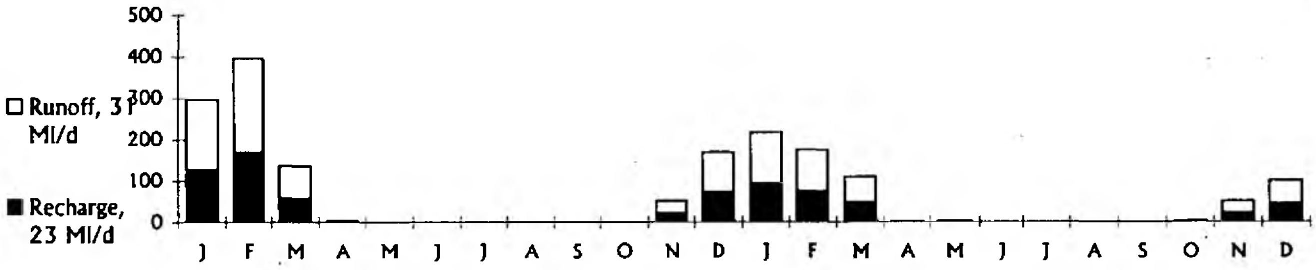
Data Source: Morecs square 130, 1991 drought year

Hydrologically Effective Rainfall for Preceding & Specified Year, mm/month

10 Yr Av	Preceding Year J	F	M	A	M	J	J	A	S	O	N	D	Specified Assessment Year J	F	M	A	M	J	J	A	S	O	N	D	Yr Tot
158 mm/a	30	40	14	0	0	0	0	0	0	0	5	17	22	18	11	0	0	0	0	0	0	0	5	10	66 mm/a

Calculated Runoff and Recharge for Preceding & Specified Year, Ml/d

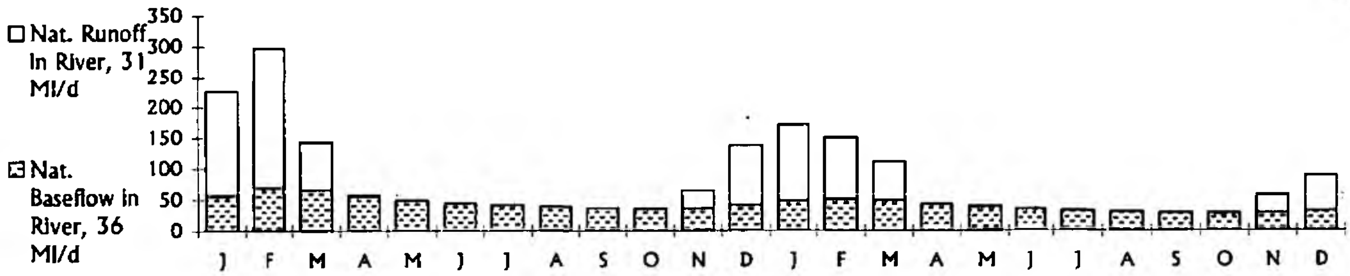
	Preceding Year J	F	M	A	M	J	J	A	S	O	N	D	Specified Assessment Year J	F	M	A	M	J	J	A	S	O	N	D	Yr Av
Runoff, 31 Ml/d	171	228	78	2	0	0	0	0	0	0	30	97	124	100	63	1	2	0	0	0	0	1	29	58	31
Recharge, 23 Ml/d	126	168	58	2	0	0	0	0	0	0	22	71	92	74	46	0	1	0	0	0	0	1	21	42	23 Ml/d



Data compilation & calculation imply av. level of confidence in this recharge is +/- 10 % i.e. error bar assumed to be +/- 2 Ml/d

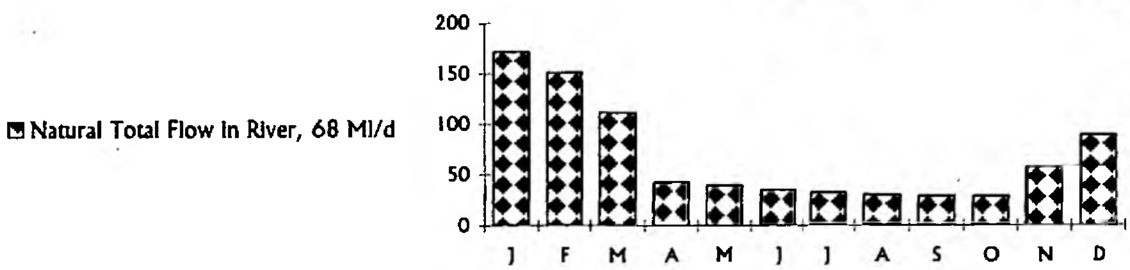
Calculated Natural Runoff and Baseflow in River for Preceding & Specified Year, Ml/d

	Preceding Year J	F	M	A	M	J	J	A	S	O	N	D	Specified Assessment Year J	F	M	A	M	J	J	A	S	O	N	D	Av.
Nat. Runoff in River, 31	171	228	78	2	0	0	0	0	0	0	30	97	124	100	63	1	2	0	0	0	0	1	29	58	31
Nat. Baseflow in River,	55	69	65	55	49	45	42	39	37	35	35	41	47	50	48	42	38	35	32	30	29	27	28	31	36 Ml/d



Natural Total River Flow = Runoff + Baseflow, Ml/d

	Ann Av		Specified Assessment Year J	F	M	A	M	J	J	A	S	O	N	D
Natural Total Flow in River, 68 Ml/d	68	Ml/d	172	151	111	43	39	35	32	30	29	28	57	89



Minimum Natural Total Flow in this Year = 28.2 Ml/d

(these Natural Flow Estimates are passed back to the 'River Outflow Calcs' sheet)

Data compilation & calculation imply av. level of confidence in this total flow is +/- 15 % i.e. error bar assumed to be +/- 10 Ml/d