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Environment Agency

User Manual for Available Resource Methodology (ARM) Spreadsheets

National Groundwater and Contaminated Land Centre

Environment Agency

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National Groundwater and Contaminated Land Centre
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Statement of use
This document describes a Framework for the assessment of acceptable abstraction impacts and water resources sustainability for a surface water or groundwater catchment area. It offers guidance for users of the spreadsheet tools which have been developed to provide optional support for the implementation of assessments within this Available Resource Methodology (ARM) Framework.
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 User Manual describes the spreadsheets which have been developed to provide optional support for the strategic assessment of water resources according to the Available Resource Methodology (ARM) Framework. The ARM has been developed with the Environment Agency to provide a Framework within which the water resources balance and sustainability of abstraction from an area can be assessed and presented. For most areas the ARM Framework provides a consistent format for resource assessment and countrywide comparison which optimises local knowledge and experience and can accommodate a variety of technical approaches (as already used by Agency staff), from first approximations to more sophisticated regional models.

Essential steps required are the delineation of the assessment area, the selection of an assessment year or hydrological scenario, the collation of river flow, abstraction and discharge data, and the recording of a conceptual understanding of the components of the hydrological cycle. River and environmental flow targets also need to be established through the Agency's internal and external consultation process. . The main output is a statement of the surplus or deficit of available resources in the area compared with these pre-defined flow protection targets. This can be used to assign a sustainability status to the resources management of the area.

Assessments are based on outflow focused estimates of resources and the artificial impacts on these. Total river flows at a defined point (including both groundwater and surface water contributions) are preferred as the focus as these are often the main management issue. Groundwater-only assessments are also possible where appropriate (e.g. for confined or coastal aquifers) but (as with any approach) will be subject to much greater uncertainties.

An integrated approach to groundwater and surface water resources recognises that borehole abstractions may often affect the water available in the river and that river abstractions may rely upon a groundwater contribution. In order to adequately represent catchments which have a large seasonal resource variation, the Framework and associated spreadsheets enable the user to consider monthly average flows, abstraction impacts and targets in a selected assessment year.

After providing a brief overview of the ARM Framework the User Manual offers step-by-step guidance for anyone using the spreadsheets developed to facilitate its implementation. Worked examples for two trial areas are also presented and discussed. The blank and trial spreadsheets are included on disc and as hard copies in Appendices.

The main sections of the User Manual are signposted overleaf for ease of reference.

Glossary

Key Terms and Abbreviations

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.

TERM/ABBREVIATION	DEFINED AS:
Maximum % Abstraction Impact	An indicator of the maximum abstraction impacts relative to natural outflows in the specified year. $= \frac{\text{Abstraction Impact} \times 100}{\text{Natural Outflow}}$
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').

1 Summary of the ARM Framework

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User Manual Contents

1. Summary of the ARM Framework

1.1 Introduction

This Section of the Spreadsheet User Manual introduces the Available Resource Methodology (ARM) which has been developed for the Environment Agency (the 'Agency') to provide a consistent Framework within which the water resources balance and sustainability of abstraction from an area can be assessed. The Framework is intended to provide a consistent basis for countrywide comparison whilst retaining the flexibility to permit optimum use of local understanding and experience. It has grown and broadened out of earlier R&D work to establish the available resources or 'reliable yield' of groundwater dominated units, and recent trials suggest that it now also works well on surface water dominated catchments.

Section 1.2 presents an overview of the Framework and what it is intended to achieve. Section 1.3 outlines the main steps within it and discusses the issues and appropriate approaches which might be relevant to each. Other optional elements which can provide useful supplementary insight into the water resources balance are described in Section 1.4. Finally Section 1.5 summarises the development of the Framework and indicates were further guidance on related approaches can be found.

The remainder of the Manual is dedicated to spreadsheets which have been developed to facilitate assessments according to the ARM framework. Section 2 lists the spreadsheets, describes what they are for and introduces their requirements (data, hardware, software, staff time etc) and plot formats. Sections 3 to 7 provide step-by-step guidance for the use of each of the four available spreadsheets. Section 8 describes how the spreadsheets may be used to investigate alternative scenarios or assumptions. Worked examples for two trial areas are presented in Section 9 and recommendations for further consultation on the wider application of the Framework and spreadsheets are drawn together in Section 10.

1.2 ARM Framework Overview

The ARM has been developed as a consistent but flexible Framework to help the Agency manage water resources sustainably across a wide variety of areas in England and Wales. It outlines the principal steps required to assess whether or not the resources management (i.e. abstraction and discharge control) of an area is sustainable given in-river and other environmental water needs. The main output from such an assessment should be a statement of the surplus or deficit of resources in the area compared with these pre-defined flow protection targets. It should then be possible to compare these surplus or deficit results between different areas, interpret and classify their degree of sustainability, prioritise remedial action and set out policy for future management.

Figure 1.1 is an overview of the principal steps within the ARM Framework. The options within each step are discussed in Section 1.3 - the following paragraphs summarise the whole process.

Assessments are based on outflow focused estimates of resources and the artificial impacts on these. Total river flows at a defined point (including both groundwater and surface water contributions) are preferred as the focus as these are often the main management issue. Groundwater-only assessments are also possible where appropriate (e.g. for confined or coastal aquifers) but (as with any approach) will be subject to much greater uncertainties.

The first step in the assessment must be to qualitatively describe the conceptual understanding of the river catchment or groundwater area in question including the hydrological processes and management issues within it. Previous studies should be reviewed and the level of understanding indicated. Thereafter the Framework requires estimation and plotting of monthly average flows and impacts for one or more specified assessment years or hydrological scenarios in order to represent seasonal variation in the resource balance

Resources are defined by estimates of average monthly natural river or groundwater outflows for the specified year. Such estimates may be based on a wide variety of commonly applied techniques such as gauge flow naturalisation, river flow models like microLOWFLOWS or regional groundwater flow models. In river outflow assessments, the natural baseflow may also be defined as a separate groundwater resource although this is not essential.

The surface water abstractions ('SWABS') and discharges ('SWDIS'), the groundwater abstractions ('GWABS') and any other artificial influences (e.g. reservoirs) which make up the management regime are then stated and their impacts estimated in order to calculate the 'scenario' outflow. These artificial influences are defined for the management scenario being assessed and may differ from the 'estimated actual' influences used in any gauged flow naturalisation process to derive natural flows. Particular care is required when considering the seasonal distribution of groundwater abstraction impacts on river flows (see Section 8.1).

The next key step in the Framework is to define the target flows which the Agency considers are required to meet in-river or environmental needs. There is, as yet, no nationally accepted method for establishing these target flows (see Section 1.3.6 for options). The criteria for determining appropriate targets will vary widely so this step may require extensive consultation within the Agency and with the public and major stakeholders to achieve consensus. With the use of pre-defined target flows the sustainability of the scenario can be assessed. If target flows have not been defined, it is still possible to express the artificial flow impacts as a percentage of natural flows but no conclusions as to the acceptability of these can be inferred.

The final calculation is simply to subtract the target flows (i.e. the river or environmental needs) from the scenario flows (i.e. the outflows for the scenario) to determine the surplus or deficit of resources available for further abstraction. If monthly flows, impacts and targets have been estimated throughout, as advocated by the Framework, then a monthly surplus or deficit profile will result which will reflect seasonal variations in resource availability for the year assessed (Figure 1.2).

Alternative years may be considered in the same way e.g. to investigate the balance for a 1 in 10 year drought or for an 'average' year. The surplus or deficit can also be expressed as a percentage of the natural outflow resource in order to make comparisons between different rivers or areas. The assessment results may then be used to assign a sustainability status based on the surplus or deficit profiles according to national guidelines if this is required (as illustrated in Figure 1.2).

The Framework is not intended to replace any part of the existing process for the determination of individual abstraction licence applications. The results of an ARM assessment apply to the whole area assessed and do not consider the distribution of abstraction stresses within it. Licence applications will remain subject to detailed scrutiny of local impacts regardless of whether or not there are surplus resources in the general area.

Assessments can be carried out within the Framework using various techniques at different levels of sophistication to produce results in a consistent format which can be readily compared. However, because it is not prescriptive in setting out exactly how each of the principle steps is to be carried out, the consistency of assessment outcomes does rely on the establishment and application of best practice throughout the Agency in areas such as flow naturalisation and target flow setting.

In summary, the ARM Framework provides a strategic overview of water resources management and abstraction sustainability focussed on river or groundwater outflows. It advocates an integrated approach to groundwater and surface water management and can take account of seasonal variations in the resource balance and in abstraction impacts. The understanding and organisation of information which is derived from a Framework assessment can also help prioritise further study, monitoring or investigations to reduce key uncertainties which are hampering effective management.

1.3 Principal Steps

This Section outlines the key issues and options relevant to each of the principal steps illustrated in Figure 1.1 which are the basis for the spreadsheets described in the remainder of the Manual.

1.3.1 Assessment Area Definition and Conceptual Description

River flow assessments are carried out for the combined surface water and groundwater catchments to a point on the river. These catchments do not have to be coincident. Although not essential, assessments should take advantage of available gauging stations wherever possible as measured flows will generally be more reliable than estimated or modelled flows and flows can be monitored against targets. For such assessments groundwater catchment delineation is only relevant to identify which groundwater abstractions are wholly or partially considered to impact flows over the gauge. The size and number of sub-catchments considered may vary from river to river according to the sensitivity of the resource management issues.

Groundwater-only assessment areas may be delineated on the basis of geological or coastal boundaries rather than surface water catchments but some understanding of the location and rate of natural groundwater outflow from the catchment area must be defined.

A qualitative description of the area is an essential starting point for any assessment. This should include a conceptual understanding of hydrological processes such as recharge, surface runoff, and factors influencing groundwater – surface water interaction. It should reference previous studies and provide an overview of historical resource development, hydrological trends and current key management issues. Sketched plans and cross-sections illustrating the main features described can be invaluable and the use of some consistent symbol and line types can facilitate understanding between regions. The uncertainties within this description should be indicated

1.3.2 Specify Assessment Year or Hydrological Scenario

The resources available to sustain any given abstraction and discharge management scenario will vary from year to year. The choice of assessment year or hydrological scenario will therefore at least partly determine the surplus or deficit profile which results. Care is therefore needed to ensure that there is consistency within and between Regions and it is recommended that the Agency identify national guidelines with this in mind.

Assessments of the same abstraction and discharge management scenario can be repeated for different years to obtain a broader view of its sustainability. Possible candidates to consider include:

- A 'long term average' (LTA) year where monthly flows are averaged over a standard period. This is useful for general resource comparisons between areas. However, unless the averaging process takes into account variations in the timing of seasonal peaks and troughs, an LTA year will smooth out seasonal variability so that resulting summer surpluses are overestimated;
- An 'average' year chosen as an historical year with river flow close to the long term average;
- An historical drought year of pre-defined return period;
- A synthesised hydrological scenario consistent with that used for the determination of source deployable outputs.

The ready availability of key river flow, abstraction and discharge data should be an important consideration if an historic year is selected. This may often pragmatically limit assessments to recent years (e.g. after 1980) when these data are more widely available within standard Agency databases.

1.3.3 Estimate Resource as Natural Outflows

A key feature of an ARM Framework assessment should be that the availability and timing of natural water resources are estimated as outflows from the area (i.e. river flow or groundwater outflow) rather than as inflows (i.e. effective rainfall or recharge). This is helpful because the timing of outflows evident from a monthly average profile includes within it information on catchment response and storage, and also so that resource management objectives may be focussed on measurable targets.

There are many standard techniques for the estimation of natural river flows which can be accommodated within the Framework:

- Gauged flow naturalisation (an optional spreadsheet for monthly average gauge flow naturalisation for use in association with the main ARM spreadsheet is described in Section 7.1);
- microLOWFLOWS;
- region specific river flow or groundwater models;
- other hydrological techniques.

Such approaches are in regular use within the Agency and are the subject of national guidelines which experienced staff can apply to ensure consistency. It may often be useful to compare and reconcile different estimates of natural river flow before proceeding with the assessment.

Natural groundwater outflows from coastal or confined aquifers are much more difficult to quantify. Leakage to a confined aquifer may be partly dependent on the pumped drawdown so that the basic assumption of a natural outflow reduced by abstraction is not valid. In the absence of groundwater models estimates may be based on hydraulic gradients and transmissivities or on simple models of the aquifer's discharge response to recharge. One such simple analytical function (the 'Aquifer Response Function') has been developed in a spreadsheet which can optionally be used to simulate monthly natural outflows from effective rainfall (see Section 7.2). These estimates should be viewed with caution and resources management will inevitably be based on monitoring of groundwater quality and levels as indicators of change.

1.3.4 Estimate the Impacts of Abstractions and Discharges

The assumptions of the management scenario should be clearly stated. It is likely that the Agency will be seeking to assess the sustainability of the current abstraction licence ledger although the acceptability of a potential future changes might also be considered. Abstractions can be seasonally profiled according to licence restrictions as average monthly rates to take account of and represent both summer spray irrigation and winter pumped storage. Abstraction rates may be based on either:

- The annually licensed rate regardless of any licence restriction clauses;
- The deployable output determined for the source as defined in the relevant UKWIR/Agency R&D Reports; or
- An estimate of the actual abstraction rate.

Here again, national guidelines could provide consistency.

Whichever option is chosen to estimate the abstraction rate, the consumptiveness of the licence use with regards to local return of water to the catchment should be taken into account (e.g. spray irrigation is 100% consumptive, fish farming is 0% consumptive). In order to take account of bulk water transfers it is recommended that public water supply abstractions be treated as fully consumptive and that sewage treatment works discharges are accounted for separately. Such discharge rates are likely to be poorly measured and associated with a high degree of uncertainty.

Surface water abstractions and discharges can be safely assumed to impact on river outflows at the same monthly rate as they are pumped (unless they are upstream from a reservoir).

The same assumption cannot be made for groundwater abstractions. Having estimated the monthly profile of groundwater abstractions from the catchment it is recommended that a separate estimate be made of the impact of these abstractions on river flows. Analytical approaches might predict delayed and smoothed impacts related to both the aquifer properties and borehole's distance from the river but the seasonal recharge dependant effects of aquifer storage may be more significant. Boreholes close to a river in a highly karstic aquifer may be considered to 'impact river flows as they pump' and can therefore be treated as surface water abstractions. However, for many aquifers the river flow reductions due to abstraction may be less in summer than in winter, and also less in drought years than in wetter years. Estimates of groundwater abstraction impacts should take into account any local experience of low flow recovery when boreholes have been turned off.

Section 8.1 discusses some simple alternative assumptions which can be used to estimate groundwater abstraction impact distribution within the ARM spreadsheets. Agency R&D on this issue is ongoing.

The existence of runoff dependent or pumped storage reservoirs and of groundwater storage based river support schemes may also be accounted for within the ARM Framework where relevant.

1.3.5 Calculate Outflows for the Scenario Assessed

Having estimated artificial impacts these are simply applied to the natural outflows to calculate the scenario outflows.

1.3.6 Define Target Outflows

One of the principal objectives of the Framework is to assess water resources status with reference to flow protection targets based on environmental and in-river needs, downstream protected rights and effluent dilution requirements. These flow targets may take into account amenity, navigational, landscape aesthetics, fisheries and eco-hydrological needs and may require wide consultation within the Agency and beyond. Such consultation should be initiated early on as its conclusions will critically affect the outcome of an assessment

The ARM Framework calls for monthly average flow targets to be established so as to enable the protection of a seasonally variable flow regime if appropriate. The natural QN95 or the gauged Q95 are commonly used as a basis for setting 'hands off flows' for surface water abstraction licences. The failure to maintain such minimum flows during severe droughts should be expected and accepted unless river support schemes are considered to be part of a sustainable resource management policy. An additional proportion of the natural flows exceeding the defined monthly minimum can also be optionally protected, in a manner similar to the principles set out in the Agency's Surface Water Abstraction Licensing Procedure (SWALP).

Framework assessments should aim to establish consensus around realistic flow targets, set in the light of estimated natural and measured existing flows (where available), and should clearly show the implications of these targets both in terms of abstraction restrictions and environmental benefits.

It is important to note that monthly flows cannot be measured – they can only be calculated retrospectively. Monthly targets are not appropriate as an operating constraint for surface water abstractions which will still require a daily flow-duration curve approach as advocated SWALP.

For groundwater-only assessments the prevention of saline intrusion may be a particular concern. As for natural groundwater outflows, targets will be difficult to define and should be associated with large uncertainty.

1.3.7 Calculate Surplus or Deficit Profile

The surplus or deficit for each month of the year assessed is simply calculated by subtracting the target flow from the scenario flow (Figure 1.2). This profile represents how much more or less abstraction impact can be considered acceptable to maintain the target flows set. Many assessments show a small surplus or a deficit during summer with large surpluses during the wetter months. In order to compare catchments of different sizes it is useful to express the same profile as a percentage of the natural outflow and the overall sustainability of abstraction management can be simplified further down to two numbers – the average surplus or deficit %, and the minimum surplus or deficit %.

1.3.8 Interpret Sustainability Status

Figure 1.2 shows monthly flow and surplus or deficit plots for a catchment in three resource exploitation conditions. In all three conditions the estimated natural and target flows for the assessed year are the same – it is only the scenario outflow which varies and results in a progressively depleted surplus profile as resources become more committed. When there are clear surpluses throughout the year there is the potential for further surface water or groundwater abstraction (subject to local impact assessment). Smaller summer surpluses may imply that groundwater abstraction should be frozen although there may be potential for further seasonally or flow restricted surface water abstractions (e.g. winter storage schemes).

In the final over-committed condition deficits are apparent in the summer months and some reduction in abstraction impacts is required. This might be achieved by reductions in groundwater abstraction throughout the year or could be realised by cutting back surface water spray irrigation abstraction. Alternatively, if groundwater abstractions are considered to have a smaller impact on river flows in the summer than the equivalent surface water abstraction, it may be appropriate to advocate a switch from surface to groundwater abstraction.

It is understood that a fivefold classification of abstraction sustainability based on such profiles is currently under consideration by the Agency as follows:

- *Lightly to Moderately Licensed*: **(Blue)** Considerable surplus of water available in all months.
- *Significantly Licensed*:. **(Green)** Surplus of water available. Possibly slight surplus in summer months. Clear surplus in winter months.
- *Fully Licensed*: **(Yellow)** Little or no surplus available. No significant summer surplus or deficit. Possibly some slight surplus in winter months.
- *Over-Licensed*: **(Orange)** Deficit in water availability exists on the basis of licensed resources but not due to actual abstractions. Deficit in most or all summer months, possibly some winter months.
- *Over-Abstracted*: **(Red)** Deficit exists on the basis of both licensed and actual abstractions. Actual deficit in most or all summer months.

Whilst the presentation of an annual average surplus or deficit is helpful for comparative purposes, it is also essential to quote the minimum surplus (or the largest deficit) as this more closely reflects the groundwater resource position. Reliance on a single annual average result fails to address seasonal aspects of resource availability and could be misleading unless critical periods are considered.

If possible, errors and uncertainties in all the estimates used to derive the surplus or deficit profile should be accumulated through the calculations to enable this final profile to include a simple representation of uncertainty (Figure 1.2). The incorporation of uncertainty in this way is a key feature of the ARM spreadsheets described in Sections 2 to 7. It allows management decisions to be made cautiously with some understanding of the possible errors involved. It also enables assessments to be carried out at different levels of sophistication from simple, broad-brush approaches based on limited data (large error bars) to more costly regional modelling approaches with more effort to collect and collate monitoring data (smaller error bars).

1.4 Other Calculation Steps and Plots

Although not essential, there are a number of further calculation steps and useful plotting representations which have been built into the ARM spreadsheets based on the data already collated during the assessment process. These include:

- Calculating the total 'acceptable abstraction impacts' as the difference between the natural and target flows (e.g. Section 4, Step 9). This represents a ceiling below which the Agency is aiming to manage the impacts of consumptive abstraction;
- Comparing groundwater abstraction impacts with natural baseflow if this has been separately defined for a river flow assessment (e.g. Section 4, Step 11);
- Combining all the monthly scenario flows and impacts as stacked histogram plots against a common Ml/d flow axis to illustrate the relative importance of the different impacts and therefore help to effectively prioritise management intervention (e.g. Section 4, Step 10);
- Stacked histograms can also be expressed in mm/month by dividing by the catchment area assessed (the surface catchment area is most convenient for river flow assessment). These plots are particularly helpful for comparison between small and larger areas. Differences between them may relate to variations in basic effective rainfall resources (e.g. Anglian Region low, North West Region high) or to local variations in groundwater catchment area (e.g. Section 4, Step 12);
- It may be useful to represent the scenario flows and impacts for a discrete reach of a river system, excluding inflows from an upstream sub-catchment. This may help to focus attention on the areas of greatest abstraction stress (e.g. Section 4, Step 12).

1.5 Background to the ARM Framework and Related Research

1.5.1 ARM Framework Trials and Development

The ARM Framework has been developed following extensive review of existing practice and research and in consultation with Agency staff from all regions through a programme of intensive workshops and trialling. The trial areas are described in Section 9 together with worked spreadsheet examples from two of the areas (the River Thet and the Brighton Chalk Block). Figure 1.3 illustrates how the outputs from the principal calculation steps outlined above (Section 1.3) can be derived and presented using the ARM spreadsheets (the example shown is taken from trials carried out at two locations on the River Ribble).

The need for an integrated resource assessment Framework and the process of trials and consultation by which the ARM has been developed are detailed in three main reports as follows:

- A Framework for Assessing Water Resource Availability and Acceptable Abstraction Impacts: Report and User Manual, May 1999. National Groundwater and Contaminated Land Centre Project Reference NC/06/01;
- Available Resource Methodology Assessments in Catchment Abstraction Management Strategy Trial Areas, March 2000. National Groundwater and Contaminated Land Centre Project Reference NC/99/68;
- Project Record for the Development of the Available Resource Methodology: A Framework for Assessing Water Resources and Abstraction Sustainability, March 2000. National Groundwater and Contaminated Land Centre Project Reference NC/99/68.

1.5.2 Other Related Research and Guidance

Related research which has been referred to during development of the ARM Framework and which provides useful guidance for some of the calculation steps includes:

- The Surface Water Abstraction Licensing Procedure (SWALP);
- Low flow studies research and microLOWFLOWS software;
- flow naturalisation guidelines;
- ongoing R&D into the impact of groundwater abstractions on river flows (IGARF); and
- UKWIR Deployable Outputs (surface water and groundwater sources).

A bibliography of key documents referred to during the development process is included in Section 11 of this User Manual.

CHOOSE RIVER OUTFLOW (PREFERABLY) OR GW OUTFLOW AS FOCUS FOR ASSESSMENT & RECORD QUALITATIVE UNDERSTANDING

SPECIFY ASSESSMENT YEAR(S) OR HYDROLOGICAL SCENARIO(S) FOR MONTHLY PLOTS

RIVER OUTFLOW

Delineate Catchment & Sub-Reaches

Determine & Plot 'Natural' River Flows, & optionally GW Baseflows & Annual Recharge minus GWABS

Determine & Plot 'Scenario' SWABS, SWDIS & GWABS Impacts on River Flows and 'Scenario' River Flows

Determine & Plot Target River Flows

Determine & Plot Surplus or Deficit Profile (= 'Scenario' - Target Flows) + Express as a Percentage of the Natural Flow Resource

Results Available for Sustainability Status

GROUNDWATER OUTFLOW

Delineate GW Catchment or 'Unit'

Determine & Plot 'Natural' GW Outflows & optionally Annual Recharge minus GWABS

Determine & Plot 'Scenario' GWABS Impacts on GW Outflows and 'Scenario' GW Outflows

Determine & Plot Target GW Outflows

Determine & Plot GW Surplus or Deficit Profile (= 'Scenario' - Target Flows) + Express as a Percentage of the Natural Flow Resource

Results Available for Sustainability Status

FIGURE 1.1 ARM FRAMEWORK OVERVIEW

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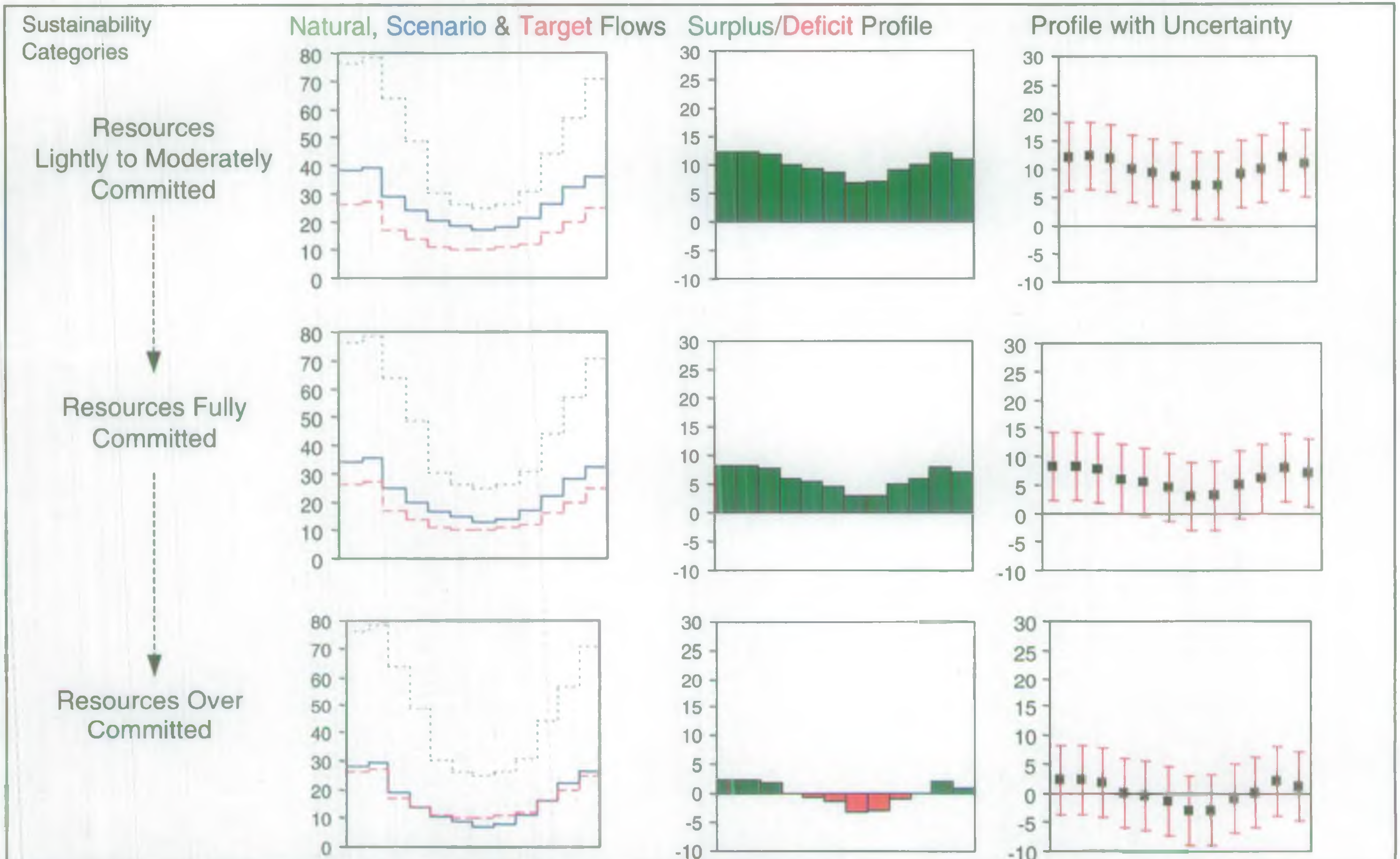

FIGURE 1.2 INTERPRETING ABSTRACTION SUSTAINABILITY STATUS

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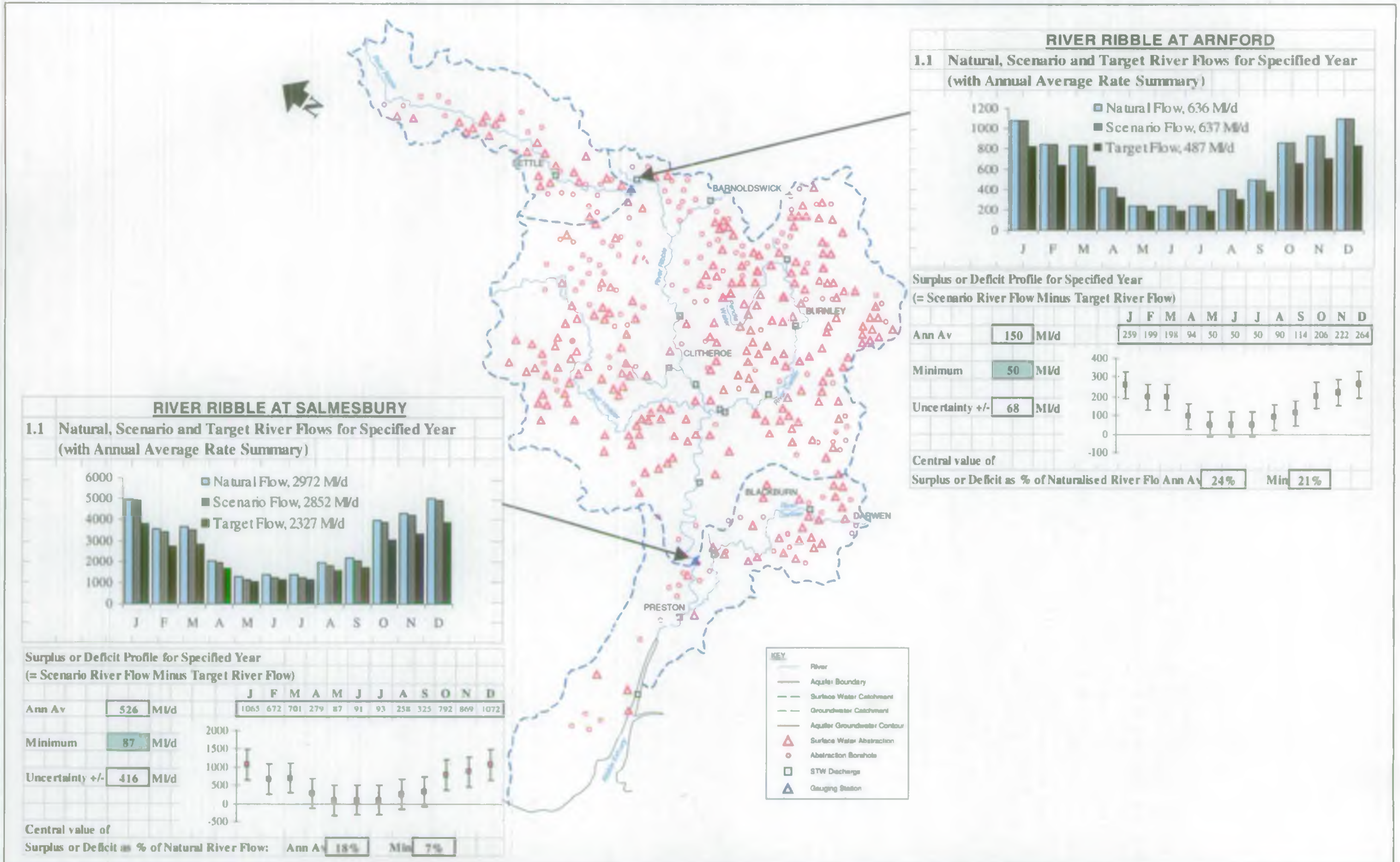


FIGURE 1.3 POSSIBLE PRESENTATION OF ARM FRAMEWORK RESULTS (Ribble Catchment Example)

Drawing No : **02019-01.S022a.ppt** Date: **MARCH 2000** Scale: **AS SHOWN**

2. ARM Spreadsheet Aims, Overview, Formats and General Guidance Notes

Sections 2 to 8 are written as a practical guide for users of the ARM spreadsheets. First time users are recommended to read Section 1 to gain an overview of the ARM as a Framework for resource assessment.

The style of these sections is deliberately sparse with emphasis on step-by-step instructions and notes to explain the assessment process. It includes the following sections:

Section	Title	Contents
2.1	Aims, Outputs and Definitions	What the assessment is for, what the calculation results are and what they mean
2.2	Spreadsheet Overview	A flow diagram and description summarising the assessment calculation steps and associated Excel spreadsheets
2.3	Staff, Time, Data, Software and Hardware Requirements	Who should do the work, how long it may take and what they need to do it
2.4	Data Entry, Audit Trails and Confidence Limits	Spreadsheet formats for entering information and how to incorporate data error bars to reflect uncertainties
2.6	Estimating Natural Outflows from Rainfall	General guidelines on options for estimating natural river or groundwater outflows from rainfall
3	Spreadsheet for Conceptual Understanding	Notes on how to use this spreadsheet to set out a simple conceptual understanding of the area
4 & 5	Two Spreadsheets for Calculating Surplus or Deficit and Impacts	Flow diagrams and calculation notes for areas where 4. river flows are important 5. outflows are as groundwater (rivers not considered)
6	Conclusions and QA Spreadsheet	Notes on presentation and interpretation of headline results and on review, approval and updating the spreadsheets
7	Optional Spreadsheets to Estimate Natural Flows	Flow diagrams and calculation notes on optional spreadsheets for estimating natural flows based on: • Gauged flow naturalisation; and • Effective rainfall using a simple analytical model.
8	Assessing Alternative Assumptions, Scenarios and Targets	How to use the spreadsheets to investigate the implications of alternative GW abstraction impact assumptions, management scenarios or flow protection targets in different assessment years

2.1 Aims, Outputs and Definitions

A full listing of key words and abbreviations used in this guide is provided in the Glossary at the front of the report. **Definitions** which are particularly central to the ARM spreadsheets are given in Table 2.1.

The **aims** of carrying out a water resource assessment using these spreadsheets are:

- To record the developed **conceptual understanding** of the water resources of the Assessment Area in a simple and nationally consistent format;
- To calculate, for the area in a specified year (or years), the **surplus or deficit** availability of water for further abstraction according to a defined management scenario and given target flows set to protect the environment and downstream flow needs;
- To express both the surplus or deficit as an average and minimum percentage of natural flows in order to facilitate comparison between areas;
- To assign a **sustainability status** (see Section 1.3.8) to the area based on this surplus/deficit profile and percentages;
- To calculate, for the area in a specified year, the total **acceptable abstraction impacts** given natural and target flows;
- To consider and represent **uncertainty** in calculated outputs and prompt further investigation when required.

The principal calculation **outputs** from an assessment for any area should therefore be:

- Availability of water for further abstraction in the specified year expressed as 12 monthly surplus or deficit values in Ml/d (and as percentages of natural flow) with associated uncertainty bands;
- An interpreted sustainability status for the area;
- Total acceptable abstraction impacts in the specified year expressed as 12 monthly values in Ml/d with associated uncertainty bands;
- The maximum scenario and acceptable monthly abstraction impact in the specified year expressed as percentages of the natural outflow from the area.

Table 2.1 Definitions

Term	Defined as:	Expressed as:
Assessment Area	The area to which the assessment applies, defined according to its outflow e.g. surface catchment and associated groundwater catchment to a point on a river, or groundwater catchment to coastal discharge boundary.	A sketched map, schematic cross-section and description
Specified Year	The historic year or hydrological scenario chosen to assess monthly flows and target flow implications e.g. a recent drought year of a known return period.	Calendar Year
Actual Flows	The flows which actually left the Assessment Area in a specified historic year (e.g. gauged river flows).	Twelve monthly averaged flows, January – December, in Ml/d +/- uncertainty
Natural Flows	The flows which would naturally have left the Assessment Area in the specified year in the absence of any artificial influences.	Twelve monthly averaged flows, January – December, in Ml/d +/- uncertainty
Scenario Flows	The flows which would have left the Assessment Area according to the abstraction and discharge management scenario being assessed.	Twelve monthly averaged flows, January – December, in Ml/d +/- uncertainty
Target Flows	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, effluent dilution, navigational, amenity or ecological criteria, or groundwater flow to prevent saline intrusion.	Twelve monthly averaged flows, January – December, in Ml/d with associated uncertainty
Abstraction Impacts	The amount by which all the abstractions in the area would reduce natural flows from it, taking into the consumptiveness of the use, the location of any effluent return and any impact redistribution related to aquifer storage and transmissivity. Can be based on the impacts of estimated actual abstraction rates (e.g. for gauge naturalisation) or on the impacts of the management scenario being assessed.	Twelve monthly averaged flows, January – December, in Ml/d +/- uncertainty
Surplus or Deficit	How much more or how much less abstraction impact is acceptable in the specified year for the scenario being assessed. = Scenario Flows – Target Flows	Twelve monthly averaged flows, January – December, in Ml/d +/- uncertainty
Surplus or Deficit as % of Natural Flows	Indicators (or full monthly profile) of the surplus or deficit relative to natural outflows in the specified year which are useful for comparison with other areas and to assign sustainability status.	An annual average % and a minimum %.
Acceptable Abstraction Impacts	The abstraction impacts which are considered acceptable given target flows in the specified year. = Natural Flows – Target Flows, or = (Surplus or Deficit) + Scenario Abstraction Impacts	Twelve monthly averaged flows, January – December, in Ml/d +/- uncertainty
Maximum % Abstraction Impact	An indicator of the maximum abstraction impacts relative to natural outflows in the specified year. $= \frac{\text{Abstraction Impact}}{\text{Natural Flow}} \times 100$ (use either scenario or acceptable impacts)	A single % for whichever month shows the maximum % impact.

2.2 ARM Spreadsheet Implementation Overview

Figure 2.1 provides an overview of the Excel spreadsheets available to implement the assessment steps laid down in the ARM Framework (as previously illustrated in Figure 1.1). Preparatory guidelines on who should do the work, the information and time required, and calculation and plot entry formats are provided in Sections 2.3 and 2.6. Each of the spreadsheets shown on Figure 2.1 is considered in more detail in Sections 3 to 7 - the following paragraphs summarise the whole process.

ARM Framework assessments for river flows investigate natural and target flows in the river at a defined point, preferably a gauging station (if one exists), and all the upstream artificial impacts on these flows. The boundaries of a river Assessment Area can therefore be drawn according to surface water and natural groundwater catchments although these need not be coincident. For many assessments however, the groundwater catchment area need only be delineated to identify which of the groundwater abstractions are considered to impact the river flows being assessed. If the main natural outflows would be as groundwater to the sea or an estuary, or if any surface flows can be ignored, then the ARM assessment area should be delineated by the groundwater catchment to the outflow boundary.

The first step of any assessment is to make a simple record of the conceptual understanding of the hydrological cycle in the area. The user, in consultation with colleagues from complementary disciplines, answers largely qualitative questions collated on the ***Conceptual Understanding*** spreadsheet. The core of this understanding is presented as sketched maps and plans which illustrate essential surface and groundwater features and locate the main abstractions and discharges. Further details can be found in Section 3.

The next task is to calculate the **surplus or deficit** profile and **acceptable abstraction impacts,** for the area, as defined in Table 2.1. One of two ARM spreadsheets is chosen according to the definition of the area:

- Total river flows, and both abstraction and discharge impacts considered – ***River Outflow Calcs*** spreadsheet in the **RIV.XLT** workbook (Section 4); or
- Groundwater (GW) outflows and GW abstraction impacts only considered – ***GW Outflow Calcs*** spreadsheet in the **GW.XLT** workbook (Section 5).

Despite their differing data requirements, both spreadsheets have common elements and steps:

- defining natural flows;
- defining the abstraction and discharge management scenario;
- estimating scenario flows;
- setting flow protection targets;
- calculating surplus/deficit and acceptable abstraction impact profiles;
- plotting the scenario flows and artificial impacts as stacked histograms.

Whichever spreadsheet has been used for the calculations, results are summarised to a common format in the ***Conclusions and QA*** spreadsheet. At this stage, interpretation is required to assign a **sustainability status** (see Section 1.3.8) to the area and the user is required to seek the review and approval of Regional Agency staff with appropriate hydrological and hydrogeological responsibilities. Further details can be found in Section 6.

The definition of natural river flows or groundwater outflows is a vital first step in both ARM spreadsheets and the user is free to derive these using any appropriate approach. Possible options include the use of microLOWFLOWS, river or groundwater flow models which include the assessed area and gauge flow naturalisation. An optional spreadsheet (**GAUGE.XLT**) has been developed to facilitate gauged flow naturalisation for use in ARM assessments which is described in Section 7. Section 7 also introduces a spreadsheet (**ARF.XLT**) which uses a simple analytical function (the 'Aquifer Response Function') to derive monthly natural flows from a series of monthly effective rainfall data according to pre-defined groundwater and surface water catchment areas, aquifer parameters and an assumed recharge/runoff split. This can be tried as a further optional alternative for estimating natural flows.

Having entered data and assumptions for one assessment of an area, alternative scenarios can easily be investigated. These may consider the implications of alternative target flows, abstraction management scenarios or calculation assumptions as described in Section 8.

2.3 Staff, Data, Software, Hardware and Time Requirements

Table 2.2 provides a summary of the suggested staff inputs, data requirements and possible sources, calculation method options and software requirements needed for each step of the assessment process. This should be viewed as a guide rather than as a prescription.

A water resource assessment within this framework requires the collaboration of Agency staff from a range of disciplines and responsibility levels. Regional hydrogeologists and hydrologists should agree on the delineation of Assessment Areas and years and should prioritise the order in which the areas are considered. Experienced staff should also have a key review role at least over the description of conceptual understanding and the assumptions used to simulate natural outflows and to estimate groundwater abstraction impacts. River flow objectives will be an essential requirement for most assessments. Input from ecological and conservation staff will be needed to help set appropriate target flows. It is recommended that the completed assessment and the key output – a sustainability status – be reviewed and approved by the appropriate line managers including the Regional Water Resources Manager.

Much of the data collation and spreadsheet entry can be done by junior staff. Before starting data collation users should have read this report and manual as well as reviewing the spreadsheet where the data will be entered. Most quantitative data are required as monthly average flow values for the assessment year and maximum use should be made of data which may have already been collated for other purposes. Work is currently in progress within the Agency to improve the interfaces between abstraction licence databases, abstraction returns data, Micro LOW FLOWS etc which should all help to facilitate data collation for the resources assessment. Pragmatic assumptions to prioritise and reduce the data collation exercise to readily manageable proportions will always be necessary – guidance is provided in Section 2.4.

Some of the data to be collated depends on the calculation method chosen (e.g. derivation of natural flows from microLOWFLOWS compared with gauge flow naturalisation).

Basic computing requirements for the spreadsheets are a PC which runs Excel v97 SR2. Conceptual sketch maps and schematic sections can be pulled together from existing digitised drawings or GIS layers and imported into the spreadsheets, or can simply be attached as hardcopy, although users should be encouraged to adopt consistent line symbols to facilitate comparison. The need for associated software such as microLOWFLOWS or the 'Impact of Groundwater Abstraction on River Flows' spreadsheets depends on the user's choice of calculation method.

Water resource assessments of this type are probably best implemented for several areas within a Region at the same time. This has the advantage of improving user consistency and comparability between areas. If the same year(s) are specified for assessment the efficiency of data collation can also be improved. In this context, once the monthly data has been collated the time taken to complete the spreadsheet assessment for each area assessed is likely to be between 1 to 3 man days of junior time plus 1 day of senior review time. These time inputs will depend on the complexity of the area and on the criticality of the resource management issues.

Table 2.2 Staff, Data and Software Requirements

Assessment Step	Staff Involved*	Alternative Methods	Report & User Guide Reference	Data/Information	Possible Data/ Information Sources
Define Assessment Area	Hg/ Hy & SR	• previously defined • SW & GW River Catch. • GW Catch. only	Section 1.3.1	Geol boundaries, SW catch., GW contours, GS locations, which GWABS impact the river to the assessed point	MicroLOWFLOWS for SW catch areas, topo, geol & hydro maps, reports
Select Assessment Year(s)	Hg/Hy, Ec & SR	• design drought • other year • hydrological scenario	Section 1.3.2	Rainfall, river flow & abstraction data availability	Reports, Hydrolog, IoH hydrometric registers, MORECS eff rainfall
Conceptual Understanding	Hg/Hy & SR	• Qualitative description of processes & issues	Section 3	Trends in flows, GW levels, abstraction, concerns	Reports, Hydrolog, staff knowledge
Collating Abstraction and Discharge Data for Management Scenario	Tec/Hg/Hy/LO	• Licensed • Actual • Deployable output • Future scenario	Sections 1.3.4 & 2.4	Licence rates/controls/ abs &STW locs, abs returns, consumptiveness & utilisation assumptions	NALD, reports, discharge consent & abs. returns databases
Setting Target Flows	Hg/Hy, LO, SR & Others (Technical & Consultative)	• Set 12 monthly flow targets	Sections 1.3.6 & 4,5	env. values, eco. objectives, prot. rights, GW qual. data	NALD, reports, consultation, SWALP assessments
Estimating Groundwater Abstraction Impacts **(Optional)**	Hg/Hy & SR	• GW flow models • IGARF spreadsheets • other assumptions for aquifer storage effects	Sections 1.3.4 & 4,5,7,8	Abs rates, month of pumping, aquifer params, distance from river, cons..& utilisation assumptions	Pumping test reports, staff knowledge, GW catch maps, Aq. Properties Man
Collating Gauged River Flow Data **(Optional)**	Tec/Hg/Hy	• Calculate 12 monthly averaged flows	Section 7	Monthly river flow data for specified year only	Hydrolog, reports
Estimating Natural Outflows from Effective Rainfall **(Optional)**	Hg/Hy & SR	• ARF Method • Micro LOW FLOWS • other	Section 7	10 yrs. monthly eff rain data, SW &GW catch areas, recharge runoff split & aquifer params river location	MORECS, Aq. Properties Man. Staff knowledge, planimetered sketch plans Micro LOW FLOWS
Investigating Alternative Assumptions or Scenarios **(Optional)**	Hg/Hy, Ec &S R	• Consider other GWABS impact assumptions, scenarios or targets	Section 8	No new information	N/A
Interpreting Results and Sustainability Status	Hg/Hy, LO, SR & Others (Technical & Consultative)	• Interpret surplus/deficit profile	Section 6	Awareness of regional & national context	National reports & previous assessments
Final Approval	RWRM	• Regional policy decisions	Section 6	No new information	N/A

* RWRM=Reg. Wat. Res. Manager, SR=Senior Reviewer, Hy=Hydrologist, Hg=Hydrogeologist, Ec=Ecologist, LO=Licensing Officer, Tec=Technician

2.4 Data Collation and Entry on Spreadsheets

2.4.1 Pragmatic Data Collation

The key to completion of a resource assessment within the proposed framework within a reasonable period of time is to adopt a pragmatic approach towards data collation. Provided assumptions and uncertainties are clearly documented, the user is encouraged to prioritise data collation efforts to focus attention on the most significant components of the local hydrological cycle and to avoid unnecessary detail.

The ready availability of data should be an important criteria in the choice of the assessment year. Brief consultation between hydrologists, hydrogeologists and licensing officers at an early stage can suggest valuable short cuts to the process by identifying previous studies or reporting exercises (e.g. associated with AMP3 or groundwater model development) which have already collated much of the required data. The spreadsheets require most data sets to be entered as twelve monthly averaged flows for the specified year, expressed as Ml/d. This corresponds with the reporting frequency required for abstraction returns but means that daily river flow data will need to be averaged for each month (or exported from Hydrolog as monthly averages). Given the uncertainties associated with many of the components of the hydrological cycle, the use of decimal places should be avoided when quoting these monthly averaged Ml/d data as this may suggest a misleading degree of precision.

National Agency guidelines on data collation for gauged flow naturalisation should be referred to but users are encouraged to enter 'first-pass' estimates of abstraction and discharge impacts into the spreadsheets at an early stage (e.g. based on total licensed amounts rather than on estimated actual abstraction). The spreadsheets combine these initial impact estimates with river flow data as stacked histograms which help to highlight the more significant data sets where time spent on a more sophisticated approach may be worthwhile.

2.4.2 Spreadsheet Formats, Audit Trails and Uncertainty

The Excel spreadsheets described in Sections 3 to 7 have been designed to facilitate data entry, checking and visualisation. Extracts from an example RIV.XLT spreadsheet are shown on Figure 2.2 to illustrate data entry formats, audit trails, plotting formats and the incorporation of uncertainty, as discussed below.

Spreadsheet cells are formatted according to the origin of the information displayed in them as follows:

- Pale yellow cells without borders are unprotected for the user to enter information or data. When pasting data into these cells from other spreadsheets it is usually advisable to use the *'paste special - values'* option as this will ensure that the existing formats of the ARM spreadsheets are retained.
- Pale green cells with light borders are write protected and present calculation output derived from data in the same worksheet.
- White cells with bold borders are write protected and present calculation output derived from another worksheet within the same workbook.

The remaining cells within the main calculation are also write protected and contain notes and information to summarise the steps and help the user to enter data correctly. The main calculation can be viewed and followed by scrolling up or down within one screen width and will print onto a series A4 portrait pages with headers which display the file and sheet names, the page number, and the print date. Columns immediately to the right of the main calculation have been formatted to provide convenient input data storage for up to three alternative scenarios. These scenarios can be investigated by copying the stored data into the main calculation cells (see Section 8). Columns further to the right of the spreadsheets have been left unprotected so that they may be used for notes or preparatory calculations.

Auditable data trails are essential to ensure that the assessment process is transparent and robust and to enable conclusions to be traced back to the information and assumptions on which they have been based. Most of the preparatory calculations required (e.g. to derive natural river flows, set target flows, combine abstractions from the Assessment Area or predict the impacts of these abstractions) are not shown within the main calculation. They may be carried out in the unprotected part of the spreadsheet, or be taken from other paper calculations or reports. In all cases cells have been allocated in the main calculation to record the source of the information used and to summarise the assumptions adopted (Figure 2.2).

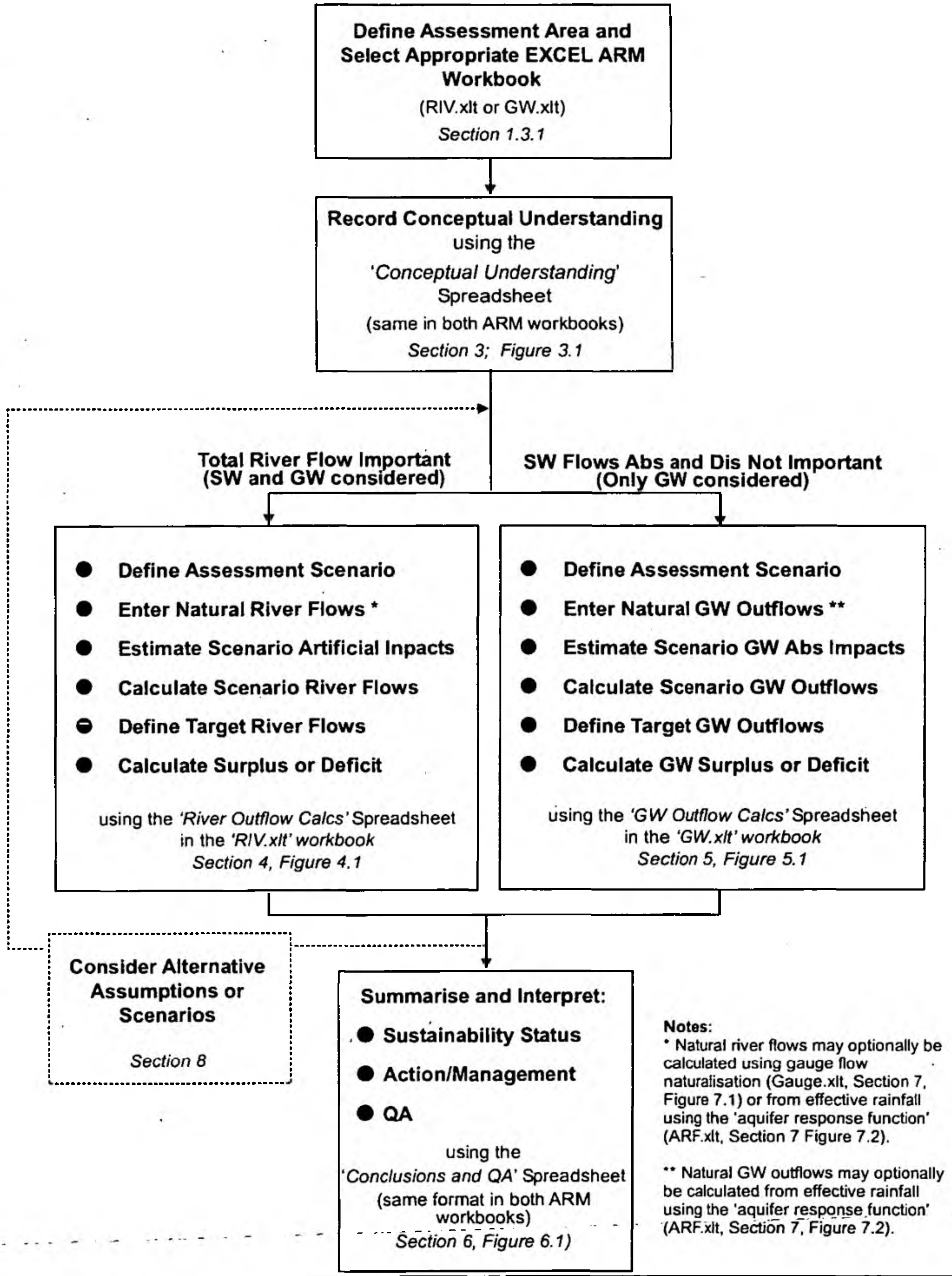
In both river (RIV.XLT) and groundwater only (GW.XLT) assessments calculations start with the definition of natural monthly flows. The user can optionally derive these by a number of alternative approaches and then enter them into the spreadsheet. These alternatives are plotted as line-and-symbol graphs (together with average and minimum flow values) which can be compared and adjusted as required before selecting one series to carry forward into the assessment (Figure 2.2).

Thereafter the basic method of visualising data entered and calculation results is the 12 month flow histogram. Some plots include adjacent histogram series e.g. to facilitate comparison between natural, scenario and target flows (Figure 2.2).

In order to take account of uncertainty however, a ± % level of confidence associated with each of the data sets is required. This level of confidence should be a 'best judgement' value based on discussion with colleagues, knowledge of possible measurement errors and the perceived uncertainty associated with any calculation assumptions adopted. The % specified is simply multiplied by the average annual flow rate for that data set to derive an associated ± error bar expressed in Ml/d. These error bars are accumulated in any subsequent combination of these data sets (by subtraction or addition) so that results can be presented with some indication of uncertainty in the form of box and whisker plots rather than as histograms which may suggest an unrealistic degree of confidence. Figure 2.2 includes a surplus/deficit profile plotted in both histogram and box and whisker format (and further examples are shown in Figure 1.2 and 1.3).

This is a simple approach to uncertainty. It relies on user judgement and focuses attention on the key data sets where monthly flows are proportionately high. It also requires the user to interpret the final calculation outputs within the context of compounded uncertainty and should help to prioritise further investigation and monitoring to reduce this uncertainty.

A further feature of the spreadsheets which should help to prioritise data collation effort and management intervention is the integration of scenario flows (e.g. river flows) and impacts (e.g. SW Abs, GW Abs and SW Dis impacts) into a single stacked histogram plot. Flows for this plot are drawn both as Ml/d (as in Figure 2.2) and also as equivalent mm/month by dividing by the surface water catchment area (for river assessments) or the groundwater catchment area (for groundwater assessments). These latter plots are useful for comparing the resources of different assessment areas. For river assessments differences between the mm/month plots may reflect variations in effective rainfall or in the relative size of the groundwater catchment area, as well as differences between the artificial flow impacts.



Notes:

* Natural river flows may optionally be calculated using gauge flow naturalisation (Gauge.xlt, Section 7, Figure 7.1) or from effective rainfall using the 'aquifer response function' (ARF.xlt, Section 7 Figure 7.2).

** Natural GW outflows may optionally be calculated from effective rainfall using the 'aquifer response function' (ARF.xlt, Section 7, Figure 7.2).

FIGURE 2.1 OVERVIEW FLOW DIAGRAM OF ARM SPREADSHEETS

Drawing No: 02019-01.S023 Date: MARCH 2000 Scale: NTS

SPREADSHEET HEADER INFO **AVAILABLE RESOURCE METHODOLOGY (ARM)**

Assessment for Areas which Drain to a River Outflow (protected worksheet)

Area: Example River at a Gauging Station | ID: ? | Version: 1 | Ledger Rev.: 1 | Date: 19/8/99

ENTERING ALTERNATIVE NATURAL RIVER FLOW AND % ERROR ESTIMATES AND CALCULATION REFERENCES

	Methods and Calculation References		Select One type 'x'		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	% Err.
a.	*Gauge* Sheet Results	ref: Gaugeegeglta.xls	x	Ml/d	170	72	278	290	259	226	168	130	96	82	72	107	143	197	6
b.	*ARF* Sheet Results	ref: ARFegeglita.xls		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	8
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	4

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

SELECTING THE NATURAL FLOW ESTIMATE TO CARRY FORWARD

Selected 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	170	72	278	290	259	226	168	130	96	82	72	107	143	197	10

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

SETTING TARGET RIVER FLOWS IN COMPARISON WITH NATURAL AND SCENARIO FLOWS

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

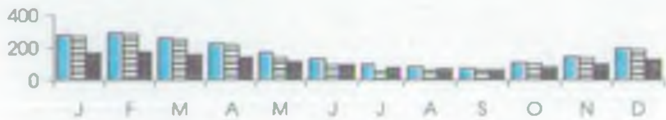
Calc/Authorisation Ref: jo bloggs

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	278	290	259	226	168	130	96	82	72	107	143	197	
Scenario River Flow, 153 Ml/d	153	56	270	282	250	216	137	92	56	59	62	99	135	189	
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	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

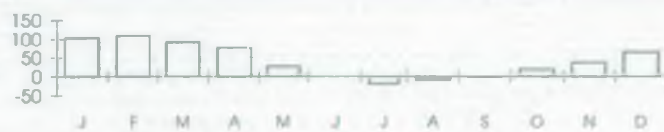
Ref: ih yearbook gauge Q95, 1962-95



CALCULATED SURPLUS OR DEFICIT HISTOGRAM AND ACCUMULATED UNCERTAINTY PLOTS

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, 41 Ml/d	41	-19.2	104	110	93	76	26	0	-19	-9	-1	19	37	63	22
Surplus or Deficit as % of Natural River Flow	24		37	38	36	34	15	0	-20	-11	-1	17	26	32	



Same surplus/deficit plot with combined error bar of +/- 22 Ml/d

Over the Whole Year,

$$\frac{\text{Annual Average Surplus or Deficit}}{\text{Annual Average Natural River Flow}} = 24\%$$

and minimum = -20%

PLOTTING SCENARIO FLOWS AND IMPACTS AS A STACKED HISTOGRAM

FIGURE 2.2 EXTRACTS FROM ARM SPREADSHEET ILLUSTRATING DATA ENTRY CALCULATION AND PLOT FORMATS

Drawing No: **02019-01.S024** Date: **MARCH 2000** Scale: **AS SHOWN**

3. *Conceptual Understanding* Spreadsheet

Any water resource assessment within the proposed framework should start with the completion of a *Conceptual Understanding* Spreadsheet. This first spreadsheet has a common format in both workbooks (RIV.XLT and GW.XLT).

This summary of the aims, format and data requirements of this spreadsheet is best read in front of a computer with a copy of any of the Excel workbooks open. Hardcopy of the trial spreadsheets are enclosed in Appendix B and Figure 3.1 is a flow diagram summarising the steps involved.

Abbreviations commonly used in the remainder of the Manual text and Figures are **SW** (surface water), **GW** (groundwater), **ABS** (abstractions) and **DIS** (discharges).

The **aims** of this spreadsheet are to:

- Delineate the Assessment Area and present a simple, qualitative conceptual understanding of its natural hydrological cycle, the relative significance of GW and SW 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 using lines and symbols which, as far as possible, are nationally consistent.

Completion of this essentially qualitative description of areas, processes, impacts and issues should prepare the user for the quantitative assessment which follows (Sections 4 or 5) as well as providing a convenient summary of understanding and perceptions which can be readily reviewed by a senior staff member with local experience. It should also provide an easy introduction for Agency staff who have no local knowledge and a useful stepping stone toward the conceptual model development required for more detailed distributed modelling.

Some of the Guidance Notes which follow have also been summarised on the spreadsheet itself.

Step 1: Area Definition, Boundaries and Surface Drainage

Having read Section 1.3.1 on Assessment Area delineation, draw a simple sketch plan with features traced from a map so that the sketch can be used to calculate areas if required. The plan may be hand drawn or in digital format and may be based on existing GIS map layers. A windows metafile (.wmf) can optionally be imported into the third page of the *Conceptual Understanding* spreadsheet itself although this will increase the memory demand of the Excel file and may consequently slow down its operation. The plan should include (as relevant): Area boundaries; SW and GW catchment boundaries as you think they were before abstraction; geological boundaries; the coast; named rivers flowing in and out; named gauging stations; names of surrounding Assessment Areas; major SWDIS, SWABS and GWABS; key wetlands;

urban areas; tidal limits etc. Many of these features may already have been summarised on previous report figures.

The use of the standard line and symbol formats and colours provided in the Key is encouraged to facilitate national comparability.

Define the Assessment Area in words beneath the sketch. e.g. "SW and natural GW catchment to the Melford gauging station on the River Thet", or "natural Chalk GW catchment to the coast from Littlehampton to Brighton".

Enter an Assessment Area name at the top of the spreadsheet (e.g. "R Thet at Melford gauge") together with identification, version and revision numbers and date. These are carried through to the other spreadsheets in the workbook.

Step 2: Geology of the Area and Schematic Cross-Section
State the main geological formation in the Area, indicate whether this is a Solid or Drift formation and whether it is an aquifer or not. If it is not an aquifer and GW is not significant, go straight to Step 5 (i.e. skip Steps 3 and 4).

Define the overlying and underlying formations and, if appropriate, illustrate with a schematic cross section (either hand drawn, or digitally imported in .wmf format).

Figures 9.2 and 9.3 include example sketch plans and schematic sections from two of the ARM trial areas.

Step 3: Recharge and Groundwater – Surface Water Interaction
Summarise the aquifer condition (confined/unconfined/mixed).

Summarise the recharge processes considered to be relevant (direct recharge/stream leakage/mains supply leakage/Drift 'recharge reduction and smoothing') and define the areas over which these processes occur on the sketch plan.

Indicate the speed at which the river baseflow or GW outflow responds to recharge (on an approximate scale from 'year' to 'day').

Indicate the degree of hydraulic connection between GW and rivers (on an approximate scale from 'poorly' to 'well' connected). Indicate the extent to which river flows are dependent on GW baseflows and whether this has changed from the 'natural' state. Add conceptual GW-SW detail to the schematic geological cross section as appropriate.

Step 4: Hydrogeological Boundaries and Groundwater Flow
Indicate whether there are significant GW flows into or out of the area and show these on the sketch plan.

Describe any barriers to groundwater flow or significant transmissivity variations within the area and show these on the sketch plan or schematic cross section as appropriate.

Describe any water quality issues which constrain groundwater abstraction (e.g. nitrates, saline intrusion etc) and show these on the sketch plan as appropriate.

Step 5: Hydrological Trends and Environmental Concerns

Provide a qualitative indication of general trends (falling/steady/rising/mixed) in GW levels, river flows, GWABS and SWABS during two time periods: 'natural' conditions to 1970, and 1970 to present. The trends before 1970 may be perceptions based on anecdotal information – there is space to comment on variations, assumptions and information sources.

Rank the existing anthropogenic influences on the hydrological cycle of the area (GWABS, SWABS and SWDIS) according to their flow rates:

e.g. 'GWABS>>SWABS>>SWDIS' or 'SWABS~SWDIS>>GWABS'

Indicate whether there are any other significant artificial influences on natural flows (e.g. surface water reservoirs, bulk water transfer schemes etc)

Summarise the main water resources related environmental concerns in the Area (river flows/wetlands/salinity/other) and describe these. Indicate perception of the problems by interested parties (e.g. the public, English Nature, water companies etc) as well as by the Agency.

Step 6: Previous Studies and Reasons for this Assessment

List previous studies carried in for the Area and explain the rationale behind the assessment being undertaken (e.g. 'to review sustainability as part of AMP4 planning', 'in advance of a licence determination', 'in preparation for distributed modelling' etc).

After summarising the concepts involved the user moves on to enter data into the Calculation spreadsheet. Depending on the delineation of the Assessment Area, and therefore the Excel template chosen for the calculations, guidance notes for these calculations follow in:

- Section 4 (*River Outflow Calcs* in RIV.XLT), or
- Section 5 (*GW Outflow Calcs* in GW.XLT).

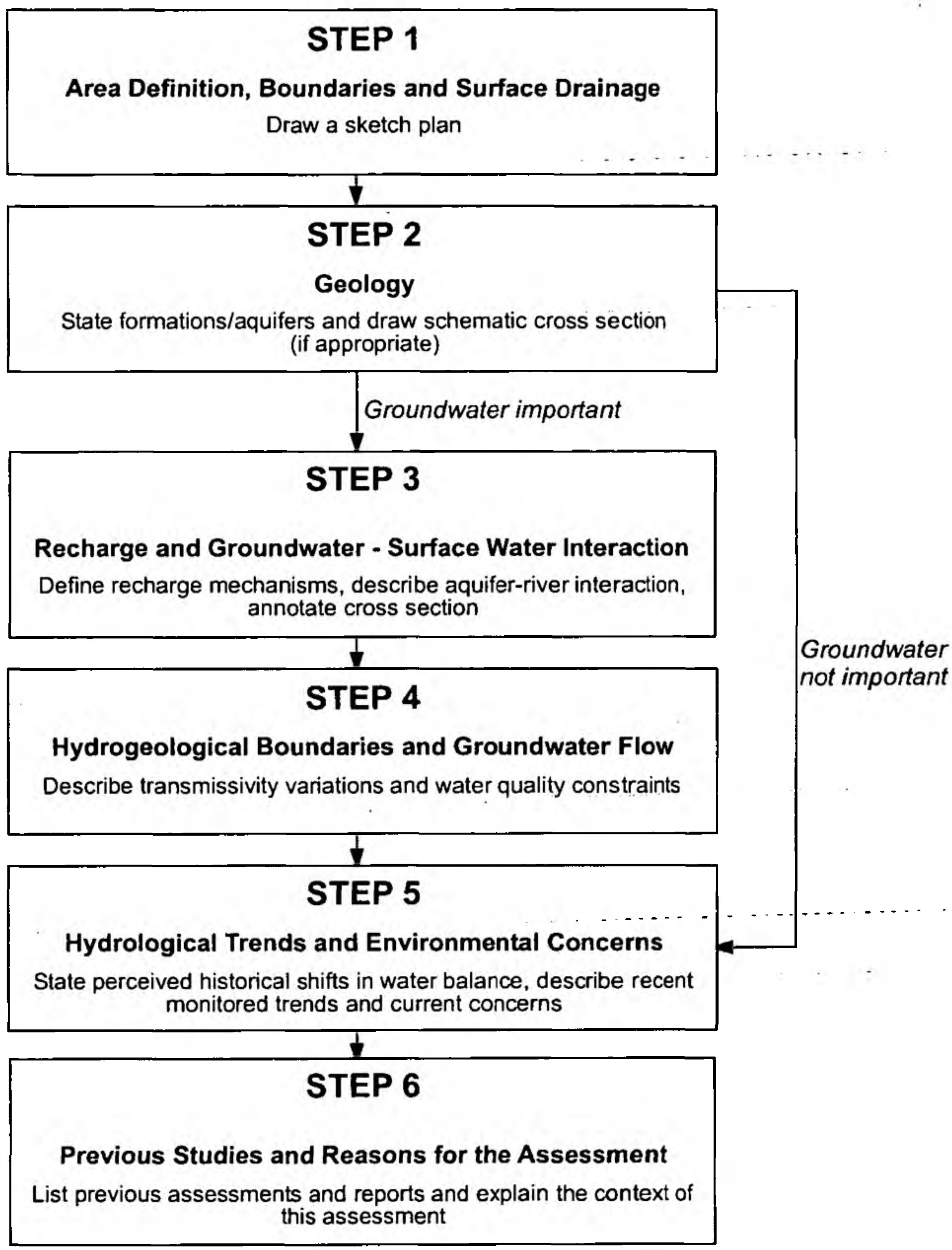


FIGURE 3.1 USING THE '*CONCEPTUAL UNDERSTANDING*' SPREADSHEET

Drawing No: **02019-01.S025** Date: **MARCH 2000** Scale: **NTS**

4. *River Outflow Calcs* Spreadsheet in RIV.XLT

Having recorded a qualitative conceptual understanding of the Area the next task is to enter quantitative data for a specified assessment year into the River or GW calculation spreadsheets.

This summary of the aims, format and data requirements of these spreadsheets is best read in front of a computer with a copy of the relevant Excel workbook open. Hardcopies of the worked example spreadsheets described in Section 9 are enclosed in Appendix B. Flow diagrams summarising the steps involved for each spreadsheet together with illustrative 12 month plots (for an idealised series of 12 average month flows) are included on Figures in this manual.

The aims of both the River and GW spreadsheets are the same for a specified assessment year:

- To define natural flows from the Assessment Area;
- To define the abstraction and discharge management scenario being assessed;
- To calculate the scenario flows from the Assessment Area;
- To enter target flows and thereby calculate the surplus or deficit profile for the specified year;
- To calculate the total acceptable abstraction impact profile for the specified year;
- To combine estimated scenario flows and artificial flow impacts in stacked histogram plots.

The results from these sheets, are carried forward to the *Conclusions and QA* spreadsheet (see Section 6) which, like the *Conceptual Understanding* spreadsheet, has a common structure in both Excel templates.

The guidance provided on pragmatic data collation, data entry formats, uncertainty and audit trails in Section 2.4 is not repeated here. Thus the instruction to 'enter data' should be viewed as shorthand for 'enter the data, and its associated uncertainty, and the auditable data source and calculation assumptions'. **In order to facilitate data entry, all workbooks have been set to perform calculations manually i.e. only when the F9 key is struck.**

There are many similarities in the calculation steps in both spreadsheets. However, guidance notes are comprehensive for each and no attempt has therefore been made to avoid repetition.

The calculation steps for ***River Outflow Calcs*** described below are summarised on Figure 4.1.

Step 1: State Surface Water Catchment Area
Enter the surface water catchment area to the assessment point on the river in square kilometres. This area is only used in the calculation of 'equivalent effective rainfall' from natural river flows (at Step 3) and in deriving the mm/month stacked histogram plots presented at Step 12.

Step 2: Specify Assessment Year
Having read Section 1.3.2, state the calendar year or hydrological scenario chosen for the Assessment. Briefly indicate the reason for the selection (e.g. 'severe drought', 'climatically average year', 'equivalent to deployable output scenario', etc.).

Step 3: Estimate Natural River Flows
Enter one or optionally more (up to four) estimates of monthly average natural river flows for the assessment year. These may be derived from gauge flow naturalisation (optionally using the GAUGE.XLT template described in Section 7), using microLOWFLOWS or other standard hydrological tools or techniques, using more sophisticated regional models or from simple effective rainfall - river flow modelling (e.g. using the ARF.XLT template described in Section 7).

Compare and review these estimates, particularly considering the minimum and average natural flows they suggest, and revise them as required to reconcile any differences in conceptual understanding they imply. Select one natural flow series to carry forward into the assessment by typing an 'x' next to the chosen approach. On striking F9 the selected series will appear as a histogram plot of natural river flows and the 'equivalent annual effective rainfall' will be calculated as the natural flow divided by the surface water catchment area.

Step 4: Estimate Natural Baseflows (Optional)
If a separate estimate of groundwater resources is required, enter one or optionally more (up to three) estimates of natural river baseflows. These are not associated with separate flow protection targets (river assessments are for total resources integrating both groundwater and surface water) but, if specified, baseflows are compared separately with GW Abs impacts in Step 11.

Baseflow estimates may be derived by baseflow separation of a daily gauged hydrograph, from a groundwater model or other appropriate technique, optionally including the ARF.XLT calculations described in Section 7. A single baseflow series is selected to carry forward which, on striking F9, will appear as a separated part of the previously defined total natural river flow histogram. An 'equivalent annual recharge' is also calculated by dividing this baseflow series by the surface water catchment area.

At this stage any discrepancies between the selected total flow and baseflow series should be resolved.

Step 5: Define the Abstraction and Discharge Scenario and Estimate its Flow Impacts
Define the assumed scenario on which abstraction and discharge impact estimates will be based (see Section 1.3.4). In any assumed scenario it is important to consider the consumptiveness of each abstraction source taking into account local returns to the catchment. Public water supply sources should be considered as being fully consumptive because sewage treatment works returns or bulk transfer discharges are considered separately. This approach allows any transfers of mains supply water into or out of the Area to be taken into account.

At Step 5.1 enter the 12 monthly consumptive abstraction rates for all surface water sources in the area. These are assumed to have an 'instant' (i.e. within the same month) impact on the natural river flows from the area.

At Step 5.2a enter the 12 monthly consumptive abstraction rates for all groundwater sources considered to impact river flows at the assessed point. These cannot be assumed to impact flows in the month of abstraction – impacts may be smoothed and lagged depending on source proximity to the river, aquifer properties, timing of abstraction and recharge, relationship between the river and groundwater levels etc.

For this reason, at Step 5.2b separately enter the 12 monthly groundwater abstraction impacts on river flows in the specified year. Alternative GW abstraction impact assumptions can be readily investigated, as discussed in Section 8.1.

At Step 5.3 enter the 12 monthly discharge rates for all sewage treatment works or river support discharges within the Assessment Area. Discharge rates for sewage treatment returns should be based on consented dry weather flows rather than including storm flows as subsequent calculations assume that they represent the return of mains supply water only to the river.

The defined management scenario is summarised in Step 5.4 by plotting a stacked histogram of +SWABS impacts (Step 5.1), +GWABS impacts (Step 5.2b) and -SWDIS impacts (Step 5.3). These are added together to define a single series of 'Net Consumptive Abstraction Impacts' plotted in Step 5.5.

Step 6: Calculate Scenario River Flows

Scenario river flows are calculated by subtracting the net abstraction impacts (Step 5.5) from the natural flows (Step 3) and are plotted next to these natural flows.

Step 7: Set Target River Flows

Enter 12 monthly averaged environmental river flow protection targets below the natural and scenario flow estimates which are carried forward and re-plotted for comparison.

Target flows can optionally be defined as two components - a minimum flow specified for each month plus a proportion of the natural flow above this. In the spreadsheet (in line with the similar SWALP based approach) a single percentage is entered defining the proportion of natural flow above the minimum that it is considered acceptable to abstract. If set to 0%, the target flow will equal the natural flow. If set to 100%, the target flow will equal the defined monthly minimum flow.

If available the gauged Q95 flow (e.g. taken from standard Agency or IoH statistics) can be recorded here for comparison with the target flows entered. The process of setting target flows should involve discussion between ecologists, hydrologists and hydrogeologists. A simple, year-round Q95 protection target may be adopted or seasonal variability may be incorporated – see Section 1.3.6 for possible approaches. Documentation of these target flows, however derived, should be referenced on the spreadsheet together with a summary of the reasoning behind them and an associated uncertainty. One strength of using ARM spreadsheets is that the implications of adopting different flow protection targets can be readily investigated (see Section 8).

The remaining calculation Steps 8 to 12 require no further information to be entered to the spreadsheet.

Step 8: Calculate Surplus or Deficit

The monthly surplus or deficit flows are calculated by subtracting the target river flows (Step 7) from the scenario river flows (Step 6) for the specified year. These surpluses or deficits are plotted as a 12 month histogram and as a box and whisker plot incorporating the combined uncertainties associated with both scenario and target flows. They are carried forward as headline results to the *Conclusions and QA* spreadsheet together with the average and minimum surplus or deficit percentages calculated as a proportion of natural flows (see Section 6).

Step 9: Calculate Total Acceptable Abstraction Impacts

The 12 monthly acceptable abstraction impacts for the specified year are calculated by adding existing surplus or deficit (Step 8) to scenario abstraction impacts (Step 5.4). These acceptable impacts are presented as a 12 month histogram and as a box and whisker plot incorporating the combined uncertainties associated with all the preceding data and calculations. They are carried forward as headline results to the *Conclusions and QA* spreadsheet (see Section 6).

Step 10: Plot Scenario Flows and Impacts as a Stacked Histogram in Ml/d

Previously calculated scenario river flows, SWABS, GWABS and SWDIS impacts are combined into a stacked histogram plot. This plot also includes the annual average flow rates for each component and for the natural river flow in the legend.

Step 11: Natural Baseflow Minus Groundwater Abstraction Impacts

If baseflow has been separately specified at Step 4, the GWABS impacts on river flows entered at Step 5.3b are subtracted from it. The resulting difference is represented both as a histogram and as an uncertainty plot to provide a separate indication of the extent of groundwater resource commitment.

Step 12: Plot Scenario Flows and Impacts as a Stacked Histogram in mm/month

This plot expresses the scenario flow and impact components as mm per month over the surface water catchment area. Each flow component and the natural flow are summarised as mm per year totals in the legend for the stacked histogram. The net scenario abstraction impact for each month as calculated in Step 5.5 is also expressed as a percentage of the natural flow in the month. The maximum percentage abstraction impact is identified together with the month in which it occurs and these results are carried forward to the *Conclusions and QA* spreadsheet.

In this final Step, the user may optionally choose to consider the scenario flows and impacts for a discrete lower reach of the total river catchment which has been the subject of most of the ARM assessment. This can be achieved by adding up scenario flows and impacts derived from assessments of all the upstream parts of the catchment which are to be excluded and pasting these values, together with the excluded surface water catchment area, into the data entry cells in Step 12.

Principal Steps

Step 1: Define Assessment Area & Record Conceptual Understanding

Step 2: Specify Assessment Year or Hydrological Scenario

Step 3: Estimate Natural River Flows

Step 4: Estimate Natural Baseflows (optional)

Step 5: Estimate Artificial Flow Impacts of Scenario being Assessed

Step 6: Calculate Scenario River Flows

Step 7: Define Target River Flows

Step 8: Calculate Surplus or Deficit & Express as Av & Min % of Natural Flows

Optionally repeat for a different year, review & assign **Sustainability Status**

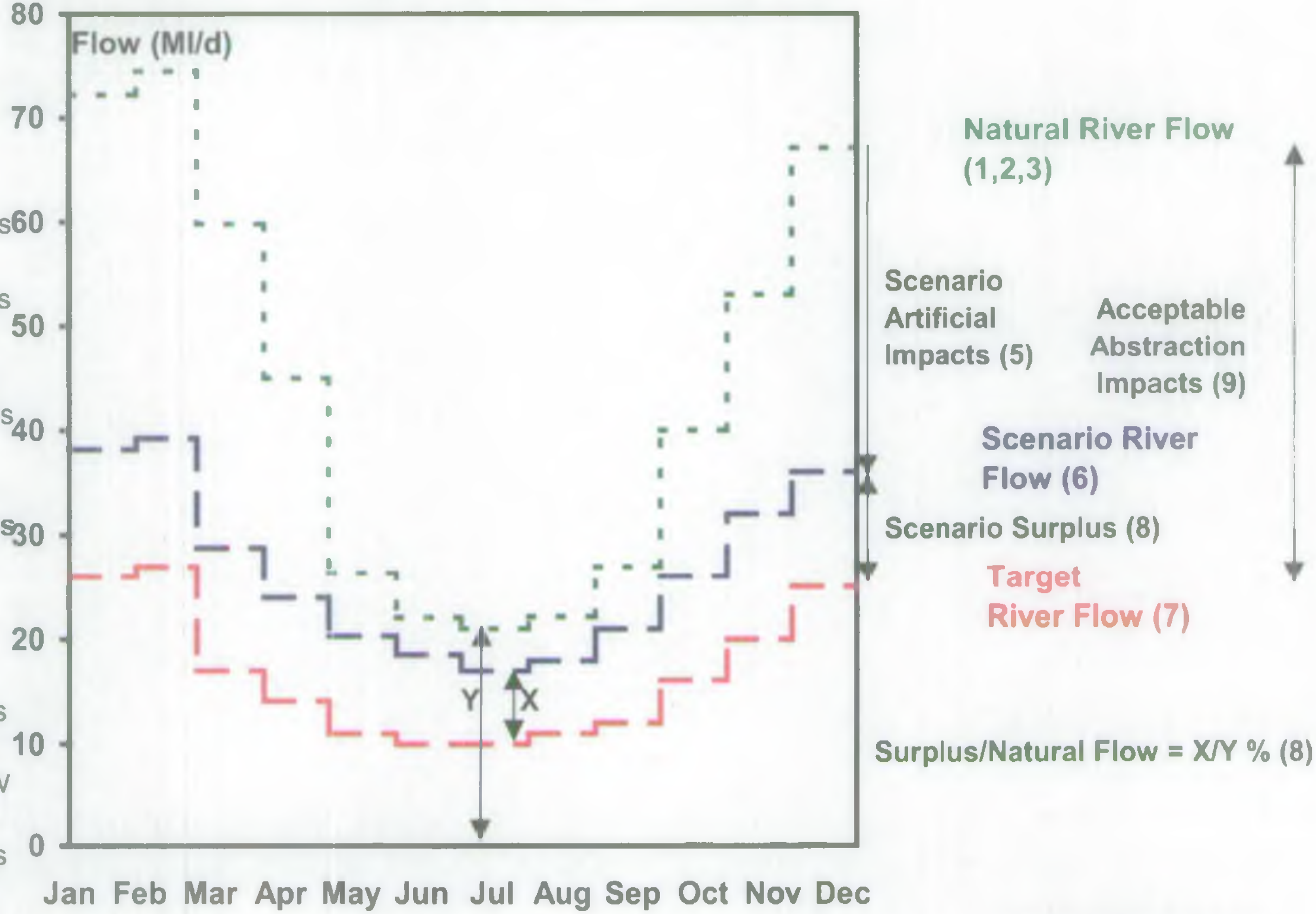
Other Steps Provided are:

9: Calculate Acceptable Abstraction Impacts

10: Plot Scenario Flows and Impacts as Stacked Histograms in Ml/d

11: Compare Natural Baseflow with GW Abstraction Impacts

12: Plot Scenario Flows and Impacts as Stacked Histograms in mm per month



file: 02019\drawings\figs.xls, sheet: Fig 4.1 River Calcs

FIGURE 4.1 USING THE *'RIVER OUTFLOW CALCS'* SPREADSHEET

Drawing No: **02019-01.S026** Date: **MARCH 2000** Scale: **AS SHOWN**

5. *GW Outflow Calcs* Spreadsheet in GW.XLT

Having recorded a qualitative conceptual understanding of the Area the next task is to enter quantitative data for a specified assessment year into the River or GW calculation spreadsheets.

This summary of the aims, format and data requirements of these spreadsheets is best read in front of a computer with a copy of the relevant Excel workbook open. Hardcopies of the worked example spreadsheets described in Section 9 are enclosed in Appendix B. Flow diagrams summarising the steps involved for each spreadsheet together with illustrative 12 month plots (for an idealised series of 12 average month flows) are included on Figures in this manual.

The aims of both the River and GW spreadsheets are the same for a specified assessment year:

- To define natural flows from the Assessment Area;
- To define the abstraction and discharge management scenario being assessed;
- To calculate the scenario flows from the Assessment Area;
- To enter target flows and thereby calculate the surplus or deficit profile for the specified year;
- To calculate the total acceptable abstraction impact profile for the specified year;
- To combine estimated scenario flows and artificial flow impacts in stacked histogram plots.

The results from these sheets, are carried forward to the *Conclusions and QA* spreadsheet (see Section 6) which, like the *Conceptual Understanding* spreadsheet, has a common structure in both Excel templates.

The guidance provided on pragmatic data collation, data entry formats, uncertainty and audit trails in Section 2.4 is not repeated here. Thus the instruction to 'enter data' should be viewed as shorthand for 'enter the data, and its associated uncertainty, and the auditable data source and calculation assumptions'. **In order to facilitate data entry, all workbooks have been set to perform calculations manually i.e. only when the F9 key is struck.**

There are many similarities in the calculation steps in both spreadsheets. However, guidance notes are comprehensive for each and no attempt has therefore been made to avoid repetition.

The calculation steps for ***GW Outflow Calcs*** described below are summarised on Figure 5.1.

Step 1: State Groundwater Catchment Area

Enter the recharge catchment area to the GW outflow boundary being assessed in square kilometres. This area is only used in the calculation of 'equivalent mm/a' from natural GW outflows (at Step 3) and in deriving the mm/month stacked histogram plots presented at Step 12.

Step 2: Specify Assessment Year

Having read Section 1.3.2, state the calendar year or hydrological scenario chosen for the Assessment. Briefly indicate the reason for the selection (e.g. 'severe drought', 'climatically average year', 'equivalent to deployable output scenario', etc.).

Step 3: Estimate Natural GW Outflows

Enter one or optionally more (up to four) estimates of monthly average natural GW outflows for the assessment year. These may be derived from estimated hydraulic gradients and assumed aquifer properties, using baseflow separation techniques or more sophisticated regional models or from recharge - baseflow analytical functions (e.g. using the ARF.XLT template described in Section 7).

Compare and review these estimates, particularly considering the minimum and average natural flows they suggest, and revise them as required to reconcile any differences in conceptual understanding they imply. Select one natural flow series to carry forward into the assessment by typing an 'x' next to the chosen approach. On striking F9 the selected series will appear as a histogram plot of natural groundwater outflows and the 'equivalent mm/a' will be calculated as the natural flow divided by the GW catchment area.

Step 4: Estimate Recharge Inflows (Optional)

If a separate, inflow based estimate of groundwater resources is required, enter one or optionally more (up to three) estimates of monthly recharge. These are not associated with separate flow protection targets (all ARM assessments focus on outflow-based resource estimates and targets) but, if specified, recharge is compared separately with GW Abstractions as pumped in Step 11.

Recharge estimates may be MORECS effective rainfall based or may be derived from soil moisture balance or recharge models. A single recharge series is selected to carry forward which, on striking F9, will appear as a monthly flow histogram. An 'equivalent annual recharge' in mm/a is also calculated by dividing the total recharge flow by the GW catchment area.

At this stage any discrepancies between the selected GW outflow and recharge (or inflow) based estimates of GW resources should be resolved.

Step 5: Define the GW Abstraction Scenario and Estimate its Flow Impacts

Define the assumed scenario on which GW abstraction impact estimates will be based (see Section 1.3.4). In any assumed scenario it is important to consider the consumptiveness of each abstraction source taking into account local returns to the groundwater. Public water supply sources should be considered as being fully consumptive because sewage treatment works returns or bulk transfer discharges are not returned to groundwater. Surface water abstractions and discharges are ignored in this 'GW only' assessment.

At Step 5a enter the 12 monthly consumptive abstraction rates for all groundwater sources considered to impact GW outflows. These cannot be assumed to impact outflows in the month of abstraction – impacts may be smoothed and lagged depending on source proximity to the outflow boundary, aquifer properties, timing of abstraction and recharge, etc.

For this reason, at Step 5b separately enter the 12 monthly groundwater abstraction impacts on GW outflows in the specified year. Alternative GW abstraction impact assumptions can be readily investigated, as discussed in Section 8.1.

Step 6: Calculate Scenario GW Outflows
Scenario GW outflows are calculated by subtracting GW abstraction impacts (Step 5b) from the natural GW outflows (Step 3) and are plotted next to these natural flows.

Step 7: Set Target GW Outflows
Enter 12 monthly averaged environmental GW outflow protection targets below the natural and scenario flow estimates which are carried forward and re-plotted for comparison.

Target GW flows can optionally be defined as two components - a minimum flow specified for each month plus a proportion of the natural flow above this. . In the spreadsheet a single percentage is entered defining the proportion of natural flow above the minimum that it is considered acceptable to abstract. If set to 0%, the target flow will equal the natural flow. If set to 100%, the target flow will equal the defined monthly minimum flow.

For most GW assessments (e.g. to prevent saline intrusion) a simple, year-round minimum flow target should be adequate. As GW outflows can never be directly measured further sophistication (such as the seasonal variability which may be important for river flows) is probably unwarranted. Indeed, GW outflow targets are likely to be very poorly constrained and should have large associated uncertainty which will be carried through to the conclusions of the assessment. Documentation of the target flows, however derived, should be referenced on the spreadsheet together with a summary of the reasoning behind them.

The remaining calculation Steps 8 to 12 require no further information to be entered to the spreadsheet.

Step 8: Calculate GW Surplus or Deficit
The monthly GW surplus or deficits are calculated by subtracting the target GW outflows (Step 7) from the scenario outflows (Step 6) for the specified year. These GW surpluses or deficits are plotted as a 12 month histogram and as a box and whisker plot incorporating the combined uncertainties associated with both scenario and target flows. They are carried forward as headline results to the *Conclusions and QA* spreadsheet together with the average and minimum surplus or deficit percentages calculated as a proportion of natural GW outflows (see Section 6).

Step 9: Calculate Total Acceptable GW Abstraction Impacts
The 12 monthly acceptable GW abstraction impacts for the specified year are calculated by adding existing GW surplus or deficit (Step 8) to scenario GW abstraction impacts (Step 5b). These acceptable impacts are presented as a 12 month histogram and as a box and whisker plot incorporating the combined uncertainties associated with all the preceding data and calculations. They are carried forward as headline results to the *Conclusions and QA* spreadsheet (see Section 6).

Step 10: Plot Scenario GW Outflows and Impacts as a Stacked Histogram in Ml/d
Previously calculated scenario GW outflows and GWABS impacts are combined into a stacked histogram plot. This plot also includes the annual average flow rates for each component and for the natural GW outflow in the legend.

Step 11: Recharge Minus Consumptive Groundwater Abstraction
If recharge has been separately specified at Step 4, the consumptive groundwater abstractions entered at Step 5a (as pumped) are subtracted from it. The resulting difference is represented both as a histogram and as an uncertainty plot to provide a separate inflow based indication of the extent of groundwater resource commitment.

Step 12: Plot Scenario GW Outflows and Impacts as a Stacked Histogram in mm/month
This plot expresses the scenario GW outflow and impact components as mm per month over the GW catchment area. Each flow component and the natural flow are summarised as mm per year totals in the legend for the stacked histogram. The scenario GW abstraction impact for each month, as calculated in Step 5b, is also expressed as a percentage of the natural GW outflow in the month. The maximum percentage abstraction impact is identified together with the month in which it occurs and these results are carried forward to the *Conclusions and QA* spreadsheet.

In this final Step, the user may optionally choose to consider the scenario flows and impacts for a part or sub-area of the GW catchment which has been the subject of most of the ARM assessment. This can be achieved by adding up scenario flows and impacts derived from assessments of all the areas which are to be excluded and pasting these values, together with the GW catchment area to be excluded, into the data entry cells in Step 12.

Principal Steps

Step 1: Define Assessment Area & Record Conceptual Understanding

Step 2: Specify Assessment Year or Hydrological Scenario

Step 3: Estimate Natural GW Outflows

Step 4: Estimate Recharge (optional)

Step 5: Estimate GW Abstraction Impacts of Scenario being Assessed

Step 6: Calculate Scenario GW Outflows

Step 7: Define Target GW Outflows

Step 8: Calculate GW Surplus or Deficit & Express as Av & Min % of Natural Flows

Optionally repeat for a different year, review & assign **Sustainability Status**

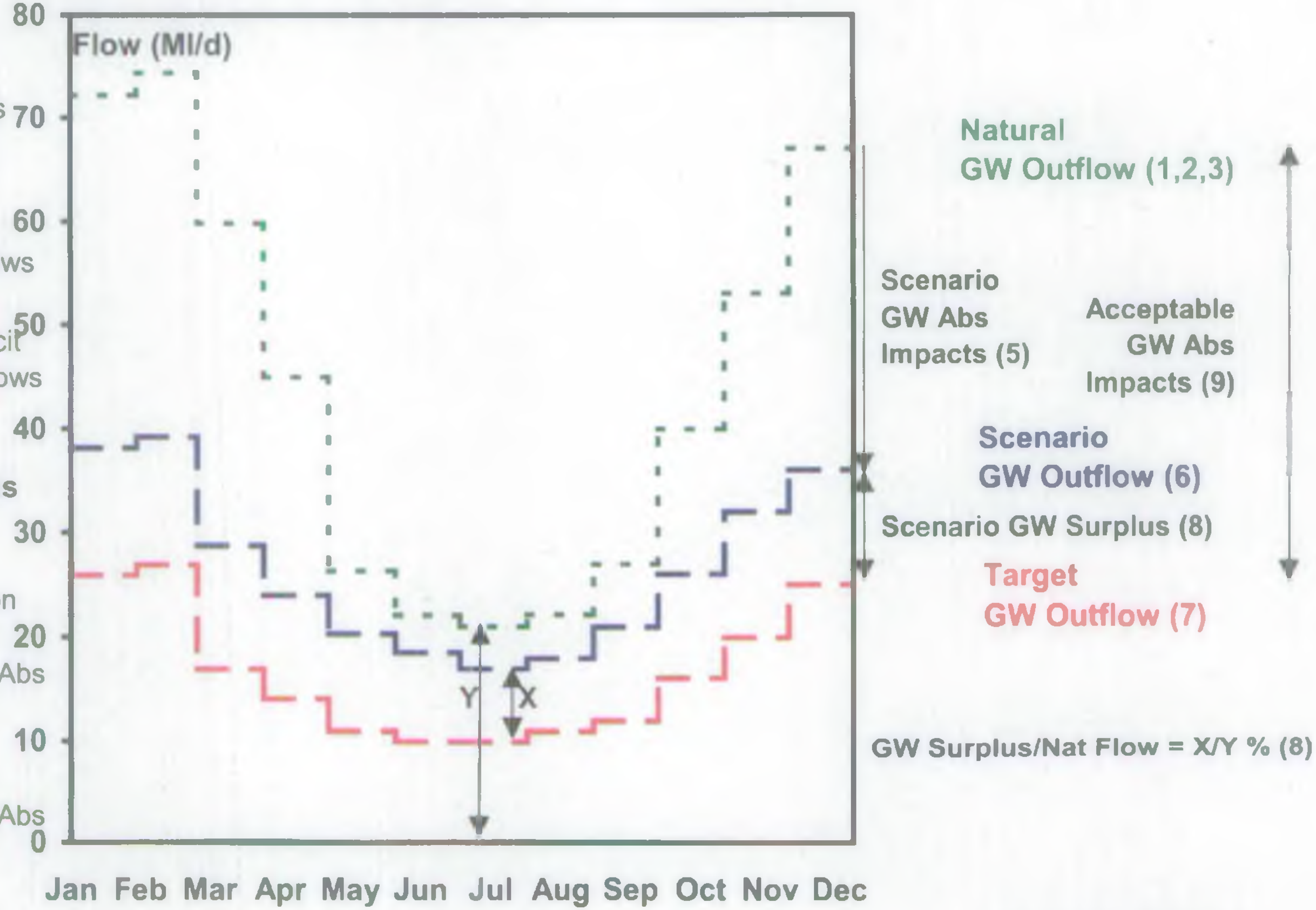
Other Steps Provided are:

9: Calculate Acceptable GW Abstraction Impacts

10: Plot Scenario GW Outflows & GW Abs Impacts Stacked Histograms in Ml/d

11: Compare Recharge with GW Abstraction as pumped

12: Plot Scenario GW Outflows & GW Abs Impacts Stacked Histograms in mm/month



file: 02019\drawings\figs.xls, sheet: Fig 5.1 GW Outflow Calcs

FIGURE 5.1 USING THE *'GW OUTFLOW CALCS'* SPREADSHEET

Drawing No: 02019-01.S027 Date: MARCH 2000 Scale: AS SHOWN

6. *Conclusions and QA* Spreadsheet

Figure 6.1 presents the steps which are common to the *Conclusions and QA* spreadsheets in both ARM Excel templates. For both types of assessment the aim of this sheet is to summarise the headline results and allow the user to interpret of the sustainability of existing abstractions and the implications for licensing policy, controls or mitigation. This spreadsheet is also where Quality Assurance records of senior review and update revisions should be made and where hardcopy authorisation by the Regional Water Resources Manager should be evident.

However, it is important to recognise that the conclusions from a river flow assessment relate to the total water resources of the river catchment whereas those from a groundwater outflow assessment relate only to the groundwater resources (surface water flows ignored).

These guidance notes are best read in front of a computer with a copy of the spreadsheet open. Hardcopies of the worked examples for the 2 trial areas described in Section 9 are provided in Appendix B.

6.1 Summarising Headline Results and Interpreting Abstraction Sustainability Status

No user inputs are required in Steps 1.1, 1.2 and 1.3 of the spreadsheet which simply summarise results from the preceding calculation spreadsheet as follows:

- Natural, scenario and target monthly flows for the specified year with average annual rate summaries;
- The artificial impact scenario (GWABS, SWABS and SWDIS impacts) combined as appropriate in a stacked histogram plot together with the maximum net abstraction impact as a percentage of natural flows, and the month in which this occurs;
- The resulting monthly surplus or deficit profile plotted with associated uncertainty and expressed as an average and minimum percentage of natural flows.

At the bottom of the first page of the *Conclusions and QA* spreadsheet (Step 1.4) the user is invited to assign a management sustainability status to the area based on a critical review of the headline results summarised above. This is an important interpretative step which recognises the judgement required to take into account all the uncertainties and assumptions involved in the calculations and the particular conditions in the assessment year (e.g. how dry it was) before deciding how much more or less abstraction should be licensed in the area. It may be useful to assess the implications of target flows and abstraction impacts in an alternative drought (or 'average') year to help make these decisions. See Section 1.3.8 and Figure 1.2 for guidance on interpreting sustainability status.

The second page of the *Conclusions and QA* spreadsheet summarises other results and plots from the assessment including the acceptable abstraction impacts profile and the mm/month stacked histogram of scenario flows and impacts. The y-axis scale of this latter plot can be fixed by region (or even nationally) to highlight resource availability differences between areas.

6.2 Interpreted Management Action Required

Based on the results presented and the interpreted sustainability status, the user is invited on page 3 of the spreadsheet (at Step 3) to state the potential for further year-round or winter only abstraction impacts, or to identify any targets for reducing impacts, as appropriate. It is important to remember that these conclusions still refer to the *impacts* of abstraction on outflows. These can only be translated directly into licensing abstraction limits or controls for surface water sources which have an 'instant' impact on outflows. Surface water abstraction licensing can be linked to gauged flow controls in order to exploit winter-only surpluses (although this will generally require the abstractor to invest in additional storage capacity).

Groundwater abstractions can only be managed in this manner in the most karstic aquifers where boreholes are close to the rivers. Practically this means that the potential for further groundwater abstraction or the need for reductions in groundwater abstraction is reflected in the minimum value of the surplus or deficit profile derived for the assessment.

Further space for comment is provided in the spreadsheets to discuss alternative ways in which outflows could be augmented in order to meet flow targets.

6.3 Review, Approval and Version Control

The final part of a water resources assessment within the ARM framework is to complete the formal records of senior review and authorisation required in Step 4 of this spreadsheet. As has already been suggested in Table 2.2 senior review inputs should not wait until the end of an assessment, they are particularly required at the earliest steps of conceptual description, but these inputs should be formally signed-off. As the conclusions may have important consequences in setting abstraction licence ceilings it is recommended that the responsibility for final authorisation should rest with the Agency's Regional Water Resources Manager.

Once an assessment has been completed to establish natural, scenario and target flows, this Version need only be reconsidered if its basic assumptions are challenged by new data or by changes in climate or environmental flow protection needs. If the assessment has indicated that critical uncertainties remain which can only be resolved by further investigations, monitoring, or a more sophisticated assessment approach (e.g. distributed modelling) then a target date and proposed action should be set.

It may be useful to update the assumed abstraction and discharge scenario in line with licensing changes. Such updates will not change estimated natural or target flows and could therefore be issued as Revisions to the current Version of the assessment.

STEP 1

Review Headline Results

- Natural, scenario and target flows
- Scenario Artificial Impacts
- Surplus or Deficit Profile
- Average and Minimum Surplus or Deficit as % of Natural Flow

↓

STEP 2

Interpret Sustainablility Conclusions and Action required

- Interpret sustainability category within regional and national context
- State how much more year-round or winter only abstraction may be permissible or by how much abstractions should be reduced

↓

STEP 3

QA Authorisation

- Record senior review and authorisation by Regional Water Resources Manager
- Record subsequent updates and revisions

FIGURE 6.1 USING THE *'CONCLUSIONS AND QA'* SPREADSHEET

Drawing No: **02019-01.S028** Date: **MARCH 2000** Scale: **NTS**

7. Optional Spreadsheets to Estimate Natural Flows

Any appropriate standard hydrological approach (or approaches) can be used to estimate the natural river flows required as a starting point for an ARM river assessment as discussed in Section 1.3.3. In some instances (e.g. where artificial impacts are small, or where large influences such as reservoirs or effluent returns have effectively become a fixed feature of the catchment) it may even be appropriate to make the simple assumption that the existing gauged flow series be taken as the natural flow series.

This Section describes two spreadsheets which have been developed to provide optional means of estimating a 12 month natural flow series with associated uncertainty which can be readily copied into the ARM spreadsheets for comparison with other estimates.

Section 7.1 presents the GAUGE.xlt spreadsheet which can be used to facilitate gauge flow naturalisation to generate a natural flow series for the *River Outflow Calcs* spreadsheet (described in Section 4).

Section 7.2 introduces the ARF.xlt spreadsheet which uses the analytical 'Aquifer Response Function' together with assumptions of the recharge/surface runoff split and the surface water and groundwater catchment areas to derive a natural flow series from monthly effective rainfall. Results from this optional 'lumped catchment response' approach can be fed into either ARM spreadsheet (*River Outflow Calcs*, Section 4 or *GW Outflow Calcs*, Section 5).

These step-by-step guides to the format and data requirements of each spreadsheet are best read in front of a computer with a copy of the relevant Excel workbook open. Hardcopies of the worked examples of these optional spreadsheets, as described in Section 9 are enclosed in Appendix B.

The guidance provided on pragmatic data collation, data entry formats, uncertainty and audit trails in Section 2.4 is not repeated here. Thus the instruction to 'enter data' should be viewed as shorthand for 'enter the data, and its associated uncertainty, and the auditable data source and calculation assumptions'. **In order to facilitate data entry, all workbooks have been set to perform calculations manually i.e. only when the F9 key is struck.**

7.1 GAUGE.xlt Spreadsheet to Naturalise Gauged Flows

The calculation steps for GAUGE.xlt described below are summarised on Figure 7.1.

Step 1: Specify Assessment Area and Year
These can be copied directly from the ARM *River Outflow Calcs* spreadsheet where the flows derived from gauge naturalisation are to be used.

Step 2: Enter Gauged Flows
Convert daily average river flows gauged at the outflow from the Assessment Area for the specified year to 12 monthly averaged flows (or simply export from Hydrolog as monthly flows) and enter at Step 2 together with reference details for the gauging station.

Step 3: Gauged Flow Naturalisation
In order to naturalise gauged flows, 'best estimates' of actual consumptive abstraction rates and discharge rates should ideally be used and Agency guidelines should be referred to. However, as discussed in Section 2.4.1, the user is encouraged to enter the most readily available 'first-pass' estimates of these artificial influences (e.g. based on fully licensed rates) early on in order to effectively prioritise the time spent in further refinement.

It is important to consider the consumptiveness of each abstraction source based on its use, taking into account local returns to the catchment. Public water supply abstractions should be considered as being fully consumptive because sewage treatment works returns are considered separately. This approach allows any transfers of mains supply water into or out of the Area to be taken into account.

At Step 3.1 enter the 12 monthly consumptive abstraction rates for all surface water sources upstream of the gauging station. These are assumed to have had an 'instant' (i.e. within the same month) impact on gauged river flows.

At Step 3.2a enter the 12 monthly consumptive abstraction rates for all groundwater sources considered to have impacted river flows at the gauging station. These cannot be assumed to have impacted flows in the month of abstraction – impacts may be smoothed and lagged depending on source proximity to the river, aquifer properties, timing of abstraction and recharge, relationship between the river and groundwater levels etc.

For this reason, at Step 3.2b separately enter the 12 monthly groundwater abstraction impacts on river flows in the specified year. Alternative GW abstraction impact assumptions can be readily investigated, as discussed in Section 8.1.

At Step 3.3 enter the 12 monthly discharge rates for all sewage treatment works or river support discharges upstream of the gauging station. Discharge rates for sewage treatment returns should be based on consented dry weather flows rather than including storm flows as subsequent calculations assume that they represent the return of mains supply water only to the river.

All these artificial impacts are summarised in Step 3.4 by plotting a stacked histogram of +SWABS impacts (Step 3.1), +GWABS impacts (Step 3.2b) and -SWDIS impacts (Step 3.3). These are added together to define a single series of 'Net Consumptive Abstraction Impacts' plotted in Step 3.5.

At Step 3.6 naturalised river flows are calculated by adding the net abstraction impacts (Step 3.5) to the gauged flows (Step 2). These flows are plotted both as a histogram and as a box and whisker uncertainty plot.

Step 4: Naturalised Flow Results Summary
The naturalised flows are summarised together with the accumulated % error associated with them so that they can be manually copied into Step 3a of the *River Outflow Calcs* spreadsheet (remember to use *paste special-values*).

Step 5: Plot Gauged Flows and Impacts as a Stacked Histogram in mm/month
This plot is included because it combines the river flows and impacts in proportion and therefore helps the user to prioritise the time needed to refine each of the data sets in the naturalisation process.

Enter the surface water catchment to the gauge (as entered in the *River Outflow Calcs* spreadsheet). This plot then expresses the gauged flow and impact components as mm per month over the surface water catchment area. Each flow component and the naturalised flow are summarised as mm per year totals in the legend for the stacked histogram.

The stacked histogram has been drawn with flows as mm per month so that the user can optionally compare the naturalised flows with independent estimates of hydrologically effective rainfall (such as those derived by MORECS) for the assessed year.

7.2 ARF.xlt Spreadsheet for Natural Flows from Monthly Effective Rainfall

Natural river flows and groundwater outflows can be estimated from monthly effective rainfall inputs and an assumed split between runoff and recharge according to hydrogeological aquifer parameters using the Aquifer Response Function (ARF). The derivation and basis of the analytical 'Aquifer Response Function' has been presented in an earlier version of this User Manual (May 1999 – full reference in Section 1.5.1).

The calculation steps in the ARF.xlt spreadsheet described below are illustrated in Figure 7.2 which shows how the natural river flow estimated from the same effective rainfall varies depending on the assumed split between recharge and runoff and on the aquifer response time..

The key simplifying assumptions to consider if using the approach provided in the spreadsheet are that:

- the % recharge, runoff, and 'karstic GW flow' splits defined by the user are assumed to be fixed throughout the year as are the GW and SW catchment areas;
- runoff and karstic GW flow are assumed to contribute to natural outflows in the same month as the effective rainfall – there are no lags or decay such as might be associated with drainage of near surface 'interflow' from drift cover. This may often be over-simplistic and may result in the underestimation of low flows because interflow processes are not represented. It may also cause discrepancies in the timing of peak monthly averaged flows if the rainfall causing the flood fell towards the end of a month;
- the ARF function used to calculate the natural groundwater outflow response to recharge is an analytical function. It simplifies the aquifer to a one dimensional strip of length L with a fully penetrating discharge boundary (e.g. a river or the coast) at one end, and transmissivity (T) and storage (S) values which are assumed

to be constant throughout the year. In practice, L is derived by dividing the area of the groundwater catchment by twice the length of the rivers or discharge boundary draining this area, as specified by the user.

The ARF is clearly a simple, linear approach which cannot take account of seasonal variations in catchment areas, runoff responses or aquifer properties. Distributed groundwater modelling can overcome many of these limitations provided an appropriate budget and timescale are available. However, as a lower level tool, the possible benefits of the ARF spreadsheet are that it:

- is based on a simple monthly time step and can use available MORECS (or other) monthly effective rainfall data to calculate natural flows for any year;
- uses the aquifer parameters Transmissivity (T) and Storage (S) which can be derived from and altered according to local hydrogeological experience;
- can be applied to any area including those without rivers where only groundwater outflows are being considered;
- can allow for non-coincident SW and GW catchments;
- does produce an estimate of natural recharge, separated from runoff which can be compared with GW abstraction and previous, groundwater-only focussed resource assessments.

All the calculations using the ARF function are implemented using Excel macros. These are contained within the ARF spreadsheet to the right of the main calculation area and the Alternative Scenario storage area (see Section 8).

Step 1: Specify Assessment Area and Year
These can be copied directly from the ARM *River Outflow Calcs* spreadsheet where the natural flows derived from the are to be used.

Step 2a: Natural River Flows or GW Outflows in an 'Average Year'
For main rivers Agency staff should already be able to readily access an estimated natural river flow-duration curve using microLOWFLOWS which can also be expressed as 12 'average month' flows. In order to provide a comparable estimate using the ARF method, the first part of the spreadsheet calculations derive monthly flows for an 'average' year before calculating the monthly flows for the specified assessment year.

The initial calculation of 'average month' flows is based on the following user specified variables:

- areas for the surface water and groundwater catchments and for the aquifer (definitions of these areas are provided within the spreadsheet);
- a long term average annual effective rainfall value;
- an average monthly distribution of this effective rainfall through the year (default 'national average' values based on 5 MORECS squares across the country are provided but can be overwritten);

- the fixed % of effective rainfall which becomes recharge to the aquifer;
- the fixed % of this recharge which contributes to 'karstic' outflows in the same month;
- the fixed aquifer parameters, T, S and drainage boundary length which are used by the ARF function to calculate the slower groundwater outflow response to the remaining recharge.

Compare the calculated Aquifer Response Time with the qualitative estimate provided on the *Conceptual Understanding* Spreadsheet and, when possible, compare the average monthly flows with those derived from microLOWFLOWS. Vary the parameters within reasonable limits to understand the sensitivities of the calculation until the 'average year' flow responses are consistent with user perceptions.

Step 2b: Natural River Flows or GW Outflows in the Specified Assessment Year
The subsequent calculation of flows in the specified year uses the same areas, % recharge splits and aquifer characteristics but requires the user to enter 10 years of monthly effective rainfall data, the tenth year being that specified for assessment.

Enter 10 years of monthly effective rainfall data at Column DI of the spreadsheet from row 24 down, year 10 being that specified for assessment. Review the calculated runoff, recharge and natural total river flows back in the main calculation area.

Step 3: Natural Flow Results Summary
The resulting natural total river flows and GW outflows (or river baseflows) are summarised together with the accumulated % error associated with them so that they can be manually copied into the appropriate step of the associated *River Outflow Calcs* or *GW Outflow Calcs* ARM spreadsheet (remember to use *paste special-values*).

Principal Steps

Step 1: Specify Assessment Year

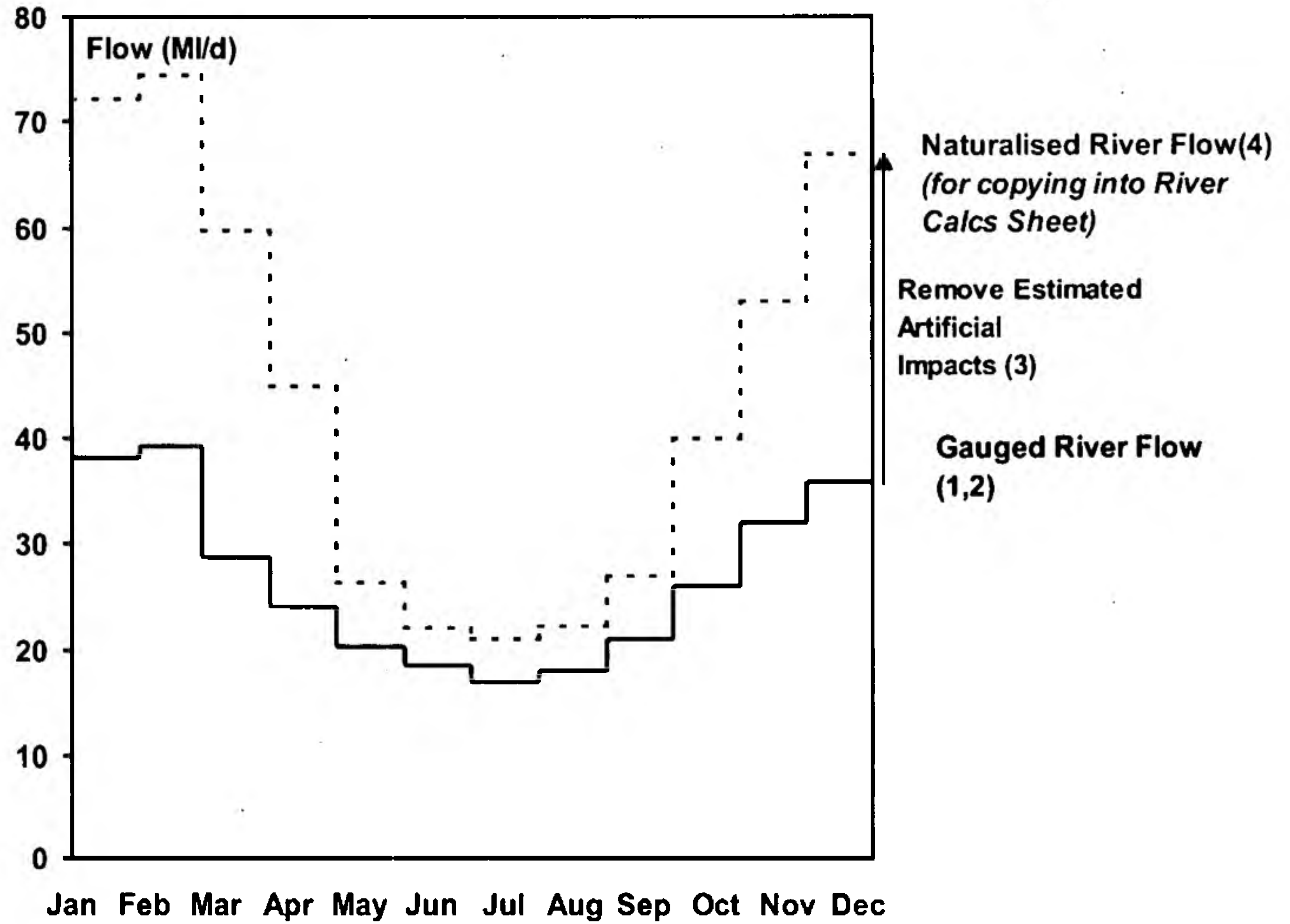
Step 2: Define Gauging Station and Monthly Average Gauged Flows

Step 3: Estimate & Remove Artificial Flow Impacts of Actual Abstraction for Specified Assessment Year

Step 4: Copy Naturalised Flow into the River Calcs ARM spreadsheet

Other Step Provided is:

Step 5: Plot Naturalised Flows and Artificial Impacts as Stacked Histograms in mm per month



file: 02019\drawings\figs.xls, sheet: Fig 7.1 Gauge Nat Calcs

FIGURE 7.1 USING THE OPTIONAL *'GAUGE.XLT'* SPREADSHEET TO NATURALISE GAUGED RIVER FLOWS

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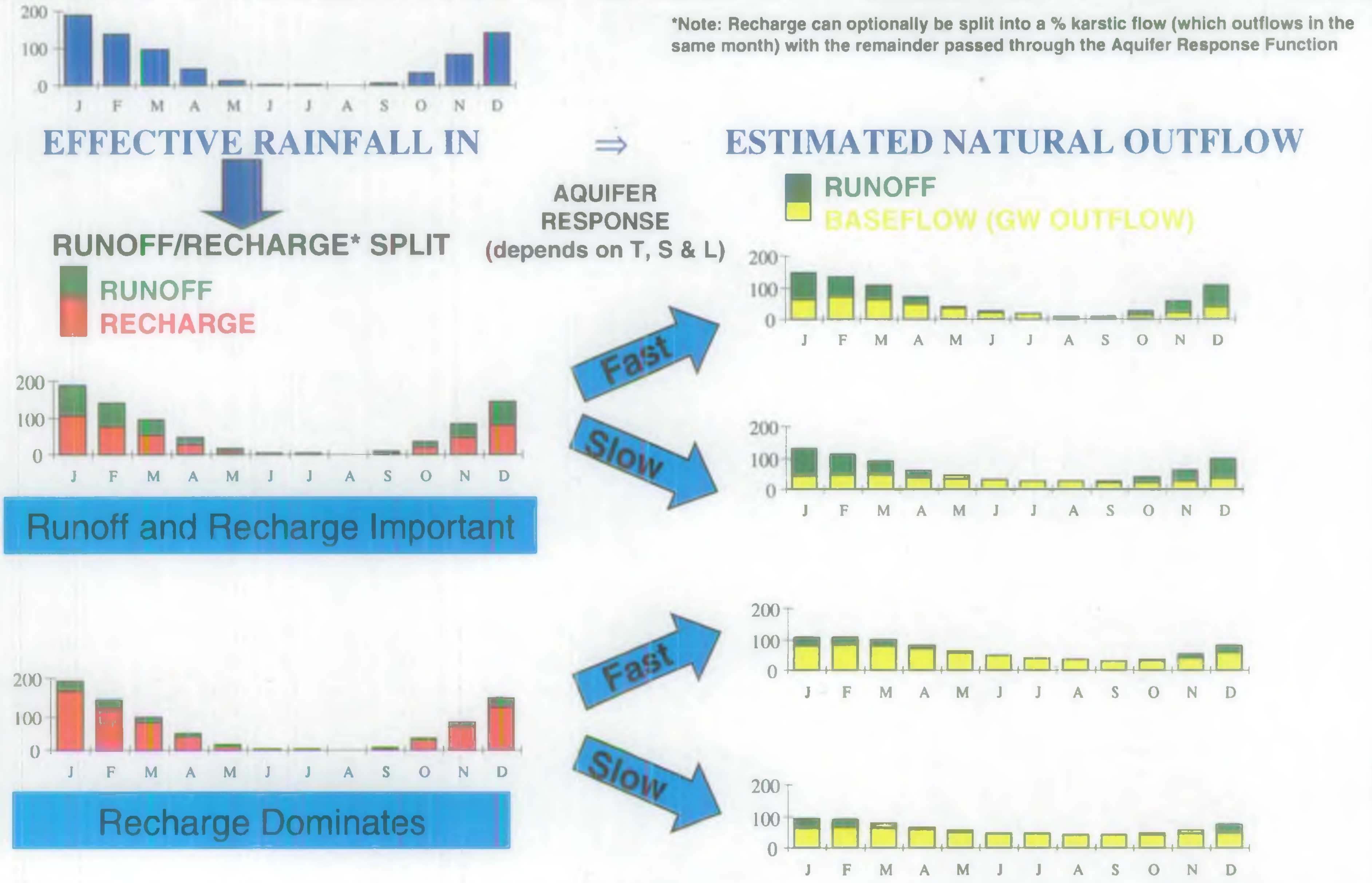

FIGURE 7.2 USING THE OPTIONAL 'ARF.xlt' SPREADSHEET TO ESTIMATE NATURAL OUTFLOWS FROM EFFECTIVE RAINFALL USING THE AQUIFER RESPONSE FUNCTION

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8. Assessing Alternative Assumptions, Management Scenarios, Target Flows and Years

A key feature of the ARM spreadsheets is the ease with which the user can investigate the implications of a range of alternative management scenarios and calculation assumptions and thereby gain a deeper understanding of the Area. In all of the spreadsheets there are columns to the right of the main calculation area where the information for up to three such scenarios can be stored. These data are only used actively if copied into the main calculation cells but otherwise provide a useful record of the alternatives considered.

8.1 Groundwater Abstraction Impact Assumptions

If groundwater abstractions are an important part of the water resources management of an area, the distribution of the impacts of these on natural river flows or GW outflows through the year is likely to be a key element of uncertainty in the ARM assessment. The relative significance of groundwater abstraction impacts (and therefore the time and effort it is worth investing in reducing the uncertainties associated with them) will be evident from any of the stacked histogram plots. Applying inappropriate assumptions to the distribution of groundwater abstraction impacts from month to month can, for example, result in misleading gauge naturalised flows and may raise false expectations of river low flow alleviation associated with the cessation or relocation of borehole sources.

There are some important differences between the Agency's Regions in the existing approaches towards the incorporation of groundwater abstraction impacts in resource assessments. The ARM spreadsheets facilitate comparison of these approaches and their consequences because the user is required to enter the distribution of monthly outflow impacts separately from the rates of monthly abstraction.

Any assessment of this issue should start with a list of the borehole sources which are considered to reduce the natural outflows being assessed. Where there is significant groundwater throughflow under the point of the river being assessed, it may be reasonable to assume that only part of the groundwater abstracted from a source close to this point is affecting the assessed flows (the remaining impacts being evident downstream).

The factors influencing how abstractions impact flow will vary from borehole to borehole and may include:

- the distance of the borehole from the river and the aquifers properties (T and S);
- the hydraulic connection between river and aquifer (bed material properties, channel width, intervening Drift properties etc);
- the seasonality of the abstraction and the time since it started;

- the variability of recharge. During summer months or in droughts, abstracted water may be drawn from aquifer storage rather than directly from the river so that river flow impacts may be redistributed towards the wetter, winter months.

Analytical functions used to calculate groundwater abstraction impacts (e.g. Jenkins or Stang, as incorporated within SWALP, microLOWFLOWS or IGARF approaches) do not take account of this last factor (aquifer storage and recharge variability) and may therefore overestimate impacts.

The impacts of each source should ideally be considered independently and then added to others within the assessment. However, after estimating the total consumptive abstraction from all sources in the month of pumping it is possible to rapidly consider three alternative 'extreme assumptions' to distribute impacts within the ARM spreadsheets. These are illustrated in Figure 8.1 and allow the user to quickly estimate the possible range of impact estimates before considering local factors specific to the source, river, aquifer and recharge.

Figure 8.1 shows monthly average river flows gauged in a simple example catchment, and a monthly profile of the consumptive abstraction rates from all the boreholes considered to influence flows at the gauge, where these are the only artificial flow impacts in the catchment. The minimum gauged monthly flow is 37 Ml/d and, as part of an 'alleviation of low flows' study, the flow recovery associated with a hypothetical cessation of all groundwater abstraction is to be investigated. The groundwater abstractions include public water supply sources with relatively steady abstraction rates, plus spray irrigation boreholes which only pump in the summer, when river flows are lowest.

The first 'extreme assumption' is that river flow impacts are the same as the pumped consumptive abstraction profile i.e. water is effectively assumed to be drawn directly from the river. This assumption in gauge naturalisation results in a large predicted low flow recovery (minimum natural flows of 63 Ml/d). However, as the storage properties of the aquifer are ignored this assumption is only likely to have some degree of validity in highly karstic aquifers where the boreholes are located next to rivers which would naturally receive baseflow throughout the year.

The second 'extreme assumption' is that the properties of the aquifer completely smooth out the summer abstraction peak so that impacts are evenly distributed throughout the year at the annual average abstraction rate. This is the most conservative prediction which could be derived from analytical approaches such as Jenkins or Stang and implies a low flow recovery to 55 Ml/d if all abstraction ceased. However, this assumption ignores the possibility that, since recharge is seasonal and the aquifer water level – river stage relationship may also vary with time, some of the water pumped during summer will be drawn from aquifer storage rather than from the river with the flow impacts being greater in the following winter.

This is the basis of the third 'extreme assumption' which redistributes impacts according to the gauged flows in the river (i.e. greater impacts in winter, less in summer), regardless of the summer abstraction peak. This results in the most conservative prediction of flow recovery to only 42 Ml/d.

In all three of these examples it has been assumed that all of the consumptive abstraction is accounted for by river flow reductions during the same year. However, according to the last 'extreme assumption' it follows that the impacts of groundwater abstraction during a drought year may not be fully accounted for by flow reductions within that year but may be spread into following years.

It is important to note that none of these three 'extremes' are likely to fully reflect the actual impacts of groundwater abstraction, they simply provide rapid upper and lower bounds to the problem and help the user to think. Any local experience of flow recovery monitored following abstraction cessation will be invaluable. However, in many groundwater dominated areas where this issue is most significant, the only adequate approach to reducing uncertainties is likely to be the development of regionally distributed groundwater and river flow models.

8.2 Abstraction and Discharge Management Scenarios

Possible choices and assumptions regarding the definition of the abstraction and discharge management scenario to be assessed have been discussed in Section 1.3.4. Alternative assumptions (e.g. based on estimate actual abstraction rates rather than on the licensed limits, or including a large new licence application under determination) can be easily stored in the spreadsheets and copied into the main calculation to investigate implications for scenario flows and the surplus/deficit profile.

8.3 Target Flows

Possible approaches for setting target environmental protection flows have been reviewed in Section 1.3.6 and the spreadsheet definition of these flow targets has been described as Step 7 of both the River and GW Outflow spreadsheets (Sections 4 and 5 respectively). Whatever approach is adopted, the target flows are plotted next to natural and scenario flows and their implications in terms of the surplus or deficit profile which results are immediately evident. Alternative target flow criteria can be readily considered in order to ensure that the conclusions of the assessment reflect pragmatically achievable environmental protection or restoration aims.

8.4 Assessment Years and Suggested Filenames

The previously described alternatives (groundwater abstraction impact assumptions, abstraction and discharge management scenarios and target flows) can all be considered for a specified assessment year as versions of one workbook. This workbook will include natural flow estimates that are specific to this year. It is therefore recommended that each workbook has a filename which reflects the type of assessment, the Assessment Area, the specified assessment year and the version number (e.g. GWBRITOT96v1.xls means 'GW assessment of the total Brighton Chalk Block in 1996, version 1'). It follows that alternative years should be assessed in a separately named copy of the workbook.

8.5 Recommended Scenarios to Consider

From previous discussion it is clear that a wide variety of alternative scenarios and assumptions can be investigated. The Agency should consider national guidelines to ensure a degree of consistency.

Experience from ARM trials to date suggest that, in formulating these guidelines it may be useful to consider three basic scenarios in the following order:

- **Scenario 1**: a 'long term average' year (derived from flow data over a standard recent period e.g. 1980 to1999) considered with seasonally variable target flows based on perceived environmental needs, and abstraction impacts based on a best estimate of actual recent rates and impacts. Consider alternative GW abstraction impact assumptions within this scenario as appropriate (**long term average scenario**). This scenario is useful to for comparison of 'average' conditions and sustainability between areas but the averaging effectively smoothes the winter high flows and summer low flows and will not provide a conservative picture of summer resources.
- **Scenario 2**: a drought year considered with seasonally variable target flows based on a natural QN95 minimum and abstraction impacts based on licensed rates and conservative 'impact as pumped' GW abstraction assumptions (**worst case scenario**).
- **Scenario 3**: an alternative year (possibly another drought year or an 'average' year) which, apart from natural river flow or GW outflow estimates is otherwise as Scenario 1 (**alternative year scenario**).

Further scenarios associated with alternative abstraction or discharge management proposals could follow this broad approach.

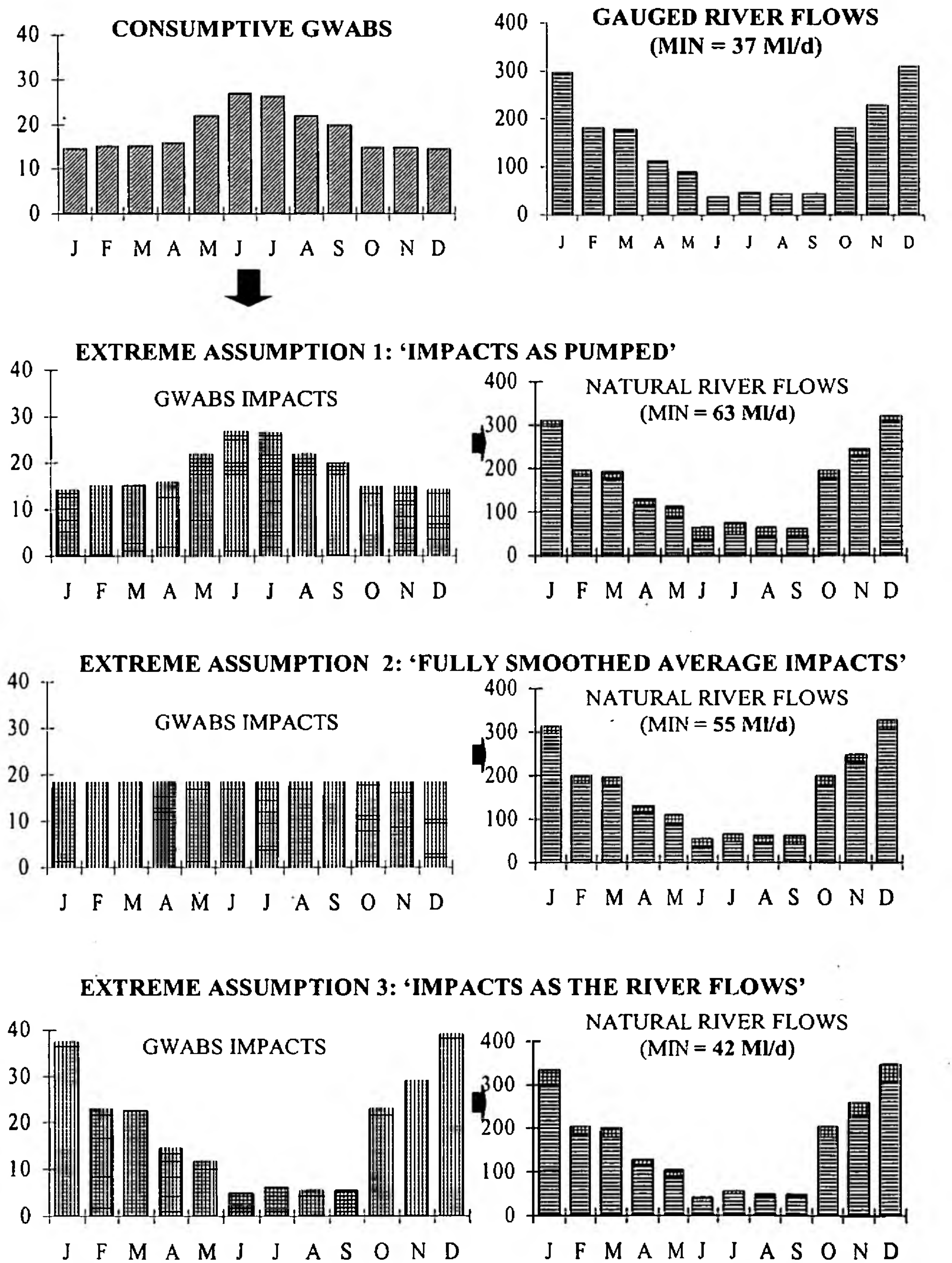

FIGURE 8.1 ALTERNATIVE 'EXTREME ASSUMPTIONS' TO ESTIMATE THE IMPACTS OF GROUNDWATER ABSTRACTION ON RIVER FLOWS

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9. Worked Examples in Trial Areas

9.1 ARM Development Trial Locations

Figure 9.1 shows that, during the research and development process, ARM Framework trials have been carried out in seven of the eight Agency Regions covering a wide variety of groundwater and surface water dominated areas including catchments which are intensively exploited and those which are almost natural. These trial areas are summarised in the Table 9.1 below and have all been previously reported (full references in Section 1.5.1).

Table 9.1 ARM Trial Locations and Reports

Assessment Area	Area Characteristics	Trial Reports
River Otter *South West Region*	River catchment with lower part which interacts with a Sherwood Sandstone aquifer.	May 1999 User Manual & March 2000 CAMS trials
Brighton Chalk Block *Southern Region*	Karstic Chalk aquifer block bounded by tidal rivers and the sea with largely unmeasured GW outflows.	May 1999 User Manual & this March 2000 User Manual
River Hull to Hempholme Gauge *North East Region*	Chalk aquifer catchment with spring discharge supporting river headwaters which subsequently flow over confining boulder clay.	May 1999 User Manual
River Worfe to Cosford Gauge *Midlands Region*	Headwaters river catchment including Sherwood Sandstone aquifer and less permeable formations.	May 1999 User Manual
River Ribble to Samlesbury Gauge *North West Region*	Large surface water dominated catchment with minor aquifers and SW reservoirs	March 2000 CAMS trials
Fylde Aquifer *North West Region*	Confined Sherwood Sandstone aquifer, poorly connected to rivers which is exploited conjunctively with SW resources during drier periods.	March 2000 CAMS trials
Rivers Little Ouse and Thet *Anglian Region*	Catchments equivalent to 2 sub-units of the Little Ouse Groundwater Unit. Boulder Clay cover Chalk with seasonally variable SW and GW Abs and a drought river support scheme.	March 2000 CAMS trials & this March 2000 User Manual
River Teifi *Wales*	Effectively 'natural' surface water dominated catchment of high environmental value.	March 2000 CAMS trials

The primary objective of all these trials has been to test whether Framework and its associated spreadsheets are sufficiently robust and flexible for wide application. In all cases basic data have been provided by the Agency but the level of involvement from Agency staff in the formulation of Conceptual understanding or review of results has been variable. For this reason, none of the trial spreadsheets should be considered as an 'Agency approved' assessment of water resources availability and the final step of assigning a sustainability status has not been taken. It is emphasised that the credibility of the Assessment Framework results is very dependent on having 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.

The ARM Framework has evolved through the trials and in response to the comments and suggestion made by Agency staff. As such, some aspects of the format and approaches adopted for the earlier trials have been superseded by subsequent development. The next two sub-sections describe worked examples presented according to the latest description of the Framework (Section 1), as implemented on the spreadsheets described in Sections 2 to 8. These two trial areas are:

- **River Thet to Melford Gauging Station:** Application of the **RIV.xlt** ARM workbook and associated (optional) GAUGE.xlt and ARF.xlt spreadsheets to a river with both surface water and groundwater flow components which is exploited by seasonally variable abstractions and includes occasional drought river support boreholes (the Great Ouse Groundwater Scheme);

- **Brighton Chalk Block**: Application of the **GW.xlt** ARM workbook and associated (optional) ARF.xlt spreadsheet to a karstic Chalk aquifer block with seasonal transmissivity variations bounded by tidal rivers and the sea with largely unmeasured GW outflows.

The spreadsheets for each worked example are provided on disc in Appendix A and as hardcopy printout in Appendix B. This Section of the report introduces each area through the sketched conceptual plans and cross sections which have been reproduced from the *Conceptual Understanding* Spreadsheets as fold-out Figures to view alongside the text. Any key references or data sources are included on the spreadsheets themselves. The text explains the decisions taken during the Assessment Framework 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 read in front of a computer with a copy of the Excel workbooks open.

The broad conclusions from the trials are briefly summarised although, as indicated above, these have not been formally reviewed or approved by the Agency. In some cases alternative scenarios 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.

The reader is encouraged to experiment with the software using these trial data sets to improve understanding of the ARM Framework and spreadsheets.

The main lessons learned from all the trials in terms of the Framework's applicability and recommendations for further consultation and review are summarised in Section 10.

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

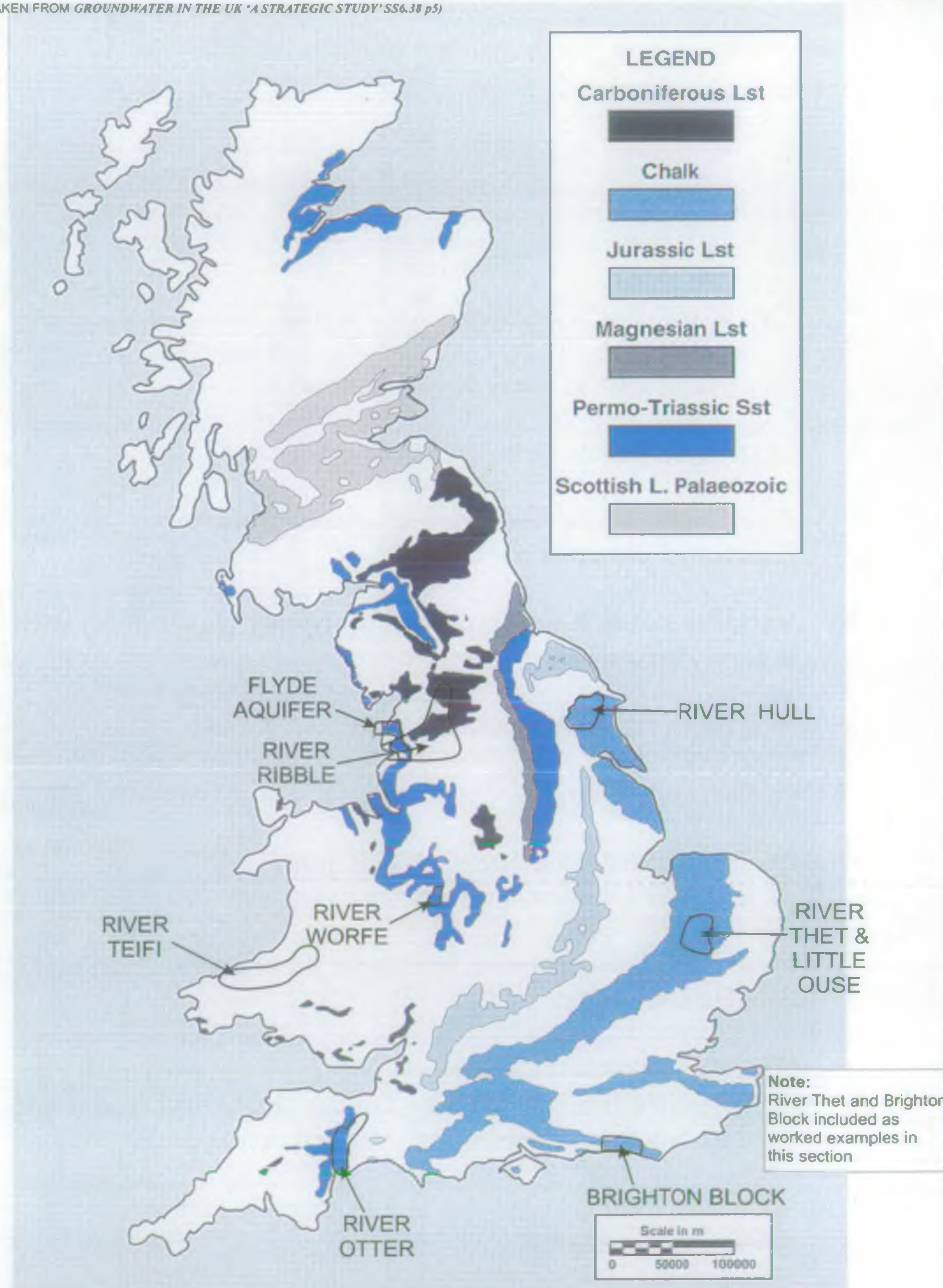

FIGURE 9.1 ARM FRAMEWORK TRIAL AND DEVELOPMENT AREAS

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9.2 River Thet at Melford Bridge Assessment

9.2.1 Area Delineation, Description and Issues

Figure 9.2 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 Anglian Region as the 'Little Ouse Groundwater Unit'. This groundwater unit 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 initially 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 9.2 includes conceptual cross sections for both of these areas drawn along lines close to the river. The remainder of this section describes the assessment carried out for the River Thet.

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 9.2 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 there are licensed Great Ouse Groundwater Scheme (GOGWS) sources to support river flows during drought years such as 1991.

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.

9.2.2 Workbook Selection and Names

ARM calculations for the River Thet have been saved in the following spreadsheets based on the RIV.xlt template:

- Rivthetmellta.xls (long term average assessment using data from 1970 to 1990);
- Rivthetmel91.xls (drought year assessment using data from 1991).

Both of the optional spreadsheets described in Section 7 have also been used to provide estimates of natural flows for both assessment years and these have the following filenames:

- Gaugethetmellta.xls and Gaugethetmel91.xls (gauged flow naturalisation);
- ARFthetmellta.xls and ARFthetmel91.xls (natural flows from MORECS effective rainfall using the Aquifer Response Function).

9.2.3 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.

9.2.4 Key Assumptions

Estimation of Natural River Flows

The assumptions made in estimating consumptive abstraction impacts for both gauged flow naturalisation and the estimation of scenario outflows are described below. Long term average (1970 to 1990) gauge naturalised flows are estimated as 170 Ml/d with a summer monthly minimum of 72 Ml/d. These have been compared at Step 3 of the ARM spreadsheet with natural flows derived using the aquifer response function (ARF) based on monthly MORECS effective rainfall and assuming:

- 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;
- aquifer parameters T = 500 m^2/d and S = 0.03.

The ARF based estimates suggest natural flows averaging 148 Ml/d with a monthly minimum of 56 Ml/d – both much lower than flows derived from gauge naturalisation. This may indicate that the ARF assumed groundwater catchment areas are incorrect or that MORECS significantly underestimates effective rainfall, or may reflect errors in the simple assumptions used to estimate actual abstractions from licensed values as part of the gauge naturalisation process.

In addition to the flow estimates derived from the gauge and the ARF approach, two other synthetic natural flow series have been entered at Step 3 of the ARM sheets. These are not based on 'real data' but have been included 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 also 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.

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 entered for illustrative purposes only. The third estimate is taken from the effective rainfall based aquifer response function calculations on the supporting spreadsheet. For the long term average assessment this is very close to the groundwater resource derived by Anglian Region's existing methodology (66Ml/d ARF average cf. 64 Ml/d Anglian Gross Resource, 51 Ml/d ARF minimum cf. 51 Ml/d Anglian reliably Available Resource). The ARF baseflow estimate and has been taken forward for later comparison with groundwater abstraction impacts.

Consumptive Abstraction Impacts

Surface water abstractions in this area are 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 (based on Anglian Region's Flow Naturalisation Good Practice Guidelines) to estimate monthly abstracted quantities. This results in an average of around 3 Ml/d over the year as a whole which is actually all abstracted from surface water during the summer months at rates of up to 11 Ml/d 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 rates from the Chalk have been estimated using the following:

- Public Water Supply. 1993 licence and actual abstraction data has been used to determine an overall uptake factor (i.e. an estimate of the proportion of the annual licence actually pumped). This factor has been applied to the total licensed abstraction quantity of 3752 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 1593 Ml/a is licensed for abstraction for spray irrigation purposes. 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 between general agriculture (370 Ml/a) and cooling (801 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.

These assumptions suggest an average annual abstraction rate of around 8 Ml/d with a summer peak of up to 17 Ml/d.

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

In the first instance an 'average or fully smoothed' approach has been adopted (see Section 8.1) where river flow impacts are assumed to occur at the annual average rate of 8 Ml/d for long-term average assessment, 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 'smooth' flow impacts for long term steady state abstractions.

Two other impact distributions, described as alternative 'conceptual extremes' in Section 8.1, 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.

- Impacts account for all the water abstracted in the year but are distributed according to natural river flows i.e. are assumed to have a greater impact on river flows during wetter months of higher flow, than during summer periods of lower flow.

At this stage Entec have not attempted to consider the distribution of groundwater abstraction impacts on a source by source basis. The regional groundwater model which is currently planned to include the River Thet should help to reduce uncertainties about groundwater abstraction impact distributions.

Prior to the early 1990's licensed discharges to surface water to the Thet upstream of the Melford Bridge gauge amounted to around 2 Ml/d. During the drought year 1991 GOGWS boreholes abstracted 11820 Ml over the period July to October to support river flows. Information from the Agency suggests that the net effect of these abstractions on the assessment area was an increase in gauged flows by rates equivalent to 40% of the rates 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 11820 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 GOGWS 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). However, the approach also results in the 'Scenario river flow minus SW Dis' series becoming negative in the stacked histogram presented at Step 10 of the spreadsheet.

Target Flows

The average scenario 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 monthly flow of 54 Ml/d in the ARM assessment was taken directly from the natural QN95 specified for protection according to the Agency's river flow model (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. In contrast the existing Anglian Methodology makes no equivalent allowance although it implicitly assumes that winter flows will be assured by the 'unreliable' groundwater flows and runoff.

9.2.5 Presentation and Discussion of Results

All of the main plots and results from the first two pages 'Conclusions and QA' sheet of the Rivthetmellta.xls and Rivthetmel91.xls workbooks are presented as hardcopy following this section.

The surplus or deficit profile resulting from the long term average ARM assessment suggests a very small minimum surplus of 3 Ml/d in September with an associated error bar of +/- 18 Ml/d. These results would not justify any change to the Agency's existing policy of no further groundwater licences in this Unit. This is encouraging. 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 5 % value.

Despite these tight summer resource position, the assumed 50% monthly extra acceptable abstraction impact implies 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 gauging station.

A brief review of the 1991 ARM spreadsheets for the River Thet shows how the impacts of the river support scheme have been taken into account. 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.

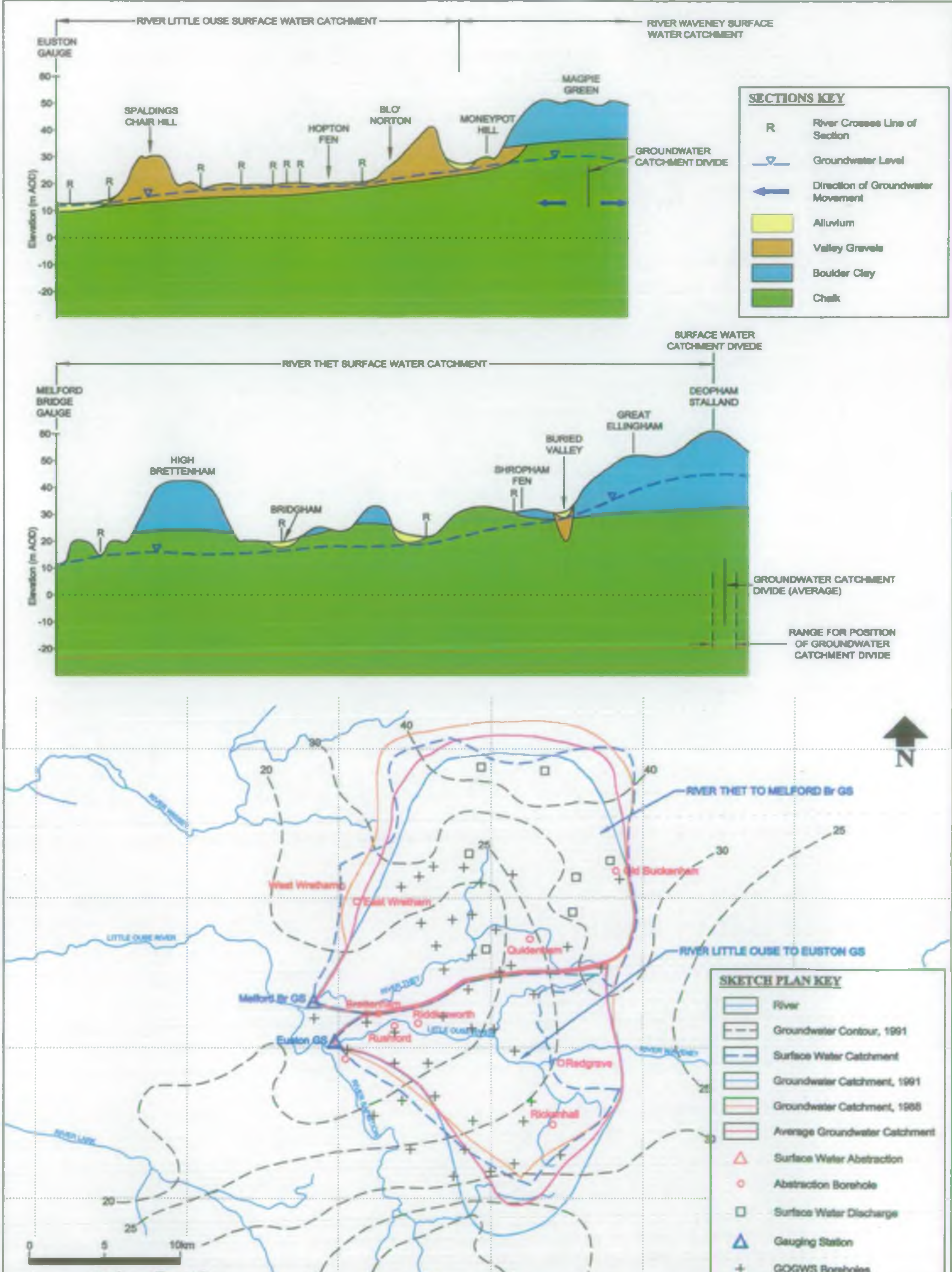


FIGURE 9.2 RIVERS LITTLE OUSE AND THET ASSESSMENT AREAS SKETCH PLAN AND CROSS SECTIONS

Drawing No: **02019-01.S033** Date: **MARCH 2000** Scale: **AS SHOWN**

AVAILABLE RESOURCE METHODOLOGY (ARM)

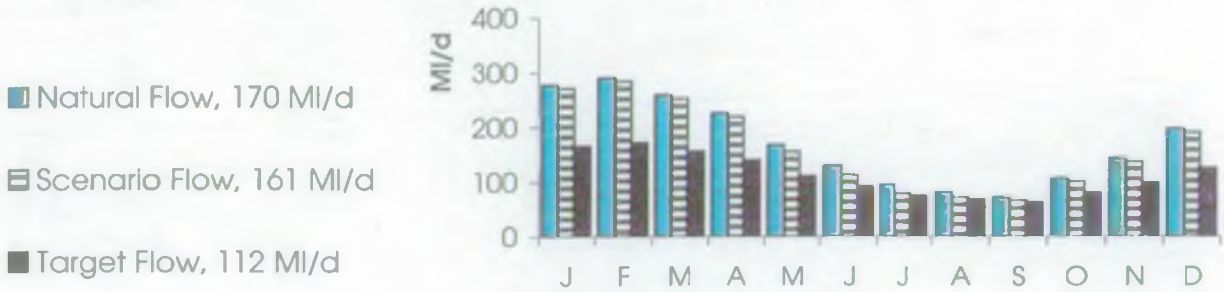
Area: R Thet at Melford Bridge GS | ID: ? | Ver: 1 | Rev: 1 | Date: 19/8/99

Assessment for Areas which Drain to a River Outflow (protected worksheet)

Specified Assessment Year: L T Average Year (1970-1990) **Conclusions & QA**

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) = 17 % in Jul

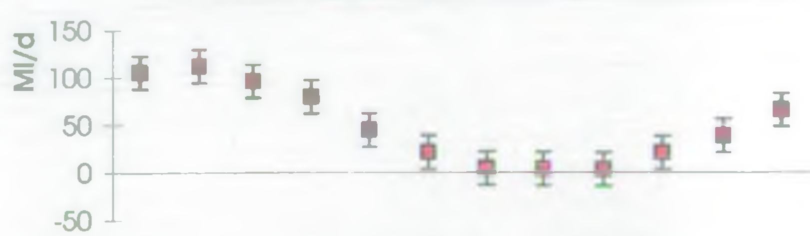
1.3 Surplus or Deficit Profile for Specified Year (= Scenario River Flow Minus Target River Flow)

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

Ann Av 49 Ml/d

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 : Not assigned at this trial stage - see discussion in Section 1.3.8 and note in Section 9.1 of the User Manual for further information. Step 3 (Management Action) also not complete

AVAILABLE RESOURCE METHODOLOGY (ARM)

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

Assessment for Areas which Drain to a River Outflow (protected worksheet)

Specified Assessment Year: L T Average Year (1970-1990) — Conclusions & QA

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

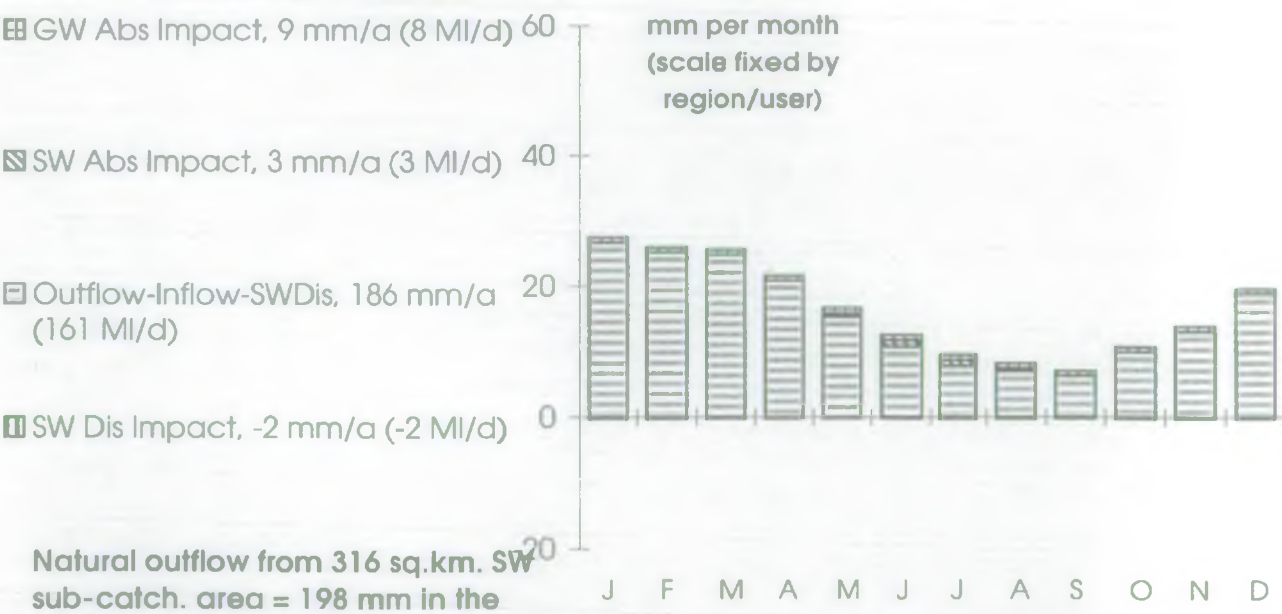
Uncertainty +/-: 8 Ml/d

	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: NONE

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



Maximum net abstraction impact for this sub-catchment area only (excluding upstream catchme

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

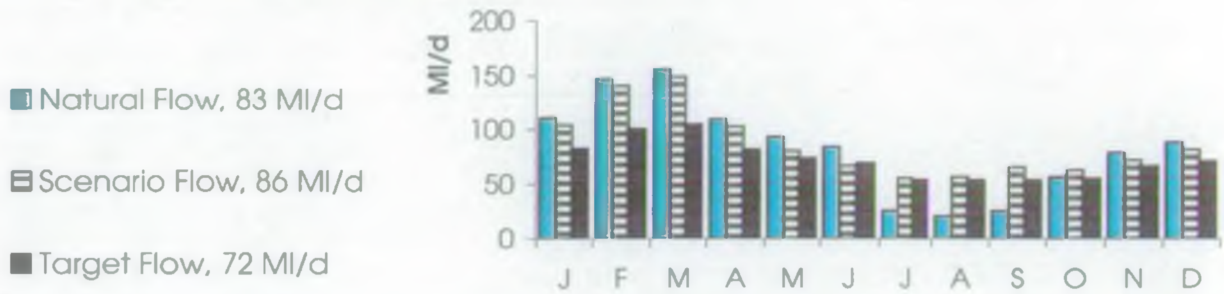
Assessment for Areas which Drain to a River Outflow (protected worksheet)

Specified Assessment Year: Drought condition 1991

Conclusions & QA

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

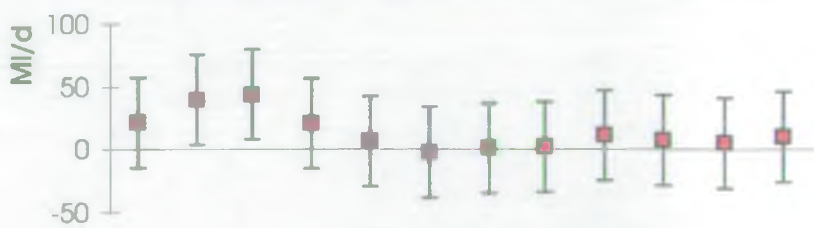
1.3 Surplus or Deficit Profile for Specified Year (= Scenario River Flow Minus Target River Flow)

J	F	M	A	M	J	J	A	S	O	N	D
22	40	44	21	7	-2	1	2	12	8	6	11

Ann Av 14 Ml/d

Minimum -2 Ml/d

Uncertainty +/- 36 Ml/d



Central value of Surplus or Deficit as % of Natural River Flow: Ann Av 17% Min -3%

1.4 Interpreted Sustainability Status of Resource Management at Outflow Point

Sustainability Status Category:

Comments : Not assigned at this trial stage - see discussion in Section 1.3.8 and note in Section 9.1 of the User Manual for further information. Step 3 (Management Action) also not complete

AVAILABLE RESOURCE METHODOLOGY (ARM)

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

Assessment for Areas which Drain to a River Outflow (protected worksheet)

Specified Assessment Year: **Drought condition 1991** **Conclusions & QA**

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

Ann Av: 11 Ml/d

Minimum: -33 Ml/d

Uncertainty +/-: 49 Ml/d

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	28	47	51	28	20	15	-28	-33	-28	1	12	17

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

Ann Av: 7 Ml/d

Minimum: -53 Ml/d

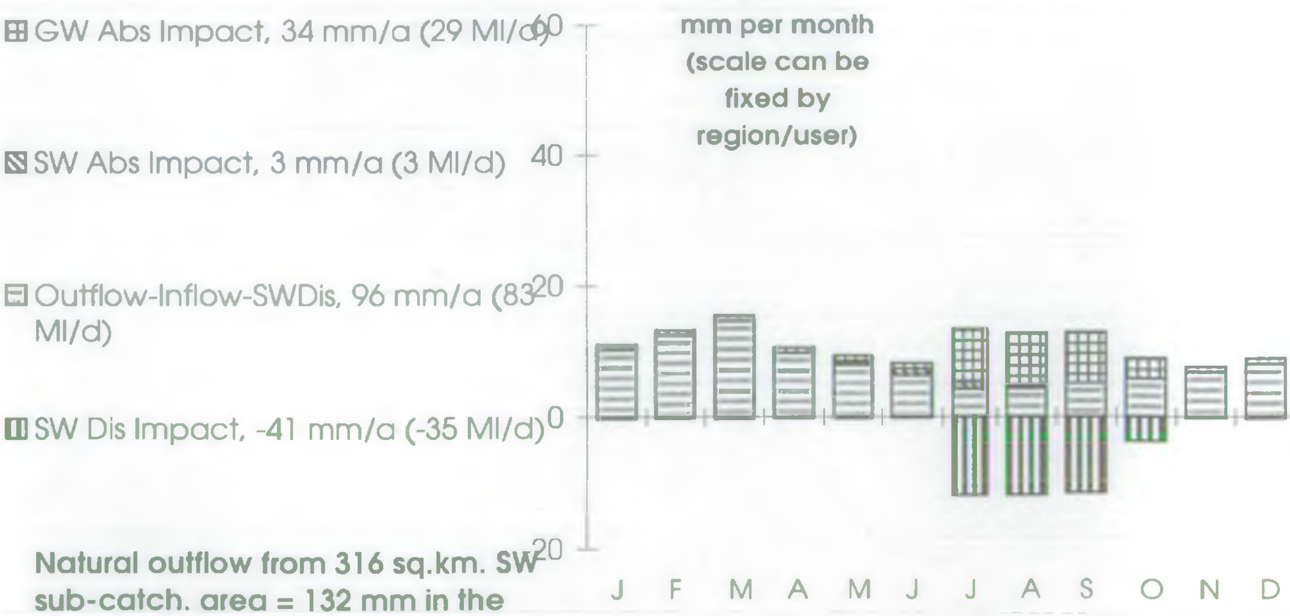
Uncertainty +/-: 11 Ml/d

	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

2 Outflow Components (Optionally Excluding Upstream Sub Catchments)

Upstream Catchments Excluded: NONE

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



Maximum net abstraction impact for this sub-catchment area only (excluding upstream catchme

Max. (sub-catchment net abs impact/sub-catchment nat outflow) = 20 % in Jun

9.3 Brighton Chalk Block Groundwater Assessment

9.3.1 Area Delineation and Description

Figure 9.3 shows the conceptual sketch plan and cross section for the Brighton Chalk Block which has been assessed. The Chalk dips gently southwards from its northern scarp face and is underlain by the Greensand with which it has been assumed to be in hydraulic continuity, and the impermeable Gault Clay. Although the Chalk outcrop continues along strike it is hydraulically bounded by the tidal River Ouse to the east and by the River Adur to the west.

The Chalk is largely unconfined and, although Head deposits may locally reduce recharge, it is considered that runoff losses from the Block as a whole are negligible – most of the effective rainfall enters the aquifer as recharge. There is no information as to the effect of urbanisation around Brighton on recharge – for this Assessment, the extra runoff losses associated with engineered drainage are assumed to offset any enhancement due to mains water leakage.

Springs drain the northern scarp but there is little permanent surface water drainage from the Brighton Block. Flows are gauged in the Winterbourne at Lewes, but these fall to zero during the summer months and the great majority of water leaves the Block as ungauged groundwater discharge to the sea or bounding rivers, or via abstraction boreholes for public water supply. There are no significant surface water abstractions and most treated effluent discharges to long sea outfall.

Transmissivity variations within this groundwater dominated systems are significant both spatially and seasonally. Fissure flow dominates with zones of greatly enhanced flow beneath dry valley and vertically within the zone of water table fluctuation. Groundwater levels vary markedly as specific yield is low. Groundwater discharge is controlled by transmissivities which can effectively be considered as karstic during the winter months but which fall during the summer.

9.3.2 Workbook Selection, Assessment Year and Filenames

All calculations for the Brighton Block have been carried out using workbooks based on the *GW Outflow Calcs* spreadsheet, in the GW.xlt template. The assessment has been carried out for the Block as a whole which has well defined boundaries.

The calendar year 1996 was selected for assessment as a recent severe drought period. According to MORECS effective rainfall data this was the 2nd driest year since 1960.

The spreadsheets for the Brighton Block included on the CD in Appendix A, and as hardcopy in Appendix B are summarised as follows:

Assessment Assumptions	Excel Workbook Template Used	Completed Filename
1996 drought, GWABS impacts on GW outflows assumed to be at average rate throughout year	GW outflows, GW.xlt	Gwbritot96v1.xls
1996 drought, GWABS impacts on GW outflows assumed to be distributed according to natural GW Outflows	GW outflows, GW.xlt	Gwbritot96v2xls
Natural GW outflow from effective rainfall (same for both versions)	ARF.xlt	ARFbritot96.xls

9.3.3 Key Assumptions

Estimation of Natural Groundwater Outflows

The first step in the Brighton Block assessment is to estimate the natural groundwater outflows from the Assessment Area. The ARF approach has been used based on MORECS effective rainfall inputs (see ARFbritot96.xls). All of the effective rainfall is assume to become recharge and, in order to simulate the perceived karstic response, 30% of this recharge has been assumed to discharge from the Area in the same month as it rained. Outflow of the remaining recharge is controlled through the Aquifer Response Function with storage set at a low Chalk value of 0.01 and transmissivity set at 127 m2/d. This transmissivity value is considered to be representative of the less permeable regions of Chalk away from the karstic dry valley corridors where flow rates are very high. The length of boundary considered to drain the Chalk block has been measured to include the length of bounding coastline, rivers, or spring line and also the length of the high T dry valley features. The high T valleys have been included in conceptual consistency with the choice of a lower transmissivity value – an alternative model might use a higher transmissivity but a shorter discharge boundary length.

The overall effect of this parameterisation is to simulate natural groundwater outflows which are very seasonally variable. In 1996 modelled natural outflows from the Block as a whole averaged 111 Ml/d but ranged from 331 Ml/d in January to only 4 Ml/d in October (ARFbritot96.xls). Even without considering the karstic proportion of flow, modelled aquifer response times are short (133 days).

In addition to the flow estimates derived from ARF approach, an extra natural flow series has been entered at Step 3 of the Gwbritot96v1.xls spreadsheets. This is not based on 'real data' but has been included to illustrate how output from a groundwater model might be taken into the assessment. Both estimates (and the results of any alternative approaches) are plotted and can be compared and revised before one (in this example, that based on the ARF spreadsheet) is taken forward.

The option of separately specifying a recharge, inflow based estimate of groundwater resources has also been taken with two alternative estimates provided and plotted. One of these (the 'recharge model output') has been synthesised and entered for illustrative purposes only. The other estimate is taken from the MORECS data for the year, as calculated in Ml/d on line 96 of the ARFbritot96.xls spreadsheet. The MORECS data (which have been taken forward for later comparison with groundwater abstraction as pumped) suggest an average 99 Ml/d recharge for 1996 including a 7 month period (April to October) with no recharge.

Consumptive Abstraction Impacts

Groundwater abstraction for public water supply is the only significant anthropogenic impact on the water balance of the Brighton Chalk Block. The abstractions should be considered as fully consumptive losses as all treated effluent discharges are to the sea.

The management scenario assessed was based on the estimated average 76 Ml/d was actually abstracted during 1996 from boreholes and adits which are mostly clustered within or close to the dry valley high T zones. Despite the different distances of these sources from the coast or from the high T zones, there was little seasonal variation in the abstraction rates reported for the drought year of 1996. There is no evidence of operational switching of abstraction away from the boreholes 'close' to the coast during the summer to avoid saline intrusion. Pumping rates remained fairly steady throughout the year at levels similar to previous years.

Comparison with estimated natural outflows from the Block for 1996 shows that whilst the average resource (111 Ml/d) exceeds the average abstraction rate (76 Ml/d), significant flow reversals are implied through the year if the impacts of steady groundwater abstraction are assumed to be constant from month to month. Adopting this assumption, as shown in (Gwbritot96v1.xls) results in estimations of 1996 scenario flows ranging from 255 Ml/d (outflow) in February to -73 Ml/d (inflow) in October.

Agency staff report that available water quality monitoring data and operational experience are not consistent with the seasonal movement of the saline front which these results imply and conclude that the water balance representation according to this assumption is inadequate. Alternative concepts are discussed in the 'Results' Section below.

Target Flows

The key factor to be considered when setting outflow protection targets for the Brighton Chalk Block is the groundwater discharge required to prevent saline intrusion. Considerable uncertainty is associated with the groundwater outflows from the Block – they cannot be measured and the complexities of spatial and seasonal transmissivity variation also makes them difficult to model, particularly using a simple lumped parameter approach such as the ARF method.

In practice operational experience from each borehole site has been applied for many years to limit abstraction to rates at which saline intrusion does not occur. It has been assumed that a small inflow of saline water (equivalent to a small shift in the saline front) should be acceptable during the driest summers. For this reason target flows have been set as a minimum of –5 Ml/d plus 30 % of the natural GW outflow above this (i.e. 70% of excess natural outflows can be reduced by abstraction - a higher proportion than would be probably acceptable if river low flows were a particular concern). This results in a protection target with large winter outflows and a short, 2 month period of small inflows. The defined target flows have been associated with a large uncertainty (+/- 30 %) which is reflected in the large error bars of the resulting surplus/deficit profile.

9.3.4 Discussion of Results

All of the main plots and results from the first two pages of the 'Conclusions and QA' sheet of the GWbritot96v1.xls workbook are presented as hardcopy following this section. The main headline result of the assessment for the 'actual 1996 abstraction scenario', as determined according to the assumptions for natural flows, groundwater abstraction impacts and target flow setting described above, is that these abstractions are unsustainable with large summer/autumn deficits (down to –70 Ml/d in October).

The average abstraction impact rate assumed for 1996 in this version of the assessment is over 20 times larger than minimum estimated monthly outflow in October (i.e. a maximum abstraction impact of 2132%). This results in an estimated maximum 72 Ml/d inflow which, given that abstractions were not drawing in saline water, is considered unreasonable and casts doubt on the adequacy of the calculation assumptions.

In order to reconcile the concept of a rapidly responsive aquifer where winter outflows are considered to be very high and natural summer outflows considerably less than the rate of steady state abstraction, with the observation that saline intrusion did not affect water quality in the boreholes, it is necessary to consider where the storage required to buffer the system might be available. During the months May to October, the main calculation in GWbritot96v1.xls suggest that a total inflow of nearly 10 000 Ml of water occurred. Assuming a Chalk specific yield of 0.01 this volume is equivalent to the water which would be released with a drop in groundwater level of around 4.7 m over the 208 km^2 area of the Chalk block. Alternatively, assuming a higher storage associated with matrix porosities, as would determine the water released through regional movement of the saline water – fresh water interface, this volume could be generated by a seasonal fluctuation of less than 50 m laterally in this interface. Either of these alternative sources of aquifer storage seem plausible and some element of both may be involved.

This effectively suggests that during the summer months, and particularly in a drought, borehole abstracted water is drawn from storage in the aquifer system. The abstracted water does not impact natural outflows directly or induce sea water inflow to the boreholes during these months because water is more readily available from aquifer storage. During the wetter months this abstraction related storage has to be replenished. In this way it can be seen that steady state groundwater abstractions have a greater impact on natural outflows during the wetter months of recharge than during the drier months. This is the rationale behind the third 'extreme assumption' for groundwater abstraction impacts described in Section 8.1.

An example of how this assumption can be implemented within the spreadsheets is provided within the GWbritot96v2.xls workbook (first two pages of the 'Conclusions and QA' sheet also follow this Section). The impacts of abstraction have been redistributed through the year according to the estimated natural outflow rate. The annual average impact rate has been set to the average rate abstracted although, during a drought year this is probably a conservative assumption (more water would be drawn from storage during a drought). By copying this impact distribution into the main calculation (at Step 5b) it can be seen that the estimated scenario (i.e. actual) outflows during 1996 remained positive throughout the year. The surplus or deficit profile also remains positive through the year although only by 4 Ml/d with large associated uncertainties.

This version of the assessment presents a much more credible picture of the sustainability of the abstractions existing in 1996 which is in line with operational experience. It would support a precautionary abstraction management strategy which would prohibit further licensing, promote ongoing monitoring of actual groundwater levels and quality and possibly seek abstraction reductions where these would result in local specific benefits. The assessment might also support investment in more sophisticated regional groundwater models in order to reduce the large uncertainties associated with abstraction impacts.

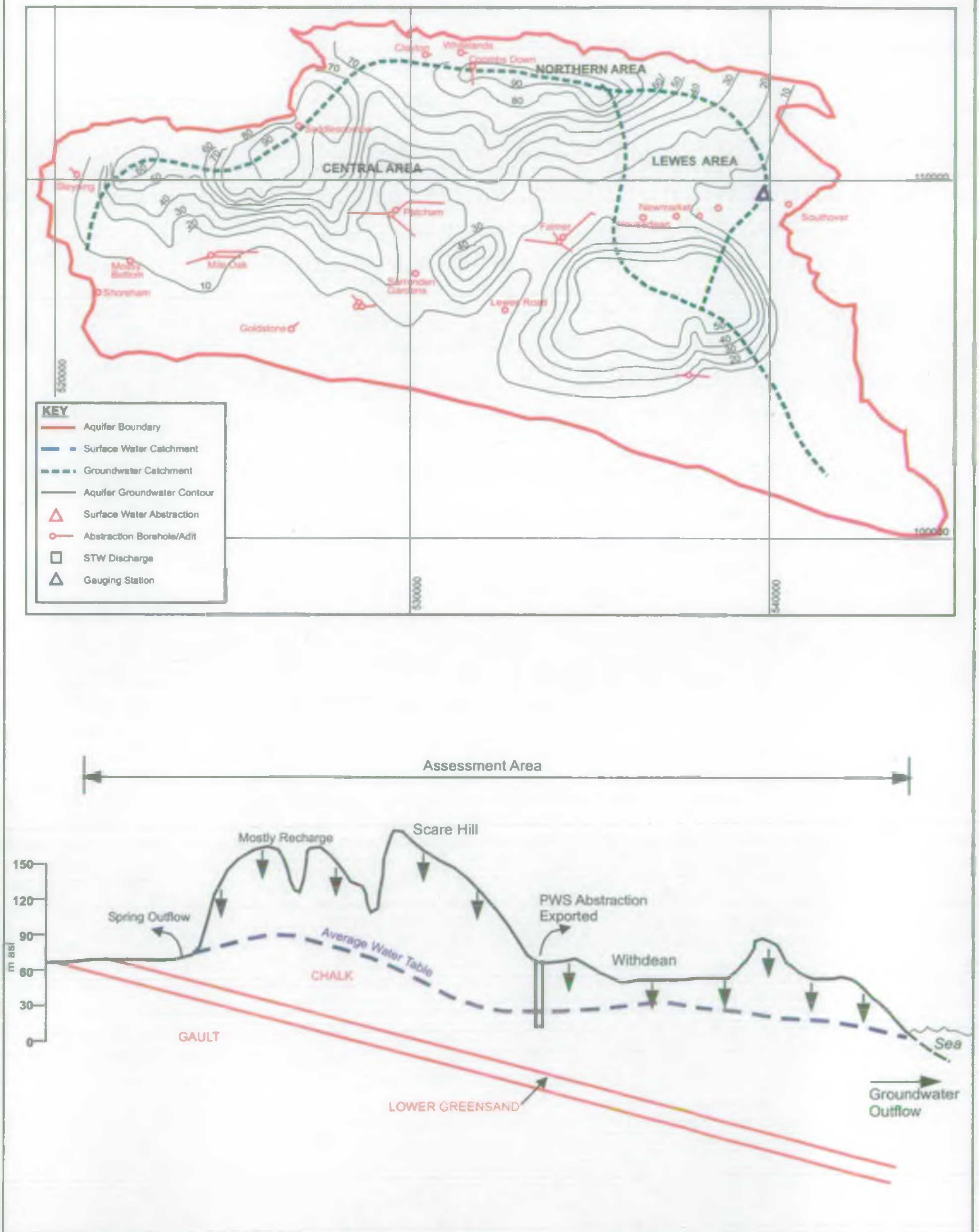


FIGURE 9.3 BRIGHTON CHALK BLOCK: CONCEPTUAL SKETCH PLAN AND SECTIONS

Drawing No: 02019-01.S034 Date: MARCH 2000 Scale: AS SHOWN

AVAILABLE RESOURCE METHODOLOGY (ARM)

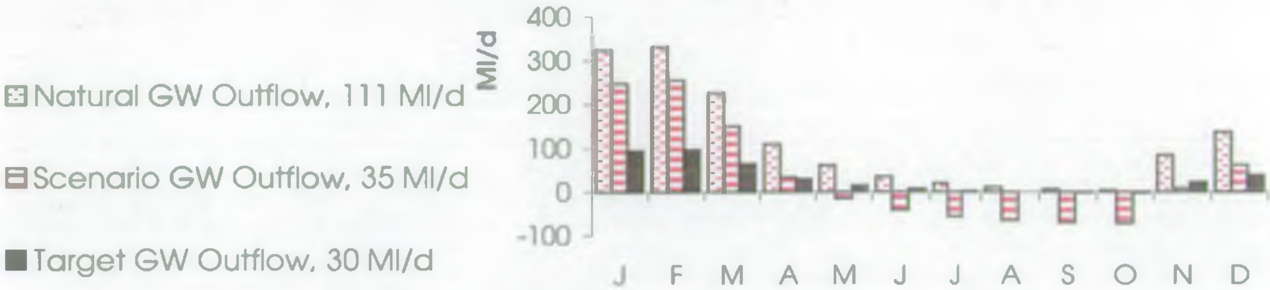
Area Brighton Chalk Block (total) **ID** ? **Ver** 1 **Rev** 1 **Date** 1/2/00

GW Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Specified Assessment Year: **Drought condition 1996** — **Conclusions & QA**

1 Results Summary for the GW Catchment to the GW Outflow Boundary

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



Target Flows based on: can allow small seasonal fluctuation of saline/freshwater interface

1.2 Scenario GW Abstraction Impacts (with Annual Average Rate Summary)

GW Abs Scenario: Estimated Actual 1996 Rates

Maximum GW abstraction impact for total area based on

Max. (GW abs impact/naturalGW Outflow from total area) = **2135** % in **Oct**

1.3 GW Surplus or Deficit Profile for Specified Year (= Scenario GW Outflow Minus Target GW Outflow)

	J	F	M	A	M	J	J	A	S	O	N	D
	154	159	86	4	-30	-48	-59	-65	-68	-70	-13	23

Ann Av 5 **Ml/d**

Minimum -70 **Ml/d**

Uncertainty +/- 42 **Ml/d**

Central value of
GW Surplus or Deficit as % of Natural GW Outflow Ann Av 5% **Min** <-100%

1.4 Interpreted Sustainability Status of GW Resource Management for the Area

GW Sustainability Status Category:

Comments : This version of the assessment does not reflect operational experience, probably because GWABS impact assumptions are wrong. See GWbritot96v2.xls which is more credible.

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area: Brighton Chalk Block (total) ID: ? Ver: 1 Rev: 1 Date: 1/2/00

GW Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Specified Assessment Year: Drought condition 1996 — Conclusions & QA

1.5 Acceptable GW Abstraction Impacts Profile for Specified Year (= Natural GW Outflow Minus Target GW Outflow)

Ann Av: 81 Ml/d

Minimum: 6 Ml/d

Uncertainty +/-: 57 Ml/d

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	230	236	162	80	46	28	17	11	8	6	63	99

1.6 Recharge Minus Groundwater Abstraction as Pumped (ignoring impact timing) if recharge has been separately defined

Ann Av: 23 Ml/d

Minimum: -78 Ml/d

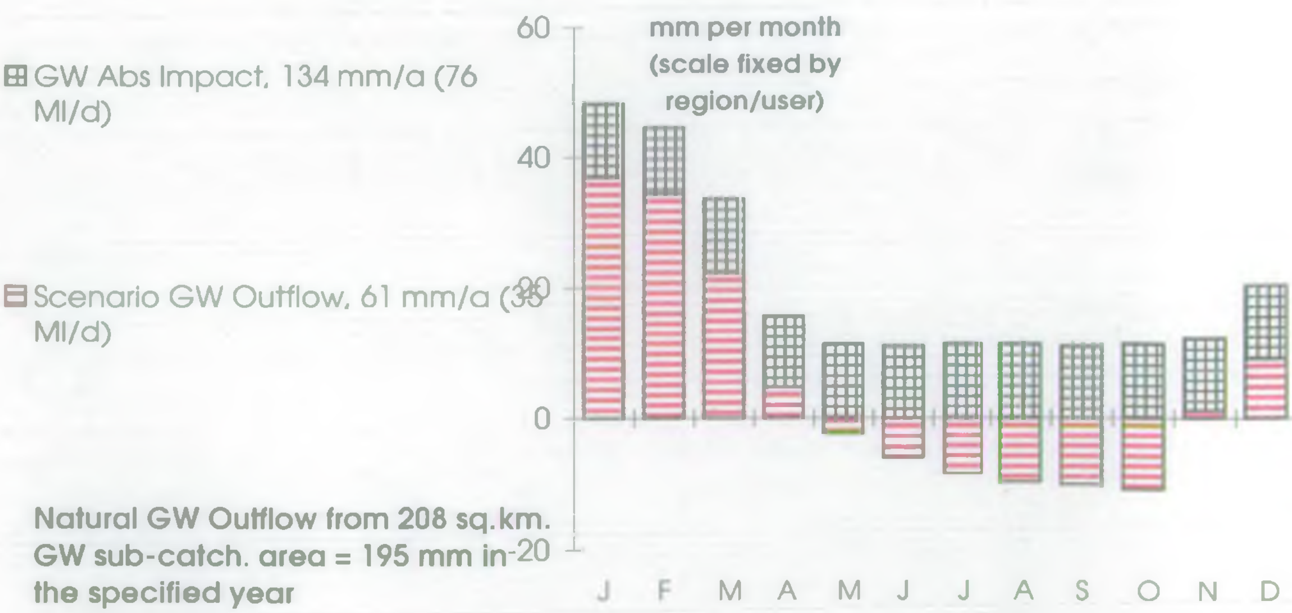
Uncertainty +/-: 12 Ml/d

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	322	245	73	-76	-77	-78	-77	-78	-77	-75	71	117

2 GW Outflow Components (Optionally Excluding Sub-Areas)

Sub-Areas Excluded: NONE

Flow Components Derived from the Remaining GW Sub Catchment Expressed in mm/month (with Annual Average Rate Summaries in mm/a and Ml/d)



Maximum GW abstraction impact for this sub-catchment area only (excluding the areas indicate

Max. (sub-catchment GW abs impact/sub-catchment nat GW outflow) = 2135 % in Oct

AVAILABLE RESOURCE METHODOLOGY (ARM)

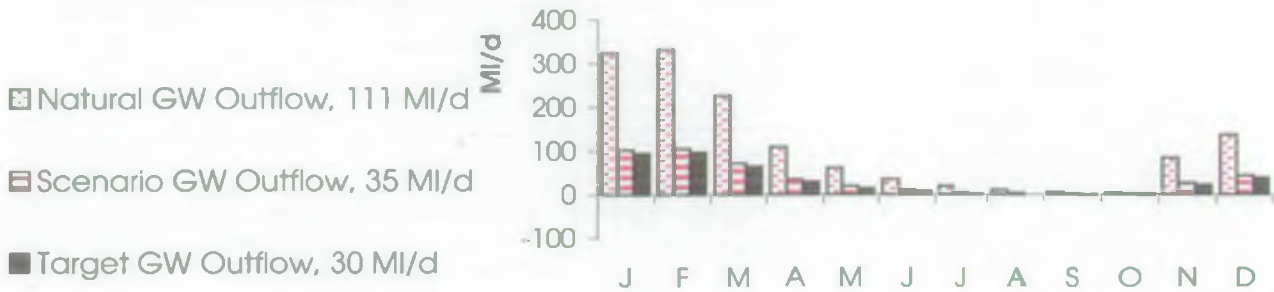
Area: Brighton Chalk Block (total) ID: ? Ver: 2 Rev: 1 Date: 1/2/00

GW Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Specified Assessment Year: **Drought condition 1996** **Conclusions & QA**

1 Results Summary for the GW Catchment to the GW Outflow Boundary

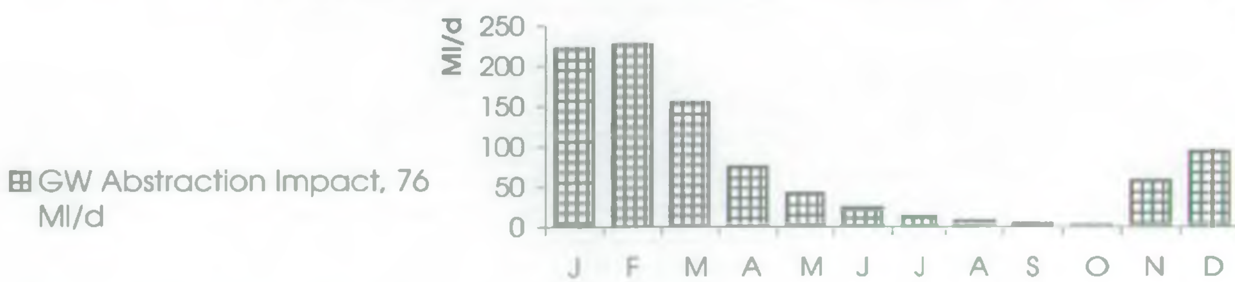
1.1 Natural, Scenario and Target GW Outflows for Specified Year (with Annual Average Rate Summary)



Target Flows based on: can allow small seasonal fluctuation of saline/freshwater interface i.e. small inflow in summer

1.2 Scenario GW Abstraction Impacts (with Annual Average Rate Summary)

GW Abs Scenario: Estimated Actual 1996 Rates



Maximum GW abstraction impact for total area based on

Max. (GW abs impact/naturalGW Outflow from total area) = **68** % in **Jan**

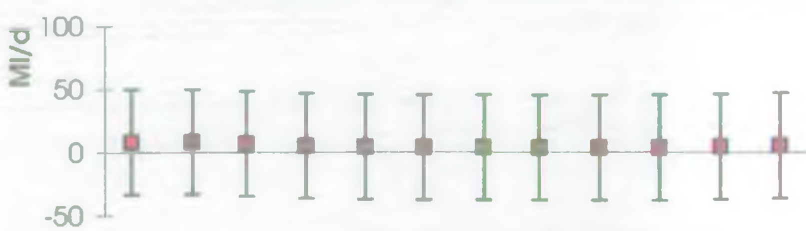
1.3 GW Surplus or Deficit Profile for Specified Year (= Scenario GW Outflow Minus Target GW Outflow)

J	F	M	A	M	J	J	A	S	O	N	D
8	9	7	5	4	4	4	4	4	4	5	6

Ann Av 5 Ml/d

Minimum 4 Ml/d

Uncertainty +/- 42 Ml/d



Central value of
GW Surplus or Deficit as % of Natural GW Outflow Ann Av 5% **Min** 3%

1.4 Interpreted Sustainability Status of GW Resource Management for the Area

GW Sustainability Status Category:

Comments : Not assigned at this trial stage - see discussion in Section 1.3.8 and note in Section 9.1 of the User Manual for further information. Step 3 (Management Action) also not complete

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area: Brighton Chalk Block (total) | ID: ? | Ver: 2 | Rev: 1 | Date: 1/2/00

GW Assessment for Areas which Drain to a GW Outflow (protected worksheet)

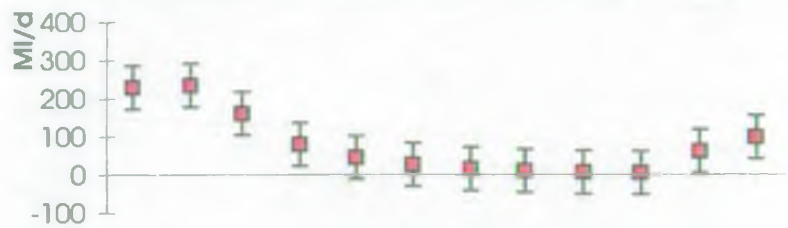
Specified Assessment Year: **Drought condition 1996**

Conclusions & QA

1.5 Acceptable GW Abstraction Impacts Profile for Specified Year (= Natural GW Outflow Minus Target GW Outflow)

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	230	236	162	80	46	28	17	11	8	6	63	99

Ann Av	81	Ml/d
Minimum	6	Ml/d
Uncertainty +/-	57	Ml/d



1.6 Recharge Minus Groundwater Abstraction as Pumped (ignoring impact timing) if recharge has been separately defined

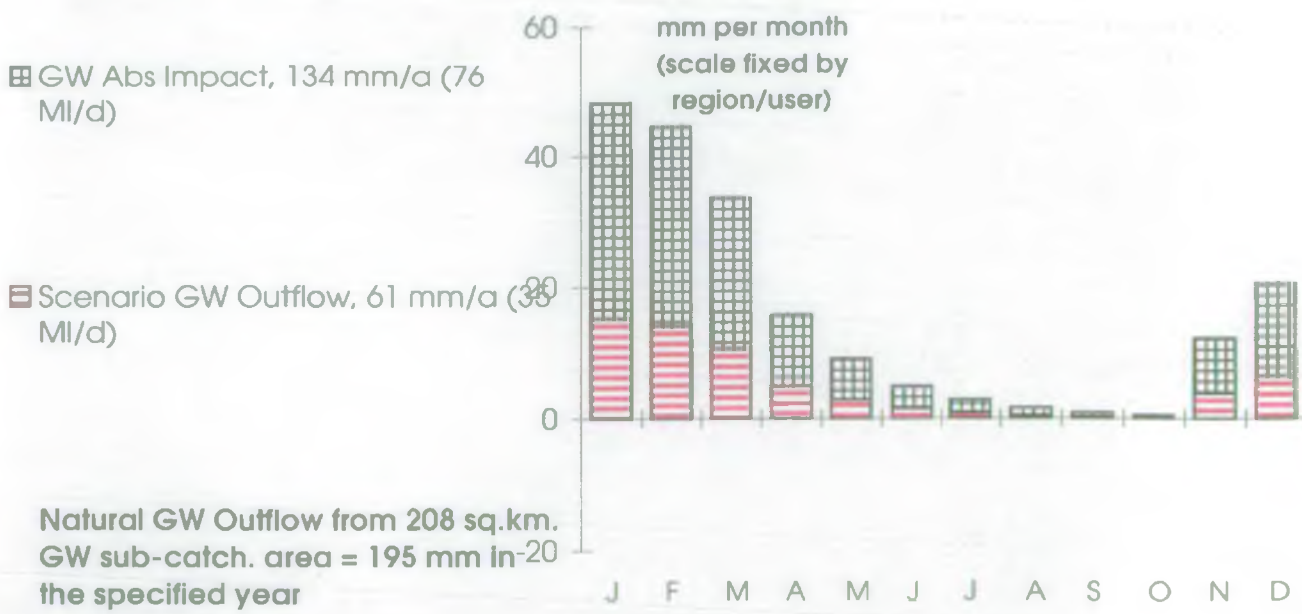
	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	322	245	73	-76	-77	-78	-77	-78	-77	-75	71	117

Ann Av	23	Ml/d
Minimum	-78	Ml/d
Uncertainty +/-	12	Ml/d

2 GW Outflow Components (Optionally Excluding Sub-Areas)

Sub-Areas Excluded: NONE

Flow Components Derived from the Remaining GW Sub Catchment
Expressed in mm/month
(with Annual Average Rate Summaries in mm/a and Ml/d)



Maximum GW abstraction impact for this sub-catchment area only (excluding the areas indicate

Max. (sub-catchment GW abs impact/sub-catchment nat GW outflow) = 68 % in Jan

10. Conclusions from ARM Spreadsheet Trials and Recommendations for Further Consultation

10.1 Applicability of the ARM Spreadsheets

Experience from the ARM trialling process is encouraging with regards to the applicability of the Framework and the spreadsheets to a wide variety of assessments and problems. 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. It also provides a consistent focus of assessment on river outflow impacts where possible which are likely to be the principal aspect of management concern.

Following extensive consultation the ARM spreadsheets are now flexible and can accommodate a variety of techniques for each of the calculation steps, including all of those currently in use in the Regions. Furthermore, the spreadsheet 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 have shown that the ARM is widely 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, the Aquifer Response Function spreadsheet 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.

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 previous resource estimates which may have been derived from effective rainfall or recharge calculations.

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 have been readily applied to the Teifi catchment whereas the timing of groundwater abstraction impacts are 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 1.3.8, 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. In such aquifers abstraction may induce further leakage from the overlying Drift so that the basic premise of a natural resource impacted by abstraction (upon which the ARM depends) may not be valid. Target groundwater outflows will also be difficult to determine and should be associated with large uncertainties. In this case the ARM spreadsheets may only offer a consistent reporting format. 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.

10.2 Recommendations for Further Consultation

The ARM Framework and spreadsheets described in this User Manual evolved over 18 months of regular discussions and trials involving Agency staff from a variety of groundwater and surface water backgrounds in National Centre, Regional and Area offices and in intensive workshops. This should perhaps be regarded as a first stage in consultation leading to the development and acceptance of a nationally consistent Framework for resource and sustainability consideration and representation.

The next stage of development should concentrate on the clear dissemination of the ideas presented and on wider consultation and discussion. This should include other Agency staff and also the key stakeholders, particularly water companies and environmental groups, whose understanding and acceptance of the Framework approach is essential if it is to become widely adopted.

11. Bibliography

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Environment Agency, 1997. Surface Water Abstraction Licensing (SWALP): Guidance for the Application for Proposed Methodology, Working Draft: Version 1.1. A Kirmond and I Barker

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Environment Agency NGCLC ProjectNC/06/28, 1999. The Impact of Groundwater Abstractions on River Flows

Erskine, A D and Papaioannou A, 1997. "The Use of Aquifer Response Rate in the Assessment of Groundwater Resources". Journal of Hydrology, **202** pp 373-391.

Appendix A
Software (Blank Spreadsheet Templates and Worked Examples on Disc)

1 Disc and Copyright/Liability Label

COPYRIGHT & LIABILITY LABELLING FOR 'ARM' PROJECT DELIVERABLES

These spreadsheets (and accompanying report and user guide) were produced under the National Groundwater and Contaminated Land Centre (NGWCLC) project 'Available Resource Methodology' (NC/99/68), 2000, by the Environment Agency and ENTEC, Shrewsbury, England.

These spreadsheets should be used in conjunction with the accompanying user guide to help ensure their appropriate application. Enquiries about these spreadsheets and accompanying reports and user guide should be made to the NGWCLC of the Environment Agency, Tel. 0121 711 5885.

We do not promise that the spreadsheets will provide any particular facilities or functions. You must ensure that the spreadsheets meet your needs. You are entirely responsible for the consequences of any use of the spreadsheets, we give you no warranty about the fitness for purpose or performance of any part of the spreadsheets. We do not promise that the media will always be free from defects, computer viruses, software locks or other similar code or that the operation of the spreadsheet will be uninterrupted or error-free. You should carry out all necessary virus checks prior to loading on your computing system.

Appendix B
Hardcopies of Worked Example Spreadsheets

RIVER THET LONG TERM AVERAGE TRIAL ARM SPREADSHEET

RIVthetmellta.xls (including Conceptual understanding sheet): 12 pages

AVAILABLE RESOURCE METHODOLOGY (ARM)

Conceptual Understanding **(unprotected worksheet)**

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

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 (month)

Groundwater - River Interaction: poorly connected - - - - - - well connected

please tick according to your conceptual feel: Y (well connected)

river flows are now: baseflow independent / baseflow dependent: Y (baseflow dependent)

'naturally' rivers were: baseflow independent / baseflow dependent: Y (baseflow dependent)

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)

Conceptual Understanding **(unprotected worksheet)**

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 Artificial Influences

Please rank by magnitude SW discharges, GW abstraction and SW abstraction

GW abs > SW dis > SW abs although summer SW abs are significant

Are there any other artificial influences on the catchment? (e.g. reservoirs, bulk transfer schemes etc.)

Great Ouse Groundwater Scheme drought river support and supply for
Ely Ouse to Essex Transfer Scheme

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)

Conceptual Understanding **(unprotected worksheet)**

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

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

see Figure 9.2 of User Manual

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)

Assessment for Areas which Drain to a River Outflow (protected worksheet)

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

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

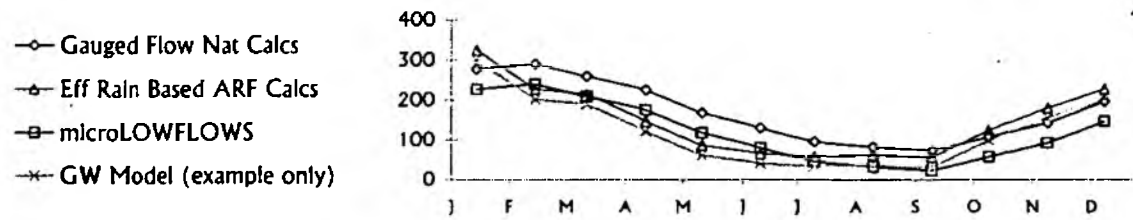
3.0 Natural River Flows in Specified Year to Define the Total Water Resource
Enter the monthly averaged natural river flows for the assessment year, and an associated % possible error, based on one or more of the following:

a. Gauged Flow Naturalisation (*use the 'Gauge' workbook & refer to Agency national guidelines*).
b. Effective Rainfall Based Aquifer Response Function Calculations (*use the 'ARF' workbook*)
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.

	Methods and Calculation References		*Select One* type 'x'		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	% Err.
a.	*Gauge* Sheet Results	ref: Gaugethetmellta.xls	x	Ml/d	170	72	278	290	259	226	168	130	96	82	72	107	143	197	6
b.	*ARF* Sheet Results	ref: ARFthetmellta.xls		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	8
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	4

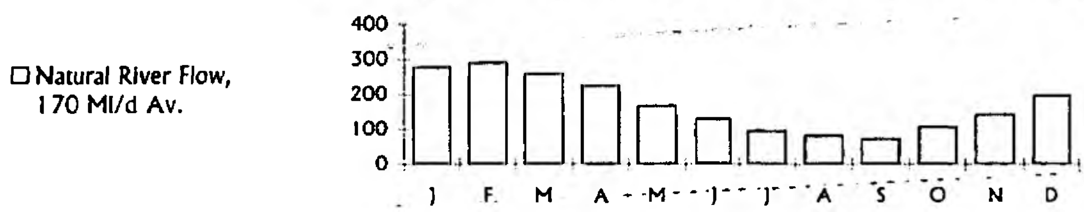
Monthly Av. Natural River Flow in Specified Year, Ml/d



	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	170	72	278	290	259	226	168	130	96	82	72	107	143	197	10

Selected Natural River Flow in Specified Year, Ml/d

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



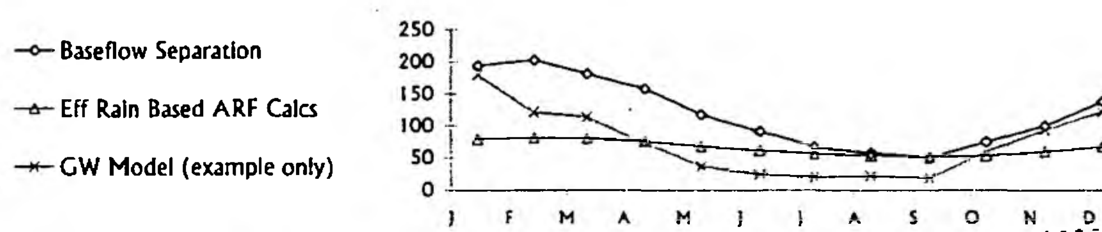
4.0 Natural River Baseflows in Specified Year to Define the Groundwater Resource (optional)
If a separate estimate of groundwater resources is required, enter the monthly averaged natural river baseflows, based on one or more of the following:

a. Baseflow Separation of Total Flow Hydrograph *(please reference method & calculations)*
b. Effective Rainfall Based Aquifer Response Function Calculations (*use the 'ARF' workbook)*
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% gauge nat flow		Ml/d	119	51	194	203	181	158	118	91	67	57	51	75	100	138	15
b.	*ARF* Sheet Results	ref: ARFthetmellta.xls	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)

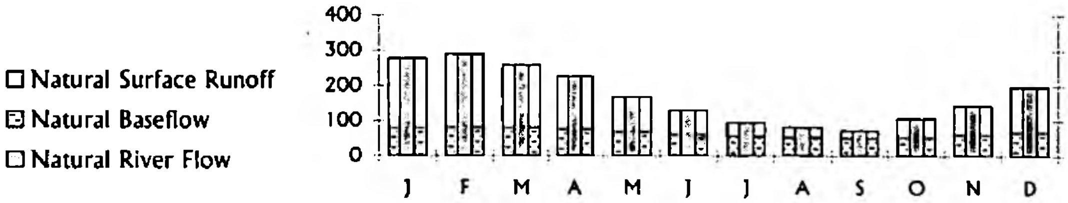
Assessment for Areas which Drain to a River Outflow (protected worksheet)

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	82	80	76	68	61	57	54	51	54	60	67	7
Implied Surface Runoff Flow	104	22	199	209	179	150	100	68	39	28	22	53	83	130	

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

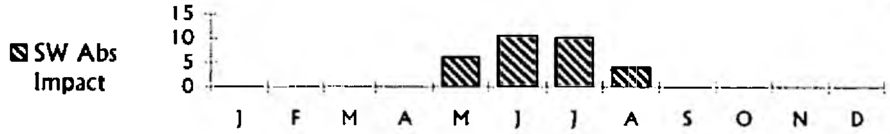
Abstraction rates should be locally consumptive (i.e. excluding any water *locally* returned to the catchment).
Public water supply abstractions should be considered as fully consumptive because sewage treatment works or transfer discharges are accounted for separately. Surface water abstractions and 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

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

Consumptive GW Abstraction, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Data compilation & calculation imply av. level of confidence in this data set is +/- 10 %	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

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

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+/-
Data compilation & calculation imply av. level of confidence in this data set is +/- 20 %	2	Ml/d	2	2	2	2	2	2	2	2	2	2	2	2	0

AVAILABLE RESOURCE METHODOLOGY (ARM)

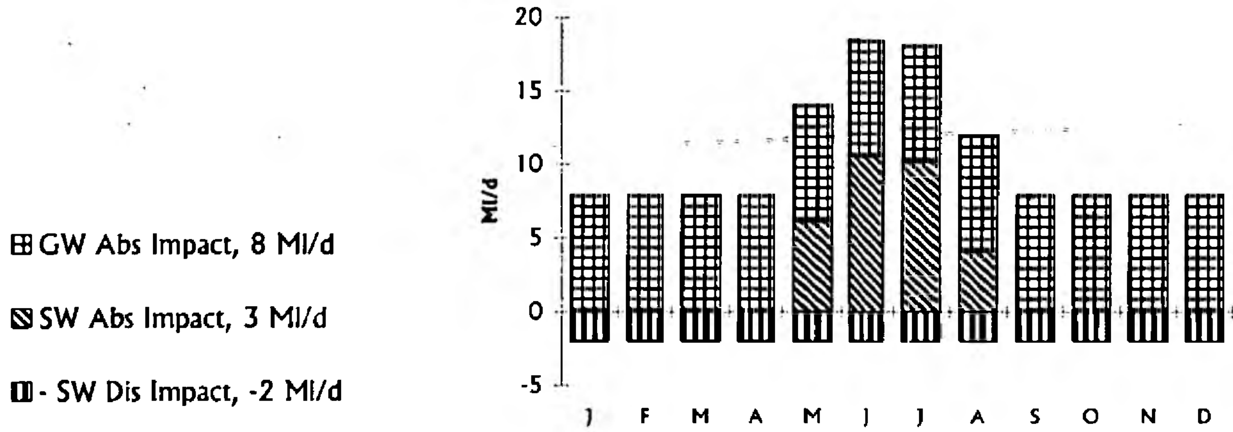
Assessment for Areas which Drain to a River Outflow (protected worksheet)

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



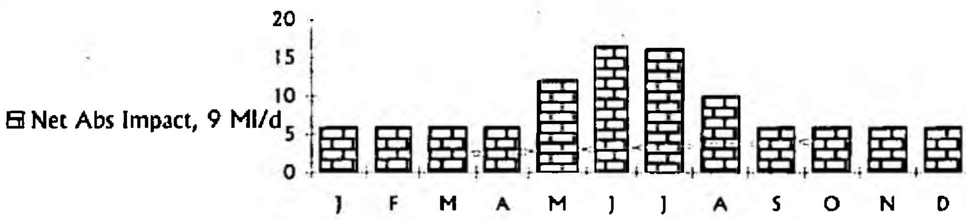
5.5 Scenario Net Consumptive Abstraction Impacts in Specified Year

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 %

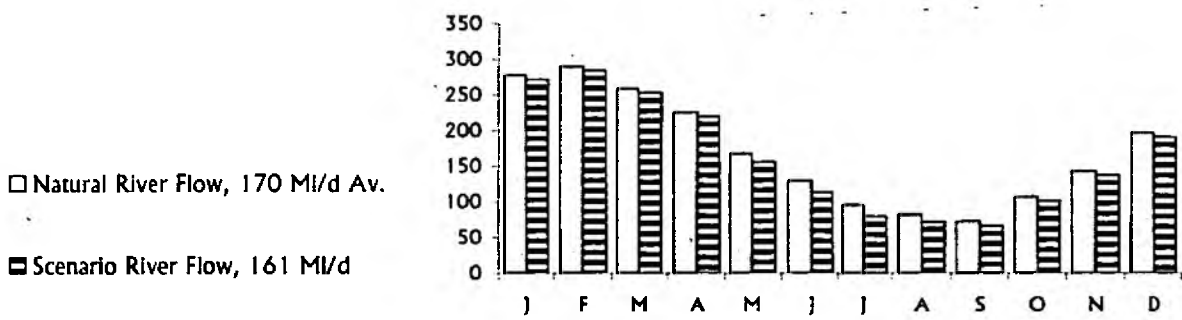
In the month of Jul



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)

Assessment for Areas which Drain to a River Outflow (protected worksheet)

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	278	290	259	226	168	130	96	82	72	107	143	197	
Scenario River Flow, 161 Ml/d	161	66	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	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

☐ Natural River Flow, 170 Ml/d

▭ Scenario River Flow, 161 Ml/d

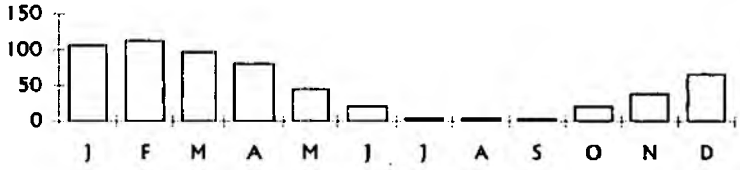
■ Target River Flow, 112 Ml/d

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

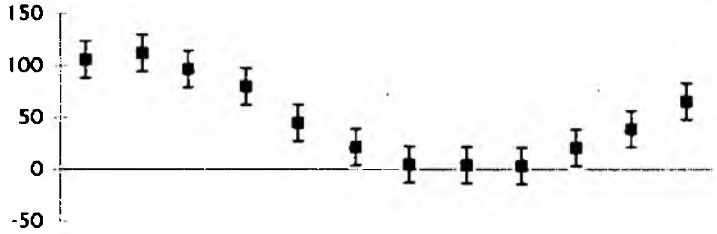
Surplus or Deficit = Scenario - Target River Flow Ml/d

	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	3.3	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	

☐ Scenario Surplus or Deficit, 49 Ml/d



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



Over the Whole Year,

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

Annual Average Natural River Flow

and minimum = **5%**

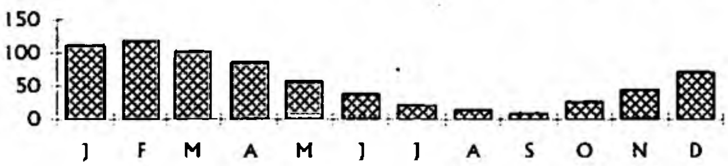
9.0 Acceptable Abstraction Impacts for Specified Year Given Target River Flows

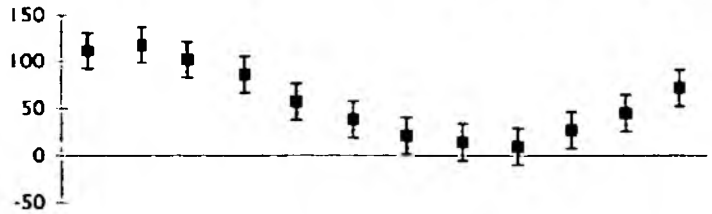
Defined as the total acceptable abstraction impact on outflows. This is simply calculated either by adding the scenario surplus or deficit to the scenario net consumptive abstraction impacts or by subtracting target from natural flows (Dependent only on natural and target flows, not on the abstraction 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	112	118	102	86	57	38	21	14	9	27	45	71	19

▩ Acceptable Abs Impacts, 58 Ml/d





Same Acceptable Abs Impacts plot with combined error bar of +/- 19 Ml/d

AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a River Outflow (protected worksheet)

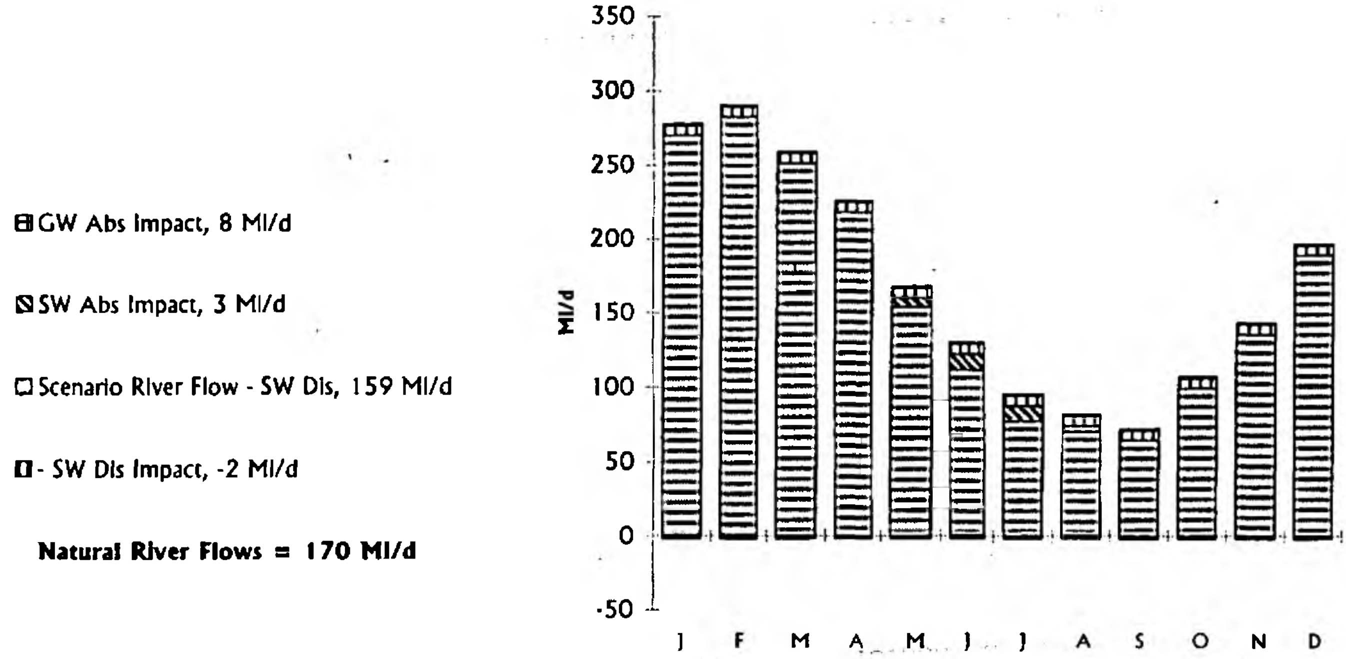
Area: R Thet at Melford Bridge GS | ID: ? | Version: 1 | Ledger Rev.: 1 | Date: 19/8/99

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)

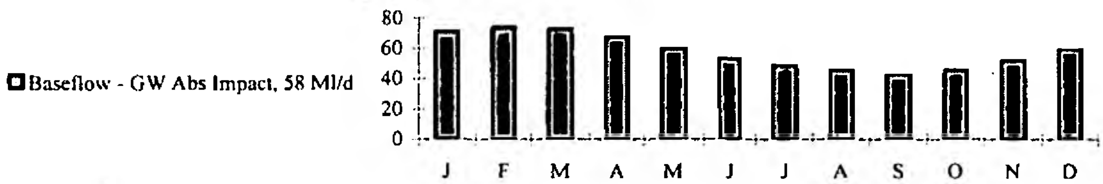


11 Natural Baseflow (Groundwater Resource) Minus Consumptive GW Abstraction Impact in Specified Year

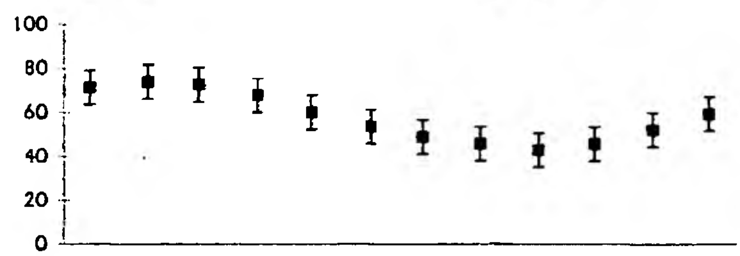
Only plotted if a baseflow has been specified at step 4.

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	8



Same Baseflow - GWAbs Impacts plot with combined error bar of +/- 8 Ml/d



AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a River Outflow (protected worksheet)

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: NONE

Combine Step 10 values from these assessments and paste values 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												

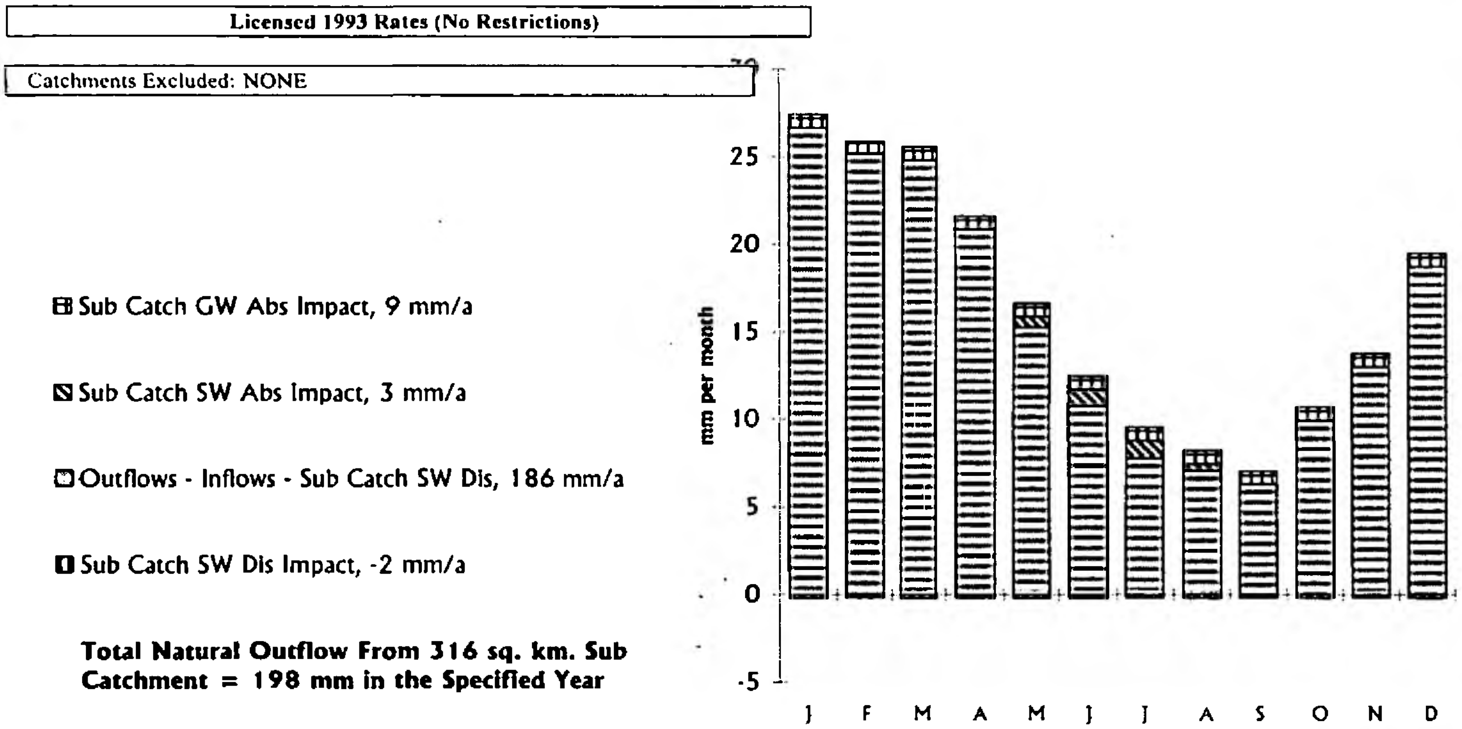
Combined Upstream SW catchment areas = sq km

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



	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** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Assessment for Areas which Drain to a River Outflow **(protected worksheet)**

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

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

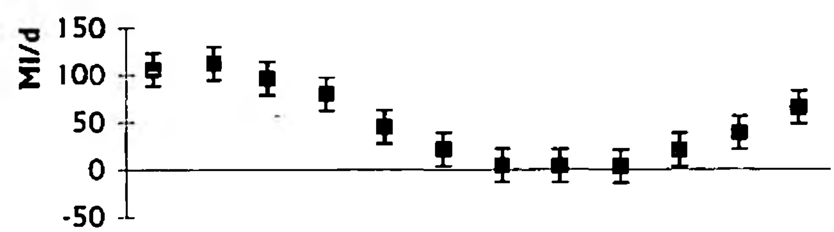
1.3 Surplus or Deficit Profile for Specified Year (= Scenario River Flow Minus Target River Flow)

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

Ann Av 49 **Ml/d**

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 : Not assigned at this trial stage - see discussion in Section 1.3.8 and note in Section 9.1 of the User Manual for further information. Step 3 (Management Action) also not complete

AVAILABLE RESOURCE METHODOLOGY (ARM)

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

Assessment for Areas which Drain to a River Outflow (protected worksheet)

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

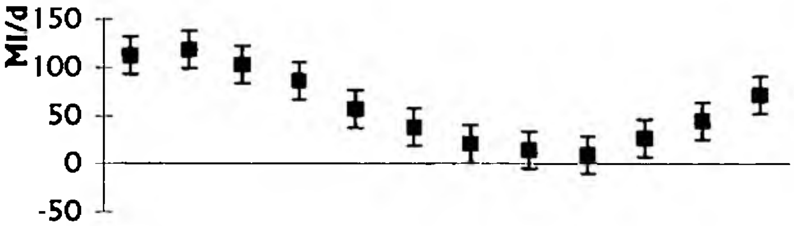
1.5 Acceptable Net Abstraction Impacts Profile for Specified Year (= Natural Flow Minus Target Flow)

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

Ann Av 58 Ml/d

Minimum 9 Ml/d

Uncertainty +/- 19 Ml/d



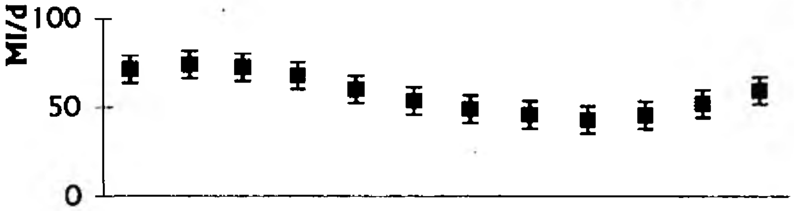
1.6 Natural Baseflow Minus Locally Consumptive Groundwater Abstraction Impact if baseflow (i.e. groundwater resource) has been separately defined

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

Ann Av 58 Ml/d

Minimum 43 Ml/d

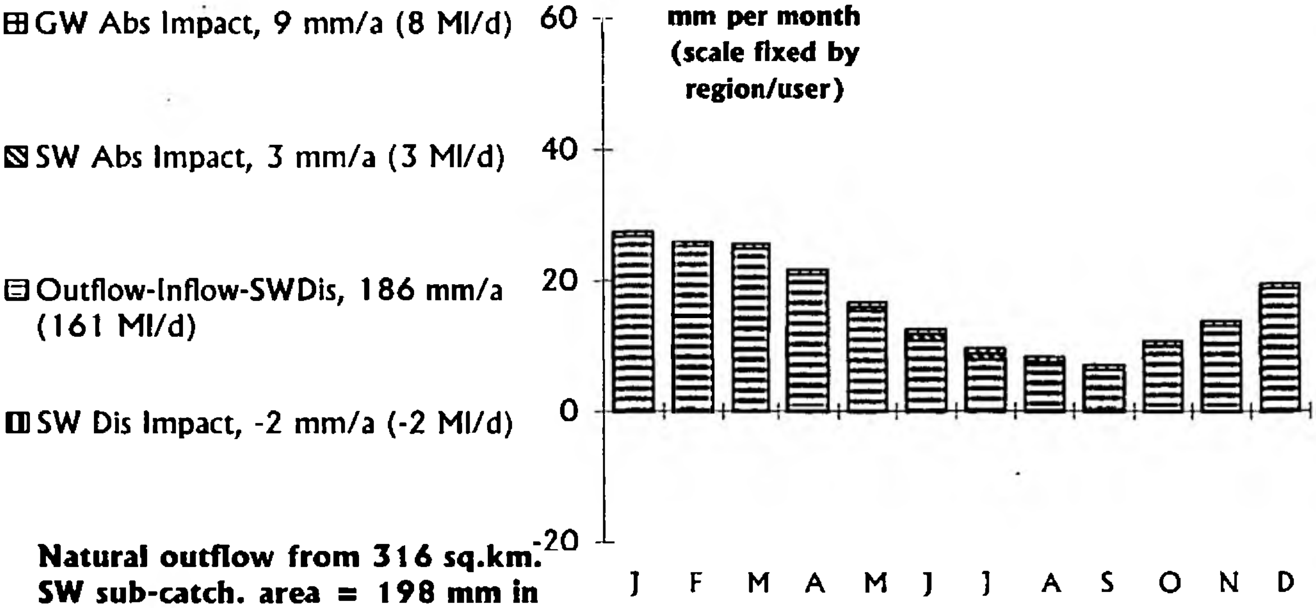
Uncertainty +/- 8 Ml/d



2 Outflow Components (Optionally Excluding Upstream Sub Catchments)

Upstream Catchments Excluded NONE

Flow Components Derived from the Sub Catchment
Expressed in mm/month Over 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 (excluding upstream catchme

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

Assessment for Areas which Drain to a River Outflow **(protected worksheet)**

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

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

(e.g. enhanced flow or level monitoring with regular licence review etc.)

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

Any need/plans to reassess resource soon?:

target date method

01/01/01 **CAMS ??**

4.2 Abstraction Ledger Update Control

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

In connection with licence numbers:

END OF SHEET

RIVER THET 1991 DROUGHT TRIAL ARM SPREADSHEET

RIVthetmel91.xls (not including Conceptual understanding sheet): 9 pages

AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a River Outflow (protected worksheet)

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

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

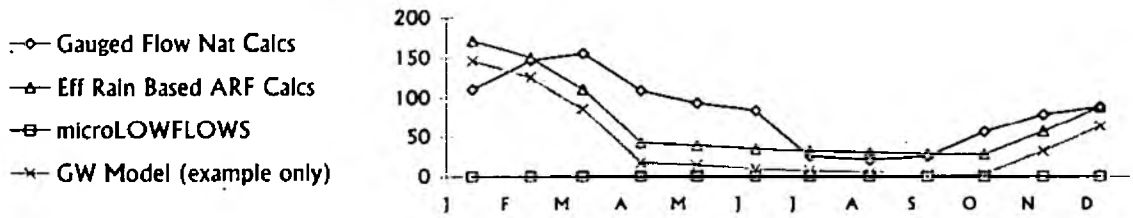
3.0 Natural River Flows in Specified Year to Define the Total Water Resource

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' workbook & refer to Agency national guidelines*),
b. Effective Rainfall Based Aquifer Response Function Calculations (*use the 'ARF' workbook*)
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.

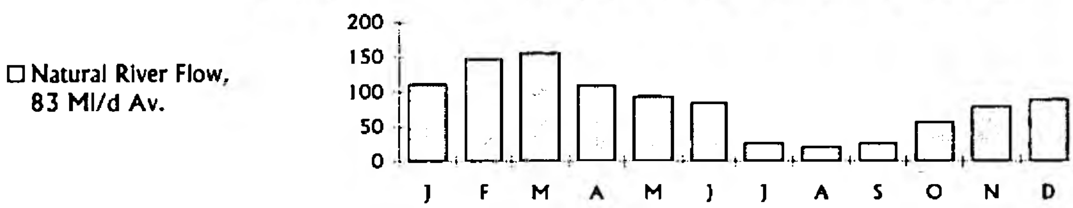
	Methods and Calculation References		*Select One type 'x'*		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	% Err.
a.	*Gauge* Sheet Results	ref: Gaugethetmel91.xls	x	Ml/d	83	21	111	147	156	109	93	84	26	21	26	56	79	88	21
b.	*ARF* Sheet Results	ref: ARFthetmel91.xls		Ml/d	68	28	172	151	111	43	39	35	32	30	29	28	57	89	15
c.	MicroLOWFLOWS	ref: none available		Ml/d	0	0													
d.	GW Model (example only)	ref: Example only for plot		Ml/d	43	3	147	126	86	18	14	10	7	5	4	3	32	64	10



Selected Method		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Natural River Flow, 83 Ml/	Gauged Flow Nat Calcs	83	21	111	147	156	109	93	84	26	21	26	56	79	88	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)

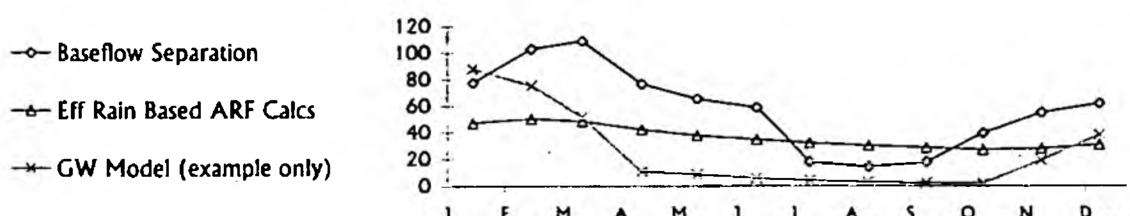
If a separate estimate of groundwater resources is required, enter the monthly averaged natural river baseflows, based on one or more of the following:

a. Baseflow Separation of Total Flow Hydrograph *(please reference method & calculations)*
b. Effective Rainfall Based Aquifer Response Function Calculations (*use the 'ARF' workbook)*
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% gauge nat flow		Ml/d	58	14	78	103	109	77	65	59	18	14	18	40	55	62	15
b.	*ARF* Sheet Results	ref: ARFthetmel91.xls	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)

Assessment for Areas which Drain to a River Outflow (protected worksheet)

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

Selected Method — **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	50	48	42	38	35	32	30	29	27	28	31	5
Implied Surface Runoff Flow	46	-10	64	97	107	67	56	49	-7	-10	-3	29	51	58	

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)**

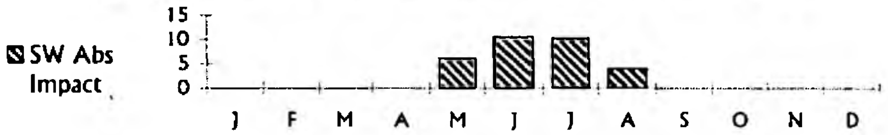
5.1 Scenario Surface Water Abstraction Impacts on River Flows in Specified Year

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

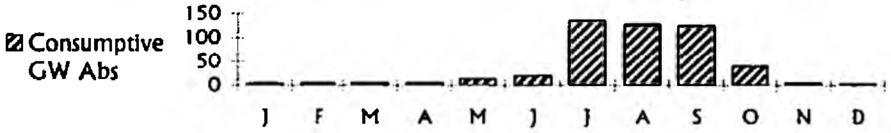
5.2 a. Scenario Groundwater Abstraction in the Month of Pumping

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



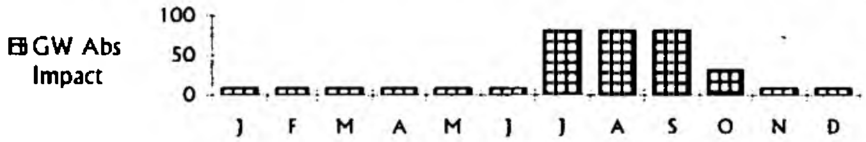
5.2 b. Scenario Groundwater Abstraction Impacts on River Flows in Specified Year

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)

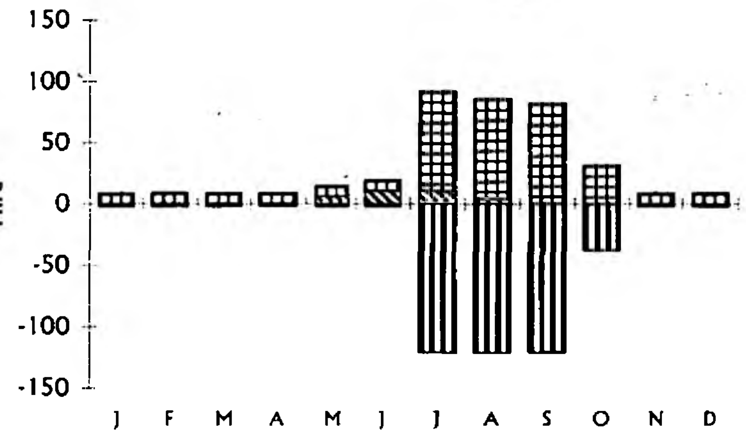
Assessment for Areas which Drain to a River Outflow (protected worksheet)

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, 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



GW Abs Impact, 29 Ml/d

SW Abs Impact, 3 Ml/d

- SW Dis Impact, -35 Ml/d

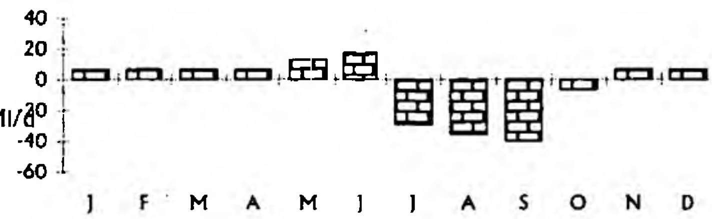
5.5 Scenario Net Consumptive Abstraction Impacts in Specified Year

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



Net Abs Impact, -4 Ml/d

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

Natural River Flow, 83 Ml/d Av.

Scenario River Flow, 86 Ml/d

AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a River Outflow (protected worksheet)

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, 83 Ml/d	83	21	111	147	156	109	93	84	26	21	26	56	79	88	
Scenario River Flow, 86 Ml/d	86	55	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 QMin 50 %	18	0	28	47	51	28	20	15	0	0	0	1	12	17	Err+/-
Target River Flow, 72 Ml/d Confidence: +/- 10 %	72	54	82	101	105	82	74	69	54	54	54	55	66	71	5

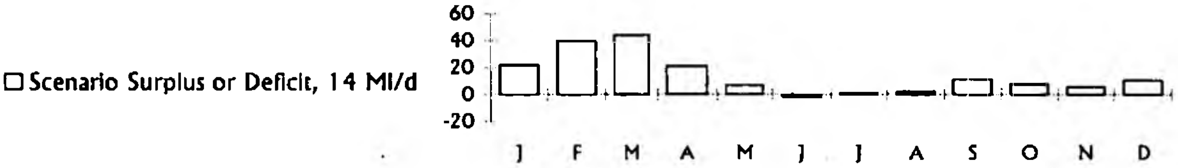
Compare with Q95 = 42 Ml/d Reported Elsewhere in

Ref: ih yearbook gauge Q95, 1962-95

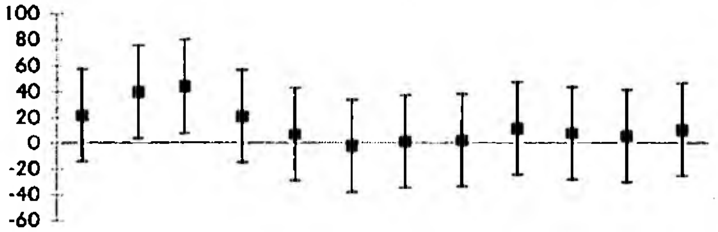
8.0 Scenario Surplus or Deficit for Specified Year, Given Target River Outflows

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, 14 Ml/d	14	-2.2	22	40	44	21	7	-2	1	2	12	8	6	11	36
Surplus or Deficit as % of Natural River Flow	17		20	27	28	19	7	-3	5	12	45	13	7	12	



Same surplus/deficit plot with combined error bar of +/- 36 Ml/d



Over the Whole Year,

Annual Average Surplus or Deficit = 17%

Annual Average Natural River Flow

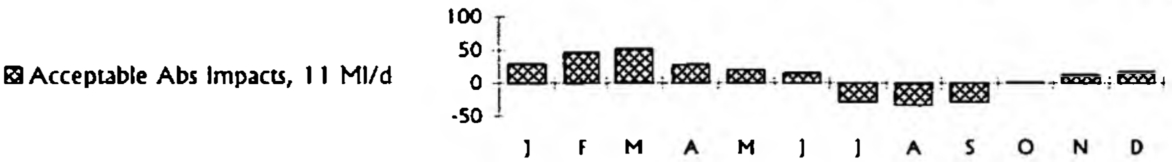
and minimum = -3%

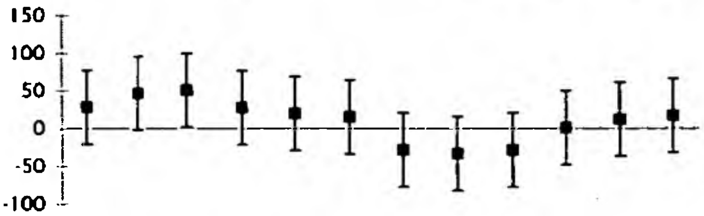
9.0 Acceptable Abstraction Impacts for Specified Year Given Target River Flows

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, 11 Ml/d	11	-33	28	47	51	28	20	15	-28	-33	-28	1	12	17	49





Same Acceptable Abs Impacts plot with combined error bar of +/- 49 Ml/d

AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a River Outflow (protected worksheet)

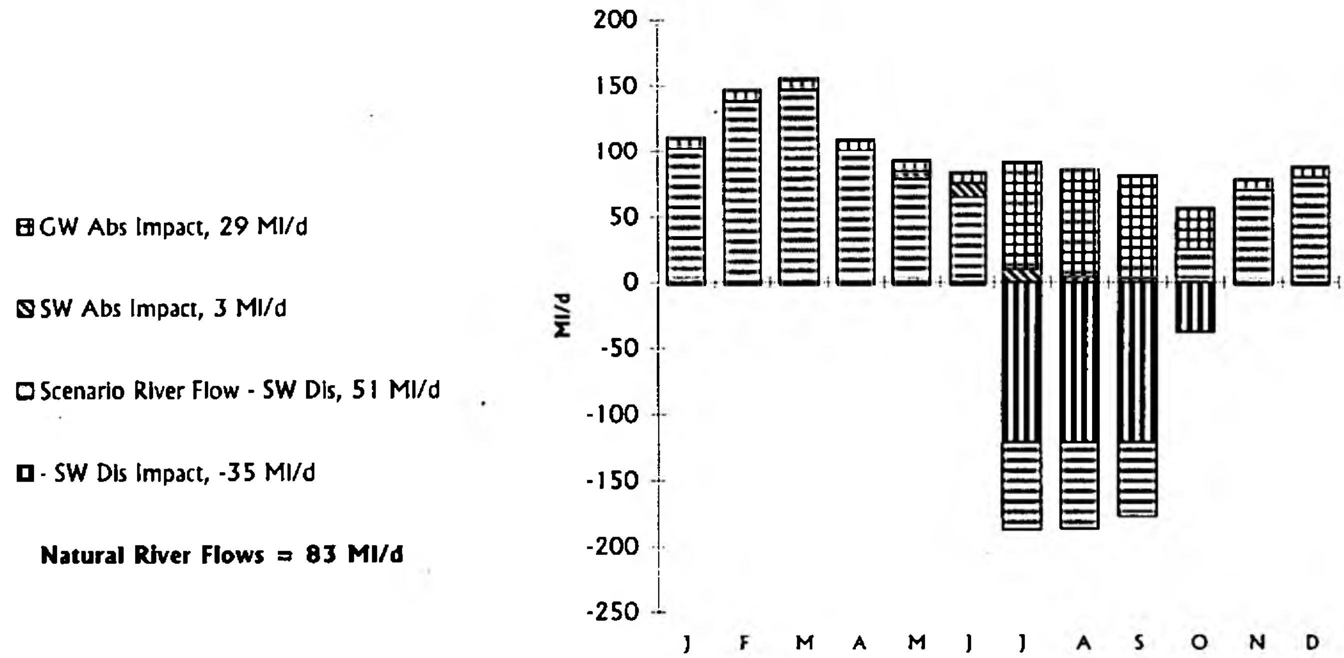
Area R Thet at Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

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, 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)

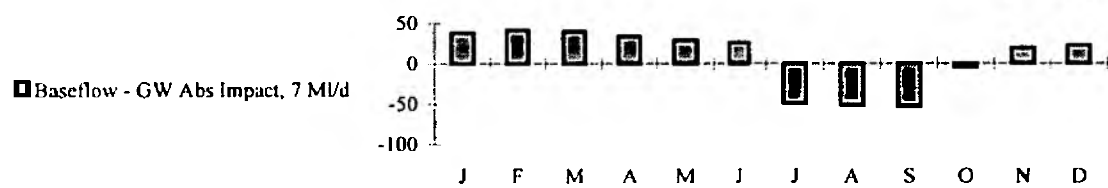


11 Natural Baseflow (Groundwater Resource) Minus Consumptive GW Abstraction Impact in Specified Year

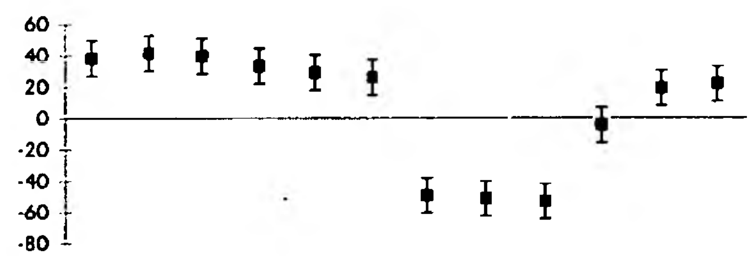
Only plotted if a baseflow has been specified at step 4.

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	11



Same Baseflow - GWAbs Impacts plot with combined error bar of +/- 11 Ml/d



AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a River Outflow **(protected worksheet)**

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: NONE

Combine Step 10 values from these assessments and paste values 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

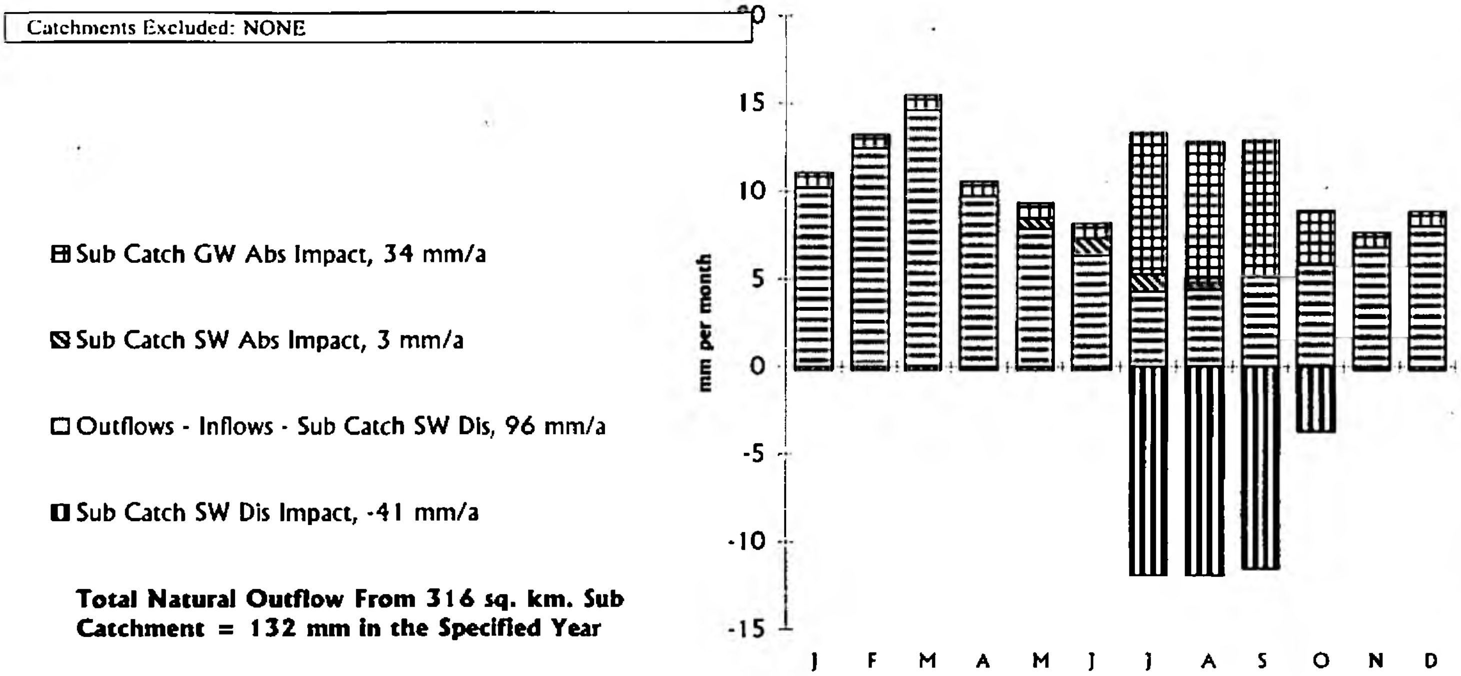
Surface Water Sub-Catchment Area for this plot 316 sq. km.

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)

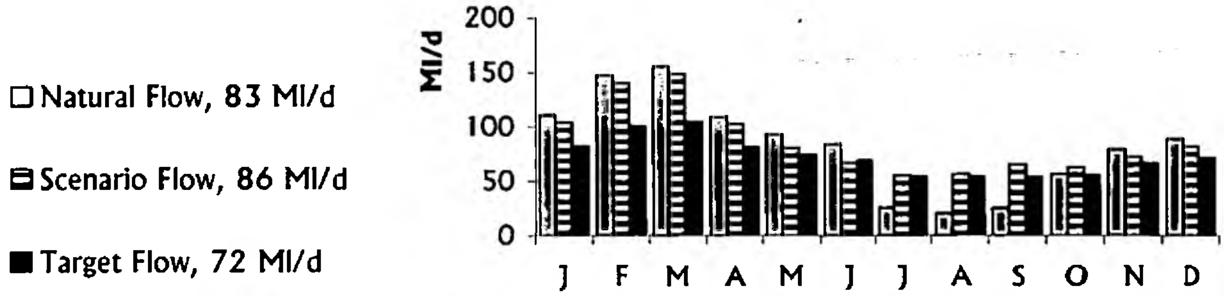
Area R Thet at Melford Bridge GS **ID** ? **Ver** 1 **Rev** 1 **Date** 19/8/99

Assessment for Areas which Drain to a River Outflow (protected worksheet)

Specified Assessment Year **Drought condition 1991** **Conclusions & QA**

1 Results Summary for the Total Catchment to the Outflow Point

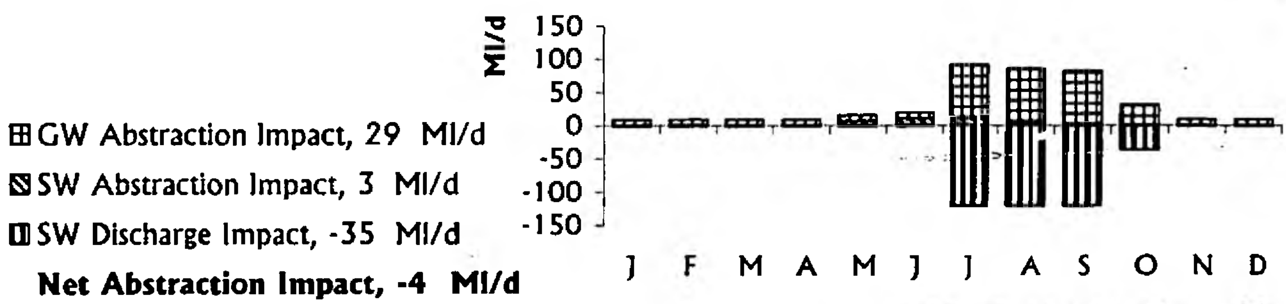
1.1 Natural, Scenario and Target River Flows for Specified Year (with Annual Average Rate Summary)



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

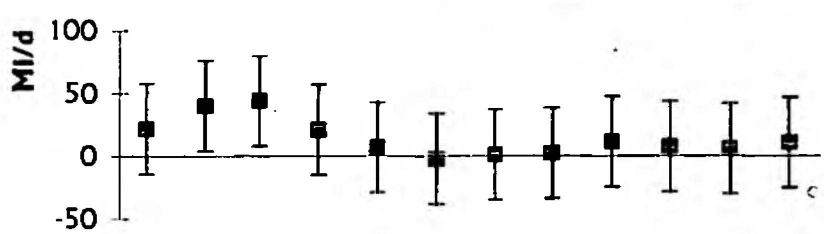
1.3 Surplus or Deficit Profile for Specified Year (= Scenario River Flow Minus Target River Flow)

	J	F	M	A	M	J	J	A	S	O	N	D
	22	40	44	21	7	-2	1	2	12	8	6	11

Ann Av 14 Ml/d

Minimum -2 Ml/d

Uncertainty +/- 36 Ml/d



Central value of Surplus or Deficit as % of Natural River Flow: **Ann Av** 17% **Min** -3%

1.4 Interpreted Sustainability Status of Resource Management at Outflow Point

Sustainability Status Category:

Comments : Not assigned at this trial stage - see discussion in Section 1.3.8 and note in Section 9.1 of the User Manual for further information. Step 3 (Management Action) also not complete

AVAILABLE RESOURCE METHODOLOGY (ARM)

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

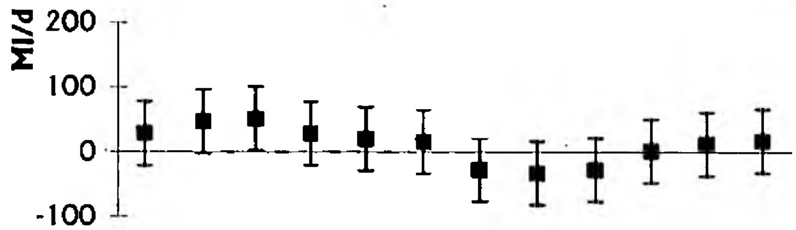
Assessment for Areas which Drain to a River Outflow (protected worksheet)

Specified Assessment Year Drought condition 1991 **Conclusions & QA**

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

Ann Av	11 Ml/d
Minimum	-33 Ml/d
Uncertainty +/-	49 Ml/d

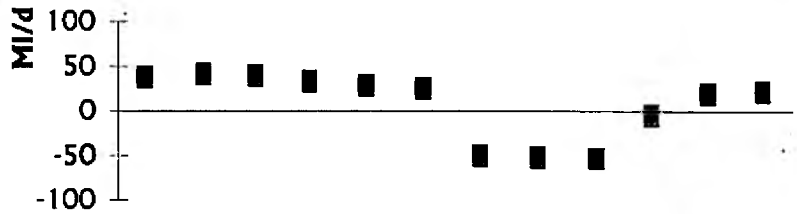
	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	28	47	51	28	20	15	-28	-33	-28	1	12	17



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

Ann Av	7 Ml/d
Minimum	-53 Ml/d
Uncertainty +/-	11 Ml/d

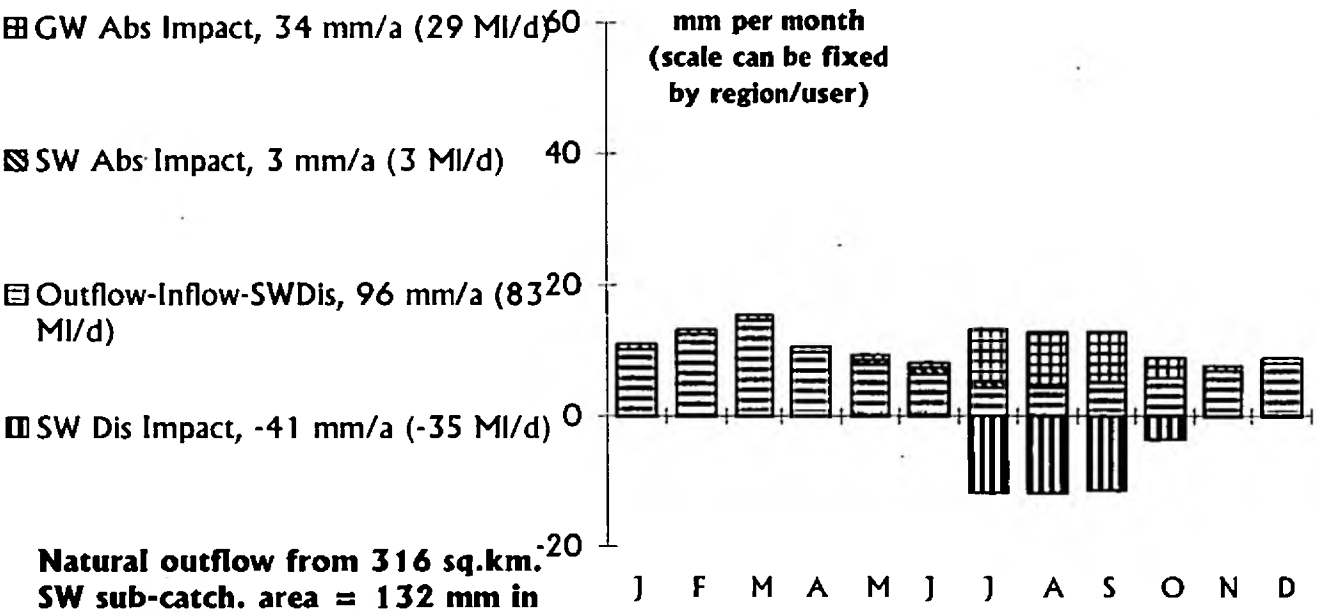
	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	38	41	40	33	29	26	-49	-51	-53	-4	19	22



2 Outflow Components (Optionally Excluding Upstream Sub Catchments)

Upstream Catchments Excluded NONE

Flow Components Derived from the Sub Catchment
Expressed in mm/month Over 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 (excluding upstream catchme

Max. (sub-catchment net abs impact/sub-catchment nat outflow) = 20 % in Jun

AVAILABLE RESOURCE METHODOLOGY (ARM)

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

Assessment for Areas which Drain to a River Outflow **(protected worksheet)**

Specified Assessment Year **Drought condition 1991** **Conclusions & QA**

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

(e.g. enhanced flow or level monitoring with regular licence review etc.)

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

Any need/plans to reassess resource soon?:

target date method

01/01/01 **CAMS the real thing**

4.2 Abstraction Ledger Update Control

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

In connection with licence numbers:

END OF SHEET

RIVER THET TRIAL OPTIONAL GAUGE NATURALISATION AND AQUIFER RESPONSE FUNCTION NATURAL FLOWS SPREADSHEETS FOR LTA & 1991 ASSESSMENTS

GAUGEthetmellta.xls & GAUGEthetmel91.xls: 2 pages each

ARFthetmellta.xls & ARFthetmel91.xls: 2 pages each

AVAILABLE RESOURCE METHODOLOGY (ARM)

(protected worksheet)

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

NATURAL RIVER FLOWS DERIVED FROM GAUGED FLOW NATURALISATION *(OPTIONAL)*

These calculations derive natural river flows by gauged flow naturalisation. Notes are provided throughout. Please also refer to Agency guidelines. Results *summarised in Step 4 can be pasted into the 'River Outflow Calcs' workbook for comparison with other natural flow estimates.*

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 should be as specified in the 'River Outflow Calcs' workbook)

2.0 Gauged River Flows in Specified Year

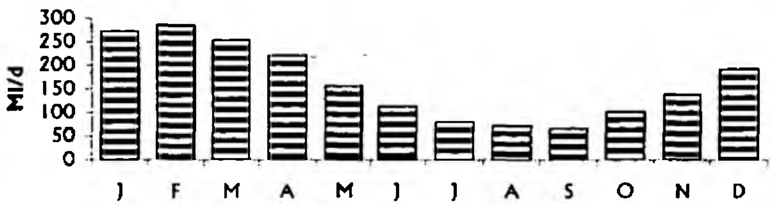
Enter the monthly averaged gauged river flows for the assessment year

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 i +/- 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 i +/- 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

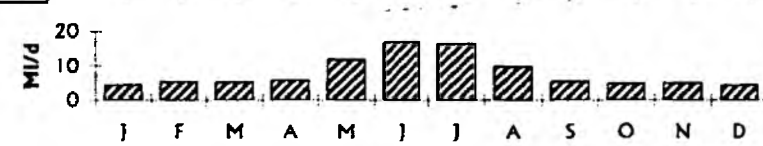
Assumptions and Calculations Ref: natcalsLTA.xls - 1993 licenced flow ignoring GOGWS * demand profile * uptake factor

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 i +/- 10 %

i.e. error bar assumed to be +/- 1 Ml/d



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

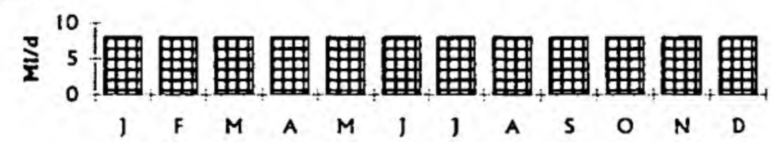
Impact Calcs Assumptions & reference: assuming fully smoothed steady state impacts

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 i +/- 20 %

i.e. error bar assumed to be +/- 2 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	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 i +/- 20 %

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

AVAILABLE RESOURCE METHODOLOGY (ARM)

(protected worksheet)

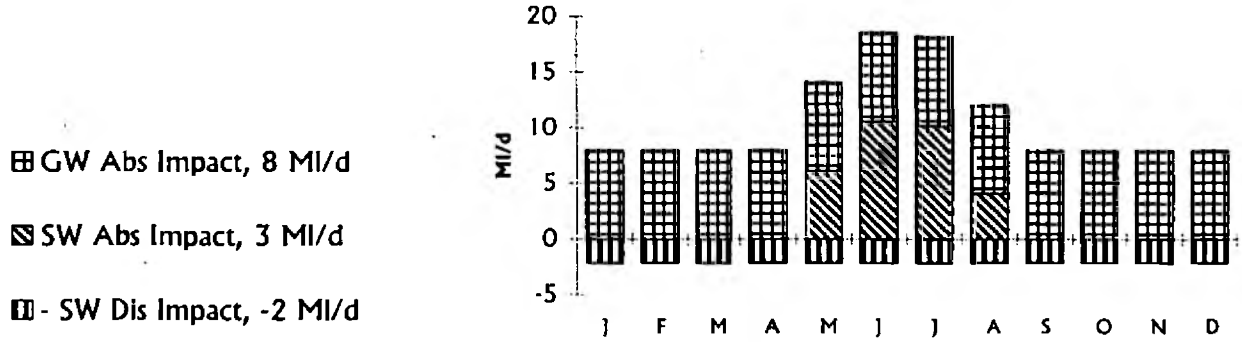
Area R Thet at Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

NATURAL RIVER FLOWS DERIVED FROM GAUGED FLOW NATURALISATION *(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

Net Abs Impacts = SW+GW Abs Impacts - SW Dis Impacts, Ml/d

Combined error bar is +/- 2 Ml/d

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

3.6 Result: Calculated Naturalised River Flows in Specified Year

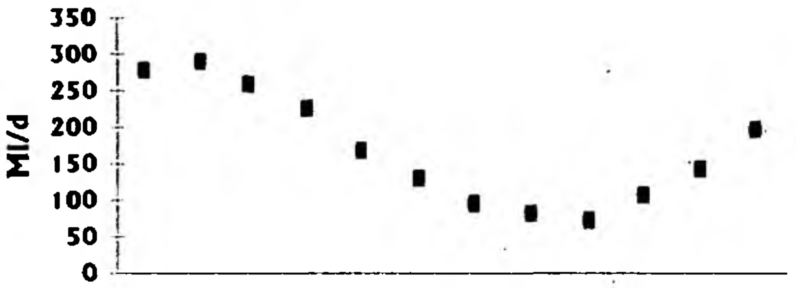
Naturalised Flow = Gauged Flows + Net Abs Impacts, Ml/d

Combined error bar is +/- 10 Ml/d

i.e. combined error bar is +/- 6 % of Average Naturalised Flows

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 Gauge Naturalised Flow Plot with Error Bars



4.0 Gauge Workbook Results Summary (copy to Riv_Outflow Workbook):

	J	F	M	A	M	J	J	A	S	O	N	D	% Err
Naturalised Total River Flow *(compare with other estimates!)*	278	290	259	226	168	130	96	82	72	107	143	197	6

('copy-paste special-values' into Step 3a of 'River Outflow Calcs' sheet)

AVAILABLE RESOURCE METHODOLOGY (ARM)

(protected worksheet)

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

NATURAL RIVER FLOWS DERIVED FROM GAUGED FLOW NATURALISATION *(OPTIONAL)*

5.0 **Naturalised River Flow Composition in Specified Year, as mm/month over Surface Catchment Area**

(For information only - equivalent of IoH yearbook 'gauged runoff' - not carried forward in calculations)

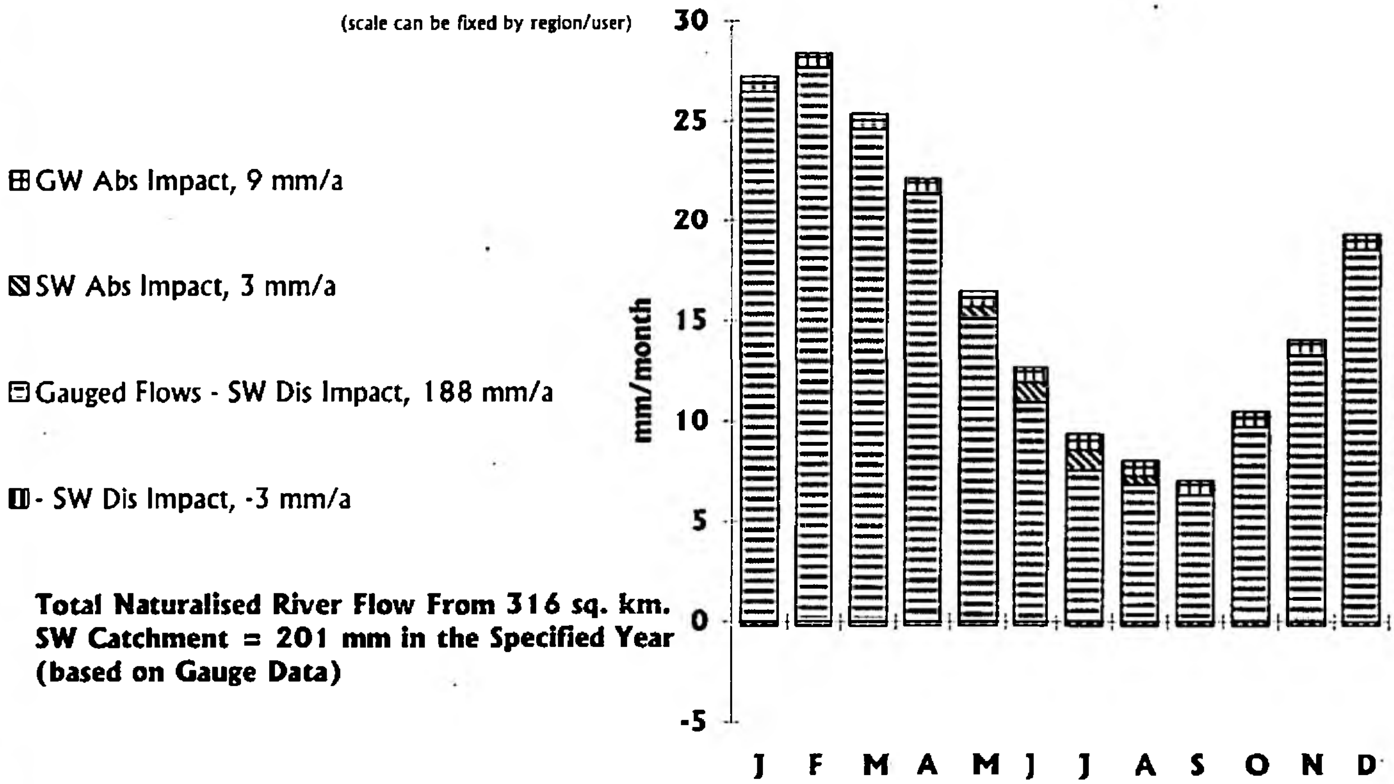
Surface Water Catchment to River Gauge in sq. km. = 316 Ref: ih hydrometric register, 91-95

(area from which runoff enters the river above the gauge) *(these should be as specified in the 'River Outflow Calcs' workbook)*

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)

(protected worksheet)

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

NATURAL RIVER FLOWS DERIVED FROM GAUGED FLOW NATURALISATION *(OPTIONAL)*

These calculations derive natural river flows by gauged flow naturalisation. Notes are provided throughout. Please also refer to Agency guidelines. Results summarised in Step 4 can be pasted into the 'River Outflow Calcs' workbook for comparison with other natural flow estimates.

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 should be as specified in the 'River Outflow Calcs' workbook)

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 i +/- 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: 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
Data compilation & calculation imply level of confidence in this data set i +/- 10 %	3	Ml/d	0	0	0	0	6	11	10	4	0	0	0	0

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

3.2 Groundwater Abstraction Impacts on River Flows in Specified Year

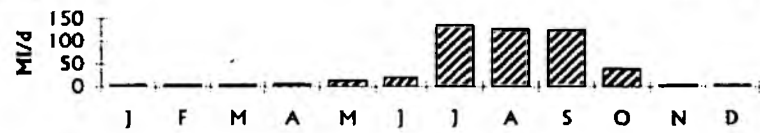
3.2 a. Groundwater Abstraction in the Month of Pumping

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
Data compilation & calculation imply av. level of confidence in this data set i +/- 15 %	41	Ml/d	4	5	5	6	14	20	135	127	125	39	5	4

i.e. error bar assumed to be +/- 6 Ml/d



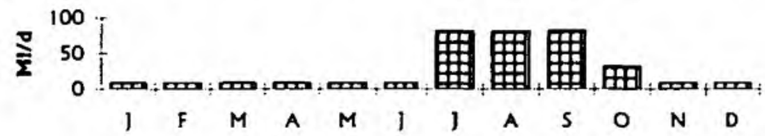
3.2 b. Groundwater Abstraction Impacts on River Flows in Specified Year

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
Data compilation & calculation imply av. level of confidence in this data set i +/- 20 %	29	Ml/d	9	9	9	9	9	9	82	82	82	32	9	9

i.e. error bar assumed to be +/- 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: 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
Data compilation & calculation imply av. level of confidence in this data set i +/- 20 %	35	Ml/d	2	2	2	2	2	2	122	122	122	38	2	2

i.e. error bar assumed to be +/- 7 Ml/d

AVAILABLE RESOURCE METHODOLOGY (ARM)

(protected worksheet)

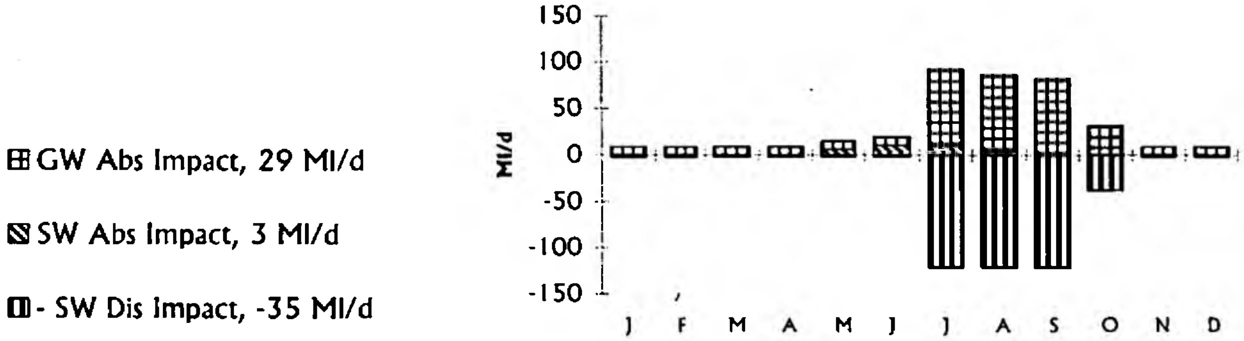
Area R Thet at Melford Bridge GS **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 19/8/99

NATURAL RIVER FLOWS DERIVED FROM GAUGED FLOW NATURALISATION *(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

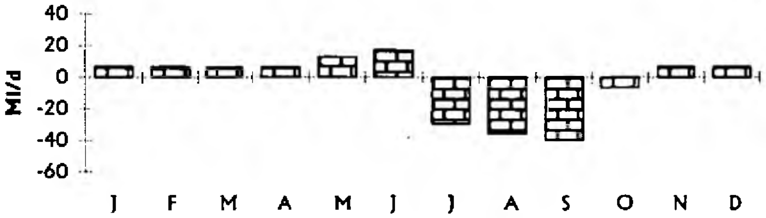


3.5 Calculated Net Consumptive Abstraction & Discharge Impacts in Specified Year

Net Abs Impacts = SW+GW Abs Impacts - SW Dis Impacts, Ml/d

Combined error bar is +/- 13 Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
-4	Ml/d	7	7	7	7	13	17	-30	-36	-40	-6	7	7



3.6 Result: Calculated Naturalised River Flows in Specified Year

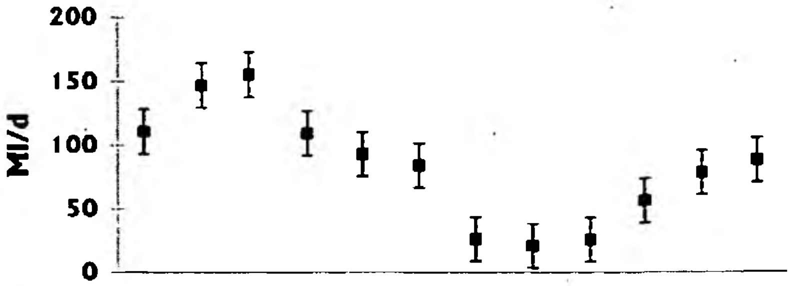
Naturalised Flow = Gauged Flows + Net Abs Impacts, Ml/d

Combined error bar is +/- 17 Ml/d

i.e. combined error bar is +/- 21 % of Average Naturalised Flows

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 Gauge Naturalised Flow Plot with Error Bars



4.0 Gauge Workbook Results Summary (copy to Riv_Outflow Workbook):

	J	F	M	A	M	J	J	A	S	O	N	D	% Err
Naturalised Total River Flow *(compare with other estimates!)*	111	147	156	109	93	84	26	21	26	56	79	88	21

('copy-paste special-values' into Step 3a of 'River Outflow Calcs' sheet)

AVAILABLE RESOURCE METHODOLOGY (ARM)

(protected worksheet)

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

NATURAL RIVER FLOWS DERIVED FROM GAUGED FLOW NATURALISATION *(OPTIONAL)*

5.0 **Naturalised River Flow Composition in Specified Year, as mm/month over Surface Catchment Area**

(For information only - equivalent of IoH yearbook 'gauged runoff' - not carried forward in calculations)

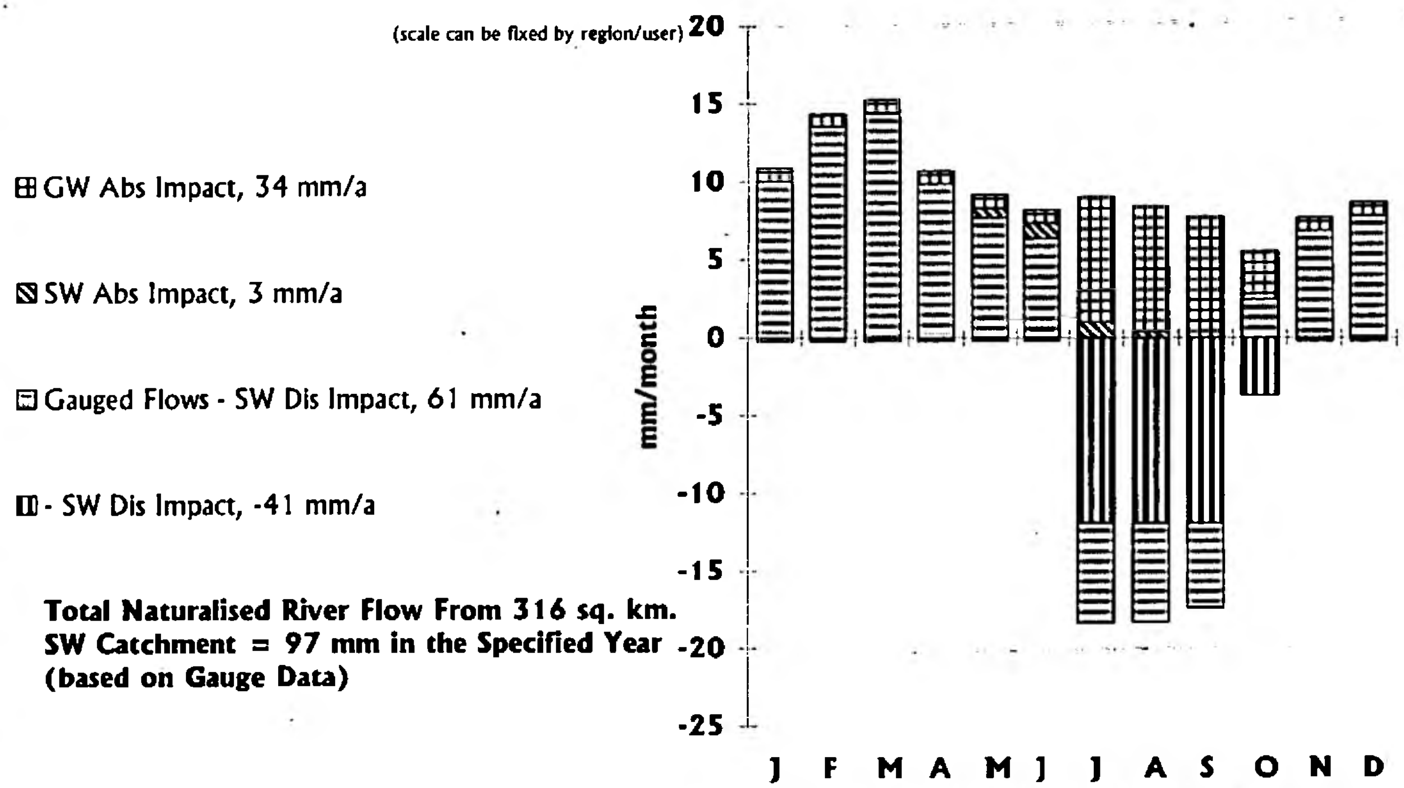
Surface Water Catchment to River Gauge in sq. km. = 316 Ref: ih hydrometric register, 91-95

(area from which runoff enters the river above the gauge) *(these should be as specified in the 'River Outflow Calcs' workbook)*

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)

(protected worksheet)

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

NAT. RIVER FLOWS & GW OUTFLOWS DERIVED FROM EFF. RAINFALL USING THE AQUIFER RESPONSE FUNCTION *(OPTIONAL)*

These calculations derive nat. total river flows & GW outflows from monthly hydrologically effective rainfall, assumptions of recharge/runoff split and catchment characteristics using the 'Aquifer Response Function' (ARF). After restating the assessment year (**Step 1**), **Step 2** calculations consider:

2a. flows in a year of 'average' rainfall (to achieve a reasonable simulation of 'average' baseflow and runoff using credible assumptions), then

2b. flows in the specified assessment year (based on effective rainfall data before and during the year and the same catchment response assumptions). Results summarised in **Step 3** can be pasted into the 'River Outflow Calcs' or 'GW Outflow Calcs' worksheets for comparison with other natural flow estimates (e.g. for river flows, estimates based on gauge flow naturalisation).

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 should be as specified in the 'River Outflow Calcs' or 'GW Outflow Calcs' workbook)

2 a. Natural River Flows or GW Outflows in an 'Average' Year Based on the Aquifer Response Function (ARF)

Areas	**sq km**	**Based on:**
Surface Water Catchment Area	316	ih hydrometric register, 91-95
*(**For Rivers**, area from which runoff drains above the assessed point. **For GW outflows**, equals GW catchment area)*		
Aquifer Area within the Surface Water Catchment	316	assume all area receives recharge
*(**For Rivers**, area from which runoff drains above assessed point and recharge enters aquifer. **For GW outflows**, equals GW catchment area)*		
Groundwater Catchment Area	316	sw c.area (approx) under avg. conditions
*(**For rivers**, aquifer area from which recharge would naturally discharge as baseflow above assessed point. **For GW outflow**, aquifer area from which recharge would naturally discharge over the outflow boundary)*		
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

Ann. Av. Recharge draining to river or across GW outflow boundary = 65.9 Ml/d = recharge % * eff rainfall * GW catch area

(equivalent to 76 mm/a over the GW catchment area)

Ann. Av. Runoff draining to river or 'lost' in GW outflow calcs = 83.9 Ml/d

=eff rainfall*(SW catch area - aquifer area in SW catch) + eff rainfall*aquifer runoff %*aquifer area in SW catch

For rivers, total discharge draining to river = 149.9 Ml/d =recharge input plus runoff input

(equivalent to 173 mm/a over the SW catchment area)

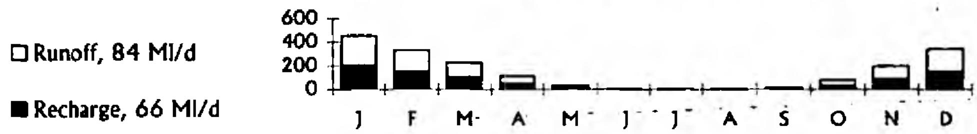
Calculated Average Distribution of Runoff and Recharge

Based on: Av = 1.00 **Av. Monthly Factors of Av. Ann. Rech & Runoff Rates**

	Av	J	F	M	A	M	J	J	A	S	O	N	D
Default values = typical MORECS square Eff. Rain. factors	1.00	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 Baseflow or GW Outflow Response to Recharge — **Based on:**

Recharge % draining to River or GW Outflow in the same month 0 % No karstic response

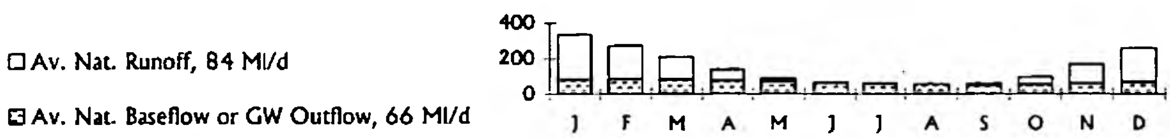
Aquifer Characteristics Controlling Slower Natural Baseflow or GW Outflow Response from Remaining Recharge

Total length of rivers or GW boundary draining GW catchment	30	km	measured length of Thet & main tribs
Average Storage (Specific Yield)	0.03	no units	approx. from Redgrave Model
Average Transmissivity	500	m2/d	approx. from Redgrave model

From these parameters and the GW catchment area, the Aquifer Response Time = 1664 days

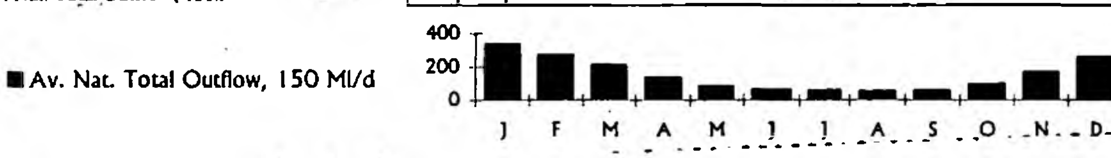
Average Natural Runoff and River Baseflow or GW Outflow — **Av. Nat. Runoff and River Baseflow or GW Outflow, Ml/d**

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Av. Nat. Runoff, 84 Ml/d	84	Ml/d	255	186	128	62	18	3	3	1	9	44	110	192
Av. Nat. Baseflow or GW Outflow, 66 Ml/d	66	Ml/d	80	84	82	76	68	61	57	53	51	52	57	68



Av. Nat. Total Outflow = Runoff + Baseflow or GW Outflow, Ml/d

	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D
Av. Nat. Total Outflow, 150 Ml/d	150	55	336	271	210	138	86	64	60	55	60	96	167	260



AVAILABLE RESOURCE METHODOLOGY (ARM)

(protected worksheet)

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

NAT. RIVER FLOWS & GW OUTFLOWS DERIVED FROM EFF. RAINFALL USING THE AQUIFER RESPONSE FUNCTION *(OPTIONAL)*

2 b. Natural River Flows or GW Outflows derived from Hydrologically Effective Rainfall in the Specified Assessment Year and Preceding Nine Years based on the Aquifer Response Function (ARF)

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

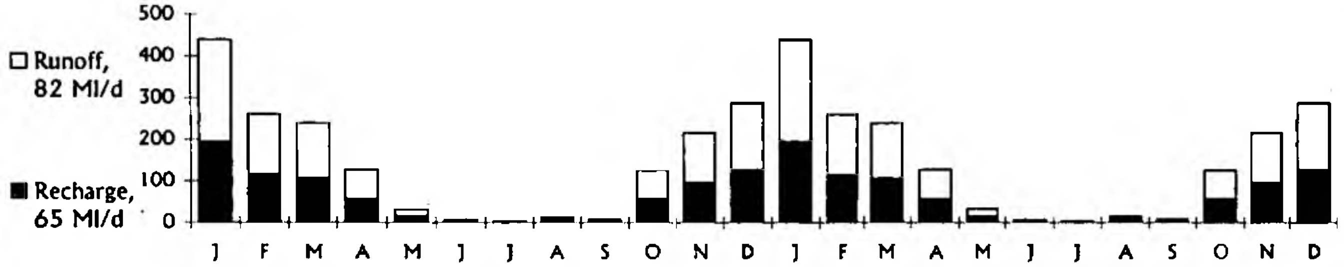
Data Source: Morecs square 130 ltav1970-90

Hydrologically Effective Rainfall for Preceding & Specified Year, mm/month

10 Yr Av		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	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

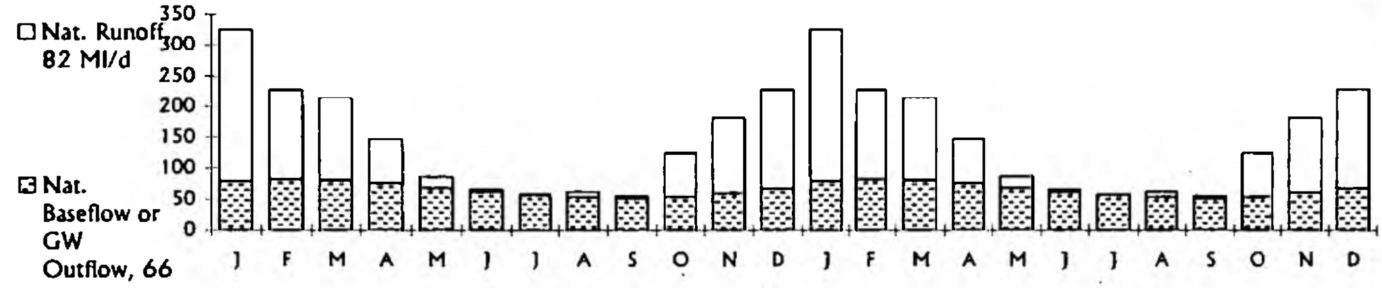
	Preceding Year												Specified Assessment Year												Yr
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	Av
Runoff, 82 Ml/d	246	146	134	71	19	4	2	8	5	71	121	161	246	146	134	71	19	4	2	8	5	71	121	161	82
Recharge, 65 Ml/d	193	115	105	56	15	3	1	7	4	56	95	127	193	115	105	56	15	3	1	7	4	56	95	127	65
																									Ml/d



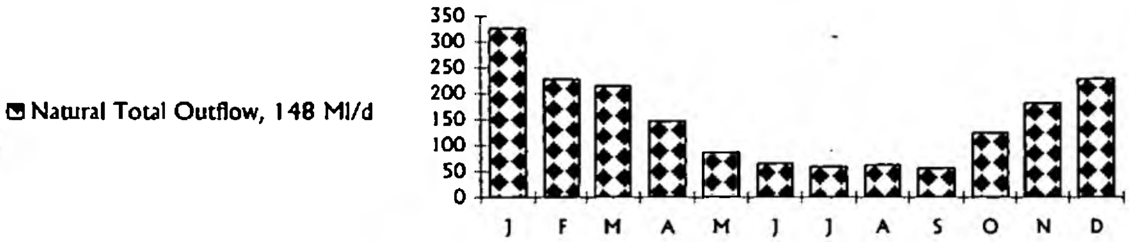
Data compilation & calculation imply av. level of confidence in this recharge is +/- 10 % i.e. error bar assumed to be +/- 6 Ml/d

Calculated Natural Runoff and River Baseflow or GW Outflow 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, 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
Nat. Baseflow or GW O	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



	Ann Av		Specified Assessment Year: Natural Total Outflow = Runoff + Baseflow, Ml/d											
			J	F	M	A	M	J	J	A	S	O	N	D
Natural Total Outflow, 148 Ml/d	148	Ml/d	325	228	215	147	87	66	58	62	56	124	181	228



Min. Natural Total Flow in this Year = 56 Ml/d

Data compilation & calculation imply av. level of confidence in this estimate is +/- 10 % i.e. error bar assumed to be +/- 15 Ml/d

3 ARF Workbook Result Summary (Copy to Riv_Outflow or GW_Outflow Workbooks):

	J	F	M	A	M	J	J	A	S	O	N	D	% Err
Natural Total River Flow	325	228	215	147	87	66	58	62	56	124	181	228	10

('copy-paste special-values' into Step 3b of 'River Outflow Calcs' sheet. Ignore for 'GW Outflow Calcs')

	J	F	M	A	M	J	J	A	S	O	N	D	Err
Natural River Baseflow or GW Outflow	79	82	80	76	68	61	57	54	51	54	60	67	10

END OF SHEET *('copy-paste special-values' into Step 4b of 'River Outflow Calcs' sheet or into Step 3b of 'GW Outflow Calcs' sheet)*

AVAILABLE RESOURCE METHODOLOGY (ARM)

(protected worksheet)

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

NAT. RIVER FLOWS & GW OUTFLOWS DERIVED FROM EFF. RAINFALL USING THE AQUIFER RESPONSE FUNCTION *(OPTIONAL)*

These calculations derive nat. total river flows & GW outflows from monthly hydrologically effective rainfall, assumptions of recharge/runoff split and catchment characteristics using the 'Aquifer Response Function' (ARF). After restating the assessment year (**Step1**), **Step 2** calculations consider:

2a. flows in a year of 'average' rainfall (to achieve a reasonable simulation of 'average' baseflow and runoff using credible assumptions), then

2b. flows in the specified assessment year (based on effective rainfall data before and during the year and the same catchment response assumptions).

Results summarised in **Step 3** can be pasted into the 'River Outflow Calcs' or 'GW Outflow Calcs' worksheets for comparison with other natural flow estimates (e.g. for river flows, estimates based on gauge flow naturalisation).

1 Year of Assessment

The year specified for this assessment is Drought condition 1991 Basis for selection of this year stressed resources & GOGWS

(these should be as specified in the 'River Outflow Calcs' or 'GW Outflow Calcs' workbook)

2 a. Natural River Flows or GW Outflows in an 'Average' Year Based on the Aquifer Response Function (ARF)

Areas	**sq km**	**Based on:**
Surface Water Catchment Area	316	ih hydrometric register, 91-95
(For Rivers, area from which runoff drains above the assessed point. For GW outflows, equals GW catchment area)		
Aquifer Area within the Surface Water Catchment	316	assume all area receives recharge
(For Rivers, area from which runoff drains above assessed point and recharge enters aquifer. For GW outflows, equals GW catchment area)		
Groundwater Catchment Area	296	sw catch area - ~20sq km for drought condition
(For rivers, aquifer area from which recharge would naturally discharge as baseflow above assessed point. For GW outflow, aquifer area from which recharge would naturally discharge over the outflow boundary)		

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

Ann. Av. Recharge draining to river or across GW outflow boundary = 61.8 Ml/d = recharge % * eff rainfall * GW catch area

(equivalent to 76 mm/a over the GW catchment area)

Ann. Av. Runoff draining to river or 'lost' in GW outflow calcs = 83.9 Ml/d

=eff rainfall*(SW catch area - aquifer area in SW catch) + eff rainfall*aquifer runoff %*aquifer area in SW catch

For rivers, total discharge draining to river = 145.7 Ml/d =recharge input plus runoff input

(equivalent to 168 mm/a over the SW catchment area)

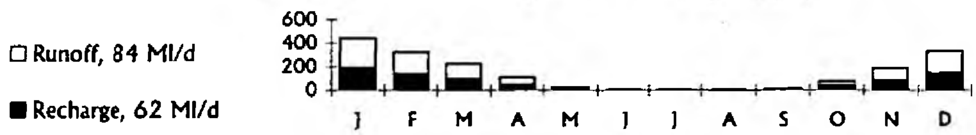
Calculated Average Distribution of Runoff and Recharge

Based on: Av = 1.00 **Av. Monthly Factors of Av. Ann. Rech & Runoff Rates**

	Av	J	F	M	A	M	J	J	A	S	O	N	D
Default values = typical MORECS square Eff. Rain. factors	1.00	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 Baseflow or GW Outflow Response to Recharge **Based on:**

Recharge % draining to River or GW Outflow in the same month 0 % No karstic response

Aquifer Characteristics Controlling Slower Natural Baseflow or GW Outflow Response from Remaining Recharge

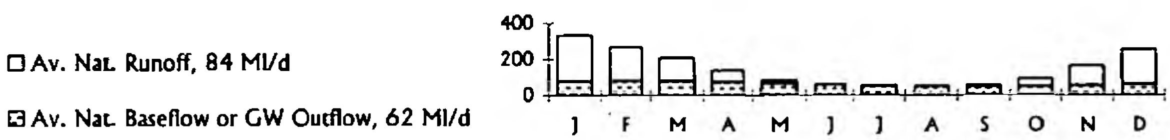
Total length of rivers or GW boundary draining GW catchment	30	km	measured length of Thet & main tribs
Average Storage (Specific Yield)	0.03	no units	approx. from Redgrave Model
Average Transmissivity	500	m2/d	approx. from Redgrave model

From these parameters and the GW catchment area, the Aquifer Response Time = 1460 days

Average Natural Runoff and River Baseflow or GW Outflow

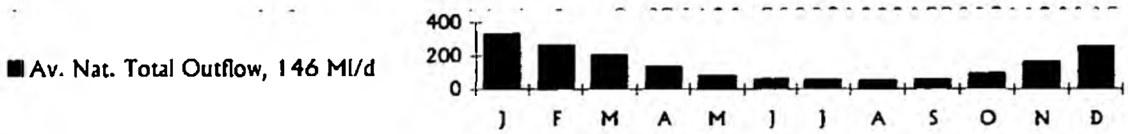
Av. Nat. Runoff and River Baseflow or GW Outflow, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Av. Nat. Runoff, 84 Ml/d	84	Ml/d	255	186	128	62	18	3	3	1	9	44	110	192
Av. Nat. Baseflow or GW Outflow, 62 Ml/d	62	Ml/d	76	80	78	72	64	57	53	49	47	48	53	64



Av. Nat. Total Outflow = Runoff + Baseflow or GW Outflow, Ml/d

	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D
Av. Nat. Total Outflow, 146 Ml/d	146	51	332	267	206	134	82	60	56	51	56	92	163	256



AVAILABLE RESOURCE METHODOLOGY (ARM)

(protected worksheet)

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

NAT. RIVER FLOWS & GW OUTFLOWS DERIVED FROM EFF. RAINFALL USING THE AQUIFER RESPONSE FUNCTION *(OPTIONAL)*

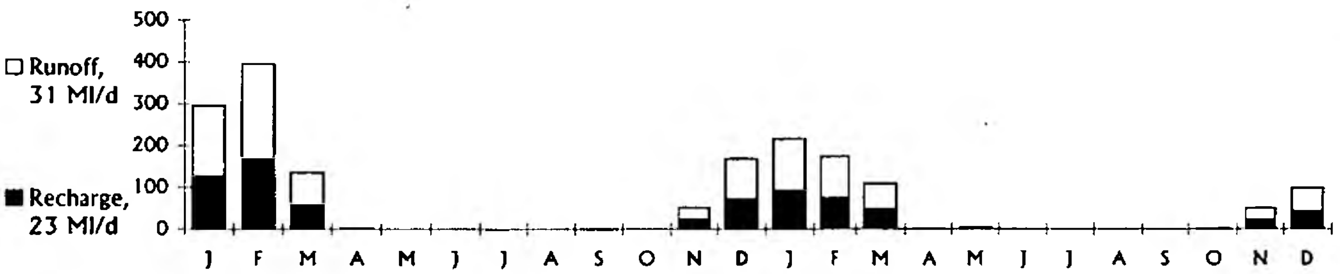
2 b. **Natural River Flows or GW Outflows derived from Hydrologically Effective Rainfall in the Specified Assessment Year and Preceding Nine Years based on the Aquifer Response Function (ARF)**
Hydrologically Effective Rainfall (HER) Data Entry
Enter 10 yrs of monthly HER values, yr 10 being that specified for assessment, in column DI from Row 24 down
Data Source: Morecs square 130, 1982 - 1991 drought year

Hydrologically Effective Rainfall for Preceding & Specified Year, mm/month

10 Yr Av		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	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

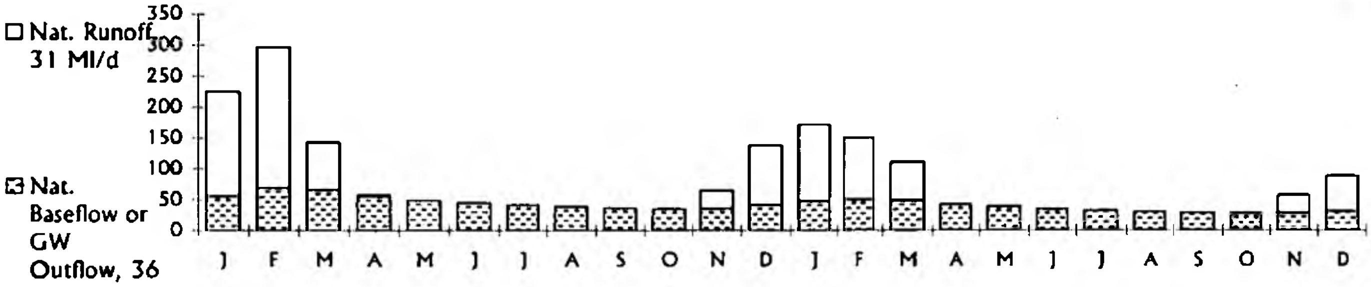
	Preceding Year												Specified Assessment Year												Yr
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	Av
Runoff, 31 Ml/d	171	228	78	2	0	0	0	0	0	0	30	97	124	100	63	1	2	0	0	0	0	1	29	58	31
Recharge, 23 Ml/d	126	168	58	2	0	0	0	0	0	0	22	71	92	74	46	0	1	0	0	0	0	1	21	42	23
																									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 River Baseflow or GW Outflow for Preceding & Specified Year, Ml/d

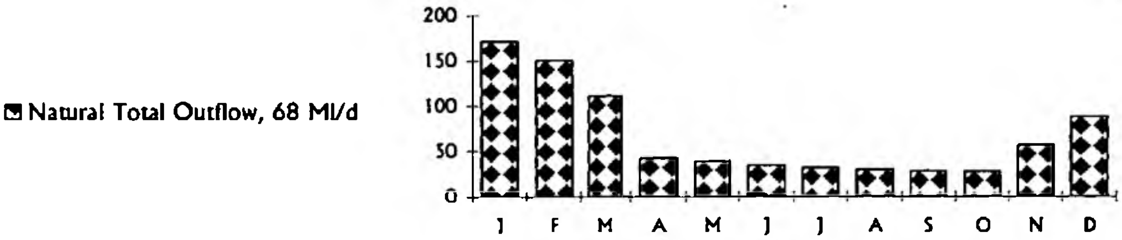
	Preceding Year												Specified Assessment Year												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	Av.
Nat. Runoff, 31 Ml/d	171	228	78	2	0	0	0	0	0	0	30	97	124	100	63	1	2	0	0	0	0	1	29	58	31
Nat. Baseflow or GW O	55	69	65	55	49	45	42	39	37	35	35	41	47	50	48	42	38	35	32	30	29	27	28	31	36
																									Ml/d



Specified Assessment Year

Natural Total Outflow = Runoff + Baseflow, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Natural Total Outflow, 68 Ml/d	68	Ml/d	172	151	111	43	39	35	32	30	29	28	57	89



Min. Natural Total Flow in this Year = 28 **Ml/d**

Data compilation & calculation imply av. level of confidence in this estimate is +/- 15 % i.e. error bar assumed to be +/- 10 Ml/d

3 **ARF Workbook Result Summary (Copy to Riv_Outflow or GW_Outflow Workbooks):**

	J	F	M	A	M	J	J	A	S	O	N	D	% Err
Natural Total River Flow	172	151	111	43	39	35	32	30	29	28	57	89	15

('copy-paste special-values' into Step 3b of 'River Outflow Calcs' sheet. Ignore for 'GW Outflow Calcs')

	J	F	M	A	M	J	J	A	S	O	N	D	Err
Natural River Baseflow or GW Outflow	47	50	48	42	38	35	32	30	29	27	28	31	15

END OF SHEET *('copy-paste special-values' into Step 4b of 'River Outflow Calcs' sheet or into Step 3b of 'GW Outflow Calcs' sheet)*

BRIGHTON BLOCK 1996 TRIAL VERSION 1 ARM SPREADSHEET (ASSUMING 'AVERAGE' RATE GWABS IMPACTS)

Gwbritot96v1.xls (including Conceptual understanding sheet): 11 pages

AVAILABLE RESOURCE METHODOLOGY (ARM)

Conceptual Understanding **(unprotected worksheet)**

Area Brighton Chalk Block (total) **ID** ? **Version** 1 **Ledger Rev** 1 **Date** 01-Feb-00

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 / Greensand 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: Gault Clay
Overlying solid or drift geology in Area: local head on downs and drift deposits along coast
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 Y Mixed
if confined, by what?

Recharge: Relevant processes (please tick):

Direct recharge:	Y
Stream/river leakage/runoff-recharge:	N
'Urban' leakage:	Y
Drift 'recharge reduction & smoothing':	Y

Recharge occurs over: All the area: Y Part of the Area:
If only part, which part: Locally reduced by head/coastal cover.Brighton mains leakage considered to make up for urban runoff losses

	year	season	month	week	day
Aquifer Response to Recharge (in words): 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:	springs & bournes only	Y
'naturally' rivers were:	springs & bournes only	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: Y No:

show on sketch plan & section and describe GW flow to sea & to tidal rivers

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

show on sketch plan & section and describe high T dry valleys & high winter T/low summer T

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

show on sketch plan & section and describe Coastal aquifer risk of summer saline intrusion

AVAILABLE RESOURCE METHODOLOGY (ARM)

Conceptual Understanding **(unprotected worksheet)**

Area Brighton Chalk Block (total) **ID** ? **Version** 1 **Ledger Rev** 1 **Date** 01-Feb-00

5 Observed Hydrological Trends and Environmental Concerns

5.1 Perceived Trends from 'Natural' to 1970

	falling	steady	rising	mixed	comment/data source
Groundwater levels:	Y?				No Data
River flows:					bournes only
GW abstraction:			Y		
SW abstraction:					No Swabs

5.2 Trends Evident from 1970 to Present

	falling	steady	rising	mixed	
Groundwater levels:		Y			
River flows:					bournes only
GW abstraction:		Y			
SW abstraction:					No SW abs

5.3 Relative Magnitude of Current Artificial Influences

Please rank by magnitude SW discharges, GW abstraction and SW abstraction

GWabs >> SWabs = Swdis to rivers = 0 (all sea outfalls)

Are there any other artificial influences on the catchment? (e.g. reservoirs, bulk transfer schemes etc.)

5.4 Water Resources Environmental Concerns

Please summarise river flows wetlands salinity Y other

Please explain: Risk of saline intrusion due to excessive pumping of coastal aquifer, winter flows in winterbourne & spring flows on northern scarp face

6 Previous Studies and Reason for this Assessment

Please List: Not fully reviewed. No recent modelling studies

Please explain why you are carrying out this assessment now:

To trial the spreadsheets in GW dominated area with spatially/seasonally variable T

AVAILABLE RESOURCE METHODOLOGY (ARM)

Conceptual Understanding **(unprotected worksheet)**

Area Brighton Chalk Block (total) **ID** ? **Version** 1 **Ledger Rev** 1 **Date** 01-Feb-00

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

see Figure 9.3 of main User Manual

Assessment Area is coincident with WHOLE BRIGHTON BLOCK within red boundary

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

END OF SHEET

AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Area Brighton Chalk Block (total) **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 1/2/00

1.0 Groundwater Catchment Area

Recharge catchment area to GW outflow boundary = 208 sq. km. Based on: planimetered sketch plan

2.0 Year or Hydrological Scenario of Assessment

The year specified for this assessment is Drought condition 1996 Basis for selection of this year stressed resources

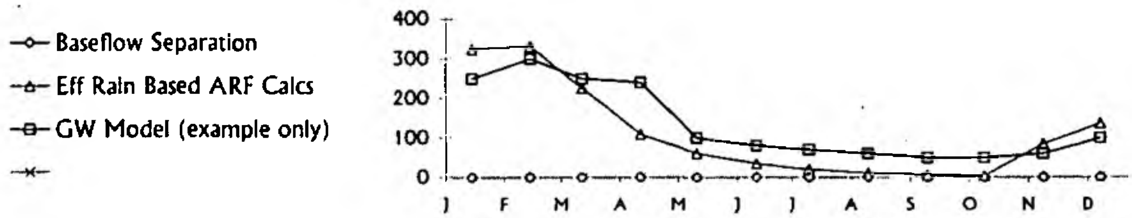
3.0 Natural Groundwater Outflows in Specified Year to Define the Groundwater Resource

Enter the monthly averaged natural GW outflows for the assessment year, and an associated % possible error, 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 'ARF' workbook)*
c. An Alternative Method e.g. Standard Hydrological Approaches, Groundwater Flow Model *(please reference method & calculations)*
d. An Alternative Method e.g. Standard Hydrological Approaches, Groundwater Flow Model *(please reference method & calculations)*

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

	Methods and Calculation References		*Select One type 'x'*		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	% Err.
a.	Baseflow Separation	ref:		Ml/d	0	0													
b.	*ARF* Sheet Results	ref: ARFBritot96.xls	x	Ml/d	111	4	324	331	226	109	61	35	20	11	6	4	85	137	25
c.	GW Model (example only)	ref: example for plot only		Ml/d	133	50	250	300	250	240	100	80	70	60	50	50	60	100	15
d.		ref:		Ml/d	0	0													



Selected Method		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Natural GW Outflow, 111	Eff Rain Based ARF Calcs	111	4	324	331	226	109	61	35	20	11	6	4	85	137	28

Annual Equivalent over GW Catchment is 195 mm/a

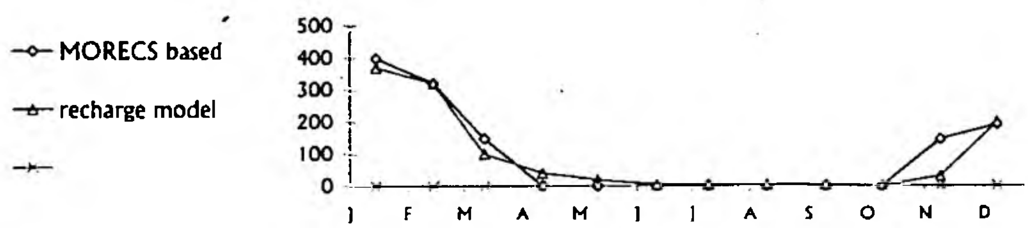
4.0 Recharge in Specified Year (optional)

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

a. MORECS effective rainfall, possibly factored to take account of drift *(please reference method & calculations)*
b. An Alternative Soil Moisture Balance Method *(please reference method & calculations)*
c. An Alternative Method *(please reference method & calculations)*

Compare these different estimates and select one to carry forward for comparison with groundwater abstractions in Step ??.

	Method and Calculation Reference		*Select One type 'x'*		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	% Err.
a.	MORECS based	ref: ARFbritot96.xls line 96	x	Ml/d	99	0	399	321	148	0	0	0	0	0	0	0	146	191	10
b.	recharge model	ref: example for plot only		Ml/d	91	0	370	320	100	40	20	5	5	5	5	0	30	200	5
c.		ref:		Ml/d	0	0													



AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Area Brighton Chalk Block (total) **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 1/2/00

Selected Method: MORECS based

Selected Recharge in Specified Year, Ml/d

		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Recharge, 99 Ml/d Av.	MORECS based	99	0	399	321	148	0	0	0	0	0	0	0	146	191	10
	Implied Surface Runoff Flow	12	-75	-75	10	78	109	61	35	20	11	6	4	-61	-54	

Annual Equivalent **Recharge** over GW Catchment is 174 mm/a

5.0 Impacts of Consumptive Groundwater Abstraction Scenario on Groundwater Outflows 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 not returned to groundwater. Surface water abstractions and discharges are ignored. Groundwater abstraction impacts on outflows 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 GWabs are based on (please describe Assumed Abstraction Management Scenario)
(e.g.full licensed 1999 rates/deployable output/actual 1999 rates) **Estimated Actual 1996 Rates**

5.0 a. Scenario Groundwater Abstraction in the Month of Pumping

Year 1996 Calcs in: briblock.xls - based on estimated actual abstraction returns

Data compilation & calculation imply av. level of confidence in this data set is +/- 3 %

Consumptive GW Abstraction, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
76	Ml/d	77	76	74	76	77	78	77	78	77	75	75	74	2

5.0 b. Scenario Groundwater Abstraction Impacts on GW Outflows in Specified Year

Impact Calcs Assumptions & reference: briblock.xls - impact conservatively assumed to be evenly distributed through the year

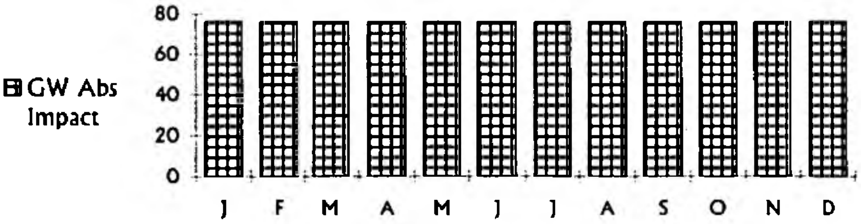
Data compilation & calculation imply av. level of confidence in this data set is +/- 20 %

GW Abstraction Impacts on GW Outflows, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
	76	Ml/d	76	76	76	76	76	76	76	76	76	76	76	76	15
GW Abs Impact/Natural GW Outflow, %	426	%	23	23	34	70	125	220	388	689	1214	2135	90	56	

Maximum Percentage Impact = 2135 %

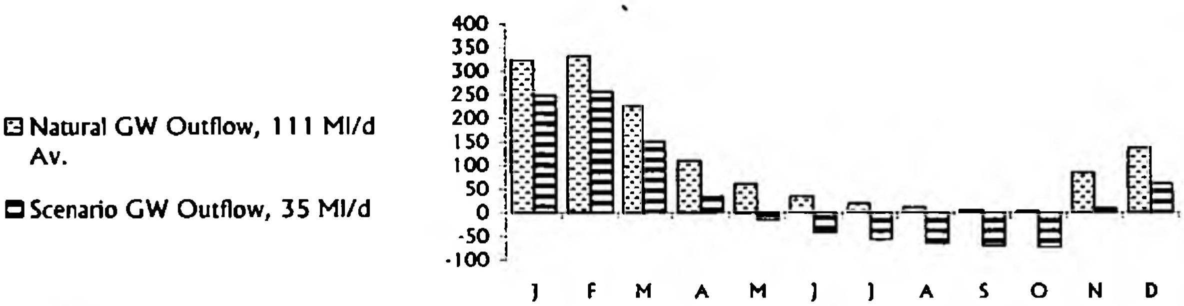
In the month of Oct



6.0 GW Outflows for this Artificial Impact Scenario in Specified Year

Scenario GW Outflow = Natural GW Flow - GW Abs Impact, Ml/d
= step 3 - step 5a

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Scenario GW Outflow, 35 Ml/d	35	Ml/d	248	255	150	33	-15	-42	-56	-65	-70	-73	9	61	43



AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Area Brighton Chalk Block (total) **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 1/2/00

7.0 Setting Target GW Outflows for Specified Year

Target flows based on (summarise): can allow small seasonal fluctuation of saline/freshwater interface

Calc/Authorisation Ref:

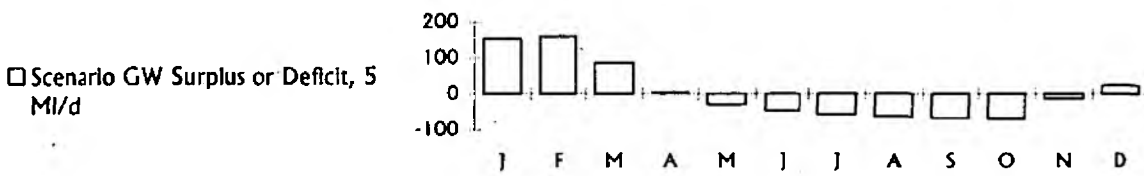
Natural, Scenario & Target GW Outflows, Ml/d

			Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	
Natural GW Outflow, 111 Ml/d			111	4	324	331	226	109	61	35	20	11	6	4	85	137	
Scenario GW Outflow, 35 Ml/d			35	-73	248	255	150	33	-15	-42	-56	-65	-70	-73	9	61	
Monthly Minimum Flow, Qmin			-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	Ml/d
% Acceptable Abs. Impact of QNat over QMin	70	%	35	3	99	101	69	34	20	12	7	5	3	3	27	43	Err+/-
Target GW Outflow, 30 Ml/d	Confidence: +/- 30	%	30	-2	94	96	64	29	15	7	2	0	-2	-2	22	38	-2

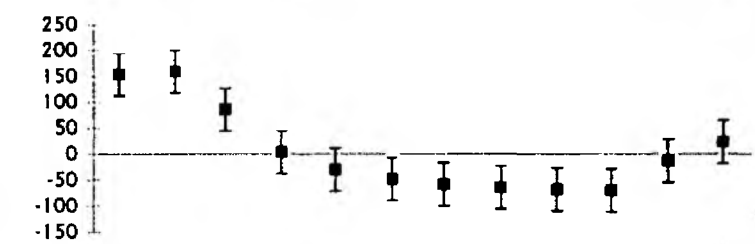
8.0 Scenario GW Surplus or Deficit for Specified Year, Given Target GW Outflows

GW Surplus or Deficit = Scenario - Target GW Outflow Ml/d

	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Scenario GW Surplus or Deficit, 5 Ml/d	5	-70.1	154	159	86	4	-30	-48	-59	-65	-68	-70	-13	23	42
Surplus or Deficit as % of Natural GW Outflow	5		48	48	38	4	-49	-140	-300	-587	-1088	-1966	-16	17	



Same surplus/deficit plot with combined error bar of +/- 42 Ml/d



Over the Whole Year,

Annual Average Surplus or Deficit = **5%**

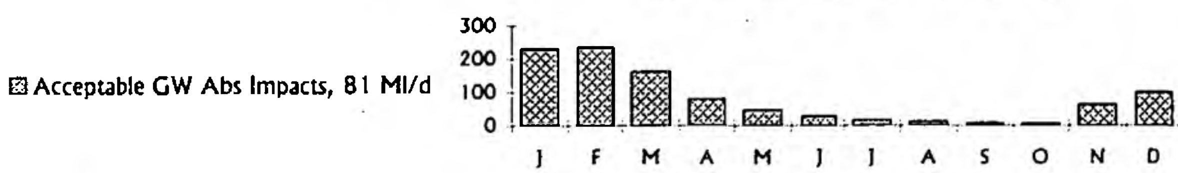
Annual Average Natural GW Outflow and minimum = **<-100%**

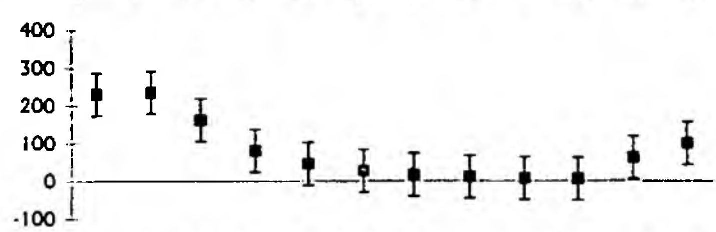
9.0 Acceptable GW Abstraction Impacts for Specified Year Given Target GW Outflows

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 GW Abs. Impacts for Specified Year, Ml/d

	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Acceptable GW Abs Impacts, 81 Ml/d	81	6	230	236	162	80	46	28	17	11	8	6	63	99	57





Same acceptable GW abstraction impact plot wi combined error bar of +/- 57 Ml/d

AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Area	ID	Version	Ledger Rev.	Date
Brighton Chalk Block (total)	?	1	1	1/2/00

10 Scenario GW Outflow Composition from Total GW Catchment in Specified Year

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Scenario GW Outflow, 35 Ml/d	35	Ml/d	248	255	150	33	-15	-42	-56	-65	-70	-73	9	61
GW Abs Impact, 76 Ml/d	76	Ml/d	76	76	76	76	76	76	76	76	76	76	76	76
Natural GW Outflows = 111 Ml/d	111	Ml/d												

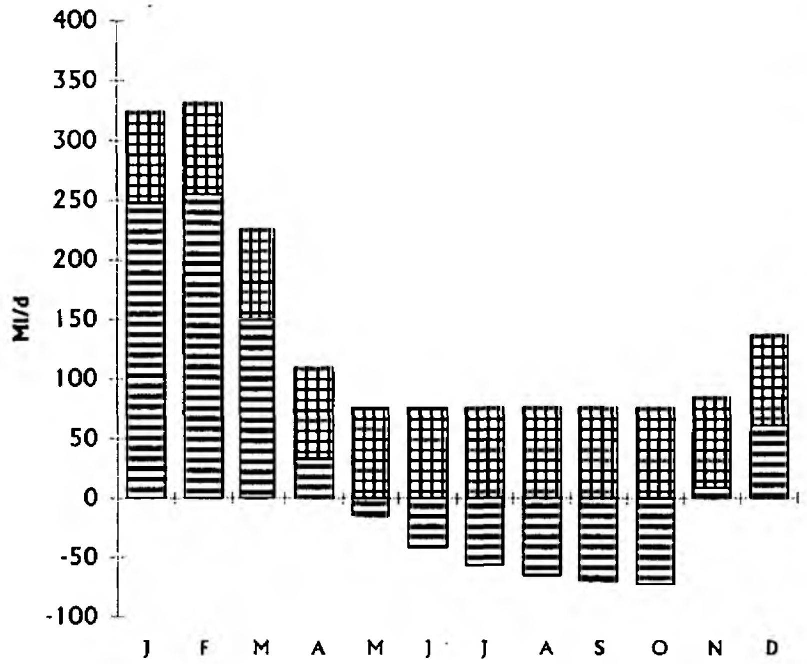
GW catchment area = 208 sq km

Estimated Actual 1996 Rates

GW Abs Impact, 76 Ml/d

Scenario GW Outflow, 35 Ml/d

Natural GW Outflows = 111 Ml/d



11 Recharge Minus Consumptive GW Abstraction (as pumped) in Specified Year

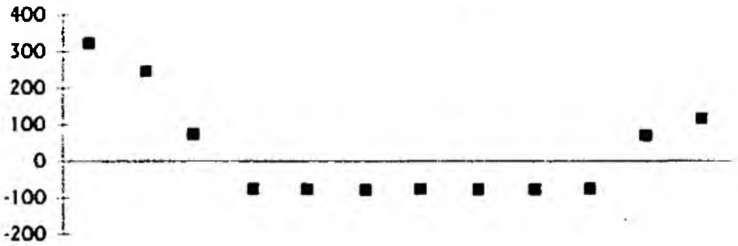
Only plotted if a recharge profile has been separately defined at step 4.

Natural Recharge - Consumptive GW Abs. As pumped, Ml/d = step 4 - step 5a

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Recharge - GW Abs, 23 Ml/d	23	Ml/d	322	245	73	-76	-77	-78	-77	-78	-77	-75	71	117	12

Recharge - GW Abs, 23 Ml/d

Same Baseflow - GWAbs Impacts plot with combined error bar of +/- 12 Ml/d



AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Area Brighton Chalk Block (total) **ID** ? **Version** 1 **Ledger Rev.** 1 **Date** 1/2/00

12 Scenario Outflow Composition from GW Catchment in Specified Year, as mm/month over GW Catchment

This plot expresses the scenario outflow components as mm per month over the groundwater catchment area.
The step 10 values from smaller parts of thie assessment areas can be combined and pasted below in order to plot the outflows from the remaining part only. If no values are pasted in, the plot represents the entire GW catchment assessed.

Identify the areas to be excluded from the plot: Areas Excluded: NONE

Combine Step 10 values from these assessments and paste values below.

Scenario Outflow Values (Step 10) from sub-areas, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Scenario GW Outflow, 0 Ml/d	0	Ml/d												
GW Abs Impact, 0 Ml/d	0	Ml/d												

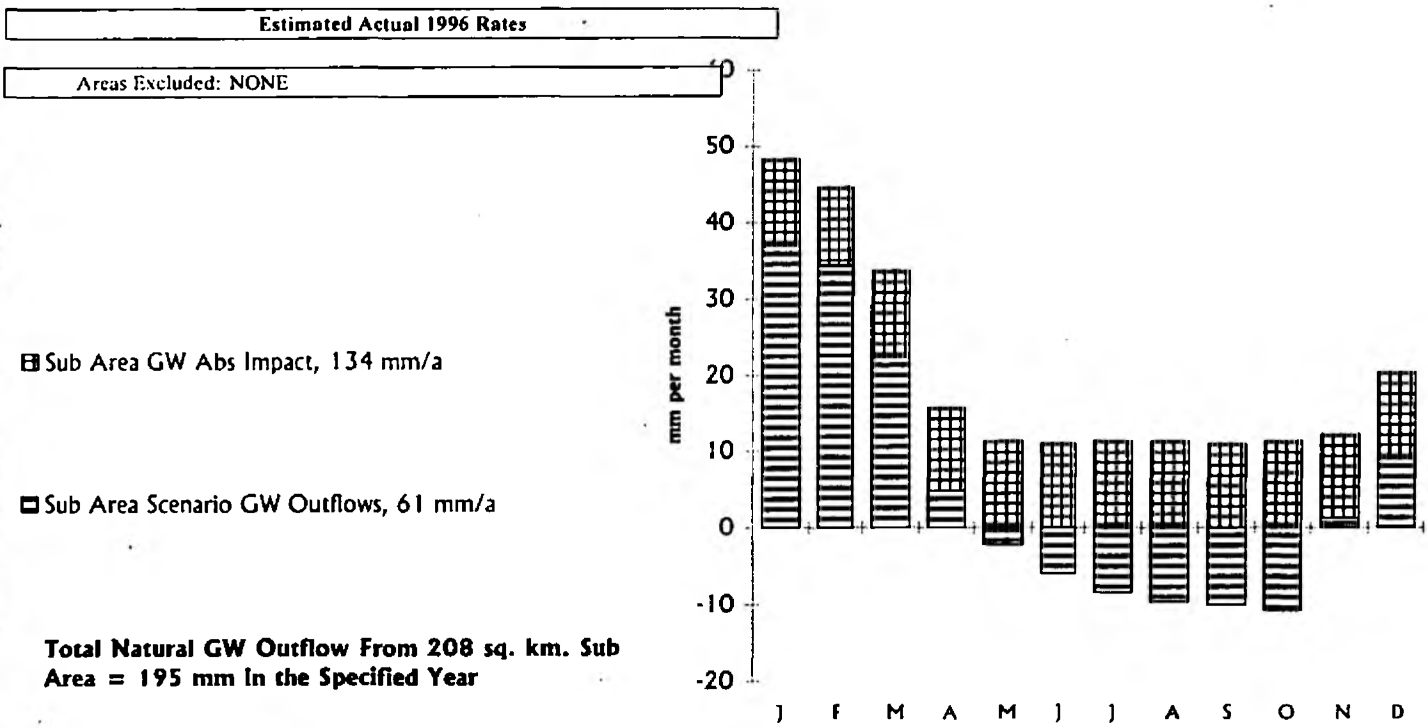
Combined GW catchment sub-areas to ignore = sq km

Groundwater Sub-Catchment Area for this plot 208 sq. km.

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

	Ann Tot		J	F	M	A	M	J	J	A	S	O	N	D
Sub Area GW Abs Impact, 134 mm/a	134	mm/a	11	10	11	11	11	11	11	11	11	11	11	11
Sub Area Scenario GW Outflows, 61 mm/a	61	mm/a	37	34	22	5	-2	-6	-8	-10	-10	-11	1	9

Total Natural GW Outflow From 208 sq. km. Sub Area = 195 mm in the Specified Year



	J	F	M	A	M	J	J	A	S	O	N	D
% (net abs impact for sub-catchment)/(nat outflow from sub-catchment) =	23	23	34	70	125	220	388	689	1214	2135	90	56

Maximum net GW abs. impact for this sub-catchment area only (exluding other sub-areas)

Max. (sub-catchment net abs impact/sub-catchment nat outflow) = 2135 % in Oct

END OF SHEET

AVAILABLE RESOURCE METHODOLOGY (ARM)

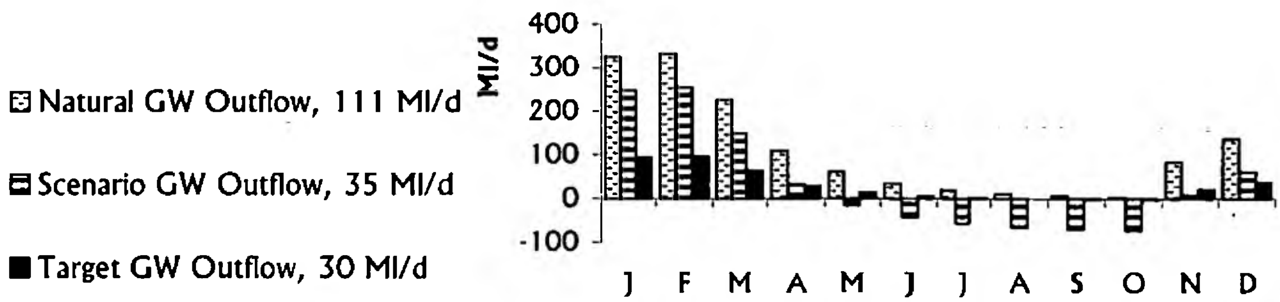
Area Brighton Chalk Block (total) **ID** ? **Ver** 1 **Rev** 1 **Date** 1/2/00

GW Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Specified Assessment Year **Drought condition 1996** **Conclusions & QA**

1 Results Summary for the GW Catchment to the GW Outflow Boundary

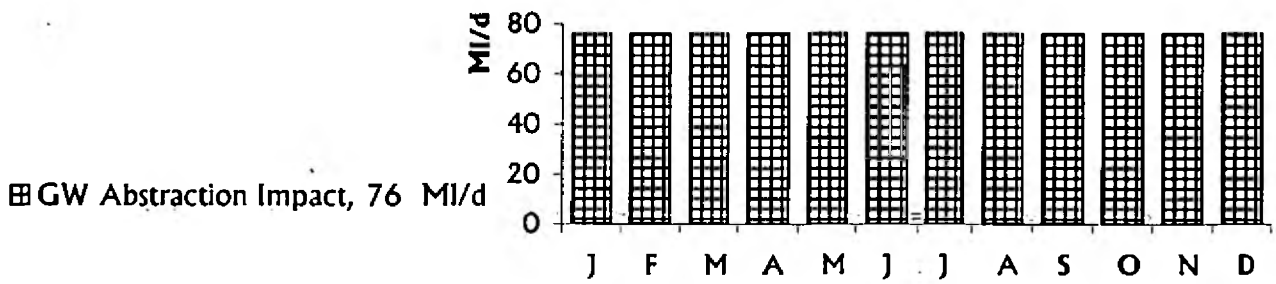
1.1 Natural, Scenario and Target GW Outflows for Specified Year (with Annual Average Rate Summary)



Target Flows based on: can allow small seasonal fluctuation of saline/freshwater interface

1.2 Scenario GW Abstraction Impacts (with Annual Average Rate Summary)

GW Abs Scenario: Estimated Actual 1996 Rates



Maximum GW abstraction impact for total area based on
Max. (GW abs impact/naturalGW Outflow from total area) = 2135 % in Oct

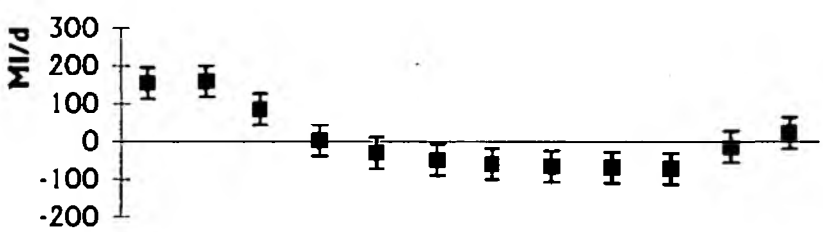
1.3 GW Surplus or Deficit Profile for Specified Year (= Scenario GW Outflow Minus Target GW Outflow)

J	F	M	A	M	J	J	A	S	O	N	D
154	159	86	4	-30	-48	-59	-65	-68	-70	-13	23

Ann Av 5 Ml/d

Minimum -70 Ml/d

Uncertainty +/- 42 Ml/d



Central value of GW Surplus or Deficit as % of Natural GW Outflow Ann Av 5% **Min** <-100%

1.4 Interpreted Sustainability Status of GW Resource Management for the Area

GW Sustainability Status Category:

Comments : This version of the assessment does not reflect operational experience, probably because GWABS impact assumptions are wrong. See GWbritot96v2.xls which is more credible.

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area	Brighton Chalk Block (total)	ID	?	Ver	1	Rev	1	Date	1/2/00

GW Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Specified Assessment Year **Drought condition 1996** **Conclusions & QA**

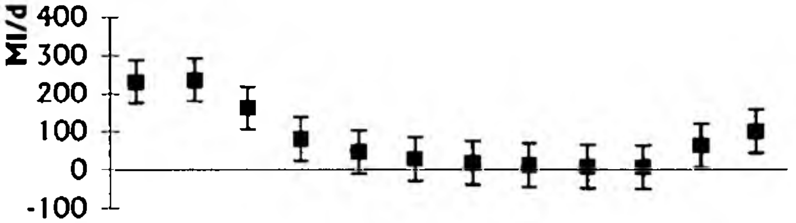
1.5 Acceptable GW Abstraction Impacts Profile for Specified Year (= Natural GW Outflow Minus Target GW Outflow)

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	230	236	162	80	46	28	17	11	8	6	63	99

Ann Av 81 Ml/d

Minimum 6 Ml/d

Uncertainty +/- 57 Ml/d



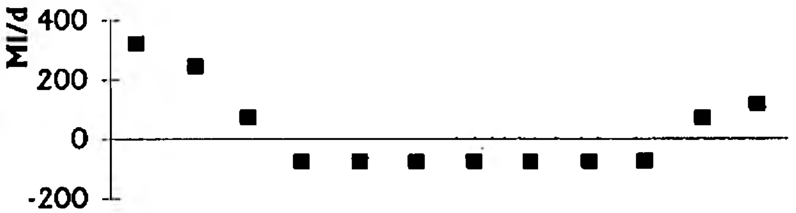
1.6 Recharge Minus Groundwater Abstraction as Pumped (ignoring impact timing) if recharge has been separately defined

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	322	245	73	-76	-77	-78	-77	-78	-77	-75	71	117

Ann Av 23 Ml/d

Minimum -78 Ml/d

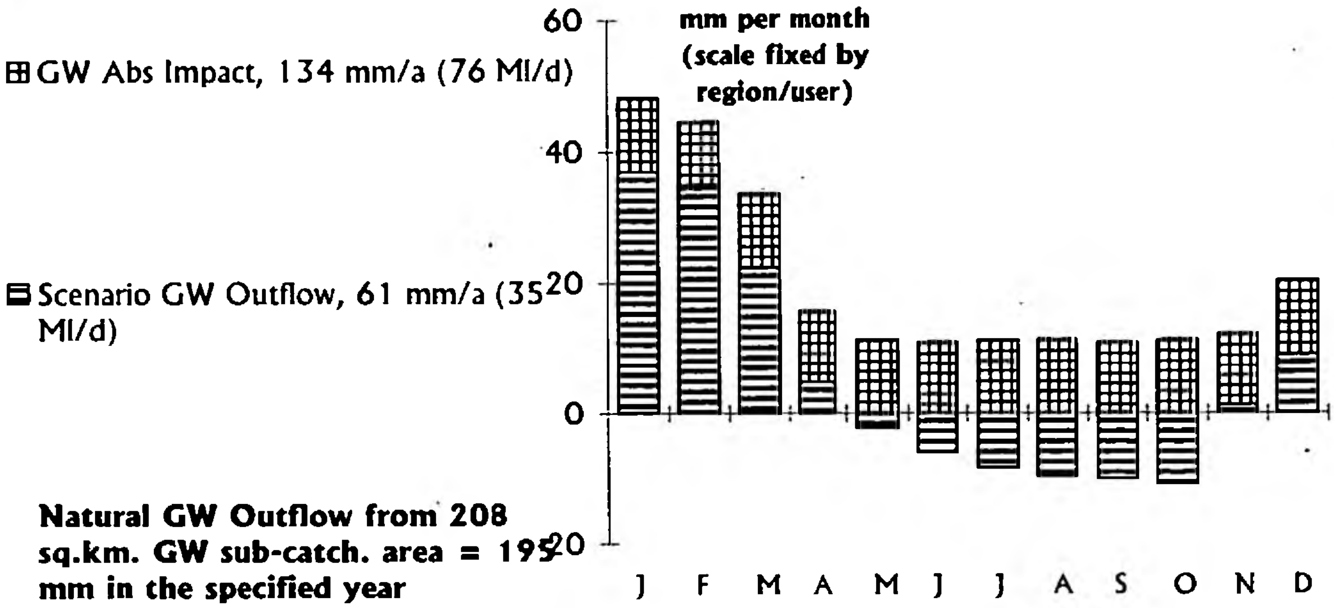
Uncertainty +/- 12 Ml/d



2 GW Outflow Components (Optionally Excluding Sub-Areas)

Sub-Areas Excluded: NONE

Flow Components Derived from the Remaining GW Sub Catchment
Expressed in mm/month
(with Annual Average Rate Summaries in mm/a and Ml/d)



Maximum GW abstraction impact for this sub-catchment area only (excluding the areas indicate

Max. (sub-catchment GW abs impact/sub-catchment nat GW outflow) = 2135 % in Oct

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area Brighton Chalk Block (total) **ID** ? **Ver** 1 **Rev** 1 **Date** 1/2/00

GW Assessment for Areas which Drain to a GW Outflow **(protected worksheet)**

Specified Assessment Year **Drought condition 1996** **Conclusions & QA**

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 GW abstraction impacts Ml/d (zero if none)

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

(difficult to manage in a 'slowly' responding aquifer)

3.2 Target For Abstraction Impact Reduction

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

3.3 Other Proposals to Improve GW Resource Management or Sustainability

(e.g. enhanced water quality or level monitoring with regular licence review etc.)

NOTE: Each licence application or reduction assessed on a case by case basis considering: proximity to rivers/wetlands/the coast, 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

Any need/plans to reassess resource soon?:

target date method

01/01/01 **CAMS the real thing**

4.2 Abstraction Ledger Update Control

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

In connection with licence numbers:

END OF SHEET

BRIGHTON BLOCK 1996 TRIAL VERSION 2 ARM SPREADSHEET (ASSUMING GWABS IMPACTS DISTRIBUTED ACCORDING TO NATURAL OUTFLOWS)

Gwbritot96v2.xls (not including Conceptual understanding sheet): 8 pages

AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Area	ID	Version	Ledger Rev.	Date
Brighton Chalk Block (total)	?	2	1	1/2/00

1.0 Groundwater Catchment Area

Recharge catchment area to GW outflow boundary = 208 sq. km. Based on: planimetered sketch plan

2.0 Year or Hydrological Scenario of Assessment

The year specified for this assessment is Drought condition 1996 Basis for selection of this year stressed resources

3.0 Natural Groundwater Outflows in Specified Year to Define the Groundwater Resource

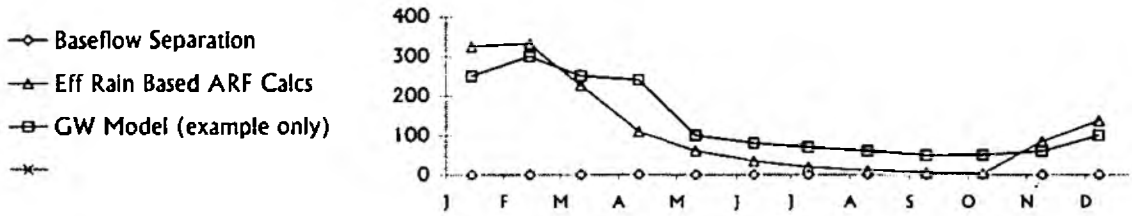
Enter the monthly averaged natural GW outflows for the assessment year, and an associated % possible error, based on one or more of the following:

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

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

	Methods and Calculation References		*Select One* *type* 'x'		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	% Err.
a.	Baseflow Separation	ref:		Ml/d	0	0													
b.	*ARF* Sheet Results	ref: ARFBritot96.xls	x	Ml/d	111	4	324	331	226	109	61	35	20	11	6	4	85	137	25
c.	GW Model (example only)	ref: example for plot only		Ml/d	133	50	250	300	250	240	100	80	70	60	50	50	60	100	15
d.		ref:		Ml/d	0	0													

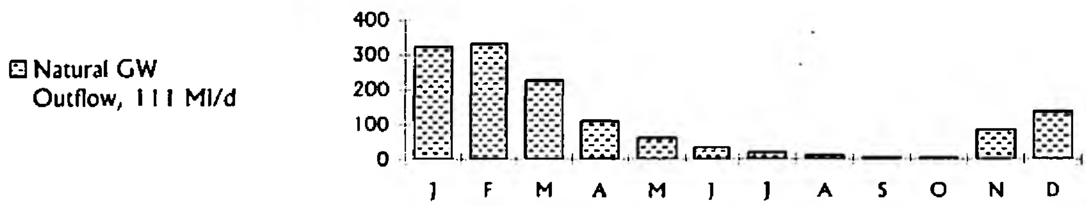
(Monthly Av. Natural GW Outflow in Specified Year, Ml/d)



	Selected Method	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Natural GW Outflow, 111	Eff Rain Based ARF Calcs	111	4	324	331	226	109	61	35	20	11	6	4	85	137	28

(Selected Natural GW Outflow in Specified Year, Ml/d)

Annual Equivalent over GW Catchment is 195 mm/a



4.0 Recharge in Specified Year (optional)

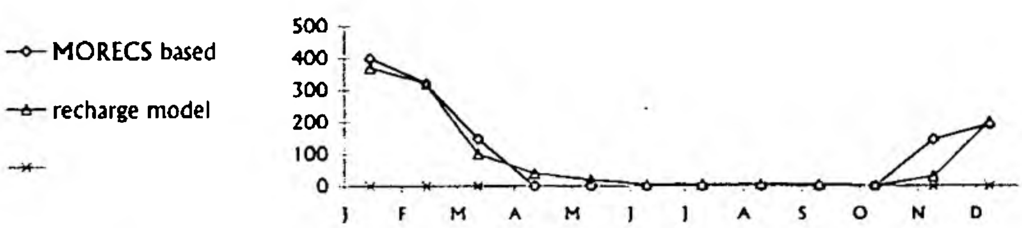
If a separate estimate of groundwater resources based on inflows is required, enter the monthly averaged recharge, based on one or more of the following:

a. MORECS effective rainfall, possibly factored to take account of drift *(please reference method & calculations)*
b. An Alternative Soil Moisture Balance Method *(please reference method & calculations)*
c. An Alternative Method *(please reference method & calculations)*

Compare these different estimates and select one to carry forward for comparison with groundwater abstractions in Step ??.

	Method and Calculation Reference		*Select One* *type* 'x'		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	% Err.
a.	MORECS based	ref: ARFbritot96.xls line 96	x	Ml/d	99	0	399	321	148	0	0	0	0	0	0	0	146	191	10
b.	recharge model	ref: example for plot only		Ml/d	91	0	370	320	100	40	20	5	5	5	5	0	30	200	5
c.		ref:		Ml/d	0	0													

(Monthly Av. Recharge in Specified Year, Ml/d)



AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Area: Brighton Chalk Block (total) | ID: ? | Version: 2 | Ledger Rev.: 1 | Date: 1/2/00

Selected Method

		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Recharge, 99 Ml/d Av.	MORECS based	99	0	399	321	148	0	0	0	0	0	0	0	146	191	10
	Implied Surface Runoff Flow	12	-75	-75	10	78	109	61	35	20	11	6	4	-61	-54	

Selected Recharge in Specified Year, Ml/d

Annual Equivalent
Recharge
over GW Catchment
is 174 mm/a

5.0 Impacts of Consumptive Groundwater Abstraction Scenario on Groundwater Outflows 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 not returned to groundwater. Surface water abstractions and discharges are ignored. Groundwater abstraction impacts on outflows 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 GWabs are based on (please describe Assumed Abstraction Management Scenario)
(e.g.full licensed 1999 rates/deployable output/actual 1999 rates) **Estimated Actual 1996 Rates**

5.0 a. Scenario Groundwater Abstraction in the Month of Pumping

Year 1996 Calcs in: briblock.xls - based on estimated actual abstraction returns

Data compilation & calculation imply av. level of confidence in this data set is +/- 3 %

Consumptive GW Abstraction, Ml/d

Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
76	Ml/d	77	76	74	76	77	78	77	78	77	75	75	74	2

5.0 b. Scenario Groundwater Abstraction Impacts on GW Outflows in Specified Year

Impact Calcs Assumptions & reference: briblock.xls - impact conservatively assumed to be evenly distributed through the year

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

GW Abstraction Impacts on GW Outflows, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
	76	Ml/d	222	227	155	75	42	24	13	8	4	2	58	94	15
GW Abs Impact/Natural GW Outflow, %	68	%	68	68	68	68	68	68	68	68	68	68	68	68	

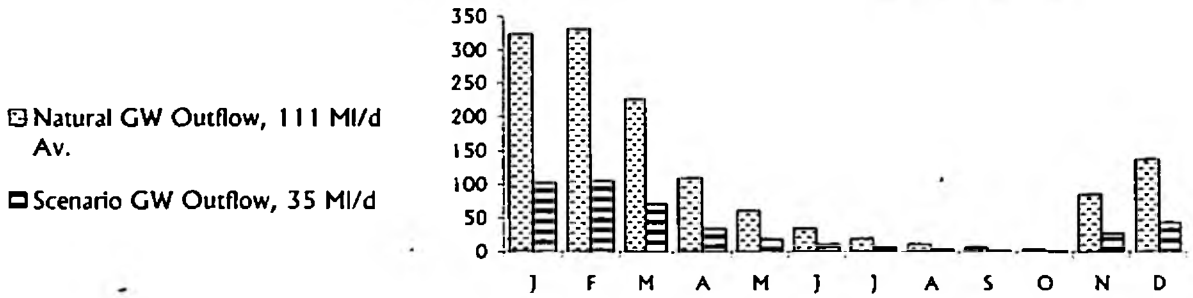
Maximum Percentage Impact = 68 %

In the month of Jan Jul

6.0 GW Outflows for this Artificial Impact Scenario in Specified Year

Scenario GW Outflow = Natural GW Flow - GW Abs Impact, Ml/d
= step 3 - step 5a

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Scenario GW Outflow, 35 Ml/d	35	Ml/d	102	105	71	34	19	11	6	3	2	1	27	43	43



AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Area: Brighton Chalk Block (total) | ID: ? | Version: 2 | Ledger Rev.: 1 | Date: 1/2/00

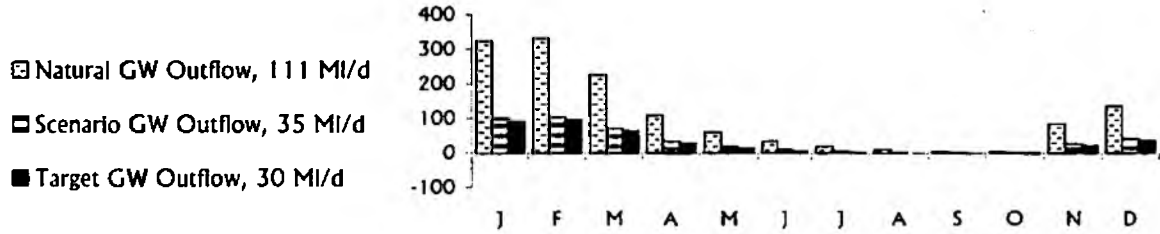
7.0 Setting Target GW Outflows for Specified Year

Target flows based on (summarise): can allow small seasonal fluctuation of saline/freshwater interface i.e. small inflow in summer

Calc/Authorisation Ref:

Natural, Scenario & Target GW Outflows, Ml/d

		Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	
Natural GW Outflow, 111 Ml/d		111	4	324	331	226	109	61	35	20	11	6	4	85	137	
Scenario GW Outflow, 35 Ml/d		35	1	102	105	71	34	19	11	6	3	2	1	27	43	
Monthly Minimum Flow, Qmin		-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	Ml/d
% Acceptable Abs. Impact of QNat over QMin	70 %	35	3	99	101	69	34	20	12	7	5	3	3	27	43	Err+/-
Target GW Outflow, 30 Ml/d	Confidence: +/- 30 %	30	-2	94	96	64	29	15	7	2	0	-2	-2	22	38	-2

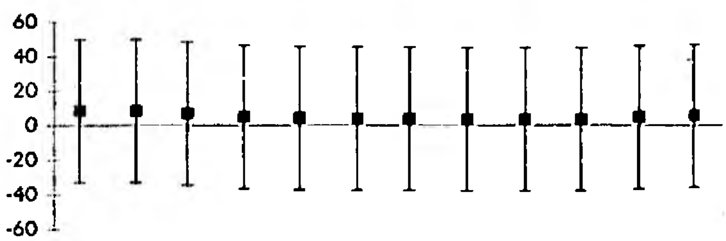


8.0 Scenario GW Surplus or Deficit for Specified Year, Given Target GW Outflows

GW Surplus or Deficit = Scenario - Target GW Outflow Ml/d

	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Scenario GW Surplus or Deficit, 5 Ml/d	5	3.6	8	9	7	5	4	4	4	4	4	4	5	6	42
Surplus or Deficit as % of Natural GW Outflow	5		3	3	3	5	7	12	19	33	57	100	6	4	

Same surplus/deficit plot with combined error bar of +/- 42 Ml/d



Over the Whole Year,

Annual Average Surplus or Deficit = 5%

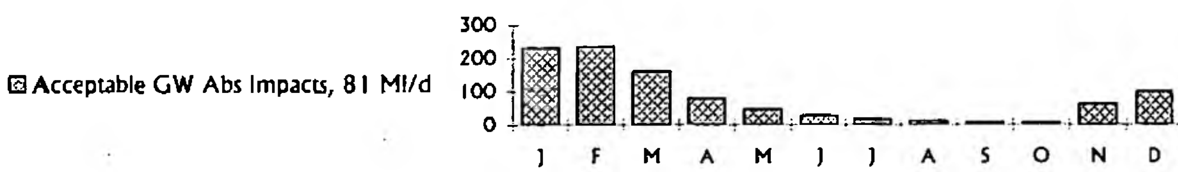
Annual Average Natural GW Outflow and minimum = 3%

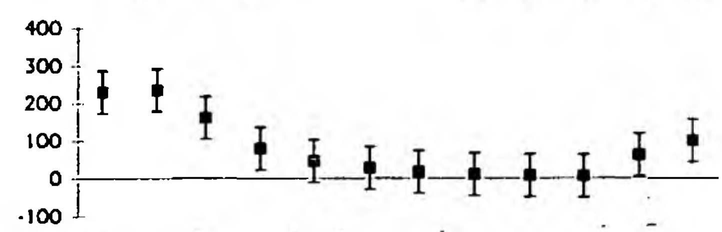
9.0 Acceptable GW Abstraction Impacts for Specified Year Given Target GW Outflows

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 GW Abs. Impacts for Specified Year, Ml/d

	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Acceptable GW Abs Impacts, 81 Ml/d	81	6	230	236	162	80	46	28	17	11	8	6	63	99	57





Same acceptable GW abstraction impact plot wi combined error bar of +/- 57 Ml/d

AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a GW Outflow (protected worksheet)

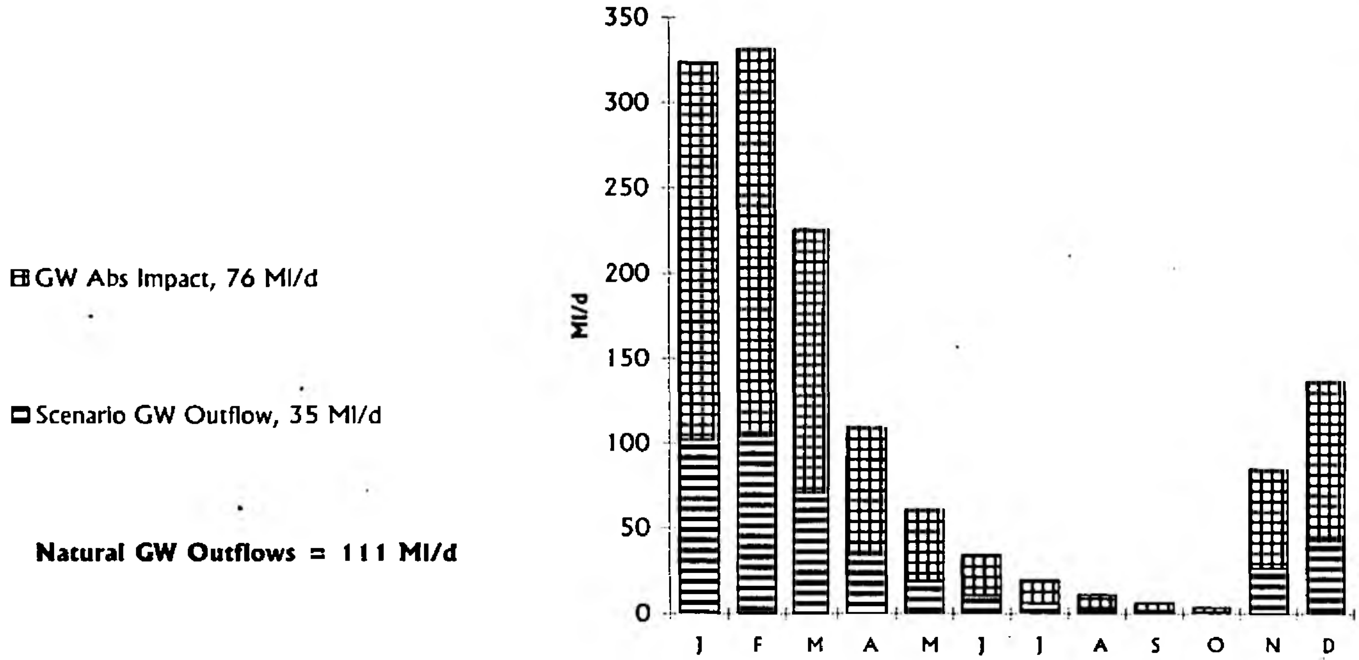
Area Brighton Chalk Block (total) **ID** ? **Version** 2 **Ledger Rev.** 1 **Date** 1/2/00

10 Scenario GW Outflow Composition from Total GW Catchment in Specified Year

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Scenario GW Outflow, 35 Ml/d	35	Ml/d	102	105	71	34	19	11	6	3	2	1	27	43
GW Abs Impact, 76 Ml/d	76	Ml/d	222	227	155	75	42	24	13	8	4	2	58	94
Natural GW Outflows = 111 Ml/d	111	Ml/d												

GW catchment area = 208 sq km

Estimated Actual 1996 Rates

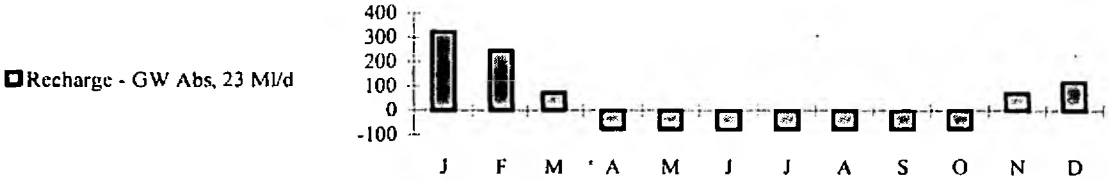


11 Recharge Minus Consumptive GW Abstraction (as pumped) in Specified Year

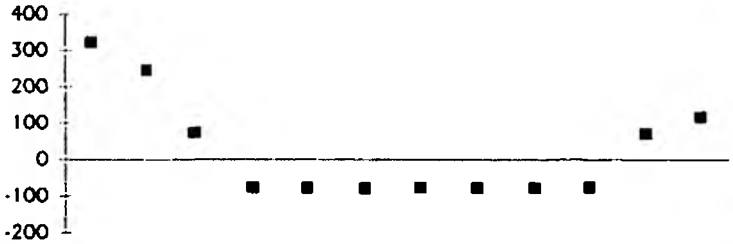
Only plotted if a recharge profile has been separately defined at step 4.

Natural Recharge - Consumptive GW Abs. As pumped, Ml/d = step 4 - step 5a

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D	Ml/d Err+/-
Recharge - GW Abs, 23 Ml/d	23	Ml/d	322	245	73	-76	-77	-78	-77	-78	-77	-75	71	117	12



Same Baseflow - GWAbs Impacts plot with combined error bar of +/- 12 Ml/d



AVAILABLE RESOURCE METHODOLOGY (ARM)

Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Area Brighton Chalk Block (total) **ID** ? **Version** 2 **Ledger Rev.** 1 **Date** 1/2/00

12 **Scenario Outflow Composition from GW Catchment in Specified Year, as mm/month over GW Catchment**

This plot expresses the scenario outflow components as mm per month over the groundwater catchment area.
The step 10 values from smaller parts of thie assessment areas can be combined and pasted below in order to plot the outflows from the remaining part only. If no values are pasted in, the plot represents the entire GW catchment assessed.

Identify the areas to be excluded from the plot: Areas Excluded: NONE

Combine Step 10 values from these assessments and paste values below.

Scenario Outflow Values (Step 10) from sub-areas, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Scenario GW Outflow, 0 Ml/d	0	Ml/d												
GW Abs Impact, 0 Ml/d	0	Ml/d												

Combined GW catchment sub-areas to ignore = sq km

Groundwater Sub-Catchment Area for this plot 208 sq. km.

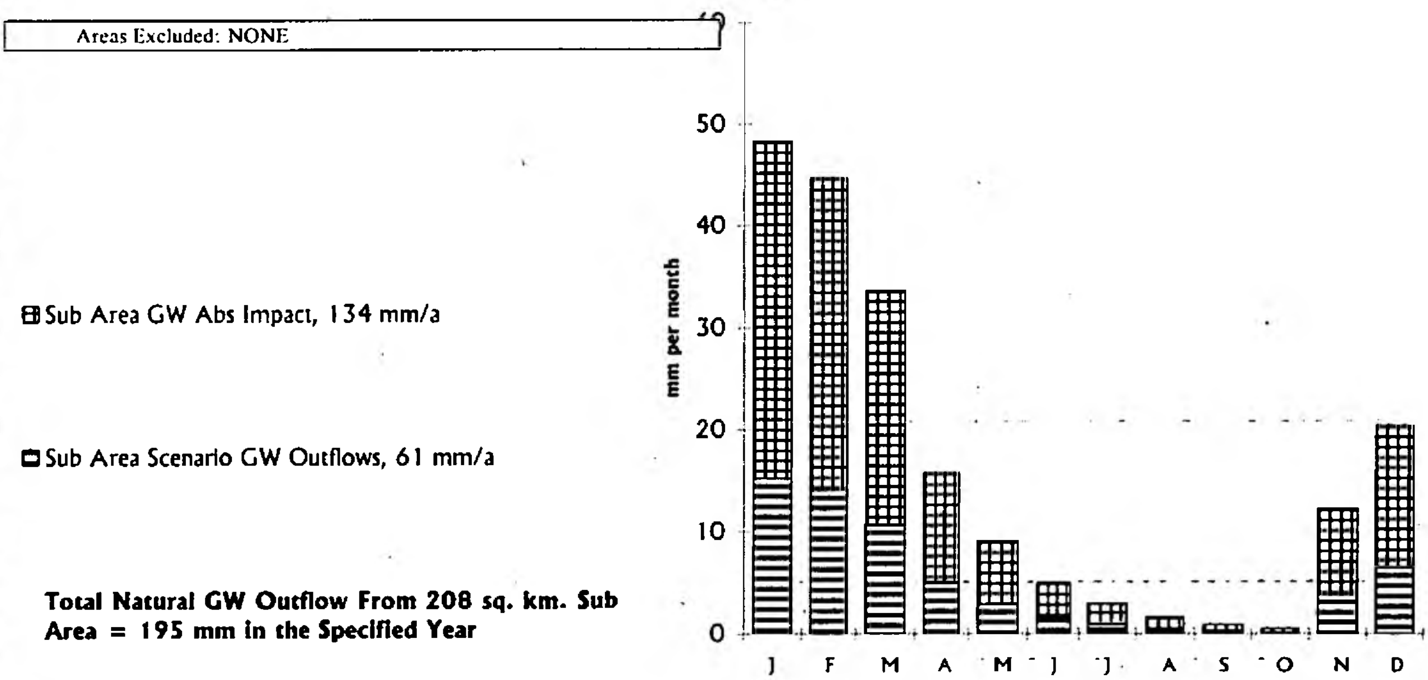
Components of Nat. Outflow as mm/month over SW sub areas.

	Ann Tot		J	F	M	A	M	J	J	A	S	O	N	D
Sub Area GW Abs Impact, 134 mm/a	134	mm/a	33	31	23	11	6	3	2	1	1	0	8	14
Sub Area Scenario GW Outflows, 61 mm/a	61	mm/a	15	14	11	5	3	2	1	1	0	0	4	6

Total Natural GW Outflow From 208 sq. km. Sub Area = 195 mm in the Specified Year

Estimated Actual 1996 Rates

Areas Excluded: NONE



	J	F	M	A	M	J	J	A	S	O	N	D
% (net abs impact for sub-catchment)/(nat outflow from sub-catchment) =	68	68	68	68	68	68	68	68	68	68	68	68

Maximum net GW abs. impact for this sub-catchment area only (exluding other sub-areas)

Max. (sub-catchment net abs impact/sub-catchment nat outflow) = 68 % in Jan Jul

END OF SHEET

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area: Brighton Chalk Block (total) | ID: ? | Ver: 2 | Rev: 1 | Date: 1/2/00

GW Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Specified Assessment Year: Drought condition 1996 — **Conclusions & QA**

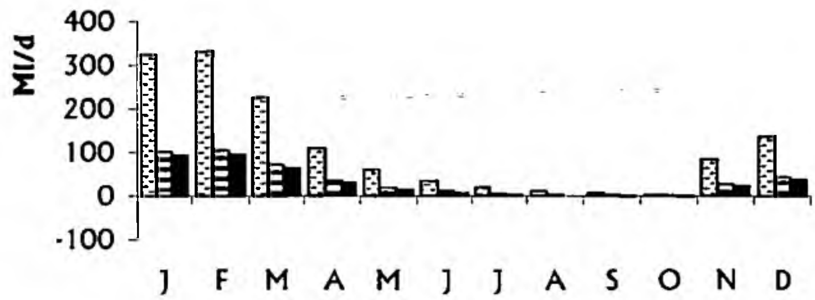
1 Results Summary for the GW Catchment to the GW Outflow Boundary

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

Natural GW Outflow, 111 Ml/d

Scenario GW Outflow, 35 Ml/d

Target GW Outflow, 30 Ml/d



Target Flows based on: can allow small seasonal fluctuation of saline/freshwater interface i.e. small inflow in summer

1.2 Scenario GW Abstraction Impacts (with Annual Average Rate Summary)

GW Abs Scenario: Estimated Actual 1996 Rates

GW Abstraction Impact, 76 Ml/d

Maximum GW abstraction impact for total area based on

Max. (GW abs impact/naturalGW Outflow from total area) = 68 % in Jan

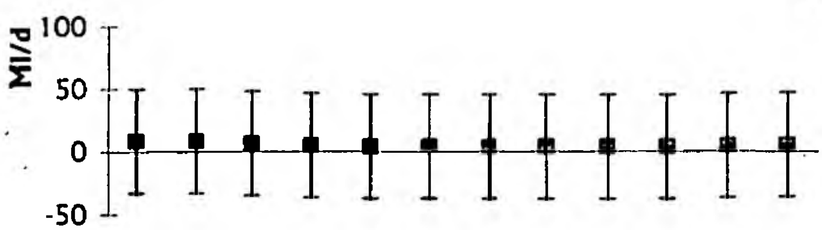
1.3 GW Surplus or Deficit Profile for Specified Year (= Scenario GW Outflow Minus Target GW Outflow)

J	F	M	A	M	J	J	A	S	O	N	D
8	9	7	5	4	4	4	4	4	4	5	6

Ann Av: 5 Ml/d

Minimum: 4 Ml/d

Uncertainty +/-: 42 Ml/d



Central value of

GW Surplus or Deficit as % of Natural GW Outflow Ann Av: 5% Min: 3%

1.4 Interpreted Sustainability Status of GW Resource Management for the Area

GW Sustainability Status Category:

Comments : Not assigned at this trial stage - see discussion in Section 1.3.8 and note in Section 9.1 of the User Manual for further information. Step 3 (Management Action) also not complete

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area Brighton Chalk Block (total) **ID** ? **Ver** 2 **Rev** 1 **Date** 1/2/00

GW Assessment for Areas which Drain to a GW Outflow (protected worksheet)

Specified Assessment Year **Drought condition 1996** **Conclusions & QA**

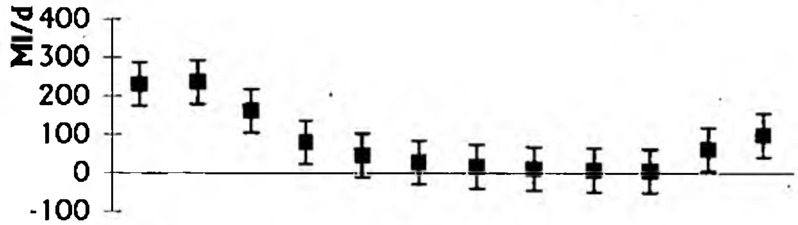
1.5 Acceptable GW Abstraction Impacts Profile for Specified Year (= Natural GW Outflow Minus Target GW Outflow)

Ann Av 81 Ml/d

Minimum 6 Ml/d

Uncertainty +/- 57 Ml/d

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	230	236	162	80	46	28	17	11	8	6	63	99



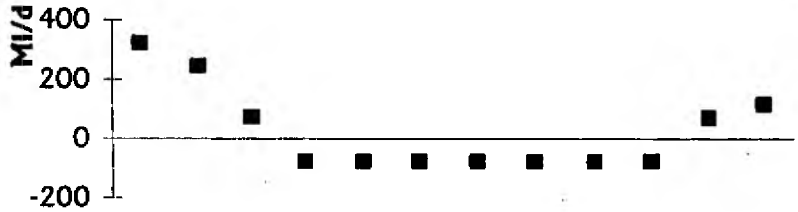
1.6 Recharge Minus Groundwater Abstraction as Pumped (ignoring impact timing) if recharge has been separately defined

Ann Av 23 Ml/d

Minimum -78 Ml/d

Uncertainty +/- 12 Ml/d

	J	F	M	A	M	J	J	A	S	O	N	D
Ml/d	322	245	73	-76	-77	-78	-77	-78	-77	-75	71	117



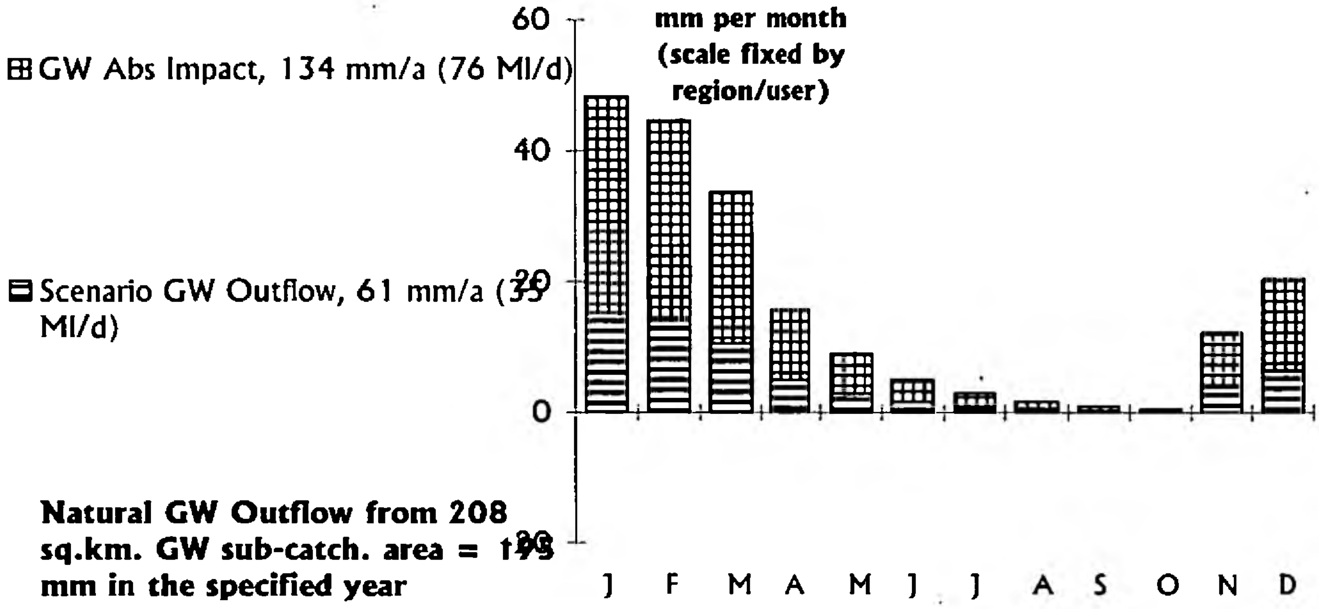
2 GW Outflow Components (Optionally Excluding Sub-Areas)

Sub-Areas Excluded: NONE

Flow Components Derived from the Remaining GW Sub Catchment

Expressed in mm/month

(with Annual Average Rate Summaries in mm/a and Ml/d)



Maximum GW abstraction impact for this sub-catchment area only (excluding the areas indicat

Max. (sub-catchment GW abs impact/sub-catchment nat GW outflow) = 68 % in Jan

AVAILABLE RESOURCE METHODOLOGY (ARM)

Area | Brighton Chalk Block (total) | ID | ? | Ver | 2 | Rev | 1 | Date | 1/2/00

GW Assessment for Areas which Drain to a GW Outflow **(protected worksheet)**

Specified Assessment Year | **Drought condition 1996** | **Conclusions & OA**

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 GW abstraction impacts Ml/d (zero if none)
Potential for additional winter-only GW abstraction impacts Ml/d (zero if none)
(difficult to manage in a 'slowly' responding aquifer)

3.2 Target For Abstraction Impact Reduction

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

3.3 Other Proposals to Improve GW Resource Management or Sustainability

(e.g. enhanced water quality or level monitoring with regular licence review etc.)

NOTE: Each licence application or reduction assessed on a case by case basis considering: proximity to rivers/wetlands/the coast, 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

Any need/plans to reassess resource soon?:

target date	method
01/01/01	**CAMS the real thing**

4.2 Abstraction Ledger Update Control

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

In connection with licence numbers:

END OF SHEET

BRIGHTON BLOCK 1996 TRIAL OPTIONAL AQUIFER RESPONSE FUNCTION SPREADSHEET FOR NATURAL GW OUTFLOWS

ARFbritot96.xls: 2 pages

AVAILABLE RESOURCE METHODOLOGY (ARM)

(protected worksheet)

Area Brighton Chalk Block (total) ID ? Version 1&2 Ledger Rev. 1 Date 01-Feb-00

NAT. RIVER FLOWS & GW OUTFLOWS DERIVED FROM EFF. RAINFALL USING THE AQUIFER RESPONSE FUNCTION *(OPTIONAL)*

These calculations derive nat. total river flows & GW outflows from monthly hydrologically effective rainfall, assumptions of recharge/runoff split and catchment characteristics using the 'Aquifer Response Function' (ARF). After restating the assessment year (Step1), Step 2 calculations consider:

2a. flows in a year of 'average' rainfall (to achieve a reasonable simulation of 'average' baseflow and runoff using credible assumptions), then

2b. flows in the specified assessment year (based on effective rainfall data before and during the year and the same catchment response assumptions).
Results summarised in **Step 3** can be pasted into the 'River Outflow Calcs' or 'GW Outflow Calcs' worksheets for comparison with other natural flow estimates (e.g. for river flows, estimates based on gauge flow naturalisation).

1 Year of Assessment

The year specified for this assessment is Drought condition 1996 Basis for selection of this year stressed resources

(these should be as specified in the 'River Outflow Calcs' or 'GW Outflow Calcs' workbook)

2 a. Natural River Flows or GW Outflows in an 'Average' Year Based on the Aquifer Response Function (ARF)

Areas	**sq km**	**Based on:**
Surface Water Catchment Area	208	planimetered sketch plan
(For Rivers, area from which runoff drains above the assessed point. For GW outflows, equals GW catchment area)		
Aquifer Area within the Surface Water Catchment	208	planimetered sketch plan
(For Rivers, area from which runoff drains above assessed point and recharge enters aquifer. For GW outflows, equals GW catchment area)		
Groundwater Catchment Area	208	planimetered sketch plan
(For rivers, aquifer area from which recharge would naturally discharge as baseflow above assessed point. For GW outflow, aquifer area from which recharge would naturally discharge over the outflow boundary)		

Long Term Annual Average Hydrologically Effective Rainfall	**mm/a**	**Based on:**
Average Annual Total Hydrologically Effective Rainfall	336	EA map (cf 304mm/a MORECS sq 184)

Assumptions Splitting Hydrologically Effective Rainfall into Runoff and Recharge			**Based on:**
Aquifer recharge as % of effective rainfall	100	%	conversation with Paul Shaw
(so Aquifer runoff =	0	%)	

Calculated Long Term Annual Average Runoff and Recharge

Ann. Av. Recharge draining to river or across GW outflow boundary =	191.5	Ml/d	= recharge % * eff rainfall * GW catch area
(equivalent to	336	mm/a over the GW catchment area)	
Ann. Av. Runoff draining to river or 'lost' in GW outflow calcs =	0.0	Ml/d	
=eff rainfall*(SW catch area - aquifer area in SW catch) + eff rainfall*aquifer runoff%*aquifer area in SW catch			
For rivers, total discharge draining to river =	191.5	Ml/d	=recharge input plus runoff input
(equivalent to	336	mm/a over the SW catchment area)	

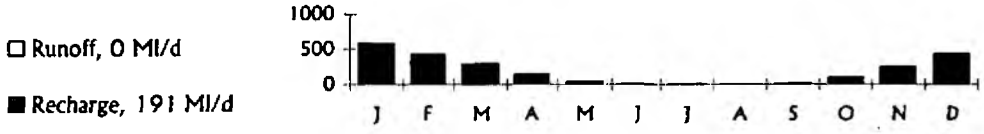
Calculated Average Distribution of Runoff and Recharge

Based on: Av = 1.00 **Av. Monthly Factors of Av. Ann. Rech & Runoff Rates**

	Av	J	F	M	A	M	J	J	A	S	O	N	D
Default values = typical MORECS square Eff. Rain. factors	1.00	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, 0 Ml/d	0	Ml/d	0	0	0	0	0	0	0	0	0	0	0	0
Recharge, 191 Ml/d	191	Ml/d	582	425	292	142	41	7	7	3	20	101	250	438



Aquifer Characteristics Controlling Natural River Baseflow or GW Outflow Response to Recharge			**Based on:**
Recharge % draining to River or GW Outflow in the same month	30	%	assume 30% of flow is karstic

Aquifer Characteristics Controlling Slower Natural Baseflow or GW Outflow Response from Remaining Recharge

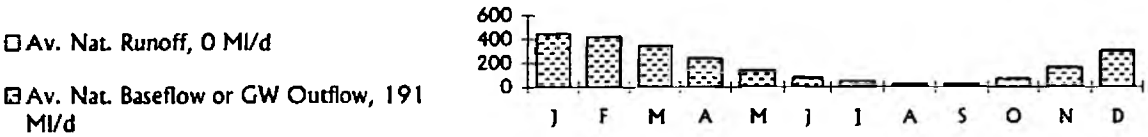
Total length of rivers or GW boundary draining GW catchment	80	km	Surrounding rivers, coast & high T dry valleys
Average Storage (Specific Yield)	0.01	no units	Typical Chalk
Average Transmissivity	127	m2/d	Map of hydraulic conductivity not inc high T

From these parameters and the GW catchment area, the Aquifer Response Time = 133 days

Average Natural Runoff and River Baseflow or GW Outflow

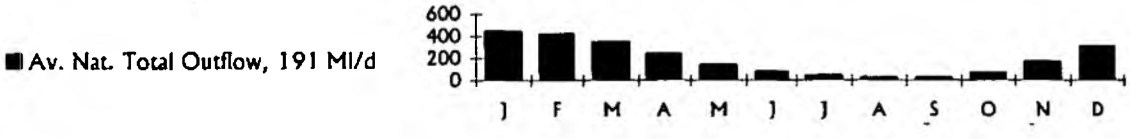
Av. Nat. Runoff and River Baseflow or GW Outflow, Ml/d

	Ann Av		J	F	M	A	M	J	J	A	S	O	N	D
Av. Nat. Runoff, 0 Ml/d	0	Ml/d	0	0	0	0	0	0	0	0	0	0	0	0
Av. Nat. Baseflow or GW Outflow, 191 Ml/d	191	Ml/d	446	420	347	240	140	78	47	27	26	69	165	307



Av. Nat. Total Outflow = Runoff + Baseflow or GW Outflow, Ml/d

	Av	Min	J	F	M	A	M	J	J	A	S	O	N	D
Av. Nat. Total Outflow, 191 Ml/d	191	26	446	420	347	240	140	78	47	27	26	69	165	307



AVAILABLE RESOURCE METHODOLOGY (ARM)

(protected worksheet)

Area Brighton Chalk Block (total) **ID** ? **Version** 1&2 **Ledger Rev.** 1 **Date** 01-Feb-00

NAT. RIVER FLOWS & GW OUTFLOWS DERIVED FROM EFF. RAINFALL USING THE AQUIFER RESPONSE FUNCTION *(OPTIONAL)*

2 b. **Natural River Flows or GW Outflows derived from Hydrologically Effective Rainfall in the Specified Assessment Year and Preceding Nine Years based on the Aquifer Response Function (ARF)**
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 184, 1987-96

Hydrologically Effective Rainfall for Preceding & Specified Year, mm/month

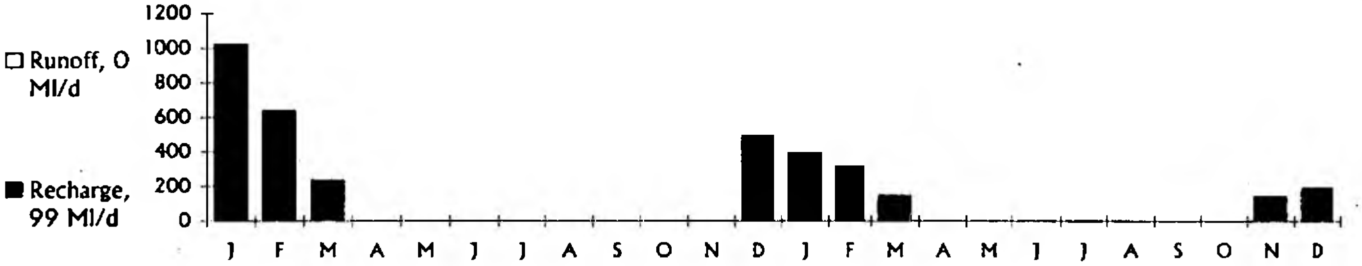
10 Yr Av		Preceding Year												Specified Assessment Year												Yr
		J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	Tot
304	mm/a	153	95	35	0	0	0	0	0	0	0	0	75	60	48	22	0	0	0	0	0	0	0	22	29	180

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, 0 Ml/d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Recharge, 99 Ml/d	1024	635	234	0	0	0	0	0	0	0	0	500	399	321	148	0	0	0	0	0	0	0	146	191	99

Ml/d

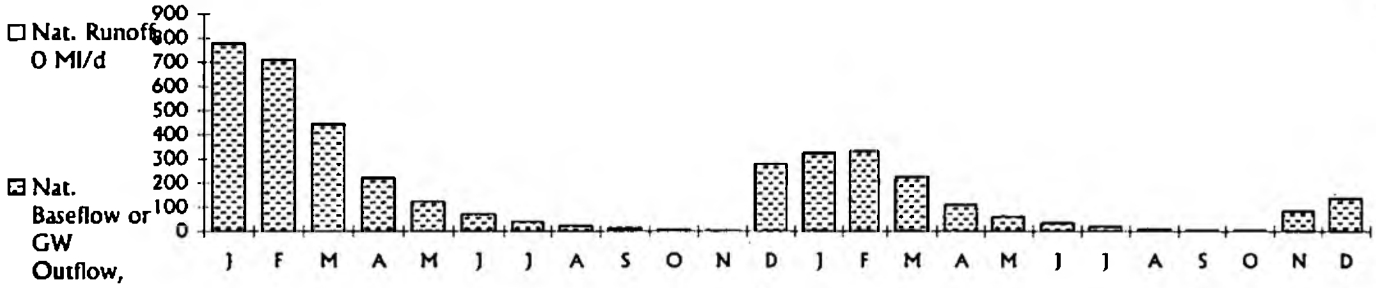


Data compilation & calculation imply av. level of confidence in this recharge is +/- 10 % i.e. error bar assumed to be +/- 10 Ml/d

Calculated Natural Runoff and River Baseflow or GW Outflow for Preceding & Specified Year, Ml/d

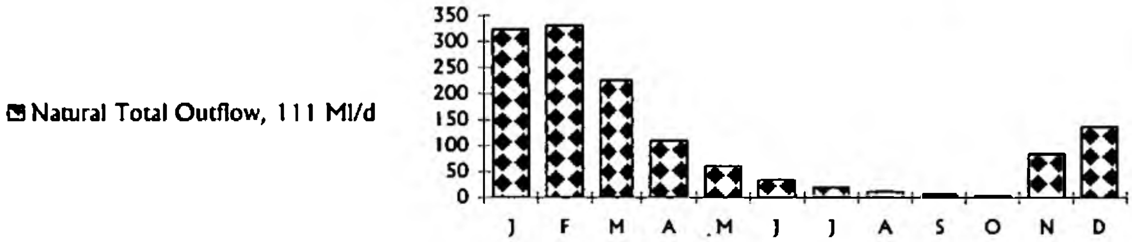
	Preceding Year												Specified Assessment Year												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	Av.
Nat. Runoff, 0 Ml/d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nat. Baseflow or GW O	778	710	445	221	124	70	40	22	13	7	4	279	324	331	226	109	61	35	20	11	6	4	85	137	111

Ml/d



Natural Total Outflow = Runoff + Baseflow, Ml/d

	Ann Av		Specified Assessment Year											
			J	F	M	A	M	J	J	A	S	O	N	D
Natural Total Outflow, 111 Ml/d	111	Ml/d	324	331	226	109	61	35	20	11	6	4	85	137



Min. Natural Total Flow in this Year = 4 Ml/d

Data compilation & calculation imply av. level of confidence in this estimate is +/- 25 % i.e. error bar assumed to be +/- 28 Ml/d

3 **ARF Workbook Result Summary (Copy to Riv_Outflow or GW_Outflow Workbooks):**

	J	F	M	A	M	J	J	A	S	O	N	D	% Err
Natural Total River Flow	324	331	226	109	61	35	20	11	6	4	85	137	25

('copy-paste special-values' into Step 3b of 'River Outflow Calcs' sheet. Ignore for 'GW Outflow Calcs')

	J	F	M	A	M	J	J	A	S	O	N	D	Err
Natural River Baseflow or GW Outflow	324	331	226	109	61	35	20	11	6	4	85	137	25

END OF SHEET *('copy-paste special-values' into Step 4b of 'River Outflow Calcs' sheet or into Step 3b of 'GW Outflow Calcs' sheet)*