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The Available Resource Methodology: A Framework for Assessing Water Resources and Abstraction Sustainability

Final Report

National Groundwater and Contaminated Land Centre

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This document describes a Framework for the assessment of acceptable abstraction impacts from an area and water resources sustainability.

The information within this document is for use by Environment Agency staff and others involved in managing water resources.

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The Available Resource Methodology: A Framework for Assessing Water Resources and Abstraction Sustainability

1. Introduction

This brief report summarises the Available Resource Methodology (ARM) which has been developed for the Environment 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 2 presents an overview of the Framework and what it is intended to achieve. Section 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 4. Section 5 summarises the trial applications and development of the Framework and indicates where further guidance on its implementation and on related approaches can be found. Finally, Section 6 indicates the further consultation required, both within and beyond the Agency, to review the appropriateness of the ARM as a widely applicable Framework.

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 is an overview of the principal steps within the ARM Framework. The options within each step are discussed in Section 3 - the following paragraphs summarise the 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 (as illustrated in Figure 2).

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 flow 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 3.4).

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 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.

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 3).

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 principal 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.

3. Principal Steps

This Section outlines the key issues and options relevant to each of the principal steps illustrated in Figures 1, 2 and 3.

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 as attempts to naturalise the flow measurements can be made (for comparison with other estimates), licence restrictions may be tied into the gauge, 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.

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 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' year where monthly flows are averaged over a standard period. This is useful for general resource comparisons between areas but tends to 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; and
- A synthesised hydrological scenario consistent with that used for the determination of source deployable outputs.

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;
- microLOWFLOWS;
- region specific river flow or groundwater models; and
- 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. These should be viewed with caution and resources management will inevitably be based on monitoring of groundwater quality and levels as indicators of change.

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 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 including any restrictions which might be associated with the chosen year or hydrological scenario; 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 should be 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 the 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 the 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.

An ongoing Agency R&D project is intended to address the seasonality of groundwater abstraction impacts.

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.

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 (Figure 2).

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 average monthly flows cannot be measured – they can only be calculated retrospectively. The control of surface water abstractions will still require a daily flow-duration curve approach such as that advocated by 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.

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 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 %.

3.8 Interpret Sustainability Status

Figure 3 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 3). This allows management decisions to be made cautiously with some understanding of the uncertainties 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).

4. Other Optional Steps

Although not essential, there are a number of further calculation steps and useful plotting representations which can be readily made 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 (Figure 2). This provides a ceiling for managing the impacts of consumptive abstraction;
- Comparing groundwater abstraction impacts with natural baseflow if this has been separately defined for a river flow assessment;
- 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;

- 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; and
- 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.

5. Trial Application Reports and Related Research

5.1 ARM Framework Trials and Development

The ARM Framework has been developed in consultation with Agency staff from all regions through a programme of intensive workshops and trialling. Figure 4 shows that 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.

The trials and development process 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; and
- 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.

Figure 5 shows an example of the results from trials carried out at two locations on the River Ribble.

5.2 ARM Spreadsheets and User Manual

Optional spreadsheet tools based on Microsoft Excel software have been developed to facilitate the calculations and plot representations within the ARM Framework described in Sections 3 and 4. These are described in a separate 'User Manual for ARM Spreadsheets' also issued in March 2000 by the NGCLC.

5.3 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);
- microLOWFLOWS research and software
- flow naturalisation guidelines
- ongoing R&D into the impact of groundwater abstractions on river flows (IGARF)
- UKWIR Deployable Outputs.

6. Ongoing Consultation

The ARM Framework summarised above has evolved during 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.

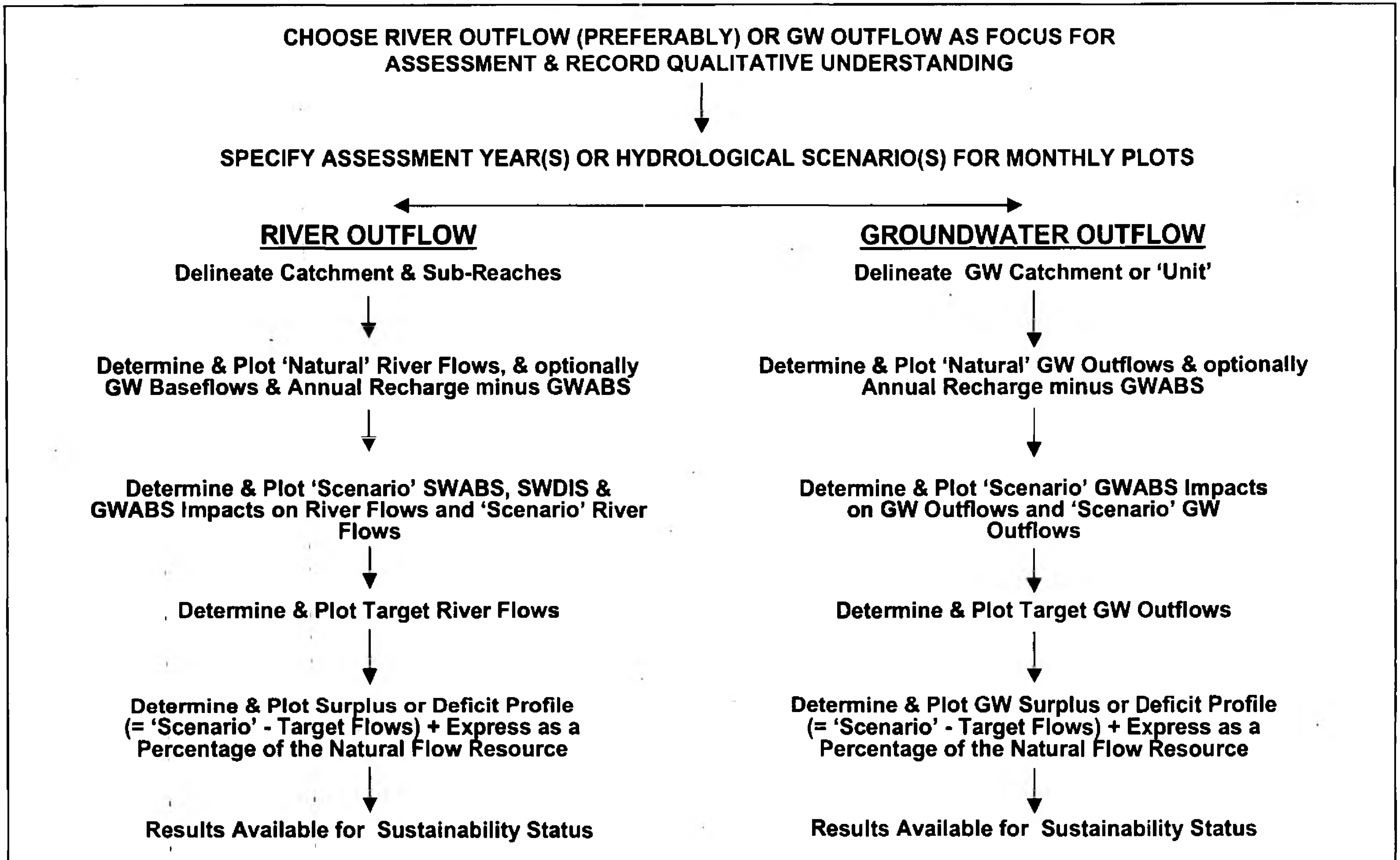

FIGURE 1 ARM FRAMEWORK OVERVIEW

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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 **Optional Steps** are:

9: Calculate Acceptable Abstraction Impacts

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

11: Compare Natural Baseflow with

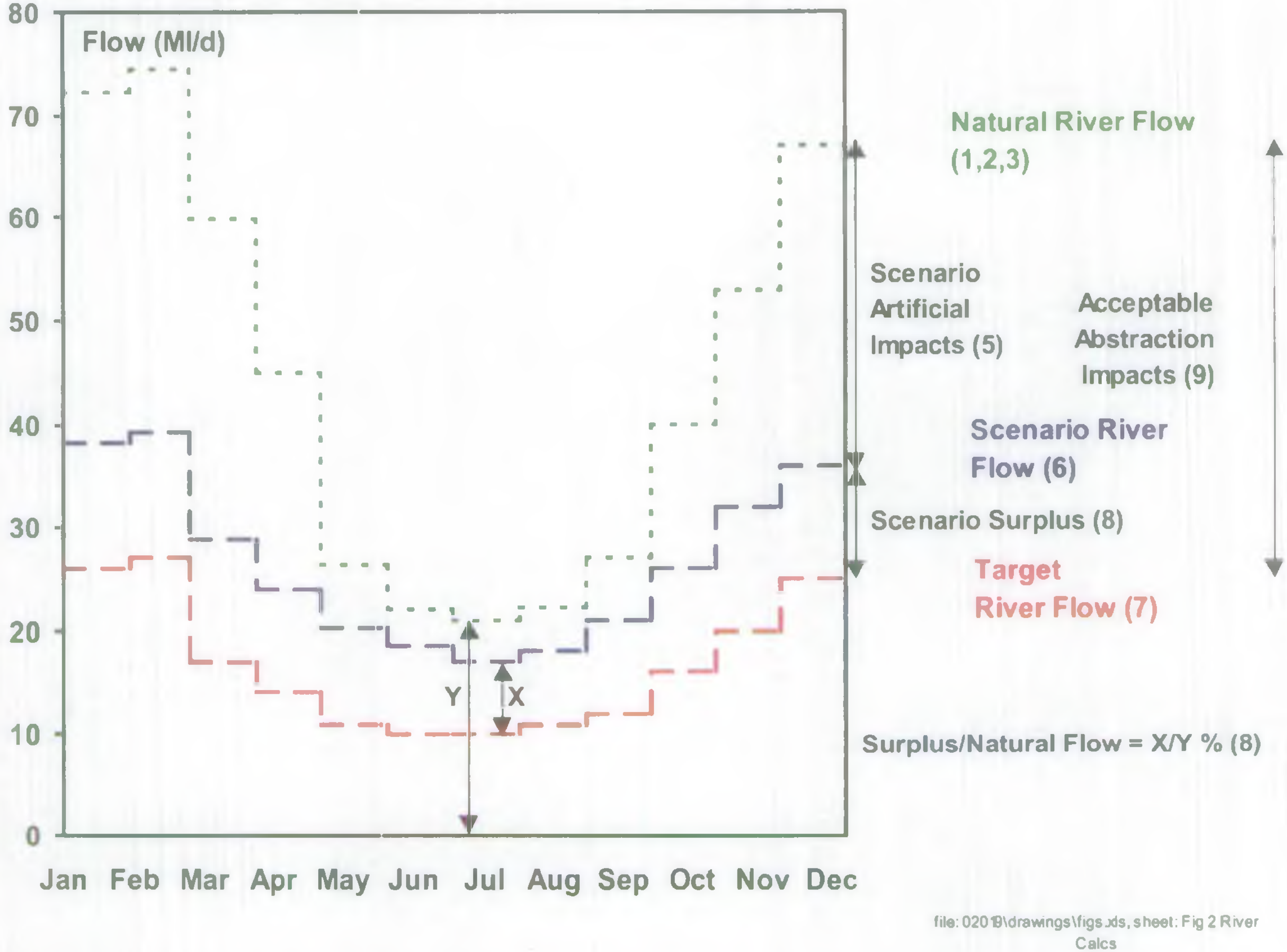

FIGURE 2 ILLUSTRATION OF CALCULATION STEPS WITHIN THE ARM FRAMEWORK

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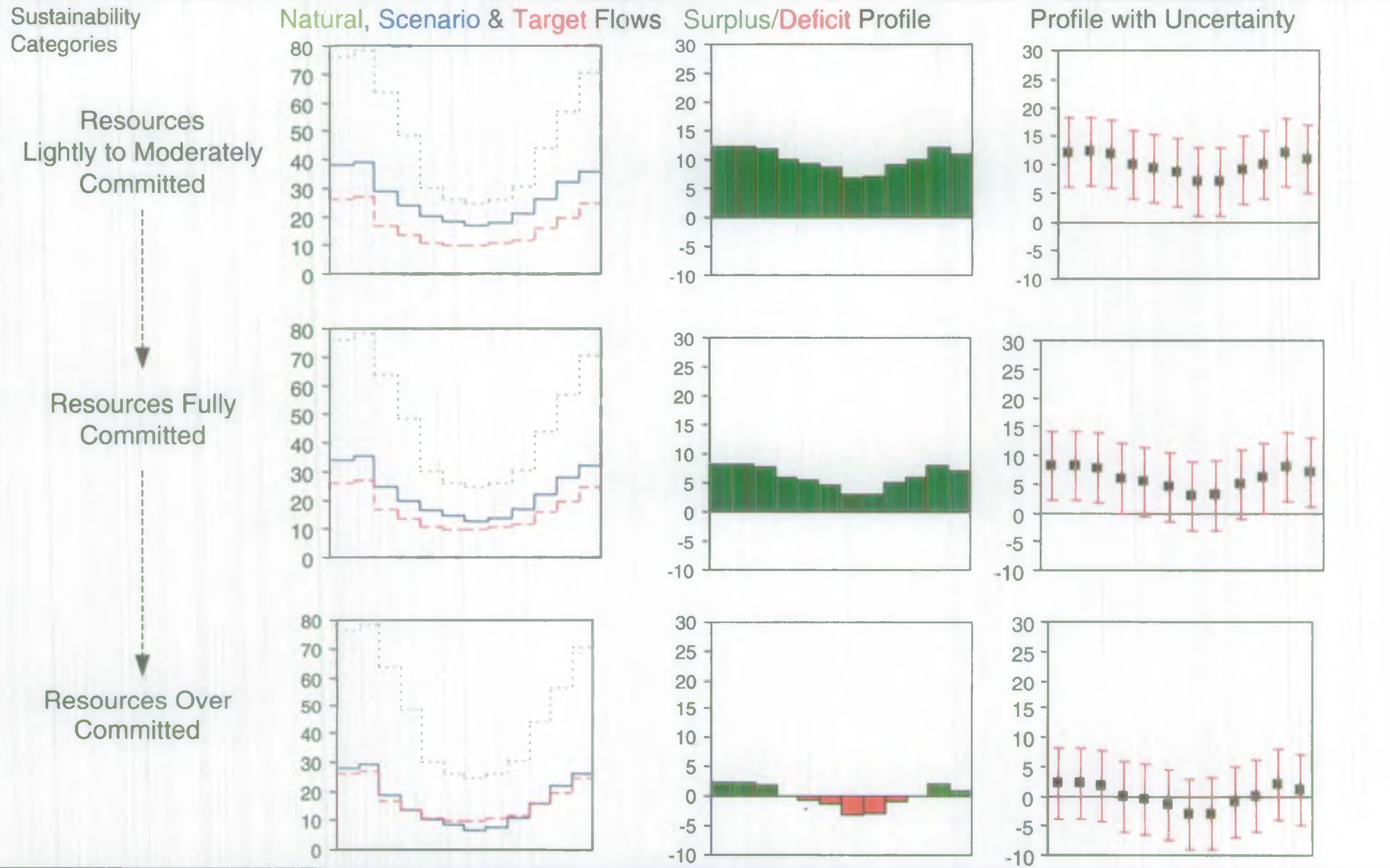

FIGURE 3 **INTERPRETING ABSTRACTION SUSTAINABILITY STATUS**

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

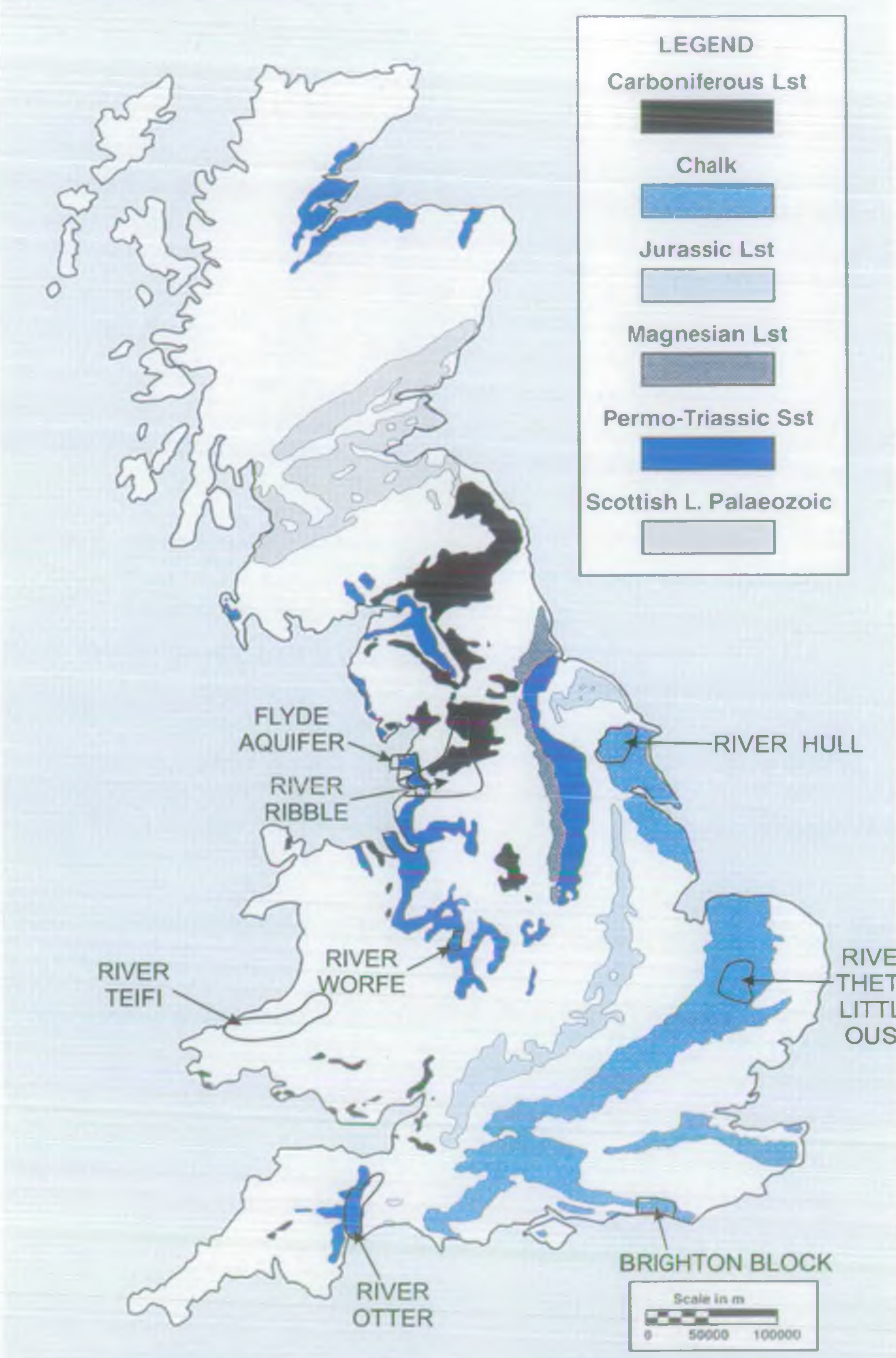

FIGURE 4 ARM FRAMEWORK TRIAL AND DEVELOPMENT AREAS

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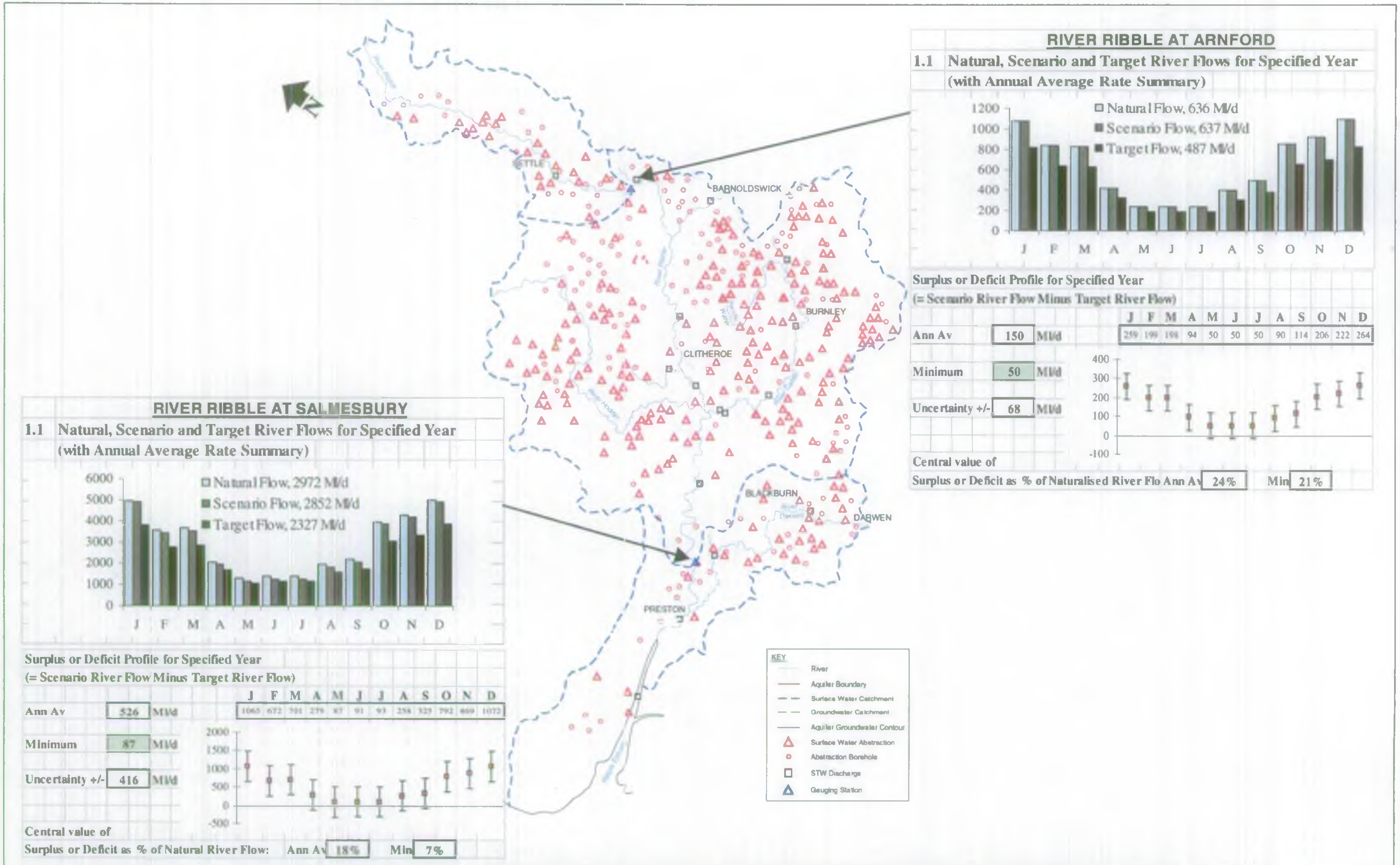

FIGURE 5 POSSIBLE PRESENTATION OF ARM FRAMEWORK RESULTS (Ribble Catchment Example)

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