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# Groundwater Resource Reliable Yield

Entec

R&D Project Record W6/i544/7



# Groundwater Resource Reliable Yield

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This document contains detailed background information, a description of the development of the project, and a summary of key meetings and of the literature review. The document contains supplementary information to that detailed in Technical Reports W9 and W10.

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## EXECUTIVE SUMMARY

The Project Record relates to the formulation of the Groundwater Resource Reliable Yield (*yield*) Methodology. The project was promoted under the National River Authority's R&D programme. The output from this document is briefly summarised below.

The overall project objectives and aims are defined. These ultimately require a suite of standard R&D deliverables including a User Manual, R&D Technical Report and Project Record (this document) to be provided.

The aim of the Methodology is to provide a means of *yield* assessment which draws upon best practice, new concepts and a recognition for the need to dovetail this with related policies and an ever increasing responsibility to protect the environment.

Considerable background to the project is outlined including meetings with and seminars for the National Rivers Authority, International Literature Review and related project initiatives. These are described in the context of the appointed consultants' general approach to the work in order to achieve an innovative Methodology formulation and development.

### Keywords

Groundwater, Methods, Resources, Yield



# 1. INTRODUCTION AND BACKGROUND

This project has been conducted under the Environment Agency's R&D Groundwater Programme.

The project commenced in October 1994 and target completion has been subject to significant change

- originally set at end August 1995
- first revision (in June 1995) to January 1996
- second revision (in December 1995) to April 1996
- final revision to December 1996

for a range of practical and development reasons affecting contributions from both the Environment Agencies' and Entecs' project teams.

## 1.1 Objectives

The aim of this project is to establish a Methodology which can be used to determine the Groundwater Resource Reliable Yield (*yield*) of part of an aquifer. The *yield* is defined as the quantity of groundwater that can be reliably and sustainably abstracted without causing an unacceptable impact to the environment. Such a Methodology will assist groundwater resource planners in balancing the allocation of available resources so as to permit sustainable abstraction development and ensure resultant impacts are acceptable. The Methodology should be simple to apply and widely applicable to the needs of the Environment Agency.

It is recognised that a wide gulf exists in current Environment Agency practice between performing simple steady state recharge calculations and studies involving the development of full-scale computer models of the groundwater flow system. There are also significant differences in the procedures adopted by the different Environment Agency Regions. A robust Methodology in use across the entire Environment Agency would therefore provide a uniform and more defensible approach to strategic assessments.

Three final deliverables have resulted from the project and these include:

- R&D Technical Report W9 - User Manual (Papaioannou and Erskine, 1996a), which provides very brief background and describes the Methodology and its application.

- R&D Technical Report W10 - Key Components in Methodology Formulation (Papaioannou and Erskine, 1996b), describing the computer modelling and analytical work used to formulate the 'alpha' term and 'type curve' which underpins the Methodology described in the User Manual.
- R&D Project Record (this document), containing detailed background information, a description of project evolution, and a summary of key meetings and literature review etc generated during the project.

## 1.2 Scope of Methodology

One of the functions of the Environment Agency is to control the allocation of groundwater resources. In practice this includes frequent decisions as to whether or not to grant a licence for a groundwater abstraction application made by water suppliers or water users.

In order to make decisions about abstraction licence applications the Environment Agency have to consider the potential impact of the abstraction. The effects may be both local and strategic. Local effects result from a lowering of the water table in the immediate vicinity of the source. Strategic effects however are concerned with the total amount of water abstracted from the aquifer. There is an upper limit to the amount of water that can be abstracted from an aquifer and this is the *yield* as referred to in this report. This value can be equally exceeded by totalling a large number of small abstractions or a few large abstractions. The total effect of such abstractions may cause problems to occur in an area that is not local to any of them. Because of such strategic considerations, applications for abstraction licences may have to be refused on the basis that the cumulative amount of abstraction exceeds a specified level. The purpose of this Methodology is to provide a means of calculation with which to derive such a strategic limit on the abstraction from an aquifer.

In general, it is envisaged that most assessments will be made on the scale of the Environment Agency's aquifer units. Aquifer units are commonly used throughout Environment Agency Regions as a means of dividing whole aquifers into discrete 'compartments' for water resource management purposes. The delineation of aquifer units can vary between Regions but boundaries are generally coincident with key geological features, hydrogeological boundaries or surface water catchments.

However, in some areas, the aquifer unit boundaries adopted are not always explained by the above. Where they are not (or where they are based on surface water catchments) the units may not form sensible aquifer sub-divisions in hydrogeological terms. Therefore, in some areas, it may be prudent to compile new hydrogeologically based delineations in order to minimise complications such as cross-boundary groundwater flow.

The Methodology requires a wide range of data input typically available to an Environment Agency hydrogeologist in order to calculate *yield* of an aquifer or a part of an aquifer. These data will usually include:

- topographical data
- geological data (maps, borehole logs, papers etc)
- hydrogeological data (maps, pumping test results, groundwater levels etc)
- current and historical abstraction data (licensed and actual)
- meteorological data
- land-use data
- hydrological data (river flows, abstractions, discharges etc)
- environmental data (river quality, use and ecology)
- miscellaneous published data and internal calculations

This Methodology is concerned with assessing *yield* from aquifer units (or whole aquifers) and not individual sources and the focus is on obtaining a 'regional' assessment for strategic planning purposes. A UK Water Industry Research project (Groundwater Development Consultants, 1995) has recently been completed on 'yield of groundwater sources' and this could potentially be used to help assess and consider more local effects. The resulting report 'A Methodology for the Determination of Outputs of Groundwater Sources (Reference WR-01/B/1)' is now also available.

Although methods do exist to calculate the yields of aquifers there is not at present a common approach. In general, existing methods calculate the recharge to the aquifer (or aquifer unit) and then set the *yield* as either a proportion of this amount, or as the difference between recharge and estimates of the total (or required) river baseflow leaving the area. The Methodology developed in this project is intended to refine the principles behind these methods to produce a logical series of calculations which are objective, adequate and robust. The method is described so that it can be applied by personnel with no extensive local knowledge of the aquifer unit being assessed. However, the value of detailed local knowledge is recognised and where this exists we encourage that any difference between the Methodology results and experienced judgement be reconciled. With this in mind, there is significant scope for Methodology users to modify many of the suggested parameter values with values considered more appropriate based upon local knowledge or circumstances.

It is not proposed to examine the problem of recharge assessment. Such a study would be a major undertaking and is considered outside the scope of this project. The latest thinking on this subject is probably best summarised in the Environment Agency's R&D Technical Report W7 - National System for Groundwater Recharge Assessment (Institute of Hydrology, in press). For those personnel making recharge assessments, calculations will normally be based on conventional hydrometeorological, soil water

budget and soil-geological controls. However, other potentially important contributions, or influences, may also include:

Natural systems

- cross-boundary inflows
- leaky rivers
- swallow holes

Manmade effects

- landuse (agriculture (crop management and drainage schemes), urban, mining, reservoirs etc)
- leaky mains services
- artificial recharge
- effluent discharge or soakaway to land
- induced recharge.

### 1.3 **Approach to the Methodology**

The *yield* of part of an aquifer has been defined as *the quantity of groundwater that can be reliably and sustainably abstracted without causing an unacceptable impact to the environment.*

The basic principles underpinning the Methodology and the evaluation of the *yield* assessment are summarised as follows:

- it is implicit that abstraction must be less than average recharge to avoid chronic groundwater level decline and *mining of the aquifer*
- the methodology concentrates on defining (or estimating) how much less abstraction must be compared to average recharge.

Defining the fraction of recharge that can be safely abstracted in order to avoid undesirable effects allows for some protection of the water environment and an allowance for the 'natural' variation in seasonal and annual hydrometeorological conditions.

As described above the impact from an abstraction may result in local and strategic effects. The distinction between what constitutes a strategic as opposed to a local issue is not always clear and unequivocal. However, as a guide, it is suggested that localised effects occur within a defined radius of a source and the Environment Agency have specified survey areas, in Groundwater Investigation Consents (Environment Agency, 1993) - Section D.10, which may be applied. Strategic impacts result from the

cumulative effects of all abstractions in an aquifer unit and this may materialise at the most environmentally sensitive part of the aquifer.

It should be noted that the division between these two aspects of resource assessment is clearly recognised in current licensing practice nationally. The licence for a groundwater source frequently defines a maximum daily abstraction and a maximum annual abstraction with the latter representing a smaller prorata rate of abstraction. It is clear that the daily maximum (which may be abstracted for many months) must be used for local assessment but for strategic assessment (where problems will usually take years to appear rather than months) the annual abstraction rate is often more critical. Seasonality in abstraction, however, is an issue that has been incorporated within the Methodology.

The definition given above for *yield* is considered in more detail below. The three conditions the *yield* must satisfy are all interdependent and defined as follows:

i) Reliable

Over and above source-specific operational and local considerations (which are not addressed here), reliability at a strategic level is usually governed by:

- actual yield being critically constrained in extreme drought conditions
- whether regulatory constraints are imposed on abstractions conditional on specified hydrological events.

For important abstraction operations, such as public water supplies, these constraints may be overcome (or reduced) by:

- developing conjunctive abstraction schemes drawing upon two or more different water resources
- introducing water conservation schemes (to increase storage) or measures (to control demand)
- introducing artificial support to maintain acceptable water resource availability and/or hydrological conditions at all times.

At present, there are no legal definitions, or strictly applied guidelines, on the level of abstraction reliability that should be aimed for. The regulator may have to make a judgement as to what may be acceptable and to inform the developer that the level of protection necessary for the environment makes their abstraction

quite unreliable. However if this is acceptable to all parties concerned then the abstraction can be permitted.

Traditional abstraction licensing practice has tended to impose constraints (where appropriate) on abstraction when river flows are at or below the 95 percentile exceedence value. However, in extreme circumstances 80 percentile exceedence values have been applied.

Therefore, in summary, abstraction licensing reliability has no strict definition and the regulator will have to consider the demands of the developer and counter these against the conflicting needs to protect the environment.

ii) Sustainable

In an ideally managed aquifer, abstraction development may be regarded as sustainable providing no long term trends of decline occur to either the groundwater levels in the aquifer or the baseflow from the aquifer. At the local and strategic scales, new aquifer hydraulic equilibriums resulting from increased abstractions, should ideally develop within several months and a few years respectively.

In this project, the focus is on establishing the *yield* that is ‘naturally’ sustainable. However, artificial support can also be considered in the overall assessment.

iii) Acceptable (no unacceptable impact to the environment)

Again this can be considered on a strategic level or a local level. At a local level the Environment Agency conduct a search within a specific radius. The radius varies from 100 m to 4 km according to the intended abstraction rate. The following possible effects are assessed:

- Springs. Reduced flow caused by declining groundwater levels.
- Abstractors. Licensed or unlicensed abstractors may suffer reduced yield or operational difficulties.
- Standing water. Lakes, pools, ponds, wetlands etc.
- Vegetation. May be affected by reduced levels. In the UK effects are usually confined to wetlands and marshes. However sometimes agriculture can be affected.



- Land drainage. Reduced subsurface irrigation and water levels.
- Rivers and streams. Reduced baseflows.
- Saline intrusion. Either from the sea or connate groundwaters or even contaminated groundwater.

In addition to the above, and recognising this is not a statutory requirement, Entec suggests that systematic considerations should also be given to:

- Geotechnical impacts and possible effects on buildings, engineering structures, underground workings and services.
- Land drainage impacts with land drainage embracing the expanded definition given in the 1991 Land Drainage Act (as opposed to the 1991 Water Resources Act) and as extended in the recent 1995 Environment Act.

Strategic considerations could potentially be as for the local assessments. However, the main focus of the Methodology will be centred on consideration of river baseflows and how they are affected. The reasons for this are as follows:

- in practical terms, reduced river baseflow is the most common environmental problem in ‘over developed’ aquifers. The various other potential environmental problems mentioned above tend to be less common and are usually of a local nature and do not generally lend themselves to a simple strategic and all embracing approach.
- maintaining baseflows in rivers will tend to inhibit any widespread lowering of water tables if the river is in good hydraulic contact with the aquifer. The exception to this may be if an environmentally sensitive area and the development site are distant from the river, higher up in the groundwater catchment.
- many rivers are environmentally sensitive. Abstractors, fishing rights, ecology, effluent dilution and amenity facilities all depend on the maintenance of adequate river flow.
- finally, the failure to maintain adequate river flow can have a dramatic visual impact and one that is very much in the public eye. From the public relations point of view, maintaining river flows is often crucial and this concern is generally on the increase.

Because of the above, it is important to closely relate this project with the resulting methodology from Environment Agency R&D Project 438 - Surface Water Abstraction Licensing Policy Development (Halcrow, 1995). From this, recommendations are given on managing and maintaining adequate river flow regimes.

The consideration of saline intrusion is a different and generally more complex phenomenon than the other environmental effects. This effect usually results from altering 'cross-boundary flow' regimes and is often exacerbated by over-abstraction. No specific methods are presented in this Methodology to address this issue and, as the assessment of saline interfaces is a complex problem, we do not recommend relying on theoretical calculations alone. Fieldwork (i.e. monitoring boreholes with regular sampling or logging) is the best way to monitor and assess the movement of the interface.

## **1.4 Limitations of Methodology**

It must be recognised that the Methodology developed is mathematically prescriptive and the user is therefore forced to make a number of simplifications and assumptions about the aquifer system. As a result, there will be occasions when the aquifer being assessed is quite different to the idealistic assumptions made such that the Methodology output must be treated with caution. The intention is to make the Methodology as robust as possible but it must not be considered exact or applicable to all situations. Furthermore, it must also be emphasised that the Methodology has only undergone very limited calibration and trialing to date and therefore, it is recommended that the Methodology is periodically reviewed and revised in the light of experience gained from its application. Clearly detailed studies using numerical models will supersede the calculations made and frequently long-term experience may provide equally or more valid estimates. In some instances, aquifer units may be better managed and assessed purely from monitoring data or specific field investigation. Additionally, monitoring and investigation data should always be used to influence any Methodology assessment.

Notwithstanding the above, it is believed that the Methodology provides a simple and strategic means of assessment which is a significant improvement on previous practices. Additional complications which may warrant consideration when applying the Methodology also include:

- Definition of acceptable impact. What may have been previously viewed as acceptable in the past, may no longer be regarded as acceptable today.
- Meeting existing policy and licensing arrangements. This is discussed in more detail below (Section 1.5).

- Nature, through extreme drought and flood occurrences, can place significant stress on the water environment and this can sometimes be far in excess of any impact resulting from abstraction.

Therefore, whilst it may be possible to define *yield*, it is unrealistic to expect a Methodology to be formulated which can be realistically or confidently applied to estimate *yield* for all eventualities. It is important that this limitation is recognised and understood when using the Methodology. However such a Methodology will provide uniformity and this may be particularly valuable in areas where there is no long-term experience.

## 1.5 **Integrating Assessment with Management Policy**

Groundwater Management is complicated by a number of factors. Those factors which may need consideration include:

- Many licensees do not use their full entitlement
- Many abstractions are very seasonal and this may impose an additional strain on the resource and this is quite common for spray irrigation and peak water supply demands. In some instances, the licensed daily rate may be more relevant to management than the total annual or seasonal volume.
- Many abstractors do not ‘consume’ the water but return it (or some of it) to the hydrological cycle. Such returns may be local or remote to the abstraction and this can be of significance too.
- Cessation (or reduction) clauses may come into effect given certain hydrological (or water quality) thresholds. Similarly conditions can be imposed requiring river flows (or wetlands) to be artificially supported given certain hydrological (or water quality) thresholds.
- In extreme circumstances, a Drought Order may be
  - sought which allows an otherwise unauthorised abstraction
  - imposed which can limit or preclude an otherwise authorised abstraction.

Traditional abstraction licensing practice normally requires licences to be granted to perpetuity and this makes long-term management further complicated because of the uncertainties and risks involved. There is however, an increasing trend to grant some new major (or sensitive) licences on a time limited basis and allow a period of further impact evaluation. It is interesting to note that in Denmark, a country 99% dependent upon groundwater abstraction for its water supplies, all abstraction licences are granted

on a time limited basis, with public supply and spray irrigation licences from groundwater being time limited to 30 and 15 years respectively.

The current extent of groundwater resource development, particularly in southern and eastern England, means that for significant areas the Environment Agency have adopted a general policy which presumes against any further consumptive abstraction development.

At present, the Environment Agency have an active nationwide scheme to alleviate low flow problems, in 40 catchments (and the number of catchments is under review and may increase), which have generally been exacerbated by excessive groundwater abstraction development, particularly prior to 1963. The solutions being formulated, which tend to prove very time consuming and costly, generally entail abstraction (and licence) reduction and/or artificial river support. *It may prove very worthwhile to systematically apply the Methodology to catchments referred to above.*

## 2. ACTUAL PROJECT PROGRAMME

The actual project programme as summarised in Figure 2.1. In brief this is summarised below.

### 2.1 Stage I

The Stage I programme commenced in October 1994 and was completed in November 1995 with a National Seminar held in London. Completion of Stage I took some six months longer than was originally proposed. Three significant project variations, the latter being a significant project breakthrough, contributed towards this extension including:

- a Questionnaire
- a Seminar at Entec's Shrewsbury office
- formulation of the 'Type Curve' Methodology.

### 2.2 Stage II

The Stage II programme commenced in December 1995 and was substantially completed in April 1996 (draft reporting) and finalised in December 1996 (final reporting). The duration of the Stage II programme has become very protracted because of preoccupation by Environment Agency staff to heavy routine workloads and the formation/reorganisation within the new Agency. The scope is also much as originally proposed with the following exceptions:

- greater effort was made in refining the Methodology than originally envisaged
- the dissemination seminar originally proposed was removed from the finally agreed programme.

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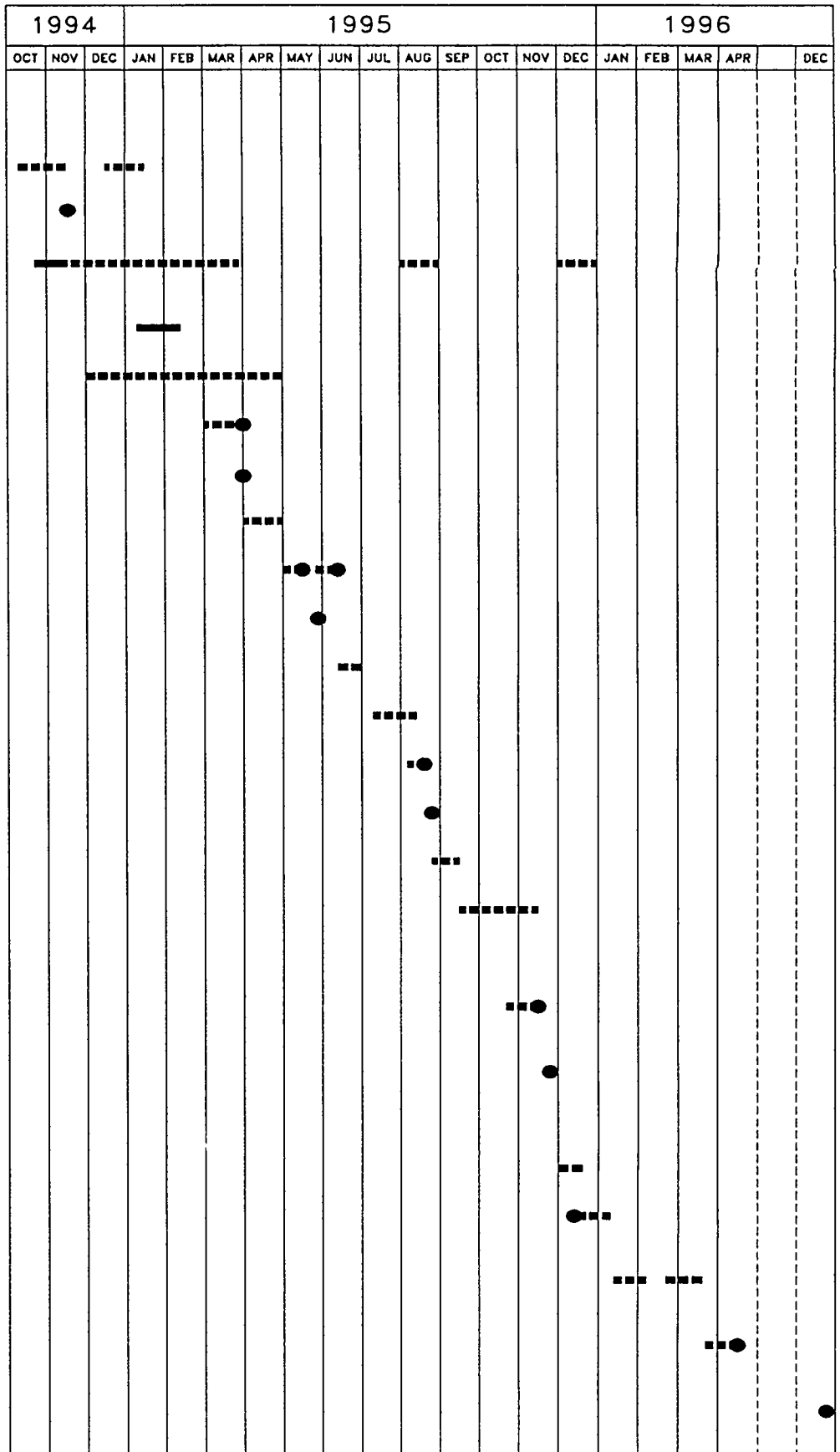


Figure 2.1  
Actual Work Programme

### **3. SUMMARY OF PROJECT WORK**

#### **3.1 Deliverables**

The final project deliverables have already been summarised in Section 1.1. Other deliverables provided during the course of the project are summarised below:

- ‘Questionnaire’, (Unpublished, December 1994)
- First Progress Report, “544/NY/1” (Papaioannou, unpublished, March 1995)
- Interim Report, 544/NY/2 (Papaioannou, unpublished, June 1995)
- Preliminary Draft Notes in Preparation of the Third Progress Report (Papaioannou, unpublished, August 1995)
- Third Progress Report, 544/NY/3 (Papaioannou and Erskine, unpublished, November 1995)
- “Final” Project Quality Plan (Papaioannou, unpublished, December 1995).

#### **3.2 Meetings and Seminars**

##### **3.2.1 Regional Meetings**

Regional visits were conducted for fact finding purposes over the period 17 January to 2 February 1995 and responses are reported in detail in Section 2.4 of the First Progress Report.

##### **3.2.2 Project Meetings**

Project ‘steering’ meetings were conducted over the course of the project. These were predominantly technically based but project progress and financial matters were also covered too. The schedule of meetings conducted were:

- Inaugural Meeting at Environment Agency Leeds, 21 October 1994 (Ref 15519M021)
- Second Meeting at Environment Agency Solihull, 29 March 1995 (Ref 15519M202 il)
- Third Meeting at Environment Agency Leeds, 25 May 1995 (no formal record made)
- Fourth Meeting at Environment Agency Warrington, 18 December 1995 (Ref 15519C471).

Copies of Notes or letters covering the above meetings are given in Appendix A.

As indicated above, no formal record was made of the Third Meeting. The main purpose of this was to discuss the draft version of the Interim Report.

### **3.2.3 Project Seminars**

Two project seminars have been conducted at

- Entec's Shrewsbury office on 23 August 1995 (Ref 15519M299 i1)
- Environment Agency London on 23 November 1995 (Ref 15519M449 i1)

and formal notes from these are given in Appendix B.

The first seminar at Shrewsbury was a presentation to a wide range of Entec staff not involved in the project aimed at:

- consolidating project findings
- providing a 'dummy run' for the National Seminar to the Environment Agency
- giving an opportunity to seek Methodology ideas from a wide audience.

The second seminar in London was a presentation to a range of Environment Agency representatives from different Regional Offices aimed at:

- providing project background
- presenting a draft Methodology
- discussing further Methodology development.

## **3.3 Literature Review**

### **3.3.1 International Literature Review**

The International Literature Review is detailed in Appendix C. This Review includes

- international publications
- Environment Agency Water Resources Strategy documents

but excludes other relevant Environment Agency R&D projects which are outlined in Subsection 3.3.2 below. The most relevant references are briefly outlined as follows:

- Modelling of Groundwater and Surface Water Systems (D B Oakes and W B Wilkinson, Water Resources Board (WRB), 1972).

*The relevance of this paper is described in Section 3 of the R&D Note and outlines the analogy between earlier WRB findings and the development of the 'alpha' term*



*and type curve in the project. These developments being pivotal to the Methodology formulated in the project.*

- Evaluation of Simplified Stream - Aquifer Depletion Models for Water Rights Administration, Groundwater 33, (M Sophocleous *et al*, 1995).

*This paper compares Glover's (1974) stream aquifer analytical solution against MODFLOW simulations for stream - aquifer depletion assessment. The key sensitive assumptions concluded are:*

- *partial stream penetration*
- *streambed conductance*
- *aquifer heterogeneity.*

*All these parameters are addressed in the Methodology development and described in the R&D Note. The significance of the first two parameters is addressed in some detail and their influence features significantly in the Methodology. However, the latter parameter, aquifer heterogeneity, is only covered briefly.*

- Model for Prescribing Groundwater Use Permits, ASCE Journal of Water Resource Planning and Management, (J Male and F Mueller, 1992, Review of Water Management Act (1986), Commonwealth of Massachusetts, USA).

*This paper reviews the procedures for technically determining abstraction permits. These procedures do take into account the 'consumptive' and seasonal nature of the abstraction and these concepts have been utilised, albeit with modification, into this project.*

- Reliable Yield of Unconfined Aquifers, Hydrological Journal 33, (L R Khan and J A Mawdsley, 1988).

*This paper examines aquifer yield (for an unconfined aquifer) using a lumped model approach. The procedure examines how reliable yield is constrained by considerations towards low flow management and return periods for recharge input. An analogy to this concept is briefly explored in Section 3 of the R&D Note.*

### **3.3.2 Related Environment Agency R&D Projects**

Already mentioned in Section 1.2 is the Agency's R&D Technical Report W7 - National System for Groundwater Recharge Assessment (Institute of Hydrology, in press). During the course of this project only the Interim Report for Project 499 has been referred to. Recharge is a fundamental input into the Methodology for this

project and therefore, use of the most refined or appropriate recharge estimate for the aquifer unit under consideration is very important.

In Section 2.2 of the User Manual there are links with the Environment Agency's R&D Project 438 - Surface Water Abstraction Licensing Policy Development (Halcrow, 1995), and the Core Report (R&D Note) for this related project has been referred to in the course of this study.

Output from Project 438 is used towards allocating a Proportion of Annual Average Baseflow (or Recharge) (PABF) to protect baseflow regimes and the reasons for conceptual departures between Projects 438 and 544 are briefly explained in the User Manual. The thinking behind the PABF concept is outlined below.

Approximate target values were presented by G Petts at a British Hydrological Society (BHS) meeting in June 1989 and consolidated in his accompanying paper, Methods for Assessing Minimum Ecological Flows in British Rivers (Petts, 1989), BHS Meeting. He highlighted a minimum flow management regime, expressed as a percentage of average daily flow (ADF), which with respect to ecological requirements gave:

- 10% ADF as a degraded or poor habitat condition
- 20% ADF as an appropriate criterion for protecting aquatic habitat
- 30% ADF as near optimum habitat for small streams (which could be reduced with increasing stream order).

At the same BHS meeting A Gustard presented findings on prescribed compensation flows from reservoirs which ranged up to ~33% ADF with the average value being typically ~17% ADF.

From the author's personal recollection, the minimum control flow operated on the River Witham at Saltersford intake of 15 MI/d maintained a good river environmental condition and it is thought that this could be regarded as a suitable target value for a river which has a fairly high hydrological sensitivity and environmental criticality. This is equivalent to ~22% ADF.

Therefore, integrating the concepts that emerged from Project 439 along with the above ideas the PABF concept was formulated.

A number of other Environment Agency R&D projects were discussed during project meetings but were not used or referred to during the course of this project. The most notable being the Environment Agency R&D Project on "Register of Aquifer Characteristics". This reference may be useful to potential users of the Methodology from this project. However, in the User Manual, it has been emphasised that aquifer

hydraulic parameters derived solely from pumping tests may not prove directly applicable, or need to be used bearing in mind their potential limitations.

### 3.4 **Methodology Development**

The Methodology is described in the User Manual (Papaioannou and Erskine, 1996a) and the R&D Technical Report W10 (Papaioannou and Erskine, 1996b).

Emphasis has very much been on considering unconfined aquifers having “classical” baseflow regimes and which interact significantly with the surface water environment.

The Methodology enables certain dynamic attributes of the hydrometeorological regime to be analysed in conjunction with the hydraulic and geometric characteristics of the aquifer. The Methodology enables the aquifer’s ‘typical’ seasonal baseflow regime to be described. From this, and by making allowances for environmental needs it is then possible to establish a safe allocation for abstraction development from (or *yield* for) the aquifer. However, groundwater resource planners are generally not highly conversant with setting such allocations against a defined (or design) reliability. The reasons which make this concept very difficult and complex include:

- natural limitations caused by drought occurrence and variability in hydrological conditions from one year to the next
- the use of impact mitigation or controls
- conjunctive water resource schemes
- abstraction consumption and fate of effluent returns
- seasonality of abstraction
- past groundwater resource management/development
- increasing environmental awareness
- possible climate change.

Many of the above factors are incorporated into the Methodology and their significance highlighted.

Ultimately, the Methodology is designed to be relatively simple and widely applicable. In this respect, Entec are very keen to assist in it’s future application and further development.



## 4. REFERENCES

*This list is restricted to references given in the main body of this document. All of the other references included in Appendix C, as part of the International Literature Review, are not repeated here.*

Papaioannou and Erskine, 1996a. Environment Agency R&D Project 544 Technical Report W9 - User Manual. Groundwater Resource Reliable Yield.

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**APPENDIX A**  
**NOTES FROM MEETINGS**

*(11 Pages)*





**Groundwater Resource Reliable Yield  
NRA R&D Project B03 (93) 01**

**Meeting of 21 October 1994 at NRA Northumbria & Yorkshire Region  
(Olympia House)**

The meeting convened at 11:00 am. The morning was spent discussing General project matters, and the afternoon concentrated on Technical approaches specific to Northumbria and Yorkshire Region. These are outlined further below.

**1. General Matters**

Present: John Aldrick (JA) ) NRA Tim Haines (TSH) )  
Mike Briers (MB) ) Martin Lack (MCL) ) *Entec Hydrotechnica*  
Angelo Papaioannou (APA) )

i) Overall Context

JA outlined the overall context and need for the project which included:

- NRA coming at the project from a Resource Management perspective
- Regional harmonisation/consistency
- Particular problems highlighted by the 89 to 92 drought
- NRA is looking at 'Aquifer Management' issues.

ii) Allied Projects

Allied projects were highlighted including:

- Recharge Assessment by IH and BGS, although JA explained that this has largely become a contract seeking to better define effective rainfall (rather than recharge) for aquifer outcrop areas. Dave Burgess (Anglian Region at Peterborough) is NRA Project Leader.
- Water Industry Research Project on "Yield of Groundwater Sources". This project has been awarded to Mott MacDonald's and a copy of the brief was handed to *Entec Hydrotechnica*. Respective project briefs include need for cross reference (links) between each project. Mike Owen (Thames Region at Reading) is the NRA's member on the project team.
- It is envisaged that this project may be followed by another R&D initiative, which seeks to set out a more sophisticated approach to Yield Assessment (possibly by modelling) which will be a follow-up to the outcome of this project once certain criteria for an aquifer have been reached.

iii) Using Readily Available Information

- TSH wondered whether output from Groundwater Vulnerability Mapping could be used in the project. This is worth further consideration.
- APA wondered whether output from the NRA R&D project on "Register of Aquifer Characteristics" (being undertaken by BGS) may be of any value. JA explained that

this was mainly a catalogue of aquifer hydraulic characteristics resulting from pumping tests but may be worth some consideration.

- APA briefly outlined how baseflow indexes (BFI's) vary across East Anglia and how this could be related to varying characteristics of drift boulder clay in the Region. As well as using readily available hydrological summaries from hydrometric data, it may be worth exploring the possible use of BGS geotechnical database.

iv) Assessing Groundwater Resource Reliable Yield

- The need for a broad brush and robust Methodology was reinforced.
- Where necessary, this could accommodate local variations as necessary.
- Where issues become complex for various reasons the Methodology may provide guidelines to conducting:
  - allied desk study investigation
  - more sophisticated assessment (possibly modelling)
  - field investigations or hydrometric measurement to reduce key uncertainties.
- This study would define trigger levels or complex issues which introduced more detailed stages of assessment.

v) Aquifer Coverage

- JA agreed that the project should cover the Sherwood Sandstone and Chalk aquifers because of their water resource significance.
- It was not clear which “minor” aquifers should be covered. JA explained the possible need to cover the Lincolnshire Limestone. In addition, JA expressed concern for overestimation of reliable recharge to the Carboniferous Limestone. APA alluded to a notional concept that he holds, this relates to possible critical ‘hydraulic responses’ for drought periods of varying duration affecting significant aquifer blocks (dependant upon storage and transmissivity characteristics) such as:

- Sherwood Sandstone      5 years
- Chalk                              2 years
- Lincolnshire Limestone    1 year

Therefore, the ability of the aquifer to buffer annual variation in recharge quantities is probably critical to reliable yield assessment and this notion, allied to design yield etc, may provide a potentially useful way forward.

It was concluded that “minor” aquifers, considered locally important, and providing they are not too complex or esoteric, should be adequately covered by the Methodology to result from this project.

vi) Regional Contacts

- JA provided a list of first points of contact for NRA Regions (see Table 1) below.

Table 1

**First Points of Contact for NRA Regions**

Contacts:

<b>NRA Region</b>	<b>First Points of Contact</b>
Severn Trent	Gwyn Williams - Solihull Steve Morley - Regional Water Resources Manager
Thames	Mike Owen - Reading, Water Resources Manager
Southern	Paul Shaw
South Western	Cliff Tubb - Exeter
Welsh	Ask Wayne Davies or Ian Barker
North West	Ask Tony Peacock
Anglian	Cameron Thomas Dave Burgess

JA also highlighted the project roles of:

Mike Briers (Northumbria & Yorkshire) - contractual  
Cameron Thomas (Anglian) - Water Resources Topic Leader  
Andrew Skinner (Severn Trent) - Co-ordinator of National Groundwater Centre.

- JA emphasized that whilst in discussion with other Regions the need to:
  - probe why they adopt certain practices
  - how strongly they feel about their current practice
  - how they view possible change
- JA agreed to send a brief letter plus ToR to all Regions to help get the “ball rolling” in advance of *Entec Hydrotechnica* seeking to arrange Regional visits. The covering letter would seek to:
  - identify the most appropriate points of contact
  - invite participation at an Area level as considered appropriate.

This would be done by the 28 October 1994.

- The possibility of combining visits/meetings for certain Regions was explored. However, JA thought that in this instance, this approach may not prove pragmatic.
- The question of possible “poor co-operation” from Regions was touched on. APA agreed to notify JA of any problems as soon as they become “significant”.

- 
- It was agreed that if Regions have good documentation on current practices and/or data, they would not need to fill in questionnaires.

vii) International Review

- It was agreed that International Review should be generally restricted to North America and North West Europe.
- APA explained sister companies in Europe, and association with Hydrosearch in US. In addition, *Entec Hydrotechnica* would consult IAH sources and may make contact with USGS independent of Hydrosearch. It was considered important to ensure adequate coverage of Denmark, Netherlands and Belgium and this will be facilitated.
- *Entec Hydrotechnica* propose to provide a Method Statement on this aspect of work as soon as possible.

viii) Contractual

- MB would aim to get a formal contract out in the week commencing 24 October 1994. No particular issues or problems were raised. Note - documentation received by *Entec Hydrotechnica* on 27 October 1994.

ix) Quality Assurance

- APA tabled a Draft Quality Plan and left copies with JA and MB inviting comments before this is finalised.
- It was agreed that only one copy of the final plan would be issued to the NRA for the attention of the Project Manager/Leader. Correspondingly, JA would decide what information, if any, should be disseminated to others within the NRA.
- APA undertook to commence "Weekly Reporting" for the week beginning 24 October 1994.

x) Miscellaneous

- APA explored the possibility of some flexibility in deadlines for Bi Monthly Progress Reports. He felt it would be useful to hold back a deadline for several days if a significant component of work in the project could be included. As coverage of all routine matters would be provided in Weekly Progress Reports including precise timings for "Bi Monthly Reporting" which could be highlighted accordingly. This was generally accepted.
- MB will let *Entec Hydrotechnica* have details of the NRA's formal reporting requirements including covers etc.
- No date was fixed for the NEXT MEETING. However, it was agreed this should be before Christmas and should be firmed up over the next 3 to 4 weeks.

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## 2. Technical Approach and Details Specific to Northumbria/Yorkshire Region

Present: John Aldrick  
Martin Lack  
Angelo Papaioannou

### i) Howard Humphries/Yorkshire Approach

- JA tabled documents outlining Licensing Management for Yorkshire that have been in use since the late 80's. He added that the approach was essentially a natural progression from the Section 14 Surveys but also developed to help assist in determination of Spray Irrigation licences which collectively can have a particularly acute impact on the water environment.
- JA explained that aquifers are classed into four categories. In general the policy was working reasonably well. However, problem areas include:
  - probable overestimation of Reliable Yield for the Carboniferous Limestone
  - acute problems in the Chalk during the recent drought
  - prescriptive control rules on groundwater levels have generally not been adopted
  - there is a lack of resources to carry out all monitoring etc for licences issued with control rules or on a time limited basis.

### ii) Other Issues in the Yorkshire Area

- JA explained that a groundwater model is being developed for the Hull Chalk Region. Here, Licensed totals equate to about 50% theoretical resources on an average yield basis with many sources in operation since the turn of the century. However, control rules, now adopted by Yorkshire Water, have been in operation for decades, which limit abstraction according to certain control criteria.

In the Hull area, conjunctive schemes operate, and as alternatives to Chalk groundwater, other sources include abstraction from the River Hull and imports from the west.

- Another area requiring special consideration is the Sandstone in the Vale of York where there is a poor understanding on the influence of the Drift on the hydrogeology of near surface features (such as ponds, wetlands and springs) and their relationship with the main aquifer.

### iii) Northumbria Area

- JA explained that practice in this area was very different for the following reasons:
  - significant groundwater development was limited to the Permian Limestones around Hartlepool/Sunderland  
Fell Sandstone around Berwick
  - significant areas are exempt from groundwater licensing.

- Consequently “pressures” on groundwater are different in this Area. In order to gain an adequate “picture” contact with either Martin Kershaw or Paul Butler of the Gosforth office would be necessary.
- APA undertook to make contact with Northumbria area and deal with matters by phone/letter. However, if other business took him to Newcastle area, he would arrange a meeting.

iv) Questionnaires

- The Draft Questionnaire (ref 15519G017) was discussed.
- The general approach was accepted, albeit a further form would be necessary to seek data specific to selected aquifer units.
- Minor amendments to the form were discussed and APA agreed to take these on board, along with development of the data questionnaire, and submit these to JA for comment before circulation.
- Questionnaires will be submitted to Regions in advance of meetings. It was agreed that if Regions have adequate documentation on Methodologies and relevant data in appropriate formats, they would not need to fill in the Questionnaire’s. In this instance, *Entec Hydrotechnica* will use data sources to fill in Questionnaires.
- If Regions have difficulty providing necessary data in reasonable time, the possibility of MCL providing assistance will be explored.

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**GROUNDWATER RESOURCE RELIABLE YIELD**  
**NRA R&D PROJECT B03 (93) 01**  
**NOTES OF MEETING**

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**Meeting of 29 March 1995 at NRA Solihull**

**Present:** Andrew Skinner (AS) - NRA  
 Richard Streeter (RS) - NRA  
 John Aldrick (JA) - NRA  
 Tim Haines (TH) - *Entec*  
 Angelo Papaioannou (AP) - *Entec*

**Apologies:** Jerry Sherriff - NRA  
 Mike Eggboro - NRA

**1. AP summarised findings from Regional Visits including:-**

- Not a significant issue in Northumbrian Area
- Groundwater management has become “highly advanced” in Thames due to development pressure from demands.
- Southern and Anglian have made attempts to ascribe a proportion of “reliably” available groundwater when compared with the average steady state value.
- Welsh welcome the project as they are currently and systematically focusing in on groundwater resource management issues for the first time.
- South Western advocate their “Green/Red” policy approach and also indicate their present difficulty in harmonising different past practices between ex Wessex and South West Regions.
- A number of Regions strongly advocate the need to consider situations and determine licences on their individual merits. This was particularly noted in North West and Severn Trent Regions.
- A number of Regions were concerned that the project may provide a “Methodology” that was considered a retrograde step and did not want anything too rigid, prescriptive or precluded the option of utilising distributed groundwater modelling.
- Environmental issues and allocation of resources featured very strongly. Also the general move away from the 95 percentile concept for riverflow to a more scientifically based evaluation.
- Anglian particularly picked up on:-
  - the need to move away from average steady state approach to something that is more stochastic and takes into account certain aquifer characteristics (relating to response time and drainage behaviour),
  - experimental work with the Howard Humphries approach indicated they would need to be far more restrictive with abstraction development than is considered appropriate.
- Uncertainty/Criticality/Sensitivity were all picked up on as potential issues.
- Development of a quantitative (lumped parameter 1-D slice) approach as a

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## GROUNDWATER RESOURCE RELIABLE YIELD

### NRA R&D PROJECT B03 (93) 01

#### NOTES OF MEETING

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Methodology would be difficult because of wide ranging hydrogeological and environmental circumstances encountered.

- i) JA highlighted the common threads in all Regional responses including:-
- Recharge and Abstraction reasonably well known (in most cases).
  - Discharge is not normally so well known except in well studied headwater systems where baseflow considerations are usually a more sensitive issue.
  - Most systematic assessments are conducted crudely. Therefore, from this, the beginnings of a Methodology can emerge.
  - There is a very large step from the systematic simple approach to detailed modelling.
- ii) AS expressed the view that the possible way forward was to:
- Develop a qualitatively based methodology which was complementary to policy/guidelines/strategy rather than a prescriptive quantitative methodology.
  - Consider all Regional Strategy/Policy statements on groundwater management/licencing.
  - Develop a strategic methodology which always leaves open the important consideration of local impacts in any evaluation/determination.
  - Take the long term view where possible (ie. perpetual licences) but allow the possibility of time limited licences where significant uncertainty exists.
- iii) In general discussions the following points emerged:-
- Aquifer “hydraulic response” is an important consideration and some matrix (or similar) should be devised which appropriately takes this into account. AS tabled a WRB paper which may provide some useful ideas.
  - Environmental considerations/allocation should draw upon current R&D work. Specific mention was made of a project being managed by Ian Barker of Welsh Region. This will be followed up.
  - The NRA discussed how the product of this project may eventually be implemented into overall policy.
  - Possible target dates highlighted are:-
    - Discussion of Interim Report findings at NRA seminar in mid June and possible combination with Recharge R&D project.
    - Training session some time in September/October.
  - The Interim Report will provide a detailed skeleton of the Methodology outlining its scope and makeup and how it will work, link and cross reference etc.



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**GROUNDWATER RESOURCE RELIABLE YIELD**  
**NRA R&D PROJECT B03 (93) 01**  
**NOTES OF MEETING**

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**2. Afternoon Meeting**

Present: John Aldrick (JA) - NRA  
Mike Briers (MB) - NRA  
Angelo Papaioannou (AP) - *Entec*

- i) JA and AP summarised progress and outlined the key points of the morning meeting and how they may impact the future programme ie.
- The outline Methodology was now already selected.
  - Task 5A was no longer considered necessary or appropriate.
  - Task 8, the National Meeting, would be coincident with the Seminar (mid June) where Methodology review (refinements) would be discussed.
- ii) The Interim Report will be:-
- Prepared in Draft and issued no later than 19 May 1995 to a restrictive list. This will accompany a brief Progress Report.
  - Discussed at a meeting scheduled for Thursday 25 May 1995 at NRA Leeds.
  - Finalised and issued in early June to Regions for discussion at the National Seminar. This will be accompanied by a separate issue of all Notes from Regional Meetings.
- iii) All future reports will have NRA covers and be numerically sequenced S44/2/NY... 544/N/NY etc. The First Progress Report was 544/1/NY.
- iv) Task 1A is recognised as a variation, but no need for a formal contract variation is required at present and this will be reviewed later.
- v) AP highlighted that actual time spent in March 1995 may be several hours less than estimated for in the invoice. Any difference will be credited in the next invoice. Invoicing is to continue quarterly.
- vi) Weekly Progress Reports will be continued whilst there is significant project activity and will aim to minimise any unnecessary repetition.
- vii) MB would make enquiries regarding R&D project managed by Ian Barker.
- viii) AP will issue JA with a Project Record on Literature Review as soon as possible (~ end of April).



# Entec

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Our Ref: 15519C471/APA/ash

22 December 1995

Your Ref:

Dr J Aldrick  
National Rivers Authority  
Northumbria & Yorkshire  
Olympia House  
Gelderd Road  
Leeds  
LS1 2QG

Dear John

## GROUNDWATER RESOURCES RELIABLE YIELD PREPARATIONS TOWARDS CONTRACT COMPLETION

Thank you for the meeting with you and your colleagues on Monday 18 December at Warrington. The main conclusions from the meeting are summarised as follows:

- the work to date forms a satisfactory basis on which to specify the final Methodology requirement.
- the project is to be completed before end March 96.
- more attention to PABF setting and selection of D<sub>T</sub> Return Period is required.
- draft Methodology and worked examples expanding on the relevant sections in the Third Progress Report and also provide further detail on conceptualisation/visualisation and limitations etc. Additional testing and analysis etc. will be kept to a minimum.
- Deliverables also include R & D Note and Record.
- Project budget variation will require written justification before being formally considered.

The following outline work programme was agreed

- |                                                                                                       |              |
|-------------------------------------------------------------------------------------------------------|--------------|
| • Redraft relevant extracts from the Third Progress Report with worked examples and illustrations etc | 19 Jan 95    |
| • R & D Note & Record                                                                                 | 16 Feb 95 *  |
| • Final Methodology and worked examples                                                               | 8 March 95 * |

(\* these targets may slip by ~1 week due to potential leave commitments etc.)

The specific areas requiring further work and the necessary scope are outlined in Table 1 below.

Cont'd...

Dr J Aldrick  
NRA Northumbria & Yorkshire

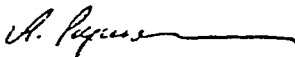
Table 1  
Scope of Further Work

	Further Analysis	Worked Examples & Illustrations	Checklist & Guidance	
Refine PABF setting & $D_T$ Return Period		Y	Y	
Refine EAL determination		Y		
Refine criteria for using the 'Baseflow' Method		Y	Y	<u>L = limited</u>
Refine the 'Non Baseflow' Method		L	Y	
Consider units with contrasting aquifer - river interaction and permeability characteristics	L		Y	
Consideration of PAR term		Y	Y	
Expand the 'Baseflow' Method and use flow data where it exists	L	Y		

The total approved budget for the project is ~ £29.2K and this compares with a total spend of ~ £33.1K on 3 December 95 (ie on that date we were ~ £4K over budget). We estimate that the final project expenditure to completion will total ~ £39.2K requiring an additional budget approval of £10K. The extra expenditure is attributed to a number of variations on the original specification, these are summarised in Table 2 attached.

We trust this fully satisfies your requirements and we look forward to your comments in the near future.

Yours sincerely



Angelo Papaioannou  
Principal Consultant

Att: Table 2

**APPENDIX B**  
**NOTES FROM SEMINARS**

*(7 Pages)*



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**GROUNDWATER RESOURCE RELIABLE YIELD**  
**NOTES OF MEETING**

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**23 August 1995 Entec, Shrewsbury**

**Present:** John Aldrick (NRA, N & Y)  
TSH, AP, ADE, ML (Project team)  
RTL, DIR, RWNS, JSS (part time)  
Pierre Chovelon (*Entec* Horizon,  
France)

**Meeting**      **Internal Seminar to discuss presentation for National Workshop**

1. AP described the organisation of the project and its programme. The key point made was that *Entec* must present a draft methodology to the various Regional NRA's at a workshop in September. Whilst it must be billed as a "workshop" to allow the NRA to contribute and influence (and thereby engender some "ownership") the presentation must also be slick and persuasive.
2. Project progress was described. Following research and interviews the Interim Report (544/NY/2) was issued in June with outline formulation of the methodology. Since then the work has focussed on developing the details of the methodology with the establishment of a simple numerical model of an idealised aquifer.
3. **Historical Basis**  
  
The history of groundwater assessment policy was described. There remain significant differences in approach in the methods used by the different NRA Regions. There is also a gulf between these methods and detailed regional groundwater modelling with little generally used between the two.
4. **Project Aim**  
  
The definition of the groundwater resource reliable yield was briefly discussed. The aim of the project is to devise a methodology for assessing the groundwater yield on a "regional" scale (aquifer units or aquifers). The consideration of local issues (as opposed to strategic issues) was not to be addressed. JA commented on the scale of the methodology and the ultimate application which was to limit the amount of resource to be licensed. The method must be defensible to experts acting on behalf of abstractors. It was also noted that the calculation of recharge should not be addressed. This was being studied by the Institute of Hydrology as a separate package of work.
5. **NRA Current Status**  
  
The various approaches were described by AP with emphasis on the differences between the regional offices.

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**GROUNDWATER RESOURCE RELIABLE YIELD**  
**NOTES OF MEETING**

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**6. Literature Review**

The results of the literature review (still ongoing) were reviewed by AP. In general descriptions of general policy are more common than precise methods of calculation with the exception of a few theoretical papers. JSS suggested investigation of Middle East policies since such countries were subject to more pressure on water supply and may have developed more advanced methods. AP considered that the lesser priority given to the environment in such countries would reduce the value of such research.

**7. Methodology and Objectives**

AP described the factors that must be taken into account. The objectives were briefly discussed (see also 4.) and the ultimate product of the project described. This would be a series of calculations using tables as necessary that could be summarised in a proforma of only a few pages. It must be easy to apply, robust and widely acceptable to the NRA Hydrogeologists who would be using it.

**8. Idealised Aquifer Model**

AP described the purpose and nature of the model. This model would be used to quantify the theoretical variation in base-flow in a river caused by seasonal variation in recharge to the aquifer for a given set of parameters. The model is a simple 1-dimensional section of the aquifer, unconfined with a no-flow boundary at one end and a constant head at the other representing the river. The parameters defining the model are K (hydraulic conductivity), S (specific yield), l (length) and b (thickness of the aquifer at the river end). The model was run for a number of years until the annual cycle was not changing.

To date both l and b had been fixed at 1 km and 1 m respectively. AP said that he thought the assumption of thickness being 1 m was poor and this had to be varied. ADE thought all four parameters must be varied. An average long-term seasonal recharge pattern had been used for the first set of runs.

The results showed the base flows varying seasonally (roughly sinusoidal) and after a few years (10 was more than enough) the pattern repeated itself. The variation in baseflow was as expected but could be quantified. The method suggested was to introduce a minimum required flow in the river and define the difference between this number and the minimum flow from the model as the resource. RTL pointed out that calculations at present used "ADF" (Average Daily Flow) for the mean base-flow whereas ABF would be a better name. Existing references often defined minimum required flow in terms of a percentage of ADF. It was recognised that this 'discrepancy' needs to be addressed.



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**GROUNDWATER RESOURCE RELIABLE YIELD**  
**NOTES OF MEETING**

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**9. Variations**

In addition to runs with various values of S and K (see above) some runs had also been carried out with special condition

- Inclusion of the calculated “resource” as an abstraction. If included close to the river the remaining “resource” was zero unsurprisingly. If included further away the model suggested that some more resource could be “squeezed” from the system.
- Use of a real series of 20-year recharge data. This reduced the available resource considerably for most of the years analysed (presumably because real data is much more spikey than time-averaged data). The average minimum flow also was less than the figure calculated using seasonal averages. The summer minima of the series could now be analysed probabalistically in order to use, for instance, a 20-year return event for the definition.

**10. Comments**

ML commented that using annual minima as the criterion did not take into account the length of time over which the low flow condition extended. This was accepted but may prove difficult to include.

DIR noted that if an average baseflow figure was available, using this method would effectively remove the need for calculating recharge to the aquifer which was the traditional starting point for resource assessment. ADE commented that ABF and recharge should be equal in theory in the idealised aquifer and therefore one of the two would be used for the method.

ADE also commented that in the event that a gauged river was available there would be no need to use the model results but simply go straight to the probabalistic assessment of minima. It was recognised that gauged data for ‘natural’ catchments is generally not available and, therefore, it would not normally be possible to adopt this approach.

JSS cast doubt on the ability of a hydrogeologist to be able to value the aquifer parameters precisely but it was generally agreed that this was an idealised situation and the limitations could be emphasised in the text of the report. JSS also made a valid comment about the importance of using the judgement of experienced personnel rather than relying upon indication from a simple model. This was recognised but it was also pointed out that a common approach is needed and the experienced personnel are not going to be available in perpetuity.

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**GROUNDWATER RESOURCE RELIABLE YIELD**  
**NOTES OF MEETING**

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It was generally suggested that examples must be found with real gauged baseflow data to prove that the models flow predictions were reasonable. Also examples of the application of the whole method were obviously required.

RTL suggested that AP's program of investigating other factors with the model (e.g. angle of dip, partially penetrating river, confined zone, conductance between river and aquifer, varied parameter distribution etc.) may be ambitious and that the model runs should be carefully targetted.

11. AP thanked all present for contributing and JA for coming. JA would consider the presentation and ask for feedback from the NRA on the return period of event they wished to allow for. The meeting ended at 17.00.

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**NRA R&D 544 - GROUNDWATER RESOURCES RELIABLE YIELD  
NATIONAL SEMINAR TO DISCUSS METHODOLOGY**

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**NRA/MAFF Office, London, 23 November 1995**

<b>Present:</b>	John Aldrick	-	NRA N&Y
	Dave Burgess	-	NRA ST
	Steve Fletcher	-	NRA ST
	Phil Stewart	-	NRA ST
	Paul Shaw	-	NRA S
	Cameron Thomas	-	NRA A
	Dave Seccombe	-	NRA A
	Sue Hunter	-	NRA T
	Alison Brooke	-	NRA T
	Tim Haines	-	Entec UK Ltd
	Angelo Papaioannou	-	Entec UK Ltd
	Alec Erskine	-	Entec UK Ltd
	Martin Lack	-	Entec UK Ltd
<b>Apologies:</b>	Darminder Chadha	-	NRA N&Y
	Mike Briers	-	NRA N&Y
	Mike Owen	-	NRA T
	Graham Warren	-	NRA S
	Mike Eggboro	-	NRA NW

The presentation and proposals were generally very well received and it was accepted that the Methodology given adequate refinement and calibration, would prove useful in strategic groundwater management.

Key discussion points about the Methodology are broken down as follows.

**1. Fundamental Approach**

- $\alpha$  term is comparable to earlier work for the WRB by Oakes et al.
- How do you define/decide on when Baseflow is Significant or not.
- Differentiating Strategic from Local Issues
  - assignment of PAR at local discretion
  - possible need to include a check list and guidance notes.
- Considering aquifers with:
  - confined zones
  - spatially/vertically variable characteristics
  - zones of gaining/losing rivers
  - high river bed resistance

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**NRA R&D 544 - GROUNDWATER RESOURCES RELIABLE YIELD  
NATIONAL SEMINAR TO DISCUSS METHODOLOGY**

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- Tightening up on the interdependence of
  - $D_T$  setting according to return period
  - PABF allocation and corresponding reliability

**2. Further Refinement**

- need to carry out pilot studies, compare with modelled catchments and carry out more validation/calibration generally.
- More guidance on defining T, S and EAL values to plug into the Methodology, ie,
  - T&S should not just be drawn from listings if pumping test observations, but where possible should include Baseflow Analyses
  - The derivation of EAL may need some more refinement
- Reliability and Return Periods
- $F_{SD}$  Factors
- Estimation of  $Q_{SW}$  should be based on licensed quantity only leaving the local assessors to undertake revised estimations, based on actual abstractions, as necessary.

**3. Internal (NRA) or Public Domain Documents**

- Concern was expressed about publishing the Methodology
- It was felt that greater assurance was required if the Method were to become 'Public'
- The possibility of the Methodology being used in Inquiries was raised

**4. Application of Method**

- The adequacy of Aquifer Unit definition (as hydrogeological entities) was discussed
- For some aquifer units having tidal boundaries, the application of the Methodology was brought into question.

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**NRA R&D 544 - GROUNDWATER RESOURCES RELIABLE YIELD  
NATIONAL SEMINAR TO DISCUSS METHODOLOGY**

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- It was recognised that  $Q_s$  indicates the safe level of abstraction development without 'support/mitigation'. There may be a need to go beyond this threshold given these measures.

**5. The Way Forward**

A number of suggestions were tabled but no definite conclusions/decisions were made.

- John Aldrick wondered if a steering/working group forum was a possible way forward
- Cameron Thomas said that this was how the 'SWAB' project had been progressed. It worked well linking technical matters with working policy but was time consuming ~ 18 months
- Angelo Papaioannou suggested some refinement and issuing of comprehensive guidelines during the life of the NRA (before March 1996) giving the new Agency the option to follow up and formalise the project further.

It was agreed that a further Contractual Meeting would be held in the next few weeks (probably mid December) to agree on the continued contract scope/programme etc.



**APPENDIX C**  
**INTERNATIONAL LITERATURE REVIEW**

*(10 Pages)*





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## INTERNATIONAL LITERATURE REVIEW - FINAL REPORT

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An International Literature Review has been undertaken as part of NRA Research and Development Project 544. The intention was to establish a database containing baseline information on groundwater resource management knowledge, expertise, experience and practice as it exists in various countries around the world for the purpose of estimating Groundwater Resource Reliable Yield.

This review also incorporates information that has been gained from discussions with NRA personnel and Entec sources. However, other related projects (with their associated reports) from the NRA R&D programme are not covered by this review.

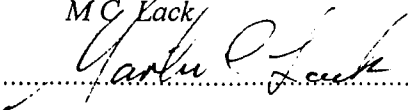
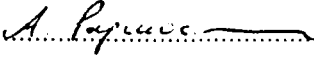
As an initial step the Geological Society Library was contacted in order to obtain a list of their 'sister' organisations in other countries. A list of geoscience organisations was obtained from Geotimes, an American Publication, and it was this list that was used as the basis for the mailshot which followed.

A letter inviting responses and requesting any useful relevant information was sent to named individuals (wherever possible) within selected geoscience organisations across Europe, Australasia, Southern Africa and North America.

In addition, the Journal of Water Resources Planning and Management (published by the American Society of Civil Engineers (ASCE)) was identified as a potentially useful source of information. The WRc Library at Swindon was found to have a good back catalogue of issues and were able to provide copies of contents pages and, subsequently, various articles which were considered to be of potential interest.

Contact was made with the Inland Waters topic centre for the European Environmental Agency (EEA) initiative, based at WRc Medmenham, and through them the Austrian Working Group on Water in Vienna who are compiling an EEA database on pan-European water resources management and policy. The results of this work are not yet available. The European Commission (DG 11) were also contacted requesting information, but were either unable or unwilling to provide any assistance. Their response was not exactly expansive.

The responses gained are summarised in Table 1. In addition, brief descriptions of those submissions considered particularly significant are contained in Annex I. Annex II outlines the Water Resources strategies for the various NRA regions (irrespective of their considered significance).

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**Table 1 Summary of Groundwater Resource Reliable Yield International Literature Review**

Entec Ref.	Country	Incoming Document(s)			Summary of Contents			Keywords / Concepts	Initial Appraisal			Cross Ref.				
		Letter / Fax	Paper	Report	Book	Source	Background		Case History	Research	Methodologic		Legislation	Very Relevant	Relevant	Not Relevant
DL111	U.K.					CIWEM				No Significant Information		Not Relevant		NO		
DL137	N.Z.					Institute of Geological & Nuclear Sciences				Sustainable Management				YES		
DL159	Germany					Federal Institute for Geosciences				GEOFIZ database				NO		
DL160	Germany					Hydrogeologie GmbH <sup>1</sup>				Management Techniques				NO		
DL161	Germany					Hydrogeologie GmbH <sup>1</sup>				Groundwater Recharge				NO		
DL162	Germany					Hydrogeologie GmbH <sup>1</sup>				Groundwater Management				NO		
DL163	U.K.					Mott McDonalds <sup>1</sup>				Recharge, Modelling				NO		
DL166	U.K.					University of Cambridge				No Significant Information				NO		
DL169	Norway					Geological Survey				No Significant Information				NO		
DL170	Denmark					Ministry of Environment				Groundwater Protection				NO		
						Geological Survey of Denmark				Annual Report 1993				NO		
						DGU				Water Quality / Quantity				YES		
DL171	U.S.A.					USGS				Water Supply				YES		
										Groundwater Resources				NO		
										Bibliography				NO		
										Case History				NO		
DL172	U.S.A.					IAH (US chapter)				No Significant Information				NO		DL171
DL194	Canada					IAH (Canadian chapter)				No Significant Information				NO		
DL204	U.K.					NRA R&D H.Q.				Low Flows Estimation				NO		
										NRA R&D Reports				NO		
DL210	U.K.					NRA-SevernTrent <sup>2</sup>				Modelling (D.B.Oakes)				YES		DL242
DL211	U.K.					WRc Swindon Library				ASCE Journal <sup>3</sup> , Contents Massachusetts, USA				NO		DL212
DL212	U.K.					Vol.118, No.5, pp543-561				Catchment Management				YES		DL227
DL213	U.K.					Vol.117, No.2, pp195-216				Regional GW Modelling				NO		DL211
DL214	U.K.					Vol.117, No.4, pp448-459				Conjunctive Management				NO		DL211
DL215	U.K.					Vol.117, No.6, pp662-678				Review of Techniques				NO		DL211
DL216	U.K.					Vol.118, No.3, pp224-237				Multicriterion Analysis				NO		DL211
DL217	U.K.					Vol.120, No.4, pp546-565				Local Perspective				NO		DL211
DL218	U.K.					Vol.120, No.6, pp984-991				Case Study				NO		DL211
DL219	U.K.					Vol.116, No.4, pp503-516				Review of Regional Policy				NO		DL211
DL220	U.K.					Vol.116, No.4, pp484-502				Artificial Recharge				NO		DL211
DL225	U.K.					M O'Shea (TWUL)				National Policy				NO		DL225
DL226	U.K.					NRA R&D H.Q.								YES		

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		Type	Source	Background	Case History	Research	Methodologies	Keywords / Concepts	Not Relevant	Very Relevant	
DL227	U.S.A.	Letter / Fax	Dept. of Env. Protection				Legislation	State Legislation		YES	DL212
DL228	Holland	Report	AA Balkema (publishers)					Contents Pages Only (See Library)		NO	DL254
DL239	U.K.	Report	NRA South West					Regional Policy		YES	
DL242	U.K.	Report	J. Hydro <sup>2</sup> (Vol22pp155-177)					Conjunctive Management		YES	DL210
DL243	R.S.A.	Report	Dept. of Water Affairs					Embryonic Policy		NO	
DL247	U.S.A.	Report	Nat. GW Assoc.					Names and Addresses		NO	
DL251	U.K.	Report	TODD, 1959 <sup>4</sup>					<i>Background to</i>		NO	DL253
DL252	U.K.	Report	D & S, 1990 <sup>5</sup>					<i>Groundwater Resource</i>		NO	DL253
DL253	U.K.	Report	TARLOCK et al, 1993 <sup>6</sup>					<i>Management in U.S.A</i>		NO	
GB1001	U.K.	Report	REEVE & WATTS, 1994 <sup>7</sup>					Groundwater Management		NO	
DL259	U.K.	Report	UKWIR					Source Reliable Yield		YES	
DL260	U.K.	Report	NRA North. & Yorks.					Regional Policy		YES	
DL261	U.K.	Report	J. CIWEM, Vol9, No3					GW Management, France		NO	
DL263	U.K.	Report	NRA Welsh					Regional Policy (Consultation Doc.)		YES	
DL264	U.K.	Report	NRA Anglian					Regional Policy		YES	
DL265	U.K.	Report	NRA Southern					Regional Policy		YES	
DL266	U.K.	Report	NRA Thames					Regional Policy		YES	
DL273	Belgium	Report	European Commission					Response to fax DL248		NO	
DL274	U.K.	Report	NRA N & Y					GW Protection Policy		NO	
DL291	U.K.	Report	BHS Proceedings of mtg.					Prescribed flows, Protection		NO	DL292
DL292	U.K.	Report	APa					APa's notes of above mtg.		NO	DL291
DL293	U.K.	Report	J. Hydo. Sciences Vol 39					Storage, Flow Augmentation		YES	
DL451	U.K.	Report	J. Hydo. Sciences					Rel. Yield of Unconfined Aquifers		YES	
DL452	U.K.	Report	Ground Water Vol 33, No.4.					Stream-Aquifer Depletion, Legislation		YES	
DL453	U.K.	Report	NRA Abst. Licensing Group					GW Investigation Consents		NO	
DL502	U.K.	Report	NRA Welsh Region					Regional Policy		NO	
DL504	U.K.	Report	QJEG Vol 26 pp335-358					GW Resource Management History (UK)		NO	
GB1197.6	U.K.	Report	IWES Manual No5					GW Occurrence, Development & Protection		NO	

Notes:

- <sup>1</sup> Obtained at Geol Soc meeting in London by Mr M Lack
- <sup>2</sup> Obtained during regional visits by Mr A Papaioannou
- <sup>3</sup> ASCE Journal of Water Resources Planning and Management
- <sup>4</sup> "Groundwater Hydrology"

- <sup>5</sup> DOMENICO & SCHWARTZ "Physical & Chemical Hydrogeology"
- <sup>6</sup> "Water Resource Management" (from British Library)
- <sup>7</sup> "Groundwater Drought, Pollution and Management"

**ANNEX I - Key International Literature Review Documents**

<b>Source of Information</b>	<b>Country of Origin</b>	<b>Entec Document Reference Number</b>	<b>Summary of Information Provided</b>
<p>Institute of Geological and Nuclear Sciences</p>	<p>New Zealand</p>	<p>15519DL137</p>	<p>The Institute, (the New Zealand, equivalent of the Geological Society) were very prompt with their reply (co-ordinated by Mr Len Brown) and offered to act as intermediaries to co-ordinate contact with the 14 regional councils (NRA equivalents).</p> <p>Enclosed with their reply was an off print from 'Groundwater Contamination and Control', Uri Zoller (editor), 1994 published by Marcel Dekker, Inc. This is a paper, by Mr Brown, which summarises the situation in New Zealand with respect to groundwater resource management. This provides some basic statistics for world ground and surface water resource demands, and discusses the urgent need for greater and more rigorous application of the notion of sustainable development to such resources.</p> <p>The paper also discusses New Zealand's particular economic environmental and legislative situation and reviews case histories. The experiences, current thinking and research of the New Zealand authorities are apparently similar to that of the NRA in England and Wales. In conclusion a Critical Path Analysis is suggested for the attainment of Sustainable Groundwater Management, in pursuance of the agreement reached under Agenda 21 of the Earth Summit at Rio de Janeiro in February 1992.</p>

<p>Ministry of Environment (Geological Survey, DGU)</p>	<p>Denmark</p>	<p>15519DL170</p>	<p>Overall a very useful response providing background information, references, off prints of published papers and enacted Danish legislation as well as an Annual Report (for 1993!) of the Geological Survey of Denmark. All of these are printed in English.</p> <p>The Water Supply Act provided is not actually current but is said to 'not differ essentially from the actual Water Supply Act' as later amended.</p> <p>Also provided are copies of the Statutory Orders. Reference is made to the Environmental Protection Act (1983) and the Environmental Protection Agency, but little or no information is available in English concerning these.</p> <p>Information provided reveals that Denmark is almost entirely dependent upon groundwater for public supply (~99%). Amongst the provisions of Danish Water Supply Act (1989); most significant is the time-limited nature of all abstraction licences to be thereby granted. This aspect of management is particularly relevant and mirrored in current legislation enacted in the state of Massachusetts in the USA (see below).</p>
<p>D B Oakes and W B Wilkinson (Water Resources Board, 1972)</p>	<p>UK</p>	<p>15519DL210</p>	<p>Introduced a technique for analysing the baseflow response of an idealised aquifer to simplified recharge input. An aquifer parameter, <math>\omega</math>, was derived which enabled the baseflow response of an idealised aquifer to a uniform block of winter recharge to be described by a simple equation.</p> <p>The technique developed by Entec in this R&amp;D project has parallels with the above. However, the Entec methodology differs most significantly in the use of long term average recharge data in the development of a quasi steady state, sinusoidal, recharge input. Furthermore, the key output is then used in a type curve to describe baseflow regimes.</p>

ASCE Journal of Water Resources Planning and Management	USA	15519DL212	<p>Paper by James Male (Department of Civil Engineering, University of Massachusetts, USA) and Frederick Mueller (then Graduate student of same institution). Review of Water Management Act (1986); which recognised need for conjunctive management of ground and surface water and need for sustainable growth and development with commensurate protection of the natural environment.</p>
Commonwealth of Massachusetts (Department of Environmental Protection (DEP))	USA	15519DL227	<p>Water Management Act (1986). Intended to establish a system whereby withdrawals of water in Massachusetts above a threshold quantity of (on average) 100,000 gallons per day (378.5 Mld). The Act required all such withdrawals to be registered by the owner/user by 1 January 1988. Such permits were/are granted for a fixed term of ten years. Provision was also made for the optional requirement of installation of flowmeters and water level recording instrumentation. All owners of permits are, furthermore, required to file an annual statement, the requirements thereof to be determined by the DEP on an individual basis.</p> <p>The methodology attempts to ensure that the consumptive or non-consumptive nature of the abstraction is taken into account when deciding to grant or refuse a permit application.</p>
UK Water Industry Research Ltd (UKWIR)	UK	15519DL259	<p>This report proposes a methodology for the assessment of the reliable outputs of groundwater sources which is intended to be applicable throughout the United Kingdom. Development of the methodology followed a detailed study of existing methods and data availability; based upon a questionnaire survey of all water undertakers in the UK, followed by consultations with many of these organisations and other interested parties. The report is divided into two parts: Part A. Background; and Part B. Methodology. Part B can be used as a manual.</p> <p>The proposed methodology is relatively simple, easy to apply, unambiguous, auditable, and sufficiently flexible so as to encompass the</p>

<p>6</p> <p>R K KACHROO in <i>Hydrological Sciences Journal 37 pp247-261</i></p>	<p>Ireland</p>	<p>15519DL293</p>	<p>full range of groundwater source types, from springs and single well sources to those consisting of many wells and complex adit systems. The methodology is applicable to all water level conditions, including that of drought, and to various demand conditions.</p>
<p>L R KHAN and J A MAWDSLEY in <i>Hydrological Sciences Journal 33 pp151-171</i></p>	<p>Bangladesh and UK</p>	<p>15519DL451</p>	<p>An attempt has been made to provide a basis on which the amounts of deficit storage occurring in the natural hydrographs of small catchments can be estimated as a function of yield and the frequency of occurrence. The yield levels envisaged constitute only small proportions of the mean flow and the deficits arise due to seasonal fluctuations only. It is presumed that any deficits built up during the dry periods of the year are made up by the winter flows, so that there is no year to year carry over. The streamflow data of 26 catchments in Ireland are analysed to obtain the series of annual maxima storages on each catchment. Assuming that they are distributed according to the extreme value type 1 distribution, the relationship between the deficit storage and its frequency of occurrence is calculated for various levels of yield on its catchment. A simple model is described which expresses this relationship in terms of a few parameters. For use on ungauged catchments, those parameters are related to the physical characteristics of the catchments by multiple linear regression.</p> <p>The various definitions of aquifer yield are reconsidered and criticised because the risk of shortages is not quantified. The concept of reliable yield is introduced and a model is proposed that can be used to estimate the yield of an unconfined aquifer to a specified annual reliability. The model is a lumped model which is suitable for the preliminary estimates of aquifer yield required at the early planning stage of water resource development. The model requires as input the recharge for various durations which will be exceeded a specified percentage of the time. Standard statistical analysis of the extreme low flow events of various</p>

<p>M SOPHOCLEOUS et al in <i>Ground Water</i> 33 pp579-588</p>	<p>USA</p>	<p>15519DL452</p>	<p>durations is used to obtain these values. Using recharge data from several unconfined aquifers in the UK, the lognormal distribution was found to be the most suitable distribution to describe the recharge. The lumped yield model requires several assumptions. These are discussed and the sensitivity of the yield to them was investigated using data from Chalk catchment in the UK. The yield was found to be sensitive to several of the assumptions.</p>
<p>The predictive accuracy of Glover's (1974) stream-aquifer analytical solutions are assessed and commonly used in administering water rights, and to evaluate the impact of the assumed idealisation on administrative and management decisions. To achieve these objectives, the predictive capabilities of the Glover stream-aquifer depletion model are evaluated against the MODFLOW numerical standard, which, unlike the analytical model, can handle increasing hydrogeologic complexity. The rank-order and the relative importance of the various assumptions on which the analytical model is based are quantified, and the three most important are found to be: (1) streambed clogging as quantified by streambed-aquifer hydraulic conductivity contrast; (2) degree of stream partial penetration; and (3) aquifer heterogeneity. These three factors relate directly to the multidimensional nature of the aquifer flow conditions. From these considerations, future efforts to reduce the uncertainty in stream depletion-related administrative decisions should primarily address these three factors in characterising the stream-aquifer process. The impact of progressively coarser model grid size on numerically estimating stream leakage is also investigated and it is concluded that grid size effects are relatively minor. Therefore, when modelling is required, coarser model grids could be used thus minimising the input data requirements.</p>			



ANNEX II - NRA Water Resource Strategy Documents

NRA (HQ)	UK	15519DL226	In 1993 the National Rivers Authority Corporate Planning department published for the first time, an NRA Water Resources Strategy. This stated the NRA's principal aim as to 'manage water resources to achieve the right balance between the needs of the environment and those of the abstractors'. To achieve this the NRA first and foremost shall seek to 'plan for the sustainable development of water resources, developing criteria to assess the reasonable needs of abstractors and the environment'. From this National Strategy document has since followed public consultations and the publication of Regional Strategy documents (with the exception, as of July 1995 of NRA North West and Severn Trent(?)).
NRA (SW)	UK	15519DL239	In the notes that follow on Regional Policies, significant additions to, or variations or enhancements of national policy are highlighted.
NRA (Northumbrian and Yorkshire)	UK	15519DL260	Specific targets for maximum mains leakage levels in litres per property per day, to delay the need for additional resource development.  Where predicted demands exceed available resources, there are three possible solutions (1) modify demands, (2) increase efficiency of current uses, (3) develop new resources.  In choosing one or a combination of these options Northumbrian and Yorkshire region have stated that 'the criterion of sustainability has been paramount'. As with South West region stress is laid upon the need to promote efficiency and 'wise use' by consumers (cf. DoE report, 1992).
NRA (Welsh)	UK	15519DL263	Discussion Document: Separate discussion of Demand Management and Resource Management is provided, and (within these) sub-topics, more efficient use of water, the reduction of losses, river regulation,

				conjunctive management and "recycling" of water resources are highlighted.
NRA (Welsh)	UK		15519DL502	Regional Policy Finalised, little substantial change noticeable from the above.
NRA (Anglian)	UK		15519DL264	A Regional 'sustainable strategy' is summarised as seeking to achieve 'secure water supplies and a better water environment'. Considerable space is given to detailed discussion of development options including various water transfer schemes, which reflects the region's heavy dependence upon groundwater.
NRA (Southern)	UK		15519DL265	NRA Southern recognises that in some parts of their region groundwater resources are already fully licensed if not over-subscribed. Policy is thus divided into action plans for protecting existing resources (river flows and groundwater) and protecting the environment. Catchment management plans have been, and are being, produced. A great deal of research has been done into the implications for planning/policy options of the 1989-93 drought period.
NRA(Thames)	UK		15519DL266	The Thames catchment is one of the most intensively managed catchments in the world, supporting a population of 11.5 million and satisfying pressures on water resources to meet the demands of public supplies, industry, agriculture, navigation and recreation. These pressures must be balanced against the need to maintain and improve the water environment. The strategy proposed for achieving this balance is much as presented by other regions in line with Nationally set objectives.
NRA (Severn Trent)	UK			NOT PUBLISHED YET
NRA (North West)	UK			NOT PUBLISHED YET