Groundwater Resource Reliable Yield

User Manual

Entec

R&D Technical Report W9

Groundwater Resource Reliable Yield

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This document provides a brief background to the project and describes the methodology and its application

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D. Otter Sandstone
E. Coventry Sandstone
F. Kennet Chalk - Og Catchment
G. Stiffkey Chalk
H. Candover Chalk

GLOSSARY

Note:
Many abbreviations and acronyms used in this project are highly specific and have no recognised meaning elsewhere.

ω (d^{-1})	Aquifer Parameter 'omega' derived by the Water Resources Board
α (d^{-1})	Aquifer Parameter 'alpha' derived in this project
ABF	Average Baseflow (sometimes expressed as a discharge 'Ml/d' or a yield 'l/s/km^2')
ADF	Average Daily Flow, expressed as a discharge (i.e. Ml/d)
ADIST (km)	Composite Distance of Abstractions from the River
AQCONF	Aquifer Configuration
AQGEOL	Aquifer Geology
AREAR (km^2)	Area of Aquifer Receiving Recharge
AREAW (km^2)	Area of Whole Aquifer
ARQ (Ml/a)	Total Aquifer Recharge Quantity
BHS	British Hydrological Society
BFS	Baseflow Significance of Aquifer unit
C (m^2/d)	River Bed Conductance, used in MODFLOW analysis
D_S	Safe Development Limit of an Aquifer, as a proportion of Recharge input
DSG	Drift Sand and Gravel
D_T	Aquifer Development Threshold, as a proportion of Average Baseflow (or Recharge input)
E_A (Ml)	Total Annual Effluent Return to the River
EA	Environment Agency
EAL (km)	Effective Aquifer Length (derived using a simple formula based on catchment area and river length)
EC	Environmental Criticality of River

E_i (Ml)	Individual Effluent Return Quantity
E_S (Ml)	Total Summer Effluent Return to the River
E_W (Ml)	Total Winter Effluent Return to the River
F_{SD}	Seasonality-Distance Factor
F_T	Transmissivity Factor from Aquifer to River
h (m)	Groundwater head
ho (m)	Constant head at rivers (fixed head in MODFLOW analysis at river cell)
HoF	Hands off Flow - flow in a river below which licences incorporating a related cessation clause must cease abstraction
HS	Hydrological Sensitivity of River
ICL	Interfluvial Chalk/Limestone plus miscellaneous hardrock aquifers
K (m/d)	Aquifer Hydraulic Conductivity
K_b (m/d)	River Bed Hydraulic Conductivity
KCL	Karstic Chalk/Limestone
L (m)	Aquifer length, used in MODFLOW analysis
L_A (Ml)	Total Licensed Annual Quantity
L_i (Ml)	Individual Licence Quantity
L_S (Ml)	Total Licensed Summer Quantity
L_W (Ml)	Total Licensed Winter Quantity
MORECS	Meteorological Office Rainfall and Evaporation Calculation System
NRA	National Rivers Authority
OSST	Other Sandstones (Cretaceous, Carboniferous etc)
PABF	Proportion of Average Baseflow (or Recharge) necessary to protect baseflow requirements
PAR	Proportion of Average Recharge necessary to protect other environmental needs
Q_{IW} (Ml/a)	Intermediate Weighted Assessment of Development
Qn_x	Naturalised river flow percentile exceedence values with x defining the percentile

	exceedence value
Q_S (Ml/a)	Safe *Yield* of an Aquifer, also referred to as the Groundwater Resource Reliable Yield
Q_{SW} (Ml/a)	Simple Weighted Assessment of Development
quasi-steady-state	MODFLOW simulation results using a cyclic input of Average Monthly Recharge data
R&D	Research and Development
RECH (mm/a)	Annual Average Recharge
RIVLEN (km)	River Length
RS_A (Ml)	Total Annual River Support Quantity
RS_i (Ml)	Individual River Support Quantity
RS_S (Ml)	Total Summer River Support Quantity
RS_W (Ml)	Total Winter River Support Quantity
S	Aquifer Storativity (sometimes S_y is substituted)
SEAS	Seasonality Factor of Abstractions
SSST	Sherwood Sandstone
S_y	Specific Yield
T (m^2/d)	Aquifer Transmissivity
T' (m^2/d)	"Effective" Transmissivity from Aquifer to River
transient	MODFLOW simulation results using an actual historic monthly recharge dataset as input
VCL	Typical Valley Chalk/Limestone
WRB	Water Resources Board
x	i) 'aquifer length' (m) applicable to the Dupuit equation ii) 'percentile exceedence' applicable to naturalised flow percentile exceedence values

EXECUTIVE SUMMARY

This project was initiated and promoted by the National Rivers Authority under its' Research and Development programme. The project aims to establish a Methodology which can be used to determine Groundwater Resource Reliable Yield (*yield*) for aquifer units.

The need for the project was recognised by the National Rivers Authority because no nationally adopted standard had been established by the predecessor Water Authorities. Consequently the extent, technique and history of strategic and analogous yield assessments, by each previous Authority, were subject to significant differences which were inherited by the National Rivers Authority Regions.

The aim of the "new" Methodology is to provide a means of *yield* assessment which is widely applicable and this is achieved by drawing upon past Water Authority experiences, a review of international approaches and incorporates new concepts along with due consideration to abstraction licensing policy and practice. It should also be stressed that this needs to be done in a context of an ever increasing requirement to afford adequate environmental protection with diministring river flows in some problem catchments being a particular and highly topical issue to address.

The Methodology that has resulted aims to establish the proportion of average annual groundwater recharge that can be safely allocated to abstraction development taking into account natural variations in recharge distribution (seasonal and drought), aquifer characteristics and environmental factors.

By idealising aquifer characteristics and undertaking a suite of groundwater modelling a relatively simple Methodology has been developed based on a Type Curve approach and an environmental allocation to define *yield*.

The formulation and application (use) of the Methodology are described in this document (the User Manual). Whilst some case examples are also given it must be stressed that the Methodology has only been subject to very limited calibration and testing to date. Therefore, a follow-up programme of calibration and sensitivity testing, along with ongoing review, is recommended to refine the Methodology and its future application.

Keywords

Groundwater, Methods, Resources, Yield

1. INTRODUCTION

The aim of this project is to a 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 NRA (and its successor).

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

- R&D Technical Report W9 - User Manual (this document), 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 this document.

- R&D Project Record (Papaioannou, 1996), containing detailed background information, a description of project evolution, and a summary of key meetings and literature review etc generated during the project.

A detailed Introduction and Background to the project is given in Section 1 of the R&D Project Record (Papaioannou, 1996).

The basic principle underpinning the Methodology described in this document and the evaluation of *yield* is to establish what fraction of average long-term recharge can safely be allocated to abstraction development.

In order to achieve this, it is necessary to establish what allocation of groundwater resources is necessary to meet a wide variety of environmental needs. This must be achieved and balanced in the knowledge that:

- most recharge and water balance assessments involve uncertainty

- seasonal and annual hydrometeorological fluctuations (including recharge) can be very extreme.

The Methodology proposed is designed to complement groundwater management and associated policies and practice. In order to achieve this it has been necessary to restrict the Methodology to a strategic assessment of aquifer *yield*. This has been done deliberately in the knowledge that each individual abstraction development is normally subject to technical assessment and local impact evaluation as part of the abstraction licence determination process.

2. METHODOLOGY FORMULATION AND DESCRIPTION

2.1 Main Principles

The Methodology was developed using an evolutionary and iterative process involving:

- discussions and seminars
- literature review
- conceptualisation
- notional and initial specifications
- scientific evaluation and detailed development.

A complete Methodology is presented, however it is important to emphasise that project constraints have limited certain aspects of the development and key areas of potential deficiency are highlighted as follows:

- trials and calibration of the complete Methodology have been relatively limited

- certain modules within the Methodology framework have only undergone limited or partial scientific evaluation. The extent of scientific evaluation and an assessment of the significance of any associated deficiencies has been annotated to the description of each module.

The main principles adopted in the proposed Methodology are outlined as follows:

STEP 1: Compile basic aquifer data

STEP 2: Conceptualise the hydrogeology of the aquifer unit being considered and decide if:

i) the unit is best dealt with as a whole or if further subdivisions are warranted. Subdivisions may be appropriate if spatially, highly contrasting aquifer properties or environmental considerations exist.

ii) the baseflow contribution to surface water (streams, rivers and estuaries), later referred to as BFS is considered significant or not.

Deciding whether baseflow contribution to surface water (BFS) *is* significant or not is a key step in the Methodology process because this will noticeably modify the way in which *yield* is calculated. This decision is somewhat subjective, however, a pictorial representation is given in Figure 2.1 which provides a guide to contrasting BFS settings. In addition, the listing below is provided to aid in the BFS decision making process.

- BFS is not significant if:
  - the whole aquifer unit is confined (or semi confined) and no significant groundwater discharge occurs to the surface environment.
  - surface water and groundwater are not hydraulically interactive.
- BFS is significant if there is a spring, stream or river which is hydraulically interactive with (and dependant upon) groundwater.
- The decision on BFS is more subjective if:
  - the aquifer is confined, artesian and provides discharge to either natural blowwells or leaking 'wild' boreholes.
  - the aquifer comprises part confined and unconfined areas
  - groundwater is interactive with surface water which is tidal
  - surface water is interactive with groundwater but little (or no) discharge from the latter occurs.
  - the extent of interaction between groundwater and surface water is uncertain or unknown.

STEP 3: Estimate the *yield* (Q_S) for the aquifer taking into account basic aquifer hydrogeological characteristics and environmental needs. Although this produces a single Q_S value, depending upon whether BFS is considered significant or not, the way in which this is derived is quite different. In addition other factors, such as seasonality, location and use, may suggest actual abstraction development can 'safely' exceed this value and these are considered separately in Steps 4 and 5.

STEP 4: Compile a simple assessment of 'effective' annual groundwater abstraction development (Q_{SW}) based upon licensed quantities taking into account seasonality and proximity to river, and compare this with Q_S.

STEP 5: If necessary (or appropriate) compile a more detailed (intermediate) assessment of 'effective' groundwater abstraction development (Q_{IW}), using Q_{SW} as a 'starting point' and taking into account the fate or extent of abstraction returns to the local river (as effluent or designed support), and compare this with Q_S.

These broad principles and their interrelationships are shown diagrammatically in Figure 2.2.

Steps 4 and 5 of the Methodology are concerned with the assessment of "Effective Groundwater Abstraction Development" for comparison with the *yield* and are largely developed for the case where BFS is considered significant. This assessment must take account of the seasonality of the abstraction, the distance of the abstractions from the river and any returns to the river. The importance of the seasonality and distance from river factors was demonstrated by some of the modelling work carried out (see R&D Technical Report W10 (Papaioannou and Erskine, 1996b) Table 2.3).

The detailed description of the Methodology procedure given below entails introduction of many parameters and subroutines. Therefore, it is likely that an adequate understanding of the procedure will only be established once Sections 2 and 3 of this report have been studied and a potential user of the Methodology has performed the procedure themselves. *The use of italics in the following subsections depicts explanatory notes which complement the Methodology description.*

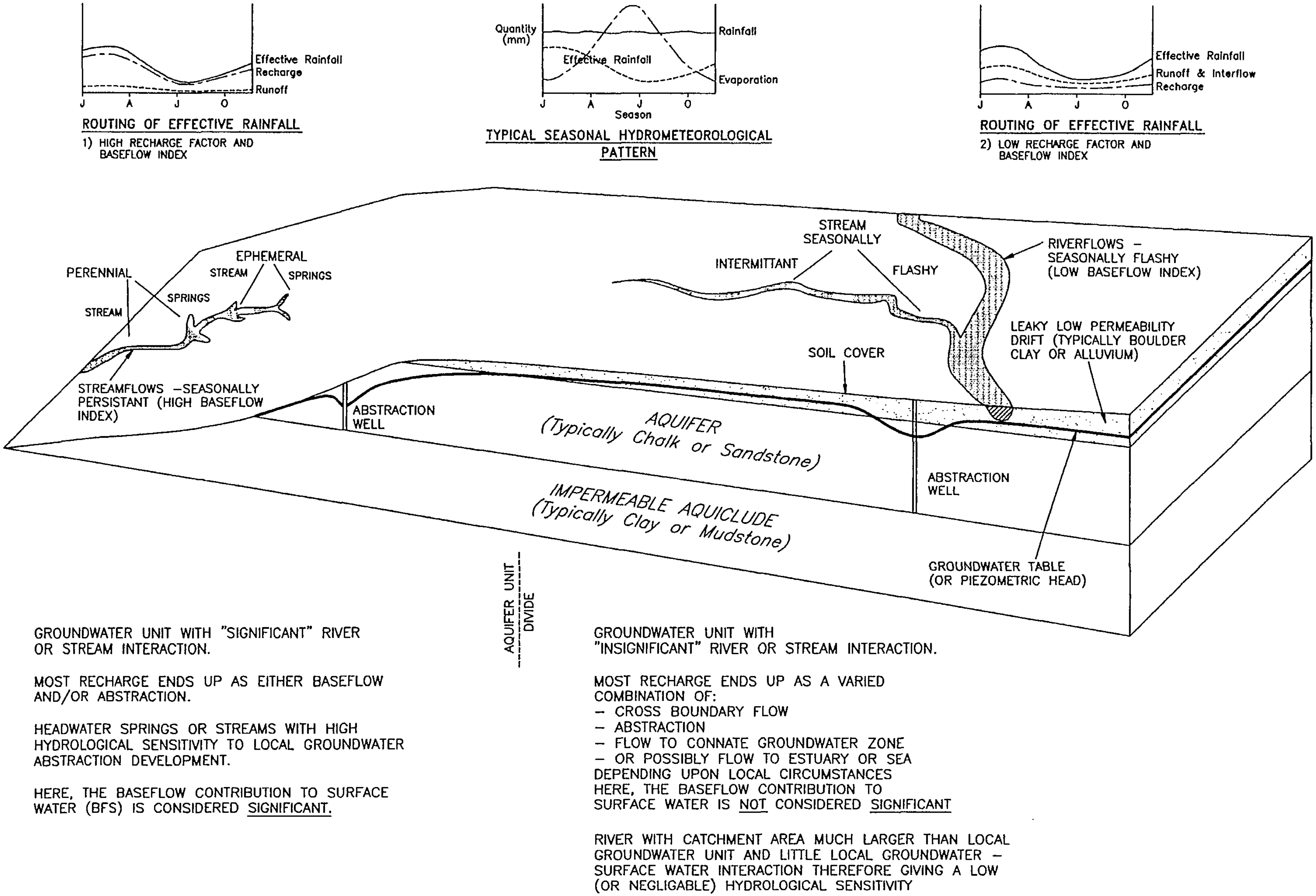


Figure 2.1
Typical Hydrogeological Settings

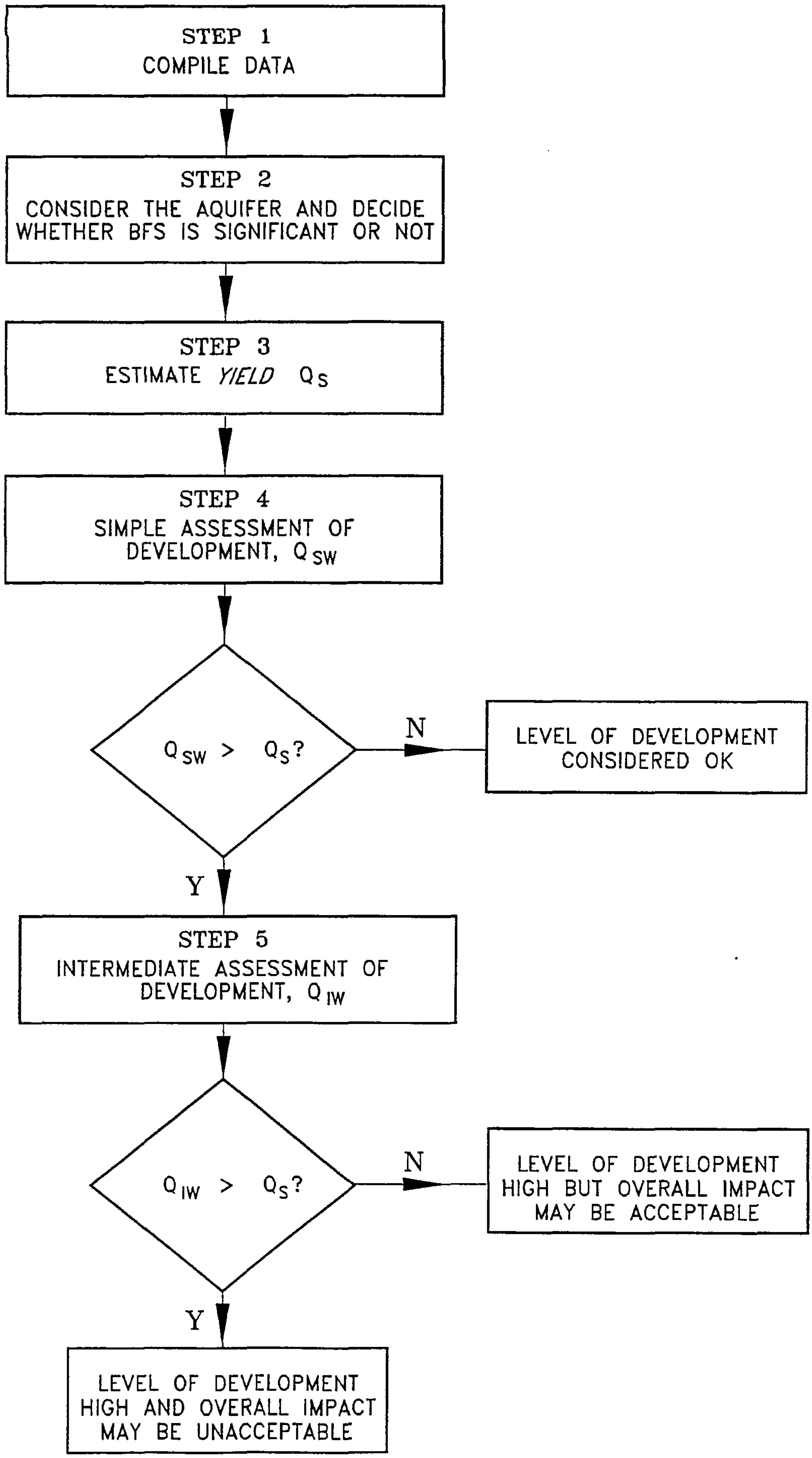


Figure 2.2
Principles of Methodology

2.2 STEPS 1 and 2: Compile Basic Aquifer Data, Consider the Aquifer and Decide on BFS

At the outset, the following parameters need to be defined.

i)	Area of whole aquifer unit	AREAW	(km^2)
ii)	Area of aquifer receiving 'significant' recharge	AREAR	(km^2)
iii)	Establish average annual Recharge for aquifer unit receiving recharge (R&D Technical Report W7 - National System for Groundwater Recharge Assessment (Institute of Hydrology, in press) may provide a useful reference)	RECH	(mm/a)
iv)	Establish Total Aquifer Recharge Quantity = AREAR*RECH	ARQ	Ml/a
v)	Using Regional BGS Hydrogeological Maps (or equivalent OS scale map) derive total length of rivers/streams over aquifer unit recharge area. *It is recommend that both ephemeral and perennial systems are included. However, it is not recommended that 'permanently' dry valleys be included.*	RIVLEN	(km)
vi)	Select appropriate Aquifer Geology Classification from:	AQGEOL	
	• Sherwood Sandstone	SSST	
	• Other Sandstones (Cretaceous, Carboniferous etc)	OSST	
	• Drift Sand and Gravel	DSG	
	• Interfluvial Chalk/Limestone plus miscellaneous hardrock aquifers	ICL	
	• Typical Valley Chalk/Limestone	VCL	
	• Karstic Chalk/Limestone	KCL	

vii)	In future, it could be possible to assign different simple aquifer configurations as appropriate. However, at present this concept has not been developed and a default configuration is assigned which is described in the R&D Technical Report W10 (Papaioannou and Erskine, 1996b) Figure 2.1	AQCONF	(numeric assignment)
viii)	For the AQGEOL selected, default transmissivity (T) and storativity (S) values are suggested in Table 2.1. However, the local hydrogeologist may wish to prescribe different and more appropriate values based upon local knowledge.		T&S default or assigned

Table 2.1

Default Transmissivity, Storage and Hydraulic Conductivity for Major Aquifer Types

AQGEOL		**T** m^2/d	**S**	**K** m/d
Sherwood Sandstone	SSST	600	0.15	5
Other Sandstones	OSST	300	0.15	5
Drift Sand & Gravel	DSG	400	0.18	20
Interfluvial Chalk & Limestone	ICL	200	0.04	1
Valley Chalk & Limestone	VCL	600	0.04	20
Karstic Chalk & Limestone	KCL	1000	0.06	40

Careful consideration should be given to the T and S values assigned in this Methodology. Circumstances where special consideration may be warranted include:

- *aquifers with spatially variable T, such as many Chalk systems which exhibit high T in valley areas and low T in interfluvial area. Evidence from limited modelling analysis (see the R&D Technical Report W10 (Papaioannou and Erskine, 1996b) Section 2.1) suggests that a simple evaluation of a 'composite' T provides an appropriate approximation. For example, assume*

  30% of unit has typical valley transmissivity ($T = 600\ m^2/d$) and 70% of unit has typical interfluvial transmissivity ($T = 200\ m^2/d$).

Giving a 'composite' $T = \frac{30 * 600 + 70 * 200}{100} = 320\, m^2\ /\ d$

- *interbedded aquifers, such as Sandstone - marl sequences, require careful thought. One of the case examples given in Section 2.3, the Otter Sandstone, illustrates this problem well. Here, it is important to highlight that S values, obtained from pumping test analysis often exhibit semi-confining properties, which are typically of the order* 10^{-3} *to* 10^{-4}. *These S values should not be used in the Methodology when baseflow contribution to surface water is deemed significant. Alternatively, it is recommended that estimates of aquifer specific yield should be applied which are typically in the range 0.1 to 0.2.*

  Specific yield (Sy) estimates can be derived from:

  groundwater level hydrograph analysis and making assumptions about seasonal recharge

  baseflow hydrograph analysis which can also give estimates of T

- *confined aquifers (part or whole) require careful thought. This topic has not received any scientific evaluation in this project. In the future, it would be possible to consider such additional aquifers configurations and expand the options available in AQCONF as originally envisaged. As with interbedded aquifers, confined S values derived from pumping test analysis must not be used in the Methodology when baseflow contribution to surface water is deemed significant. In this instance, and assuming part of the aquifer is unconfined where interaction with surface water occurs, then as with interbedded aquifers, Sy estimates should be applied instead.*

- *River bed conductance may be an important consideration when baseflow contribution to surface water is deemed significant and alluvial deposits exist. A factor to allow for this potential effect has been developed in the Methodology procedure, see Table 2.3).*

- *T and S values derived from pumping test analyses alone, unless obtained in 'classical' well behaved unconfined aquifers exhibiting 'primary' permeability characteristics can be potentially misleading for the following reasons:*

  - *T values in aquifers with 'secondary' (fissure flow) permeability characteristics can be locally enhanced, and misleadingly high, when compared with regionally indicative values.*

  - *S values derived in confined or semi-confined aquifers are not meaningful if used in the Methodology procedure. In this instance, Sy estimates should be alternatively adopted.*

ix) STEP 2, is the aquifer baseflow contribution to surface water (streams, rivers, estuaries, etc) of significance and requiring of protection/ consideration? *See Figure 2.1 and Section 2.1 for further guidance.* BFS (ans, Y/N)

2.3 STEP 3: Estimating Groundwater Resources Reliable Yield *(yield)*

The broad Methodology for estimating *yield* (or Q_S) using the basic aquifer characteristics data (described above) is set out in Figure 2.3 which also highlights the extent of evaluation (from notional to detailed scientific) for each module in the process. Depending on Step 2, the significance of baseflow contribution to surface water (BFS), plus the aquifer geology classification (AQGEOL) the appropriate Development Threshold (D_T) for the aquifer is derived. This is the potential resource available for exploitation expressed as a proportion (or percentage) of the annual average recharge (or theoretical average baseflow if applicable).

In future, this concept could be further developed to include variations such as:

- different simple aquifer configurations (AQCONF)
- different design return periods for reliability (this concept has been considered in some detail where baseflow to surface water is significant)

These additional developments are further discussed in the R&D Technical Report W10 (Papaioannou and Erskine, 1996b) Section 3 and Figure 3.2.

The calculation of Q_S *(yield)* is set out below.

i) The calculation of D_T (the Development Threshold) is as follows:

a) If baseflow contribution is not significant, the D_T value selected is notionally related to aquifer storage characteristics as indicated in Table 2.2. This is done by adopting varying proportions of annual average recharge to the aquifer being reliably available for potential exploitation. This concept has only been developed notionally to date and is further outlined in Figure 2.4. This figure shows a Gumbel plot of historic annual effective rainfall (for MORECS grid square 109) and how values for different aquifers could be related to either return period or equivalent D_T Value. The general notion being that the lower the storage capacity characteristics of the aquifer the lower the D_T value. The default values suggested can be modified by the local hydrogeologist who can select different values based upon local knowledge.

Table 2.2

Notional Suggestions for D_T Values in Aquifers Having No Significant Baseflow Contribution to Surface Water

AQGEOL		Suggested D_T	Equivalent Return Period (yrs)
Sherwood Sandstone	SSST	0.9	2.4
Other Sandstones	OSST	0.8	2.8
Drift Sand & Gravel	DSG	0.75	3.0
Interfluvial Chalk & Limestone	ICL	0.75	3.0
Valley Chalk & Limestone	VCL	0.65	4.0
Karstic Chalk & Limestone	KCL	0.6	5.0

b) If baseflow contribution is deemed significant, the D_T value adopted is calculated quite differently.

- An Effective Aquifer Length (EAL) is calculated (in km) as AREAW/(2*RIVLEN). *This recommended formula should work well for aquifers with 'simple' and 'regular' river basin geometries. However, where the geometry is very 'distorted', or baseflow is concentrated to one or two district springflow discharge points then the local hydrogeologist will have to use judgement to arrive at a suitable EAL value.*

- Consideration is then given to the general riverbed properties (such as hydraulic conductivity and overall conductance). From this a transmissivity factor F_T is derived, as indicated in Table 2.3. This is then used to factor the T value to establish T' (the 'effective' transmissivity to the river).

- Then a parameter, alpha (α), is calculated as $T'/S\ (1000*EAL)^2$ from the 'effective' transmissivity (T') and storage or specific yield (S) values (default or assigned).

- The D_T value is finally derived by reading off the value from the 'Type Curve' shown in Figure 2.5.

In this situation (where BFS is significant) D_T actually represents the ratio between the natural theoretical minimum baseflow and average baseflow from an undeveloped aquifer.

The scientific basis behind the above derivation of D_T Methodology *is* further detailed in the R&D Technical Report W10 (Papaioannou and Erskine, 1996b) Sections 2 to 4.

Table 2.3

Suggested Transmissivity Factors (F_T) for Different River Bed Properties

River Bed Alluvium Characteristics				Aquifer Transmissivity T (m^2/d)					
Thin alluvial deposits (~1 m)		**Thick alluvial deposits (~10 m)**		**10**	**50**	**100**	**200**	**500**	**1000**
k_b = 10 m/d	Medium sand			-	-	1.0	1.0	1.0	1.0
k_b = 1 m/d	Silty sand	k_b = 10 m/d	Medium Sand	-	1.0	0.99	0.95	0.93	0.90
k_b = 0.1 m/d	Silty	k_b = 1 m/d	Silty Sand	0.99	0.90	0.75	0.60	0.40	0.25

Note:

k_b = river bed hydraulic conductivity

- *Factors are not given for thick silty (low permeability) alluvium deposits as there is doubt over the merit in such an application*

- *It is suggested that for river bed alluvial deposits up to 3 m thick, that the equivalent F_T value for a thickness of 1 m is selected and raised to the power equivalent to the total thickness, i.e. for 3 m of silty sand river bed contiguous with an aquifer having a T of 200 m^2/d then $F_T = 0.95^3 \sim 0.86$*

- *Further details on the derivation of the above factors is given in the R&D Technical Report W10 (Papaioannou and Erskine, 1996b) Section 2.2.*

ii) A proportion of the total resource is allocated to protect baseflow regimes (PABF) as follows:

If the baseflow contribution (BFS) is not significant, the protected baseflow (PABF) is set as zero.

When baseflow contribution (BFS) is deemed significant, a dedicated proportion (or percentage) of annual average aquifer recharge (or theoretical annual average baseflow) is allocated to protect baseflow regimes (PABF) dependent upon river hydrological and environmental factors as shown in Table 2.4. However, if preferred, the local hydrogeologist can assign a different value instead of adopting the default value suggested.

Table 2.4

Allocating a Proportion of Annual Average Baseflow (or Recharge) to Protect Baseflow Regimes (PABF)

Hydrological Sensitivity (HS)	Environmental Criticality (EC) Low (0 - 17)	Medium (18 - 26)	High (27 - 32)
Low (0 - 17)	0.05	0.10	0.15
Medium (18 - 26)	0.10	0.15	0.20
High (27 - 32)	0.15	0.20	0.25

Notes:
EC combines the scores of the Fishery and Ecology Scoring Systems
HS combines the scores of the Physical Character and Baseflow Dependence Scoring Systems

Originally, it was intended to dovetail the PABF setting very closely with the Hands off Flow (HoF) concepts developed in NRA R&D Project 438 - Surface Water Abstraction Licensing Policy Development, Core Report (Halcrow, 1995). However, there have been a number of significant departures between the two projects for the reasons summarised below.

HoF Concept, R&D Project 438

- Halcrow (1995) uses a HoF concept with values based on the naturalised flow percentile exceedence (Qn_x) with percentile exceedence (x) in the range 95 to 99.5 prescribed to rivers classed in the range sensitive to insensitive respectively.

- Sensitivity depends upon environmental weighting (EW) which is derived from the sum of three scoring systems which classes (scores) the rivers physical character, fishery and ecology.

- This concept generally links with historical river management practice, with many abstraction controls and effluent discharge consents having been based on the flow percentile exceedence basis. However a potential problem here is that historically, much management has been based on gauged rather than naturalised flow values.

- This concept does not generally dovetail well with historical groundwater management practice. If it were applied directly it would prove very restrictive in terms of groundwater resource development and afford a level of protection to the water environment which is not realistic. Therefore, it is felt that a different concept is necessary to protect baseflows.

PABF Concept, R&D Project 544 (This Project)

- During the course of this project a PABF concept was developed with values based on a proportion of the natural theoretical average baseflow from the aquifer unit. In general, the setting varies from 0.05 (5%) to 0.25 (25%) for increased river sensitivity and this concept is further explained in the R&D Project Record (Papaioannou, 1996).

- Sensitivity depends upon a matrix of Environmental Criticality (EC) and Hydrological Sensitivity (HS) of the river receiving baseflow.

- Environmental Criticality (EC) combines the scoring systems developed in Halcrow (1995) for fishery and ecology both reproduced in Appendix A.

- Hydrological Sensitivity (HS) uses the scoring system developed in Halcrow (1995) for physical character reproduced in Appendix B but also combines this with a new scoring system, baseflow dependence, developed in this project.

- The baseflow dependence scoring system should be applied with reference to a suitable strategic location on the receiving river which may be coincident with a:

  gauging or monitoring point
  hydrological control
  hydraulic control
  discharge or augmentation point.

The suggested scoring system should be evaluated as shown in Table 2.5 and based on the following:

the proportion (or percentage) of the aquifer unit area receiving recharge (AREAR) compared with the total catchment area to the strategic location;

the proportion (or percentage) of combined support/regulation scheme plus total Dry Weather Flow (DWF) effluent discharge to the river and comparing this with the gauged (or assessed) average daily flow (ADF).

Table 2.5

Baseflow Dependence Scoring System

% Aquifer Unit Area Compared with Strategic Location Catchment Area ***(Natural Dependence)***	**% of combined support/regulation plus total DWF effluent discharge capacities compared with gauged (or assessed) ADF at Strategic Location** ***(Artificial Influences)***				
	<5%	>5%	>10%	>15%	>20%
>80%	16	14	11	8	5
>60%	14	11	8	5	3
>35%	11	8	5	3	1
<35%	8	5	3	1	1

Note:
Highest Scores depict the most sensitive systems

As already indicated, the local hydrogeologist may wish to assign a different PABF value than that inferred from Table 2.4. Typical reasons for this may include:

- Statutory flow (or level) control designations.
- Water quality and effluent dilution considerations.
- Consideration to protected rights.
- High river amenity considerations and the 'political sensitivity' of any local community to 'their' river environment.

iii) A further proportion of the total resource may be allocated to other protected groundwater related environmental needs (PAR) as follows:

- prevention of saline intrusion
- sustaining cross boundary flows
- maintaining groundwater levels in environmentally sensitive areas.

This allocation is left to the discretion of the local hydrogeologist and the default value would otherwise be zero.

iv) **The Safe Development (D_S) of the aquifer when expressed as a proportion of the total resource is calculated as follows:**

$$D_S = D_T - PABF - PAR.$$

This represents the resource remaining after allowances to protect the baseflow requirement in the river (PABF) and other groundwater related environmental needs (PAR) have been subtracted from the 'potential resource available' (D_T) or the Development Threshold. This concept is illustrated in Figure 2.6 for the situation where the baseflow contribution is deemed significant and the derivation of D_T is dictated by the baseflow regime. In the case where baseflow contribution is not considered significant the equation may be simplified to $D_S = D_T - PAR$.

v) **Calculate Q_S as a total yield for the aquifer**

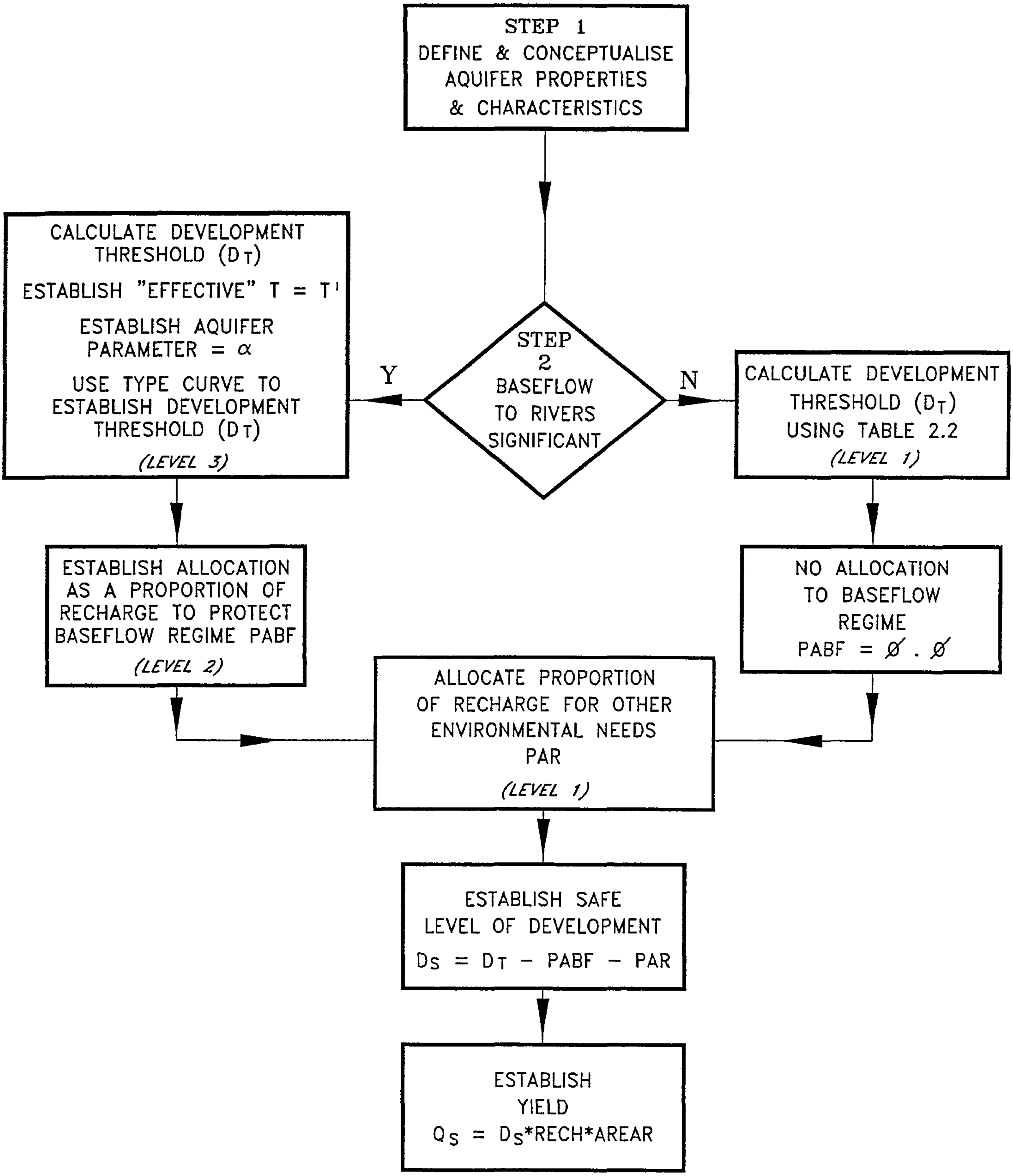
The *yield* (Q_S) for the aquifer is then calculated in Ml using D_S and the recharge over the aquifer:

$$Q_S = D_S * RECH*AREAR$$

In general, Q_S represents the *yield* that can be developed without any locally engineered mitigation schemes (such as river support). It may be possible to safely enhance abstraction development beyond Q_S providing such mitigation schemes are included.

Another commonly adopted method for permitting abstraction development beyond Q_S is to impose cessation clauses under certain threshold conditions. Thereby, permitting water resource usage when it is readily and safely available.

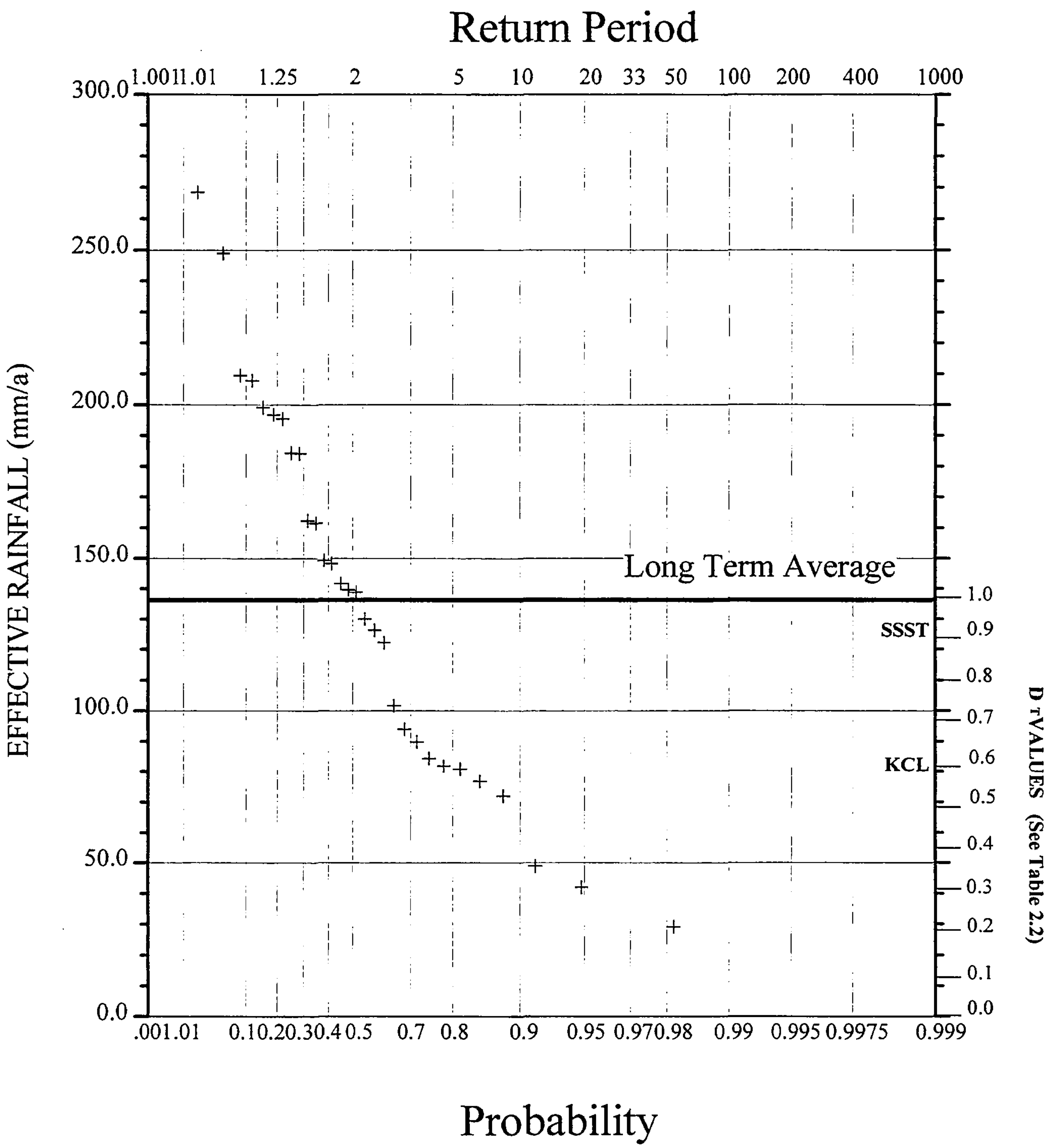
Having calculated the safe development value (Q_S) this term can then be compared with actual abstraction development to judge the groundwater resource development situation.



LEVEL OF DEVELOPMENT

1. *NOTIONAL*
2. *SOME SCIENTIFIC INVESTIGATION*
3. *EXTENSIVE SCIENTIFIC INVESTIGATION*
4. *EXTENSIVE SCIENTIFIC INVESTIGATION AND FULLY VERIFIED*

Figure 2.3
Step 3 Estimating Groundwater Resource Reliable Yield (Qs)



Note: The Historic Effective Rainfall Dataset Plotted is for the Period 1961-1990

Figure 2.4 Gumbel Probability Plot of Annual Effective Rainfall - MORECS Square 109

***Note:** **THE TYPE CURVE IS DERIVED FROM A 'BEST FIT' OF RESULTS FROM QUASI-STEADY-STATE MODEL RUNS**

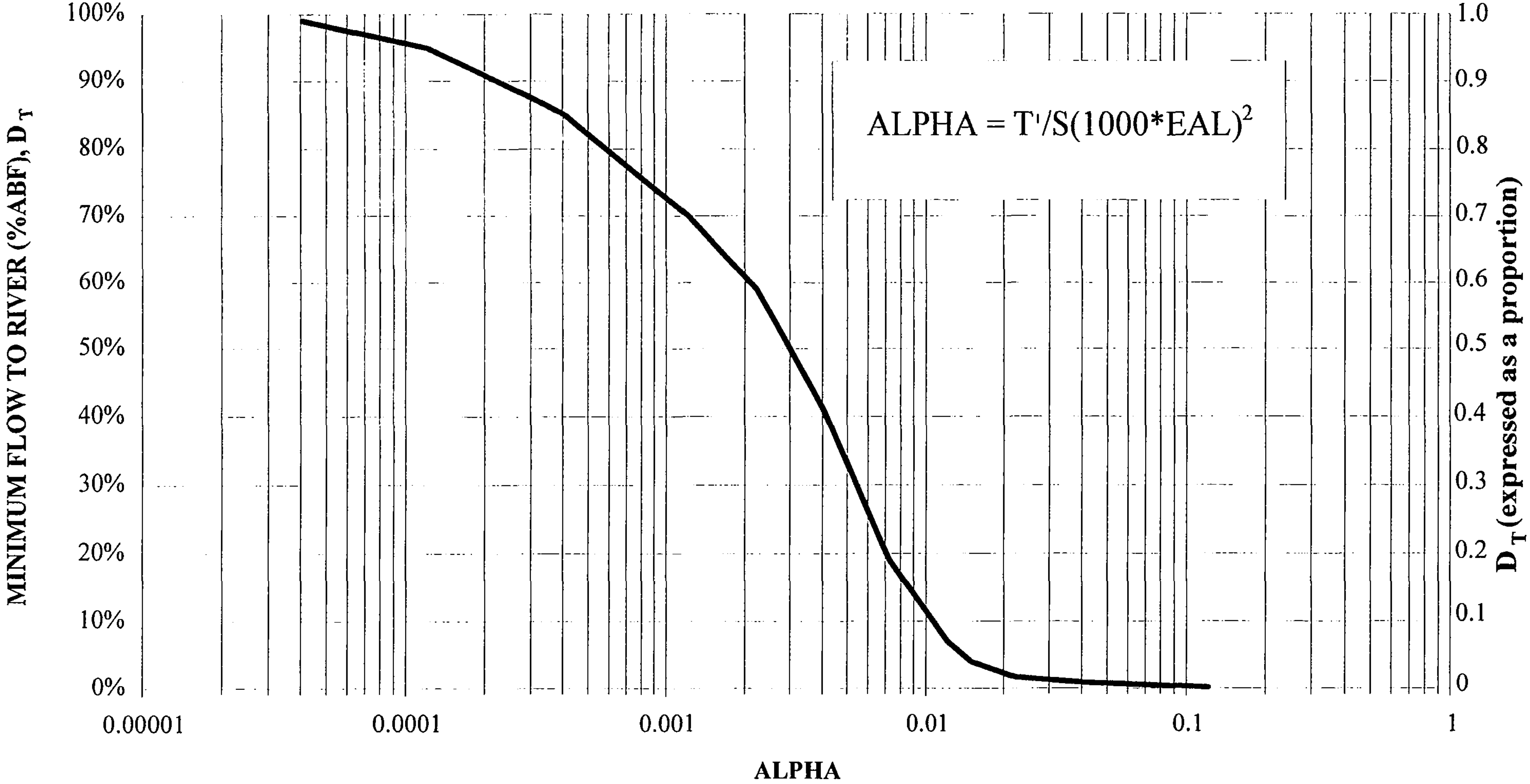
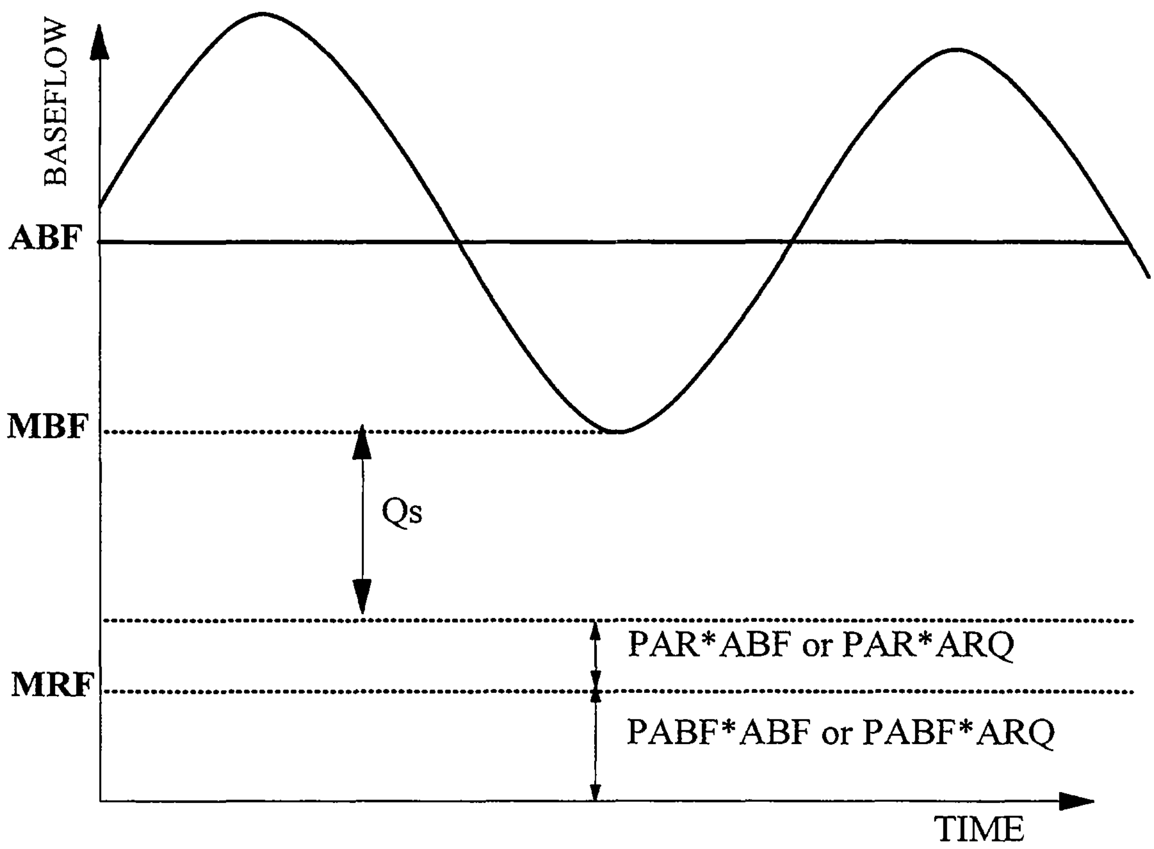


Figure 2.5 **Type Curve of D_T**

NOTE: This Representation only Applies to Aquifers in which the Baseflow Component is Considered Significant.



ABF = Average Baseflow (Natural)
MBF = Minimum Baseflow (Natural)
MRF = Minimum Required Flow = PABF * ABF
ARQ = Total Aquifer Recharge Quantity = AREAR*RECH

D_T = MBF/ABF = Development Threshold
Q_S = MBF - MRF - ABF * PAR = *Yield*
= ABF * (D_T - PABF - PAR)
= ABF * D_S or alternatively AREAR * RECH * D_S where Total Aquifer Recharge Quantity (ARQ) and Average Baseflow (Natural) are Equivalent
D_S = Safe Development Threshold

Figure 2.6 Physical Representation of D_T

2.4 STEP 4 - Simple Assessment of Groundwater Abstraction Development

The simple assessment is based upon consideration of total licensed quantity and giving regard to both seasonality and proximity to river. The procedure is illustrated diagrammatically in Figure 2.7.

i) The total annual abstraction development (licensed plus estimates for non-licensed) quantities is compiled (L_A).

ii) If $L_A > Q_S$ then, dependent upon the aquifer baseflow contribution to surface water being deemed significant or not the situation is summarised as follows:

- if baseflow is not significant then no allowance is made for abstraction seasonality and proximity to river and the abstraction development is considered too excessive. The local hydrogeologist may wish to also consider the situation given actual abstractions rather than total licensed quantities. Other than this no further assessment is recommended.

- if baseflow is significant the abstraction development may be excessive and an allowance of abstraction seasonality and proximity to river is required before the assessment can be further progressed and evaluated as described below.

iii) Sum the total summer season (May - October) abstraction development (licensed plus estimates for non licensed) quantities, L_S in Ml. The winter abstraction (November - April), L_W, must be the difference, L_A-L_S.

From the L_S/L_A ratio calculate the abstraction seasonality (SEAS).

iv) For the aquifer abstractions, calculate a composite weighted distance of the abstraction locations from the river. The formula used for this is:

$$\mathrm{ADIST} = \frac{\sum \mathrm{Li} * \mathrm{Ri}}{\mathrm{L_A}}$$

where L_i are the individual abstraction licensed quantities and R_i are the distances to the river. Consider the need to adjust this weighting appropriately if significant seasonal variation in abstraction exists.

As this task may prove fairly onerous, an educated guess of this value may suffice for preliminary assessment purposes. Alternatively, and as a conservative measure, a default value could be used which assumes that all abstractions are very close to the river, giving ADIST less than 0.3 km.

v) Use Table 2.6 to establish the seasonality-distance factor (F_{SD}).

Examination of the table will indicate to the local hydrogeologist the level of sophistication appropriate to calculating (or estimating) ADIST.

Table 2.6

Abstraction Seasonality - Distance Factor (F_{SD})

Seasonality		Composite Distance from River (km) ADIST			
Comment	**L_S/L_A (SEAS)**	**<0.3**	**0.3 - 0.5**	**0.5 - 1.0**	**>1.0**
very high summer	>0.8	1.8	1.6	1.4	1.2
high summer	0.6 - 0.8	1.5	1.3	1.2	1.1
little	0.4 - 0.6	1.1	1.1	1.0	1.0
high winter	<0.4	0.9	0.8	0.7	0.6

The F_{SD} values suggested in the above table are based on very limited evaluations as reported in the R&D Technical Report W10 (Papaioannou and Erskine, 1996b) Section 2.2 and Table 2.3. Therefore it is recommended that values be regarded as indicative only until further evaluation and refinement has been performed.

vi) Weight the annual quantity (L_A) by the above factor to give a 'simple' weighted effective abstraction (Q_{SW})

where $Q_{SW} = F_{SD} * L_A$

If $Q_{SW} > Q_S$ the abstraction development may be considered excessive, and if so an Intermediate Assessment is recommended. Otherwise, the level of development is probably acceptable being within the safe *yield* Q_S.

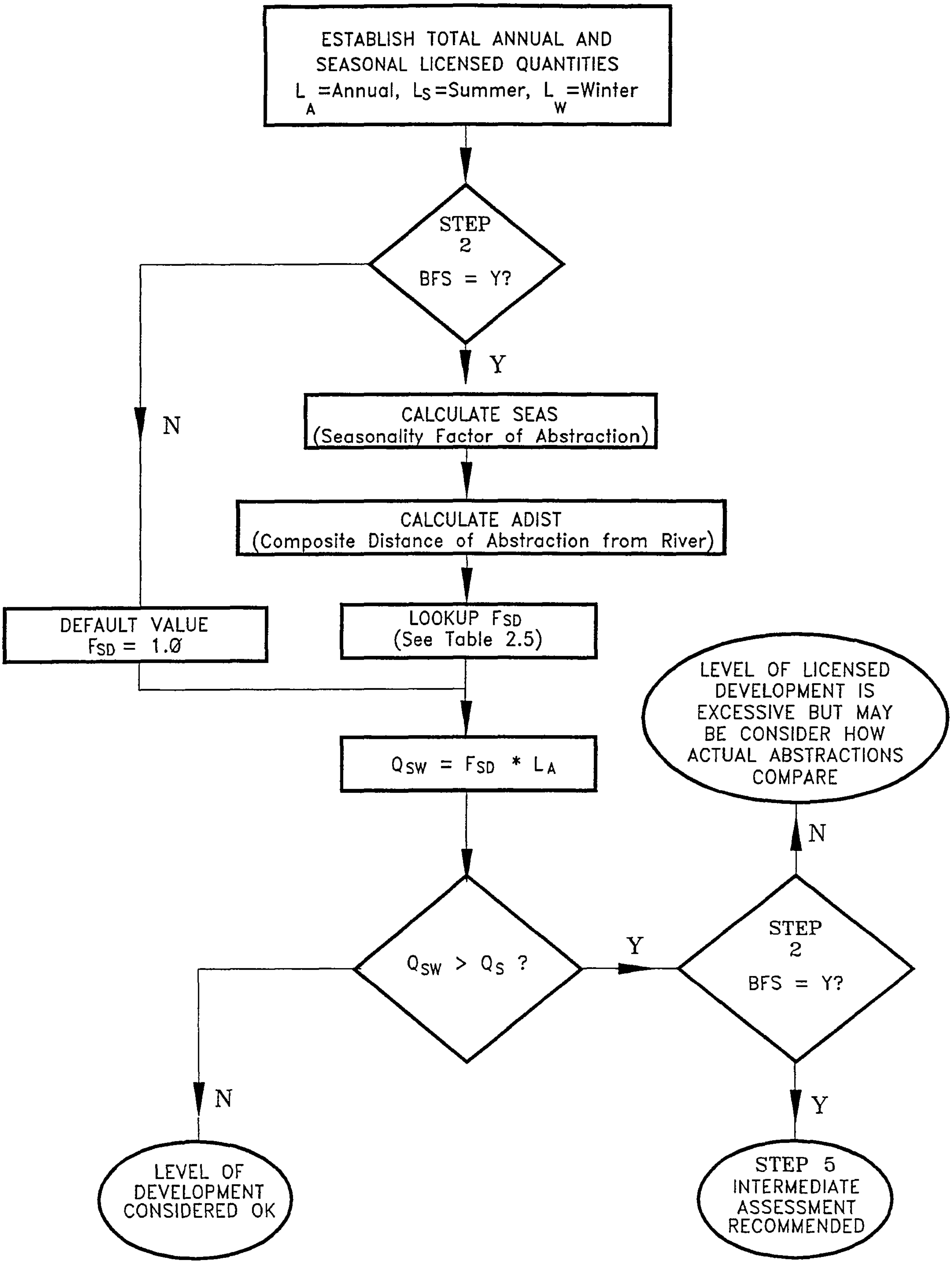


Figure 2.7
Step 4 Simple Assessment of Groundwater Abstraction Development

2.5 STEP 5 -Intermediate Assessment of Groundwater Abstraction Development and Overall Water Resource Situation

The intermediate assessment is only applied if the baseflow contribution to surface water is deemed significant and follows on from the simple assessment as shown in Figure 2.8, making an allowance for the fate of effluent (or augmentation) returns and whether they are discharged locally (back to the resource).

Before undertaking the detailed intermediate assessment it is worth checking that the total licensed quantity (L_A) does not exceed the potential resource or the Total Aquifer Recharge Quantity (ARQ), where ARQ = RECH * AREAR. If this is the case, groundwater abstraction in the aquifer is certainly over licensed and there is little point in proceeding with the intermediate assessment unless actual abstractions are reliably and significantly less than the licensed quantity (L_A). If this if the case, the local hydrogeologist should use their judgement and consider undertaking this assessment substituting actual abstraction for licensed quantity.

The intermediate assessment is compiled as follows:

i) Sum reliable annually and seasonally available effluent returns to resource derived from groundwater abstractions in the unit (Ml)

annual	E_A
summer	E_S
winter	E_W, where $E_A = E_S + E_W$

ii) Sum reliable annually and seasonally available groundwater abstraction in the unit used for river support (Ml)

annual	RS_A
summer	RS_S
winter	RS_W, where $RS_A = RS_S + RS_W$

iii) Use the seasonality-distance factor (F_{SD}) established in Table 2.6 when conducting Step 4.

iv) For the appropriate seasonal bias calculate the abstraction development/resource situation as follows. *In the following expression, it is assumed that no abstraction seasonality occurs (i.e. the 'annual' values are taken) and therefore*

$$Q_{IW} = F_{SD} * L_A - E_A - RS_A$$

where Q_{IW} = 'Intermediate' abstraction development assessment.

Abstractions with a summer or winter seasonal bias (as opposed to no seasonal bias) would be similarly considered as follows:

summer $Q_{IW} = F_{SD} * L_A - 2 * (E_S + RS_S)$

winter $Q_{IW} = F_{SD} * L_A - 2 * (E_W + RS_W)$

iv) If the appropriate $Q_{IW} > Q_S$ then the groundwater resource is considered over-licensed and its overall impact on water resources is probably too great. *The local hydrogeologist may also wish to further consider the situation given actual abstractions rather than total licensed quantities.*

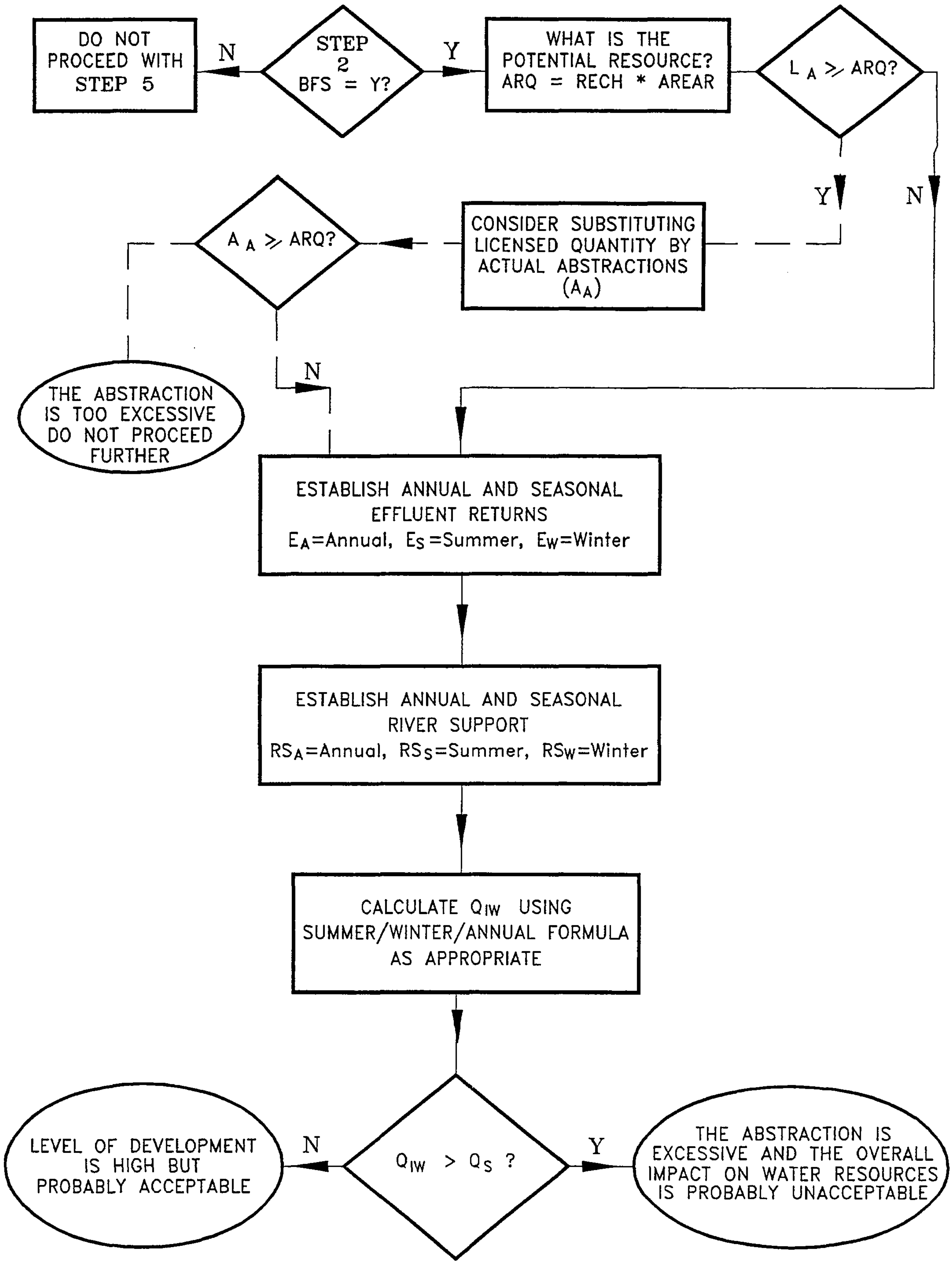


Figure 2.8
Step 5 Intermediate Assessment of Groundwater Abstraction Development

3. APPLICATION OF METHODOLOGY

3.1 Introduction

The Methodology developed in this project is complete but would benefit from further development, trials and calibration. Certain aspects of the Methodology are based on principles which are only notional or subject to limited evaluation at present. These include the handling of:

- Confined Aquifers
- Aquifers with little or no interaction with surface water
- Aquifers, like the Chalk, which may exhibit high to low (spatially variable) hydraulic conductivities from valley to interfluvial areas respectively
- Aquifers, like interbedded sandstones and marls, which may exhibit highly contrasting vertical and horizontal hydraulic conductivity.

Within this project, the only environmental allocation of groundwater resources which is systematically evaluated and quantified is that needed to protect river baseflow regimes. However, it is recognised that allocations are needed to meet other potential environmental needs such as:

- saline intrusion
- cross boundary flows
- the piezometric regime which may affect
  - other abstractors
  - wetland environments
  - agriculture
  - artesian conditions
  - ground geotechnical properties.

Therefore, it is suggested that the local hydrogeologist should allocate a proportion of the resource (PAR) considered appropriate to safeguard these requirements. In future, the Methodology could be expanded to include more rigorous guidelines for the evaluation to meet these needs.

It must also be noted that the Methodology will not be universally applicable to every aquifer unit. There will be examples that are so different from the idealised aquifer configurations implicit in the Methodology that they cannot be adequately assessed by this Methodology. Therefore, for each application of the Methodology it is recommended that the local hydrogeologist considers and comments on the 'confidence level' of the assessment.

3.2 Case Studies

Five 'case studies' have been subject to the Methodology and these are presented in Table 3.1. The case examples selected cover a wide range of conditions and illustrate the application of the Methodology and how the results can be interpreted. Some of the parameter values used have been estimated in the absence of definitive data and these are highlighted. Furthermore, not all of the assumptions made, or estimated values presented, have received comment or verification by Environment Agency hydrogeologists. The case studies are outlined below.

i) Selby Sandstone

The Selby Sandstone is a block of Sherwood Sandstone which is semi-confined by variable thick drift deposits and where groundwater abstraction is highly developed from the aquifer. The aquifer is believed to be 'hydraulically divorced' from major river systems which overly it and hence the aquifer is deemed to have no baseflow significance (see Appendix C for further details).

The estimated recharge through the drift has been locally assessed as 101 mm/a, when compared with the effective rainfall of 209 mm/a, this represents a recharge factor of ~0.48 (see Table C.1). T values for the aquifer are typically in the range 250 to 750 m^2/d, averaging approximately 500 m^2/d.

From analysis of short pumping tests, S values are typically of the order 10^{-3} revealing semi-confined characteristics. However, long-term pumping tests reveal delayed yield characteristics, and their analysis suggests specific yields in the range 0.1 to 0.15, more indicative of the default S values suggested for the Sherwood Sandstone.

As previously defined, the aquifer has no baseflow significance and therefore no allocation of resources is made to protect baseflow regimes. In the Selby area, upconing of saline water from Permian strata has caused problems in the past and it could be argued that a small PAR term should be allocated to safeguard against the phenomenon. However, in this instance, no PAR allocation is made.

Hence, the resultant Q_S value for the aquifer equates to 18, 998 Ml/a

Table 3.1 Methodology and Case Examples

Parameter	Proposed Nomenclature	Units		AQUIFER:	Sandstone			Chalk		
				AQUIFER UNIT:	Selby	Otter	Coventry	Og	Stiffkey	Candover
				NRA REGION:	(N & Y)	(SW)	(S-T)	(Thames)	(Anglian)	(Southern)
Basic Input Data (STEP 1)										
Aquifer Geology	AQGEOL	-			SSST	SSST	OSST	VCL	VCL	VCL
Area of Whole Aquifer	AREAW	km^2			209	145	90	59	77.1	105
Area Receiving Recharge	AREAR	km^2			209	96	90	59	77.1	105
Recharge (Ref R&D 499)	RECH	mm/a			101	333	187	@ 361	161	380
Total Aquifer Recharge Quantity	ARQ	Ml/a	AREAR * RECH		21,109	31,968	16,830	21,299	12,413	39,900
Aquifer Transmissivity	T	m^2/d	See Table 2.1 and footnote		500	200	150	300	1000	2000
Aquifer Storativity	S or S_y	-	See Table 2.1 and footnote		0.15	0.15	0.15	0.04	0.06	0.04
Aquifer Configuration	AQCONF	-	Only one configuration is available at present		1	1	1	1	1	1
Baseflow Significance (STEP 2)	**BSF**	**YES/NO**			NO	YES	YES	YES	YES	YES
			If BSF = Yes	If BSF = No						
Calculation of Q_S (STEP 3)										
River Length	RIVLEN	km	Measured from map	N/A	N/A	100	44	6.25	30	15
Hydrological Sensitivity of River	HS	-	See Table 2.5 and R&D 438	N/A	N/A	Medium	Low	Medium	High	High
Environmental Criticality of River	EC	-	See R&D 438	N/A	N/A	High	Low	Medium	High	Medium
Transmissivity Factor	F_T	-	See Table 2.3	N/A	N/A	0.6	0.5	0.95	0.25	0.9
"Effective" Transmissivity to River	T'	m^2/d	F_T * T	N/A	N/A	120	75	285	250	1800
Efective Aquifer Length	EAL	km	AREAW/(2*RIVLEN)	N/A	N/A	0.725	1.023	4.720	1.285	3.500
Aquifer Parameter	α	d^{-1}	$T'/S(1000*EAL)^2$	N/A	N/A	1.52E-3	4.78E-4	3.20E-4	2.52E-3	3.67E-3
Aquifer Development Threshold	D_T	-	See Fig 2.5	see Table 2.2	0.9	0.65	0.84	0.87	0.53	0.42
Protect Baseflow	PABF	-	See Table 2.4	0.0 *	0	0.2	0.05	0.15	0.25	0.2
Protect Other Needs	PAR	-	At Discretion of Hydrogeologist		0	0.05	0	0.25	0	0
Safe Development Limit	D_S	-	$= D_T$ - PABF - PAR		0.9	0.4	0.79	0.47	0.28	0.22
Safe *Yield*	Q_S	Ml/a	$= D_S$*RECH*AREAR		18,998	12,787	13,296	10,011	3,476	8,778
Calculation of Q_{SW} (STEP 4)										
Sum of Individual Licensed Annual Quantities	L_A	Ml	Σ Li		37230	12449	16170	5110	3670	11572
Sum of Individual Licensed Summer Quantities	L_S	Ml	Σ Li	N/A	N/A	6449	8085	2555	2308	7000
Derive Winter Quantities	L_W	Ml	$=L_A - L_S$	N/A	N/A	6000	8085	2555	1362	4572
Seasonality Factor	SEAS	-	$=L_S/L_A$	N/A	N/A	0.52	0.50	0.50	0.63	0.60
Composite Distance	ADIST#	km	$= \Sigma(Li*Ri)/L_A$	N/A	N/A	0.8	0.8	0.5	0.4	0.3
Establish F_{SD} Factor	F_{SD}	-	See Table 2.6	1.0 *	1	1	1	1.1	1.3	1.3
Simple Weighted Assessment	Q_{SW}	Ml/a	$= F_{SD}*L_A$		37,230	12,449	16,170	5,621	4,771	15,044
Comparison With Q_S	Q_{SW}/Q_S	-	$= Q_{SW}/Q_S$		1.96	0.97	1.22	0.56	1.37	1.71

Table 3.1 Methodology and Case Examples (continued)

Parameter	Proposed Nomenclature	Units		AQUIFER: AQUIFER UNIT: NRA REGION:	Sandstone Selby (N & Y)	 Otter (SW)	 Coventry (S-T)	Chalk Og (Thames)	 Stiffkey (Anglian)	 Candover (Southern)
If $Q_{SW}/Q_S > 1.0$; Calculate Q_{IW} (STEP 5)										
Sum of Individual Annual Effluent Returns	E_A	Ml	Σ Ei	N/A	N/A		730		350	1000
Sum of Individual Summer Effluent Returns	E_S#	Ml	Σ Ei	N/A	N/A		365		180	500
Derive Actual Winter Effluent Returns	E_W	Ml	$= E_A - E_S$	N/A	N/A		365		170	500
Sum of Annual River Support Quantities	RS_A	Ml	Σ RSi	N/A	N/A		0		530	2000
Sum of Summer River Support Quantities	RS_S#	Ml	Σ RSi	N/A	N/A		0		530	1500
Derive Actual Winter River Support Quantities	RS_W	Ml	$= RS_A - RS_S$	N/A	N/A		0		0	500
Seasonality Factor	SEAS	-	$= L_S/L_A$	N/A	N/A		0.50		0.63	0.60
Establish F_{SD} Factor	F_{SD}	-	See Table 2.6	N/A	N/A		1		1.30	1.30
Intermediate Weighted Assessment	Q_{IW}	Ml/a	See below	N/A	N/A		15440		3351	11044
Comparison With Q_S	Q_{IW}/Q_S	-	$= Q_{IW}/Q_S$	N/A	N/A		1.16		0.96	1.26

Notes:

Shading denotes an estimated value.

* Use the Default Value as indicated.

@ Includes a significant proportion of mains leakage

N/A If BSF = No, the calculation of this parameter is not applicable.

\# It may prove very onerous to calculate these values as prescribed. Therefore an educated guess or use of a conservative value may prove adequate.

Calculation of Q_{IW}
- If SEAS > 0.6: $= F_{SD} * L_A - 2*(E_S + RS_S)$
- If SEAS is between 0.4 and 0.6: $= F_{SD} * L_A - (E_A + RS_A)$
- If SEAS < 0.4: $= F_{SD} * L_A - 2*(E_W + RS_W)$

Values for 'development' gives Q_{SW} = 37 230 Ml/a and Q_{SW}/Q_S = 1.96 and suggests that the aquifer is significantly overdeveloped in terms of licensed quantity. Actual abstraction equates to approximately two-thirds the total licensed quantity. Therefore, the extent of over development is moderated when actual abstractions are considered. The 'actual' groundwater resource situation for the aquifer is summarised in Figure C.1 (Appendix C).

Although the local Environment Agency Region recognise that development in this aquifer unit is very high and possibly in need of reduction the situation requires more thorough investigation. Groundwater level monitoring of the aquifer unit does not indicate any long-term declining trend, and therefore, it is possible that the water balance for the aquifer is not adequately understood. Current estimates of recharge are not well constrained, and the overall value could be potentially greater as a result of:

- the present recharge factor being underestimated
- leakage being induced from overlying rivers
- cross boundary inflows occurring from other groundwater units

and these possibilities probably require further investigation.

ii) Otter Sandstone

The Otter Sandstone is a block of Sherwood Sandstone which is largely unconfined and in which groundwater abstraction is moderately developed. The Hydrogeological Map of southwest England illustrates the hydrogeology and hydraulic properties of the aquifer very well and extracts from this are reproduced in Appendix D. The estimated composite recharge to the aquifer is estimated as 333 mm/a.

Local estimates of aquifer hydraulic parameters derived from pumping test analysis give:

- T values of the order 100 to 300 m^2/d
- S values of the order 10^{-3} to 10^{-4}.

For the purpose of the Methodology a T value of 200 m^2/d is assumed.. However, the above S values are typical of a semi-confined response and indicative of an interbedded sandstone - marl sequence. As highlighted in Appendix D, the specific yield is typically in the range 0.1 to 0.2, and it is recommended that the S_y value is adopted and the default value of 0.15 is used in the Methodology.

The Otter Valley is infilled with alluvium and this is spatially very variable and difficult to class hydrologically. Overall, it is considered that the alluvium does present some impediment to groundwater - surface water interaction. For the purpose of this assessment it has been classed as comparable to 1 m of silty alluvium giving a F_T of 0.6 and a resultant 'effective' transmissivity (T') of 120 m^2/d to the river.

The river length of 100 km is taken from the rivers marked on the Hydrogeology Map and as highlighted in Figure D.1. This does not include any part of the Otter catchment upstream of the Fenny Bridges gauging station (hydrometric reference 45008) which includes areas extending beyond the aquifer block. Using this, the effective aquifer length (EAL) for the Otter Sandstone aquifer equates to 0.725 km.

The aquifer provides a significant baseflow component to local sensitive rivers and hence the PABF value is set at 0.20. In addition, potential saline ingress to the aquifer is an issue and the PAR is ascribed a value of 0.05.

The resulting Q_S for the aquifer is 12 787 Ml/a and this compares with a Q_{SW} of 12 449 Ml/a giving Q_{SW}/Q_S of 0.97. Therefore, it is considered that the licensed quantity for the aquifer as a whole is only just within acceptable limits, although the adequacy of aquifer S values and stream baseflows used in this case example may require further consideration.

iii) Coventry Sandstone

The Coventry Sandstone unit is a block of Permo-Carboniferous interbedded sandstones, from which groundwater abstraction is highly developed. Further details are given in Appendix E.

The estimated composite recharge to the aquifer is 187 mm/a. Of this approximately 67 mm/a is derived from leaking mains (mainly water mains) in the Coventry area and 120 mm/a is derived from meteoric recharge. Effective rainfall for the area equates to 300 mm/a.

The Permo-Carboniferous Sandstone comprises interbedded sandstone - marlstone sequences. The marlstone gives rise to two important hydrogeological controls as follows:

- restricts recharge
- inhibits gross vertical hydraulic conductivity

Composite meteoric recharge for the unit equates to 120 mm/a giving a gross recharge factor of 0.60. However, the total unit includes much of Coventry which also has significant effects on the gross recharge factor from leakage and impermeable coverage. If the effects of Coventry were removed, then the revised and natural composite recharge factor would equate to 0.69.

Local estimates of hydraulic parameters derived from pumping test analysis give:

- T values of the order 150 m^2/d
- S values of the order 10^{-4}

For the purpose of the Methodology a T value of 150 m^2/d is assumed. However, the S values are typical of semi-confined response and indicative of an interbedded sequence similar to the case for the Otter Sandstone described previously. In this instance it is recommended that the specific yield is adopted believed to be about 0.15.

The tributaries of the upper Sowe and River Sherbourne which drain the unit have valleys with fairly extensive silty alluvium deposits up to 5 m thick. For the purpose of this assessment it is assumed that the valley alluvium is typically 2 m thick on average. From this F_T is assumed to be approximately 0.5 (from 0.7^2) and this results in an 'effective' transmissivity (T') of 75 m^2/d to the river.

The streams in the unit are largely sustained by baseflow from the aquifer unit although the level of abstraction developed has caused significant depletion and flows are very low and intermittent in many headwater locations, and along certain stretches flows are only sustained by effluent discharges. Both sensitivity and criticality of the rivers are classed as low giving a PABF of 0.05. No PAF allocation is made for any other environmental needs.

The resultant Q_S for the Coventry Sandstone aquifer equates to 13 296 Ml/a. This compares with a total licensed quantity of 16 170 Ml/a which equates to approximately 96% of the annual average recharge to the aquifer (including mains leakage).

Values for 'development' give:

- Q_{Sw} = 16170 ml/a and Q_{SW}/Q_S = 1.22;
- Q_{IW} = 15440 ml/a and Q_{SW}/Q_S = 1.16;

clearly showing the aquifer to be overlicensed.

Actual abstractions equate to approximately 54% of licensed quantity. Hence, if the above 'development' assessments were revised using actual abstractions instead of licensed totals the results would indicate that actual abstractions fall within Q_S. However, a significant proportion of recharge to the aquifer is derived from mains leakage and this itself cannot be guaranteed. Therefore, the derived Q_S value of 13296 ml/a needs to be treated with some caution.

iv) Kennet Chalk - Og Catchment

The Og catchment of the Kennet Chalk is a block of unconfined Chalk in which groundwater abstraction is moderately developed. The estimated recharge is 361 mm/a. A composite T value of 300 m^2/d is estimated from information supplied by the Environment Agency and a default S value of 0.04 is adopted for the purpose of assessment.

Alluvial deposits in the Og valley are generally very thin and of a permeable nature. Therefore, little retardation to groundwater - surface water interaction occurs. From this F_T is estimated as 0.95 and the resultant 'effective' transmissivity (T') as 285 m^2/d to the river.

The Chalk provides significant baseflow to local rivers of medium environmental sensitivity resulting in an estimated PABF value of 0.15. A further and significant allocation (PAR) is made to maintain a high cross boundary (catchment) groundwater flow to the adjacent Knighton catchment, equivalent to 0.25.

Many of the streams in the Og catchment only flow on an intermittent basis. However, these are included in the river length equivalent to 6.25 km.

This results in a Q_S value of 10 011 Ml/a and compares with a Q_{SW} of 5621 Ml/a giving Q_{SW}/Q_S of 0.56. Therefore, it is considered that the licensed quantity for the aquifer as a whole is well within acceptable and safe *yield* limits.

Some of the relevant hydrogeological details for the Og unit used in the assessment are given in Appendix F.

v) Stiffkey Chalk

The Chalk of the Stiffkey catchment is covered extensively with boulder clay in the interfluvial areas and partly with sand and gravel in valley areas.

In general the bounder clay is quite permeable allowing significant recharge and groundwater - surface water interaction where it is present. In some locations it is also tapped for small groundwater abstractions and can be regarded as a minor aquifer.

Effective rainfall for the area is estimated as 230 mm/a and the average recharge is approximately 161 mm/a giving a composite recharge factor of 0.7.

Groundwater abstraction development is high especially in the valley areas where high transmissivity exists, here T values are in the range 500 to 3000 m^2/d. In interfluvial areas, data on transmissivity are more scarce but, T values in the range 50 to 100 m^2/d have been measured. Storage values from pumping tests are generally in the range 0.01 to 0.06. However, the very low values probably reflect responses to semi-confined conditions and the higher values are believed to be most indicative, especially as some zones will experience enhanced delayed yield from contiguous sands and gravels. For the purpose of the assessment a composite T value of 1000 m^2/d and an approximate S value of 0.06 will be adopted.

Alluvium in the river valleys is generally very thin and slightly variable from peaty to sandy but predominantly silty. Hence, a F_T value of 0.25 is assigned which gives an 'effective' transmissivity (T') value of 250 m^2/d to the river.

Some of the hydrogeological and water resources details from the Stiffkey unit are shown in Appendix G.

The PABF allocation for the river, which is deemed highly sensitive and critical, is 0.25. No PAR allocation is made for any other environmental needs.

The resultant Q_S for the Stiffkey catchment equates to 3476 Ml/a. This compares with a total licensed quantity of 3670 Ml/d which is equivalent to approximately 30% of the annual average recharge to the aquifer unit.

Values for 'development' give:

- Q_{SW} = 4771 Ml/d and Q_{SW}/Q_S = 1.37
- Q_{IW} = 3351 Ml/a and Q_{IW}/Q_S = 0.96.

The Q_{SW} and Q_{IW} values are high and partly influenced because most abstractions are close to the river and river support provisions give rise to a summer bias in abstraction leading to a F_{SD} value of 1.3. This results in the Q_{SW} values being well in excess of Q_S. However, a significant component of the summer licensed quantity is designated to river support which moderates the Q_{IW} value. Therefore, in total licensed terms, the Stiffkey Chalk catchment appears over developed, but when usage etc are taken into account the overall situation appears marginal.

Actual abstractions in the catchment equate to approximately 90% of licensed quantity. Hence if the above 'development' assessments were revised using actual abstractions instead of licensed totals the above results would be slightly reduced.

One area of major uncertainty and sensitivity in this assessment is the application of the F_T value, 0.25 in this instance, to allow for river bed conductance properties. In circumstances where the factor is as significant as in this case it is worth carrying out extensive desk study research to ensure that an appropriate factor is applied.

For this area data does exist to allow:

- further evaluation of the aquifer parameter (α) from river baseflow analysis
- evaluation of river bed conductance from controlled test pumping and induced river leakage which has been monitored.

In a real application of the Methodology, such data should be fully evaluated so as to reduce key uncertainty in the assessment.

vi) Candover Chalk

The Chalk of the Candover catchment is unconfined and extensively drift free. Alluvium is restricted to the lower part of the river valley upstream of the confluence with the River Itchen.

Effective rainfall is estimated as 380 mm/a and it is assumed that all of this provides groundwater recharge.

The groundwater and surface water catchments for the Candover stream depart significantly and the former is larger than the latter with areas of 105 km^2 and 71 km^2 respectively. Further details are given in Appendix H.

The hydraulic properties of the Candover Chalk are complex and difficult to summarise. There is much evidence to suggest a thin, near surface, zone of highly active chalk in which values of T and S up to 10 000 m^2/d and 0.06 have been estimated. However, as groundwater levels recess (or are drawndown) within this thin active zone, the predominant aquifer thickness gives typical T and S values of 1000 m^2/d and 0.01 respectively. For the purpose of the assessment, we will assume a composite T value of 2000 m^2/d and a default S value of 0.04. In this range, the safe yield assessment procedure is very sensitive and greater effort would be warranted in reducing the uncertainty in the interpretation of the most appropriate values using baseflow analysis.

The Candover stream is baseflow dominated having a baseflow index of 0.96. In much of the upper catchment the valleys are permanently dry. Flow in the middle reaches is ephemeral and only the lower stretches flow perennially, the resultant river length (RIVLEN) including perennial and ephemeral reaches, equates to approximately 10 km. Therefore, the estimated effective aquifer length (EAL) equates to 3.5 km.

As river valley alluvium is restricted to the lower reaches of the stream and this appears to be thin and of a silty-sandy nature, an assumed F_T value of 0.9 is assigned giving an 'effective' transmissivity (T') of 1800 m^2/d to the river.

The river is classed as high sensitivity and medium criticality leading to PABF of 0.2. No PAR allocation is made to meet other environmental needs.

The resultant Q_S for the Candover catchment equates to 8778 Ml/a. This compares with a total licensed quantity of 11572 Ml/a which equates to approximately 29% of the annual average recharge to the aquifer unit.

Values for development give:

- Q_{SW} = 15044 Ml/a and Q_{SW}/QS = 1.71
- Q_{IW} = 14200 Ml/a and Q_{IW}/QS = 1.26

The above values are very high, indicating over development, and are exacerbated because many abstractions are close to the river, and river support provisions give rise to a summer bias in abstraction. The river support operations are designed to sustain target flows in the River Itchen further downstream. Overall, the licensed total is well in excess of safe *yield.*

Actual abstractions equate to approximately 52% of licensed quantity. Hence, if the above development assessments were revised using actual abstractions instead of licensed totals the results would indicate that actual abstraction is operated close to the safe *yield.*

It should also be noted that the licensed groundwater abstractions totalled in the above assessment only includes those within the Candover surface water catchment. Within the groundwater catchment (which extends well beyond the surface water catchment in places) there is a major additional public supply abstraction at Lasham, licensed for 5455 Ml/a, of which it is estimated that 80% of this is sourced from the Candover groundwater unit. Obviously, if this quantity were added to the above 'development' assessments, the extent of over development would be even more severe.

3.3 Ongoing Review and Refinement

It is considered that the Methodology proposed will provide a very useful 'tool' enabling improved and more efficient strategic assessment of groundwater resources for many aquifer units.

The Methodology has some limitations in its application to:

- complex or esoteric hydrogeological regimes

- highly developed groundwater abstraction systems which may also be operationally related to and controlled by the 'state' of the water environment.

In addition, the scope of the Methodology development has been constrained by tight project budgetary limits. Therefore, many of the developed routines and resulting parameters have only received partial evaluation, and the whole Methodology has only undergone limited trialing and calibration.

Therefore, whilst it is strongly encouraged that the Methodology be used, it is also recommended that this use should be complemented by a proactive programme of ongoing review and refinement. More specifically, it may be worth considering more targetted refinement by conducting a controlled performance assessment. This could be done by selective application to an appropriate range of aquifer units, covering various hydrogeological regimes and groundwater development states. Additionally, these should be well researched and in which water balance uncertainties are considered to be relatively small.

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APPENDIX A

SCORING SYSTEM FOR ENVIRONMENTAL CRITICALITY (EC)

Extract from Halcrow (1995) Surface Water Abstraction Licensing Policy Development - Core Report. R&D Note 438, NRA, Bristol. pp47-55.

(9 Pages)

3.3.3 Fisheries Characterisation

Basis

The fisheries scoring system is based upon likely sensitivity of fish community types of reductions in flow. This is largely a reflection of the vulnerability of the habitat to reduced flows, and to that extent there will be an element of "double counting". However, this is seen as a justified reinforcement of recognition of a critically sensitive ecosystem. The scoring system is shown in Table 3.3.

Table 3.3 - FISHERIES SCORING SYSTEM

SCORE	DESCRIPTION
16	Major salmonid spawning and/or nursery area
12	Adult salmonid residents
10	Adult salmonid passage and/or rheophile coarse fish - barbel grayling etc
8	Flowing water cyprinids - dace, chub, bleak, gudgeon etc
5	Slow/still water cyprinid fish - roach, bream, tench, carp etc
2	Poor coarse fishery
1	No fisheries interest, sticklebacks and eels only or no fish

The highest score of 16 is afforded to major salmonoid spawning and nursery areas. These areas are very sensitive to reductions in flow at all times of year. In summer, when flows are lowest and demand for water highest, the main constraint will be area of stream bed offering suitable habitats for young salmon and trout. The "carrying capacity" of a stream is limited by the territorial behaviour of the young fish, which leads to the displacement downstream of surplus or weak fish. Salmonoid nursery streams are generally shallow and fast flowing, and falling flow leads to a reduction in wetted area, with some becoming too shallow for the young fish, and water velocities falling below the optimum for salmon in particular.

The next score level is twelve, for stream reaches occupied by adult salmonoids (particularly trout) but without major spawning and juvenile rearing areas. Such fish require reasonable water velocities, and adequate depth of water associated with cover afforded by rocks, aquatic vegetation and bankside vegetation. Low flows can leave many potential "lies" untenable.

A score of ten is given to all other river reaches with a significant run of salmon or sea trout passing through, even if they are of lowland character. This reflects the dependence of such fish on flow events for stimulation of upstream migration. This score is also given to reaches with populations of strongly rheophilic coarse fish, particularly barbel and grayling. These species are only associated with strongly flowing water.

There is a further group of cyprinids which are associated predominantly with flowing water, including dace, chub and gudgeon. Reaches with dominant populations of these species are awarded eight points.

Reaches with good populations of slow-water cyprinids such as roach and bream are given five points, while poor coarse fisheries are given two points. Reaches with little or no fisheries interest are awarded one point.

Data Needs

Allocation of a fisheries score to a particular reach clearly requires a reliable knowledge of the local fish communities (as shown in Figure 4). In practice local fisheries officers and their staff are generally highly knowledgeable about the waters in their area and have little problem allocating scores. This knowledge is based upon bankside observations, anglers' catches, and electric fishing surveys carried out as part of a general monitoring operation. The experience during the trialing exercise suggests that the system is workable and not too time-consuming.

Occasional difficulties arose over delimiting the changeover point between one score and another, particularly where the change was gradual. This only becomes a matter justifying concern when the scores, combined with those for physical character and ecology, put it on the borderline of weighting classes. Another problem arose with very small tributaries and headwaters, where the limits of salmonoid nursery areas have not been established. This is rarely likely to cause a problem as such streams are usually of little interest in terms of abstraction. The way ahead here is either to classify them as scoring 16 to their source, or to leave them unclassified until or unless an application for an abstraction is received; a specific survey could then quickly establish the fishery status.

With clear base maps provided, it would appear that a knowledgeable fisheries officer and his staff could categorise a medium-sized catchment in a matter of an hour or two. Clearly where extra surveys are needed, or the fishery status is changing eg with a polluted river being improved, longer would be required.

3.3.4 Ecological Characterisation

Basis

As with the fishery assessment, ecological characterisation focuses upon species/community sensitivity and vulnerability to factors changed by flow volume reductions resulting from abstractions. Key factors likely to be reduced include velocity, depth, wetted area and oxygen levels; increased vulnerability from desiccation and changes towards finer particles in the substrata composition may also occur. Biota included in the sensitivity assessment therefore reflect this - ie species of ponded conditions and fine sediments score lowest, and those with a requirement for clean, well aerated gravels and fast current velocities score highest.

Scoring principles for the ecological characterisation of rivers are summarised in Table 3.4. They complement the physical characterisation process in that the higher scores are given to plant and animal communities which depend upon with fast-flowing, shallow habitats; lower scores are assigned to communities associated with sluggish and ponded watercourses. Again, scores are intended as a measure of sensitivity to change which might result from abstraction; in this case the attributes upon which the sensitivity of the system is based are the instream, marginal bank and riparian habitats and their associated flora and fauna.

Table 3.4 - SUMMARY OF ECOLOGY SCORING SYSTEM - EXAMPLE SCORES AND DESCRIPTIONS

SCORE	DESCRIPTION
16	Riffle biota vulnerable to desiccation as wetted area is reduced - ie species sensitive to velocity, coarse substrate and high oxygen levels - such as certain dragonfly and stonefly larvae (eg *Cordulagaster and Perlodidae*) - and some mosses and liverworts requiring regular submergence or splashing (eg *Scapania, Hygrohypnum*) or species at margins needing high humidity (eg filmy fern, *Hymenophyllum*) OR Totally water-table/inundation dependent habitats adjacent to the river where abstraction would change summer water levels significantly enough to change the hydrological regime of the site (ie water levels not maintained by structures or natural features).
13	River biota dominated by species which thrive in fast/moderately flowing water such as crowfoot, mosses/liverworts (eg *Fontinalis sqamosa, Chilocyphus*) range of stoneflies, (eg *Perlidae* and *Leuctridae)* mayflies (eg *Heptagenidae* and *Ephemerellidae*), caddisflies (eg *Goeridae* and *Rhyacophilidae*), damselflies (eg *Calopteryx virgo*).
10	Variable and rich pool, slack, run and riffle biota with species dependent on clean gravels/pebbles and fast flows. River reaches with extensive marginal habitats dependent on water-logging, and not protected by structures, also included. Submerged dead-wood habitat and fauna noteworthy for the sub-catchment. Typical species are riffle beetles (*Elmidae*), Mayfly (*Ephemerellidae*) , caddisfly larvae (eg *Goeridae* and *Limnephilidae*) and pea mussels (*Sphaeridae*). Typical macrophytes are crowfoot, milfoil and variety of mosses. OR Riffle and other vulnerable habitats dominate but biological data are too limited to make assessment.
6	Very rich flora/fauna of sluggish/ponded river dominate, with few species indicating pollution or stress. Limited/nil sensitivity to reduce volumes provided level and water quality are maintained but given high score to protect the very best examples. Typical species include white water lily (*Nymphaea alba*), pollution sensitive pondweeds (eg *Potomogeton lucens*, shining pond weed and *Potamogeton natans*, broad-leaved pondweed) mayflies (eg *Baetidae* and *Ephemeridae*), caddisflies (eg *Limnephilidae*) and alderflies (*Sialis sp*). OR riffles and more sensitive habitats where the present communities are poor but would improve if water quality and other factors were addressed.

Table 3.4 (Cont'd)

SCORE	DESCRIPTION
3	Mixed community of species dominated by pond species or those thriving in slow-flowing water or high water quality. Typical species include fennel pondweed (*Potamogeton pectinatus*), Nuttall's pondweed (*Elodea nuttallii*), Arrowhead (*Sagittaria sagittifolia*), freshwater shrimps (*Gammarus sp*), the mayfly (*Ephemera danica*) and various marginal beetles and bugs.
1	Assemblages very limited, containing virtually only pollution tolerant biota such as blood worms (*Chironomidae*), dominant blanketweed (*Cladophora sp*). OR species thriving only in ponded conditions such as duckweed (*Lemna*), hornwort (*Ceratophyllum*), water boatmen (*Conxidae*), hog lice (*Asellidae*) and ramshorn snails (*Planorbidae*). Additional Weighting (1-6) for terrestrial SSSI wetland sites, riverine SSSIs' or designated/rare species which have specific habitat associations with areas most likely to be impacted by abstraction (ie fast flow, coarse substrates).

It is important to note that, by using perceived sensitivity to changes in flow regime as the basis for ecological scoring, other indicators - for example community diversity, richness or presence of rare species - have apparently been put aside. In practice such indicators are "secondary effects" - that is, their presence results from the appropriate combination of physical, fisheries and primary ecological attributes. Currently the only biota used for ecological scoring are invertebrates and macrophytes; other animals are not included because they depend upon the well-being of the invertebrates, fish and macrophytes. Otters and river birds will be protected if their food source is maintained. Even so, it is recommended that a cautious approach to ecological scoring should be adopted if protected species are present - findings should be double-checked, and a slightly higher score assigned if there is uncertainty about the significance of any habitats for such species.

In the majority of cases, ecological scores are based on the macrophytes and invertebrates known to occur within the river. The principles behind the scoring (Table 3.4) are that highest scores are reserved for sites dominated by species which demand coarse bed materials and rapid/fast current velocities and lowest scores for sites dominated by species which are common in still-water habitats and capable of withstanding considerable eutrophication.

To derive an ecological score, the user gathers information on the occurrence of species within each assessment reach and utilises Tables 3.5 and 3.6 to judge whether the community is typical of the lower, middle or higher range of sensitivity scores. Professional judgement is required, since many of the species which are used in the assessment span a band of scores. Thus the most common species of a reach should provide the primary guidance for determination of the ecological score, while data on the presence of less common species can be used if appropriate to refine the position on the continuum scale.

Where no species information is available, and it is impossible to gather it in the time available, a cautionary approach for deriving ecological scores from the physical features may suffice in the short-term for very minor abstractions. The "inferred scores"are suggested in Table 3.4. Highest ecological sensitivity ratings are given if high quality wetlands lie adjacent to a river in which surface abstractions could lower the local water table and thus affect their interests.

Data Needs

In common with other aspects of the environmental weighting system, the approach to ecological characterisation has been devised to make best use of data already routinely collected and held by the NRA through biological monitoring and other survey programmes. It is not the intention that further fieldwork of a nature relevant solely to application of the revised abstraction licence determination methodology should become necessary.

The type of data required may be inferred from Tables 3.5 and 3.6. In the first instance, all relevant information on invertebrates and macrophytes which is available should be used to derive a best estimate of sensitivity score by reference to these tables. Some professional judgement will be required due to the overlap of species but, provided a range of species is considered rather than one or two only, a realistic indicative score should be deduced. Where some data are lacking, it should still be possible to make a reasonably informed judgement of ecological score which can be confirmed later when more information becomes available. Alternatively, the regional biological monitoring programme could be modified so that the missing information is obtained sooner than would otherwise be the case.

Table 3.5

SPECIES NAME	COMMON NAME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Vaucheria sp (p) (Dominant)	Mole-pelt alga																
Enteromorpha sp (p) (Dominant)	Tubeweed																
Lemna sp (p)	Duckweed																
Elodea nuttallii	Nuttall's Pondweed																
Glyceria maxima	Reed Sweet-grass																
Potamogeton pectinatus	Fennel pondweed																
Cladophora agg. (Dominant)	Cott/Blanketweed																
Nymphoides peltata	Fringed Water-lily																
Ranunculus circinatus	Fan-leaved Water-crowfoot																
Potamogeton natans	Broad-leaved Pondweed																
Sagittaria sagittifolia	Arrowhead																
Ceratophyllum demersum	Common Hornwort																
Zannichellia palustris	Horned Pondweed																
Groenlandia densa	Opposite-leaved Pondweed																
Nuphar lutea	Yellow Water-lily																
Nymphaea alba	White Water-lily																
Rorippa amphibia	Great Yellow-cress																
Potamogeton berchtoldii/ pusillus	Small Pondweeds																
Potamogeton natans	Broad-leaved Pondweed																
Sparganium emersum	Unbranched Bur-reed																
Myriophyllum spicatum	Spiked Water-milfoil																
Scirpus lacustris agg.	Clubrush/bulrush																
Sparganium erectum	Branched Bur-reed																
Butomus umbellatus	Flowering Rush																
Fontinalis antipyretica	Willowmoss																
Rhynchostegium riparioides	Moss																
Veronica anagallis-aquatica	Blue Water-speedwell																
Nasturtium officinalis	Water-cress																
Ranunculus aquatilis	Common Water-crowfoot																
Amblystegium fluviatile	Moss																
Callitriche obtusangula	Blunt-fruited Water starwort																
Oenanthe fluviatilis	River Water-dropwort																
Ranunculus fluitans	River Water-crowfoot																
Berula erecta	Lesser Water-parsnip																
Ran. penic. subsp. pseudofluitans	Brook Water-crowfoot																
Callitriche hamulata	Intermediate Water-starwort																
Myriophyllum alterniflorum	Alternate Water-milfoil																
Juncus bulbosus	Bulbous Rush																
Scirpus fluitans	Floating Club-rush																
Fontinalis squamosa	Upland Willow-moss																
Potamogetan polygonifolius	Bog Pondweed																
Lemanea fluviatilis	Wire Alga																
Hygrohypnum	Moss																
Chiloscyphus polyanthos	Liverwort																
Marsupella spp	Liverwort																
Nardia spp.	Liverwort																
Scapania	Liverwort																
Sphagnum	Moss																
Hymenophyllum	Filmy fern																
Jungermannia	Liverworts																

MACROPHYTE INDICATORS OF SENSITIVITY

Table 3.6

TAXON	COMMON NAME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Acroloxus lacustris (Ancylidae)	Lake Limpet																
Corduliidae	Emerald Dragonfly																
Naucoridae	Saucer Bug																
Phryganeidae	Cased Caddisfly																
Molannidae	Cased Caddisfly																
Gyrinidae	Whirlygig Beetles																
Libellulidae	Dragonfly																
Psychomyiidae	Caseless Caddisfly																
Planorbidae	Ramshorn Snails																
Coenagrion spp. (Coenagriidae)	Damselfly																
Centroptilum spp. (Baetidae)	Mayfly																
Gerridae	Pond Skater																
Lymnaeidae	Pond Snails																
Notonectidae	Greater Water-boatman																
Corixidae	Lesser Water-boatman																
Asellidae	Water Hog-louse																
Caenidae	Mayfly																
Erpobdellidae	Leech																
Sialidae	Alderfly																
Gammarus spp. (Gammaridae)	Freshwater Shrimp																
Viviparidae	River Snail																
Corophiidae	Tube Building Shrimp																
Sphaeriidae	Pea/Orb Mussels																
Theodoxus fluviatilis (Neritidae)	Neritte Snail																
Potamopyrgus jenkinsii (Hydrobiidae)	Jenkins Spire Snail																
Ephemeridae	Mayfly																
Leptophlebiidae	Mayfly																
Calopteryx splendens (Calopterygidae)	Banded Demoiselle (Damselfly)																
Simuliidae	Black-fly																
Hydropsychidae	Caseless Caddisfly																
Lepidostomatidae	Cased Caddisfly																
Platycnemis pennipes	White-legged Damselfly																
Aphelocheiridae	Saucer Bug																
Astacidae	Crayfish																
Ancylus fluviatilis (Ancylidae)	River Limpet																
Ephemerellidae	Mayfly																
Glossosoma (Rhyacophilidae)	Cased Caddisfly																
Goeridae	Cased Caddisfly																
Elmidae	Riffle Beetle																
Philopotamidae	Caseless Caddisfly																
Rhyacophila spp. (Rhyacophilidae)	Cased Caddisfly																
Leuctridae	Stonefly																
Perlidae	Stonefly																
Heptagenidae	Mayfly																
Calopteryx virgo (Calopterygidae)	Beautifull Demoiselle (Damselfly)																
Perlodidae	Stonefly																
Cordulegaster boltonii (Cordulegasteridae)	Golden-ringed Dragonfly																
Plectrocnemia geniculata (Polycentropodidae)	Caseless Caddisfly																

NB.. Species and generic names have only been used where sensitivity varies markedly within a family

INVERTEBRATE INDICATORS OF SENSITIVITY

As with physical and fisheries scoring, ecological scoring of a river only needs to be done once, unless a significant change occurs in the catchment. Once available, the EW can be used to guide any number of licence determinations in a particular catchment.

A fundamental point of information regarding ecological characterisation of rivers concerns the existence of associated water table dependent habitats. If high quality water table dependent habitats occur on the river banks, or special interests exist on the river margin or waterside fringe, it is important that their sensitivity to water level fluctuations is properly reflected in the evaluation of water resources available for abstraction (see Sections 3.4 and 3.5).

The necessary information on such habitats should be available through river corridor survey work routinely carried out by NRA conservation staff. If none has been carried out, consultation with external bodies such as the local Wildlife Trust and/or EN or CCW will be necessary if changes in water table are likely. In reality most riverside wetlands will not be vulnerable to abstractions of the type likely to be assessed, but a cautious approach is vital. Similarly, if winter storage is proposed, the NRA should encourage sensitive siting of the lagoon and ensure it is not built on a valued wetland.

APPENDIX B

SCORING SYSTEM FOR THE PHYSICAL CHARACTER COMPONENT OF HYDROLOGICAL SENSITIVITY (HS)

Extract from Halcrow (1995) Surface Water Abstraction Licensing Policy Development - Core Report. R&D Note 438, NRA, Bristol. pp43-46.

(4 Pages)

3.3.2 Physical Characterisation

Basis

The physical characterisation parameter is closely allied to, but assessed independently of, the ecological score. It is intended to reflect the fact that certain habitats require good flow rates whilst others survive well with little or no flow for extended periods.

Critical factors which determine physical character are flows:

- water velocity and depth;
- wetted area;
- frequency/duration of inundation;
- river water levels and their relationship with abutting/riparian water table levels;
- miscellaneous substrate changes, oxygen exchange, etc.

A summary of scoring principles for the physical character of a river is presented in Table 3.2. This is supplemented by a photo-guide showing representative river reaches for each score, and associated guidance notes (see User Manual). The approach adopted has similarities with the rule-based system used for water quality protection in rivers.

As with the fisheries and ecology scoring systems, vulnerability to change is a key consideration - for example, a wide, shallow riffle with a gravel bed is more vulnerable to abstraction upstream, because of the wetted area, velocity and substrate changes that may result, and would thus be awarded a high score. Conversely a comparably sized abstraction will not have such a marked effect on a ponded reach above a navigation lock; such a reach is less vulnerable and is awarded a lower physical character score.

The physical characterisation process determines how the river should be divided into reaches for all environmental scoring - that is, fisheries and ecology should be scored for each reach where there is a change in physical score. Scores should only be changed significantly where clear changes occur; the approach should be to typify reaches according to their likely sensitivity to reduced flow, and not to adjust scores for short lengths of atypical character unless there is clear justification for doing so.

It should be noted that assignment of a physical score to a river reach is based upon a range of considerations and features, some of which span several points within the overall range of 1-16. Conversely, some

reaches may not obviously match particular descriptions in Table 3.2 and the User Manual. Professional judgement is therefore required in assessing scores, although variations of one or two points on the "ideally correct score" are not considered to be significant within the overall EW evaluation.

Data Needs

The data requirements for physical characterisation may be inferred by reference to Table 3.2 and the photo-guide and accompanying notes in the User Manual (Table 3.2 should not be used in isolation). Essentially, a good appreciation is needed of the typical appearance of the river at a range of flows, and how this develops and evolves between its source and downstream limit. Particular features of high landscape value such as spectacular waterfalls or reaches that flow through a designated National Park should also be considered, and a discretionary approach adopted as to whether they are significant enough to justify increasing the awarded score to bring the reach into a higher environmental weighting band, or carrying out an environmental assessment.

Table 3.2 - SUMMARY OF PHYSICAL CHARACTER SCORING SYSTEM
(See User Manual for full details)

PHYSICAL CHARACTER CLASSES HIGHEST SCORES = MOST SENSITIVE	
SCORE	DESCRIPTION
16	Rivers with greatly reduced wetted perimeter at low flows
15	Small, even gradient rivers with runs and shallows
14	Large, steep, and even gradient rivers dominated by runs and shallows
13	Waterfall/pool (upland) rivers or large rivers with fast-flowing runs and deep pool/riffle sequences
12	Small, often high gradient riffle-dominated rivers
11	Small pool/riffle, low gradient rivers with natural character
10	Large pool/riffle rivers
9	Semi-natural low gradient (usually also lowland source) rivers
8	High base flow rivers
7	Managed lowland rivers with good instream edge habitats and steeper gradient rivers with constrained banks
6	Winterbournes
5	Ditches with extensive shallows
4	Heavily managed low gradient rivers
3	Ponded/impounded rivers where edge and bank structure is semi-natural
2	Ditches/channels with minimal gradient
1	Rivers unnaturally ponded and/or with minimal habitat structures

It may be seen that physical characterisation provides a framework for applying in a quantitative and structured way information which conservation staff already possess, or can readily obtain through discussion with others if they themselves are not familiar with the river in question. Such application can be refined as experience with the scoring system increases.

It should also be noted that geomorphological river typing, currently under development as part of the River Habitat Survey (RHS) research and development project (see Section 2.4.1), may be a useful point of reference for assessing physical characterisation scores. Discussions with those involved with RHS development show that the segment types 1-11 cannot be adequately equated with sensitivity to abstraction, due to great variations of physical character within some of the types. The RHS system is also still in its refinement stage; however it is expected to be a valuable tool in the relatively near future for determining the physical typology of rivers which can in turn be used for assessing potential sensitivity to surface water abstractions.

APPENDIX C

SELBY SANDSTONE

(2 Pages)

Table C.1

Effective Rainfall (ER) = 205 mm/a

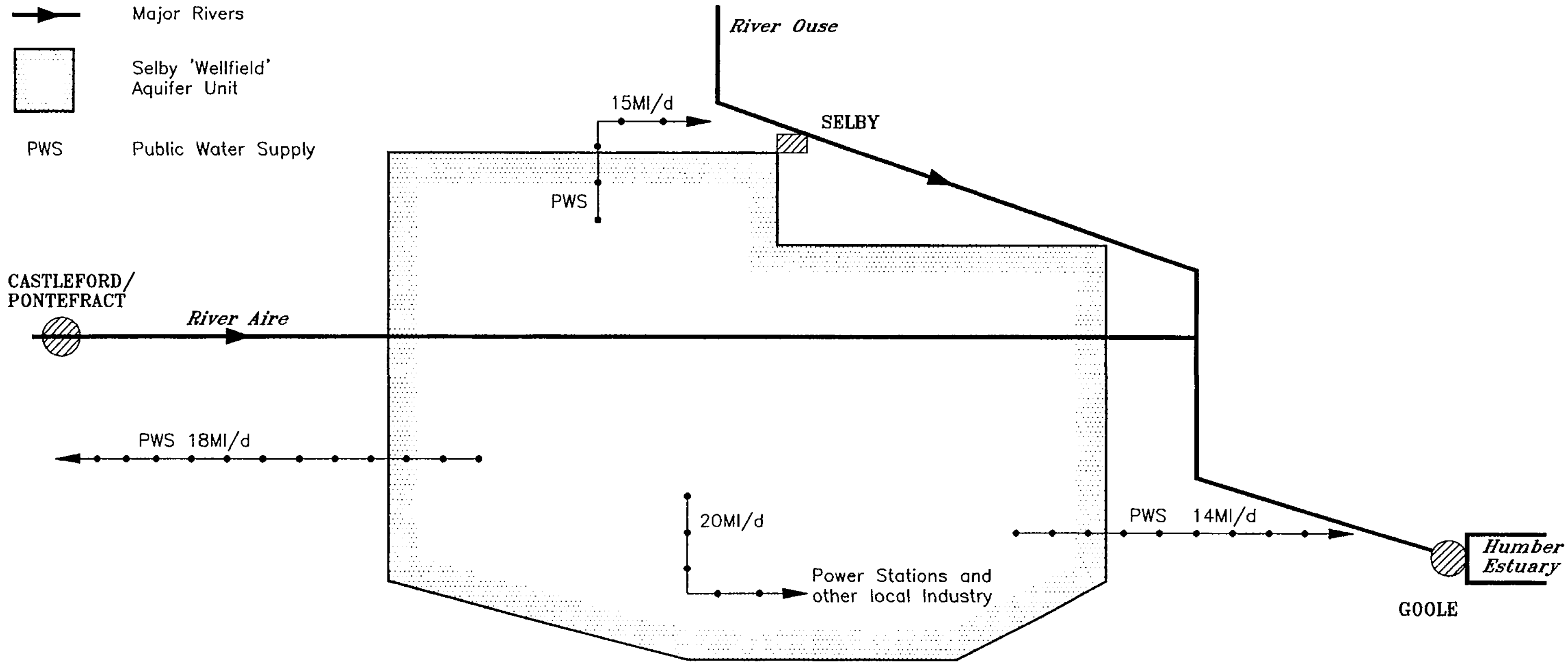
For various drift cover recharge is estimated as:

Drift Class (DC)	Area (km^2)	Equivalent Clay Thickness in Drift	Recharge (R) (mm/a)
1	23.53	zero (or no drift)	ER
2	56.61	<5 m	(2/3) x ER
3	107.28	<10 m	(1/3) x ER
4	16.65	<15 m	50
5	6.93	<20 m	25
6	-	>20 m	zero

Composite Recharge $= \dfrac{\sum_{1}^{6} R * \text{Area}}{\sum_{1}^{6} R \text{ Area}}$

$= 101$ mm/a

(cross ref: 15519X045)



SELBY 'WELLFIELD' AQUIFER UNIT

Area 209 km^2
Composite Recharge 101 mm/a
Groundwater Resource 21109 Ml/a (≡ 58Ml/d)

Licensed Quantities:–	Annual	Average Daily
Public Supply	27777 Ml/a	76 Ml/d
Industrial ($^2/_3$ Power, $^1/_3$ Other)	9348 Ml/a	26 Ml/d
Total	37125 Ml/a	102 Ml/d

APPROX. ACTUAL AVERAGE ABSTRACTION

Public Supply	45 Ml/d
Industrial	20 Ml/d
Total	65 Ml/d

PUBLIC SUPPLY ZONES & INDUSTRIAL*

Castleford/Pontefract	18 Ml/d
Selby and Local Area	15 Ml/d
Goole (Exported)	14 Ml/d
*Power Stations	16 Ml/d
*Other	4 Ml/d

ASSUME 90% EFFLUENT RETURN TO LOCAL RIVERS

Castleford/Pontefract	16.2 Ml/d
Selby and Local Area	13.5 Ml/d
Industrial	18.0 Ml/d
Total	47.7 Ml/d

Figure C1 Schematic Representation of Groundwater Resource Management in the Selby 'Wellfield' Aquifer Unit

APPENDIX D

OTTER SANDSTONE

(4 Pages)

Sherwood Sandstone Group can be divided into the Otter Sandstone and the underlying Budleigh Salterton Pebble Beds; together they form the major aquifer of the area. The Otter Sandstone comprises fine- to medium-grained, red-brown, ferruginous, micaceous and calcareous sandstones with minor silt and thin but laterally extensive conglomeratic beds. Although the sandstones are generally uncemented, cemented bands occur throughout the sequence. The formation reaches its maximum thickness of 155 m in the Otter Valley. Farther north, in the Culm Valley, it thins to about 60 m. Around Wellington iron cementation occurs, and farther north again, where its outcrop has been dissected by faulting, the formation thickens to 70 m and consists of fine-grained, hard, calcareous sandstone with coarse sandstone, conglomerate, clay and marlstone beds and nodules.

In Devon the Budleigh Salterton Pebble Beds consist of well-rounded pebbles, cobbles and boulders of metaquartzite in a matrix of unconsolidated medium- to coarse-grained micaceous sands with marl lenses. In Somerset they comprise well-consolidated, rounded or angular grit and conglomerate pebbles with a calcareous cement in the west and iron oxide cement near Wellington. Pebble size decreases northwards.

The two formations act as one aquifer throughout the area, although the degree of hydraulic interconnection varies. However the aquifer can be divided into two parts, one in Devon, where primary intergranular permeability predominates (although fissure flow also occurs), and the other in Somerset, where all the permeability is from secondary joints and fissures. In Devon most boreholes penetrate both formations and hydraulic conductivities are usually in the range of 1-5 m/day for the aquifer as a whole. The permeability of the Pebble Beds is particularly variable and can be several times higher than in the overlying sandstone. Therefore the overall effect in the Otter Valley is of a multi-layered aquifer, which although unconfined on a regional scale (water table fluctuations indicate a long term specific yield of 0·1 to 0·2) always gives a leaky-confined response to pumping tests ($S = 10^{-3}$ to 10^{-4}). Many boreholes exhibit marked responses to fluctuations in barometric pressure, indicating that marl lenses in the Pebble Beds and cemented layers in the sandstones can cause confined or semi-confined conditions. Several differential pressure heads are present in the different layers, those in the Pebble Beds usually being highest and capable of producing overflowing artesian conditions locally, reflecting the higher topography of their recharge area.

In the Otter Valley water levels in the sandstone have a response time to rainfall of between 2 and 12 weeks and annual fluctuations average 0·7 m; in the Pebble Beds the lower storativity leads to larger annual fluctuations (1·4 m). A thinner unsaturated zone at outcrop produces a faster response to rainfall (2-8 weeks). Springs occur at the down-dip junction of the Pebble Beds with the overlying sandstone; the streams produced are generally in hydraulic continuity with the water table and strongly gaining. However recent development of the Greatwell, Dotton and Harpford areas has caused a fall of nearly 2 m in water levels, causing streams to become losing locally and borehole yields to be limited (by licence) at times by the residual flow requirements of these streams.

Yields of boreholes depend primarily upon the depth of saturated aquifer penetrated and the degree of connection with the River Otter; a well at Greatwell (SY 1084 9557) yields up to 45 l/s for a long term drawdown of 25 m, and one near Dotton (SY 0797 8807) provides 30 l/s for 46 m drawdown, whereas other sources nearby (SY 083 882) in hydraulic continuity with the river yield up to 61 l/s for only 12 m drawdown. Because of the unconsolidated nature of the aquifer, wells must be carefully designed and constructed to limit the ingress of sand.

In Devon, the Otter Sandstone at outcrop yields an excellent quality, moderately hard water which changes under cover of the Mercia Mudstone to a harder but still potable calcium bicarbonate water. Water from the Budleigh Salterton Pebble Beds is acidic with low total dissolved solids, calcium and bicarbonate contents; it is therefore potentially corrosive. These chemical differences imply that although the two formations are hydraulically connected, little or no mixing of the groundwaters occurs; where it does complex conditions result and deterioration of groundwater quality occurs due to the solution of iron (see Lower Otter Valley hydrochemical inset).

North of the Culm Valley yields decrease rapidly owing to the changes in lithology and are generally less than 7 l/s. The decrease in porosity causes annual water level fluctuations to be significantly higher in Somerset. Borehole yields are very variable, being dependent on their striking water-bearing fissures. At Pitt Farm, near Wellington, a combined yield from the sandstones and the Pebble Beds of 25 l/s is obtained. Some faults act as positive boundaries where horizons of differing permeabilities are juxtaposed and at Ash Priors 11 l/s are obtained from an adit. Elsewhere fault planes are highly cemented and act as barriers to groundwater flow. Despite the consolidated nature of the aquifer, the ingress of fine sand can clog pumps, if boreholes are not correctly designed. The waters from both formations are chemically identical, hard with high calcium, magnesium and bicarbonate concentrations; nitrate levels are also high locally due to changes in agricultural practice.

Throughout the area, where the Pebble Beds overlie older less permeable formations, springs are common at the base of the Triassic.

Figure D4
EXTRACT FROM HYDROGEOLOGICAL MAP SOUTH WEST ENGLAND
Scale 1:100,000

APPENDIX E

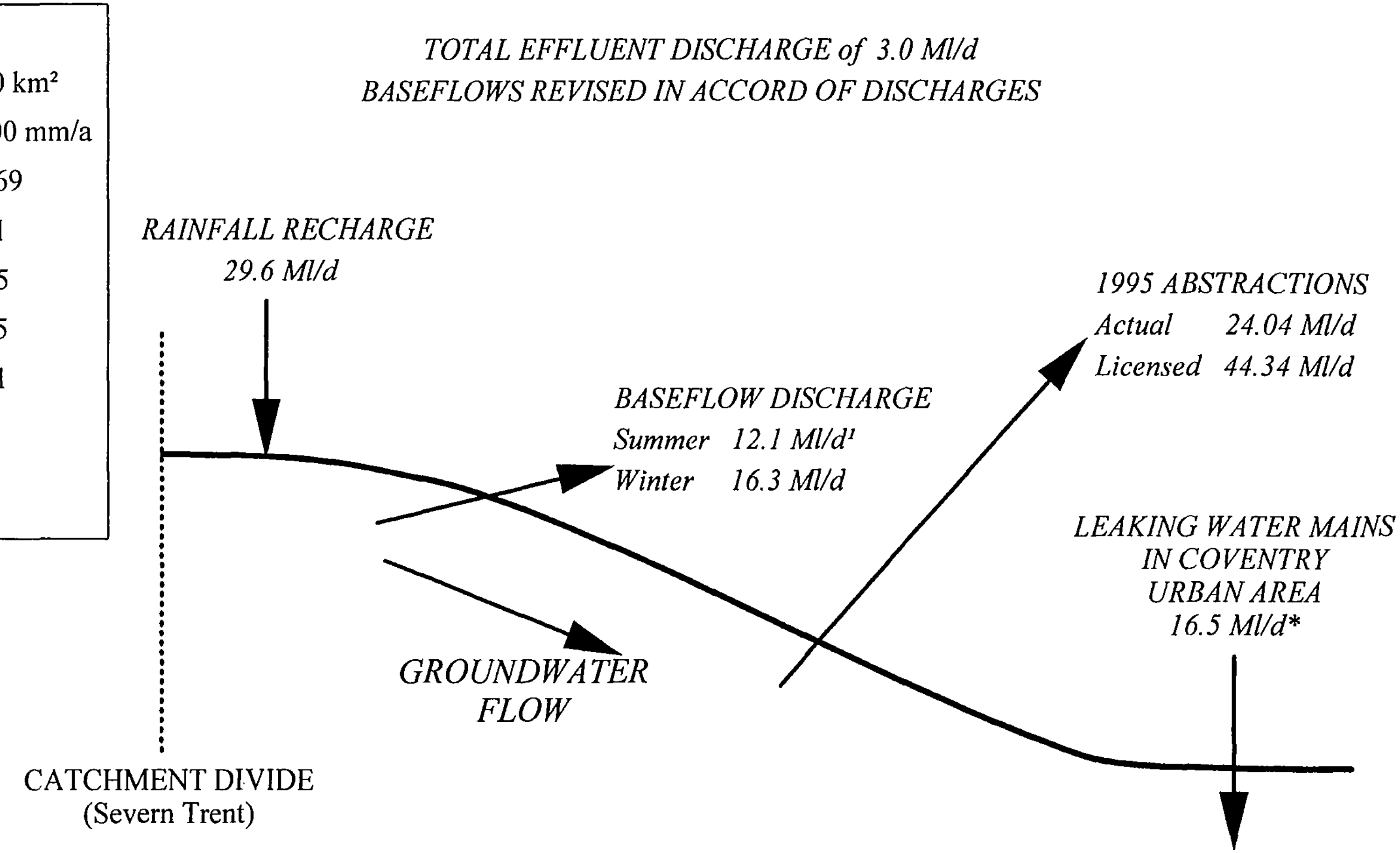
COVENTRY SANDSTONE

(2 Pages)

FACTORS USED

Unit Area	= 90 km²
Effective Rainfall	= 300 mm/a
Geology Infiltration Factor	= 0.69
Urban Factor (20km²)	= 0.1
Suburban Factor (13km²)	= 0.5
Rural Drift < 5m Thick (16km²)	= 0.5
Rural Drift > 5m Thick (6km²)	= 0.1

* Reduced from Lerner (1993) to 16.5 Ml/d on an Area Basis



* The residual value is a measure of uncertainty in the water balance. The largest uncertainty is probably the baseflow estimate of 14.2 Ml/d which is based largely on Summer 1995 measurements (when flows were low) for the Sherbourne Catchment. These were scaled up to represent the Upper Sowe Catchment for which there are no measurements. It is considered likely that baseflow is probably 20 Ml/d on average.

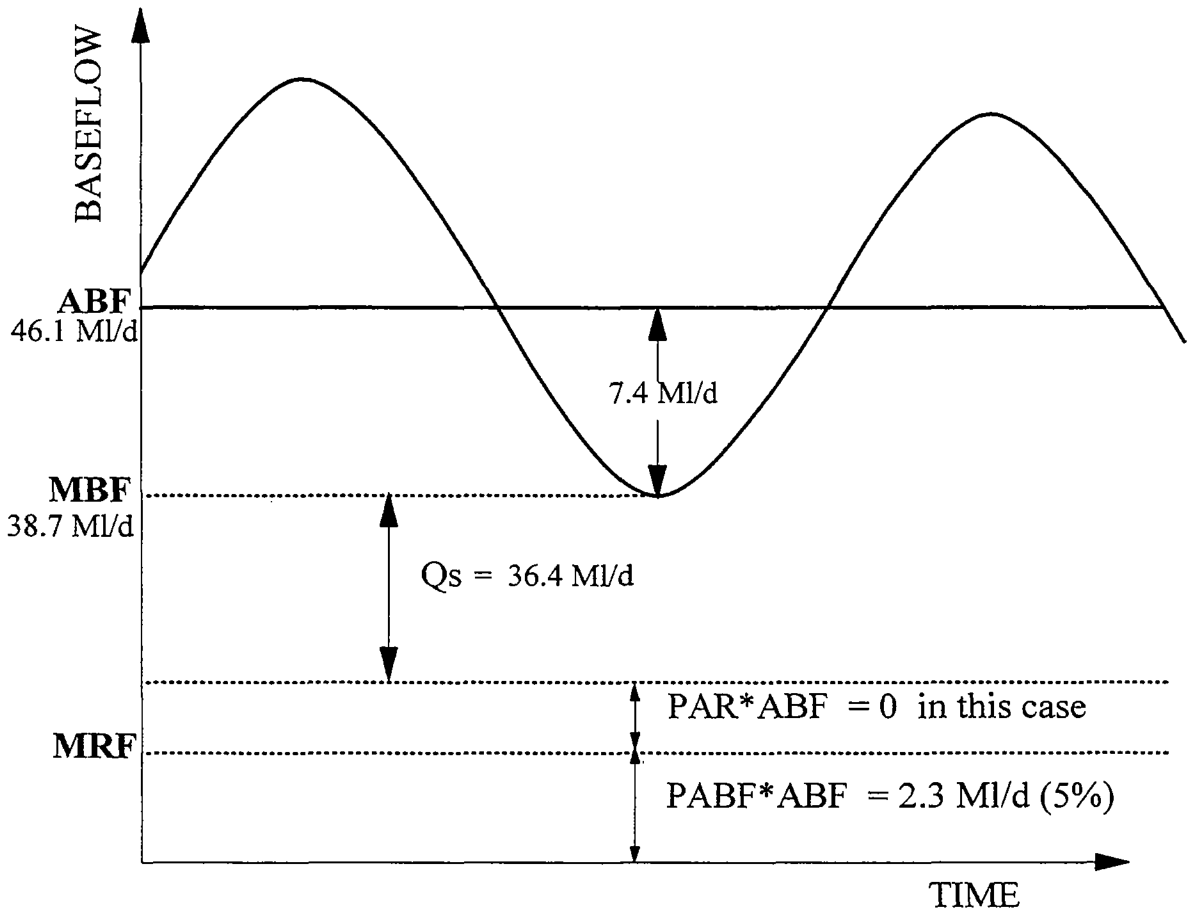
WATER BALANCE

Residual = Inflows - Outflows

= (29.6 + 16.5) - (24.04 + 14.2)

Residual = 7.86 Ml/d*

FIGURE E1 REVISED COVENTRY UNIT WATER BALANCE



ABF = Average Baseflow (Long Term Average Recharge)

MBF = Minimum Baseflow

MRF = Minimum Required Flow = PABF * ABF

In this instance, the MRF has been set at a very low value

D_T = MBF/ABF = Development Threshold

Q_S = MBF - MRF - ABF * PAR = Yield

= ABF * (D_T - PABF - PAR)

= ABF * D_S

D_S = Safe Development Threshold

FIGURE E2 GRAPHICAL REPRESENTATION OF THE APPLICATION OF THE RELIABLE YIELD METHODOLOGY TO THE REVISED COVENTRY UNIT

APPENDIX F

KENNET CHALK - OG CATCHMENT

(2 Pages)

Table F1

WATER BALANCE

Area: Kennet Catchment
Sub Area: River Og (Unit 2)

General

Topographic Area: 59 km²:
Year: 1987/88 (average year)

Meteorological information

	mm	Ml/d
Annual Rainfall:	808	131
Annual Potential Evaporation:	521	84
Annual Actual Evaporation:	447	72
Annual Rainfall excess:	361	58

Groundwater

Inputs

Natural Recharge:	56
Leakage from mains:	2 (1.99)
Leakage from streams:	-
Sewage effluent:	0 (0.004)
From other G/w units:*	-
From other aquifers:	-
Total inputs:	58

Outputs

Actual Abstractions:	5 (5.36)
Agricultural Abstractions:	0 (0.23)
Export by springs:	4
Flow to rivers:	27
To other G/w Units:*	22
To other aquifers:	-
Net change in storage:	-
Total outputs:	58
Licensed Abstractions:	13.9

Rivers

Inputs

Surface runoff:	2
Gains from G/w:	27
Effluent:	-
Net flow from canal:	-
Water from upstream:	-
Total inputs:	29
Consented Discharge:	-

Outputs

Actual abstractions:	-
Loss to G/w:	-
Agricultural abstractions:	-
Net flow to canal:	-
Flow out of catchment:	29
Total outputs:	29
Licensed Abstractions:	-

Water Supply (Abstraction/Effluent)

Effluent

To G/water:	0 (0.004)
To rivers:	-
Mains/sewer leakage:	2 (1.99)
Inputs to zone:	-
Outputs from zone:	3 (3.07)

Abstractions

From G/w:	5 (5.36)
From rivers:	-

Hydrological Serivces - Catchment Control January 1990

units are Ml/d

Note: an * indicates the component is estimated.

APPENDIX G

STIFFKEY CHALK

(2 Pages)

Table G.1

Catchment Resource Situations

	Quantity tcma	Equiv Effective Rainfall mm/a
a) Potential Net Export Licensed (1991)	3 175	4
b) Actual Abstraction Exported (1975 to 1990)	2 600	34
c) Gauged river flows (allowing for estimated corrections)	15 420	c200
d) Approximate Net Resource (effective rainfall = (b + c)	17 733	c230
e) Estimated Catchment Recharge = 0.7*(d)	12 413	c161
f) Estimated Recharge over sand and gravel, and Chalk areas = 0.9*(d), which represents 30% catchment area	4 788	c207
g) Estimated Recharge over boulder clay areas = [(e) - (207 * 0.3]/0.7 which represents 70% catchment area	7 625	c141

Note:
c141 = An approximate value

APPENDIX H

CANDOVER CHALK

(2 Pages)

Figure H2

COMPARISON BETWEEN GROUNDWATER & SURFACE WATER CATCHMENTS