Final Report **Project WFD53**

Criteria for WFD Groundwater Good 'Quantitative Status' and a Framework for the Assessment of Groundwater Abstractions

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<u>Use of this report</u>

The development of UK-wide classification methods and environmental standards that aim to meet the requirements of the Water Framework Directive (WFD) is being sponsored by UK Technical Advisory Group (UKTAG) for WFD on behalf its member and partners.

This technical document has been developed through a collaborative project, managed and facilitated by SNIFFER and has involved the members and partners of UKTAG. It provides background information to support the ongoing development of the standards and classification methods.

Whilst this document is considered to represent the best available scientific information and expert opinion available at the stage of completion of the report, it does not necessarily represent the final or policy positions of UKTAG or any of its partner agencies.

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EXECUTIVE SUMMARY

WFD53: Development of a Framework for Determining the Regulatory Standards for Groundwater Abstractions (September, 2005).

Final Report: Criteria for WFD Groundwater 'Good Quantitative Status' and a Framework for the Assessment of Groundwater Abstractions.

Project funders/partners: SNIFFER, Environment Agency, Geological Survey of Ireland.

Background to research

The aim of this project was to determine a framework to evaluate the criteria for Water Framework Directive (WFD) 'good quantitative status' within each groundwater body and a further framework to assess applications groundwater abstractions to maintain good status.

The WFD explicitly states that member states should ensure a balance between the abstraction and recharge of groundwater and implicitly establishes the need for member states to regulate groundwater abstractions through an assessment and control regime.

It is intended that outcomes from the project concerning the criteria for good status have application throughout the UK and Ireland. Subsequent recommendations regarding an appropriate assessment framework and tools are intended for application in Scotland, Northern Ireland and Ireland and are tailored as appropriate for the hydrogeological environments and legislative regimes in these countries.

Objectives of the Research

The objectives of the research were to set the criteria for good groundwater quantitative status and to develop a regulatory assessment framework. These objectives were subdivided into the following phases:

- An assessment of the criteria for good quantitative status based on the Directive and associated guidance;
- A review and critical evaluation of existing methodologies internationally and within the UK;
- Proposals for the criteria to determine good groundwater status; and the
- Development of a comprehensive framework for the assessment of applications for groundwater abstraction.

Key Findings and Recommendations

Criteria for Good Quantitative Status
An international review concluded that many countries use a regional or aquifer specific 'groundwater management plan' rather than applying a 'one system fits all' approach. This avoids the over-regulation of 'minor' aquifers and focuses management on aquifers with hydraulic properties which can allow over exploitation in areas where abstraction pressures are greatest.

Based on the WFD and UKTAG Guidance five tests were proposed as the criteria for groundwater good quantitative status:

Test 1: That the total abstraction from the groundwater body should not exceed the recharge to the groundwater body, after an allowance for dependent ecosystems if no assessment of these has been possible.

Test 2: That groundwater abstraction should not cause a reversal in groundwater flow direction which results in the significant intrusion of saline or other poor quality water into the groundwater body.

Test 3: That groundwater flows to dependent surface water bodies should not be diminished by groundwater body related pressures to the extent that they do not achieve good status, or that their status is reduced from high to good.

Test 4: That groundwater body related pressures should not diminish groundwater flows or levels supporting groundwater dependent terrestrial ecosystems (GWDTEs) such that these ecosystems suffer "significant damage" in relation to conservation objectives.

Test 5: That a review of available groundwater level monitoring data is conducted. Groundwater levels, on their own, rarely provide a reliable indication of quantitative status in relation to the groundwater body scale balance between abstraction and recharge but may be helpful in investigating potential abstraction impacts on GWDTE receptors.

Indicators of the confidence in the status assessment are presented in Table 6 of the report, based on consideration of all the available evidence.

Framework for the Assessment of Groundwater Abstractions
Assessment of applications for groundwater abstraction must aim to avoid a deterioration in quantitative status and to permit good status to be maintained or achieved. A Good Status classification of a groundwater body does not automatically permit abstractions where these would result in unacceptable stress to surface water bodies or groundwater dependent terrestrial ecosystems, or cause saline intrusion. Equally, Poor Status does not preclude groundwater abstractions where it can be demonstrated that the proposed abstraction does not increase the stress which resulted in the Poor Status classification.

The assessment of groundwater abstraction should be based on the criteria for determining quantitative status (summarised above). Additional criteria also include practical considerations (e.g. borehole yield), impacts on other abstractors or receptors, socio-economic considerations, consultation and sustainability assessments.

The level of assessment of an application (i.e. detail, site investigation and time required) should be linked to the risks it poses and the consequent confidence required in the predicted impacts. A GIS based desk-study is recommended as a first screening tool for all abstraction applications. Further site specific assessment, including water features surveys, pumping tests and, in some cases, numerical groundwater modelling may be required which must be scoped according to the local risks and hydrogeology.

Simple examples of application of the groundwater abstraction assessment framework to contrasting groundwater bodies in Scotland and England are presented.

Key words: GROUNDWATER, ABSTRACTIONS, WATER FRAMEWORK DIRECTIVE

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1 INTRODUCTION

1.1 Introduction to the Project

With regards to groundwater body good quantitative status objectives, Article 4.1(b) (ii) of the Water Framework Directive (WFD) states that:

"Member States shall…ensure a balance between abstraction and recharge of groundwater with the aim of achieving good groundwater status .. by 2015 .. in accordance with the provisions in Annex V…"

Section 2.1 of Annex V states that the parameter for the classification of quantitative groundwater status is the groundwater level regime and that good status means that this level regime is such that:

"…the available groundwater resource is not exceeded by the long term average annual rate of abstraction."

Additionally that:

"anthropogenic alterations should not result in:

- …failure to achieve environmental objectives…for associated surface waters;
- any significant diminution in the status of such waters;
- any significant damage to terrestrial ecosystems which depend directly on the groundwater body;
- or any flow direction changes leading to saltwater or other intrusion."

The Article therefore implicitly establishes the need for member states to regulate groundwater abstractions through an assessment and control regime.

The aim of this project was to determine a framework to evaluate the criteria for WFD 'good quantitative status' within each groundwater body and a further framework to assess licences or consents for individual groundwater abstractions to maintain good status.

The project was initiated and is funded through the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER) and project funding partners are the Environment Agency and the Geological Survey of Ireland. It is managed by a steering committee which includes representatives from the Scottish Environment Protection Agency (SEPA), Environment and Heritage Service Northern Ireland (EHS), Geological Survey of Ireland (GSI) and the Environment Agency of England and Wales (EA).

It is intended that initial outcomes from the project concerning the criteria for good status have application throughout the UK and Ireland. Subsequent recommendations regarding an appropriate regulatory framework and tools are intended for application in Scotland, Northern Ireland and Ireland and should be tailored as appropriate for the hydrogeological environments and legislative regimes in these countries. It is anticipated that the Environment Agency in England and Wales will continue to operate its existing abstraction licensing process, possibly modified to meet Water Framework Directive needs.

1.2 Project Objectives

The objectives of the project as specified in the Invitation to Tender (WFD 53) can be summarised as follows:

- To set the criteria for good groundwater quantitative status; and
- To develop a regulatory assessment framework for groundwater abstractions.

These objectives are to be achieved through the following four phases of work.

Phase 1: Identify and report the criteria by which good groundwater quantitative status can be defined.

Phase 2: Review and critically evaluate existing methodologies, tools and guidance to determine those that are suitable for use in the Scotland, Northern Ireland and the Republic of Ireland. Identify gaps where no tools currently exist.

Phase 3: Based on the above review, develop a comprehensive framework for determining if an existing or proposed future groundwater abstraction is likely to result in an adverse impact on the environment (defined according to WFD objectives). This framework would be tested with case study examples agreed with the steering group.

Phase 4: Report on the above phases focussing on the agreed framework and the criteria for regulatory control.

1.3 Layout of This Report

This report forms the final deliverable and documents all phases of the project. A separate report on the Criteria for Good Quantitative Status has been produced as a standalone document to provide a reference point for the Environment Agency in England and Wales.

This report presents an overview of the key issues, and makes proposals for the criteria by which WFD good quantitative status can be defined. It includes a critical evaluation of existing regulatory criteria for groundwater abstraction in other countries and assesses their application for use in the Scotland, Northern Ireland and Ireland. A framework for assessing groundwater abstraction applications is proposed and four case study examples are worked through this framework.

This document is structured as follows:

- Section 2 provides a background to the WFD, its key Articles and Annexes, and places this project into context within it;
- Section 3 is a review of the methodologies used to determine an aquifer's quantitative status both internationally and within England and Wales;

- Section 4 critically evaluates the requirements for WFD Quantitative Good Status based on the above review, UKTAG documents and consultation with relevant organisations;
- Based on this critical review Section 5 presents proposals for determining the quantitative status.

The above sections form the standalone report on the Criteria for Good Quantitative Status. The following sections document the proposed framework for assessment of abstraction applications.

- Section 6 summarises the criteria for the assessment of groundwater abstractions, based on the criteria for maintaining good quantitative status of the groundwater body;
- Section 7 is a short review of current abstraction control regimes in Scotland, Northern Ireland and the Republic of Ireland;
- Section 8 proposes a decision support framework for this assessment process and Section 9 presents short case studies in Scotland and Northumberland based on the proposed framework;
- The references in the report are presented in Section 10 and a glossary of terms in Section 11.

1.4 Key Terms and Definitions

A full glossary of WFD terms is presented in Section 11 but definitions of the key terms as used in the report are summarised below.

It is important that the groundwater abstraction regulatory ‘framework’, as developed in this report, is not confused with the Water Framework Directive (WFD). For this reason the WFD is always referred to as an acronym or with the full title. In this report a ‘***framework***’ defines the structure linking proposed evaluation tools and how users interface with these tools. A ‘***tool***’ is an approach that evaluates the potential pressures or impacts associated with groundwater abstraction.

For the purposes of this report the terminology used to **characterise** risks to a groundwater body and **classify** its status have been standardised. An anthropogenic ‘***activity,***’ such as public water supply, is considered to apply a ***‘pressure’*** to the water body at individual ***‘sources’*** (e.g. groundwater abstractions). The vulnerability of the water body to the pressure may vary according to its ‘***sensitivity***’. The ‘***exposure pressure***’ or ‘***stress***’ is determined by a combination of the pressure and the sensitivity. The ‘***impact***’ is the monitored evidence (e.g. falling groundwater levels) of the influence of the pressure on the hydrological regime. The term ***‘impact’*** can also be understood to relate to the ***ecological effects*** which are a consequence of changes to the hydrological regime. These effects which may in turn affect the ***ecological status*** of dependent surface water bodies, or result in ***‘significant damage’*** to dependent terrestrial ecosystems, thereby influencing the status of the groundwater body.

‘Good groundwater quantitative status’ is the condition of the groundwater body when its quantitative status is at least good, as defined by the WFD according to the Articles summarised in Section 1.1. The definition of good groundwater quantitative status is discussed in more detail in Section 2.2.

Initial Characterisation of groundwater bodies for the WFD was concluded in December 2004. This delineated groundwater bodies and sought to identify which were 'at risk of failing to achieve good status (quantitative and chemical) by 2015'.

Further Characterisation is the subsequent more detailed assessment of those groundwater bodies considered initially to be 'at risk'. In relation to the quantitative status objectives this may require investigations and monitoring to refine and develop the conceptual understanding underpinning the characterisation of relationships between groundwater abstraction, groundwater body water levels and flows, and impacts on dependent ecosystems (surface water or terrestrial).

Classification is the process of defining the status of each groundwater body (good or poor) for the first River Basin Management Plan (RBMP). Classification can be considered to follow Further Characterisation and should, as much as possible, be based on comparison of field monitored parameters with previously determined good status criteria or thresholds. However, whilst this reliance on field measurement may be achievable for surface water body classification, it is more problematic for groundwater bodies where hydrological and ecological dependencies can be complex, and groundwater level monitoring is rarely a representative indicator. Simple pressure screening approaches applied during characterisation may therefore also have to play a role in classification. The characterisation and classification processes can thus be considered to lie along the same spectrum within the river basin planning cycle from risk assessment to status reporting.

2 OVERVIEW OF THE WATER FRAMEWORK DIRECTIVE

2.1 Introduction to the Water Framework Directive and Groundwater Bodies

The WFD (2000/60/EEC) is the most significant European water legislation to emerge to date and is intended eventually to replace the majority of water related directives and form a holistic strategy for managing the water environment. The Directive uses the planning concept of river basin districts (RBDs) – a river catchment or a group of catchments. Integrated river basin management plans (RBMPs) are to be developed for each district, which will include the characterisation and risk assessment of all water bodies (surface water and groundwater).

The WFD requires that groundwater bodies are defined as a distinct volume of groundwater within an aquifer or aquifers. The definition of an aquifer is any rock type that allows a significant flow or contains significant quantities of groundwater available for abstraction. Following Common Implementation Strategy (CIS) guidance, the tests of significance are:

- Whether the aquifer can deliver more than 10 m^3/d as an average or supply more than 50 persons with potable water; or
- Whether the removal of groundwater flow would result in a significant diminution in the ecological quality of a surface water body or a directly dependant terrestrial ecosystem.

Under these criteria most rock types in the UK and Ireland, with the exception of some Tertiary or Jurassic clay formations, will qualify as aquifers and be contained within groundwater bodies.

For the purposes of initial reporting, groundwater bodies across the UK and Ireland have generally been delineated according to the hydrogeological properties of the solid geology sub-crop, or of significant superficial deposit aquifers where these overlie unproductive strata, within relatively large scale catchment boundaries. These groundwater body boundaries have been mapped in plan for reporting purposes but not in cross-section. A more detailed three-dimensional delineation which distinguishes different aquifers at different depths below the surface has not been reported and may not be practical. It should be possible to ensure that, where pressures such as groundwater abstractions are applied to an aquifer confined by other strata, they are assessed in relation to the resources of that aquifer, with results mapped at its outcrop. The local pressures of abstraction sources on dependent ecosystem receptors must also be considered with regard to the local aquifer pathways between them. However, where several aquifers overlie each other (e.g. where shallow superficial sands and gravels overlie solid aquifers) they are likely to continue to be mapped and reported together for WFD purposes – as part of a larger scale 'layered' aquifer groundwater body.

2.2 Groundwater Quantitative Status Environmental Objectives

The environmental objective for groundwater quantitative status is contained within Article 4.1b (ii) and this is to: "Protect, enhance and restore all groundwater bodies, ensuring a balance between abstraction and recharge, with the aim of achieving good status by 2015".

Annex V 2.1.1 of the WFD defines the parameter for the classification of quantitative status, as the 'groundwater level regime'. Annex V 2.1.2 defines 'good quantitative status' as "the level of groundwater in the groundwater body such that the 'available' groundwater resource is not exceeded by the long-term annual average rate of abstraction."

As interpreted from the above definitions, to meet the requirements for good quantitative status, groundwater abstraction across the groundwater body must not:

'Exceed the available groundwater resource.' For initial characterisation, thresholds were set which assumed that, rather than recharge simply exceeding abstractions, a proportion of recharge needs to be reserved to protect the baseflow needs of dependent surface water bodies and terrestrial ecosystems. Due to uncertainty in the recharge requirements these thresholds of groundwater abstraction/recharge were set to protect a large proportion of recharge for dependent ecosystems (80% or 90%) and this was used as part of the assessment of groundwater bodies 'at risk of failure'.

Within this project the assessment of 'available' groundwater resource will continue to be suggested as a 'groundwater body representative' proxy for 'groundwater levels'. However, the appropriateness of applying such precautionary thresholds for classification purposes, in the absence of other lines of evidence, will be re-examined. Enhanced level monitoring may also be needed locally according to the degree of abstraction pressure and associated risks. Under Annex II 2.4[1], member states must review the impact of changes in groundwater levels.

It is also important to recognise that the use of the term ***'available'*** groundwater resource applied to groundwater bodies should not be understood to mean that abstraction is practically possible. Whilst there may be a surplus resource available in theory, it may not be possible to exploit it economically because of the low transmissivity or storage of the aquifer. Similarly the distribution of available groundwater may vary across the groundwater body in relation to local ecological receptors – it should not be considered to be uniformly available everywhere.

'Result in the failure of the Directive's objective for any associated surface water bodies; diminution of status of surface water bodies or damage to terrestrial ecosystems.' This is important as many surface water bodies and terrestrial ecosystems are maintained, at least for part of the year, by groundwater. Abstraction related changes groundwater levels, flows or chemistry may impact on the ecological status of dependent surface water bodies including rivers, lakes and estuaries, or may result in 'significant damage' to terrestrial wetland ecosystems.

'Result in an alteration to the groundwater flow direction which has or will result in intrusions of seawater or water of a different chemical composition.' The UKTAG Guidance Paper 11b interpretation of this is that "Alterations to flow direction resulting from level changes may occur temporarily, or continuously in a spatially limited area, but such reversals do not cause saltwater or other intrusion, and do not indicate a sustained, clearly identified, anthropogenic induced trend in flow direction likely to result in such intrusions." All groundwater abstractions will result in localised reversals in groundwater

[1] Review of the Impact of Changes in Groundwater Levels
Member States shall also identify those bodies of groundwater for which lower objectives are to be specified under Article 4 including as a result of consideration the effects of the status of the body on:
(i) surface water and associated terrestrial ecosystems;
(ii) water regulation, flood protection and land drainage; and
(iii) human development.

gradients close to the borehole. However, the criteria is focussed on wider area reversals. This can be important for local intrusion of seawater from abstractions within aquifers close to coastal areas. Additionally, abstractions close to historic mining areas or areas of significant contamination need to be considered to determine if they could result in a reversal of groundwater gradients. An understanding of baseline groundwater quality is vital in this regard – aquifers may be naturally saline at depth close to the coast even in the absence of any abstraction pressures.

2.3 Review of Groundwater Levels and Groundwater Body 'Available' Resource Assessment as Status Indicators

The WFD specifies that the 'groundwater level regime' is to be used for the classification of good groundwater status and for good quantitative status, but also implies that an assessment of the available groundwater resource is required. Member States need to translate this into criteria that support classification schemes as outlined within Annex 2 of the WFD.

This section critically considers the use of groundwater levels and groundwater resource estimations as indicators of WFD groundwater body quantitative status. A review of the appropriateness of groundwater levels and 'available' groundwater resource assessment is summarised in Table 1.

The conclusions from the comparison in Table 1 are that 'available' groundwater resource assessment can offer a practical approach towards determining consistent initial thresholds for groundwater abstraction and help to prioritise investigation. However, water level & quality monitoring and an understanding of the impacts of groundwater abstraction on dependent ecosystems should often play a more important role in quantitative status determination.

Groundwater levels within a groundwater body vary temporally and spatially according to natural and anthropogenic influences. Existing and future monitoring boreholes may be useful for the assessment of abstraction impacts and the effectiveness of measures to reduce these, thereby providing evidence to help determine whether the groundwater body is achieving its environmental objectives or not. Monitoring may need to be extended if a groundwater body is identified as being at risk of failing to achieve its objectives. This should be locally targeted on the abstraction sources and ecological receptors associated with the highest levels of risk.

However, a broader scale pressure based assessment will also be required based on the proportion of recharge to a groundwater body represented by current rates of abstraction from it. Simple thresholds of abstraction/recharge are proposed to determine status and to protect groundwater environmental requirements. Any such generic thresholds can be considered only in support of explicit assessment of the ecosystems which actually depend on the groundwater body. This abstraction/recharge, pressure based assessment is intended to deliver the '*available* groundwater body resource' required by the WFD (bearing in mind important caveats with respect to the word '*available*', as set out in Section 2.2).

Table 1 Assessment of Groundwater Levels and 'Available' Groundwater Resource Assessment as Groundwater Body Status Indicators

	For	Against
Groundwater Levels (i.e. field measurement)	Explicitly required by WFD. Easy to monitor – existing monitoring in place, new monitoring can be linked to new abstractions. Investigative monitoring can reveal abstraction signals to 'prove' a hydrological impact pathway between abstractions and receptors at a local scale. A monitored regional groundwater level network is essential to define groundwater flow lines and catchment divides in very permeable aquifers where groundwater catchments can differ significantly from surface water catchments. An understanding of groundwater level spatial distributions and temporal responses is a vital component of the conceptual understanding of very permeable aquifers.	Seasonal and wet-drought year fluctuations which are natural can make the interpretation of long-term anthropogenically related trends difficult. Single point water levels are rarely representative of the groundwater body as a whole. This is a problem in both poorly permeable and more productive aquifers. Water levels are influenced by the proximity to pressures, rivers and springs. Water levels can vary with depth depending on local piezometer connections within layered aquifers. Aquifer storage results in a time lag between the change in a pressure and a resultant change in monitored water level. Actions on pressures are only triggered when levels have fallen and resultant damage has occurred. Absence of abstraction related signals does not rule out a potential hydrological impact pathway.
'Available' Groundwater Resource Assessment (i.e. desk based groundwater body estimate considering recharge and allowable abstraction rate thresholds)	WFD requires that groundwater abstraction must not exceed recharge. Representative of a groundwater body as a whole. Consistent replicable desk based pressure assessment - full coverage of all groundwater bodies possible. Groundwater body sensitivity related thresholds can be set(e.g. based on specific yield). Can also be applied as receptor focused calculations (e.g. buffers around wetlands or adjacent to the coast) for simple screening and prioritisation purposes.	A groundwater body available resource assessment does not, on its own, account for local pressures on dependent terrestrial ecosystems and surface water body receptors. Application of more stringent thresholds such that groundwater abstraction must be much less than recharge is not an explicit WFD requirement – status depends on the consequent impacts on dependent surface water bodies or terrestrial ecosystems. Not a measurable/monitorable parameter.

A more detailed investigation of ecological receptors (i.e. groundwater dependent terrestrial ecosystems and surface water bodies) is required if monitoring or pressure based risk assessment indicates their ecological condition may be at risk in relation to groundwater abstraction. This is discussed further in Section 4.

3 REVIEW OF EXISTING GROUNDWATER RESOURCE ASSESSMENT SYSTEMS

3.1 Introduction

The existing methodologies used for groundwater resource assessment internationally and in England and Wales were reviewed. The aim was to assess how countries allocate groundwater resources to abstraction and environmental needs. This review was based on an internet search and through consultation with the project team.

The consultation findings are presented in the sections below.

3.2 International Groundwater Resource Allocation Systems

A summary of the outcomes from the international review are presented in Table 2.

Some key concepts are apparent in the systems used internationally for the assessment of the 'available' groundwater resource:

The proportion of the calculated groundwater 'resource' allocated to groundwater abstraction is dependent on:

- The certainty of the groundwater resource assessment (i.e. modelling vs. simple balance or proportion of effective rainfall or recharge);
- The 'type' of resource (e.g. distributed and reliable seasonal recharge; indirect river recharge; or occasional recharge events); and
- The historical demand for groundwater in comparison with the total recharge resource.

Countries where there is a greater recharge resource can 'afford' more environmental flows (and, as a consequence, more stringent environment standards) than those where demands are great and resources scarcer (e.g. Australia, Spain or Oman). In the driest areas with the highest demand, groundwater abstraction rates may be greater than recharge (i.e. the groundwater is mined).

Many countries use a regional or aquifer specific 'groundwater management plan' rather than applying a 'one system fits all' approach everywhere. This avoids the over-regulation of 'minor' aquifers and focuses management on aquifers with hydraulic properties which can allow over exploitation in areas where abstraction pressures are greatest. In many poorly permeable groundwater bodies the drawdown and flow impacts of groundwater abstraction are 'regulated' by the hydrogeological characteristics of the aquifers themselves.

Table 2 International Groundwater Resource Allocation Processes

Country and Region	Defined Groundwater Resource Units	Technique used to estimated Groundwater Resource	Proportion of Estimated Resource Available for Groundwater Abstraction	Comments	Source
New Zealand (Canterbury)	30 Groundwater Allocation Zones defined using flow lines.	1st Order Approach % of Average Annual Rainfall. Or 2nd Order Approach estimated land surface recharge including stream and irrigation recharge.	15% of Average Annual Rainfall. Or 50% of Average Annual Recharge	Higher uncertainty in the groundwater resource indicates lower proportion available for abstraction. Abstraction for Domestic and stock is exempt	http://www.ecan.govt.nz/Plans+and+Reports/Water/Groundwater/Groundwater-Allocation-Limits-Guidelines-for-Canterbury-u04-02.htm
Australia (Victoria)	Groundwater Management Areas (GMAs) established.	Permissible annual volume (PAV) set for each GMA. PAV is defined as the long-term available resource. This is estimated from water balance and modelling calculations and decided by consultation with an 'expert panel'.	70%. If groundwater exceeds 70% of the PAV then a Groundwater Source Protection Area (GSPA) is declared and a management plan is implemented.	An extensive state groundwater level monitoring network is in place and used to assess pressure on the resource. Abstraction for stock and domestic use is exempt.	http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/water-gw_gmas_management
US (Kentucky)	Water Supply Plans developed on a County Basis.	Resource plans account for all surface water demands including environmental requirements.	Proportion set specific to each county management plan.	Licences all groundwater abstractions > 10 000 gpd (~ 45 m^3/d)	http://www.water.ky.gov/gw/ http://www.uky.edu/KGS/water/library/webintro.html
South Africa (Building Block Method)*	Groundwater catchments	Estimation of groundwater recharge and determination of the recharge required to maintain groundwater levels	Individual to each groundwater catchment	National Water Act (Act No. 36 of 1998) requires an environmental 'reserve' to be set for each declared groundwater catchment.	http://www-dwaf.pwv.gov.za/Documents/Policies/WRPP/
Netherlands	Defined groundwater bodies for WFD. Used a GIS system REGIS which integrates all groundwater data (geology, hydrographs, water quality).	Numerical groundwater modelling.	States that the 'available' groundwater resource is the long term annual rate of recharge less the LTA flow required to meet the ecological objectives.	Extensive groundwater monitoring of levels and abstraction licensing system in place.	http://www.nitg.tno.nl/ned/appl/g_resources/groundwater/501.shtml
Denmark	Defined groundwater bodies for WFD. National Water Resources Model (NWRM) developed using MIKE-SHE	NWRM to define groundwater resource availability.	Linked closely to Low Flow objectives for dependent surface water bodies. Site and aquifer type groundwater surface-water interaction.	Extensive groundwater monitoring of levels and abstraction licensing system in place.	http://www.vandmodel.dk/artikler.htm and http://www.geus.dk/publications/geo-nyt-geus/dvk-gi97-2-uk.htm

Country and Region	Defined Groundwater Resource Units	Technique used to estimated Groundwater Resource	Proportion of Estimated Resource Available for Groundwater Abstraction	Comments	Source
Sweden	Defined groundwater bodies for WFD	Not determined.	Not determined	Permit required for groundwater extraction (domestic use exempt). Permit application through 'Environmental Court'	http://www.regeringen.se/sb/d/108/a/1348
Jersey	No groundwater bodies defined	Conceptual model of hydrogeology developed for the Island. This was used to estimate the groundwater resource availability.	Determined by that the limited connectivity and low transmissivity of the aquifers resulted in a low potential for groundwater abstraction to exceed the available resource.	No permit required for groundwater extraction	Scrutiny Review of the Draft Water Resources (Jersey) Law
Spain	Defined 442 groundwater bodies	Assessed the recharge to abstraction ratio for each groundwater body.	>100%. Currently 51 groundwater bodies have abstraction/recharge ratios greater than 1.0 and 18 have been declared as overexploited.	Historical demand for groundwater has resulted in over-exploitation of the groundwater resource. Groundwater management plans being developed for groundwater bodies	http://reports.eea.eu.int/92-9167-056-1/en/page007.html

Notes: *The South African Building Block Method provides a holistic approach to the assessment of hydrological regime requirements for rivers based on site-by-site workshop collaboration of specialists to achieve consensus. It has been primarily developed for the assessment of large water resource schemes, often involving the construction of reservoirs which can effectively control and substantially modify the full range and timing of river flows. As such, although it includes a module to consider the role of groundwater within the 'whole catchment context', the BBM is not primarily aimed at groundwater abstraction management and has not established thresholds or standards for this purpose.

3.3 England and Wales RAM Framework

The Resource Assessment and Management (RAM) framework is used by the Environment Agency in England and Wales within the Catchment Abstraction Management Strategy (CAMS) process (Environment Agency, 2002). The RAM framework aims to develop an understanding of the groundwater and surface water resource within the defined CAMS area.

The RAM Framework assumes that all groundwater abstractions must reduce groundwater outflows somewhere at sometime. Most commonly flow reductions will be assigned to river flows but reductions in discharge to the sea may also be locally important. As most groundwater abstractions cannot be effectively constrained with respect to 'hands off flow' (HOF) conditions, impacts generally continue throughout the lowest, most critical flow periods. Acceptable groundwater abstraction limits are thus often most critically set by the allowable reductions of low flows (e.g. QN95 – the flow exceeded for 95% of the time), as determined by the difference between natural and minimum river flow objective at CAMS river assessment points (often gauged catchments larger than 50 km^2).

RAM Framework river flow objectives are set according to the sensitivity of the river reach to abstraction which is based on a four component scoring system (macro-invertebrates, physical habitat, macrophytes and fish) and typically becomes less sensitive towards downstream, lowlands reaches. These river flow objectives are intended to define the flow requirements to support WFD 'Good Ecological Status' for rivers. They are currently being reviewed in the light of experience from five years of application and considering the findings of the SNIFFER project WFD48 which is intended to derive river and lake regulatory standards for hydrological regime. This review should ensure that they remain appropriate for resource assessment and abstraction licensing in England and Wales. At present, the proportion of natural QN95 allowable for abstractions (including groundwater abstractions) ranges from 5% for 'very highly sensitive' river reaches to 30% for 'very low sensitivity' reaches. However the 'resource availability status' derived for each river assessment point (AP) depends more directly on comparison of river flow objectives and scenario flows at QN70 where higher abstraction proportions are acceptable i.e. the RAM Framework allows for some derogation of the lowest 30% of river flow objectives before promoting investigation of resource recovery options.

Beyond the assessment of groundwater abstraction as a river flow pressure, the RAM framework also requires an independent groundwater resource assessment. This is based on five 'groundwater management unit' tests which determine the preliminary groundwater 'Resource Availability Status' and can be mapped onto some elements of WFD status classification. Groundwater management units are only delineated for aquifers with a significant resource potential i.e. 'major' or 'CAMS' aquifers and, where possible, are drawn as groundwater sub-catchments between CAMS river assessment points. These units are therefore usually smaller than WFD groundwater bodies which (in England ad Wales) extend to CAMS catchment boundaries within aquifer types distinguished by their resource development potential (i.e. principal, secondary, unproductive). However, groundwater management units are also typically larger than the river water body sub-catchments delineated for initial characterisation which include numerous smaller headwater catchments supporting little or no abstraction. The five groundwater management unit tests are outlined below:

Test 1: That the long term average annual recharge plus groundwater inflow is greater than the long term annual average abstraction.

Test 2: That the impacts of groundwater abstraction on summer groundwater outflows (to springs, surface water baseflow or groundwater outflow) are acceptable.

Test 3: That there is no monitored evidence of significant groundwater level or groundwater quality related impacts (e.g. declining water levels, salinity).

Test 4: That there is no evidence of significant historical impacts of groundwater abstraction.

Test 5: Optional - Other locally appropriate rules.

The results of Test 1 can be mapped directly onto the WFD requirement that abstraction should be less than recharge. Results from the more critical, lower flow period Test 2 have also been applied to develop more stringent 'available groundwater resource' thresholds for WFD initial characterisation, as described in Section 4.3.

The need to review associated groundwater salinity and level trends is picked up in Test 3. However, users must carry out this test based on local judgment in the light of experience and with an understanding the longer term history of groundwater abstraction variations, rather than by application of any mechanistic rule or trend analysis technique.

The inclusion of groundwater abstractions in the assessment of river flow impacts is also a sound principle in relation to WFD criteria for dependent river water bodies but the distribution of CAMS assessment point results cannot be readily mapped onto the smaller river or lake water body scale. RAM Framework river sensitivity based thresholds have been applied as part of the initial characterisation risk assessment for groundwater abstractions in England and Wales. This was based on the assumption that it would indicate the extent to which groundwater abstractions might potentially cause the hydrological regime to fail to support good ecological status (although the actual classification of status is likely to be based on biological monitoring and tools in England and Wales). More recently the Agency's EMCAR project has considered the implications of applying more stringent, 'closer to natural flow' thresholds in relation to the classification of High Ecological Status river water bodies. The WFD and CIS guidance states that the hydrological regime (and therefore groundwater abstraction impacts on it) must be explicitly assessed as meeting High Status criteria, alongside morphological, biological, and chemical criteria. This means that the existence of groundwater abstraction pressures may have a more direct bearing on the classification and regulation of High Status surface water bodies than of Good Status water bodies where the hydrological regime plays a supporting role. This issue may be significant in parts of Scotland and Ireland.

A key aim of the current review of the RAM Framework is to ensure that it becomes more fully aligned with WFD classification needs. This will require a simplified extension beyond the current focus on 'major' or 'principal' aquifer groundwater management units to include secondary aquifers, at a coarser, groundwater body scale. It will also require more explicit consideration of lakes and of wetlands (i.e. groundwater dependent terrestrial ecosystems), together with a review of WFD river water body scale abstraction screening. Such consideration is explicitly important for High Ecological Status classification, but is also required in support of Good Ecological Status, with consequential implications for groundwater body status classification in both cases.

4 DISCUSSION OF THE CRITERIA FOR GOOD GROUNDWATER QUANTITATIVE STATUS

4.1 Introduction

The WFD links all objectives for both groundwater and surface water back to ecological status. Groundwater is important to surface ecosystems through several routes:

- The provision of groundwater baseflow to surface water lakes, rivers and estuaries;
- The influence of groundwater level regimes on surface water level and depth regimes in 'offline' groundwater dependent lakes; and
- The support provided to groundwater dependent terrestrial ecosystems such as raised bogs, marshlands and areas of deep rooted vegetation.

In addition the WFD requires that groundwater body abstraction should not exceed recharge and should not result in the intrusion of groundwater of poorer water quality – criteria relating to the groundwater body itself, as a sustainable abstraction resource.

The reality of determining a classification for a groundwater body is that it is necessary to map all available evidence in relation to the elements listed above.

This section considers the different elements contributing to the determination of groundwater quantitative status. These are the groundwater body resource assessment (Section 4.3); groundwater levels (Section 4.4); groundwater flow direction and intrusion (Section 4.5); dependent surface water bodies (Section 4.6) and terrestrial ecosystems (Section 4.7). The integration of these elements is then considered in Section 4.8.

4.2 Review and Consultation

The findings for Section 4 were developed through a review of the following documents and some consultation with their authors.

- A review of UKTAG guidance (characterisation, classification & monitoring) principally:
  - Abstraction & Recharge Pressures on Groundwater (Paper 7h), together with Paper 7b which sets out net abstraction thresholds for screening surface water body flow risks (both developed for the purpose of WFD initial characterisation);
  - Outline of Groundwater Classification for the purposes of the Water Framework Directive (Paper 11b); and
  - Guidance on Monitoring Groundwater (Paper 12a).
- Input from the SNIFFER project (WFD 48) on defining the Environmental Standards for Surface Water Resources. The outcomes from this project are currently in three draft reports which present an international review of environmental standards and methods (SNIFFER WFD48, 2005a), a review of

lake and river typology (SNIFFER WFD48, 2005b), and the development of regulatory standards (SNIFFER WFD48, 2005c). Drafts of further modifications to the standards proposed for rivers have also been considered.

4.3 Groundwater Body Resource Assessment

The WFD requires the determination of the 'available' groundwater resource for a groundwater body as outlined in Section 2.2. It is proposed in UKTAG Paper 11b that this should involve a groundwater body scale comparison of current abstraction against long term average recharge which also takes into account environmental groundwater flow requirements. This is illustrated in Figure 1 (from UKTAG Paper 11b).

The assessment of the 'available' groundwater resource requires the determination of ecological requirements for both surface water bodies and GWDTEs. For most groundwater bodies the accurate determination of this requirement will not be known. As a result precautionary thresholds for the available resource were set during initial characterisation as a proxy to protect ecological requirements of receptors in a general way.

4.3.1 WFD Initial Characterisation Approach

England and Wales

For initial characterisation risk assessment it was proposed (in UKTAG Paper 7h) that thresholds be imposed on the amount of recharge available for abstraction. These thresholds were taken to indicate the proportion of long term average recharge which can be abstracted without risking ecologically detrimental flow regime impacts in dependent receptors.

Recharge is seasonally limited whereas many groundwater abstractions continue to pump throughout the year, having a proportionally larger impact on river flows and wetlands during summer. The risk assessment thresholds were therefore set to protect groundwater baseflow support for these dependent receptors during summer, low flow periods. These thresholds were much lower than a simple 100% value which would simply highlight groundwater bodies where abstraction exceeds recharge.

The percentage recharge thresholds applied to groundwater bodies were intended to be independent of the ecological sensitivity of river reaches draining them. It was recognised (in Paper 7h) that this might not protect the most sensitive headwater reaches (where flows would naturally be lowest) which is why a separate assessment screening river water body flows according to groundwater abstraction pressures was also recommended (and carried out in England and Wales based on RAM Framework thresholds of abstraction impacts relative to the QN70 flow statistic - the naturalised flow exceeded for 70% of the time).

RAM Framework results from CAMS groundwater management units in England and Wales were used to develop the groundwater abstraction to recharge ratio thresholds recommended in Paper 7h for groundwater bodies. Groundwater abstraction was plotted as a percentage of long term average (LTA) annual recharge (GWABS/RECH) against the resulting Resource Availability Status for 128 GWMUs within 27 CAMS areas, as completed and collated at the time (Figure 2). This plot was categorised according to the reported groundwater management unit values of aquifer transmissivity, specific yield and summer/average flow ratio in order to investigate options for differentiating the ‘sensitivity’ of the resource availability status to the groundwater abstraction/recharge ratio. Theoretical estimates of the summer/average groundwater outflow ratio can be derived using the ‘aquifer response function’ for any groundwater body based on estimates of its transmissivity, specific yield and size (or drainage path length). Further details of this, as developed for groundwater reliable yield estimation, can be found within the Agency’s RAM Framework User Manual (Environment Agency 2002).

The Figure 2 initial characterisation plots suggested that none of the assessed units with a licensed GWABS/RECH ratio of less than 10% were considered Agency staff to be ‘Overlicensed’. Additionally, if the specific yield of the groundwater body is considered as the simplest indicator of ‘sensitivity’ to abstraction, then a higher threshold of 20% could be applied to groundwater bodies with a specific yield of greater than 5%. The plots indicate that the summer to average groundwater outflow ratio could also have been applied to identify thresholds.

However, to keep the assessment simple, the specific yield based thresholds were used to inform the ‘Exposure Pressure Thresholds’ stated in UKTAG Paper 7h, as presented in Table 3.

Table 3 Assessment of Groundwater Abstraction Exposure Pressures for Initial Characterisation (from UKTAG Paper 7h)

	Exposure Pressure based on average Specific Yield (Sy) of the Groundwater Body	
GWABS/RECH in 2015	**Low Storage (Sy < 5%)**	**High Storage (Sy > 5%)**
(as a % for the groundwater body)	**(or ‘fissured/fractured’ flow mechanism)**	**(or ‘intergranular’ flow mechanism)**
> 40%[1]	High	High
30 to 40%	High	High
20 to 30%	High	Moderate
10 to 20%	Moderate	Low
2 to 10%	Low	Low
<2%	No	No

Notes:

[1] i.e. GWABS is greater than 40% of the LTA Recharge.

Table 3 was used in association with evidence of declining groundwater levels or saline intrusion to assess the risk to groundwater body quantitative status in relation to the ‘available’ groundwater resource criterion. This test was complemented by others considering groundwater abstraction risks to receptors including river water bodies, offline lakes, and Habitats Directive protected ecosystems (including wetlands).

Figure 1 Illustration of the steps involved in estimating the 'available' groundwater resource for a body of groundwater (UKTAG Paper 11b)

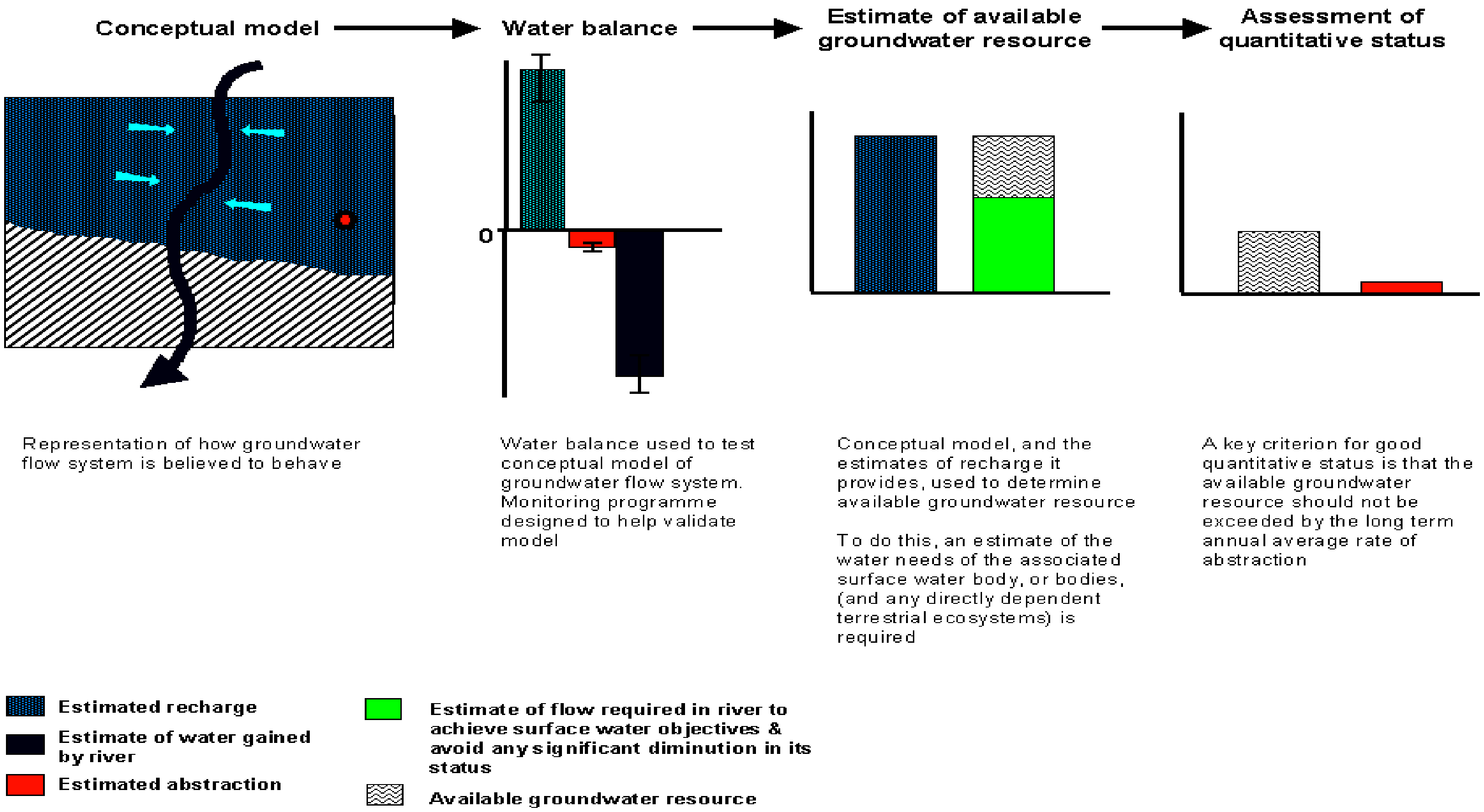
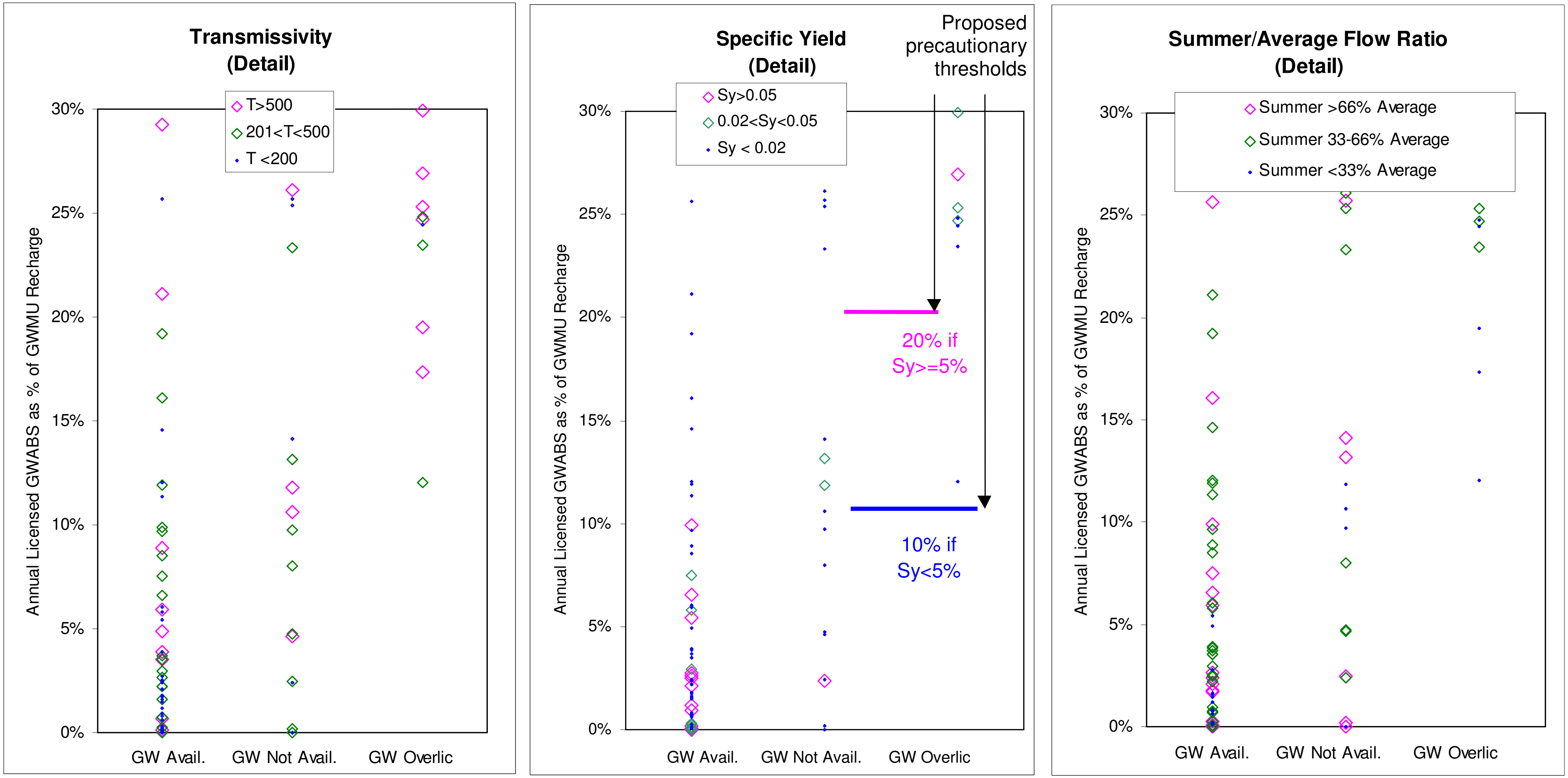


Figure 2 Determination of the Groundwater Abstraction/Recharge Thresholds for Initial Characterisation



Scotland and Northern Ireland

The same groundwater abstraction thresholds of 10% recharge for low storage aquifers and 20% recharge for high storage aquifers were adopted for the initial characterisation assessment in Scotland and Northern Ireland. However, due to the uncertainty associated with rates of groundwater abstraction in these countries (in the absence of a groundwater licensing regime) the estimates of groundwater abstraction in each groundwater body were doubled.

Ireland

The UKTAG 7h thresholds were also used in Ireland with the exception that the thresholds were tightened to 5% for groundwater bodies which contained catchments to low lying fen groundwater dependent terrestrial ecosystems.

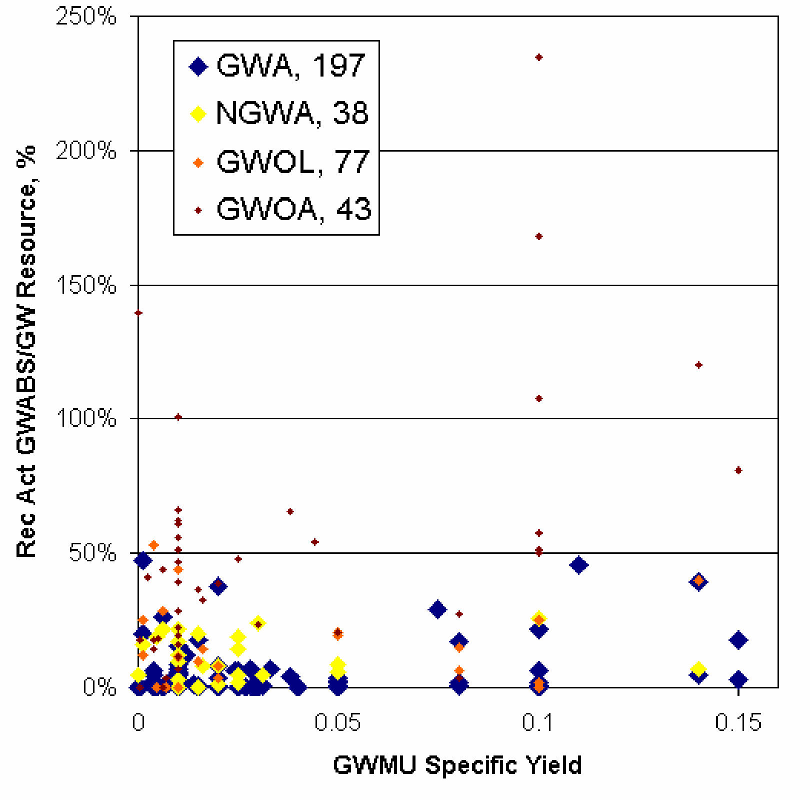
4.3.2 Appropriateness of the Groundwater Resource Assessment Approach and Thresholds for Classification

One of the WFD criteria for Good Groundwater Quantitative Status is that average groundwater abstraction from a groundwater body should not exceed the average recharge or groundwater inflow to it. This represents an abstraction threshold of 100% recharge which is only likely to be exceeded in very few heavily exploited major aquifer groundwater bodies. Initial characterisation groundwater body GWABS/RECH thresholds for risk assessment across the UK and Ireland have been much more precautionary, as described in Section 4.3.1, as a proxy for general protection of dependent ecosystems, in addition to the river, lake and protected area focussed assessments also carried out.

Moving forward from initial characterisation, through further characterisation towards classification itself, it is not appropriate to retain these stringent thresholds as a 'stand-alone' criterion for good quantitative status.

The ongoing review of the RAM Framework for England and Wales has provided an expanded data-set of CAMS groundwater management units with information on specific yield, GWABS/RECH ratios, and preliminary groundwater resource availability status results to facilitate a critical review of the initial characterisation thresholds. Figure 3 shows data from 331 CAMS groundwater management units. There is a large scatter of ratios for any given specific yield within each of the final groundwater resource availability status categories which emphasises how precautionary the initial characterisation thresholds (10% for Sy less than 0.05, 20% for Sy greater than 0.05) are and suggests they provide a very crude proxy for actually monitored receptor impacts. A less precautionary interpretation to draw from this figure would be that virtually all groundwater management units where groundwater abstraction exceeds 50% of recharge are deemed to be 'over-abstracted', and that a significant number of units of lower specific yield (i.e. less than 0.05) are deemed to be 'over-abstracted' if abstraction exceeds 20% of recharge. In the absence of any other information on the condition of dependent ecosystems, groundwater level or salinity issues, these less precautionary groundwater body available resource thresholds (20% recharge for Sy less than 0.05, 50% recharge for Sy greater than 0.05) might be used in support of classification.

Figure 3 Review of Groundwater Resource Availability Status for 331 CAMS Groundwater Management Units



Notes: **CAMS GW Management Unit Resource Availability Status**
GWA: GW Available
NGWA: No GW Available
GWOL: GW Overlicensed
GWOA: GW Overabstracted (and overlicensed)

331 CAMS Groundwater Management Units processed.

Regardless of the thresholds adopted for classification, there is value in estimating groundwater abstraction/recharge ratios as part of the pressure screening of all groundwater bodies in order to prioritise the need for further investigations. The requirement for the installation of new groundwater level monitoring boreholes could, for example, be triggered if a GWABS/RECH threshold is exceeded, either for the groundwater body as a whole, or for buffers drawn around receptors.

However, the appropriateness of a GWABS/RECH assessment for groundwater bodies in Scotland, Northern Ireland and Ireland has also been considered in relation to the aquifer types typically present. This review was based on the groundwater flow types used to delineate groundwater bodies for initial characterisation in these countries and is presented in Table 4.

In low permeability rocks groundwater abstraction is limited by the ability of the aquifer to yield the water. Additionally, the recharge to the groundwater body is limited by the permeability and porosity of the rock. Within such aquifers there is abstraction in localised areas only and exploitation of groundwater resource on a larger scale is not technically or economically feasible.

In karstic aquifers, groundwater flow is dominantly through discrete fissures which, in some carboniferous limestones could be described as ‘underground rivers’ or ‘cave systems’. In such aquifers the comparison of groundwater abstraction rates aggregated from boreholes across a groundwater body with an a really distributed average recharge estimate of resource may have only limited value. The groundwater resource available for abstraction, and the impacts of abstraction are thus extremely variable and difficult to predict for new sources.

Table 4 Appropriateness of Groundwater Body Abstraction/Recharge Assessment and Proposed Thresholds for Scotland, Northern Ireland and Ireland

Groundwater Body Flow Type	Example Aquifer	Groundwater Body Scale Linked Flow	GWABS/RECH Assessment Applicable	Proposed GWABS/RECH Thresholds for Good Status: Precautionary/ More confident/ Mandatory
Low permeability palaeozoic bedrock	Pre-Cambrian and Cambrian ‘basement’ bedrock	Unlikely	No[1]	-
Productive fractured bedrock aquifers	Caithness Flagstones and some Carboniferous Limestones	Some	Yes	10% / 20% / 100%
Karstic flow aquifers	Carboniferous Limestones and some mining areas	Some – high connectivity in specific zones	Possibly[1]	-
Fracture flow aquifers with some matrix flow	Devonian and Permian Sandstones	Yes	Yes	10% / 20% / 100%
Fracture and matrix flow aquifers	Chalk	Yes	Yes	10% / 20% / 100%
Matrix flow aquifers with some fracture flow	Triassic Sandstones	Yes	Yes	20% / 50% / 100%
Intergranular flow aquifers	Sand and gravel deposits	Yes	Yes	20% / 50% / 100%

[1] Although a groundwater body scale resource assessment does not indicate ‘resource availability’ in these groundwater bodies a GWABS/RECH assessment can be applied for consistency though explicit thresholds are not recommended. The assessment could be used to prioritise and justify further investigation and monitoring.

In summary, the GWABS/RECH assessment can be undertaken for all groundwater bodies although in low permeability and karstic groundwater bodies it is important that this assessment is not considered to indicate the economically available groundwater resource within the aquifer.

4.4 Groundwater Level Monitoring Review

A review of the groundwater level monitoring data must be completed for each groundwater body. Given the issues presented in Table 1 it is proposed that this review of monitoring is completed at a 'de minimus' level with respect to the groundwater body as a whole. WFD requirements to install new monitoring wells in relation to the groundwater body 'available' resource could be linked to GWABS/RECH trigger thresholds i.e. any groundwater body exceeding the precautionary thresholds listed in Table 4 needs at least one groundwater level monitoring point (spring or borehole) to be reviewed for classification.

It is much more likely that further characterisation may require the installation of new observation boreholes targeted to consider localised groundwater abstraction impacts where these are perceived to be a possible cause of impacted dependent ecosystems. However, the monitoring and analysis of water levels in such boreholes will be investigatory – requiring relatively intensive periods of monitoring and testing in relation to abstraction signal or pumping tests, rather than repeated monthly dipping over a long term period.

4.5 Alteration to Groundwater Flow Direction Resulting in Intrusion of Poor Quality Water

Under the WFD Annex V 2.1.2 Definition of Good Quantitative Status "groundwater flow directions resulting from level changes do not cause saltwater or other intrusion, and do not indicate a sustained and clearly identified anthropogenically induced trend in flow direction likely to result in such intrusions."

Additionally, under the definition of good groundwater chemical status (Annex V 2.3.2) "changes in conductivity are not indicative of saline or other intrusion into the groundwater body."

Therefore, in areas where abstraction related risks to groundwater quality are perceived to be significant, there is a requirement to monitor groundwater levels, flow directions and electrical conductivity to demonstrate that saline or other poorer quality intrusions into a groundwater body are not occurring.

This implies that abstraction pressure related screening (e.g. possibly related to GWABS/RECH percentages within a coastal buffer strip) may be helpful in initially locating risk areas, alongside a review of available groundwater quality monitoring data. The WFD does not contain an indication of the threshold at which a change in conductivity indicates saline intrusion. The EC Drinking Water Directive (98/83/EC) sets a standard for electrical conductivity of 2 500 µS/cm at 20°C or 250 mg/l for chloride. More precautionary thresholds should be used to trigger investigation of saline intrusion issues through further characterisation. Such thresholds could be set at the median value monitored in all boreholes across each country or, in the absence of sufficiently representative data, could be set at around 25% of drinking water standards (i.e. ~ 600 µS/cm or 60 mg/l chloride).

Further characterisation investigations should review the evidence for deviation from a baseline concentration in electrical conductivity or other parameters of concern. This would require repeated measurement over a period long enough to prove the influence of abstraction/intrusion (i.e. a rising trend). An understanding of the natural variations in baseline hydrochemistry spatially across the groundwater body and seasonally with time is also important for such an assessment, as is a knowledge of the abstraction history. The time lag taken for abstraction pressures to result in monitored water quality impacts can also be expected to depend on aquifer flow and storage parameters, as well as on the location of monitoring points.

For more confident poor status classification a greater reliance on the monitored exceedence of a threshold closer to the drinking water standard, together with repeated monitoring to prove a continued upward trend is recommended. A threshold of 75% of drinking water standards (i.e. ~ 1 800 µS/cm or 180 mg/l chloride) is suggested in this regard.

Groundwater quality issues will probably be initially detected in an abstraction borehole, or possibly in a monitoring borehole between the abstraction and the source of the intrusion. If a trend is identified upward from the baseline or the precautionary threshold exceeded an assessment of the baseline concentrations in the groundwater body should be completed. It would also be necessary to know that the electrical conductivity of the groundwater has increased from the baseline or exceeded the threshold as a result of groundwater abstraction, and to understand any continuing trends or regulatory measures already in place to manage the issue. Thereafter more locally appropriate water quality thresholds and monitoring compliance points could be established to feed into ongoing management on a site-by site basis.

Beyond the need to identify and control abstraction related water quality deterioration on a local site-by-site basis, this element of anthropogenically induced impact must also feed into the classification of the groundwater body with respect to both quantitative and chemical status. In this regard the scale of the impacted areas may need to be considered. All borehole abstractions are likely to induce local drawdown and changes in flow direction but this should only influence the status of the groundwater body if these damage dependent surface ecosystems or result in poor quality intrusion. If groundwater quality impacts are limited to the area in the immediate vicinity of one abstraction well, it is questionable whether this alone should lead to a poor status classification for the much larger groundwater body within which it is located. However, higher rates of abstraction from several boreholes inducing wider scale drawdown and ingress of poorer quality water into a larger part of the groundwater body should clearly result in a poor status classification.

The possibility of re-drawing groundwater body boundaries to isolate such areas and manage them separately should not be ignored but can only be considered after all of the other classification criteria have been considered (i.e. 'available' groundwater resource, groundwater levels, and dependent surface water and terrestrial ecosystems). This is discussed further in Section 5.2.

4.6 Impacts on the Status of Dependent Surface Water Bodies

4.6.1 Introduction

Surface water flow regimes are complex and are characterised by the timing, magnitude, duration and frequency of flows, and their translation into water depths, velocities, wetted perimeter etc.; all of which are important for different aspects of surface water ecosystems. To produce operational standards, there is a need to identify a small number of parameters that capture its most significant characteristics. Most standards focus only on flow, or flow exceedence percentile statistics, which only partially capture the breadth of characteristics of the flow regime.

The WFD 48 SNIFFER R&D project (2005a, b and c) has reviewed previous studies, hydroecology texts and international practice and elicited understanding of the links between hydromorphology and ecology through expert workshops to determine net abstraction limits required to support the achievement of Good Ecological Status (GES) in river and lake water bodies. These 'guaranteed to support GES' limits do not allow for any abstraction impacts on low flows and are therefore considered to be very precautionary as they would require complete cessation of abstraction (and public water supply) during droughts. In the latest version of the report (still under review) a set of more practical (less stringent) 'regulatory standards' have been proposed in relation to High, Good, Moderate and Poor status classifications for application at an overview or screening level, without the need to consider site specific measurements. They are intended for risk assessment as part of a surface water abstraction regulatory framework but may not be directly applicable for the assessment of larger individual licence applications (where more site investigation is essential). The WFD48 final report (under review) suggests that these standards can be used as part of the *determination* of ecological status (High, Good, Moderate or Poor). However, WFD CIS guidance suggests that hydro-morphological quality elements (of which such abstraction standards are part) should be an explicit consideration in the determination of High Ecological Status only – they must *support* Good Ecological Status which should itself be determined by biological quality elements where possible.

The WFD 48 project was not intended to consider the freshwater inflow requirements to transitional water bodies, and did not explicitly incorporate the development of status criteria or regulatory standards for groundwater bodies (the subject of this WFD53 project report). However, as summarised in Section 3.3, groundwater abstractions usually impact flows or levels in rivers or lakes somewhere so that standards set for these surface water bodies are also implicitly relevant for the groundwater bodies on which they partially depend.

This section provides a summary of WFD guidance on the role of hydrological regime assessment within the ecological status classification process (Section 4.6.2) and suggests possible criteria for groundwater abstractions in relation to high status rivers or lakes. It then provides an overview of the standards suggested to support good status by the WFD48 project and reviews their applicability for groundwater abstractions (Section 4.6.3).

4.6.2 Hydrological Regime Assessment in Ecological Status Classification and Possible Criteria for High Status

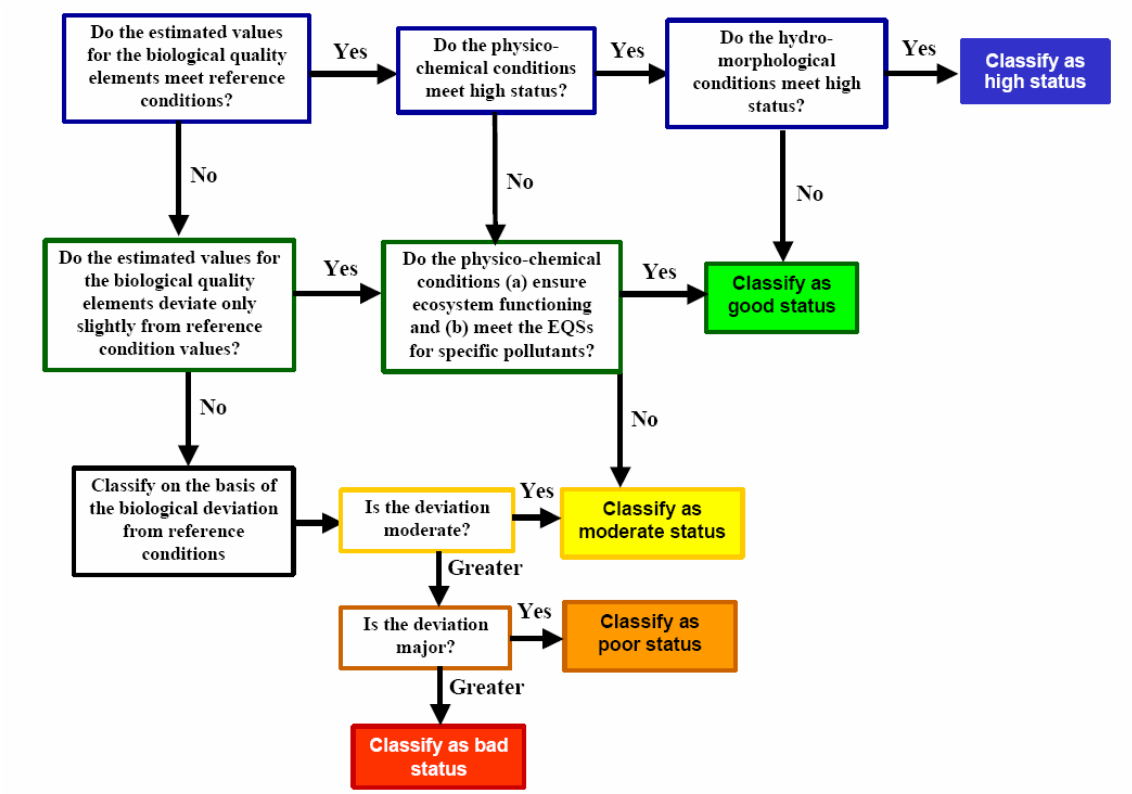
The classification of Ecological Status for surface water bodies under the WFD is based on the assessment of three quality elements. These three elements are biological quality, physico-chemical quality and hydromorphological quality. Of these three elements, biological quality provides the ultimate determination of Ecological Status, with the physico-chemical and hydromorphological quality elements supporting the biological element. The relationship between the three elements in the classification of Ecological Status is shown in Figure 4, taken from WFD CIS guidance.

It can be seen that the hydromorphological quality element (of which the hydrological regime is part) only requires explicit consideration in Ecological Status classification at High Status. Below this level, the hydromorphological quality element plays a supporting role, being required to have conditions consistent with the achievement of the values specified for the biological quality elements.

The WFD definition of hydrological regime required for High Status classification for rivers is that:

"The quantity and dynamics of flow, and the resultant connection to groundwaters, reflect totally, or nearly totally, undisturbed conditions."

Figure 4 The Role of the Three Quality Elements in the Classification of Ecological Status



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The Environment Agency in England and Wales is currently investigating the use of relatively simple, abiotic, pressure-based criteria to identify river and lake water bodies which are 'candidate High Status' with respect to this 'not far from natural' definition of hydrological regime (Entec, 2005a). For simple abstraction or discharge pressures, it is proposed to screen out any surface water body where the maximum of total abstraction or total discharge within the upstream catchment exceeds 5% of the long term QN95 at the outflow point (using a desk based GIS or Lowflows2000 tool).

The definition of good quantitative status for groundwater bodies requires that abstractions should not result in the diminution of dependent surface water body status. According to the proposed high ecological status screening criteria this suggests that if total groundwater abstraction *by itself* exceeds the 5% of low flow, QN95 threshold at the outflow point of a river or lake *which would otherwise meet high status standards* (for biological, physico-chemical and morphological elements), then this should result in a poor quantitative status classification for the groundwater body within which it is located.

It is important to note that this low flow screening threshold differs from any proposed for screening in relation to good ecological status in that it considers the maximum, rather than the net influence of abstractions and discharges. In this respect alone it can be considered to be more precautionary than tests relating to good ecological status. The 5% threshold is also itself still under review.

The SNIFFER WFD 48 project (2005c) has proposed an alternative set of *net* abstraction thresholds (i.e. abstractions – discharges) for High Ecological Status rivers. which vary depending on the flow in the river. The proposed *low* flow standards are most relevant for groundwater abstractions. These range from 5 to 15% of a seasonally determined QN95, depending on the typology (and related abstraction sensitivity) of the river water body. These WFD48 standards are more complex and, in some cases, less restrictive than the "5% of long term QN95 maximum impact" proposed in Entec (2005a) because:

- They are based on net abstraction rather than maximum impacts (thereby not screening out water bodies with net discharge impacts, or with 'critically depleted reaches' in between balancing abstractions and discharges; and
- They allow for net abstraction up to 15% of QN95, depending on typology.

For these reasons it is suggested that the"5% of long term QN95 maximum impact" proposed in Entec (2005a) may be a more appropriate criteria for the determination of High Ecological Status in river water bodies. Such a standard could also be relatively simply assessed in relation to groundwater abstraction pressures.

The proposed WFD48 High Ecological Status standards have been derived by simple extrapolation from those suggested for Good Ecological Status (i.e. they are typically 5% lower than the values presented in Table 5). The report also suggests that there may be some equivalence between these and the Habitats Directive protected river flow objectives which are currently set according to a limit of around 10% of the natural flow anywhere on the protected reach on any day. However, whilst it is clear that the WFD must seek to incorporate the conservation objectives of protected areas, it does not seem appropriate to equate these with the definition of high status water bodies. Many of the Natura 2000 designated SAC rivers have hydrological regimes which are clearly much further from natural conditions than non-designated headwater river reaches which are subject to little or no anthropogenic pressures.

4.6.3 Surface Water Standards to Support Good Ecological Status Classification

As this project is concerned with determining the criteria for good groundwater *quantitative* status the surface water body parameters of river flow and lake level are considered to be critical indicators. However, it is recognised that groundwater discharge (as summarised by the baseflow index) also determines the degree of mixing of surface water and groundwater within surface water systems. This degree of mixing will influence additional ecologically important parameters such as oxygen concentrations, temperature and water chemistry.

Hydrological regime factors work alongside habitat morphology and chemical parameters to support and influence the surface water biota. However, (as set out in Section 4.6.2) the WFD states that, as far as possible, biological quality monitoring should directly determine whether a surface water body is above or below the Good/Moderate Ecological Status boundary. In England and Wales the Environment Agency is planning to maximise the use of data from the long standing biological monitoring network to cover the river water bodies in this respect. Work is in progress to develop classification tools for this purpose (e.g. the RIVPACS artificial intelligence (AI) project, LEAFPACS etc.).

In Scotland and Ireland, where data are scarcer, classification tools will have to be more high level and desk-based and hydrological regime screening may play a more prominent role in the classification of good ecological status. The WFD 48 project has therefore sought to identify improved prediction of expected ecologies and associated environmental standards based on parameters which can be defined from meso-scale catchment characteristics.

WFD 48 has recommended a macrophytes based typology system for river water bodies. This is similar to that incorporated within the RAM Framework for macrophytes but the other scoring components of abstraction sensitivity used in the RAM Environmental Weighting System (i.e. physical, macro-invertebrates and fish scores) are not adopted in the WFD 48 typology.

Separate standards for rivers have been developed through expert workshops for macrophytes, macro-invertebrates and fish in relation to both good ecological status and good ecological potential criteria (the latter being appropriate for heavily modified or artificial water bodies). WFD 48 has also distinguished between the methods and standards appropriate in relation to reservoir influences (where the whole flow regime, including peak, medium range and low flows may be impacted and require *active management* to 're-build' an appropriate flow hydrograph), and those appropriate for simpler run-of-river or groundwater abstraction impacts (i.e. *restrictive management* where low flows are often the main focus).

For all river typologies the expert-derived standards for restrictive management require that when flows would naturally fall below a 'Hands Off Flow' (HOF) threshold, all abstraction impacts should cease. The HOF specified is seasonal i.e. QN95 for flows March to May, and QN97 for flows from June to February. In other words, for flows at or below these HOF levels abstraction must be 0% of natural flows.

Unless some allowance is made for unconstrained flow impacts (i.e. below QN100), any abstraction without an effective HOF condition (i.e. virtually all groundwater abstractions) would be screened out as unacceptable, despite the need to continue supplying water through droughts. This is not considered to be a realistic criterion for assessment of the hydrological regime necessary to *support* good ecological status surface water bodies, or for the regulation of groundwater abstractions.

As the expert-derived management criteria would thus effectively prohibit the operation of any groundwater abstractions or surface water abstractions intended to maintain public supply through low flow periods, the final WFD48 report proposes less restrictive (more practical) regulatory standards, condensed into a single table (Table 5).

Table 5 quotes the proposed allowable net abstraction as a percentage of the natural flow on any day. It assumes that QN95 is a critical flow below which more stringent standards are required and QN95 varies with the season. In addition, more stringent standards apply for the period March to June (covering macrophyte reproduction and cyprinid spawning) for generic types A1 to D2. For salmonid spawning and nursery areas the critical period is October to April.

A detailed comparison of these revised standards with initial characterisation and RAM Framework thresholds (as part of work to support the Environment Agency's development of WFD hydrological regime methods and to review the RAM Framework) indicates that for many river types they are *less* restrictive than those used in the RAM Framework. Further review and consultation with hydro-ecological experts may be required but, subject to final agreement, they could be applied to screen river water bodies for consumptive groundwater abstraction pressures in isolation (to indicate the extent to which groundwater body pressures may potentially impact surface water flows), in addition to their primarily intended use for screening net abstraction pressures (i.e. total surface plus groundwater abstraction minus total discharges). In this way GIS maps can be prepared to highlight river water bodies where net abstraction pressures exceed the recommended thresholds AND groundwater abstraction is responsible for a significant proportion of this pressure. Such maps should then be reviewed based on the conceptual understanding of the groundwater body and groundwater – surface water body interactions in order to determine whether the status of the groundwater body should be affected.

Table 5 Proposed WFD48 Hydrological Regime Standards to Support Good Ecological Status (as % allowable net abstraction of natural flow)

Type	More than QN95		Less than QN95	
	March – June	**July – Feb.**	**March - June**	**July - Feb**
A1	25	30	15	20
A2	15	20	10	15
B1, B2, D1	20	25	15	20
C2, D2	15	20	10	15
Salmonid spawning and nursery areas (not Chalk rivers)	October – April 15	May - September 20	October - April 10	May - September 15

The WFD 48 project has also reported on the regulatory standards for lakes, although no recent revisions comparable with Table 5 have been seen. It is assumed that the later chapters of SNIFFER WFD48 (2005c) which integrate the standards for rivers and 'online' natural lakes (i.e. those with a river inflow or outflow) will also be re-visited in the light of these revisions. If the GIS based assessment point network for river and online lake water bodies can be integrated, this would simplify the application of the integrated flow related thresholds with regards to upstream groundwater abstraction impacts.

However, some lakes may be considered to be 'offline' (i.e. lacking a surface water outflow) and may have level regimes which are at least partly dependent on surrounding groundwater levels. Such lake water bodies (e.g. some turloughs in Ireland) need to be identified and the drawdown pressures and impacts of any groundwater abstractions on lake levels characterised as a precursor to groundwater body status classification. If lake level impacts related to groundwater abstractions are considered sufficient in themselves to cause the lake ecological status to be less than good, then the groundwater body supporting the lake should be reported as being at poor quantitative status.

4.7 'Significant Damage' to Groundwater Dependent Terrestrial Ecosystems

The ecologically important parameters for Groundwater Dependent Terrestrial Ecosystems (GWDTEs) in relation to groundwater abstraction pressures include shallow groundwater levels, groundwater quality and rates of groundwater flow required to meet evapotranspirative demand and support groundwater flows and levels. It is intended that these parameters should be more comprehensively summarised in a related project on significant damage. This project will focus on both the ecological and hydrogeological identification and assessment of GWDTEs across the UK. The links between groundwater abstraction impacts on groundwater levels and flows, diffuse and point pollution pressures, drainage, wetland management practices and consequent ecological effects will all need to be explored.

The project should also aim to improve the understanding of groundwater body related "significant damage" to ecology, with recommendations relating to further characterisation, classification and monitoring. It will build on experience from Habitats Directive investigations, particularly in England and Wales, with knowledge from relevant work in Scotland and Ireland also included.

A report on the monitoring requirements for GWDTEs (Entec, 2005b) found that initial lists of GWDTEs produced by English Nature (EN) and the Countryside Council for Wales (CCW) included sites which hydrogeologists do not consider 'groundwater dependent' and excluded other sites which are groundwater dependent. This highlighted the need for both hydrogeologists and ecologists to work together to determine the ecologically important parameters for groundwater dependency. The work and subsequent discussions have highlighted several issues:

The list of GWDTEs to be assessed is still uncertain because:

- An agreed 'level of designated protection' (e.g. all SACs and SPAs, plus SSSIs) needs to be established in discussion with the conservation Agencies i.e. it will not be possible to assess every groundwater dependent 'puddle'. However, this may effectively mean that the GWDTEs are a sub-set of the 'protected areas' being assessed in related to their own designated objectives. The relationship between these objectives and the definition of the WFD term 'significant damage' must therefore be clearly established;

- The determination of ecological impact on sites is still being debated in practical terms and therefore the number of sites that may be affected cannot be exactly determined;
- There are conflicts between groundwater dependence determined by the vegetational screening compared to that determined according to simple hydrogeological screening;
- Within some fen sites the existing drainage (which could potentially be identified as 'groundwater abstraction') has created the GWD **Terrestrial** Ecosystem (the ecosystem would otherwise be aquatic!) and in these systems drainage should not be considered a pressure. In Ireland also it has been considered that local drainage is not a groundwater abstraction pressure and in many areas intersects perched groundwater but does not intersect the deeper groundwater table. However, deeper arterial drainage could be considered a groundwater body related pressure to some GWDTEs (e.g. turloughs and fens) and therefore should be assessed as such (D.Daly, pers. comm.).

The report made a number of recommendations:

- That both vegetation information and hydrogeology should be used to determine whether a site is groundwater dependent and that the GWDTEs should be identified against a backdrop of the WFD surface water bodies which will be assigned an ecological status (so as not to omit groundwater dependent aquatic ecosystems which have not been delineated as surface water bodies);
- That the environmental and conservation agencies need to agree to the groundwater dependent site listing or methods used to determine sites that are potentially GWDTEs as the methods trialled have a number of flaws;
- That in terms of monitoring, all sites need to have some form of ecological monitoring undertaken regularly, even those that do not currently show ecological impacts, to determine whether a site is improving from a damaged state or is currently deteriorating.

The drafting of a UKTAG joint Wetlands and Groundwater Task Teams paper providing guidance on GWDTE identification, monitoring, and the definition/assessment of significant damage is understood to be under development. This should be referred to for a more up to date view of the issues raised above.

4.8 Integration of Assessment Elements

The criteria to achieve good quantitative status for a groundwater body can be summarised in the following statements, developed from UKTAG paper 11b in Table 6:

1. That the total abstraction from the groundwater body should not exceed the recharge to the groundwater body, after an allowance for dependent ecosystems if no assessment of these has been possible. This test should incorporate a review of available groundwater level monitoring data where appropriate.

2. That groundwater abstraction should not cause a reversal in groundwater flow direction which results in the significant intrusion of saline or other poor quality water into the groundwater body.

3. That groundwater flows to dependent surface water bodies should not be diminished by groundwater body related pressures to the extent that they do not achieve good status, or that their status is reduced from high to good.

4. That groundwater body related pressures should not diminish groundwater flows or levels supporting GWDTEs such that these ecosystems suffer significant damage in relation to conservation objectives.

Table 6 Classification Criteria for Good Quantitative Status of a Groundwater Body

Elements of Assessment	**Available resource is not exceeded by long term annual average abstraction.**	**Groundwater Levels**	**Saline or other intrusions**	**Meet Article 4 objectives for associated surface waters including no significant future deterioration in status.**	**No significant damage to directly dependent terrestrial ecosystems, now or in the future.**
Translate Objectives into measurable parameters	Comparison of recharge and abstraction	Water level monitoring	*Saline* : hydraulic gradients sufficient to prevent movement of saline interface. *Other intrusions:* no major flow reversals with other waters	Use ecological criteria to define acceptable surface water flows and/or levels for standing waters	Prevent significant damage (departure from conservation objectives due to levels or flows)
Key parameters	Recharge and abstraction estimates, levels and flows	Spatial and areal trends in groundwater water levels	Level + other indicators (<u>hydraulic gradient</u>, groundwater balance)	Level + other indicators (hydraulic gradient, groundwater baseflow or inflow and groundwater balance)	
Test of anthropogenic impact	Available resource exceeded by abstraction	Long-term areal decline linked to other tests of pressure.	Much reduced or negative hydraulic gradients, combined with significant rise in conductivity and/or other pollutants	Significant change in indicators, particularly baseflow	Significant change in indicators, particularly groundwater inflow
Initial screening	None - Water balance mandatory.	None – monitoring is mandatory.	Consider potential for intrusions – do not set standards if no likelihood. Consistency between quantitative & chemical assessments essential.	If there is no significant hydraulic connection do not set thresholds for these criteria. If there is no significant pressure do not set thresholds for these criteria.	
Thresholds	Set levels and define other indicators if applicable and set compliance regimes	No. Linked to results from other tests.	Set levels, gradients etc and cross reference to chemical assessment		Set levels and define other indicators if applicable and set compliance regimes
Related R&D Work Packages	**WFD 53**	**WFD53**	**WFD53**	**WFD53 & WFD 48**	**WFD53 & WFD 62**

5 PROPOSALS FOR QUANTITATIVE STATUS ASSESSMENT

5.1 Introduction

Section 4 discussed a number of elements or tests which are required to be passed for a groundwater body to be at 'good quantitative status'.

It is useful to consider these different tests or elements in terms of a **hierarchy of confidence**, and to break down the sequencing of tasks according to the WFD split between **Further Characterisation** (narrowing investigations to refine understanding of initial risks & confidence) and **Classification** (the **tests** & hierarchy of confidence involved in determining status). This confidence is linked to the certainty of the test outcomes and the degree of conceptual understanding of the groundwater body (i.e. a tiered, risk-based characterisation spiral).

The classification reality is that a process is required where the results from tests based on all the available information/evidence are mapped together to determine status and that this is informed by the conceptual understanding, risk and degree of confidence in the assessment. However classification of groundwater body quantitative status cannot be completed without consideration of **all** the tests.

5.2 Scale of Impacts and Groundwater Body Re-delineation

It is important to understand the scale of impacts as part of the tests for classification. Does failure of a test within a small part of a groundwater body cause failure for the whole groundwater body? In relation to the test criteria, what proportion of the groundwater body must be affected (e.g. by saline intrusions) for the groundwater body to be considered as being at poor status? If only a single monitoring point is indicating failure in good status then it is likely that this is associated with specific (single or few) groundwater abstraction pressures. In this instance programmes of measures targeted at these single pressures may be more appropriate than classifying the whole groundwater body at poor status.

Observation borehole groundwater level trends often relate to 'local' and 'short term' changes in the recharge – discharge (including abstraction) balance. By implication, this indicates that localised impacts on groundwater levels should not 'determine' status. However, it could also be reasonably argued that 'local abstraction impacts' on a GWDTE *should* be a determining factor towards status if monitoring indicates that the GWDTE was ecologically impacted as a result (i.e. 'significantly damaged').

In some cases re-delineation of a large groundwater body which is principally at good status but with a minor area of poor status may warrant consideration. Certain rules are proposed for redelineation of groundwater bodies as follows:

- Boundaries of a groundwater body should only be delineated on a hydrogeological basis and be constrained by hydrogeological boundaries (e.g. aquifer boundaries, flow lines, divides or outflow boundaries to the sea);

- The resultant groundwater bodies should not be of an unworkable size or re-delineation result in an unworkable number of new groundwater bodies;
- Groundwater bodies should be representative of the hydrogeological environment across the area and not be specific to either single receptors or pressures;
- Re-delineation would need to consider all other pressures and receptors to ensure that delineation on the basis of quantitative status did not conflict with chemical status; and
- Sub-division decisions should not be influenced by the need for monitoring which can be considered in relation to 'representativeness' across groundwater bodies.

Given this list of caveats, and the data storage and reporting instability which would be associated with frequently changing groundwater body boundaries, it is apparent that re-delineation should probably be considered as a last resort - applied in only a few cases.

5.3 Tests to Determine Quantitative Status

A proposed framework of tests to determine the status of each groundwater body is presented in Table 7. These tests recognise the need to associate the resulting determinations with a degree of confidence. The confidence in declaring good quantitative status for a groundwater body will be linked to the available information and investigative work completed at the time of classification. The table has therefore been structured to indicate that a status can be assigned to a groundwater body with only the most basic level of understanding from each test. However, this would result in a lower confidence.

All of the tests should be considered for all groundwater bodies with the lowest resulting status and confidence result adopted for the groundwater body as a whole.

It is not intended to develop detailed assessments and management plans for all groundwater bodies and the tests consider the 'de minimus' level for groundwater body classification.

Specifics relating to each test are outlined in the Sections below. In some cases initial proposals for threshold levels to be applied are made based on the discussion in Section 4. In other cases the related research to support such thresholds is still in its early stages so recommendations are limited to the key assessment principals which will need to be considered (as for Test 5 – significant damage to dependent terrestrial ecosystems).

It is considered that, at the simplest level of assessment, some of the groundwater body status tests could be applied within a Geographical Information System (GIS) and reference to this has been made within the sections. However, the classification process must be flexible enough to reference the best available level of conceptual understanding, estimates of groundwater abstraction impacts and locally appropriate thresholds rather than insisting on a 'one simple technique and threshold fits all' approach. The investigation of the possible relationships between impacted ecosystems and groundwater body related abstraction pressures is likely to require expert judgment which cannot be reliably automated.

Table 7 Proposed Tests for the Determination of Good Groundwater Quantitative Status

Status	Confidence	Test 1 GW Body GWABS/ Recharge Assessment *	*Test 2* *Groundwater Levels*	Test 3 Saline or other intrusions **	Test 4 Surface water bodies***	Test 5 Groundwater Dependent Terrestrial Ecosystems****	Conceptual Model
Good Status	High Confidence	*GWABS < 10%, 20% GWRECH*	*Strong Evidence of Stable GWLs*	*Coastal buffer GWABS < 10%, 20% GWRECH,* evidence of good water quality.	No dependent SW Bodies or all at High or Good Ecological Status (H/GES).	No GWDTE present or GWDTE in favourable condition.	Extensive monitoring, good field data, interpreted pumping tests, distributed assessment.
	Low Confidence	*GWABS < 20%, 50% GWRECH*	*Limited Evidence of Stable GWLs*	***Coastal buffer GWABS < 20%, 50%* GWRECH, no evidence of water quality.**	**Some SW bodies < H/GES but GWABS pressure< SW standard threshold or not significant in relation to breach.**	**GWDTE effected but GWABS pressure < GWDTE threshold.**	Some field evidence, knowledge of groundwater recharge & discharge mechanisms.
Poor Status	Low Confidence	*GWABS < 100% GWRECH*	*No Evidence of Falling GWLs*	**Some evidence of GWABS related intrusion. Identified trends or exceedance of precautionary threshold.**	**Dependent SW Bodies at < H/GES, GWABS pressure > SW standard threshold, some evidence.**	**GWDTE effected, GWABS pressure > GWDTE threshold, some other evidence.**	Some field evidence, knowledge of groundwater recharge & discharge mechanisms.
	High Confidence	GWABS > 100% GWRECH	***GWABS Related Evidence of Falling GWLs***	Monitored exceedence of classification threshold and currently rising salinity trends & associated high GWABS pressure.	**Dependent SW Bodies < H/GES, monitored GWABS impact evidence, or GWABS >> SW standard threshold.**	**GWDTE 'significantly damaged' by monitored GWABS effect.**	Extensive monitoring, good field data, interpreted pumping tests, distributed assessment.

Notes:
Tests in *italics* are supporting evidence only.
Tests in **bold** require expert judgement where review of the conceptual understanding of the groundwater body and its interaction with dependent ecosystems is essential.
* % thresholds determined according to the aquifer types tabulated in Table 4, or according to specific yield based sensitivity (less than or greater than 5%)
** Re-delineation possible to exclude the saline areas. Preliminary hydrochemical thresholds to trigger investigation suggested in Section 4.5.
*** Surface water body abstraction related thresholds to be taken from standards discussed in Section 4.6, developed from WFD48
****GWABS pressure thresholds for GWDTEs remain to be determined by WFD62.

5.4 Test 1: Groundwater Body Abstraction/Recharge Assessment

It is accepted by the project steering group and other EU States that groundwater abstraction should be less than recharge to a groundwater body, as a long term average (i.e. GWABS/RECH <100%). This is a WFD requirement. However, the use of any more stringent thresholds which reserve a portion of recharge for 'the environment' should only be considered support other classification elements, as a relatively insensitive but easily calculated **'proxy'** for the assessment of dependent ecosystems or intrusion issues i.e. a higher level of confidence obtained in the other tests could allow a higher threshold to be set for the 'available resource'. It is important that, although these thresholds are set to protect "dependent ecosystems" (UKTAG Paper 11b), they should not be too precautionary.

The thresholds suggested in Table 6 have been based on the ongoing RAM framework review of CAMS groundwater management unit assessments, as described in Section 4 and would be differentiated according to the specific yield (low/high), flow mechanism (fracture or fissue/intergranular), or aquifer type (i.e. Table 4) of the groundwater body.

As an example, a 'hard rock' low transmissivity aquifer which has a shallow groundwater flow system will have a specific yield (Sy) of < 0.05 (5%). If groundwater abstraction is less than 10% of estimated recharge to the body this might support a high confidence classification of good quantitative status depending on the results of other tests. If abstractions represent more than 10% but less than 20% of recharge and there is no other information to suggest a worse result, this would result in a lower confidence classification of good status.

The following data requirements are identified for this test:

- Long term average recharge estimates for each groundwater body;
- Estimates of the average groundwater abstraction rates from each groundwater body (for all consented uses, regardless of consumptiveness, based on 'recent' typical rates of abstraction). This implies the need for a framework to acquire and assess (and possibly licence or consent) these groundwater abstractions. Proposals for this are detailed in Section 8;
- Estimates of specific yield and/or determination of the groundwater flow mechanism or aquifer type (i.e. from Table 4).

As an alternative the Aquifer Response Function could be used for different aquifer types to determine the appropriate thresholds and could be part of the 'regulatory toolkit' for groundwater reliable yield work (further details in Environment Agency, 2002).

5.5 Test 2: Groundwater Level Monitoring

Discussion in Section 2.3 and Table 1 explains why groundwater levels generally do not provide a reliable indication of the overall balance between groundwater body abstraction and recharge, although monitoring may be essential to characterise more local abstraction impacts. However, to comply with the explicit requirements of the WFD, groundwater levels must be considered alongside all the other strands of evidence in the context of the conceptual model to determine status. For some confined aquifers groundwater levels may indeed provide crucial evidence but elsewhere groundwater levels on their own are of limited value as an indicator of the groundwater body 'available' resource.

Existing groundwater level monitoring from at least one site, deemed most representative within each groundwater body should be reviewed to determine if significant long-term trends are discernible. This review should be carried out using expert judgement against the mapped distribution of groundwater abstraction pressures (e.g. simply represented by drawdown or 'equivalent recharge circles' – see Figures 5 and 6) and discharge/recharge zones, in the context of the results of Test 1 and conceptual understanding of the groundwater body. Where no existing monitoring data are available, it should only be necessary to install new observation wells if groundwater body GWABS/RECH ratios exceed the precautionary 10% or 20% thresholds applied for initial characterisation (based on the specific yield, flow mechanism or Table 4 aquifer type of the groundwater body). If initial data review suggests declining groundwater levels then further monitoring points and development of the conceptual understanding of groundwater flow within the body should be considered. Groundwater level trends support classification but should not determine status by themselves. Associated evidence is also required i.e. that they are related to abstraction which exceeds long term average recharge for the groundwater body, or is resulting in poorer water intrusion or ecosystem impacts (Tests 1, 3, 4 or 5).

5.6 Test 3: Saline or other Intrusions

It is intended that this assessment for classification is a further development of that undertaken by the agencies for initial characterisation. A number of tasks are proposed and these are detailed below.

1. Review and investigate further historical reported 'falling groundwater level' or areas of 'saline intrusion'.

2. Review of existing monitored groundwater quality evidence. Groundwater quality evidence is generally available from boreholes pumping for public water supply. Whilst long term trends in quality could be used there is usually insufficient data for such an assessment. It is therefore proposed that a threshold electrical conductivity is set above which further characterisation is triggered. In the absence of other thresholds, a trigger set at around 25% of the Drinking Water Directive standard is proposed (i.e. around 600 μS/cm, or 60 mg/l chloride), as measured in an abstraction or observation borehole.

   Above this trigger further characterisation would include the need to prove that the salinity was induced by groundwater abstraction, that a reversal in hydraulic gradients and groundwater flow directions has occurred, and that the areas of the groundwater body affected are significant in relation to future sustainable abstraction. Such an assessment should also consider the effectiveness of any existing regulatory measures to control the intrusion, and should explore options for re-delineation of freshwater groundwater boundaries where historic over-abstraction has resulted in irreversible salinisation.

3. A more confident classification of poor status could be made based on the results of these location specific investigations as part of further characterisation. A generic threshold of 75% of the Drinking Water Directive standard of is suggested (i.e. around 1 800 μS/cm, or 180 mg/l chloride), associated with a currently rising

trend as a test of significance, although locally set water quality thresholds and targets may be more appropriate.

4. Undertake a GIS screening assessment of abstraction pressures within 2 km of the coast (or a buffer zone varied according to the aquifer transmissivity or type, as in Table 4). This may help to identify areas where there is the potential for coastal saline intrusions even though impacts on abstraction or monitoring borehole water quality are not yet apparent. If an ‘equivalent recharge circle’ representation of the abstraction borehole pressure is used (as Figure 6), this GIS screening could indicate the percentage of each kilometre long portion of the buffer zone covered by these circles. The same abstraction/recharge thresholds suggested for Test 1 could be adopted within this buffer but the results, which are only indicative of risks, should be viewed as supporting classification, rather than determining status automatically;

5. Review available evidence for minewater rebound in response to the cessation of drainage pumping. This may also highlight areas where changes in gradients and flow directions relating to anthropogenic influences could present the risk of poorer water quality intrusion.

6. Review available groundwater level monitoring data but avoid a prescriptive groundwater body level monitoring requirement. Groundwater level monitoring information may be the only information available, particularly in confined aquifers.

The **historical context** of saline or other intrusions requires consideration. If a historical saline intrusion problem has been controlled the groundwater levels, flow direction and water quality may be in the process of restoration to natural baseline conditions. If the trend in salinity (chloride) concentrations or electrical conductivity indicates improvement over the long-term should the groundwater body be classified as poor status until the salinity has reached a required classification threshold (which could be set at the Drinking Water Standard of 2 500 μS/cm) or can the groundwater body be classified at good status?

Although not the focus of this project, decisions regarding the good/poor classification of groundwater bodies in relation to saline intrusion and other groundwater abstraction issues should also incorporate consideration of the option to apply for and set ‘less stringent objectives’ in relation to technical or economic/sustainability constraints.

5.7 Test 4: ‘Status Impacted’ Surface Water Bodies

The groundwater assessment should focus on the possible impacts to the naturalised hydrological regime (including groundwater levels for ‘offline lakes’ and baseflow for rivers and ‘online lakes’) from the groundwater abstraction pressure. Further refinement of the surface water body focused screening approaches for groundwater abstraction pressures applied for initial characterisation is recommended in order to:

- Prepare information highlighting surface water bodies which are potentially subject to the highest GWABS pressures (i.e. in relation to low freshwater flow statistics, or potential drawdown in offline, groundwater supported lakes) to facilitate investigation of any which are considered to fail **Good Ecological Status** according to biological tests. In contrast with the ‘fully consumptive’ abstraction rates assumed for Test 1 comparisons with recharge, groundwater abstraction pressures for Good Ecological Status screening should be calculated to take account of any water LOCALLY returned to the catchment (i.e. 'close' to the point of abstraction – effectively within the same surface water body). Possible thresholds, expressed as a proportion of QN95 natural low flows according to the water body type (~10 to 20% of QN95), have been discussed in Section 4.6.3 (i.e. Table 5 for rivers) and could be applied using a GIS based or Lowflows2000 system. They should be considered in relation to NET abstraction minus discharge estimates (which includes groundwater abstraction), AND for groundwater abstractions alone, to develop an understanding of the relative proportion of impacts which may be attributable to groundwater body pressures;

- Consider similar screening results, which assume all groundwater abstractions to be fully consumptive (as for Test 1), in relation to hydrological regime thresholds as a direct influence on **High Ecological Status** classification. The proposed test (i.e. MAXIMUM abstraction or discharge) and threshold (i.e. less that 5% of QN95) suggested in Section 4.6.2 are more stringent than those which may be used to assess 'risks to good status'.

All groundwater abstractions eventually result in reduced baseflow discharge to a surface water body flow or to the coast (as demonstrated in Figure 5, taken from Environment Agency, 2003). The impacted surface water bodies may lie outside any of zones commonly drawn to try and indicate the area of influence of the abstraction: i.e. 'Zone of Contribution' (ZOC or source catchment area), 'Equivalent Recharge Circle' (i.e. a circle centred on the source with an area representing the area of annual average recharge required to balance the abstraction rate) or Zone of Drawdown' (ZOD – which might be drawn based on Theim (steady state drawn to the nearest river) or Theis (transient, assuming no recharge) assumptions). As a result, these 'proximity' screening tools are not considered appropriate for assessment of groundwater abstraction pressures on surface water body flows, (although they may have value in relation to drawdown impacts on groundwater dependent offline lakes).

For this reason it is more appropriate to screen surface water body low flows for groundwater abstraction pressures based simply on the surface water catchment in which they fall, or according to groundwater catchment boundaries, where these are known to be distinct (i.e. some major aquifers with extensive spatially distributed groundwater level monitoring information). Where groundwater abstraction rates **by themselves** exceed trigger thresholds (as discussed in Section 4.6), AND biological classification indicates that the surface water body ecological status is less than high or good, further investigation to support groundwater body classification must consider the distribution of groundwater abstraction impacts in more detail. An appreciation of the location and rates of abstracted groundwater returned to the catchment (e.g. as treated effluent surface water discharges to the river network, or as soakaways to ground) will be essential in this regard, as will a fuller assessment of any existing programmes of measures designed to ameliorate low flow impacts (e.g. groundwater – river support schemes etc).

The first level of flow threshold related assessment could be automated in GIS or using Lowflows 2000. If greater levels of sophistication are required (e.g. if the impacts of abstraction are considered to be distributed between two rivers, rather than simply assigned to one, or for groundwater – river support scheme impacts), use of other tools may be appropriate such as the Environment Agency's Impact of Groundwater Abstractions on River Flows package (Environment Agency, 1999) or possibly numerically distributed groundwater modelling.

It is likely that the ecological status of many surface water bodies may be compromised by a variety of factors and pressures of which abstraction from the groundwater body is just one. In such cases a decision will need to be made as to whether the groundwater abstraction influence is by itself potentially responsible for the diminution of status, or whether it is implicated only in combination with other pressures. Simple indicators of groundwater dependency such as the baseflow index of a river should highlight surface water bodies where groundwater influences are likely to be particularly important. In practice it may also be helpful to remember that the classification of poor groundwater quantitative status will be expected to be followed by, or associated with, the development of programmes of measures to restore the groundwater body to good status. The realistic consideration of possible groundwater abstraction related measures in terms of their perceived effectiveness and sustainability can then influence decisions made for status classification.

The investigation of groundwater body related impacts on dependent surface water bodies will thus inevitably require expert judgment based on all the available strands of evidence. It will be influenced by the final outputs of the WFD48 project, by the water body status reports; by the RAM Framework Review and by investigations already undertaken for the Habitats Directive. In addition, reference to the Environment Agency's Hydrological Impact Assessment guidance (Environment Agency, 2003) is recommended as a key part of the toolkit. Development of an appropriate conceptual understanding of groundwater – surface water interactions is essential and assessment of the issues presenting the greatest risks may require site visits, investigations and enhanced local monitoring.

5.8 Test 5: 'Significantly Damaged' Groundwater Dependent Terrestrial Ecosystems

Ecological degradation of a GWDTE may result from impacts which are not groundwater body related (e.g. adjacent surface water body pressures, shallow drainage, invasive species, climate change, landuse or land management).

If a protected terrestrial ecosystem is indicated by ecological monitoring or surveying to be 'seriously impacted', groundwater investigation should be considered to assess the following:

- The extent to which the site is groundwater dependent (conceptual model), including an understanding of the spatial and temporal role played by groundwater in supporting the ecosystem, to an appropriate level of detail;
- If the ecological impacts are groundwater body pressure related and therefore should affect groundwater body status (i.e. abstraction and possibly 'deep arterial drainage' in relation to quantitative status, or groundwater pollution in relation to chemical status); and
- The management measures, triggers or thresholds to prevent or reverse any groundwater body related 'significant damage'.

The definition and derivation of a 'significantly damaged GWDTE' list is critical for the groundwater assessment and the SNIFFER WFD62 project should aim to provide guidance (for both hydrogeologists and ecologists) on this task.

WFD62 should consider the relationship between the WFD term 'significant damage' and the possibly more stringent or precautionary tests of 'no adverse ecological effect' applied for Habitats Directive assessments with regard to site conservation objectives.

Beyond the designation level of the sites included (e.g. SAC cf SSSI cf National Nature Reserve), does the term ‘significant’ have any bearing on the extent (areal or temporal) of site ecological impacts? Also, if ‘significant damage’ implies that groundwater body pressures are responsible for the damage, do these include any types of arterial drainage which drain the water table, as well as groundwater abstractions?

The monitoring requirements to establish ‘impacted ecology’ should also be investigated – does this simply require repeated walkover surveys, comparison with standards and conservation objectives, or more comprehensive monitoring?

If there are no GWDTEs within the groundwater body, or if none of them are considered to be ‘damaged’ (e.g. if they are in favourable condition?), this test has no influence on the final status assigned. If potential issues do need to be investigated, many of the comments discussed in the preceding section on establishing the relationship between groundwater body pressures and dependent ecosystem damage apply to GWDTEs, as to surface water bodies.

Simple pressure screening approaches, which can be automated with GIS, will continue to be useful through further characterisation. A variety of representations of ‘zones of groundwater abstraction influence are shown on Figure 5 and have been introduced in Section 5.7. These might be used to make estimate cumulative drawdown associated with all groundwater abstractions at a central assessment point within the GWDTE, or to assess the proportion of area occupied by equivalent recharge circles within buffers or catchment areas drawn around the receptor. Figure 6 (taken from Environment Agency 2002) shows an example of the ‘equivalent recharge’ representation in which simple, pressure centred circular areas calculated from rate of abstraction/groundwater body recharge.

At the early stages of investigation these tools could be applied based on generic assumptions of aquifer properties and recharge may be adequate for this purpose. As the potential risks associated with groundwater abstractions become greater it may be necessary to reduce conceptual uncertainties through site visits, enhanced investigations with associated testing (e.g. pumping or signal tests) and monitoring. In some cases, the use of distributed groundwater models may also be required.

Figure 5 Schematic Cross-section of Groundwater Flow to a SW Body or GWDTE with Alternative Representations of ‘Zones of Influence’

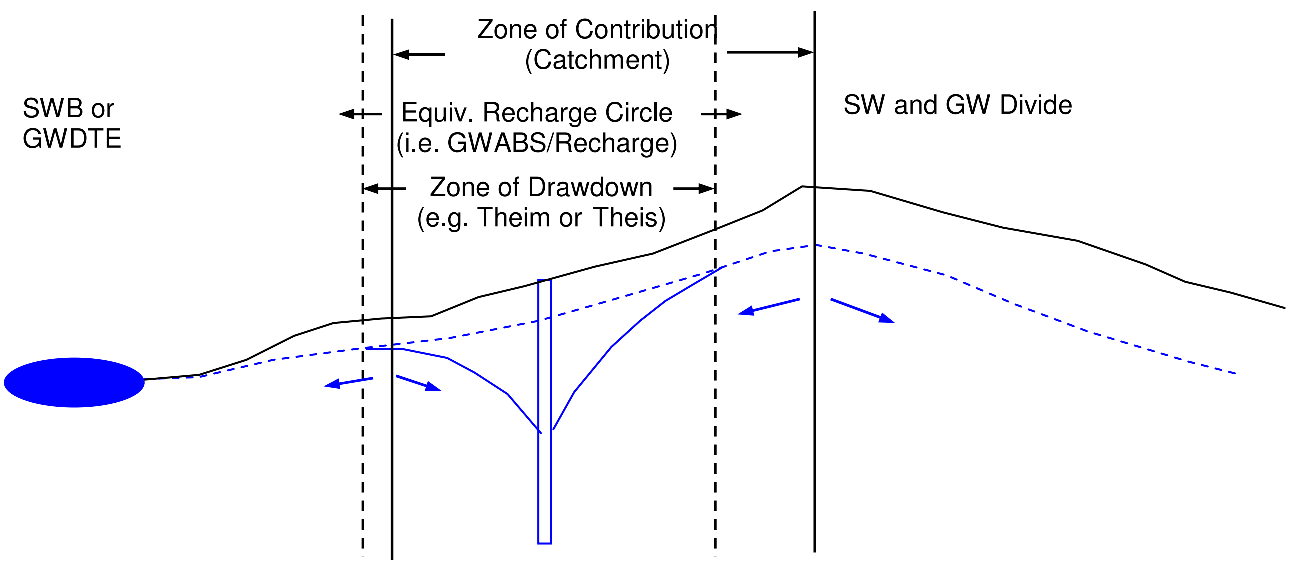
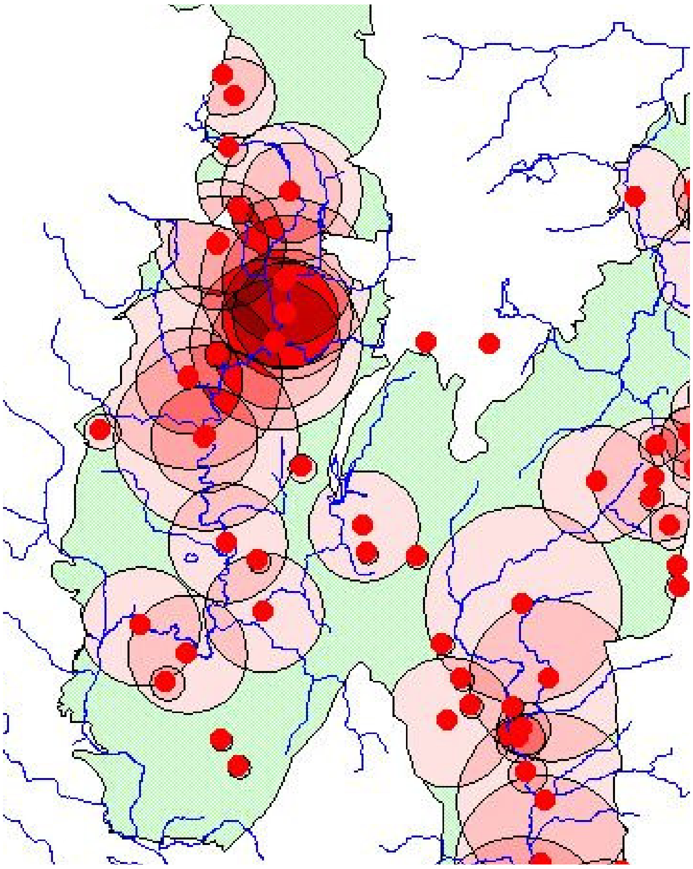


Figure 6 Equivalent Recharge Circles Example



6 REQUIREMENTS FOR AN ABSTRACTION ASSESSMENT FRAMEWORK

6.1 Introduction

Current and future groundwater abstractions and their associated pressures within a groundwater body could effect the quantitative status of that groundwater body. It is therefore necessary to consider the effects from each application for groundwater abstraction in its own right. Good status of a groundwater body does not necessarily permit groundwater abstractions where these abstractions would result in stress to dependent systems (SWBs, GWDTEs) or cause saline intrusion. Equally, poor status of a groundwater body does not disallow future groundwater abstractions where it can be demonstrated that the proposed abstraction does not increase the stress which resulted in the poor status classification.

6.2 WFD Requirements

In addition to the requirements for good quantitative status, WFD Article 11.3(e) (Programme of Measures) requires:

"controls over the abstraction of fresh surface water and groundwater, and impoundment of fresh surface water, including a register or registers of water abstractions and a requirement for prior authorisation for abstraction and impoundment. These controls shall be periodically reviewed and, where necessary updated. Member states can exempt from these controls, abstractions and impoundments which have no significant impact on water status."

There is, therefore, in the WFD an explicit requirement for countries to adopt a groundwater abstraction 'control' regime. It is considered that this would normally be enacted by the regulatory agencies in each country with a system of renewable abstraction licences.

This section describes the current and proposed groundwater abstraction control regimes in place in Scotland, Northern Ireland and Republic of Ireland.

The term groundwater abstraction is used in this report to include proposals for both pumped abstraction of groundwater (from borehole or other construction) and 'arterial drainage' related to engineering schemes where this causes a pressure to the groundwater body (this may not necessarily be actively pumped).

6.3 Principal Assessment Criteria

The principal assessment criteria need to be based on the Criteria for determining quantitative status. However, the tests need to be appropriate for all applications for abstraction within the groundwater body and should therefore not preclude applications in unstressed areas within a groundwater body which is not at good status.

The tests presented in detail in Section 5 provide guidelines for a proposed groundwater abstraction within a groundwater body. These are outlined in the points below:

1. The groundwater abstractions to recharge ratio (GWABS/RECH) threshold provides a good guide to whether the groundwater body or management unit is under pressure. However, the rule on its own should not be used to exclude applications for further groundwater abstraction. Abstractions could be permitted in areas and aquifers within the groundwater body or management unit which are not stressed. It would be necessary in these areas to demonstrate that abstraction proposals do not increase the stress to the groundwater body.

2. Falling groundwater levels (over more than a 'localised' drawdown area around the borehole).

3. Reversal of groundwater gradients (over more than a 'localised' drawdown around the borehole) resulting in intrusion from a saline or groundwater body with poor water quality.

4. Diminution of the status of a surface water body. Consideration of this may require incorporation of the location and amount of returned water from the abstraction to the surface water body. The proportion of effect from the groundwater abstraction causing a status diminution in the surface water body to result in reduction of the status of the groundwater body is currently under consideration.

   In addition, UKTAG is currently considering if the 'diminution' of surface water body status from High to Good, as a result of groundwater abstraction effects, causes the diminution of groundwater body status (agreement on this has yet to be reached – July, 2005). As a note, 'High' surface water body status should incorporate specific, simple hydrological regime screening, it should therefore be possible to screen groundwater abstraction flow impacts against these thresholds.

5. 'Significant damage' to a Groundwater Dependent Terrestrial Ecosystem (GWDTE). This is monitored hydrological impact caused by groundwater abstractions.

An important note from the above 'tests' is that it is considered that permission for groundwater abstraction (licence, consent or otherwise) could be given when a groundwater body is at less than good quantitative status if Tests 4 and 5 (Surface water body and GWDTE) are met. The use and returned volume and location of the abstracted water are important considerations in this assessment.

However, permission for abstraction should not be given which would result in a groundwater body deteriorating in status (High to Good or Good to Poor).

6.4 Additional Assessment Criteria

In addition to the criteria to meet good quantitative status for a groundwater body it is considered that the following four additional assessment criteria would require consideration when assessing an application for groundwater abstraction:

a) *Practical Considerations*. Can the proposed borehole deliver the proposed yield or is the proposed borehole and pump over-scoped for the stated yield?

b) *Socio-economic Considerations*. Is the abstraction the only option for a community water supply or a necessary industry? This can be considered under the WFD disproportionate cost argument for less stringent objectives.

c) *Consultation*. A consultation process should be pursued with interested parties and an application for abstraction should be advertised to allow concerns and/or objections from existing users to be expressed. Impacts to groundwater abstractions of existing users should be assessed.

d) *Sustainability*. Efficient use of the abstracted water should be demonstrated and the location & proportion of returned water should be considered. Potential effects on local groundwater dependent features which are not part of the groundwater body quantitative status should be assessed.

6.5 Considerations

6.5.1 Abstraction Effects

All abstractions have a **flow** effect on one or more of the following (EA, 2003):

- Existing abstractions;
- Baseflow to a surface water body;
- Flow to a GWDTE; or
- Subsurface flow out of the groundwater body.

This effect on flows may be proportioned between the above receptors based on the magnitude of flows and distance from the abstraction.

Groundwater abstractions may also have important water **level** effects on GWDTEs, other groundwater abstractions, offline lakes and coastal areas (causing saline intrusion).

A smaller abstraction close to a sensitive groundwater dependent system (GWDTE, SWB or abstraction) could have a more significant impact in the short term than a larger abstraction at a distance from the GWDTE or SWB. But in the longer term all GWABS must reduce natural outflows somewhere.

6.5.2 Assessment Costs

Assessment of proposals for groundwater abstraction could require significant time, resource and cost input from both the applicant and the regulator. It is therefore important that this input is appropriate to the risk posed by the abstraction to sensitive receptors. By using an initial risk assessment of abstractions effort can be focussed on those abstractions which have the potential to cause greatest impact.

This risk to the groundwater body, existing abstractors and the environment is not only determined by the volume of the abstraction but by the sensitivity of water features and existing abstractors within the zone of influence (*catchment)* of the abstraction.

6.5.3 Source Protection Zones Schemes

Large public and private water supply abstractions (e.g. > 500 m^3/d) will derive their resource from a large catchment area. Source protection zones should be defined for these abstractions to ensure protection of the supply through application of suitable planning control measures.

Definition of these source protection schemes do not form part of the assessment application process, as they are concerned with potential effects on the proposed abstraction rather than potential effects on the environment caused by the abstraction. However, SPZs form an important component of ensuring the sustainability of supply from the abstraction.

A good conceptual understanding of the groundwater flow system is required to determine the SPZs and numerical modelling of the groundwater travel times could be required. As a result delineation of SPZs is more appropriate as a condition for an approved abstraction rather than part of the assessment process. For additional information refer to EA/GSI guidance.

The process for completing these SPZs should be considered by the regulatory authorities. Whilst the initial definition of the zones may be a requirement of the applicant the regulatory authority must be involved at the review stage to ensure that the zones defined are hydrogeologically correct, appropriate and justifiable.

6.5.4 Borehole Sanitary Protection

To ensure proper protection of the groundwater body and of the abstracted supply guidance should be given by the regulatory authority on best practice for the construction of groundwater boreholes. This may be appropriate as a formal condition of any permission to drill. Guidelines are beyond the scope of this project but reference is made to the SEPA Guide to Good Practice on “Water Supply Borehole Location, Construction and Headworks” in addition to hydrogeological texts such as Driscoll, 1986.

It should be a requirement of any assessment regime that full construction details are submitted to the regulatory authority subsequent to the drilling and prior to the issuing of any consent or licence. This will allow the regulator to enforce any remedial action in the construction if required.

7 REVIEW OF CURRENT ABSTRACTION CONTROL REGIMES

7.1 Introduction

To place proposals for assessment of groundwater abstractions into context the current and proposed regulatory regimes in Scotland, Nothern Ireland and Ireland are briefly reviewed.

7.2 Scotland

7.2.1 Previous Regimes

Major water supply schemes, like urban supply abstraction, required Scottish Water to obtain Water Orders from the Scottish Executive.

Abstraction is also currently controlled by Control Orders (made under the Natural Heritage (Scotland) Act 1991). In these Control Order areas water cannot be abstracted from watercourses (including surface and groundwater) for any purpose unless an authorisation is issued by SEPA. Currently there are only two catchments where an order has been made - West Peffer Burn in East Lothian and Ordie Burn in Perthshire.

7.2.2 Water Environment (Controlled Activities) Regulations

The principal of abstraction control has been drafted into the Water Environment and Water Services (Scotland) Act 2003 (WEWS). This Act forms the enabling legislation of the WFD in Scotland. The Water Environment (Controlled Activities) (Scotland) Regulations (2005) describe the abstraction control regime to implement the Act.

Under these regulations a proposed licensing framework for Scotland has been developed by SEPA. The current proposal is for:

- **No Action** – Abstractions < 10 m^3/d (policy seeks to protect but the Control Regulations do not require any regulatory action);
- **Abstraction Registration** – Abstractions 10-50 m^3/d;
- **Simple Licence** – Abstractions 50-100 m^3/d where no potential negative effect is indicated by an initial assessment;
- **Complex Licence** – Abstractions > 100 m^3/d and < 100 m^3/d where potential negative effect is indicated by the initial assessment.

The tasks currently proposed by SEPA (M. Roberts, pers. comm.) for each of these stages are outlined in the sections below.

Abstraction Registration

Abstractions of 10-50 m^3/d would have a screening using a GIS screening tool. Where the abstraction does not indicate a risk to resource or groundwater dependent receptors within the screening distance then the borehole is "registered". If the screening does indicate a risk then the enquiry is passed to the "Environment Protection and Improvement" (EPI) team for more detailed assessment.

Simple Licence

After assessment with the GIS screening tool a simple licence would be issued for drilling and a pumping test. If the screening indicates a risk then the enquiry is passed to the "Environment Protection and Improvement" (EPI) team for more detailed assessment.

Complex Licence

Abstractions where a Complex Licence was required or which indicated a possible risk to the groundwater resource would have a detailed assessment by a member of the EPI team. This could include a further resource assessment using Low Flows 2000, followed by a water features survey and application of an impact assessment tool such as IGARF or SPIGARF to determine the potential proportioned impact on water resources. Following this, and if appropriate, a "Drill and Pump Test licence" would be issued. If the pumping test indicated acceptable impacts on the water resources and existing users an Abstraction Licence would then be issued.

7.3 Northern Ireland

The Water (Northern Ireland) Order (1999) give powers to make regulations for the control of water abstraction.

Recently the Water Resources (Environmental Impact Assessment) Regulations (Northern Ireland) 2005 were introduced under the Environmental Impact Assessment Directive (85/337/EEC).

These regulations require an environmental screening above a 200 m^3/d limit of any proposed water management project for agriculture (i.e. abstraction or impoundment) to ensure that the activity is not causing significant harm to the environment. If initial screening indicates that the activity or project has the potential to cause significant harm, an environmental impact assessment is required and consent given before the activity can proceed.

7.4 Republic of Ireland

In Ireland, the only formal control of groundwater abstraction is currently through the provisions of the EC Environmental Impact Assessment Directive (85/337/EEC) which were given effect under EC (EIA) Regulations 1989 (S.I. No. 349 of 1989). In March 1997 EC Directive 97/11/EC amended Directive 85/337. This amending directive was given effect by EC (EIA) (Amendment) Regulations, 1999 (S.I. No. 93 of 1999).

Under the 1999 regulations specified developments require an Environment Impact Statement (EIS) for

- Drilling, other than test drilling, for water supplies, where the expected supply would exceed 2 million cubic metres per annum;
- Groundwater abstraction and artificial groundwater recharge schemes where the average annual volume of water abstracted or recharged would exceed 2 million cubic metres;

- Works for the transfer of water resources between river basins where the annual volume of water abstracted or recharged would exceed 2 million cubic metres.

A local authority proposing to undertake any of the above specified developments within its own functional area, now has to submit the EIS to An Bord Pleanála for approval.

8 PROPOSED DECISION SUPPORT FRAMEWORK

8.1 Introduction

A framework is required by regulators to provide a rigorous justification of the assessment of application for groundwater abstractions. This assessment could link to a licence decision process.

There is a need to maintain and promote Good Quantitative Status. Therefore, any assessment framework for existing or proposed groundwater abstractions is required to link closely with the Criteria for Quantitative Status whilst taking cognisance of additional abstraction specific criteria.

The potential effects of groundwater abstraction on surface water flows and GWDTEs results in a need to cross reference the surface water regulatory framework in relation to abstractions, discharges and impoundment impacts. Outcomes from SNIFFER project WFD48 (Surface Water Assessment) and WFD62 (GWDTE Significant Damage) will contribute to this.

8.2 Risk Assessment

It is proposed to determine the extent of evaluation required for an abstraction application based on a risk assessment. It is appropriate that this assessment is based on the tests outlined in Section 5. Therefore, it is proposed that the risk assessment comprises two sections: those applicable to an individual abstraction (Abstraction Specific Tests) and those based on the assessment of Criteria for Quantitative Status and presented in Section 5 and summarised in Table 7 of this report.

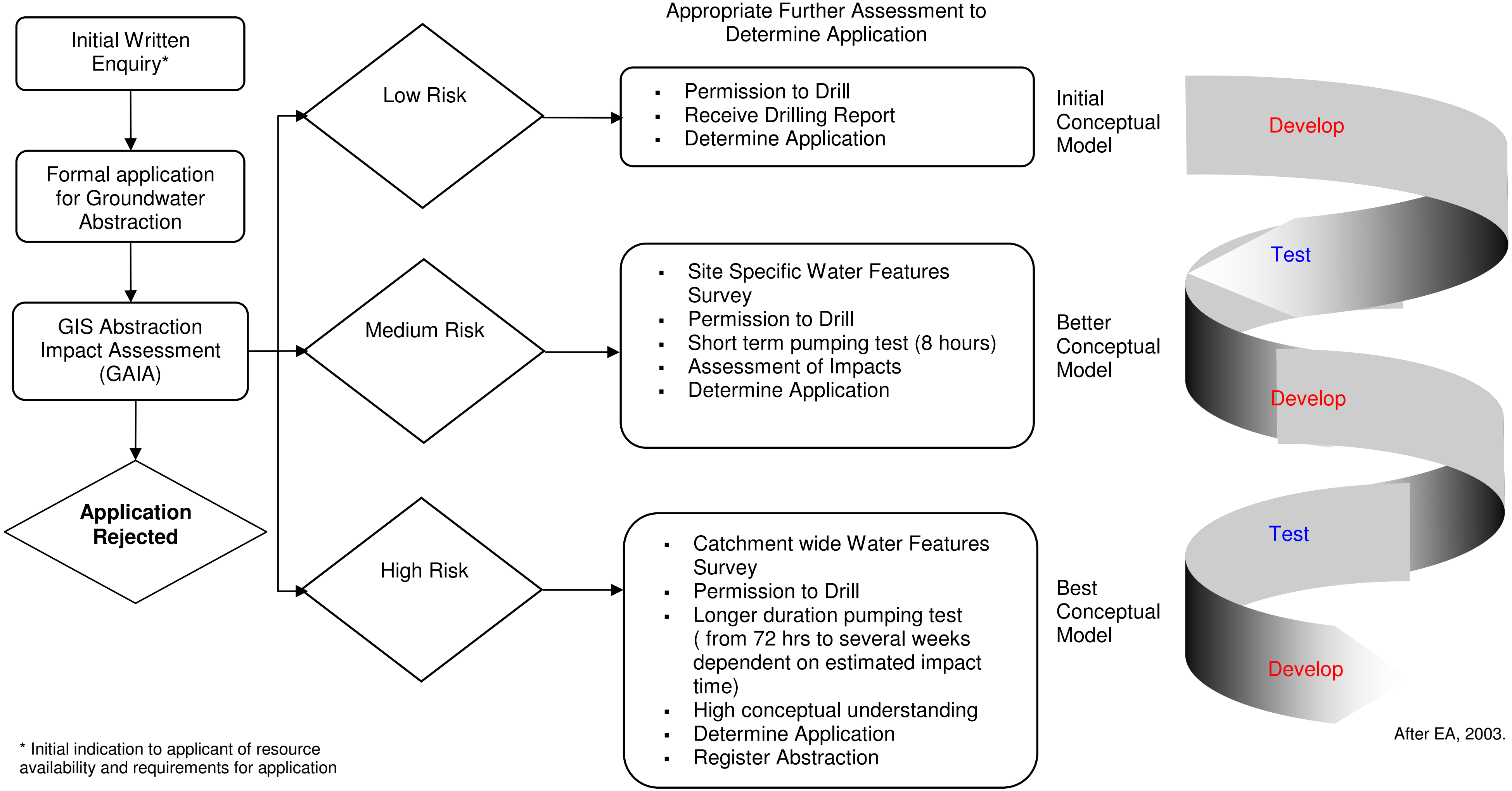
A matrix for the risk assessment is presented in Table 8. The final risk of the applicant abstraction would be determined from the highest risk indicated by any of the tests. It is considered that some of the tests in this matrix could be applied using a GIS based system and this is described further in Section 8.4. The resultant level of further assessment is presented in Figure 7 and outlined further in Section 8.5.

Table 8 Risk Assessment for Proposed Abstractions

Risk Assessment	**Abstraction Specific Tests**			**Criteria for Quantitative Status Tests**				
	Test AS1	**Test AS2**	**Test AS3**	**Test QS1**	**Test QS2**	**Test QS3**	**Test QS4**	**Test QS5**
	Proposed Abstraction Volume	**Drawdown on Existing Groundwater Abstractions**	**Drawdown on Local Groundwater Dependent Features**	**Groundwater Abstractions to Recharge Ratio**	***Groundwater Levels***	**Saline or other intrusions**	**SWB Ecological Status**	**GWDTE Condition**
Very Low Risk	Q < 10 m3/d	No measurable impact anticipated.	No measurable impact anticipated.	GWABS < 10%, 20% GWRECH	*Strong evidence of stable GWLs.*	Coastal or intrusion buffer zone. Monitored good water quality.	No dependent SWBs or all at Good Ecological Status (GES).	No GWDTE present or GWDTE in favourable condition.
Low Risk	Q 10-100 m3/d	Possible measurable impact.	Possible measurable impact.	GWABS < 20%, 50% GWRECH	*Limited evidence of stable GWLs.*	Coastal or intrusion buffer zone. No evidence of intrusion by poor water quality.	Dependent SWB at < GES, GWABS pressure < SW standard threshold but no other evidence.	GWDTE effected but GWABS pressure < GWDTE threshold, expert judgment.
Medium Risk	Q 100-500 m3/d	Likely measurable impact.	Likely measurable impact.	GWABS < 100% GWRECH	*No evidence of falling GWLs*	Some evidence of GWABS related 'intrusion'. Identified trends or exceedance of threshold.	Dependent SWB at < GES, GWABS pressure > SW standard threshold but no other evidence.	GWDTE effected, GWABS > GWDTE threshold, some pressure evidence, expert judgment.
High Risk	Q > 500 m3/d	Large measurable impact anticipated.	Large measurable impact anticipated.	GWABS > 100% GWRECH	*Strong evidence of GWABS related falling GWLs.*	Strong evidence of 'intrusion' trends and associated high GWABS pressures. Exceedance of thresholds	Dependent SWB < GES, monitored GWABS impact evidence and GWABS > High Status threshold.	GWDTE 'significantly damaged' by monitored GWABS pressure. GWABS > GWDTE threshold.

Notes:
1. Tests in *italics* are supporting evidence only.
2. Tests in **bold** require expert judgement.
3. Assessment requirements should be based on the highest risk scoring outcome from the above tests.

Figure 7 Proposed Levels of Assessment



After EA, 2003.

* Initial indication to applicant of resource availability and requirements for application

8.3 GIS Abstraction Impact Assessment (GAIA)

A GIS abstraction impact assessment (GAIA) tool is proposed to provide a screening analysis of the potential effect of the abstraction on receptors based on the tests presented in Table 8. This could be conducted by the regulator on receipt of an application for abstraction. Outcomes from the screening would guide the regulator in the determination of the application and requirement for further work from the applicant. It is considered that once populated with all data the GAIA would take in the order of a few hours per application to be completed by the regulator.

The components of GAIA are presented in the sections below.

8.3.1 Abstraction Specific Tests

Abstraction Volume (Test AS1)

The abstraction volume does not require GIS assessment and should be used as the initial guide to determine risk. Consideration of both peak daily volume and total annual volume would be appropriate. Higher volumes abstracted from a groundwater body result in a higher risk of impacts on other receptors (surface features, existing users or the groundwater body).

Drawdown on Existing Groundwater Abstractions (Test AS2)

GIS tools could be used to calculate an accumulated drawdown effect from all existing abstractions across the groundwater body. A proposed abstraction would be included in this calculation and assessment made of the increase in drawdown effects on the existing abstractions. Calculations would require estimations of transmissivity, storage and a ‘hydraulic connection factor’ for the groundwater bodies and impacted receptors.

Applications for which the GIS test indicates an increase to the accumulated drawdown of, say, 1% of the existing drawdown would be considered to be at medium risk and 10% at high risk.

Local Groundwater Dependent Features (Test AS3)

Local groundwater dependent features may be local springs, ponds, wetlands which are not identified within the quantitative status assessment of the groundwater body but which are existing features within the natural hydrological ecosystem and require protection.

The drawdown and flow diminishing effect of the existing abstractions and the proposed abstraction should be considered on these features.

8.3.2 Quantitative Status Tests

Groundwater Abstraction Recharge Ratio (Test QS1)

Groundwater abstraction recharge ratios (GWABS/RECHs) need to be calculated for each groundwater body and once calculated the results can be built into a GIS interface. Proposed groundwater abstractions would be added into the calculated GWABS/RECH and the thresholds presented in Table 2 applied. An abstraction causing the

GWABS/RECH threshold to be exceeded would not necessarily be refused but a higher risk rating could be applied and a greater assessment required.

The same GWABS/RECH thresholds could also be applied within defined receptor centred buffer zones. In addition, equivalent recharge circles calculated for each abstraction would assist in assessing the abstraction pressure in areas of the groundwater body.

Groundwater Levels (Test QS2)

Areas of known falling groundwater levels can be included as a GIS layer. Applications within these areas would fall into a High Risk category and may be immediately rejected (presumption against) unless those applications were, for example, for river support, spring or wetland compensation or aquifer recharge schemes.

Saline Intrusion Buffer Zone (Test QS3)

Buffer zones around the coast, areas of known saline intrusion and areas of poor groundwater quality (e.g. historic mining areas) can be built into the GIS. The buffer zones could be sized based on aquifer properties (e.g. lower transmissivity or higher specific yield results in a smaller buffer zone). Applications within these buffer zones would result in a higher risk classification and consequently increased justification.

SWB Flow Impact Assessment (Test QS4)

The impact of a proposed abstraction on the flow in the river should be calculated. This could be estimated from a simple proportioning of the abstraction between water features within the catchment. This would be appropriate for many unconfined near surface fracture flow groundwater bodies in Scotland, NI and the RoI.

Buffer zones, based on aquifer transmissivity and storage, could be appropriately applied to SWB receptors. However, it should be recognised in the assessment that the effect of a groundwater abstraction could extend beyond any ascribed buffer zones.

Use of Low Flows 2000 and other tools to look at the Q95 and Q70N impacts.

GWDTE Flow and Level Impact Assessment (Test QS5)

For the assessment of flow impacts on identified GWDTEs a procedure such as that developed for the SWBs is appropriate.

Impacts on the groundwater levels within a GWDTE could be assessed using GIS based tools accumulating drawdown from 200 day Theis calculations at centroids of GWDTEs. These require the estimation of Transmissivity, Storage and a Hydraulic Connection Factor ‘HCF’ for each receptor site.

8.3.3 Conclusions from the Tests

It is proposed that the *highest* risk classification indicated by any of the tests would be used to determine the appropriate level of further assessment required to determine the application (effectively a ‘one out, all out’ combination rule similar to that proposed for status classification). These further assessments are outlined in Section 8.4.

An alternative approach to the combination of Table 8 test results could be to score them individually and then add the scores together, optionally weighting those considered to be most significant, with the final level of risk indicated by banding of the total score. This is being considered by the Environment Agency as part of the 'Streamlining Abstraction Processes' initiative to determine the likely time for abstraction licence determination.

8.4 Further Assessment to Determine the Application

8.4.1 Introduction

The purpose of the further assessment is to improve the conceptual understanding (and consequently reduce the uncertainty) to the point at which the regulator has a high enough level of confidence with which to determine the application.

This further assessment will include use of one or more of the tools identified below:

- Site specific or catchment wide water features survey;
- IGARF/SPIGARF Impact Assessment;
- Receptor Distance Drawdown Analysis;
- Pumping test and monitoring; and/or
- Numerical model.

These tools are outlined in the sections below.

8.4.2 Water Features Survey

A water features survey is a component to the development and understanding of the conceptual model for the catchment. Full guidance on the requirements for a water features survey is presented in the Environment Agency HIA Report (EA, 2003).

Water features as receptors within the defined catchment area of the abstraction would be identified on a map of the catchment. These water features need to be tabulated in the following groups:

- Boreholes, wells and other groundwater abstractions (e.g. arterial drainage). What are the total depth, screened depth and water level within each of the existing abstractions (the regulator will hold information on this);
- Spring, seepages and issues. Location, flow volume, ordnance survey elevation;
- River, stream, burn reaches. It is important for the assessment to determine if there is a groundwater-surface water interaction (e.g. Is the stream influent/effluent or is the river is perched?). Evidence of groundwater levels from other local boreholes or springs close to the river, together with the hydrogeological conceptual understanding will assist with this;
- GWDTEs – fens, wetlands, bogs and turloughs.

Hydrochemical information, if available, may assist with the conceptual understanding of the catchment. For example groundwater with differing hydrochemical signatures may indicate different recharge scenarios or resident time scales. Hydrochemistry may also indicate interaction with surface water bodies or GWDTEs.

The sensitivity of each of the identified receptors to changes in groundwater level and flow should be assessed. For some of the receptors this work will link with the surface water body status assessment or the consideration of ecological effects to GWDTEs. However, some proportioning of the abstraction between flows to each of the identified receptors should be attempted. It is likely that this cannot be automated and will require expert judgement.

It is considered that this work would normally be completed by the applicant and submitted for review to the regulator.

8.4.3 IGARF, SPIGARF and Distance-Drawdown Analysis

IGARF (Impacts from Groundwater Abstractions on River Flows) or SPIGARF (spatial IGARF) can be used, where sensitive receptors have been identified (e.g. from the water features survey) to determine the proportion of the river or wetland flow which would be reduced by the abstraction.

IGARF is a spreadsheet based methodology developed by the Environment Agency (EA, 1999). It uses the analytical solutions of Theis, Hantush or Stang, dependent on the aquifer type to determine potential impacts on surrounding receptors from a proposed abstraction. As such, the methodology is suitable as a scoping tool but should not be used in isolation. It is better suited to aquifers where Darcian flow conditions dominate and should therefore be used in catchments where karstic or shallow fracture based flow conditions and low storage dominates with caution.

SPIGARF is a GIS based calculation of the IGARF algorithms and therefore carries the same health warnings.

8.4.4 Distance Drawdown Assessment

A desk based distance drawdown assessment using simple analytical tools should be considered. This is useful for determining suitable monitoring locations for a proposed pumping test and estimating level impacts on GWDTEs and offline lakes (e.g. turloughs). However, the analytical solutions cannot provide site specific predictions and results should not be used inappropriately.

An example of an unconfined and confined distance drawdown spreadsheet is presented in Appendix II.

8.4.5 Pumping Test & Monitoring

Advice on the requirements for a pumping test are presented in the Environment Agency HIA report (EA, 2003). There is a general consensus that pumping tests should be requested, where appropriate, to improve the understanding of groundwater bodies in Scotland, NI and the RoI. However, it should be noted that the pumping test is not, on its own, enough to make a decision on an application for abstraction unless that test has been for an extended period through drought groundwater conditions. The pumping test should be viewed as contributing to the conceptual understanding of the system.

It is proposed that the length of the pumping test is linked to the risk assessment of the proposed abstraction (see Figure 7). This risk should also determine the need for purpose drilled monitoring boreholes, radius of investigation and level of interpretation of the test.

Medium Risk Abstraction Applications

It is proposed for an applications considered to be of medium risk that an 8-hour pumping test is a reasonable request for the applicant by the regulator. The pumping test should commence with a step test which should increase in four incremental 100 minute steps up to 100% of the proposed abstraction rate. Monitoring would be restricted to water levels within the borehole and any local water features of which there is considered a risk of impact.

High Risk Abstraction Applications

For high risk applications the design of the test should be specific to each application.

Before any fieldwork, a virtual pumping test (EA, 2003) should be completed with initial estimates of aquifer properties to determine at what distance the effects are likely to be observed. Standard pumping test software (e.g. AquiferWin32) can be used for this. The initial test would then guide decisions on monitoring locations and requirements. It should enable the answering of questions such as: Can existing water features be used for monitoring or should monitoring piezometers be requested? It is considered that this initial desk-based virtual pumping test would be conducted by the regulator to guide the requirements for the test from the applicant.

The EA Groundwater Licensing Manual (REF) and the British Standard code of practice for test on pumping water wells (BS 6316:1992) should be referred to for guidance on the planning and execution of pumping tests.

The pumping test should be commenced with a step test to derive some information about well losses and local aquifer properties. The constant rate section of the test should be at the peak daily flow required by the applicant and the total duration of the test should inform the conceptual model (i.e. be sufficiently long to enable the anticipated impacts to be observed). Collection of the data should be planned before the test with data loggers located where impacts are anticipated. Monitoring of hydrochemical data through the test should be considered if this will inform the conceptual understanding (e.g. demonstrate groundwater surface water interactions, intrusions or water from a different hydrogeological unit).

The interpretation technique used to assess the pumping test should be appropriate to the hydrogeological setting (confined, semi-confined or unconfined) and should enable long term prediction of the effects from the groundwater abstraction to be determined. The interpretation of the test should just not be an academic exercise to determine hydraulic parameters.

8.4.6 Numerical Groundwater Modelling

For large abstraction applications or difficult conceptual flow models (complex groundwater – SW relationships, layering, in combination, many receptors) with potential high risks to sensitive receptors then a numerical groundwater model such as MODFLOW (McDonald and Harbaugh, 1988) could be considered.

This could be undertaken either by the developer (under guidance from the regulator), the regulator or a consultant employed by either party. Time for completion of this work could range from several weeks through to several months.

8.5 Issues in Hard Rock and Karstic Flow Regimes

Applications for groundwater abstraction in both hard rock (i.e. low transmissivity basement bedrock) and karstified aquifers requires a number of additional considerations to be determined by the applicant and/or the regulator. These are discussed below.

8.5.1 Hard Rock Hydrogeology

Hard rock aquifers are dominated by fissure and fracture flow within shallow zones. Effects of abstraction are often very localised and consideration of the application beyond the immediate environs of the borehole may not be required. The sustainable yield from a borehole will be dependent on the interception of permeable (fracture and fissure) zones. Initial yields from the borehole may be a poor indicator of the long term yield due to dewatering of the fractures and fissures in connection with the borehole. Pumping tests may not therefore be applicable and the regulator/applicant may obtain better information from the specific capacity of other boreholes within the groundwater body. The use of geophysics to locate more permeable fracture/fissure zones may be appropriate to the applicant.

8.5.2 Karstic Hydrogeology

Karstified limestone aquifers present an extreme form of groundwater fracture flow. Drilling for groundwater supply is often difficult and can often result in poor yields. However, where karstic conduits are intercepted significant yields result and the effect of the abstraction can be observed over a wide catchment. Significant abstractions can result in the reversal of groundwater flow over large areas and this should be taken into consideration in the determination process.

There is therefore a higher level of uncertainty in the effects from an applicant abstraction and consequently a need to determine a greater level of conceptual understanding of the baseline (pre-abstraction) flow system and the effected (post abstraction) system. Coastal buffer zones within karstic areas need to be large and based on the conceptual understanding.

The uncertainty can make the definition of adequate monitoring difficult and the relationship of surrounding water features (lakes, turloughs, springs) to the conceptual model should be considered when determining monitoring needs.

9 CASE STUDIES

9.1 Introduction

To demonstrate the principles of the initial GIS screening approach proposed in Section 8 four case study examples have been developed. These were chosen to show the range of aquifer types in Scotland and focussed on areas of groundwater abstraction pressure where data are available. One example is located in Northumberland to illustrate the use of some of the data not yet developed in Scotland.

For the purposes of this exercise (hypothetically taking place *after* classification), the case study examples have assumed that the initial characterisation risk assessment results have been translated directly into the classification of groundwater body status.

9.2 Fell Sandstone (Fissured Productive Aquifer)

Groundwater abstractions are located in the Fell Sandstone, Northumberland (see Figure 8). These are used for public water supply to the town and environs of Berwick on Tweed. During the WFD initial characterisation process the Fell Sandstone was identified as having falling groundwater levels. In addition, calculations of equivalent recharge indicated significant abstraction pressure and downstream reaches of SWBs were indicated as being impacted by abstraction pressures in their headwaters. Abstractions within the area of confined Fell Sandstone are applied to the recharge area within the sandstone.

Four fictional applications for abstractions (A-D) have been located in the area as indicated on Figure 8. The applications are assessed in Table 9.

Table 9 Fell Sandstone Abstraction Risk Assessment

Abstraction	Volume (m3/d)	Risk Rating	Comment and Further Assessment Proposed
A	20	Very Low Risk	Abstraction is within a GWB which has exceeded its GWABS/RECH threshold but is away from areas of falling GWLs and SWB pressure. No further assessment proposed. Determine application based on the desk study data available.
B	60	Medium Risk	Abstraction is within area of falling GWLs. Further assessment proposed to include a water features survey and a short term pumping test.
C	60	Low Risk	Abstraction is away from area of falling GWLs but close to effected SWB. However, SWB is affected by abstraction in headwaters. No further assessment proposed. Determine application based on the desk study data available.
D	3000	High Risk	Large abstraction is within the area of falling GWLs. Detailed further assessment proposed to include at least a water features survey and a long term pumping test. High conceptual understanding, possibly requiring numerical modelling will be required to determine application even if abstraction is for a river support scheme.

9.3 Howden Springs (Sand and Gravel Aquifer)

Several large groundwater abstractions are located in the catchment of Howden Springs, near Selkirk, Scottish Borders (see Figure 9). These are located in alluvium deposits along the Ettrick Water just upstream from its confluence with the River Tweed to the west of Selkirk. The Ettrick water has not been classified as 'at risk from groundwater abstraction pressures' but the River Tweed has been classified as having GWDTEs along the river which are 'at risk from abstraction pressures'.

Four fictional applications for abstractions (A-D) have been located in the area as indicated on Figure 9. The applications are assessed in Table 10.

Table 10 Howden Springs Abstraction Risk Assessment

Abstraction	Volume (m3/d)	Risk Rating	Comment and Further Assessment Proposed
A	20	Low Risk	Abstraction is within a GWB which has exceeded its GWABS/RECH threshold but is not identified as having falling GWLs or status impacted SWBs. No further assessment proposed. Determine application based on the desk study data available.
B	60	Medium Risk	Abstraction is close to status impacted SWB/GWDTE. Further assessment to include a water features survey and short term pumping test proposed.
C	60	Medium Risk	Abstraction is within the headwaters of a status impacted SWB. Further assessment to include a water features survey and short term pumping test proposed.
D	3000	High Risk	Detailed further assessment proposed to include at least a water features survey and a long term pumping test. High conceptual understanding, possibly requiring numerical modelling will be required to determine application even if abstraction is for a river support scheme.

9.4 West Peffer (Fissured Productive Aquifer)

The West Peffer catchment is located in East Lothian, south of Berwick Head (see Figure 10). The initial characterisation assessment indicated areas of saline intrusion and status impacted SWBs. Several large existing abstractions are located within the catchment.

Four fictional applications for abstractions (A-D) have been located in the area as indicated on Figure 10. The applications are assessed in Table 11.

Table 11 West Peffer Abstraction Risk Assessment

Abstraction	Volume (m3/d)	Risk Rating	Comment and Further Assessment Proposed
A	20	Low Risk	Abstraction is within a GWB which has exceeded its GWABS/RECH threshold but is not identified as in an area of falling GWLs, saline intrusion or status impacted SWBs. No further assessment proposed. Determine application based on the desk study data available.
B	60	Medium Risk	Abstraction is close to status impacted SWB. Further assessment proposed to include a water features survey and a short term pumping test.
C	60	Medium Risk	Abstraction is within an area of identified saline intrusion. Further assessment proposed to include a water features survey and a short term pumping test.
D	3000	High Risk	Detailed further assessment proposed to include at least a water features survey and a long term pumping test. High conceptual understanding, possibly requiring numerical modelling will be required to determine application even if abstraction is for a river support scheme.

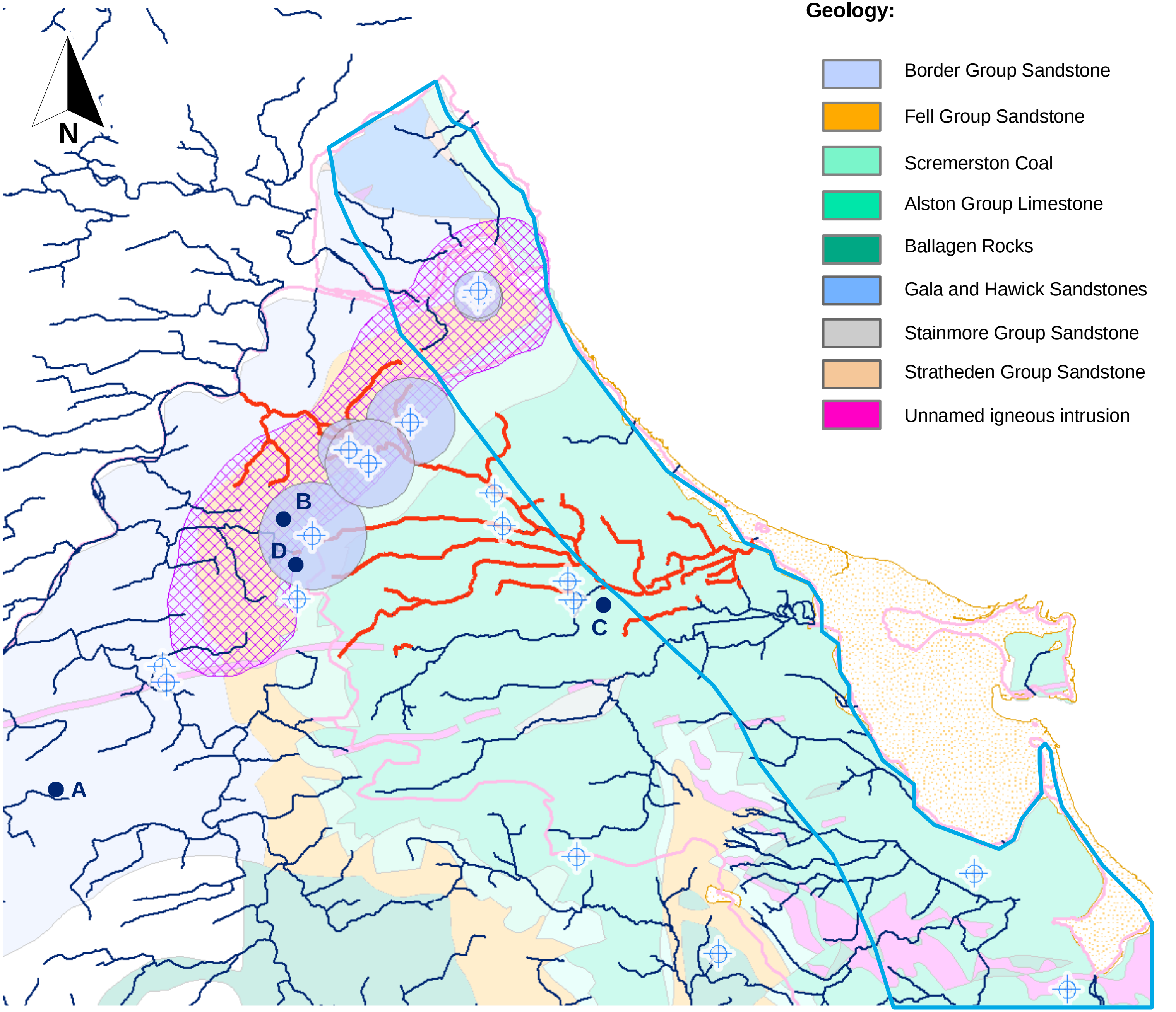
9.5 Lochcarron, Torridon Sandstone (Poorly Productive Aquifer)

The Torridon Sandstone has small groundwater abstractions developed for local domestic and industrial (fish-farming) supply (see Figure 11). The aquifers will not support large groundwater abstractions and can be considered as self regulating. There is potential for localised impact on sensitive SSSIs.

Four fictional applications for abstractions (A-D) have been located in the area as indicate on Figure 11. The applications are assessed as follows:

Table 12 Lochcarron Abstraction Risk Assessment

Abstraction	Volume (m3/d)	Risk Rating	Comment and Further Assessment Proposed
A	20	Very Low Risk	Abstraction will not cause effect to SWBs or GWDTEs. No further assessment proposed. Determine application based on the desk study data available.
B	60	Medium Risk	Abstraction is close to SSSI. Further assessment proposed to include a water features survey and short term pumping test.
C	60	Medium Risk	Abstraction is within an area of potential saline intrusion. Further assessment proposed to include a water features survey and short term pumping test.
D	3000	High Risk	Large abstraction proposed within an aquifer unlikely to deliver the required yield. Discussion with applicant proposed.



WFD53 Groundwater Abstraction Framework

Figure 8
Berwick Catchment

November 2005
14722 HAREE

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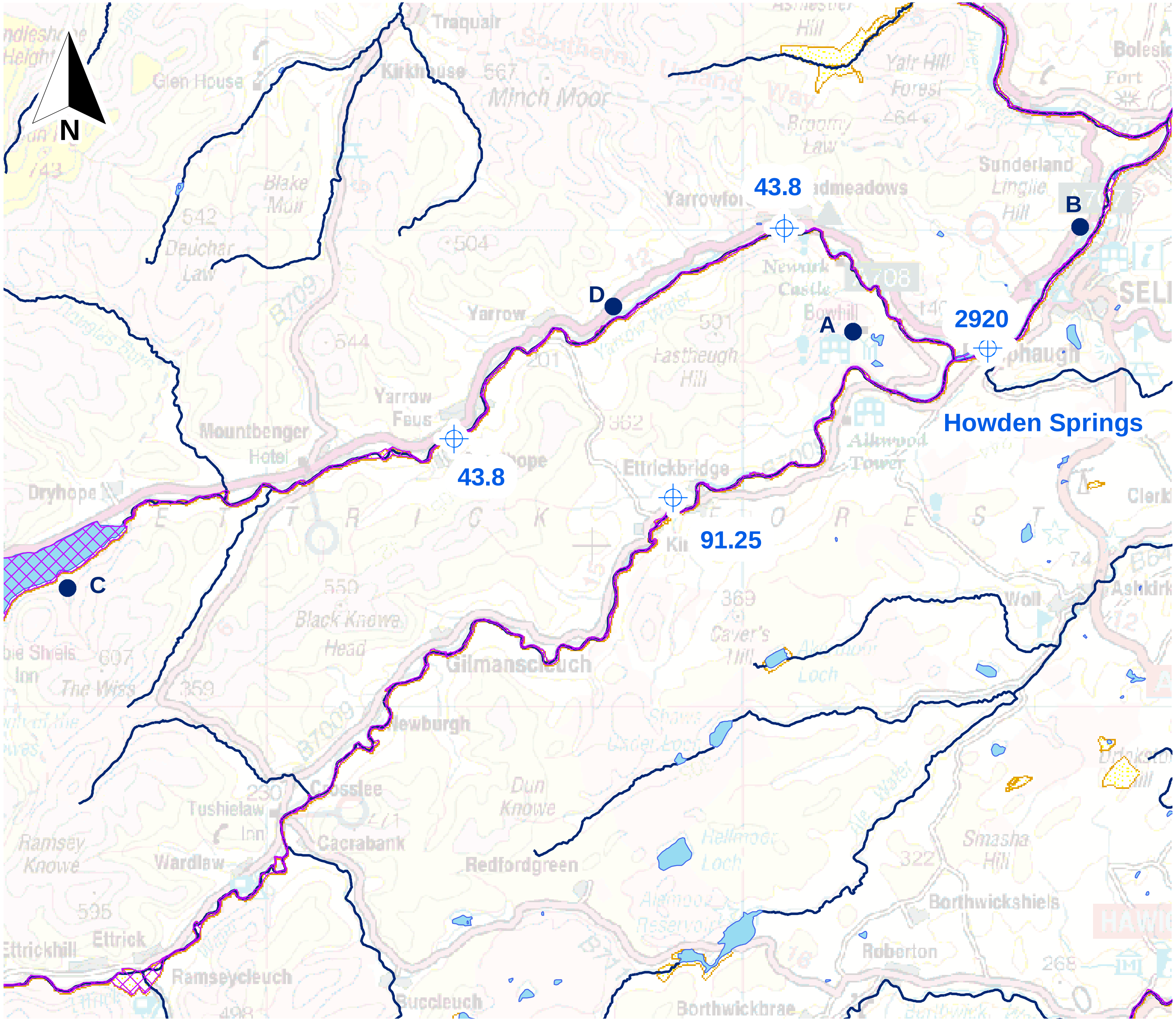

Key:

Existing Abstraction Boreholes (Annual Yield-ML/a)

Lakes

Areas of SSSI

Main Rivers (SEPA Classification 2001)

GWDTEs with Groundwater Abstraction Pressures

Surface Water bodies with Groundwater Abstraction Pressures

Fictional Proposed Groundwater Abstraction

0 5,000 Meters

Scale: 1:125000 @ A4

WFD53 Groundwater Abstraction Framework

Figure 9
Howden Springs Catchment

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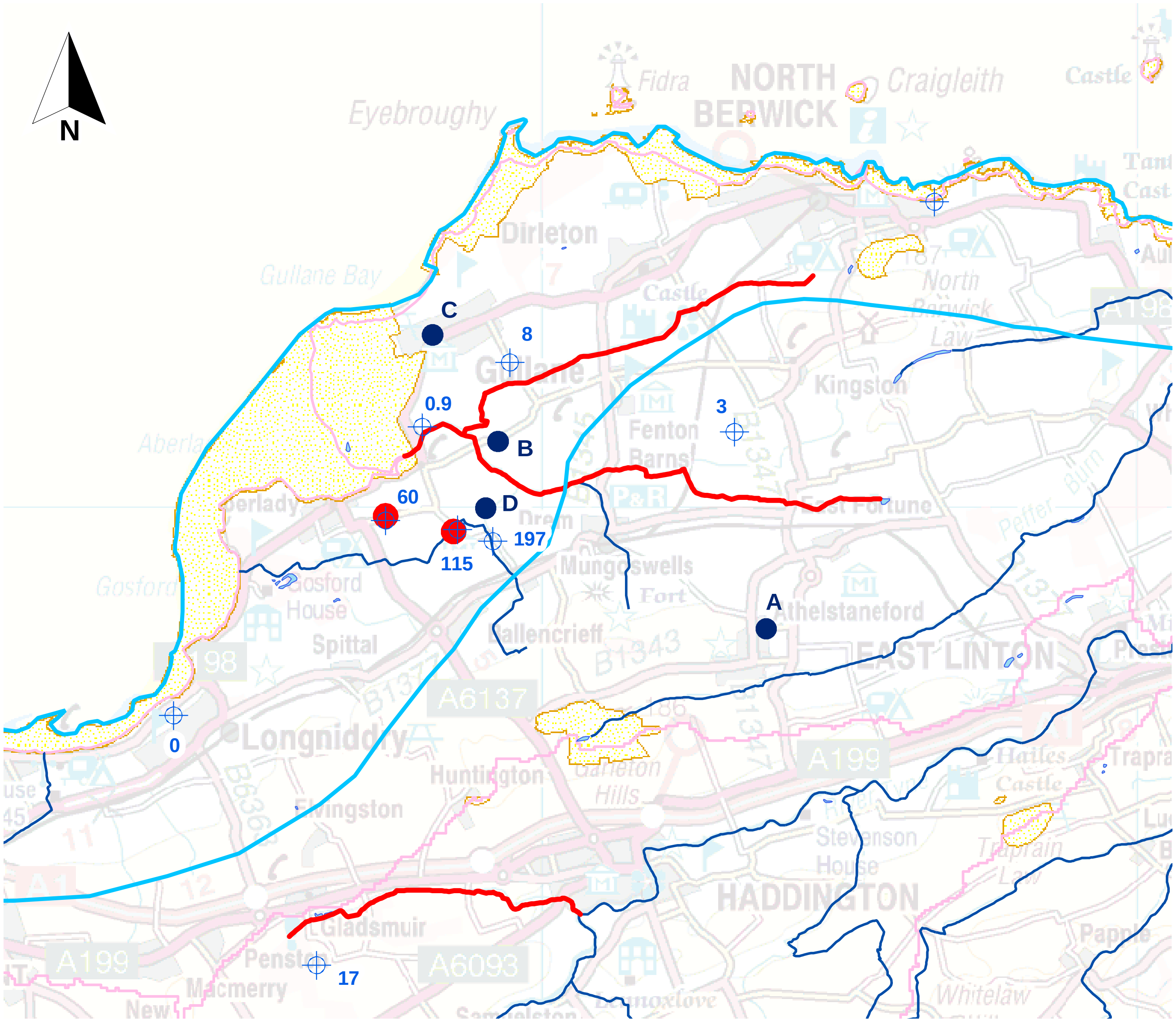

Key:

- Existing Abstraction Boreholes (Annual Yield-ML/a)
- Groundwater Body Boundaries
- Lakes
- Areas of SSSI
- Main Rivers (SEPA Classification 2001)
- Surface Water Bodies with Groundwater Abstraction Pressures
- Indicators of Saline Intrusion (EC> 1000uS/cm in >25% samples)
- Saline Intrusion Buffer Zone
- Fictional Proposed Groundwater Abstraction

0 2500 5000 Meters

Scale: 1:100000 @ A4

WFD53 Groundwater Abstraction Framework

Figure 10
West Peffer Catchment

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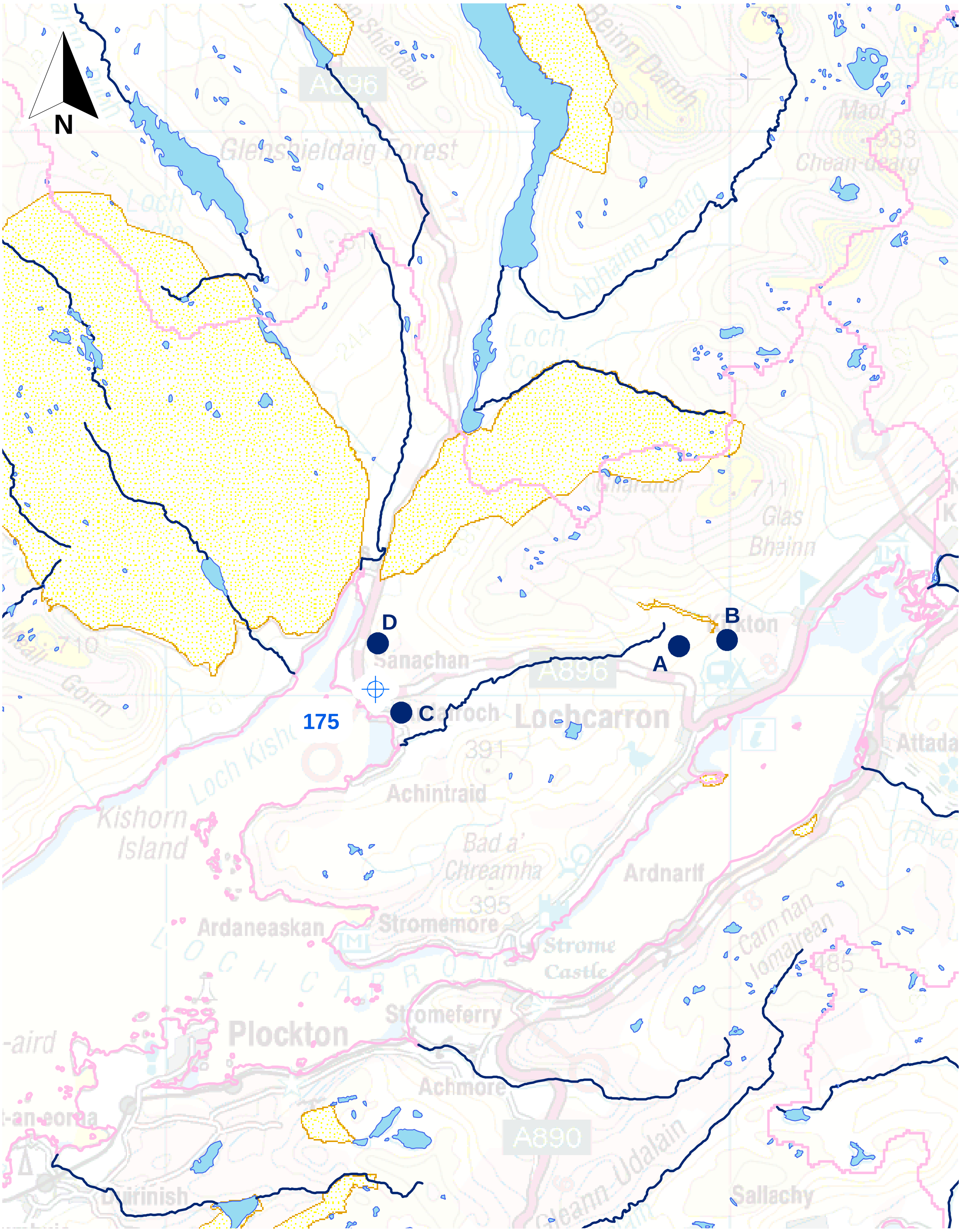

Key:

- Existing Abstraction Boreholes (Annual Yield-ML/a)
- Areas of SSSI
- Groundwater Body Boundary
- Main Rivers (SEPA Classification 2001)
- Lakes
- Fictional Proposed Abstraction Boreholes

0 1,250 2,500 5,000 Meters

Scale: 1:100000 @ A4

WFD53 Groundwater Abstraction Framework

Figure 11
Loch Carron Catchment
(Torridon Sandstone)

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11 GLOSSARY OF TERMS

Aquifer	Any rock type that allows a significant flow or contains significant quantities of groundwater for **abstraction**. A subsurface layer or layers of rock or other geological strata of sufficient porosity or permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater.
Aquifer Response Type	Anticipated rate at which the aquifer is expected to respond to a change in pressure. This applies to both chemical and quantitative pressures.
'available' groundwater resource	The long term annual average rate of overall recharge of the body of groundwater less the long term annual rate of flow required to achieve the ecological quality objectives for associated surface waters specified under Article 4, to avoid any significant diminution in the ecological status of such waters and to avoid any significant damage to associated terrestrial ecosystems.
Competent authority	SEPA (Scotland), EA (England and Wales), EHS (Northern Ireland), EPA (Ireland)
Environmental objectives	Objectives set out in Article 4.
Framework	Defines the way the structure in which the evaluation tools proposed are used and how users interface with the tools.
Good Groundwater Status	The status achieved by a groundwater body when both its quantitative and its chemical status are at least good.
Good quantitative status	The status defined in table 2.1.2 of Annex V.
Groundwater	All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.
Groundwater body	Distinct volume of groundwater within an aquifer or aquifers
Groundwater Body Exposure Assessment	An assessment of the whole groundwater body to the pressure of abstraction from the groundwater body.
Groundwater status	The general expression of the status of a body of groundwater determined by the poorer of its quantitative and its chemical status.
Measure	A process implemented with the purpose of achieving 'Good Status'.
Poor status	See Threshold Value
Pressure	Is an activity which results in '**stress'** (chemical or quantitative evidence of the pressure) to a groundwater body
Protected area	Areas lying within each river basin district which have been designated as requiring special protection under specific Community legislation for the protection of their surface water and groundwater or for the conservation of habitats and species directly depending on water.
Protected area objective	Member States shall achieve compliance with any standards and objectives at the latest 15 years after the date of entry into force of this Directive, unless otherwise specified in the Community legislation under which the individual protected areas have been established.
Programme of Measures	The measures applied to a River Basin and published within the River Basin Management Plan with the purpose of achieving Good Status.
Quantitative status	An expression of the degree to which a body of groundwater is affected by direct and indirect abstractions.
Receptor Impact Assessment	An assessment of the evidence within a groundwater body and dependent receptors for stress including ecological indicators in wetlands and river reaches.
River Basin District	The area of land or sea, made up of one or more neighbouring river basins together with their associated groundwaters and coastal waters which is identified under Article 3(1) as the main unit for management of river basins.
Stress	A ***'stress'*** is normally identified through monitoring (e.g. water levels or flow).

Threshold value	Means a concentration limit for a pollutant in groundwater, exceedance of which would cause a body of groundwater or groundwater bodies to be characterised as having poor chemical status.
Tool	A '***tool***' is an approach, algorithm or model that evaluates the groundwater recovery.

APPENDICES

Appendix I Aquifer Response Function

Appendix I Aquifer Response Function

Aquifer Response Function

The aquifer response function is based on the Dupuit approximation to one-dimensional groundwater flow. It can be used to estimate recharge to and baseflow from an idealised unconfined aquifer based on groundwater heads and aquifer parameters. The one-dimensional linearised version of the Dupuit equation is:

$$\frac{\partial}{\partial x}\left(T(x)\frac{\partial h}{\partial x}\right) = S\frac{\partial h}{\partial t} - q(x,t) \tag{1}$$

where

- h(x,t) is groundwater head (m);
- t is time (d);
- x is distance (m);
- q is recharge (m/d);
- T is aquifer transmissivity (m^2/d); and
- S is aquifer storage coefficient (dimensionless).

An idealised aquifer receiving annual sinusoidal with one end as a no flow boundary (e.g. a watershed) and the other as a constant head boundary signifying a river is represented in Figure 5.1. The annual recharge fluctuations for this aquifer can be approximated to:

$q(x,t) = q_A(1-\cos wt)$ (2)

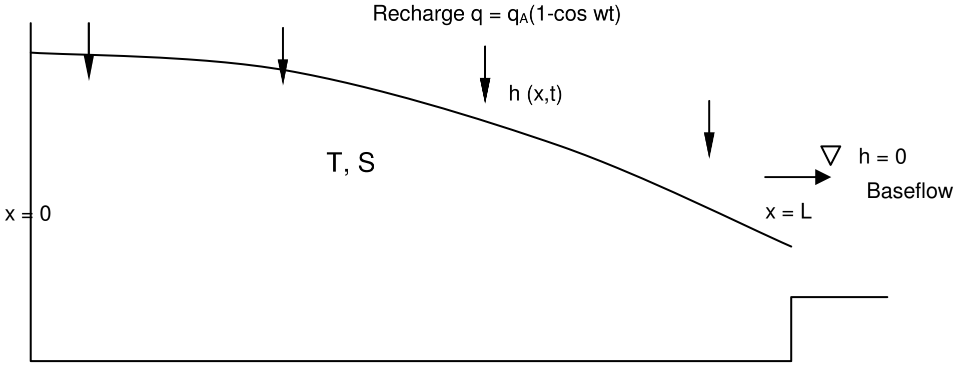
where:

$w = 2\pi/365$ and q_A is annual recharge expressed as m/d.

The above was solved for a steady-state solution (Erskine and Papiannaou, 1997) to:

$h = -q_A(x^2-L^2)/2T$ (3)

Figure A.1 Idealised aquifer receiving recharge



1. CALCULATION OVERVIEW

An overview of the assumptions and input parameters used to calculate natural recharge derived groundwater outflows from a GWMU by the ARF approach has been described in Section 8 (Test 2) within the main User Manual. Recharge data in mm per month are converted to Ml/d flows according to surface water catchment and groundwater catchment areas. This water is then routed through the GWMU as karstic groundwater flow, which is assumed to flow out of the GWMU during the month of rainfall, or as 'slow groundwater flow' which discharges according to the aquifer response function (ARF). The karstic and slow groundwater discharge responses are re-combined and reported/plotted as the groundwater outflow from the GWMU.

It is important to emphasise that whilst the ARF calculations in the spreadsheets provide a simple 'first pass' indication of groundwater outflows, the RAM Framework does not rely on these estimates. If the user has access to a calibrated groundwater Model or to a reliable groundwater baseflow series, this can be used to override the ARF calculation results.

2. CALCULATION OF THE 'SLOW' GROUNDWATER OUTFLOW RESPONSE TO RECHARGE USING THE AQUIFER RESPONSE FUNCTION

2.1 Background - Response to Sinusoidal Recharge Input (Calculations used in CAMS Ledger Spreadsheet)

The theory behind the aquifer response function concept, which was first developed as part of previous Agency R&D work on groundwater reliable yield, is presented in Erskine & Papaioannou (1997). In this paper a simple idealised one-dimensional aquifer is assumed with a sinusoidal recharge on an annual cycle varying around a mean value, say *q*, with amplitude also set to be *q*.

It is shown that the resultant baseflow to the river is also a sine wave around the equivalent mean (*q*L per unit length of river where L is the distance of the river from the aquifer edge). However the amplitude has been decreased by a factor and a time lag is also imposed.

The equation of the flow to the river can be shown to be:

$$Q(t) = qL(1+A\cos\omega t+B\sin\omega t)$$

with $A = \dfrac{\sin u + \sinh u}{u(\cos u + \cosh u)}$ and $B = \dfrac{\sin u + \sinh u}{u(\cos u + \cosh u)}$

and $u^2 = 2L^2S\omega/T$

where

ω is the angular frequency, $2\pi/365$ in this case (/d)
T is the aquifer transmissivity (m^2/d)
L is the distance from river to groundwater divide (m)
S is the aquifer storage (dimensionless)

The aquifer response time is usually defined as L^2S/T, in units of time. Aquifers can be categorised as 'fast' or 'slow' in terms of their response time and this concept is very useful in understanding such systems.

The flow can therefore be evaluated on the 15th day of each month. However, in order to improve accuracy over the length of a month and be able to take account of different month lengths, the integrated version of the above equation can be used.

If equation (1) defines the flow then the average flow from t_1 to time t_2 is determined by:

$$Q = qL\left(1 + \frac{A(\sin\omega t_2 - \sin\omega t_1) + h\,(\cos\omega t_1 - \cos\omega t_2)}{\omega(t_2 - t_1)}\right) \qquad (2)$$

In reviewing this earlier work during the current research it was considered that the sinusoidal representation of recharge inputs was too simplistic. Monthly effective rainfall data are readily available across the country for each MORECS 40 km by 40 km square and a method was sought to use these monthly data or other Agency generated recharge data to generate a monthly baseflow response.

2.2 Unit Response to Monthly Recharge Inputs

In order to take account of individual events a solution for the unit response curve has been sought. It turns out that such a solution exists, can be expressed as a sum of a series and moreover is fairly easy to compute.

Suppose for the one-dimensional aquifer with transmissivity *T*, storage *S* and length *L*, a recharge event occurs at time t_1 of magnitude q_0 and continues indefinitely. The resultant flow to the river can be shown to be:

$$Q(t) = \begin{cases} 0 & t < t_1 \\ q_o L A(\beta(t - t1) & t > t_1 \end{cases} \qquad (3)$$

where $A(x) = 1 - \frac{8}{\pi^2}\sum_{n=1,odd}^{8}\frac{\exp(-n^2 x)}{n}$

and $\beta = \pi^2 T / 4SL^2$

This appears to be a very useful result which has not been noted in the literature. The function *A(x),* which will be referred to as the **aquifer response function**, takes the value 0 when $x = 0$ increasing monotonically to 1. The series converges fairly quickly for most values of *x* except when *x* gets very small. In practice this is not a problem over the range of values of β generally encountered since when x is smaller than a certain value the function can be set to zero.

A macro has been attached to the GWMon spreadsheets which calculates the value of this function. For non-zero *x*, it can be shown that after a certain number of terms the ratio of succeeding terms is getting smaller which means that an upper bound can be set on the sum. Using the value of this upper bound the accuracy of the summation is known. The function in the spreadsheet uses this principle to check that the solution is adequately accurate. At present, the function is set to return an error if the maximum error on the sum is greater than 0.1%.

As before with the sinusoidal solution, to calculate the average flow over a period of time the above solution must be integrated. As before, this allows us to improve accuracy over the length of a month and take account of the different month lengths.

This is not a problem and in fact is to be recommended since the resultant series converges even faster. A second function has therefore been defined called *AI(x)*, the *integrated aquifer response function* as follows:

where $$AI(x) = \frac{\pi^2}{12} = \frac{\pi^2}{8} \sum_{n=1,odd}^{8} \frac{\exp(-n^2 x)}{n^4} \qquad (4)$$

The constant ensures that the function is zero when $x = 0$. This function has also been set up as a macro attached to the spreadsheets, again returning an error if the maximum error in the function is greater than 0.1%.

The average flow to the river during a period t_3 to t_4 caused by a recharge, q, over an earlier period t_1 to t_2 is therefore:

$$Q = \frac{qL}{\beta(t_4 - t_3)} \left[AI(\beta(t_4 - t_1)) - AI(\beta(t_3 - t_1)) - AI(\beta(t_4 - t_2)) + AI(\beta(t_3 - t_2)) \right] \qquad (5)$$

This expression can be used to calculate the flow in a period by considering all the previous recharge history as a series of flow events and superimposing. This is a relatively easy task using spreadsheets.

Recharge rates *(q)* passed through the ARF are converted from mm/month to Ml/d by dividing the monthly effective rainfall by the number of days in the month, removing the runoff and karstic flow fractions and then by multiplying by the groundwater catchment area. Transmissivity *(T)* in m^2/d and Storage *(S)* are defined by the user (copied into the GWMon spreadsheet from the CAMS ledger spreadsheet). The one dimensional effective aquifer length (L) is calculated by dividing the groundwater catchment area by twice the length of the discharge boundary which may be a river or the coast and is defined in kilometres. This approximation becomes increasingly unreasonable for more irregular aquifer geometries.

2.3 Repeated 'Average Year' Solution (Calculation Used in GWMon Spreadsheet)

In order to calculate the groundwater outflow in an 'average year', two approaches are possible:

- Use the sinusoidal solution
- Use a repeated cycle of average monthly recharge values. If repeated 10 times the result will usually have reached a quasi-steady state (as long as the aquifer response time is not too large).

The advantage of the first approach is that it is easy to compute. The second approach is not restricted to sinusoidal recharge but has the disadvantage that the input curve is flat-topped.

The spreadsheets use the second approach of a repeated annual cycle. For each month in the tenth (last) year, the flows deriving from each previous period of recharge (of which there are at least 108) are calculated according to equation (5). The flow deriving from the current period is also added in - this can be generated with the same formula as long as *AI(x)* is defined to be zero for *x*<0.

The monthly distribution of recharge which (together with the karstic % split) defines the recharge to be passed through the ARF for this 'average year' can be specified by the user within the spreadsheet as a series of 12 monthly factors by which the long term annual average recharge is multiplied. These factors can be derived for any area by dividing the average of all the January recharge values by the long term annual average, and then doing the same for February, March etc. 'National average' default factors have been provided within the spreadsheet templates base don an analysis of MORECS monthly effective rainfall for grass data reported over the period 1961 to 1996 for 5 squares across the country. The factors are averages for MORECS squares numbered 109, 129, 135, 169, 179 and 184.

2.4 Calculation of Slow Groundwater Outflow for the Specified Assessment Year (Calculation used in GWMon spreadsheet)

It is straightforward to modify the 'average year' approach to deal with a specific year. The user simply enters 10 years of monthly recharge values, in the units mm/month into the data entry cells in **column AX** of the 'Illustrative Year Data for Plots' sheet of the GWMon workbook. Superposition of the response of recharge in each of the preceding months allows the resulting groundwater outflow in the 9th and 10th years to be calculated.

The inaccuracies introduced by only considering the previous 9 years are likely to be extremely small for most aquifers and will certainty be insignificant in comparison to the effects of various simplifying assumptions required to model a real aquifer according to this simple one dimensional analysis.

2.5 Reference

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