Final Report **Project WFD25**

Derivation of a Methodology for the Assessment of Groundwater Recovery Times to Achieve Good Status: Tests for Feasibility and Disproportionate Cost

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FINAL REPORT

October, 2004

Entec UK Limited

Report for

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Statement of Use

This document is a research and development (R&D) report and is not, therefore, formal guidance for the Environment Agency (England and Wales), Scottish Environment Protection Agency and Environment Heritage Service of Northern Ireland. This document is intended to form a starting point which will help to inform the above agencies when applying the Articles within the Water Framework Directive. In particular, the application of time scale extensions and less stringent objectives.

Derivation of a Methodology for the Assessment of Groundwater Recovery Times to Achieve Good Status: Tests for Feasibility and Disproportionate Cost

Entec UK Limited, August, 2004.

WFD25

Key Words: Groundwater, Recovery Timescales, Water Framework Directive

Executive Summary

This project was initiated by the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER). Its purpose was to propose a framework for the technical and economic assessment of groundwater recovery timescales to achieve Water Framework Directive 'good environmental status'.

This document is a research and development (R&D) report and is not, therefore, formal guidance for the Environment Agency (England and Wales), Scottish Environment Protection Agency and Environment Heritage Service of Northern Ireland. This document is intended to form a starting point which will help to inform the above agencies in the assessment of groundwater recovery timescales.

Under the Water Framework Directive timescale, good environmental status for surface water and groundwater bodies is to be achieved by December 2015. An **extension to the timescales** of two river basin management plan cycles (i.e. up to December 2027) can be invoked to allow phased achievement of the environmental objectives provided that no further deterioration in the status of the affected water body occurs.

In addition, **less stringent objectives** can be set for a groundwater body where achievement of the environmental objectives by 2027 are technically unfeasible or disproportionately expensive. These less stringent objectives must be the least possible deviation from the 'good groundwater status' and it is intended that the objectives would work towards 'good environmental status' for the water body. Applications for both timescale extensions and for less stringent objectives will require technical and economic justification to Europe.

Groundwater bodies likely to require less stringent objectives will be identified in the initial characterisation reports (December 2004) and the actual less stringent objectives will be specified in each river basin plan. Failure to achieve these less stringent objectives would be a breach of the WFD.

The requirement for either timescale extensions or less stringent objectives will depend on the type, history and extent of the existing pressure (chemical or quantitative) and the ability of the groundwater body or affected receptor to recover from this pressure under an implemented measure or combination of measures.

A clear conceptual understanding of processes within the groundwater body is important to determine the level of uncertainty in the groundwater recovery estimation. Key influences on the recovery time of the groundwater body will be the residence time within the overlying strata and unsaturated aquifer and the rate of flushing through the saturated aquifer.

A framework is presented which details the assessment process from initial characterisation, through further characterisation to the submission and revision of the river basin management plans.

For the initial characterisation, a **basic assessment** is proposed which will, through categorisation primarily based on expert opinion, identify those groundwater bodies likely to require timescale extensions or less stringent objectives. This basic assessment uses a risk scoring matrix system to consider the influence of the pressure giving rise to failure to achieve 'good status' and the likely recovery timescales for the recovery of the groundwater body or affected receptor.

For the further characterisation and revision of the river basin management plans more **detailed assessments** are proposed which will provide an estimation of the times to achieve good environmental status (recovery times) and less stringent objectives, where required. The detailed assessments will consist of three tiers of calculation where Tier 1 is a simple calculation; Tier 2 is a spreadsheet based flushing cell (chemical) or aquifer response calculation and Tier 3 is a distributed model. Tools for the implementation of these three tiers are suggested. It is intended that these tiers are implemented sequentially and that the subsequent tier is utilised where the uncertainty in the outcome from the previous tier justifies it.

Lastly, a framework for the **economic justification** of proposed recovery measures is detailed. It will be necessary to present reasons of disproportionate cost to the European Commission where technically feasible measures are not implemented and where this leads to requirements for either a timescale extension or the setting of a less stringent objective.

It is proposed that the cost-effectiveness of measures can be assessed by considering the range of likely costs, the expected impact on concentrations of contaminants or quantitative status by 2015, and the timescale thought to be required to meet WFD environmental objectives.

Contents

1. Introduction

1.1 Introduction

Under Annex II (2.4 and 2.5) of the Water Framework Directive (WFD), those groundwater bodies for which lower objectives are to be specified must be identified and included in the Article 5 report, to be completed by December 2004. The Article 5 document details the results of initial characterisation, the review of the impact of human activity and the economic analysis of water use.

Recovery times are important in the assessment of whether timescale extensions to attain ‘good status objectives’, as allowed for under Article 4.4 of the WFD, are likely to be needed, as well as the feasibility of meeting the trend reversal objective for groundwater.

The determination of lower objectives, as allowed under Article 4.5 of the WFD, is a key issue as many groundwater bodies that are identified as likely to fail their good status objectives will not be capable of recovery to meet these objectives within the timescales required by the WFD.

The aim of this project is to derive a framework and methodology for the assessment of groundwater recovery times to achieve good status and, where appropriate, to identify the circumstances where less stringent environmental objectives will be needed. It was initiated and is funded through the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER) and is managed by a steering committee which includes representatives from the Scottish Environment Protection Agency (SEPA), Environment and Heritage Service Northern Ireland (EHS) and the Environment Agency of England and Wales (EA). The environmental agencies are all funding member contributors to SNIFFER and it is intended that outcomes from the project have application throughout the UK.

1.2 Project Objectives

The objectives of the project as specified in the Invitation to Tender (WFD 25) can be summarised as follows:

- **Phase 1**: To develop a framework for determining the technical feasibility of groundwater recovery to good status within the timescales specified in the directive (2015, 2021 and 2027);
- **Phase 2**: To provide a methodology for identifying appropriate less stringent environmental objectives where groundwater recovery by 2027 is not feasible; and
- **Phase 3**: To develop guidance on selecting the most cost-effective combination of measures technically capable of achieving good groundwater status, and the application of economic tests to assess the applicability of either time derogation or less stringent objectives.

Developing assessment tools to determine trend reversals was not specified in the WFD 25 project brief and appropriate methodologies have not been developed in this report. For completeness the current understanding of trend reversals are detailed in the background to the project (Section 2).

Additional objectives for the project were identified as:

- To review relevant research and existing assessment methodologies in the context of WFD requirements and data availability constraints (including consultation with experts from other organisations involved in similar work);
- To identify data requirements and associated availability and confidence issues, and where necessary to recommend improvements in data acquisition; and
- To provide guidance on the developed methodologies.

It is intended that the final document should provide guidance to the agencies on the techniques available for the calculation and justification of recovery timescales and appropriate 'less stringent' environmental objectives. These may be used to support proposed extensions of timescales under Article 4.4 of the WFD and specifications for any 'less stringent' objectives under Article 4.5. The work would also underpin any recommendations to UK Government concerning potential breaches of the WFD due to long recovery times and any potential need for formal derogations from the Directive.

The project is not aimed at identifying specific groundwater bodies which will require time extensions or less stringent objectives but rather deriving the framework and identifying the tools and associated guidance required to facilitate this identification. It is also not intended to provide these tools ready prepared for use. Discussion with SEPA and the EA has indicated that this will be the result of further work.

1.3 Purpose and Layout of This Report

This report documents the findings of the project. It presents an overview of the key issues and makes formal proposals for a framework. It details a background to the relevant Articles of the WFD to give a context to the work and provides frameworks and methodologies for assessment of recovery timescales and less stringent objectives. Guidance on the assessment of disproportionate cost and the cost effectiveness of combinations of measures is also presented.

It is intended that this report should be subject to peer technical review, with approval of the steering committee and suggested consultees are listed in Appendix A.

Section 2 provides a background to the WFD, the key Articles and Annexes and places this project into context within it. Section 3 presents a conceptual model of chemical and quantitative recovery and details the factors which will influence the rate of groundwater recovery. Section 4 presents the requirements for a recovery framework and Sections 5 and 6 propose an assessment process for basic and detailed assessment of chemical and quantitative recovery rates. Section 7 then presents the cost effectiveness and disproportionate cost guidance. Conclusions and Recommendations are provided in Section 8 with the References in Section 9.

1.4 Key Definitions

Definitions of the key concepts used in the report are summarised below. All are discussed in further detail within Section 2 of this report.

It is important that the 'framework' as applied to the methodology 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 the proposed evaluation tools and how users interface with these tools. A '***tool***' is an approach, algorithm or model that evaluates the groundwater recovery.

In addition, under WFD a ***'pressure'*** is an activity which results in '**stress'** (chemical or quantitative evidence of the pressure) to a groundwater body. A ***'stress'*** is normally identified through monitoring (e.g. water levels or water quality).

'Good groundwater status' is the condition of the groundwater body when both its chemical and quantitative status are at least good.

Timescale extensions are allowed by Article 4.4 for the purposes of phased achievements of the objectives for bodies of water, provided that no further deterioration occurs in the status of the affected body of water and when a number of conditions are met. These allow the extension of two further cycles of river basin management plans to attain the 'good status' environmental objectives.

Less stringent environmental objectives may be set in cases where a body of water is so affected by human activity such that it may be unfeasible or unreasonably expensive to achieve good status within the two further river basin planning cycles. This must be justified on the basis of appropriate, evident and transparent criteria, and all practicable steps should be taken to prevent any further deterioration of the status of waters.

Derogations are needed when there is a deviation from the principal aims of the Directive. In the case of meeting the main status objective (good status by 2015), derogations are allowed within the terms of the Directive by virtue of the provisions for time extensions and less stringent objectives. In this report the term ***'formal derogation'*** is used in the context of a breach of the Directive e.g. if a Member State knew that a groundwater body was going to deteriorate in status due to unavoidable delays in pollution impacts and no other derogation was available within the terms of the Directive.

For consistency with the WFD groundwater vulnerability classification terminology the following hydrogeological definitions are used throughout this report:

- ***Overlying Strata*** - Unsaturated soils and subsoils and saturated non-aquifer material.
- ***Unsaturated Aquifer*** - The unsaturated layer of bedrock and unconsolidated (e.g. sand and gravel) aquifers.
- ***Saturated Aquifer*** - The saturated layer of bedrock and unconsolidated aquifers.

A full glossary of terms is provided at the end of this report.

2. Background

2.1 Water Framework Directive (2000/60/EEC)

2.1.1 Introduction

The WFD is the most significant European water legislation to emerge to date and is intended eventually to replace the majority of water related directives to 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). Taking into account the results of characterisation an appropriate Programme of Measures (PoM) to achieve the Directive's Article 4 environmental objectives for all water bodies within each river basin are to be defined.

Responsibility for the assessment and delivery of the RBMPs in each country sits with the **'*competent authority*'**. In Scotland this authority is SEPA, in England and Wales it is the EA and in Northern Ireland it is EHS.

The WFD requires that groundwater bodies are defined; a groundwater body being a distinct volume of groundwater within an aquifer or aquifers. 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 will qualify as aquifers and be contained within groundwater bodies.

2.1.2 WFD Timescales

The major milestones in the UK implementation of the Water Framework Directive are presented below:

Date	**Activity**
Dec 2000	Directive entered into force.
2000 – 2003	UK Government consultation period.
March 2003	National legislation in Scotland (Water Services and Water Environment Act) enabled.

Dec 2003	Directive implemented in UK legislation, identify 'competent authorities'. The Water Environment (Water Framework Directive) (England and Wales) Regulations 2003 laid before parliament.
Dec 2004	Analysis of impact on surface and groundwaters for each area to be completed and a register of Protected Areas established. Identify groundwater bodies for which lower objectives are required.
Dec 2006	Establishment of monitoring networks.
Dec 2009	Publish finalised first RBMPs and PoMs. The initial status of waters declared (from which there should be no subsequent deterioration), less stringent objectives and justification declared.
Dec 2012	The PoMs must be fully operational.
Dec 2015	Main environmental objectives of plans to be met. 'Good status' of water bodies to be achieved. Protected Area objectives must be met by this date, but timescale extensions are allowed to achieve good status objectives. First revision of RBMPs published.
Dec 2021	Second revision of RBMPs published.
Dec 2027	Third revision of RBMPs published. Final date to meet objectives for groundwater bodies with timescale extensions.
Dec 2033	Fourth revision of RBMPs published. Less stringent environmental objectives must be met.

2.2 Current WFD Characterisation Work

The initial characterisation phase of the WFD is currently underway. In this the competent authorities are required to undertake the following groundwater related actions:

- delineate the surface water and groundwater bodies;
- identify pressures to which the groundwater bodies are liable to be subject;
- identify groundwater bodies for which there are directly dependent surface water ecosystems or terrestrial ecosystems;
- identify the general character of the overlying strata in the catchment area from which the groundwater body receives its recharge;
- conduct a groundwater body characterisation and initial assessment of the risk that groundwater bodies will fail to meet environmental objectives by 2015; and
- identify the groundwater bodies for which less stringent objectives need to be set.

This phase is required to be completed by December 2004 and reported to the Commission by March 2005.

2.3 Environmental Objectives

In order to determine the requirements and definition of 'groundwater recovery to WFD good status', it is necessary to cross reference the environmental objectives noted in Article 4.1 with the provisions of Article 4.4 (timescale extensions) and 4.5 (less stringent objectives).

The environmental objectives for groundwater are contained within Article 4.1 (b) and can be summarised as follows:

(i) **Prevent or limit the input of pollutants into groundwater and prevent deterioration in status.** This is not explicitly linked to the provisions of Articles 4.4 or 4.5 and therefore it must be assumed that these measures must be in place by December 2012 when the first PoM must be fully operational. Though the objective should not be altered, the detailed measures to implement this may be adjusted by the proposed Groundwater Daughter Directive (GWDD) to the WFD discussed in Section 2.4.

(ii) **Protect enhance and restore all groundwater bodies, ensure a balance between abstraction and recharge, with the aim of achieving good status by 2015.** This is subject to both Articles 4.4 and 4.5. The detailed requirements of Articles 4.4 and 4.5 are outlined in Sections 2.3.1 and 2.3.2 below. The definition of good status, currently noted in Annex V 2.3.2, may be further expanded within the proposed GWDD.

(iii) **Implement measures to reverse any significant and sustained upward trend in the concentration of any pollutant.** As with (i), this is not explicitly linked to Article 4.4 or 4.5. There is a default provision for trend reversal at 75% of established EU standards and the GWDD may establish criteria for assessing such trends, including the definition of starting points for trend reversal.

The **Protected Area objective** noted in Article 4.1(c) requires compliance with Protected Area standards and objectives by December 2015 and is not subject to either Articles 4.4 or 4.5. However, although 'Protected Area Objectives' may be achieved, a groundwater body which constitutes or contains a Protected Area and which fulfils its 'Protected Area Objectives' may fail its status objectives for other reasons and as such require timescale extensions or less stringent objectives for these status objectives. 'Protected Area Objectives' are not negotiable and failure of 'these' objectives cannot justify time extensions or the setting of less stringent objectives.

The Drinking Water Protected Area (DWPA) objective noted in Article 7.3 implies that there should be no deterioration in water quality at the point of abstraction that could cause an increase in treatment.

Though the definition of good quantitative status is given in Annex V 2.1.2 and the equivalent definition of good chemical status in Annex V 2.3.2, linkages exist between the groundwater bodies and surface ecosystems. In particular, not only should good status be achieved in the groundwater body but there should be no deterioration in the existing status of surface waters due to groundwater influences. However, whilst the achievement of good surface water status is subject to Articles 4.4 and 4.5, the 'no deterioration in status' objective is not subject to these Articles and therefore, in common with its groundwater equivalent, the measures to achieve this must be fully operational by December 2012.

2.3.1 Timescale Extension

Article 4.4 allows an extension to the timescales to be invoked for "*the purposes of phased achievement of the objectives for bodies of water, provided that no further deterioration occurs in the status of the affected body of water when all of the following conditions are met:*

(a) Member States determine that all necessary improvements in the status of bodies of water cannot reasonably be achieved within the timescales set out in that paragraph for at least one of the following reasons:

(i) the scale of improvements required can only be achieved in phases exceeding the timescale, for reasons of technical feasibility;

(ii) completing the improvements within the timescale would be disproportionately expensive;

(iii) natural conditions do not allow timely improvement in the status of the body of water.

(b) Extension of the deadline, and the reasons for it, are specifically set out and explained in the River Basin Management Plan required under Article 13;

(c) Extensions shall be limited to a maximum of 2 further updates of the River Basin Management Plan except in cases where the natural conditions are such that the objectives cannot be achieved within this period;

(d) A summary of the measures required under Article 11 which are envisaged as necessary to bring the bodies of water progressively to the required status by the extended deadline, the reasons for any significant delay in making these measures operational, and the expected timetable for their implementation are set out in the River Basin Management Plan. A review of the implementation of these measures and a summary of any additional measures shall be included in updates of the River Basin Management Plan."

In summary, Article 4.4 states that the deadlines given for achievement of Article 4 environmental objectives may be extended, subject to a number of provisions and provided that there is no further deterioration in status of affected water bodies. As all the provisions appear to be related to status it has been interpreted that these timescale extensions do not apply to prevent or limit, trend reversal or Protected Areas. Timescale extensions are restricted to two further RBMP cycles beyond 2015 (i.e. reported in December 2021 and December 2027) and although they must be justified this process is relatively straightforward.

Where achievement of good status cannot be achieved by 2027 because of natural conditions there is no time limit to the extension and member states can set and aim to meet less stringent objectives under Article 4.5 detailed below.

2.3.2 Less Stringent Objectives

In Article 4.5 "*Member States may aim to achieve less stringent environmental objectives for specific bodies of water when they are so affected by human activity, as determined in accordance with Article 5.1, or their natural condition is such that the achievement of these objectives would be unfeasible or disproportionately expensive, and all the following conditions are met:*

(a) *the environmental and socio-economic needs served by such human activity cannot be achieved by other means, which are a significantly better environmental option not entailing disproportionate costs;*

(b) *Member States ensure,*

- *for surface water, the highest ecological and chemical status possible is achieved, given impacts that could not reasonably have been avoided due to the nature of the human activity or pollution;*

- *for groundwater, the least possible change to good groundwater status, given impacts that could not reasonably have been avoided due to the nature of the human activity or pollution;*

(c) *no further deterioration occurs in the status of the affected body of water;*

(d) *the establishment of less stringent environmental objectives, and the reasons for it, are specifically mentioned in the River Basin Management Plan required under Article 13 and those objectives are reviewed every 6 years."*

In summary, Article 4.5 allows for less stringent environmental objectives to be set but these only explicitly relate to status. For groundwater the target must be the least possible change to good status (note that the wording 'lower objectives' is used in Annex II of the WFD whereas Article 4.5 uses 'less stringent objectives' – it is assumed that these are synonymous).

For example, areas in which long term human activity (e.g. agricultural or some historical mining areas) results in levels of contamination or groundwater drawdown where recovery to the good status objectives is unfeasible with the WFD timescales (2015, 2021 and 2027), then lower objectives may be set.

These lower objectives must have extensive technical justification and an economic appraisal of the options for the individual or combination of measures proposed. The less stringent objectives must have the least possible deviation from the good status objectives given the disproportionately expensive argument and the overriding principle that deterioration in the status of the groundwater is not permitted.

2.3.3 Conclusions from Assessment of the WFD

From the above assessment of the WFD, some important conclusions can be made that are pertinent to the assessment of groundwater recovery times and the application of this study's findings to the application of timescale extensions, less stringent objectives and potential need for derogations:

- Groundwater and associated surface water status must not deteriorate from the initial status assessment published in the first RBMPs in December 2009. Formal derogations would be needed if this were to occur. Given the time lag effects in some groundwater systems this is a likely scenario and is therefore a particular focus for recovery time assessment.

- The initial December 2015 deadline for achieving Good Status may be extended to a maximum of December 2027 providing this is justified in accordance with the provisions of Article 4.4. Some slow response aquifers that are of poor status in 2015 will take far longer to recover than 2027, therefore less stringent objectives will be needed for these (it is assumed that wherever possible, the potential for derogations should be minimised). This project seeks to provide a framework which can distinguish between those systems that can respond within timescales of 10-15 years and those where longer timescales are inevitable due to the nature of the hydrogeological regimes.

- The groundwater bodies which will require less stringent objectives must be identified in the December 2004 initial characterisation reports. The actual objectives are published in the RBMPs and it is assumed that adjustments to less stringent objectives may be made once the GWDD is agreed and at the start of each RBMP cycle. Justification of less stringent objectives must be made in accordance with Article 4.5 and demonstrate that there is a minimal deviation from good status. The workload implications are a driver to minimise the number of bodies for which less stringent objectives are required. However, the uncertainties regarding groundwater recovery times and the need to avoid formal derogations if possible are a counter driver to make use of these provisions.

2.4 Article 17 - Groundwater Daughter Directive and Default Provisions

The WFD includes a provision, Article 17, stating the requirement for future measures to control and prevent pollution including criteria for assessing the good chemical status of groundwater, identifying significant and sustained upward trends in pollutants and defining a starting point for trend reversal.

To support the WFD, the European Commission (EC) has adopted a proposal for a Groundwater Daughter Directive (GWDD) in September 2003. At the time of writing it seems likely that this proposal will not be agreed until the latter half of 2004 or early 2005, with implementation in 2006/7. The proposals are likely to be revised during the debates in the European Parliament and Council, therefore any assessment of their potential impact must be treated with caution. Whilst recognising the main elements of the proposal this study cannot take into account its detail.

The GWDD covers the following:

- control and protection of groundwater;
- definition of significant trends;
- definition of trend reversal; and the
- requirement to set groundwater quality standards and threshold values for groundwater pollutants.

The potential changes to the definition of groundwater status that may be brought about by the GWDD are a complicating factor. Moreover, in the absence of agreement of a new Directive, Member States are required by Article 17 to produce their own criteria for status assessment and trend reversal by December 2005. These criteria could influence the need for less stringent objectives. These possibilities cannot be taken into account as part of this current study but may influence the implementation of any procedures arising from the assessment of recovery times, post-December 2004.

2.4.1 Trend reversal

Though not explicitly subject to timescale extensions or less stringent objectives, the feasibility of attainment of the trend reversal objective will be subject to the same factors that influence the assessment of recovery times to achieve good status. Indeed the ability to reverse trends will be an indicator of the ability of the groundwater system to respond to measures to achieve good status.

In the GWDD proposal (Article 2) a 'significant and sustained upward trend' means any statistically significant increase of concentration of pollutant when compared to the initial concentrations measured at the start of the assessment period, though in Annex IV this is qualified to focus on environmentally significant trends. Both in the default provision of Article 17 and in the GWDD a starting point of 75% of relevant standards is either required (Art. 17) or advised (GWDD) for implementation of measures to achieve trend reversal. The assessment of recovery times will also be helpful in determining what effect the 75% starting point will have on the achievement of good status.

CIS Working Group 2.8 has produced guidance on statistical techniques on the assessment of trends which may be helpful in providing confirmation of the onset of groundwater recovery (Grath et al., 2001). Subsequent to the approval of the GWDD, CIS Working Group 2C on Groundwater is due to produce further guidance in 2005/6.

2.4.2 Definition of Groundwater Quality Standards and Threshold Values

Groundwater Quality Standards and Threshold Values as detailed in the GWDD are essentially the same with the distinction that Groundwater Quality Standards are set by the GWDD and therefore apply across all Member States whilst Threshold Values are set by the individual Member States either at a national, groundwater body or receptor level.

It is also possible that the Groundwater Quality Standards could be locally adjusted if it was demonstrated that surface water or terrestrial ecosystem were being harmed.

It is of note that surface water Environmental Quality Standards (EQSs) will have to be set for all Priority Hazardous Substances, Priority Substances and Specific Polluting Substances under Article 16 of the WFD. Whilst these are primarily for use in surface waters this work will be of relevance to groundwater assessments and the EQS values may become local thresholds/quality standards to protect identified surface water receptors that are dependent on groundwater.

As defined in the GWDD proposal a 'Threshold Value' is the concentration limit for a pollutant in groundwater for which exceedance would cause a groundwater body to be characterised as having poor chemical status.

On this basis three groups of threshold values are proposed as detailed in the sections below.

Pan European

The GWDD proposes pan-European standards to be achieved for nitrates and pesticides (active ingredients including metabolites) in groundwater of 50 mg/l and 0.1 μg/l, respectively.

Minimum List

The GWDD also proposes a minimum list (Article 4 and Annex III) of pollutants for which each member state is required to establish threshold values to be used for the status assessment of groundwater under Article 5 of the WFD. The final list is likely to change but at the time of writing it includes the following parameters:

- Ammonium;
- Arsenic;
- Cadmium;
- Chloride;
- Lead;
- Mercury;
- Sulphate;
- Trichloroethylene; and
- Tetrachloroethylene.

Other Pollutants

The member states are also required to establish threshold values for other pollutants which have been identified as contributing to the characterisation of groundwater bodies defined as being at risk.

This provision is also present within the WFD which requires not only that significant pollutants should be identified but also that the natural and the anthropogenic components should be distinguished. Only the anthropogenic components can contribute to the failure to meet good status, therefore in the case of all significant polluting substances that can also occur naturally it will be necessary to determine the natural background concentrations. Any assessment of recovery times must factor in such natural concentrations and any associated spatial and temporal trends.

2.5 This Study

2.5.1 Context

This study is required to provide frameworks to provide technical and economic justification of timescale extensions and 'less stringent' environmental objectives as allowed under WFD Articles 4.4 and 4.5. The framework methodology is to be applicable to the whole of the UK, whilst taking account of the availability and differences in hydrogeological, environmental and economic data. Within the short timescale for the initial characterisation to be completed there is also a need for a practical approach to be taken.

The framework is required to predict the timescale for recovery in the groundwater body to achieve the environmental objectives defined within Article 4.1(b). The key requirement is how quickly the aquifer systems react and recover based on the measures implemented.

2.5.2 Limitations

The WFD understanding and implementation is currently developing at a rapid rate regionally, nationally, at the UK level, and within Europe. The methodologies for initial and further characterisation are in the process of being developed. Definitions, justifications, threshold values and overall understanding of the implications of the WFD are in a state of progress and flux. This position presents limitations to this study in the technical reports underpinning areas of the WFD relevant to this work. Some obvious limitations are presented below:

- The chemical threshold values for the minimum list and other pollutants identified during the characterisation are still to be defined;
- The monitoring network for assessment of the chemical and quantitative status is under development; and
- Assessment procedures for the definition and reversal of trends are to be finalised (some work has already been carried out by CIS WG2.8).

2.6 Parallel Projects

Several EA projects are currently underway or recently completed which have overlapping objectives to the determination of less stringent environmental objectives for groundwater bodies (i.e. they are concerned with developing models and tools to determine the impact on groundwater of activity pressures). These projects are summarised in the paragraphs below.

A DEFRA funded project on the GWDD is currently underway by the British Geological Survey (BGS), (J. Chilton, pers comm.) to develop a framework for determining the application of trend reversals.

A project has been initiated by the Land Quality section of the Science Group within the EA (R&D P5-081) to develop a GIS based policy decision support tool to interpret environmental outcomes caused by changes in land use and agricultural activity. The objective is to combine spatial datasets such as landuse, soil types and meteorological data with robust algorithms to determine recharge hydrology, soil leaching and pesticide and nutrient fate and transport. This will be used to conclude the impact from ‘what if’ scenarios including climate change or application of measures.

A recently completed EA project has developed a new framework for groundwater vulnerability assessment (NC/99/27). This uses a combination of the activity pressure and the ability of the overlying strata and unsaturated aquifer to attenuate this activity to define the vulnerability. The framework has included the initial development of soil leaching algorithms to determine pesticides concentrations entering the saturated aquifer.

2.7 Principles of Groundwater Recovery in a WFD Context

2.7.1 Chemical Pressure Impact Assessment

For chemical pressure impact assessments the recovery predictions will be validated at appropriate monitoring points both within the groundwater body (monitoring springs and boreholes) and potentially within linked surface water bodies (e.g. wetlands, low flows within rivers).

In the first graph of Figure 2.1, the following examples are displayed where for a particular pollutant causing stress to a groundwater body:

(a) The good status objective (threshold value) is achieved within the WFD timescale (2015).

(b) The good status objective (threshold value) is achieved within the final WFD timescale extension (2027) justified under Article 4.4. Justification to the EC would be required for a time extension.

(c) Less stringent objectives (threshold values) are achieved within the extended WFD timescales (2027) justified under Article 4.5. Justification to the EC for less stringent objectives would be required.

To reiterate, groundwater bodies which are likely to require less stringent objectives (c) need to be identified by December 2004. The less stringent objectives themselves together with an appropriate level of technical and economic justification needs to be included within the first RBMP published in December 2009.

The first graph indicates that measures were initiated in 2003. In most circumstances measures will be initiated between 2003 and the 2012 deadline (no further deterioration in status is allowed).

In the second graph of Figure 2.1 the ‘reversal of significant and sustained trends’ argument is presented. The measures are initiated at 75% of the threshold concentration and the reversal of the trend is achieved by 2015. The measures required to address the trend reversal objective must be started by 2012 at the latest. The WFD however, does not specify any timescale for achieving the trend reversal objective although this may be further clarified in the GWDD.

2.7.2 Quantitative Pressure Impact Assessment

Further work on the detailed procedures for defining good groundwater quantitative status is currently underway by the United Kingdom Technical Advisory Group (UKTAG).

Groundwater levels within a groundwater body vary temporally and spatially. Existing and future appropriate assessment points (monitoring boreholes) will form an important measurement tool for the assessment of the measures and the evidence for the groundwater body achieving its environmental objectives. This monitoring will be extended where the groundwater body is identified as being at risk of failing to achieve its objectives. However, regional pressure-based assessment will also be required. This will form two parts as described below:

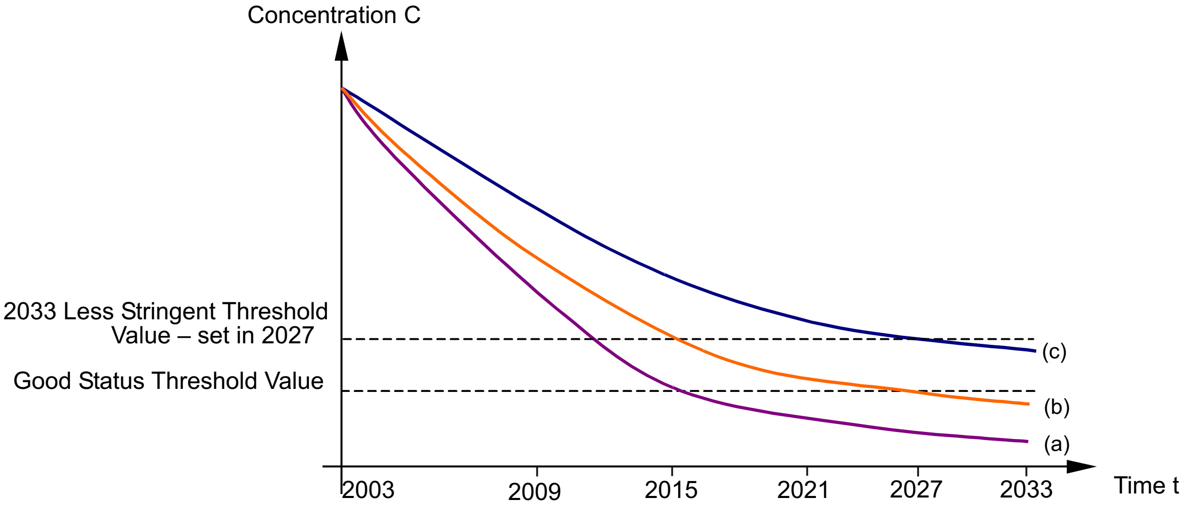
Groundwater Body Exposure Assessment

This is an assessment of the whole groundwater body to the pressure of abstraction. This is comparable to the Catchment Abstraction Management Strategy (CAMS) process of the EA (Environment Agency, 2001) and based on the estimation of recharge to a groundwater body and consideration of the current abstraction and environmental requirements of water from the groundwater body.

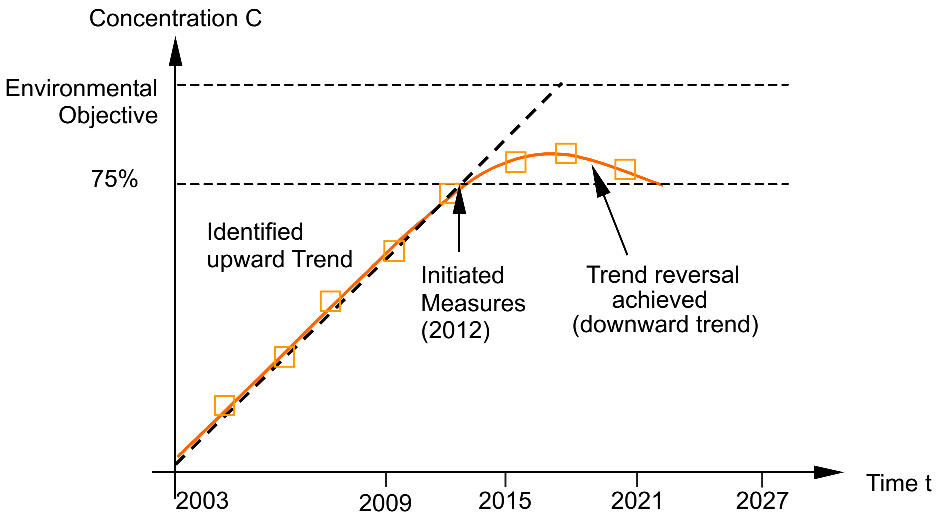
Receptor Impact Assessment

This is an assessment of the evidence within a groundwater body and its associated dependent receptor systems for stress linked to abstraction processes. For groundwater dependent surface water and terrestrial ecosystems, ecological indicators constitute the primary feature of this assessment process.

Contaminant Concentrations



Trend Reversal



WFD25: Derivation of a Methodology for the Assessment of Groundwater Recovery Times to Achieve Good Status

Figure 2.1
Time Series Contaminant Concentrations.

Summary

The WFD is to be implemented by the designated **competent authority** for each member state. The **WFD timescales** are initial characterisation by December 2004, first river basin plan in December 2009, programmes of measures operational in 2012 and main environmental objectives to be met by December 2015.

An **extension to the timescales** of two river basin management plan cycles (i.e. from December 2015 to December 2027) can be invoked to allow phased achievement of the environmental objectives provided that no further deterioration in the status of the affected water body occurs.

Less stringent objectives can be set for a groundwater body where achievement of the environmental objectives are technically unfeasible or disproportionately expensive. Technical and economic justification must be made for the setting of these lower objectives and they must have the least possible deviation from the good groundwater status.

Groundwater bodies likely to require less stringent objectives will be identified in the initial characterisation reports (December 2004) and the actual 'less stringent' objectives will be specified in each river basin plan. It is intended that the objectives would work towards good status. Failure to achieve the 'less stringent' objectives set would be a breach of the WFD.

The proposed **Groundwater Daughter Directive** provides definitions of 'significant trends' and 'trend reversals' for groundwater bodies used by the WFD. It also provides an initial list of groundwater quality standards to be set and met by the member states.

Several WFD focussed projects to define outcomes from WFD for groundwater bodies within the UK and provide guidance on the implementation of WFD within the UK are currently underway.

This study is to provide a technical and economic framework for justification of both timescale extensions and less stringent objectives both for the initial characterisation reporting (December 2004) and further characterisation up to the submission of the river basin management plans (December 2009 and six yearly thereafter).

3. Conceptual Model of Factors Influencing the Rate of Recovery

3.1 Introduction

Groundwater recovery will be dependent on a range of factors. These include the following:

- The **pressure** that has given rise to the failure of the groundwater body to achieve environmental objectives.
- The **pathway** from the pressure to the groundwater body and to the groundwater dependent receptors (e.g. overlying strata, unsaturated aquifer and saturated aquifer).
- The **measures** implemented to achieve environmental objectives, i.e. return the groundwater body to good status.
- The degree of recovery needed for a groundwater body to achieve **environmental objectives**, for example how much do contaminant concentrations need to be reduced to achieve the objective.
- The **hydrogeological setting** to include hydraulic properties of the overlying strata and aquifer such as transmissivity and effective porosity – for example derived from the aquifer properties manual (BGS, 1997).
- **Inflows and outflows** (such as recharge, abstraction) to the groundwater body which will affect the rate that resources are replenished (quantitative status) or the rate at which contaminants are removed and/or diluted (chemical status).
- The **properties of the contaminant** (chemical pressures only) such as partition coefficient and degradation rate.

This chapter describes the factors that can influence groundwater recovery.

3.2 Pressures

3.2.1 General

For the December 2004 deadline, a risk assessment is being undertaken to identify those groundwater bodies that are at risk of failing to achieve their environmental objectives as a result of human activity. This work is being undertaken according to the methodologies determined by UKTAG. For groundwater bodies identified to be 'at risk', then the WFD requires that an assessment is undertaken to identify which of these failing water bodies will require timescale extensions or less stringent objectives to be set. This report describes the methodology to be adopted to identify such bodies.

3.2.2 Sources of Chemical Pressures

The UKTAG paper 7i defines how the risk assessment for pollutants is being undertaken. The key human activities being considered are:

- agricultural practices, such as fertiliser and pesticide application to crops;
- farming practices, such as manure, waste sheep dip and waste pesticide disposal to land;
- septic tank discharges from (rural) domestic housing, caravan parks, hotels and unsewered villages;
- soak-away discharges from suburban and urban developments and from highways;
- underground storage tanks at petrol stations;
- quarrying and engineering works;
- historic and current mining activities;
- landfills; and
- industrial activities (PPC Part A and Part B).

Agricultural and farming practices are a significant source of widespread diffuse pollution to a groundwater body. Historical mining activities have also resulted in widespread pollution to groundwater bodies as a result of rebounding acid minewaters and continued leaching from mine and other spoil material. For groundwater bodies with sensitive receptors point source contamination could result in the risk of failure to achieve good status.

3.2.3 Sources of Quantitative Pressures

UKTAG paper 7h defines how the risk assessment for quantitative processes is being undertaken. The key human activities being considered are:

- Abstraction for water supply, agricultural, domestic, industry and/or mining any quarrying;
- Impacts to recharge as a result of land use changes and climate change;
- Secondary influences such as:
  - SUDS;
  - Flood management – level control; and
  - Physical interference by construction, mining etc.

3.3 Receptors

The **environmental objectives** set for groundwater may depend on the receptor. The receptors relevant to this work include:

- Groundwater Bodies;
- Protected Areas (e.g. Drinking Water Protected Areas);
- Groundwater Dependent Surface Water Bodies; and
- Groundwater Dependent Terrestrial Ecosystems.

A groundwater body may be identified to be 'at risk' due to the risk of failure to achieve the environmental objectives for one or more receptors associated with that body. The assessment will need to consider whether groundwater recovery will be achieved for all of the receptors that are at risk.

A risk assessment is therefore required for:

- A groundwater body scale recovery assessment;
- A targeted groundwater dependent surface water body and terrestrial ecosystem assessment; and
- A protected area recovery assessment.

3.4 Controls on the Rate of Groundwater Recovery

This section provides an overview of the main factors that will determine the quantitative and chemical recovery of a groundwater body. Additional details of some of these factors are given in Table 3.2.

Some of the concepts (particularly for chemical recovery) have been illustrated using a flushing cell model in Figures 3.1 to 3.3. A conceptual model of chemical pressure scenarios is presented in Figure 3.4 and a model of quantitative pressure scenarios is presented in Figure 3.5.

3.4.1 Pressures and Measures

The rate of recovery will depend on the scale of the pressure, its history and the measures implemented to control, reduce or remove the pressure.

Chemical

The main factors that are relevant to chemical pressures are:

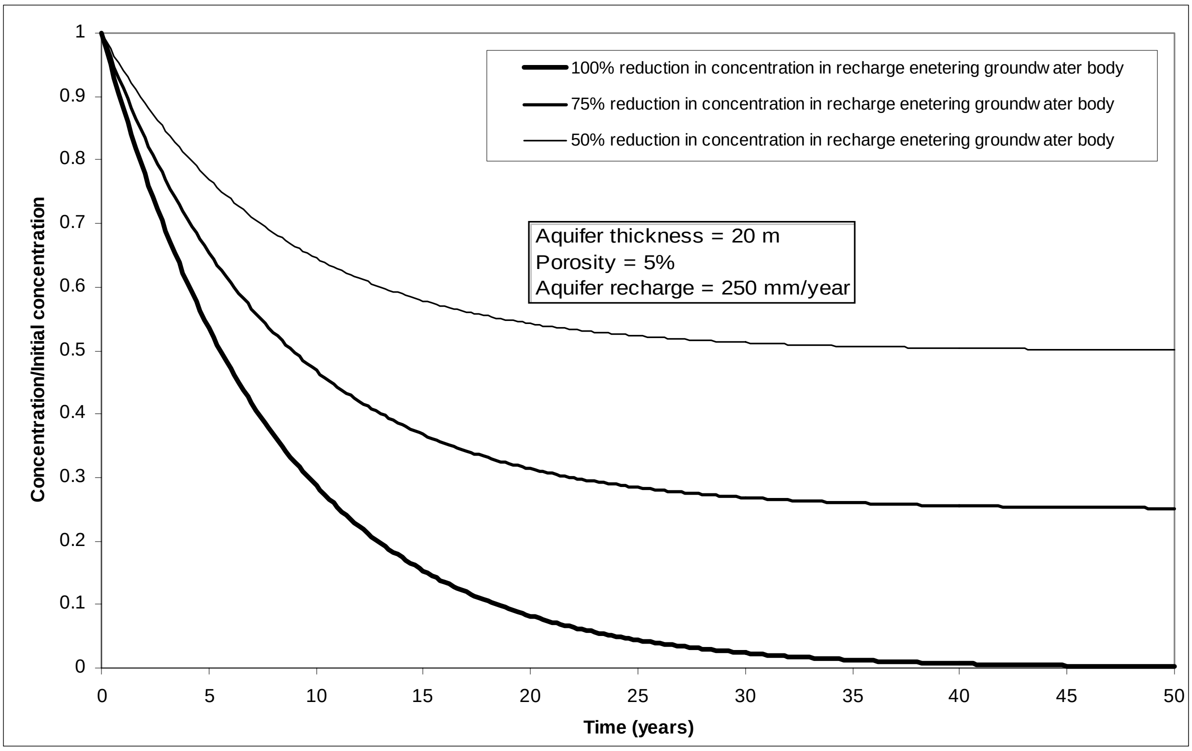
- The areal extent of the pressure (i.e. point or diffuse pollution) and the concentration and/or contaminant loading.
- The location of the pressure (ground surface, overlying strata, unsaturated aquifer or saturated aquifer). For examples, nitrogen applied to the soil which must pass through the overlying strata and unsaturated aquifer compared to a landfill site where no overlying strata (and possibly unsaturated aquifer) is present.
- The degree to which the pressure is controlled, reduced or removed through implementation of a measure. In some cases there will need to be a balance between control of the pressure and cost benefit, such that total removal of the source may not occur.

- Presence of residual contamination and its location (overlying strata, unsaturated aquifer or saturated aquifer). For many cases, even after removal of the source there will be residual contamination in the overlying strata, unsaturated aquifer and/or saturated aquifer which will need to be flushed from the system before environmental objectives are achieved. The extent of residual contamination will be a function of the history and the nature of the contaminant.

In general, the recovery time for point source pollution is likely to be less compared to diffuse sources due to the smaller volume of the aquifer affected. However, where the point source is characterised by high concentrations of a retarded contaminant, then recovery rates may be slow and in the order of decades. For diffuse pollution it has been shown (Silgam et al, 2003) that where Nitrate Sensitive Areas (NSAs) have been implemented then reduction of nitrate leaching from the overlying strata had, in some areas, a measurable impact on concentrations at the abstraction point within two years (e.g. Old Chalford - Oolitic Limestone). However, in other areas (e.g. Pollington – Triassic sandstone) no measurable impact at the abstraction point had been detected and modelling indicated that the time lag from leaching would be in the order of decades.

The degree to which groundwater quality fails to meet the environmental objective and the degree to which the pressure is reduced will have a major influence on the time for recovery. This is illustrated by Figure 3.1 which shows the rate of improvement of a conservative contaminant for different percentage reductions in the concentration entering the aquifer.

Figure 3.1 Influence of Reducing Contaminant Loading to the Groundwater Body



The main factors that are relevant to quantitative pressures are:

- The location of the pressure in relation to the receptor (for example, the distance of an abstraction from a river where flows have been reduced as a result of the abstraction pressure). This does not apply to groundwater body scale assessments of the recharge-abstraction balance.
- History of the activity (for the extent to which groundwater levels have been lowered due to historic abstraction).
- The degree to which the pressure is controlled, reduced or removed through implementation of a measure. For example, the pressure could be totally removed by ceasing abstraction.

If the pressure is as a result of abstraction, the pressure can be managed by removal or decrease in the abstraction rate. In some groundwater bodies with low storativity this could result in almost instantaneous removal of the impact of the pressure and return of the groundwater levels to that required for good status. In groundwater bodies with higher storativity, the recovery rate could take from months through to years or even decades.

3.4.2 Aquifer Properties

The rate of recovery of a groundwater body in response to a change in a pressure will be determined by its hydrogeological characteristics and the magnitude of inflows and outflows to the body. In addition, the rate of chemical recovery, will be determined by the physio-chemical properties of the contaminant and the aquifer environment. These factors are considered below.

Hydrogeological Characteristics

To provide a framework which will allow an assessment of the rate of recovery within all groundwater bodies within the UK, some generic groupings of hydrogeological environments are proposed and are summarised in Table 3.1 below. These are taken from the recent SNIFFER WFD groundwater vulnerability project (BGS, 2003 – in draft).

The SNIFFER classification has resulted in five vulnerability classes (1-5) from Extreme to Low. This classification is determined from:

- the presence, thickness and vertical hydraulic conductivity of the overlying strata; and
- the presence, thickness and flow path type of the unsaturated aquifer.

The unsaturated aquifer element is only considered relevant in those bedrock and superficial aquifers with significant primary porosity. Taking these principles, it is assumed for the purposes of this document that the unsaturated aquifer element will not be relevant in many of the fractured rock aquifers in Wales, Scotland and Northern Ireland.

The characteristics of the overlying strata, unsaturated aquifer and saturated aquifer will have a large influence on the rate of recovery of a groundwater body. For example, a low porosity fissured aquifer in a high recharge area will have a more rapid recovery from pressures than a high porosity matrix dominated aquifer in a low recharge area.

Overlying strata or an unsaturated aquifer may potentially be absent or not relevant to the recovery rate calculations dependent on release point for the source and depth to groundwater.

These characteristics are described separately for chemical and quantitative pressures.

Table 3.1 Hydrogeological Domain Groups (from Groundwater Vulnerability Work)

	Material Type	Groupings	UK Wide Examples	Anticipated Pathway
Overlying Strata	**Soil**	**Soil Association**	HOST Category	Fast - Slow
Overlying Strata	**Unsaturated Superficial Deposits**	**H**igh Permeability	Well sorted sands and gravels	Fast
Overlying Strata	**Unsaturated Superficial Deposits**	**M**oderate Permeability	Silts, poorly sorted sands and gravels	Moderate
Overlying Strata	**Unsaturated Superficial Deposits**	**L**ow Permeability	Clays	Slow
	Unsaturated and Saturated Aquifer	**Groundwater Body**	**Aquifer Example**	**Aquifer Response[1]**
		Superficial Deposits	Sands and Gravels	Fast
		Some fractured flow, dominantly intergranular flow	Triassic Sandstones	Moderate
		Intergranular and fractured flow	Chalk	Slow – Moderate
		Some intergranular flow, dominantly fractured flow	Devonian Sandstones	Moderate
		Productive Fractured Bedrock Aquifers	Lower Carboniferous Limestones	Fast
		Poorly productive Fractured Bedrock Aquifers	Basement	Slow - Fast
		Karstic Flow	Some Carboniferous Limestones	Fast
		Man-made pathways	Coal measures	Fast[2]

[1] Calculation of the aquifer response times are discussed in more detail in Sections 5 and 6.
[2] The rate of flushing through mine adit systems may be fast but the time to flush the source may be over much longer time periods.

Quantitative

A key function of the overlying strata and unsaturated aquifer will be its influence on the rate and quantity of recharge to the aquifer. With the notable exception of variations in effective rainfall, recharge will be determined largely by the hydraulic conductivity, the presence of preferred pathways (such as fissures, macropores) and the potential for fingering of the wetting front. Different pathways (fissures, pores) may be associated with different rates of recharge within the same aquifer.

The recovery of groundwater levels and discharges (to dependent surface water bodies) will be determined largely by the transmissivity and storage of the aquifer. High transmissivity and low storage aquifers will be characterised by rapid rates of recovery.

Structural geological features (e.g. faults, synclines and anticlines) will often control and form boundaries to subsurface groundwater flow patterns. This will affect the extent of active groundwater flow and groundwater levels within the groundwater body.

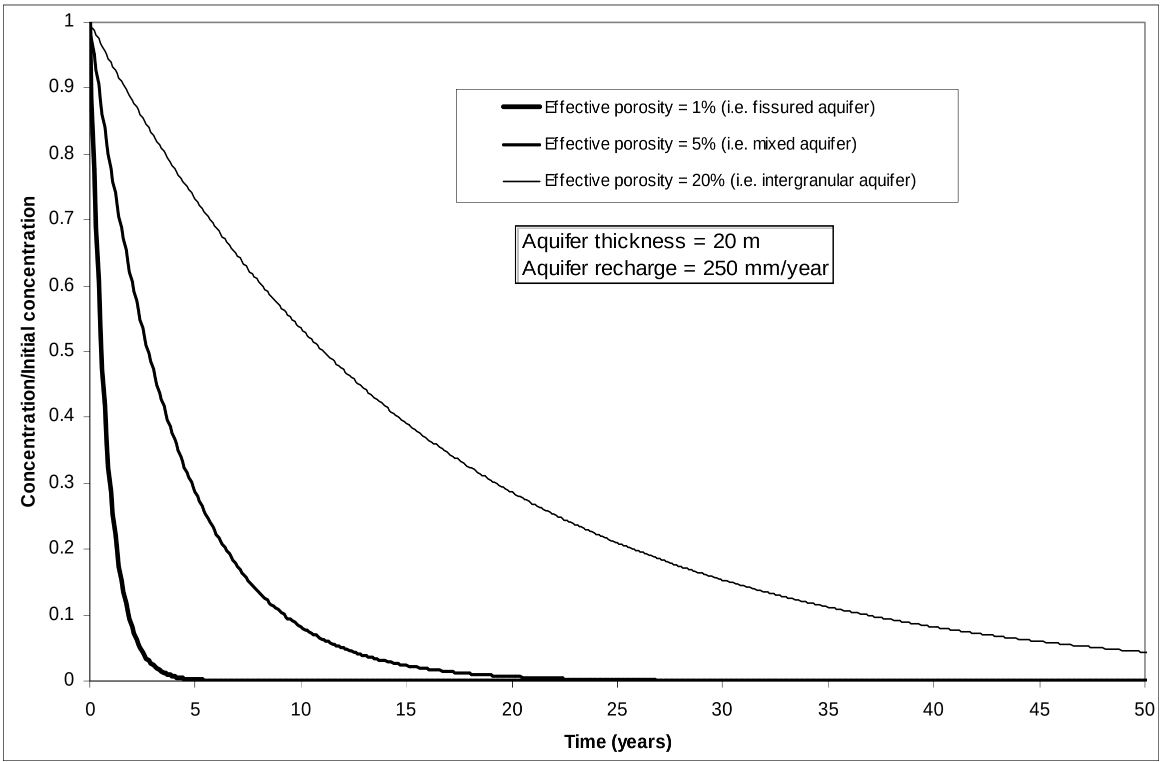
Chemical

The properties of the overlying strata, unsaturated aquifer and saturated aquifer will determine the rate at which contaminants are flushed from the system and therefore the time for recovery. The main factors in order of their pathway from the surface through to a potential receptor dependent on groundwater flow are:

- Thickness of the overlying strata and unsaturated aquifer which will determine the time for contaminants to move through these layers. These may be characterised by by-pass flow;
- The upper-most soil layer is characterised by higher organic content and by a higher microbial activity. A higher organic content will tend to retain (sorb) organic compounds, whereas the higher microbial activity may enhance rates of biotic degradation.
- Flow mechanism (fissure, intergranular, mixed – dual porosity). Fissured systems are likely to be characterised by faster recovery rates;
- Hydraulic conductivity and hydraulic gradient which will determine the rate and quantity of groundwater flow through an aquifer and hence the rate of flushing.
- Effective porosity. Purely fissured aquifers are likely to be characterised by porosities of 0.5 to 2%, whereas purely intergranular aquifers are likely to be characterised by porosities of 15 to 40%. Dual porosity aquifers (e.g. Chalk) may have small fissure porosity (typically 1 to 2%) but large matrix porosity (typically 30 to 40%). The influence of porosity on the rate of recovery is illustrated by Figure 3.2.
- Structural controls and heterogeneity of the aquifer. Groundwater recovery is likely to be slower in heterogeneous and complex aquifer systems due to variation in flow through such systems.

Some aquifers may be characterised by dual porosity. The Chalk is the best example as it is characterised by a small fissure porosity (typically 1 to 2%) and a large intergranular porosity (typically 30 to 40%). Groundwater flow movement occurs entirely by fissure flow (micro or macro fissures), but contaminant migration can be affected by the larger intergranular porosity due to molecular diffusion exchange between the fissure and pore water. The rate of diffusion will depend on the concentration gradient, the molecular diffusion coefficient, the fissure water velocity, the pore water porosity, and the width and spacing of fissures. In some situations, there may be rapid exchange such that there is effectively equilibrium between the fissure water and pore water, in which case contaminant movement is controlled by the total fissure and pore water porosity. For high fissure velocities and low fissure densities then diffusion exchange may be limited.

Figure 3.2 Influence of Aquifer Porosity on Flushing Rate



The above description takes a relatively simple view of the processes affecting recovery. A key additional control is the distribution of the contaminant within the aquifer and the heterogeneity of the aquifer. For example, groundwater flow will be concentrated through more permeable layers (higher rate of flushing and hence recovery), whereas the contaminant may be present in less permeable layers (lower rate of flushing and hence slower recovery).

Therefore, to assess rates of groundwater recovery, it will be essential to determine the contaminant flow mechanism.

3.4.3 Inflows and outflows

Inflows (such as recharge from rainfall, leakage from rivers and water mains) and outflows (such as abstraction and baseflow discharge by the aquifers to rivers and wetlands) will determine the rate at which groundwater resources are replenished and the rate at which contaminants are diluted and removed (flushed) from the groundwater body.

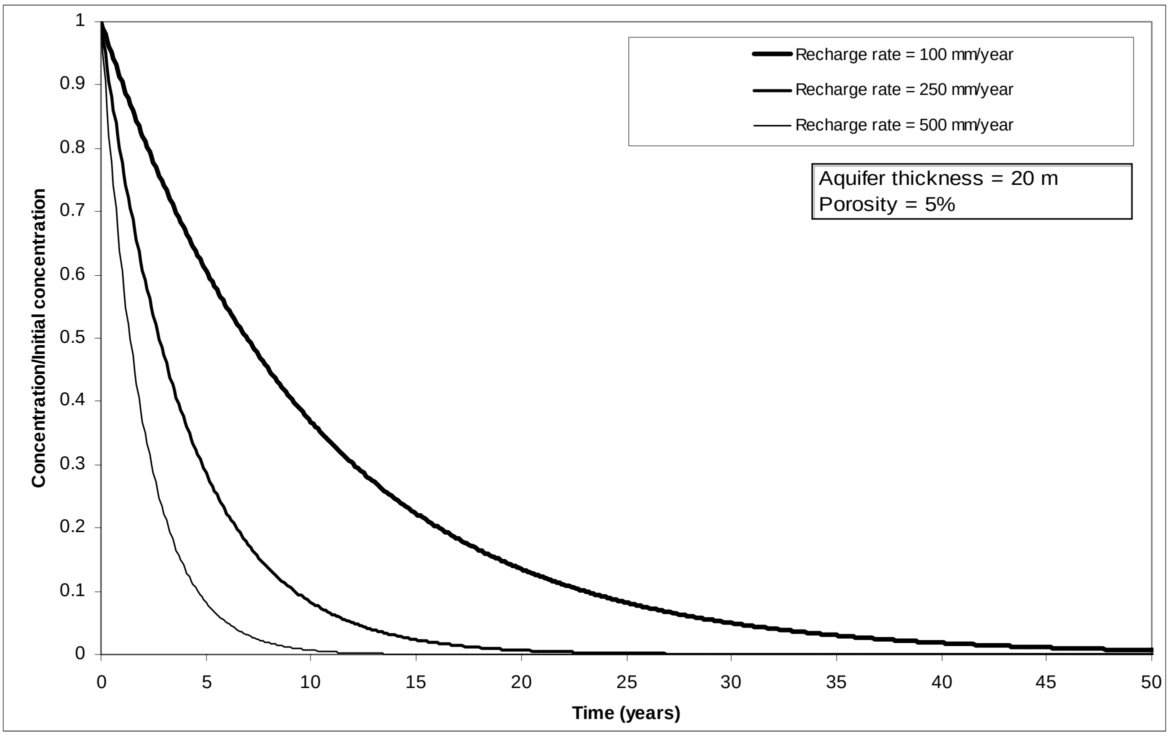
Recharge. Climatic, land use and drainage factors determine the potential recharge available to the groundwater body. The presence, thickness and type of the overlying strata and unsaturated aquifer will determine the actual recharge which reaches the groundwater body. The ability of the groundwater body to accept the recharge will be a key influence in some low permeability aquifers. Recharge will reflect both seasonal cycles and annual variations (drought and wet years) and these seasonal and temporal variations may influence the recovery of a groundwater body, particular from quantitative pressures.

Groundwater/surface water flow interactions can dilute contamination or dampen abstraction influences. The resultant effect on both the surface water concentrations and the baseflow requires consideration.

Abstraction may be locally significant in removing contaminants from an aquifer. However, conversely abstraction can result in the return of contaminants to the groundwater body through recharge (e.g. irrigation).

The influence of the rate of recharge on groundwater recovery is illustrated by Figure 3.3.

Figure 3.3 Influence of Recharge on Flushing Rate



3.4.4 Physiochemical Characteristics

Contaminant concentrations and mobility may be affected by physio-chemical processes such as degradation, solution-precipitation, sorption and cation exchange (Table 3.2). The main processes that are likely to affect recovery are degradation and sorption. Degradation will result in loss of contaminant and a reduction in concentration and therefore a decrease in recovery times. However in some cases the degradation process may generate secondary compounds which pose a higher risk (for example, the degradation of tetrachloroethene will result in the production of vinyl chloride). Sorption can retard the movement of contaminants through the aquifer and hence increase recovery times. The rate of sorption is dependent on the pollutant load, contaminant nature and the properties and amount of the material available for sorption. Sorption may also become reversible if the chemical properties of the sorption environment change (e.g. pH).

Degradation may be abiotic (e.g. hydrolysis) or biotic. Biodegradation usually occurs at faster rates than abiotic processes. Degradation is often represented as a first order reaction as illustrated by Equation (1) below.

$$C = Co.\exp(-\ln(2)t/HL) \quad (1)$$

where:

C = concentration after time t (mg/l);

Co = initial concentration (mg/l);

t = time (years); and

HL = Half life for degradation (years).

Half lives for biodegradation can vary from days to tens of years. For some contaminants degradation may be negligible or the environmental conditions unsuitable for this process.

The degree of retardation will be dependent on the partition coefficient (Table 3.2), the porosity of the soil or aquifer matrix, and the bulk density of the soil or aquifer matrix. Some compounds (such as nitrate and chloride) are not retarded (sorbed) to the soil and aquifer matrix. These are referred to as conservative contaminants and their rate of movement through the aquifer will be the same as water. The retardation factor can be estimated from equation 1 as follows:

$$R_f = 1 + \frac{K_d.\rho}{n} \quad (2)$$

where:

R_f = retardation factor;

K_d = partition coefficient (ml/g);

ρ = soil bulk density (gm/cm^3); and

n = porosity.

The retardation factor can indicate how much longer it will take to flush a retarded contaminant from an aquifer (i.e. multiply recovery time by the retardation factor) but this must be placed in the context of the pollutant source. For some contaminants, such as polyaromatic hydrocarbons which are highly sorbed to the aquifer matrix, then retardation factors may be 10's to 100's and may effectively immobilise a finite pollutant load (i.e. recovery times are likely to be slow and possibly measured in decades). However, for other contaminants sorption/retardation may only delay movement of a steady-state contaminant source.

Degradation and sorption may be influenced by the geochemical environment (pH, temperature, redox see Table 3.2). For example degradation of some organics may be inhibited under anaerobic (low oxygen) conditions and the mobility of some metals may be increased with pH.

3.4.5 Rate of flushing (chemical)

In summary, the time for chemical recovery will largely be a function of:

- The extent and degree of contamination (this will be a function of the area, depth and effective porosity of the aquifer affected and the point of entry of the pollutant).
- Reduction in the pollutant pressure (source loading).

- Rate of recharge and groundwater flow through the aquifer.
- Pressure of residual contamination.
- Removal of contaminants due to abstraction and/or discharge to dependent surface water bodies.
- Removal of the contaminant due to degradation.
- Sorption of the contaminant to the soil or aquifer matrix.

In addition, for contaminants moving through the overlying strata and/or unsaturated aquifer then an allowance needs to be made for the delay in moving through these layers. The simplest method of calculating this delay is given by Equation 3:

$$t = \frac{dn}{I} \qquad (3)$$

t = time to move through the overlying strata and unsaturated aquifer (years)

d = thickness of the overlying strata and unsaturated aquifer (m)

I= infiltration rate (m/year)

n = effective porosity

3.5 Uncertainty

In assessing groundwater recovery times consideration needs to be given to the uncertainty in the understanding and characterisation of the problem. Uncertainty can arise due to:

- Our understanding of the system. For example, will natural degradation reduce contaminant concentrations and what processes control this degradation?
- Definition of the parameters controlling the rate of recovery such as aquifer transmissivity. Uncertainty may be associated with our measurement of the parameter (e.g. potential errors in measurements or test results) or our knowledge of the natural variation in a parameter value. Hydraulic conductivity, for example, will vary spatially within an aquifer and this variability will be reflected in test results. Both natural variability and uncertainty need to be considered when assigning values to input parameters.
- Can the behaviour of the system be adequately represented by a mathematical model? Application of a mathematical model will require a number of assumptions to be made about the system behaviour.

3.6 Conceptual Model (Conceptual Understanding)

The first stage in the assessment of groundwater recovery must be the development of a conceptual model (conceptual understanding) for the groundwater body which should include:

- The nature of the pressure giving rise to failure;
- The extent to which the groundwater body and dependent ecosystems are currently being, or have historically been, impacted by the activity. The potential for increased loading associated with future contaminant impacts;
- The likely changes in the pressures as a result of implementation of the measure;
- The hydrogeological setting;
- The type and magnitude of inflows and outflows to the aquifer;
- The physio-chemical processes that will affect the fate and transport of the chemical;
- An assessment of the adequacy of the available data as this will determine the level of sophistication of any analysis and the confidence that can be attached to the results;
- How the rate of recovery will be assessed (see Section 5);
- Uncertainty in the above factors (i.e. how well has the hydraulic conductivity of the aquifer been defined) and how this will be taken into account in the analysis.

Table 3.2 Key Parameters and their influence on Quantitative and Chemical Groundwater Recovery

Parameter	Chemical (C) or Quantitative (Q) Effect	Effect on Groundwater Recovery
Hydrogeological characteristics		
Aquifer flow mechanism	Q/C	The flow mechanism (e.g. fissure, intergranular or dual porosity) will have a significant control on the rate of recovery. Fissured systems are likely to be characterised by rapid recovery times. Dual porosity or intergranular systems are likely to have much slower recovery times.
Aquifer Type	Q	Confined, leaky, semi-confined or unconfined systems will all behave in different ways to changes in abstraction.
Aquifer geometry (size, shape)	Q	The area over which groundwater levels have been lowered will be a major control on the time for recovery.
	C	The area and depth of the aquifer affected by groundwater contamination will be a major control on the time for recovery.

Parameter	Chemical (C) or Quantitative (Q) Effect	Effect on Groundwater Recovery
Hydraulic conductivity	Q	Hydraulic conductivity will determine the rate at which groundwater levels respond to changes in abstraction. The higher the value, the more rapid the recovery in water level to a reduction in abstraction.
	C	The hydraulic conductivity will determine the rate at which groundwater moves through the aquifer. The higher the value the faster the recovery rate.
Transmissivity	Q/C	As per hydraulic conductivity. The quantity of groundwater flow through an aquifer will be dependent on the transmissivity.
Specific Yield or Storage Coefficient	Q	The response to cessation of abstraction within a fractured basement bedrock with low storage may be relatively rapid (in the order of days or weeks). The response from cessation of long term pumping in a sandstone aquifer with high storage coefficients may be relatively slow (in the order of months or years).
Effective porosity	C	The rate of flushing/time for recovery will be dependent on the effective porosity of the aquifer.
Overlying Strata and Unsaturated aquifer thicknesses	C	The thickness of the overlying strata and unsaturated aquifer will determine the time for recharge and contaminants leached from the soil to arrive at the water table.
Piezometric level	Q	The extent to which groundwater levels have been lowered by historical abstraction, will determine the time for groundwater recovery.
Vertical hydraulic conductivity	Q/C	Often an order of magnitude or more less than the horizontal hydraulic conductivity. Within the overlying strata and unsaturated aquifer constrains actual recharge to the groundwater body and can constrain groundwater flow between hydrogeological units and to dependent receptors.
Hydraulic gradient	Q/C	The rate and quantity of groundwater flow will be a function of the hydraulic gradient. Higher hydraulic gradients are likely to allow more rapid flushing of contaminants and a faster recovery. However, low permeability aquifers are likely to be characterised by a higher gradient, such that a steep gradient is not necessarily consistent with a fast recovery.
Fraction of organic carbon	C	Sorption of organic compounds will be a function of the fraction of organic carbon. The higher the organic content, the greater the potential for retardation and the slower the rate of recovery.
Clay content and cation exchange capacity	C	The clay content and other minerals providing CEC will increase the ability to adsorb and thus retard contaminants such as metals and ammonia.
Multi-layered Aquifer	Q/C	Flow between and within discrete hydrogeological units within the groundwater body. The assessment of recovery times for multi-aquifers is likely to be complex and the confidence in the assessment is likely to be lower.
Inflows/outflows		
Abstraction rate	Q	Reduction in abstraction will increase the rate of aquifer replenishment.
	C	Abstraction will result in removal of contaminants from the aquifer. The assessment should consider seasonal variations in abstraction.

Parameter	Chemical (C) or Quantitative (Q) Effect	Effect on Groundwater Recovery
Actual recharge	Q	Higher recharge allows a greater balance against abstraction and can allow groundwater levels to rebound.
	C	Higher recharge also allows greater flushing of contaminants through the aquifer.
		Recharge will be a function of effective rainfall, land use type, land slope, climate and the presence of low permeability strata. The assessment should consider seasonal variations in recharge.
River groundwater interaction (leakage/discharge)	C/Q	Effluent (flows from) and influent (flows into) leakage through rivers, canals, reservoirs, lakes and other surface water bodies.
	Q	Influent leakage will increase the rate of aquifer replenishment.
	C	Influent leakage (unless this is also contaminated) will increase the rate of flushing of contaminants.
	C	Effluent leakage will remove contaminants from the aquifer system although this may have a secondary impact on dependent systems
Urban leakage rate	Q	Leakage from unpressured sewers and pressured water mains should increase the rate of aquifer replenishment.
	C	However leakage from sewers may affect chemical recovery
Contaminant properties		
Contaminant type	C	The properties of a contaminant will determine its rate of sorption, degradation and how quickly its concentration can be reduced to the threshold level.
Concentration	C	The higher the initial concentration relative to the environmental objective, the greater the recovery time to achieve the objective.
		The rate of recovery will also be determined by the degree to which contaminant concentrations entering the aquifer need to be reduced as a result of the measure.
Retardation/sorption	C	Contaminants may be sorbed to the soil or aquifer matrix. Sorption will decrease the rate of recovery.
		Sorption will be a function of the soil water partition coefficient, the bulk density and porosity of the soil or aquifer.
Soil-water partition coefficient	C	Many contaminants will sorb onto the soil or aquifer matrix to varying degrees depending on the type of surface (clays, sands) and the contaminant. Soil water partition coefficients (Kd) are normally used to describe the extent to which the contaminant is likely to sorb.
		For organic compounds the partition coefficient will be dependent on the fraction of organic carbon and the organic partition coefficient.
Degradation rate	C	Degradation will reduce the contaminant mass and therefore have a major influence on the rate of groundwater recovery.
		Degradation will be dependent on a range of factors including: contaminant concentration (may be inhibited at high concentrations), and environmental conditions (temperature, pH and redox),
Dispersion *(is included here for convenience, but is strictly a function of the hydrogeological characteristics of the aquifer)*	C	Dispersion describes the spreading out of a contaminant along the groundwater flow path.
		The greater the mechanical dispersion the greater the spreading of contaminants and mixing with less contaminated water. This will reduce contaminant concentrations and is therefore likely to decrease the time for recovery.

Parameter	Chemical (C) or Quantitative (Q) Effect	Effect on Groundwater Recovery
Effective diffusion coefficient	C	Molecular diffusion will be of most significance for dual porosity systems in determining the rate of diffusion between mobile pore water and immobile pore water. The greater the diffusion coefficient, the greater the movement of solutes between the matrix porosity and fissures. Greater diffusion is likely to decrease the time for groundwater recovery.
Groundwater density	C	Essential to the assessment of saline intrusion. The higher the salinity, the greater the amount of flushing for recovery.
Geochemical environment		
Temperature	C	Degradation rates and volatile loss can increase with temperature. Therefore faster recovery rates may occur in aquifers which are characterised by higher temperature (such as shallow aquifers).
Redox	C	Redox may affect the rate of degradation processes, for example some organics will only degrade under aerobic environments.
pH	C	pH is an important control on the mobility and sorption of some compounds, particularly metals.

Notes:

Parameters highlighted in **BOLD** are considered to be those essential for a basic assessment of chemical or quantitative recovery.

Recharge

- Rate of flushing of aquifer
- Additional contaminant loading

Diffuse Sources (agricultural)

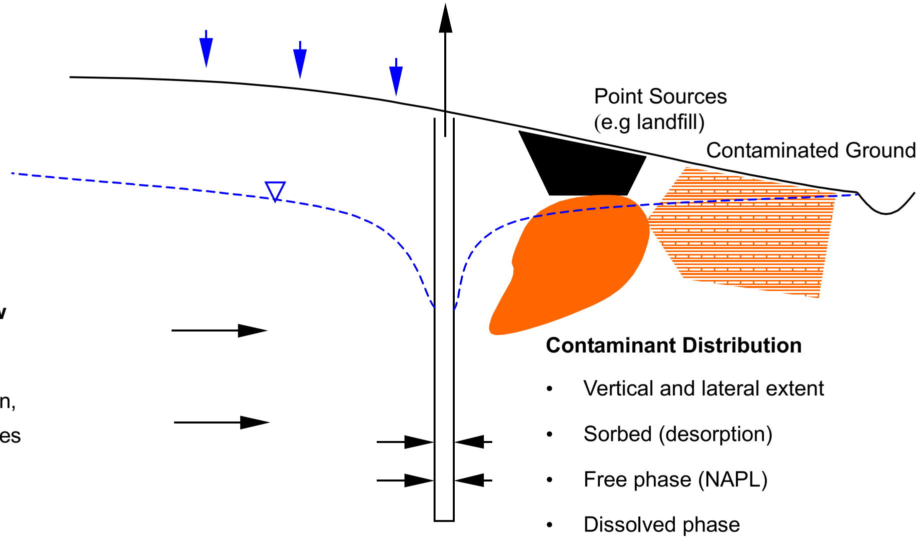
- Change in landuse
- Pesticides and fertliliser
- Spreading

Abstraction

- Control or removal of contaminant source
- Removal of contaminants through abstraction

Unsaturated aquifer

- Contaminants stored in soil zone
- Difficult to control
- Delay for migration



Outflow

- Discharge of contaminants
- Groundwater-Surface Water Mixing

GroundwaterThroughflow

- Rate of flushing
- Contaminant - advection, dispersion, diffusion rates

Contaminant Distribution

- Vertical and lateral extent
- Sorbed (desorption)
- Free phase (NAPL)
- Dissolved phase

Contaminant Degradation

- Contaminant physical/chemical properties
- Degradation rates (abiotic or biotic)
- Geochemical environment (aerobic or anaerobic)
- Path length
- Travel time: porosity and partitioning/ retardation rates

Aquifer Properties

- Fissure, matrix or dual porosity flow
- Aquifer geometry
- Effective porosity
- Hydraulic conductivity
- Bulk Density
- Clay content, Foc, CEC

Contaminant Properties

- Degradation Rate
- Solubility
- Partition Coefficicent
- Density

WFD 25: Derivation of a Methodology for the Assessment of Groundwater Recovery Times to Achieve Good Status

Figure 3.4
Controls on Chemical Recovery

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Recharge

- Balance with abstraction
- Climate change
- Change in land use

Land use

- Change in landuse
- Surface Drainage
- Underdrainage
- Irrigation
- Urban leakage (mains and sewer)

Anthropogenic Factors

- Abstraction changes
- Regulatory Pressures

Receptor Groundwater Dependant Ecosystem

- Wetlands
- River reaches
- Terrestrial
- Ecosystems

Unsaturated aquifer

- Removal from Storage
- Slower infiltration
- Reduced actual recharge (interflow)

Impacts

- Change in species
- Falling water levels
- Reduced baseflow
- Saline intrusion
- Flow reversal

Groundwater Throughflow

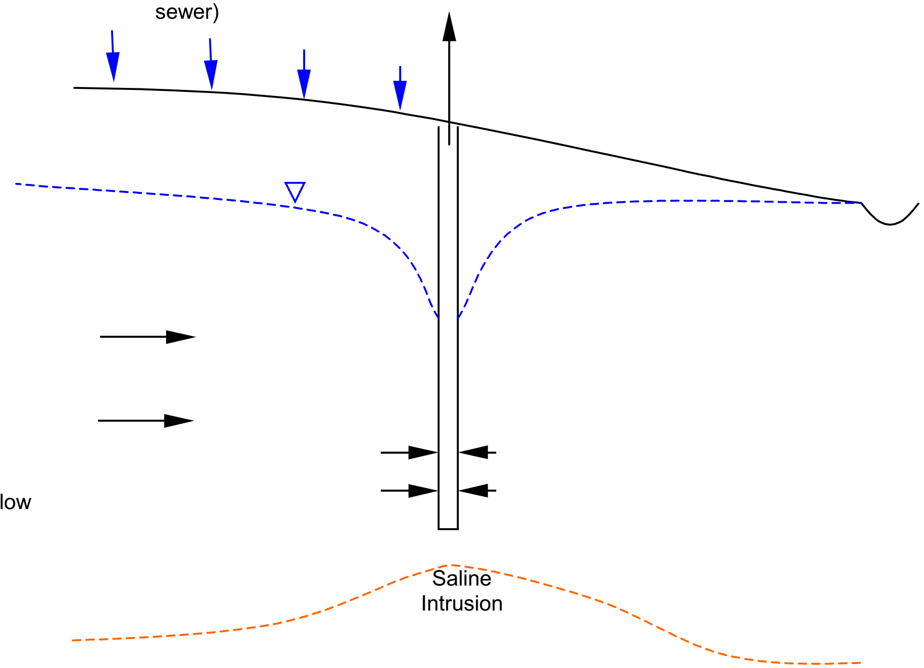
- Balance with abstraction

Aquifer Properties

- Fissure, matrix or dual porosity flow
- Aquifer geometry
- Hydraulic Conductivity
- Storage coefficient
- Aquifer Type (unconfined, confined)

Outflow

- Baseflow contribution
- Groundwater-Surface Water Interaction



WFD 25: Derivation of a Methodology for the Assessment of Groundwater Recovery Times to Achieve Good Status

Figure 3.5
Controls on Quantitative Recovery

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Summary

The **rate of groundwater recovery** will depend on a range of factors including the source pressure (location, extent and type), hydrogeological properties, programme of measures and environmental objective.

Sources of chemical pressures are either diffuse or point source. The type, history of application and location of the pressure will influence the removal and recovery timescale (e.g. application of nitrogen to the surface across a widespread area or acid minewaters within a deep mine adit system).

The **type of receptor** determines the environmental objectives set (e.g. groundwater bodies, protected areas, groundwater dependent surface water bodies or terrestrial ecosystems).

Aquifer hydraulic properties will influence the rate of recovery. The groundwater vulnerability concepts of overlying strata, unsaturated bedrock aquifer and saturated aquifer are used to provide a framework to the hydrogeology.

The presence or absence of the **overlying strata** (soils and subsoils) or **unsaturated aquifer** will influence the time for impact of measures. Residence time is controlled by the flow mechanism (fissured versus intergranular), vertical hydraulic conductivity and thickness.

Chemical recovery will also be controlled by the **recharge** and groundwater **abstraction**; **physiochemical characteristics** of the contaminant and the **geochemical environment** which will control degradation; **flushing rate** through the aquifer.

The **conceptual understanding** of processes within the groundwater body will control the **uncertainty** in the groundwater recovery estimation.

4. Assessment Framework

4.1 Identification of Requirements

The requirements for a framework to determine groundwater recovery rates have been determined through consultation with relevant experts in Scotland, Northern Ireland, England and Wales (a list is provided in Appendix A) and a review of pertinent legislation and guidance documents from WFD.

There are two primary outputs required for the initial characterisation reports: identification of groundwater bodies which will achieve the Article 4 objectives by 2015 and identification of bodies which are not likely to achieve good status objectives by 2027 and as such require less stringent objectives. By default the process to identify the above will also identify groundwater bodies which are not likely to recover by 2015 but are likely to recover by 2027 and as such will require timescale extensions. However, the latter data do not require reporting within the 2004 initial characterisation report.

Technical and economic justification for both timescale extensions and less stringent objectives will be reported in the first river basin management plans published for public consultation in December 2008. It is understood that because of the considerable uncertainties surrounding the production of a list of groundwater bodies requiring less stringent objectives for 2004 there will need to be a fair degree of flexibility. The list will need to be amended following further characterisation and in the publishing of each of the RBMPs.

4.2 Framework Process

The assessment of recovery times for a groundwater body and the subsequent use of time extensions or less stringent objectives requires a phased approach. Subsequently a framework is proposed to guide the 'competent authorities' through the process and to the use of the appropriate tools.

Though linkages between the frameworks exist (e.g. abstractions from a groundwater body can result in saline intrusion and result in failure of good chemical status), in most cases assessment of chemical and quantitative pressures can be considered independently.

The first step in the assessment process for each groundwater body is to define what Article 4 environmental objectives are relevant. A risk assessment of the groundwater body failing to achieve these objectives is then conducted. UKTAG has agreed four classes of groundwater bodies identified from the risk assessments as not meeting the Article 4 environmental objectives and these are summarised as:

(1a) At significant risk;

(1b) Probably at significant risk;

(2a) Not at significant risk (limited data/confidence); and

(2b) Not at significant risk (high confidence).

Only groundwater bodies of class (1a) or (1b) will initially be considered as requiring further assessment for potential time extensions or less stringent objectives. Groundwater bodies falling within class 2a will be considered during subsequent iterations of the characterisation process.

A staged assessment process is proposed so that the detail of the assessment can be tied to the time stage of the assessment, the level of justification required, the risk of failure of the groundwater body achieving the Article 4 environmental objectives and the confidence in the assessment. The level of data available to undertake the assessment would link into the confidence level of the result.

The outputs at each stage of the WFD process are outlined below.

Initial Characterisation (December 2004)

1. Identify groundwater bodies likely to require lower objectives i.e. groundwater bodies which **are not likely** to achieve environmental objectives **by 2027**.

2. Identify groundwater bodies likely to require a timescale extension; i.e. groundwater bodies which **are likely** to achieve environmental objectives between **2015 and 2027**. This is not a requirement of the Directive but a likely output from the above identification.

The above information will require basic assessment of technical feasibility and disproportionate cost in broad 'outline' terms only.

Further Characterisation (Post December 2004 to December 2008 – draft 1st RBMP)

3. Reassess December 2004 outputs and where necessary revise groundwater body listings of those requiring time extensions and lower objectives. Utilise data from monitoring networks for the assessments as they become available. Detailed economic and technical assessments will be required to provide the justification for both the bodies targeted for timetable extensions or lower objectives and the lower objectives themselves which will require to be defined in time for the 1st RBMP.

Revision of RBMPs within Timescale Extensions (Post December 2009 – publication of draft RBMP's in December 2026)

4. Reassess previous outputs and utilise monitoring data from networks established in December 2006 to further inform anticipated chemical and quantitative recovery curves/data and amend lower objectives where required. Potential breaches of the Directive due to recovery times and delayed pollution impacts will also need to be identified and reported to UK Government. Possible detailed modelling of groundwater bodies with high uncertainty in less stringent objectives.

Revision of RBMPs outwith Timescale Extensions (2027 RBMP and beyond)

5. The 'less stringent objectives' as set in 2027 and future RBMPs must be met. Reassess previous outputs and utilise monitoring data from networks to further inform anticipated chemical and quantitative recovery curves/data and amend lower objectives where required. Further detailed modelling of groundwater bodies with high uncertainty in less stringent objectives.

A flow diagram using these above stages to indicate the assessment requirements is presented in Figure 4.1.

Figure 4.1 Groundwater Recovery Assessment Flow Diagram

Requirement	Identification of groundwater bodies which are likely to achieve the environmental objectives by 2015	Identification of groundwater bodies requiring less stringent objectives	Assessment for measures that are technically feasible and not disproportionately costly that are likely to achieve the environmental objectives by 2027 (i.e. timescale extensions)	Assessment for measures that are technically feasible and not disproportionately costly that are likely to require less stringent objectives beyond 2027	
Confidence in achieving requirement prior to assessment	High	N/A	High to Low	High to Medium	Low
Data required for assessment	Low	Low	Low	Medium	High
Justification required by the EC	Low	Low	Low	Medium	High
Recommended Assessment	**RCBA Initial Characterisation**	**Basic Assessment**	**Detailed Assessment** **Tier 1**	**Tier 2**	**Tier 3**
Timeline		Dec 2004	2005 – Dec 2021	2022 and beyond	

Notes:

(a) The tier of detailed assessment are recommendations and could be changed on a case specific basis. For the detailed assessment of most groundwater bodies it is considered that the tiers would be considered sequentially, i.e. the work would be conducted for Tier 1 and then work for Tier 2 and/or Tier 3 would be considered where there was a low confidence in the Tier 1 calculation, data was available and a higher level of justification was required by the EC.

(b) The tier calculations may highlight the need to obtain further data to allow a higher level of assessment.

Determination of the time for groundwater levels and contamination within a groundwater body to achieve required threshold values defined in the GWDD and the WFD will require the use of a range of tools or model solutions (e.g. look-up matrices, spreadsheet calculations, analytical solutions or complex numerical models). In several cases existing techniques and tools may need to be adapted to suit the calculation of recovery times.

The assessment of impacts from pressures must occur both regionally (across the whole groundwater body) and with reference to specific groundwater dependent receptors (e.g. drinking water abstractions and surface water ecosystems). The tools must be suitable for this range of objectives, such that no one tool is likely to be suitable for the range of scenarios that may need to be considered.

It is recognised that numerical groundwater flow and contaminant transport models are data hungry and time and cost intensive. The data required for most models are unlikely to be available for the majority of groundwater bodies. For these reasons a phased approach is recommended so that the level of calculation is aligned to the level of confidence required for the recovery time estimation, based on the available data, and the level of justification required for WFD. The data requirements and assessment time/cost will increase with each level, i.e. from the basic to the detailed assessment levels. This is outlined below.

The **Basic Assessment** would be used to identify groundwater bodies requiring less stringent environmental objectives which are to be reported in 2004. Groundwater bodies requiring timescale extensions would also be an output from this stage (though not required to be reported to the EC in 2004). The basic assessment would need to be precautionary, to take account of the uncertainty associated with the use of ‘relatively’ simple classifications.

The basic assessment would comprise the development of a conceptual model and the application of a qualitative (expert opinion) assessment based on the type of pressure. If necessary it could include the use of relatively simple numerical methods such as look-up tables based on the hydrogeological properties of aquifers (or aquifer response type).

The **Detailed Assessment** would be a more sophisticated analysis and it is suggested that this consists of several tiers which would be linked to the availability of data for the assessment; the uncertainty in the aquifer recovery times and the level of justification required to the EC. It is suggested that the Tier 1 is used for both the assessment of timescale extensions and less stringent objectives and that Tiers 2 and 3 are used for further assessment of less stringent objectives, where appropriate. However the higher tiers could be used for assessment of timescale extensions where the uncertainty and data availability justified this.

It is suggested that the tiers are used sequentially – i.e. the calculation would build on information gained from the previous tier. Tier 1 would be a broad groundwater body scale calculation. Tier 2 would use relatively simple ‘spreadsheet’ calculations such as aquifer response function calculations for a groundwater body (quantitative) and flushing cell model calculations (chemical). Retardation and degradation parameters could be incorporated in the flushing cell model calculations if appropriate.

The highest tier, Tier 3, would require a numerical model (both economic and groundwater) and consequently have high data and user input (and therefore cost) and necessitate the development of a detailed conceptual understanding of the groundwater body.

4.2.1 Assessment Requirements

The requirements are detailed as follows:

i) Determine the reasons for the assessment:

- Is the purpose of the assessment to calculate the time for recovery and the need for a time extension or for the determination of less stringent environmental objectives?
- What time period applies to the assessment (e.g. 2009 – 2015 or 2009 – 2027)?

ii) Develop a conceptual model for the groundwater body which identifies all factors for consideration including:

- Identification and characterisation of the pressure(s);
- Determination of the need to include the soil and the unsaturated aquifer in the assessment;
- Identification of the processes that will control the rate of groundwater recovery. For the initial assessment level only the main processes are likely to be considered;
- Selection of how these processes will be represented
- Definition of parameter values (e.g. aquifer hydraulic parameters and chemical properties of contaminants).

iii) Select the modelling level required for the assessment - based on the level of justification required and the confidence needed in the prediction.

iv) Collate and review the data available for the groundwater body. This will influence the choice of the model technique selected and determine the requirement for additional data collection;

v) Identification of the main sources of uncertainty and the level of confidence that can be associated with the assessment.

The assessment tools for Basic Assessments are outlined in the following section. The tools for Detailed Assessments are outlined in Section 6.

Summary

A **framework** for the assessment process has been proposed. This identifies the assessment requirements from initial characterisation, through further characterisation to the submission and revision of the river basin management plans.

A **basic assessment** is proposed for the initial characterisation reports which will, through categorisation primarily based on expert opinion identify those groundwater bodies likely to require timescale extensions or less stringent objectives. This basic assessment uses a risk scoring matrix system to categorise the groundwater bodies.

For the further characterisation and revision of the river basin management plans model **detailed assessments** are proposed which will provide a numerical estimation of the times to achieve good environmental status (recovery times) and less stringent objectives, where required. The detailed assessments will consist of **three tiers** of calculation. It is suggested that the tiers are used sequentially but selection of the ultimate tier for a groundwater body would be driven by the uncertainty in the calculation and the data availability.

Tier 1 would be a broad groundwater body scale calculation; Tier 2 is a spreadsheet based flushing cell (chemical) or aquifer response calculation and Tier 3 is a distributed numerical model.

5. Basic Assessment Framework and Methodologies

5.1 Introduction

The basic level assessment should involve relatively simple approaches such as look-up tables or scoping calculations. Selection of the appropriate approach will depend on:

- pressure (location, type and extent);
- hydrogeological situation; and
- available data.

It is recognised that the available data will be a major limitation to the initial characterisation required by December 2004 and therefore a qualitative assessment which will categorise groundwater bodies likely to fail to attain good status by 2015 and 2027 is considered appropriate. Assuming the implementation of the first programme of measures by 2012 this would allow 15 years to achieve good status (to 2027).

It is proposed to use a risk assessment structure to determine the likelihood for achieving the good status for the groundwater body by 2015 or within the timescale extensions. A risk scoring assessment is proposed and outlined in the sections below.

5.2 Risk Scoring Framework

A flow diagram for this risk scoring assessment is presented in Figure 5.1 and the matrices for use in this risk scoring are outlined below. This flow diagram is designed to be used with both quantitative and chemical assessments and identifies the scoring assessments required for the recovery assessment.

It is proposed to assess the influence of the source – in terms of its type, extent and history. If the source indicates a likely risk of failure then this source assessment would be combined with a matrix based assessment of the overlying strata, unsaturated aquifer and saturated aquifer to the recovery timeframe. Therefore, a non-conservative source which was limited in extent would only be of concern (for the recovery timescale) if the overlying strata and unsaturated aquifer assessments indicated a long residence time and the saturated aquifer indicated a slow response time.

Matrices for these assessments are presented in the following sections. It should be emphasised that the matrices proposed are draft only and require further detail and site and pollutant specific calibration before implementation.

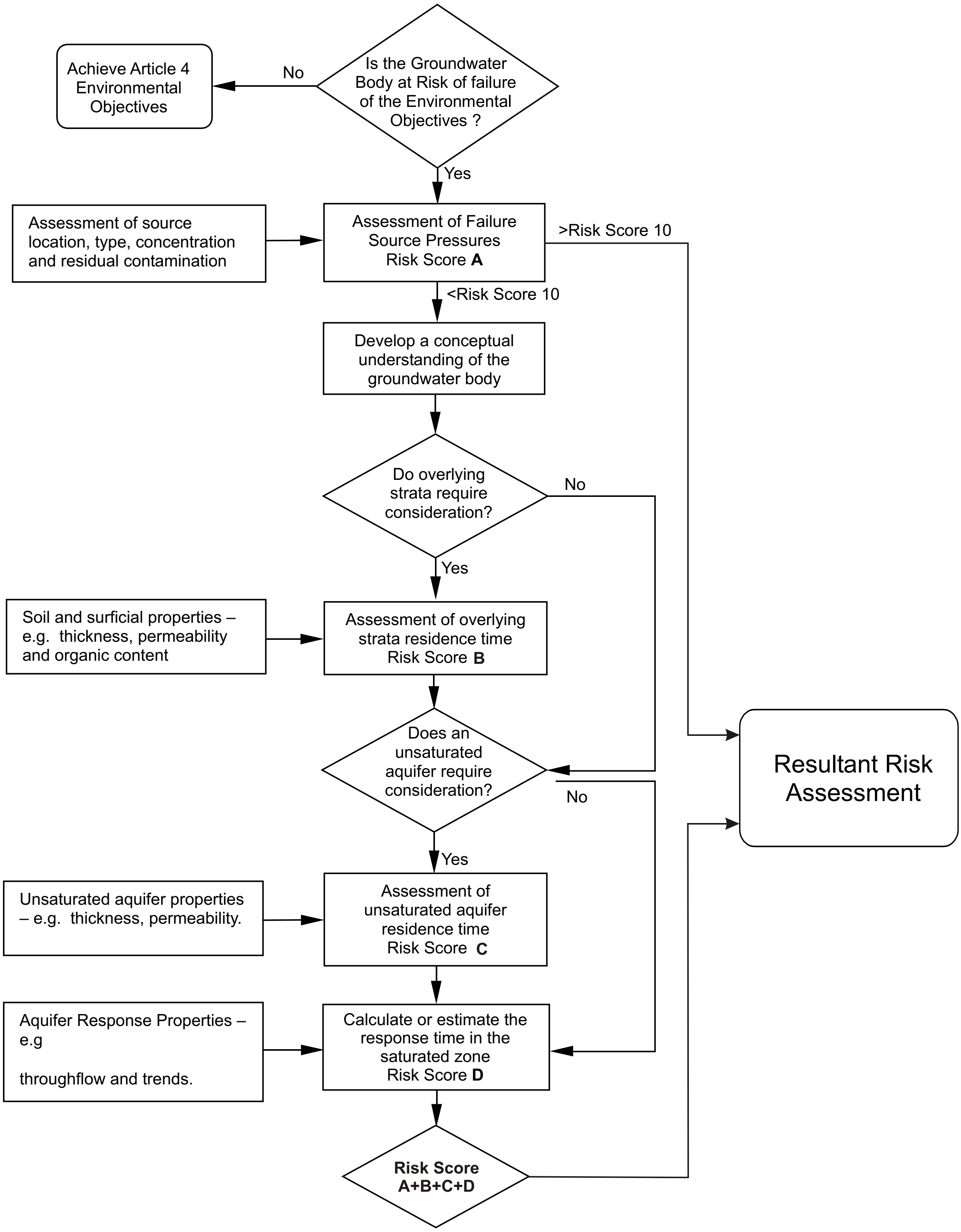

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Figure 5.1
Basic Assesment Flow Diagram

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5.3 Risk Matrices

5.3.1 Introduction

The actions proposed based on the resultant risk scores are identified in Figure 5.1 above and outlined in Table 5.1.

Table 5.1 Actions resulting from Risk Assessment Scores

Risk Score	Action
0 – 10	Groundwater body is likely to recovery before 2027. Consider a detailed assessment during further characterisation dependant on the confidence in the result and the data availability.
10 – 15	Groundwater body may recover before 2027 dependent on the measures implemented and the actual source and hydrogeological environment. Consider monitoring and additional assessment during further characterisation using the detailed assessment tiers.
> 15	Groundwater body is not likely to recover before 2027. Identify the groundwater body as requiring less stringent objectives. During further characterisation use the detailed assessment tiers and monitoring to determine less stringent objectives for the groundwater body.

5.3.2 Source Assessments

For some failing groundwater bodies the type, location, extent and history of the contamination present means that the groundwater body is likely to fail to achieve good status by 2015 or 2027 on the technical feasibility and disproportionate cost arguments. Therefore, detailed consideration of pathway, groundwater body and dependent receptors would not be required for initial characterisation.

For this purpose a risk scoring matrix which weights the source contamination is proposed and an example is presented in Table 5.2.

It is proposed that a ‘significance’ (high, medium, low) is calculated based on rate of contamination, concentration and timeframe. This could be achieved using a multiplier to determine a total contaminant loading (e.g. rate of loading * concentration * timescale). Where a ‘High Significance’ is achieved then failure to achieve ‘good status’ within the timescales is likely and further consideration of the groundwater body and dependent receptors would not be required.

The High, Medium and Low significance would need to be determined for each pollutant of concern.

Table 5.2 Risk Code for Source Type

Source Type		Example	Significance		
			Low	Medium	High
Conservative	Diffuse	Nitrate	5	10	15
	Point Source	DNAPL, bromate	5	10	15
Non-conservative	Diffuse	Phosphate, pesticides	5	10	15
	Point Source	Hydrocarbon, pesticides	5	10	15
Deep, Long term		Mine water	5	10	15

5.3.3 Overlying Strata and Unsaturated aquifer Assessments

Impacts resulting from changes to the source concentration as a result of the measure will be delayed by the presence of the overlying strata and unsaturated aquifer, where present. The thickness, flow type and vertical hydraulic conductivity of these layers will control the residence time of infiltrated waters, and associated contaminants, within the overlying strata and unsaturated aquifer and therefore the time that 'current' surface or 'historic' source concentrations would take to reach the saturated aquifer.

The risk scoring matrix proposed is based on an estimate of the residence time within the overlying strata and unsaturated aquifer based on the hydrogeological properties of the deposits. Residence time is dependent on travel times where:

a) Travel time through the overlying strata is a function of the thickness, effective porosity and actual recharge where:

$$t = \frac{d.\theta}{R} \qquad (1)$$

where t is time (days), d is thickness (m), θ is effective porosity (dimensionless) and R is recharge (m/d).

b) Travel time through the overlying strata and unsaturated aquifer is a function of the flow type (e.g. purely fissured, intergranular or dual porosity) and thickness.

Examples have been drawn up and are presented in Tables 5.3 and 5.4. The classes and thicknesses used in this table are derived from the SNIFFER WFD aquifer vulnerability research project. Residence times are currently estimated but could be calculated using simple analytical solutions and ranges of permeabilities for each rock type. However, for many groundwater bodies there may be limited or no data on the thickness of the unsaturated aquifer, and an unsaturated thickness may need to be assumed based on the aquifer type. For low porosity (fissured) aquifers, then the delay for a contaminant to migrate through the unsaturated aquifer may not be significant to groundwater recovery times.

Table 5.3 Risk Code for Overlying Strata

No.	Thickness (m)[1] / Vertical Conductivity	< 1	1-3	3-10	10-30	> 30
1	Low K	2	3	3	4	4
2	Medium K	1	2	2	3	3
3	High K	0	0	1	2	2
Comments on Colour Coding		Likely to be < 3 years (i.e. between implementation of measures 2012 and 2015)		Likely to be < 15 years (i.e. between 2012 and 2027)		Likely to be > 15 years

[1] Thickness categories from the SNIFFER WFD Aquifer Vulnerability categories

Table 5.4 Risk Code for Unsaturated Aquifer Residence Time

No.	Unsaturated Thickness (m)[1] / Unsaturated Aquifer Flow Type	< 1	1-3	3-10	10-30	> 30
1	Superficial deposits, intergranular flow	3	3	4	4	4
2	Dominantly intergranular flow, limited fissure flow	2	2	3	3	4
3	Intergranular and fractured flow (dual porosity)	1	2	3	3	4
4	Dominantly fractured flow , some intergranular flow	0	0	1	2	2
5	Fractured bedrock	0	0	0	0	0
6	Karstic flow and mine systems	0	0	0	0	0
Comments on Colour Coding		Likely to be < 3 years (i.e. between 2012 and 2015)		Likely to be < 15 years (i.e. between 2012 and 2027)		Likely to be > 15 years

[1] Thickness categories from the SNIFFER WFD Aquifer Vulnerability categories

5.3.4 Saturated Aquifer Response Assessments

It is proposed that the aquifer response or reaction time is used to determine a risk code for the assessment. This can be used to assess both quantitative and chemical recovery times. An example of a similar matrix was developed by BGS for assessing relative rate of response of aquifer at outcrop to nitrate in rainfall recharge.

Table 5.5 Risk Code for Aquifer Response or Reaction Time

No.	Dominant Flow Mechanism	Example	Aquifer Response Rate Fast	Slow
1	Superficial deposits, intergranular flow	Sands and Gravels	1	3
2	Dominantly intergranular flow, limited fissure flow	Triassic Sandstones	2	4
3	Intergranular and fractured flow (dual porosity)	Chalk	2	4
4	Dominantly fractured flow, some intergranular flow	Carboniferous Limestones	1	2
5	Fractured bedrock	Basement	2	3
6	Karstic flow and mine systems	Basement	3	4
Notes:	Aquifer response relates primarily to the rate of flushing taking into account recharge rate, storativity, transmissivity and depth of flow. **High** response rates correspond with aquifer systems where the annual volume of recharge would be expected to be similar to the total volume of water stored in the aquifer. **Low** response rates correspond with aquifer systems where the annual volume of recharge would be expected to be significantly lower than the total volume of water stored in the aquifer.			

5.4 Example Calculations

To demonstrate use of the matrices three example calculations are presented below:

1. Deep, historical, contaminated minewater within fully saturated Coal Measures of central Scotland would result in a high source significance. Therefore, the source type alone would score 15 points and indicate that the groundwater body is likely to require less stringent environmental objectives. Further assessment of the pathways and aquifer response is therefore not required at the initial characterisation stage.

2. Recent diffuse agricultural sourced nitrate contamination resulting in a 'medium' source significance within a fully saturated sand and gravel aquifer with 1 m of medium permeability drift cover would score:

    - Source type – 10 points
    - Overlying strata – 2 points
    - Unsaturated aquifer – 0 points
    - Saturated aquifer (fast response) – 1 point
    - Total – 13 points.

    Therefore the score recommends that the groundwater body may recover to its good status objectives by the end of the timescale extensions (2027) if the programme of measures are implemented by 2012.

3. Recent diffuse agricultural nitrate contamination resulting in a ‘medium’ source significance within a slow response chalk aquifer at outcrop with 10 m of unsaturated aquifer.

    - Source type – 10 points
    - Overlying strata – 0 points
    - Unsaturated aquifer – 3 points
    - Saturated aquifer – 4 points
    - Total – 17 points.

The total score therefore indicates that the groundwater body is likely to require less stringent environmental objectives.

4. To demonstrate the use of the matrix for a quantitative recovery assessment it is assumed that a public water supply within a Chalk aquifer below 3 m of low permeability Drift and a 10 m unsaturated zone is impacting on a surface water body.

    - Source type – 0 points
    - Overlying strata – 3 points
    - Unsaturated aquifer – 3 points
    - Saturated aquifer – 4 points
    - Total – 12 points.

This would indicate that the groundwater body may recover to the required status within the timescale extension period dependent on the measures implemented. However, further assessment and monitoring should be considered.

It is important to emphasise that these are scoping calculations only to indicate the relative importance of the source, pathway and groundwater body characteristics in terms of groundwater recovery times. The values do not relate to any physical property. Expert judgement should be used to determine if the category indicated by the calculation is suitable for the actual groundwater body being assessed. Calibration of the values against worked actual examples is proposed.

5.5 Data Requirements and Knowledge Gaps

The basic assessment has minimal actual data requirements and is principally reliant on expert opinion for categorisation of the groundwater bodies. The actual knowledge required is:

- Assessment of the source to determine the significance factors.
- Aquifer type.
- Presence and type of overlying strata including estimation of thickness and vertical hydraulic conductivity.
- Presence of unsaturated aquifer including determination of flow type and estimation of thickness and vertical hydraulic conductivity.

This opinion can use supporting calculations based on equation (1) above, where appropriate, to improve the confidence in the assessment.

For the supporting calculations knowledge (or estimation based on expert opinion) of the following is required:

- effective porosities;
- recharge estimations; and
- thickness of the unsaturated aquifer.

Draft aquifer response maps have been created for aquifers at outcrop in England and Wales by the BGS, specifically to assess nitrate pollution and recovery. Similar maps could be created to give an initial assessment of response times for quantitative and generic chemical assessments.

5.5.1 Knowledge Gaps

Monitoring of water levels within many groundwater bodies is currently inadequate. However the UK environment agencies are working towards establishing groundwater level monitoring networks that will meet the requirements of the WFD by Dec 2006. Many groundwater bodies in England and Wales, Scotland and Northern Ireland do not have rigorous pumping test calculations of transmissivity and storage. This is highlighted as a data requirement for further characterisation.

The contaminant properties defined in the literature are for generic soil and subsoil types. There are very few site specific calculations of contaminant leaching, soil-water partitioning, degradation rates available in the UK. Further investigation and sponsored research would be required to define these parameters for the wide range of UK soil and subsoil types.

5.6 Confidence in the Basic Assessment

It is important to note that the uncertainties with the values obtained from a matrix are high and therefore there is a consequent danger of placing undue emphasis on the values obtained. The response matrices would be developed from expert guidance but to gain confidence in the system it would need to be calibrated using a significant number of real examples with a full conceptual understanding.

The matrices would not account for variations across the groundwater body or differences in the flow systems that characterise them. The chemical response matrix would be for a generic contaminant and would not allow for variations in degradation or retardation.

The confidence that can be attributed to a groundwater body recovery time assessment is based on several factors including the:

- Natural variability in aquifer and chemical parameters;
- Availability of specific chemical contaminant properties;
- Availability of groundwater body specific properties;
- Accuracy of the recharge calculation (flushing and balance to abstraction);
- Accuracy of the method used to calculate recovery times.

The inherent uncertainty and hence the confidence in the hydrogeological and chemical parameters has been identified in Section 3.5 above. The level of uncertainty in the recovery timescales will decrease with the increase in conceptual understanding, monitoring and assessment derived for the Detailed Assessments (Section 6).

Examples to illustrate the degree to which the calculations times may be in error are presented in the paragraphs below.

The **effective porosity** of a groundwater body is a key parameter in the estimation of recovery rates. Values typically range from 0.5% to 40%, such that there is a potential for an order of magnitude difference in recovery times. This is most likely to apply for dual porosity aquifers identified as having dominantly fracture porosity, but where a degree of interaction with matrix pore water may occur. The decision to use a fissure porosity (typically 1 to 2%) or the matrix porosity, which may be an order of magnitude greater, is a factor that compounds this inherent uncertainty. Effective porosity is not straight forward to estimate as, typically, this parameter is estimated on laboratory test results (only a small volume tested) or tracer tests.

The **transmissivity** within a groundwater body can vary by several orders of magnitude. In multiple aquifer systems the bulk transmissivity will depend on the representative elemental volume (REV) of the aquifer being considered. Whilst fracture zones within an aquifer may be quickly flushed, the less transmissive matrix may only be flushed slowly and continue to store contaminants. Groundwater recovery from reduced abstraction will improve quickly close to the abstraction points and more slowly at a distance from the abstraction.

Estimations regarding the likely confidence associated with **recharge** calculations presented in the WFD Groundwater Recharge project (WFD 12, Entec, 2003) indicated that the calculations could be in error by a factor of 2.

As a result, the Basic Assessments for 2004 will be quite precautionary. From assessment of the potential errors in the key input parameters an order of magnitude (factor of 10) could be applied to the calculations. For example, if the recovery time is calculated as 1 year, error bars from one month to 10 years would apply.

The Detailed Assessments conducted during further characterisation will have a higher confidence (lower uncertainty). The calculations are groundwater body specific and relate to the actual recharge and aquifer and chemical properties. In addition, the chemical calculations can include an allowance for degradation and retardation, however, the calculations at Tier 2 are 'whole aquifer' calculations and do not describe the variations found within the groundwater body.

For the 2009 RBMP an increasing level of detail will be applied to the characterisation process. This characterisation will include data collection from monitoring and improved definition of contaminant properties and aquifer parameters from field investigations. This will reduce the uncertainty in the recovery timescale estimations.

Summary

The basic assessment is to be used to identify (by December 2004) groundwater bodies that are likely to require less stringent objectives. A **risk scoring** framework is proposed which uses matrices to consider the overlying strata, unsaturated aquifer and saturated aquifer. This 'pathway' assessment is then combined with an assessment of the source, in terms of its total loading, to determine the 'likely' time period for recovery.

This allows **sources** with a long **history of contamination** or **conservative nature** that cannot be quickly removed to categorise the groundwater body as likely to require timescale extensions or less stringent objectives.

Similarly, the likely **residence time** within the **overlying strata and unsaturated aquifer** can be accounted for.

The rate of flushing or recovery of water levels within the **saturated aquifer** is categorised dependant on the **flow mechanism**.

The basic assessment has inherently a high level of uncertainty. The process is intended to flag those groundwater bodies likely to require less stringent objectives and therefore will require more detailed assessment during 'Further Characterisation'.

6. Detailed Assessment Framework and Methodologies

6.1 Introduction

Section 5 identified a proposed framework for the basic assessment of groundwater bodies likely to require less stringent objectives.

A framework proposing the process for a detailed assessment is required for the justification of the less stringent objectives and a suggested approach is detailed in the sections below. This framework could be used within the first three river basin planning cycles (up to 2027) to assess and justify the timescale extensions. The assessment process could link closely, and the need for more detailed assessment could be guided by, the ongoing monitoring of the groundwater body.

6.2 Process for Identifying Less Stringent Environmental Objectives

6.2.1 Overview

The application of less stringent environmental objectives to a groundwater body are defined under WFD Article 4.5. The Article and its implications have been discussed in Section 2.3.2.

Less stringent environmental objectives are required to be set under Article 4.5 by the 'competent authority' for each failing stress (groundwater flows/levels or contaminant concentration) within each at risk groundwater body identified in the initial characterisation reports (2004). Although the justification of 'timescale extension' would apply for each of the identified groundwater bodies until 2027, it is understood that the less stringent objectives for groundwater bodies likely not to meet good status in 2027 would be set in each RBMP (first published in 2009).

These less stringent objectives must have the least possible deviation from the good status objectives. Additionally, a deterioration in the status of the groundwater from that published in the RBMP (first published in draft in 2008) is not allowed.

6.2.2 Components for Setting Less Stringent Objectives

An extensive **technical justification** is required for the less stringent objectives within each River Basin PoM. It has been assumed for the purposes of this report that the less stringent objective will be a target value (e.g. values of concentration, loadings, flows or levels). As a target value needs to be defined a numerical assessment of the impact of a measure or combinations of measures on the groundwater system will usually be required. However, it may not always be possible to give precise numerical targets (for example, when assessing the impacts on dependent terrestrial ecosystems) and a semi-quantitative or even a qualitative assessment may only be possible.

An **economic appraisal** (detailed in Section 7) of the options for the combination of measures is required to determine the preferred measures under the cost effectiveness and disproportionately expensive arguments. Where several measures are identified which are not 'disproportionately expensive' then the combination of measures which results in the least deviation from the good status objectives should be selected.

There could be an iterative process between what is technically achievable towards the environmental objective given a particular measure and the estimated cost of implementing that measure.

The objectives which could be achieved in the groundwater body for each of the measures could be calculated using the technical framework outlined in this Section below. Additionally, the cost effectiveness of implementing each measure could be assessed using the framework outlined in Section 7. An options appraisal could then be conducted to determine the preferred combination of measures and the chosen less stringent objective.

6.2.3 Scope of Work

In the scope of work for defining the less stringent environmental objectives there is a need to consider the following:

- different receptors (i.e. groundwater body, abstraction, wetlands, rivers), each will require different flow processes to be modelled.
- different pressures (e.g. quantitative and chemical): again this may determine processes to be understood, characterised and modelled.
- implications of the modelling approach:
    - applicability of a particular model/tool to the assessment of the process;
    - time/resources;
    - data requirements;
    - development requirements;
    - calibration/validation; and
    - accuracy/reliability of model predictions.
- confidence in the assessment process.

The different receptors and pressures and the controls affecting the rate of recovery from these pressures have been detailed in Section 3 of this report. The confidence in the assessment process is an outcome of the modelling approach.

6.2.4 Environmental Targets

The environmental objectives for good status are set out in the WFD and GWDD and then these objectives are subject to operational interpretation in CIS and UKTAG guidance. The less stringent environmental objectives will be established in relation to the classifications defined under UKTAG guidance.

6.2.5 Timescale for Determinations

Less stringent environmental objectives are to be assessed for each cycle of the RBMPs (first published in draft in 2008) and an objective set to be achieved for the next RBMP (six years). Forecasting towards the 'good status' environmental objectives is not explicitly required under WFD but would be advisable to ensure that the good status objectives are ultimately achievable under the set PoM and that the less stringent environmental objectives set at each RBMP can be achieved. If a threshold concentration/level is achieved under the first PoM then it may be revised under subsequent PoMs in order to achieve the least possible deviation from good status, subject to the tests of technical feasibility and disproportionate cost.

6.2.6 Uncertainties in the Definition of the Less Stringent Environmental Objectives

Calculation of a less stringent environmental objective for a failing groundwater body requires forecasting or prediction of the changes within a groundwater body. There will therefore be uncertainty in whether the implemented measure can achieve the target value (less stringent environmental objective).

The level of this uncertainty is dependant on the understanding of the:

- Impact of the measure(s) on the future source loading;
- Confidence that the measure(s) can be implemented as proposed;
- Hydrogeological and hydrological flow processes within the groundwater body;
- Attenuation/degradation of the contaminant (chemical) or recovery of the water level (quantitative);
- Historical loading of pressures (chemical and quantitative) within the groundwater body (e.g. residual contaminants or abstractions);
- Time lag for the impact of the measure(s) to be observed in the receptor.

It is necessary for the setting of the less stringent objectives to understand the level of uncertainty in the calculation of the values. The following points would improve the understanding of this uncertainty:

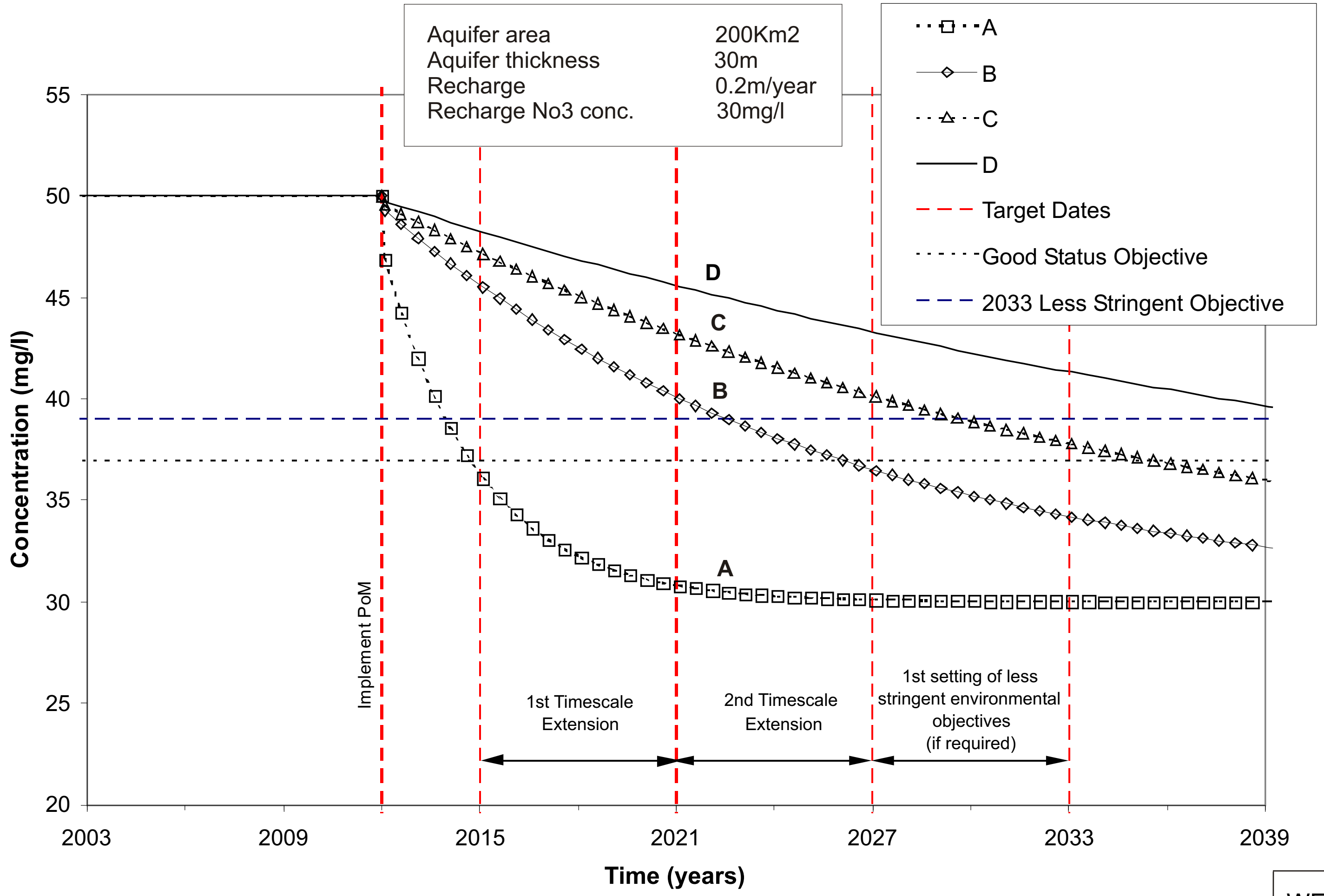
- Historical and current calculations for the source loadings and future predictions based on the implemented measures;
- Comparison with previous examples of the success of such measures, should these exist;
- Parametric data for the groundwater body (hydraulic gradients, parameters, recharge calculations etc.);
- Understanding of the physical and chemical processes affecting a contaminant within the soil, unsaturated and saturated aquifers;
- Historical and current monitoring of the groundwater levels or concentrations;

- Validation of numerical calculations based on calibration against historical data;
- Sensitivity analysis of a prediction to develop an envelope of confidence.

To illustrate the uncertainty in making a prediction, some of the issues in the determination of a less stringent objective are discussed below.

Figure 6.1 shows for an example contaminant the effect of an example PoM on the concentrations in the groundwater body. A target environmental objective and less stringent objective have been set. In the illustration the effective porosity of the aquifer has been modified within the range 2% to 20%. At 2% effective porosity (Line A) the groundwater body achieves the good status environmental objectives by 2015; At 9% porosity (Line B) the groundwater body achieves the environmental objective within the timescale extension; At 15% porosity (Line C) the groundwater body achieves the 2033 less stringent environmental objectives, whereas at 20% porosity (Line D) the groundwater body fails to achieve the 2033 less stringent objectives.

This indicates the uncertainty present in setting less stringent objectives. If the initial characterisation of the groundwater body identified a range of 2-20% effective porosity (e.g. a dual porosity aquifer) then the less stringent objective needs to be set at a target where failure of the objective is unlikely (i.e. in this case at the higher 20% effective porosity). This illustrates the importance of further studies to constrain key variables for failing groundwater bodies. This may indicate that probabilistic determination of the likely range of recovery times given a likely range of input parameters may be appropriate.



WFD 25: Derivation of a Methodology for the Assessment of Groundwater Recovery Times to Achieve Good Status

Figure 6.1
Illustration of Uncertainty in the Determination of Less Stringent Enviromental Objectives.

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6.2.7 Level of Justification

The technical requirements to set a target value, the uncertainty in achieving/predicting the value and the level of justification required by the EU (i.e. that the objective is the least possible deviation from the good status objective) indicate that some level of assessment will be required to justify a less stringent objective. The rigour of this assessment should be apportioned on a risk basis dependent on the uncertainty of the less stringent objective being required.

The implications of poor 'prediction' are that:

- The measure chosen may be inadequate resulting in the less stringent objectives not being achieved and a need to apply to the EU for derogation; or
- The measure may exceed the requirements to achieve the objectives (overkill).

It is considered that the development of any assessment should follow a staged approach which would build on the level of data, processing and time/cost required and as a consequence improve on the understanding of the uncertainty in the calculation. The confidence in the input data is an important criterion in determining the confidence which should be placed on the subsequent results.

The framework, available tools, data requirements, and resultant confidence in the calculation is developed in the sections below.

6.3 Determination Process

A phased approach for determining the less stringent objectives is proposed in the flow chart presented in Figure 6.2.

The initial stages of the determination process would include:

- Translation of good status objectives into operational measures;
- Collation of data; and
- Conceptual model of the groundwater body.

These would normally be determined in the initial characterisation risk assessment and form part of the assessment of the pressure.

After collation of the required information an initial **Tier 1** 'spreadsheet based' assessment of the impact of the measures would be calculated using empirical solutions. This initial assessment can be used to shortlist the proposed measures adequate to achieve a less stringent objective. The shortlisted measures would then be assessed in more detail. It is then proposed that the detailed modelling would have a two further tiers. **Tier 2** would use simple models (for example lumped water balances and basic soil leaching calculations) and **Tier 3** would include distributed numerical models.

Selection of the tier would depend on the:

- Level of confidence required from the assessment. This would depend on the above criteria.
- Level of confidence in the result of the previous tier.
- Cost and economics for the predictions and the implementation of the measures.
- Number and relative environmental importance of individual receptors – for example, there would be a difference in assessment for a principal aquifer developed for public water supply and a secondary aquifer with limited use.
- Complexity of the system.

Supplementary considerations for the tier choice would include:

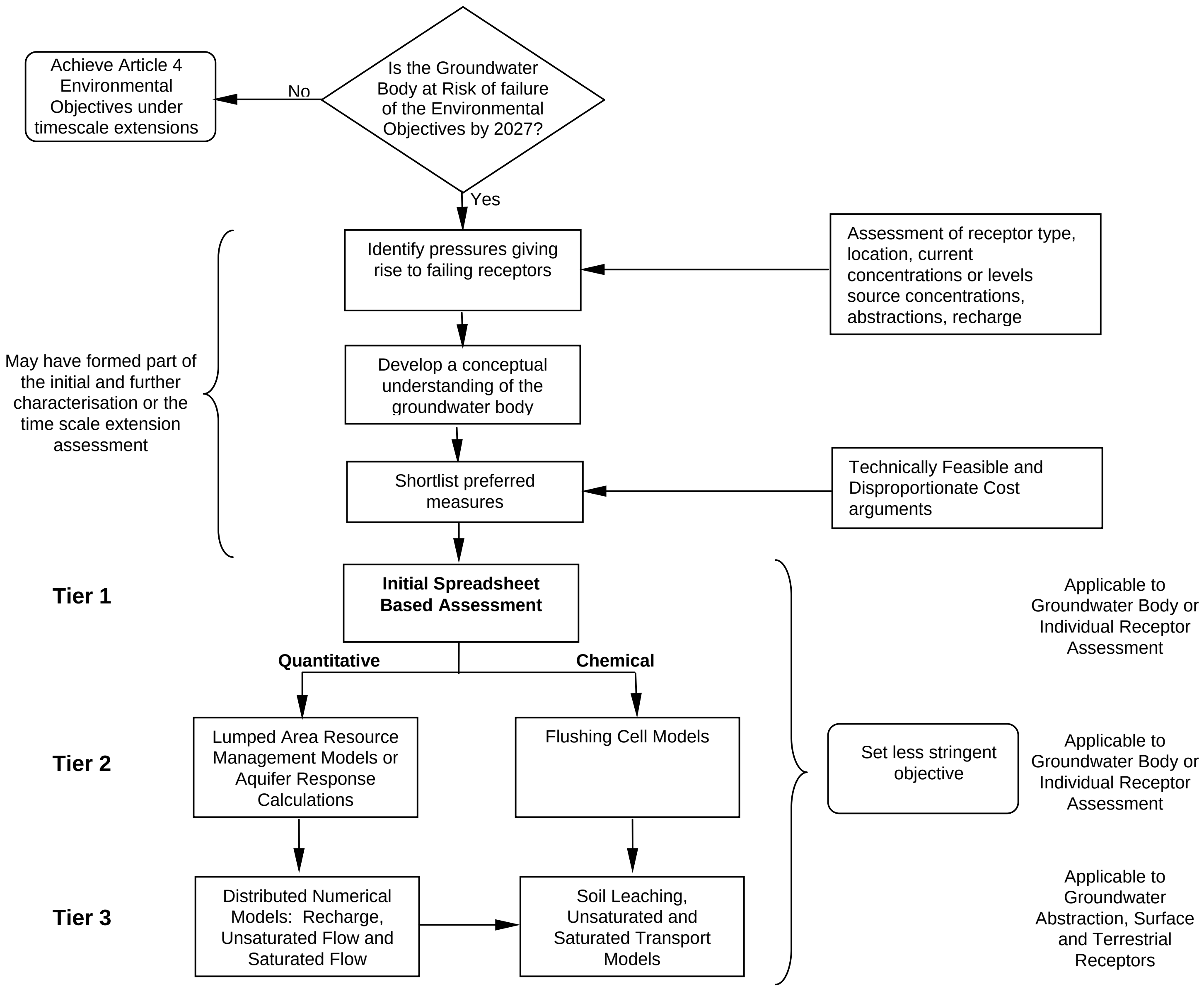
- Availability of the data.
- Understanding of the groundwater flow system.

These potentially would identify the need for further data collation or investigative studies.

The inclusion of relevant flow and transport/fate modules (soil, unsaturated and saturated) is dependant on the location of both the source and the receptor. Sources located below the soil and unsaturated aquifer (e.g. a landfill or underground storage tank) would not consider the soil leaching or possibly unsaturated aquifer transport. If the receptor of interest (i.e. failing receptor) is the groundwater body then saturated transport within the groundwater body need not be considered. If the receptor of interest is a groundwater abstraction or wetland then saturated flow and surface water-groundwater interactions will require consideration (modelling).

The assessment tools proposed for each tier are identified in Sections 6.5 and 6.6.

Figure 6.2 Flow Diagram to Assess Less Stringent Environmental Objectives from Shortlisted Measures



6.4 Quantitative Assessment Tools

6.4.1 Introduction

Proposals for the three tiers of detailed assessment are presented below. The level of assessment required for the determination of less stringent environmental objectives will be dependant on the factors detailed in Section 6.3.

6.4.2 Objectives

The assessment tools need to identify the environmental objective for the receptor which is at risk. Examples of calculations or assessments which may be required are:

- The annual balance in recharge and abstraction for the groundwater body.
- The potential groundwater level recovery in metres for a given positive increase in recharge-abstraction.
- The flow gradients and the potential reversal of any gradients.
- The potential to reverse or prevent saline intrusion (if applicable).
- The groundwater levels for the maintenance of minimum baseflow levels in surface water bodies.

Therefore the first stage in any assessment is to identify the objectives to be achieved. These will be based on the required ‘good status’ environmental objectives. The chosen approach or model will be determined by these objectives.

6.4.3 Tier Selection for Detailed Quantitative Assessment

It is considered that the tier(s) selected for the determination of the less stringent objectives should be based on the understanding of the uncertainty in the calculation and the sensitivity of the receptor to this uncertainty. If variations in some parameters within the acceptable range could result in failure of the objective then a higher tier should be used. In this way all assessments would pass through Tier 1 and some move on to Tier 2 and/or Tier 3.

6.4.4 Tier 1: Initial Quantitative Assessment

A flow diagram to indicate the initial Tier 1 assessment is presented in Figure 6.3. Initially, the conceptual model developed during the initial characterisation should be refined based on results from the further characterisation.

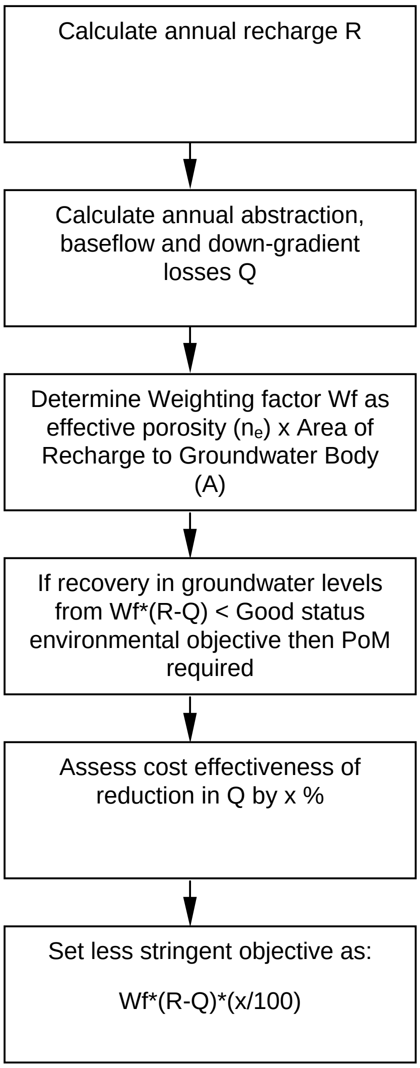
The assessment is a coarse water balance to broadly determine if the selected measures could (given any timescale) achieve the ‘good status’ environmental objectives. It is proposed that this is used to shortlist suitable measures.

These calculations might follow a similar process to the Resource Assessment and Management (RAM) framework (Environment Agency, 2002) used by the Catchment Abstraction Management Strategy (CAMS) process (Environment Agency, 2001) to calculate the resource allocation for a CAMS groundwater management unit (GWMU). The weighting factor is used as a sensitivity parameter for drought susceptibility or ecological sensitivity.

Data requirements for each groundwater body in this case are therefore:

- Annual Recharge;
- Annual Abstraction;
- Minimum Baseflow requirements;
- Aquifer down-gradient discharges; and
- Weighting factor (based on effective porosity and area of aquifer).

Figure 6.3 Tier 1: Initial Quantitative Assessment



6.4.5 Tier 2: Lumped Area Resource Management Models

For a Tier 2 detailed assessment it is proposed to use lumped catchment area calculations to develop a water balance. These would typically assess inflows and outflows across a catchment area on a more rigorous scale than the initial assessment to determine groundwater levels and flows and surface water levels and flows at key locations within the groundwater body (e.g. a downstream surface water gauging location or the groundwater abstraction point).

Two alternative methods are summarised below.

IGARF

IGARF (Impact of Groundwater Abstractions on River Flows) is a simple spreadsheet tool developed by the Environment Agency based on analytical approaches. The University of Newcastle have recently (2001) developed a numerical approach (IGARF II) to represent gaining or losing rivers which are in hydraulic connection with aquifers. It was realised that in the assessment of many groundwater abstraction licence applications there is neither the data nor the time to support distributed numerical modelling and therefore an "intermediate" technique was required.

The University of Newcastle approach uses a combination of numerical model simulations of generic river-aquifer systems and neural networks to quantify the impacts on river flows under more complex and realistic conditions.

The artificial neural network 'mimics' the results from a large set of generic numerical model simulations. A user-friendly Graphical User Interface (GUI) and embedded neural network software, was developed for use by licensing officers.

Once the tool is calibrated for a catchment area it could be used to predict the changes to the river flows from changes in abstraction implemented as part of the PoM.

Aquifer Response Function Calculations

An alternative, is to use an aquifer response function to provide a statement of average response for an aquifer system or groundwater body from changes to recharge (e.g. seasonally and drought variations) and abstraction. The technique has been developed (Erskine and Papaioannou, 1997 and Downing et al., 1974) to assess the ability of the aquifer to smooth out the impact of these changes on the baseflow in rivers. The function could be used in combination with the calculated recharge to estimate groundwater recovery for specific groundwater bodies.

Input requirements are basic hydraulic and geometric parameters for the groundwater body. The aquifer response rate is defined as:

$$\alpha = T/(SL^2)$$

where:

α is the aquifer response rate (/d)

T is the aquifer transmissivity (m^2/d)

S is the aquifer storage coefficient (dimensionless)

L is the length representing the distance from the river (or groundwater dependent receptor) to the groundwater divide (m)

The aquifer response rate is an indication of how well the groundwater body acts as a reservoir in storing water and therefore acts as a buffer in regulating baseflow. High aquifer response rates indicate rapid response to changes (e.g. abstraction or drought conditions) and consequently low flexibility in the aquifer for groundwater resource development. A low aquifer response rate indicates a high buffering capacity and a slower response to changes in abstraction regime or drought conditions.

The total recharge to the aquifer multiplied by the aquifer response function is referred to as the Reduction Factor (Rf) for which a type curve against the 'aquifer response time' can be derived. The rate of impact on groundwater levels within the aquifer from the balance of recharge to abstraction and baseflow can be estimated from this aquifer response time curve.

Limitations

Response function assumes the presence of an isotropic aquifer system and as such is not representative of dual porosity systems. In addition, it cannot be used for significantly confined systems where the storage is related to the compressed storage coefficient and not specific yield. As such, the method strictly lends itself to unconfined or leaky systems but in terms of recovery times and impacts this is likely to be the primary focus of initial WFD assessments.

6.4.6 Tier 3: Distributed Grid Based Models

For complex groundwater bodies with unacceptable levels of uncertainty from the Tier 2 calculations construction of a distributed groundwater model may be required. Calibration of these models requires a significant investment in;

- spatial and temporal data collation (e.g. climatic, soils, landuse, aquifer properties, aquifer and surface water starting conditions);
- acquisition of a suitable modelling package;
- model construction, calibration and predictive runs; and
- synthesis of data for predictive runs (potentially to include land use changes, climate change –UKCIP02).

Construction of these models is time and data intensive, typically in the order of a six month to five year timetable.

Distributed grid based groundwater models use finite difference or finite element calculations across a three dimensional grid to solve for the groundwater flow equations. Many texts exist detailing the data requirements and process of groundwater modelling (e.g. Rushton and Redshaw, 1979, McDonald & Harbaugh, 1988). In addition, the EA has published guidance on the development of conceptual and numerical models (EA, 2002). Therefore, it is intended below to present a summary of how these models can be used in the determination of less stringent environmental objectives.

A number of regional models constructed have been developed to answer specific questions on local groundwater issues (e.g. management of particular groundwater abstractions). Therefore the model grid and geometry is constructed and calibrated to the abstraction in a particular location. Significant changes to abstraction rates or relocation of abstractions will result in the model moving out of its range of calibration and therefore many models may be unsuitable for use in determining the less stringent environmental objectives for a groundwater body.

MODFLOW, developed by the United States Geological Survey (McDonald & Harbaugh, 1988) is the most widely used and validated of the saturated finite difference codes. This provides a transient and steady-state determination of the hydrologeological flow system. Several commercially available 'front end' packages have been developed which add pre and post processor user interfaces to the MODFLOW code. These include Groundwater Vistas, GMS and Visual MODFLOW. Groundwater Vistas adds a stochastic Monte Carlo approach to MODFLOW, MODPATH and MT3D which allows uncertainty and probability analysis.

Model Data Requirements and Calibration

A groundwater model constructed for a specific groundwater body, sub-set of a groundwater body or group of groundwater bodies would be calibrated against historical monitoring data. The model would require the following data inputs:

Actual Recharge	this may be calculated as a lumped recharge across the area or using a distributed recharge model such as 4R (Entec, 2002). This in turn requires climatic, soil, land-use and urban leakage data.
Aquifer Properties	transmissivity, specific yield, storage coefficient.
Surface water properties	transient water levels, bed leakage coefficients, surface areas.
Abstractions	transient data on groundwater and surface water abstractions.
Boundary Conditions	conceptualisation of the transient conditions at each model boundary – requirements for constant heads, specified flux or general head boundaries.
Starting Conditions	knowledge of the historical and current groundwater levels.

The model parameters identified above are adjusted within expected bounds to achieve a calibration of the model (i.e. the model groundwater heads, flows and water balance matches historical data).

The uncertainty from the knowledge of the input parameters would be reduced through the calibration process. However, uncertainty in the predicted values will still be present through the non-unique solution and future climatic scenarios. Therefore this needs to be included in less stringent objective estimations.

Estimation of Less Stringent Environmental Objectives

A calibrated model can then be used to predict the changes in groundwater levels, flows and surface water levels based on proposed measures and synthesised future data for climate and surface water flows.

A sensitivity analysis predicts how the model will behave by altering a parameter (e.g. transmissivity) to determine a feasible range of target values. Uncertainty analysis will use a range of synthesised data (e.g. wet and drought years) to determine a range of predictions for each measure implemented.

6.5 Chemical Assessment Tools

6.5.1 Introduction

Proposals for the three tiers of assessment are presented below. The available tools, where they are appropriate for use, details of the assessment requirements and likely level of understanding in the uncertainty of the results are summarised. The level of assessment required for the determination of less stringent environmental objectives will be dependant on the factors detailed in Section 6.3.

6.5.2 Objectives

Key decision factors in the selection and suitability of an assessment tool are:

- Ability to represent the measure or control mechanism applied to the pressure;
- Presence of an unsaturated aquifer;
- Flow mechanisms and complexity (fissure, intergranular, multi-phase);
- Physical and chemical transport and degradation processes to be represented (dilution/sorption/reaction).
- Receptors (may be more than one);
- Spatial variation in the pressure concentration across catchment; and the
- Boundary conditions for the groundwater body.

One difficulty with prediction for diffuse pollution is the lack of spatially precise information at the field scale. This results in uncertainty in the prediction of leaching concentrations to groundwater at a site-specific scale.

6.5.3 Tier Selection for Chemical Assessment

A chemical assessment needs to consider which tools best represent the flow processes occurring between the source and receptor. These can include one or all of:

- Soil leaching;
- Unsaturated transport;
- Saturated transport; and
- Contaminant reaction and degradation.

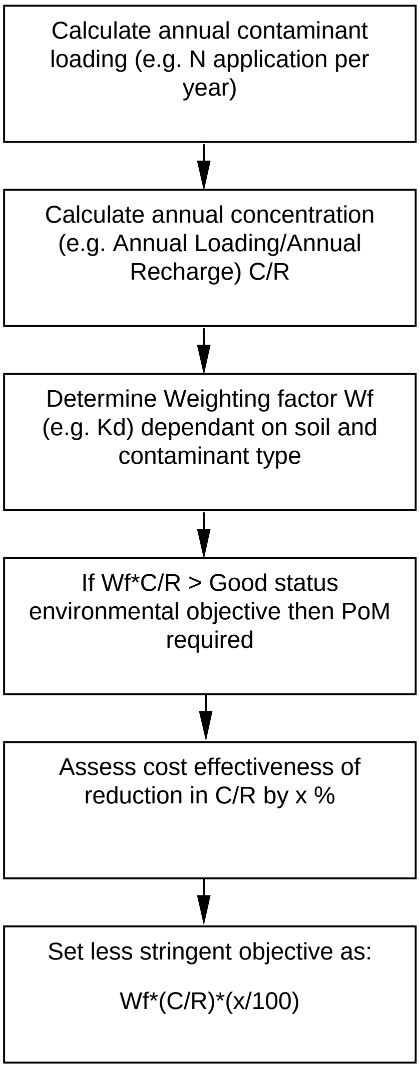
Calculation of all these processes requires knowledge of the groundwater flow through the system and therefore some solution of the Quantitative Assessment detailed in Section 6.4 is necessary.

It is considered that the tier(s) selected for the determination of the less stringent objectives should be based on the selection criteria presented in Section 6.3. All assessments would pass through Tier 1 and some move on to Tier 2 and/or Tier 3.

6.5.4 Tier 1: Initial Chemical Assessment

A flow diagram to indicate the Tier 1 assessment is presented in Figure 6.4. This assessment is to determine whether an identified measure can (given any timescale) achieve the ‘good status’ environmental objectives.

Figure 6.4 Tier 1: Initial Chemical Assessment



The assessment requires the consideration of:

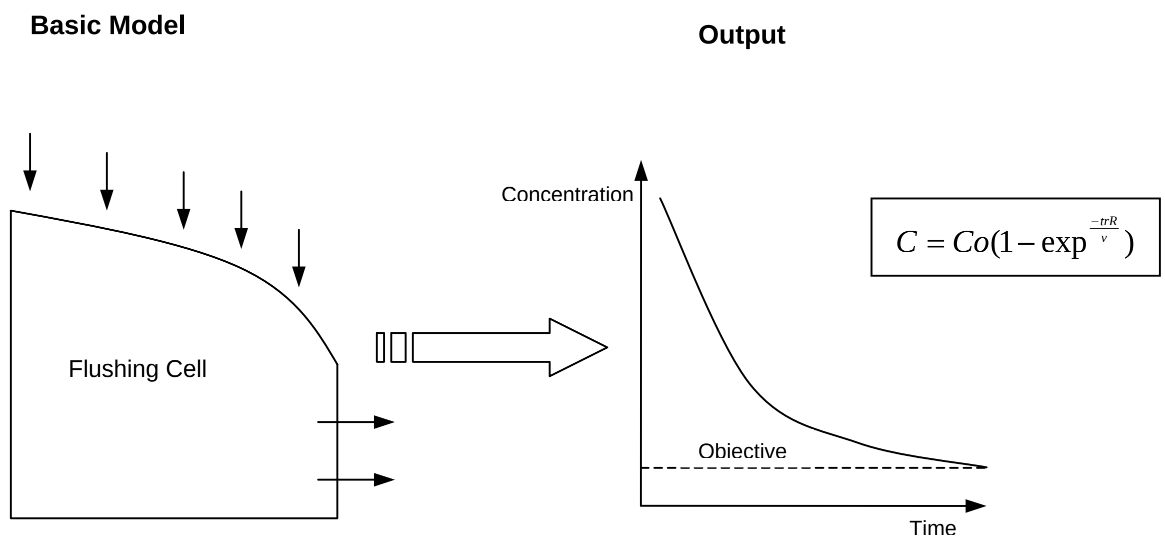
- Annual source concentrations (input loading and recharge).
- A weighting factor to estimate the concentration leached to groundwater. This could potentially be based on the soil-water partition coefficient.

The assessment does not indicate the impact of historical practices on a groundwater body, residual contaminants within the system (overlying strata, unsaturated or saturated aquifers), delays for transport of the contaminants through the system to the receptor or the timescale to reach the objective given a stepped decrease in contaminant loading.

6.5.5 Tier 2: Flushing Cell Model Calculations

A flushing cell model calculates the mixing rate for a conservative contaminant using estimations of groundwater recharge and flow through, or flushing of, a unit cell within the groundwater body. The calculation is presented schematically in Figure 6.5 and calculation sheets for a worked example are presented in Appendix B.

Figure 6.5 Conceptualisation of the Chemical Recovery Flushing Cell Model



This type of model can be amended to include attenuation parameters and possible options are included in Table 6.1.

Table 6.1 Contaminant Fate Processes

Possible Options	Processes			Required Input Parameters				
	Dilution	**Sorption**	**Degrad-ation**	**Recharge**	**Aq. vol. & porosity**	**Kd**	**λ**	**Co**
Flushing of conservative contaminant (e.g. NO3)	✓			✓	✓			✓
Flushing of sorbed contaminant	✓	✓		✓	✓	✓		✓
Flushing of degrading contaminant	✓	✓	✓	✓	✓	✓	✓	✓
Flushing with continued input (source not removed)	✓	✓	✓	✓	✓	✓	✓	✓ + Cr

Cr = Concentration of input source after time zero.

Limitations

The flushing cell model assumes a homogeneous, isotropic system of a ‘bucket’ style aquifer (i.e. the aquifer geometry is not considered). The model does not currently consider the influence of aquifer throughflow though it could possibly be adapted for this. It is assumed that all of the aquifer recharge contributes to the dilution of the contaminant and that this mixing occurs linearly across the aquifer.

Some of the additional issues that would need to be considered are:

- The variation in the thickness of the unsaturated aquifer over the groundwater body – particularly between valleys and interfluves. In developing the conceptual model it will be necessary to determine whether it was appropriate to use a minimum or average thickness.
- Whether the contaminant is likely to be retarded in the unsaturated aquifer.
- Whether the contaminant is likely to be degraded in the unsaturated aquifer and whether it is appropriate to use a simple first order decay calculation.
- The properties of the source – source history, time period for removal, presence of residual contamination.

Degradation or retardation processes are applied with the use of single factors which delay or accelerate the rate of the flushing. The models cannot account for complex aquifers (e.g. multi layered systems, confined aquifers).

6.5.6 Tier 3: Numerical Models

Introduction

For the Tier 3 assessment of groundwater chemical recovery a contaminant transport model is required to:

- Represent spatial catchment and temporal variations in the contaminant source. In addition it may be necessary to consider historical practices and the influence of the unsaturated aquifer, i.e. there may be a large store of contaminant in the unsaturated aquifer. If this isn't included then any prediction will be optimistic.
- Predict the change in chemical concentration within the groundwater body with time.
- Be applicable to the recharge, land use, soil type and other conditions present in the area of the groundwater body.
- Represent variations in the loading of the contaminant source (including total or partial removal of the source).

Applications are likely to be limited to well defined chemical processes (i.e. nitrate) where the data are available to describe the source.

A range of soil leaching models and saturated transport models are available for diffuse and point source contamination to determine the concentrations leached into groundwater. These models include a range of contaminant fate processes and can be subdivided into categories dependant on the contaminant being considered.

Diffuse

- Pesticides (and their metabolites); and
- Nutrients – models are dominantly available for nitrogen (N) as nitrate, the soil leaching processes for phosphorous (P) as phosphate are complex and accurate models are not available;

Point Source

- Metals; and
- Organics.

A review of relevant available models was undertaken and a summary of some of these models is presented in Appendix C. An assessment of the applicability of the models to determining environmental objectives for WFD receptors is presented in the sections below.

This report does not attempt to provide an exhaustive list of soil leaching models or a detailed description of available models but to illustrate how they may be used to calculate the recovery times.

Diffuse Contaminant Soil Leaching Models

The models and algorithms appropriate for the Tier 3 modelling are dependant on the contaminant of interest. All the models work on a one dimensional (vertical) flow equation through the soil and unsaturated aquifer to calculate the concentration of leachate to groundwater. Therefore further development would be required to combine these models with saturated transport where required.

The meta-models, POPPIE and MAGPIE have been developed into decision support tools with GUI front-end interfaces. Both models use the validated algorithms detailed above to provide a drainage concentration from the unsaturated aquifer. Use of the models would need to include a simple flow transport calculation for the saturated aquifer dependent on the receptor.

Pesticides - POPPIE, SWAT and SWATCATCH

POPPIE (Prediction of Pesticide Pollution In the Environment) is a GIS tool to predict the potential for pesticide pollution in controlled surface waters. This uses a modified version of the SWAT model which was developed (Brown and Hollis, 1996) to predict concentrations of agriculturally applied pesticides moving to surface waters. The POPPIE model is based upon the hydrology of soil types (HOST) by Boorman et al. (1995) which establishes a direct hydrological link established between soil type and the amount of water moving rapidly to streams in response to rainfall. Attenuation factors describe the decrease in concentrations of pesticide between field application and loss in water moving from the site into surface waters based on these HOST classifications.

Nitrates - MAGPIE, ANNA and NEAP-N

Similarly to POPPIE, MAGPIE is a GIS based decision support meta-model system which uses a range of soil leaching models (NEAP-N, NITCAT) to predict nitrate leaching. MAGPIE (**M**odelling **AG**ricultural **P**ollution and **I**nteractions with the **E**nvironment) was developed by the ADAS. The system integrates nitrate leaching models with a national environment database, including information on long-term mean climate and soil attributes. It includes the use of land use data (e.g. MAFF Agricultural Census), comprising areas of crops and numbers of livestock recorded at the parish scale. The data is then applied to embedded pollution models such as NEAP-N and NITCAT.

Point Source Contaminant Models with Simple Groundwater Transport

Most of the point source plume contamination assessment models (e.g. LandSim, ConSim and the P20 spreadsheet) are designed for assessing the potential concentration at a distant receptor from the contamination source. They are designed to set site-specific remedial targets for contaminated soil and groundwater dependent on the maximum concentrations at a receptor. They are not, therefore, detailed flow transport assessment models and do not, generally, assess transient conditions though some have now been adapted to include time prediction (RAM).

The models have tiered assessment levels from assessment of soil porewater concentrations through to contaminant transport in groundwater. The models use analytical solutions such as the derivation of the Ogata Banks equation to determine the concentrations at specific distances from a source. Models such as RAM allow the prediction of contaminant breakthrough at a receptor for specific time slices (currently 5).

Several of the computer models calculate the Ogata Banks contaminant transport equation (P20 spreadsheet, ConSim, RAM) and include degradation and attenuation algorithms. RAM and ConSim allow for a declining source term as contamination is removed.

An issue is that the risk assessment models detailed are for use with a homogeneous Darcian flow regime. The range of flow systems encountered within UK aquifers (fissured, multi-layered, karstic and dual porosity) are not provided for.

Saturated Transport Models

Several particle tracking, physical contaminant transport and chemical reactive modules (for example MODPATH, MT3D and RT3D) have been developed to use the flow output data provided by MODFLOW (described in Section 6.6 above) as the transport mechanism.

The following saturated transport models are included within processor modelling packages such as GMS, Groundwater Vistas and Visual MODFLOW.

MODPATH	Conservative particle tracking
MT3DMS	Contaminant transport modelling for advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems
RT3D	Contaminant reaction modelling simulating natural attenuation processes, accelerated bioremediation schemes, and dissolution of NAPLs

As an example in the application of the above models, the assessment of the effectiveness of nitrate sensitive areas (NSA) (Silgram et al, 2003) used MODFLOW and MODPATH to define the groundwater flow, travel distances and times for areas around groundwater abstraction points within each NSA. An analytical solution for Multiple Analytical Pathways (MAP) was used to model flow and transport along a series of streamtubes defined with MODPATH. These then solved to give a nitrate concentration at the groundwater abstraction point

6.6 Implications of the Tier 3 Assessment Approach

Implications of the Tier 3 approach taken for determining less stringent objectives are discussed in the sections below.

6.6.1 Applicability of models

Transient numerical models (quantitative and/or chemical) may be required in complex groundwater bodies to calculate the chemical concentrations or groundwater levels which could be achieved within each cycle of the RBMP under a range of applied measures. As a result a more detailed data compilation, investigation, conceptualisation and assessment is needed than for the determination of timescale extensions. The models will be case specific and need to include predictions from the applied measures.

It is probable that a single modelling tool is not available that can represent the whole groundwater flow, contaminant transport and fate processes through the full system (i.e. activity through to receptor). Therefore there may be the need to combine models with output from one model forming the input to the next model. Most existing models only represent sections of the flow, transport and fate assessment process. Attributes of model packages which can determine their suitability for the purpose of determining less stringent objectives are outlined below.

Model Scale

The type of model suitable may be dependent on the scale of the receptors. For example:

- A lumped water and mass balance model may be sufficient for assessment at a catchment or groundwater body scale where the groundwater body is the identified receptor. Lumped models may also be suitable for the determination of in-stream flow concentrations at a downstream monitoring point.
- Conversely, a distributed groundwater flow and transport model would be required to determine concentrations at a groundwater abstraction point. A distributed model can be adequate at a coarse scale (e.g. 5-10 km grid cells) for catchment scale assessments and these could require refinement down to sub kilometre cell sizes close to the groundwater abstraction or wetland location.

Model Elements

The contaminant transport and contaminant fate models require a hydrological/hydrogeological flow system to be defined. The contaminant models are then ‘conveyed’ on this defined flow system.

For example, output from a physical near surface flow processes (“soil moisture balance recharge”) model may be required as hydrological input to a soil leaching model and as input to a saturated flow model. Output from the saturated flow model will be used as the flow system for the transport model. In turn, output of concentrations from the soil leaching model may be used as input to a saturated transport model.

6.6.2 Time and Resource Requirements

Mathematical models allow a more sophisticated assessment of potential recovery times. The key implications are:

- The increase in input data collation and processing;
- Longer times for the model development, build and running; and
- An increase in the validation of the model results.

These will all result in a substantial increase in the data collection, time and expertise required to run the assessment and a consequent increase in cost to the competent authority. However, these models will result in a better definition of the problem conceptualisation and understanding of the uncertainty in the model predictions.

6.7 Data Requirements

To indicate the data requirements for the detailed assessments key data sources are summarised in Table 6.2. Detailed field data for complex groundwater body calculations may not be yet available and will need to be sought within the further characterisation. However, the table indicates that data for broad (Tier 1 and Tier 2) calculations are available.

Table 6.2 Key Data Sources

Parameter	Data Requirement	Data Availability
Objectives/Targets	Receptors, Article 4 environmental objectives.	Defined under the initial characterisation for each groundwater body.
Defining History	Sources, historical contamination, time period of contamination, history of abstractions.	Probably more available to the EA than to SEPA and EHS. Part IIA information relevant for the contamination history.
Aquifer Types	Delineation of the groundwater body, rock type, flow mechanism	WFD groundwater body delineation maps, hydrogeological maps (England), geology maps (Scotland and NI), conceptual understanding of the groundwater body. SPZ evaluation reports (England & Wales)
Abstraction Rates	Public and Private Water supply licences and returns	Available in England and Wales, require estimation in Scotland and Northern Ireland (large PWSs known).
Recharge	Climate, Land use, Soils and Vegetation data.	Calculated as part of the initial characterisation.
Transmissivity	Mapped Distribution	Major and minor aquifer properties manual (E&W), relevant literature, Robins (1990) – Scotland and 1996 (NI)
Storage Coefficient and Effective Porosity	Mapped Distribution	Major and minor aquifer properties manual (E&W), relevant literature, Robins (1990) – Scotland and 1996 (NI)
Retardation Factor	Defined for different aquifer types and contaminants.	ConSim and LandSim manuals, ADAS, Macaulay and NSRI literature.
Degradation Factor	Defined for different contaminants.	ConSim and LandSim manuals, ADAS, Macaulay and NSRI literature.

Summary

The setting of less stringent objectives requires a technical justification given a particular combination of measures and an economic appraisal to determine the preferred programme taking into account technical feasibility and disproportionate costs.

A three **tiered assessment process** is proposed where the use of more detailed assessments can be linked to the uncertainty in the original basic assessment, the availability of the data and the justification required to the European Commission.

For the assessment of **quantitative recovery** rates given a particular measure or combination of measures the following tools are proposed:

Tier 1 – an initial numerical calculation using estimates of recharge and abstraction.

Tier 2 – a catchment based assessment using tools such as IGARF and aquifer response calculations.

Tier 3 – a distributed numerical model such as MODFLOW.

For the assessment of chemical recovery rates the following tools are proposed:

Tier 1 – an **initial calculation** based on the annual loading rates of the chemical to the groundwater body, the annual recharge rates and a loading factor.

Tier 2 – a **flushing cell calculation** using groundwater body specific hydraulic parameters and recharge rates.

Tier 3 – a distributed contaminant **transport model** with soil leaching and saturated transport.

Suggestions for the data requirements for each of the tiers are presented.

7. Guidance on Cost Effectiveness and Disproportionate Cost Assessment

7.1 Introduction

The previous sections of this report have considered the factors affecting groundwater recovery rates in order to provide a framework for considering timescales to meet the Article 4 environmental objectives and, where appropriate, the setting of less stringent objectives. However, justification for time extensions or less stringent objectives must be made on the basis of both technical feasibility and disproportionate cost (see Figure 4.1). In addition, where an objective may be achieved using one of a number of possible measures, the decision is to be made based on a cost effectiveness analysis. Therefore, it is necessary to consider the costs associated with any programme of measures that could potentially be implemented to meet environmental objectives.

Although the requirement for economic assessment under the Water Framework Directive is the same for surface and groundwater, there are a number of factors particular to groundwater that will make the practical assessment of costs and effectiveness different in the two cases. It will be crucial that these are fully considered in assessing potential programmes of measures.

1. There is an increased uncertainty in the behaviour and fate of chemical contaminants in groundwater.

2. The effect of measures on the chemical and quantitative status of groundwater are more uncertain than effects of measures for surface water. This is due to the difficulties in assessing the impacts and the often unknown influence of the unsaturated zone and associated rate of vertical movement to the water table.

3. Groundwater may be significantly affected by diffuse sources of pollution, which can have a long residence time in the soil, subsoil or unsaturated zone resulting in residual contamination. In the case of nitrate contamination the source cannot be removed; it can only be reduced through good agricultural practice tied in to regulation.

4. The time taken for any measure to affect groundwater status may be many decades, depending on the factors affecting contaminant migration and transport (see Section 3 of this report). This is in contrast to the relatively short times taken for many surface water measures.

5. There may be more significant technical difficulties in implementing measures to improve groundwater status, with more measures falling within the technically unfeasible or disproportionately expensive groups. Those measures that are neither unfeasible nor disproportionately expensive are still likely to be associated with high costs. This is particularly true of measures that are required to access the soil, subsoil and unsaturated zone.

In order to make decisions about the relative merits of various measures and programmes of measures, it is necessary to consider a number of issues. These are outlined in Figure 7.1 and are considered more fully in the sections below. In particular, the figure highlights that a programme of measures is developed by considering the cost-effectiveness of measures that are both technically feasible and not disproportionately expensive.

Technical Feasibility

The technical feasibility of the measure is, by necessity, an intrinsic and early part of the assessment. A measure may not be technically feasible in one of the following situations:

- The technology required to achieve good status has not yet been developed;
- The technology required to achieve good status takes longer to deploy than the time available within the planning cycle;
- The technical capacity to implement the technology is inadequate (e.g. the available competence in the necessary technology is insufficient to implement the technology within the planning cycle); or
- The cause of the failure to achieve good status is not yet known and therefore the technology required to achieve good status cannot be identified.

Where a measure is not considered to be technically feasible, it should not be included in the characterisation of possible measures or the cost-effectiveness assessment.

Disproportionate Cost

The figure also shows that the disproportionate cost argument may be made at two or more points in the decision making process. Where the initial assessment highlights that a measure is technically feasible, but is associated with unacceptably high costs to a large number of individuals or sectors, this measure may be excluded from further assessment. This early assessment of disproportionate cost allows those measures that are clearly associated with unacceptably high costs or extremely low effectiveness to be disregarded from further assessment, allowing analysis to concentrate on meaningful alternatives. Where it is not immediately clear that a measure is disproportionately expensive, this may become obvious after consideration of the costs and effectiveness. Therefore, a measure may be identified as disproportionately expensive following the cost-effectiveness analysis.

Disproportionate costs are not defined in the Water Framework Directive, but are expected to be determined on a case-specific basis. At a general level, disproportionate costs could be defined in a number of ways:

- Costs to achieve good status by 2015 could be disproportionate compared to benefits;
- Costs to achieve good status by 2015 could be disproportionate compared to costs over a longer time frame, i.e. costs need not be disproportionate by 2021 or 2027. This is more likely for groundwater than for surface waters;
- Costs to achieve good status by 2015 could be disproportionate compared to the costs of achieving a lower objective; or
- Costs to achieve good status by 2015 could be disproportionate compared to a given baseline (cost, cost for a unit change in contaminant concentration, cost for a unit change in quantitative status, cost for a percentage change in

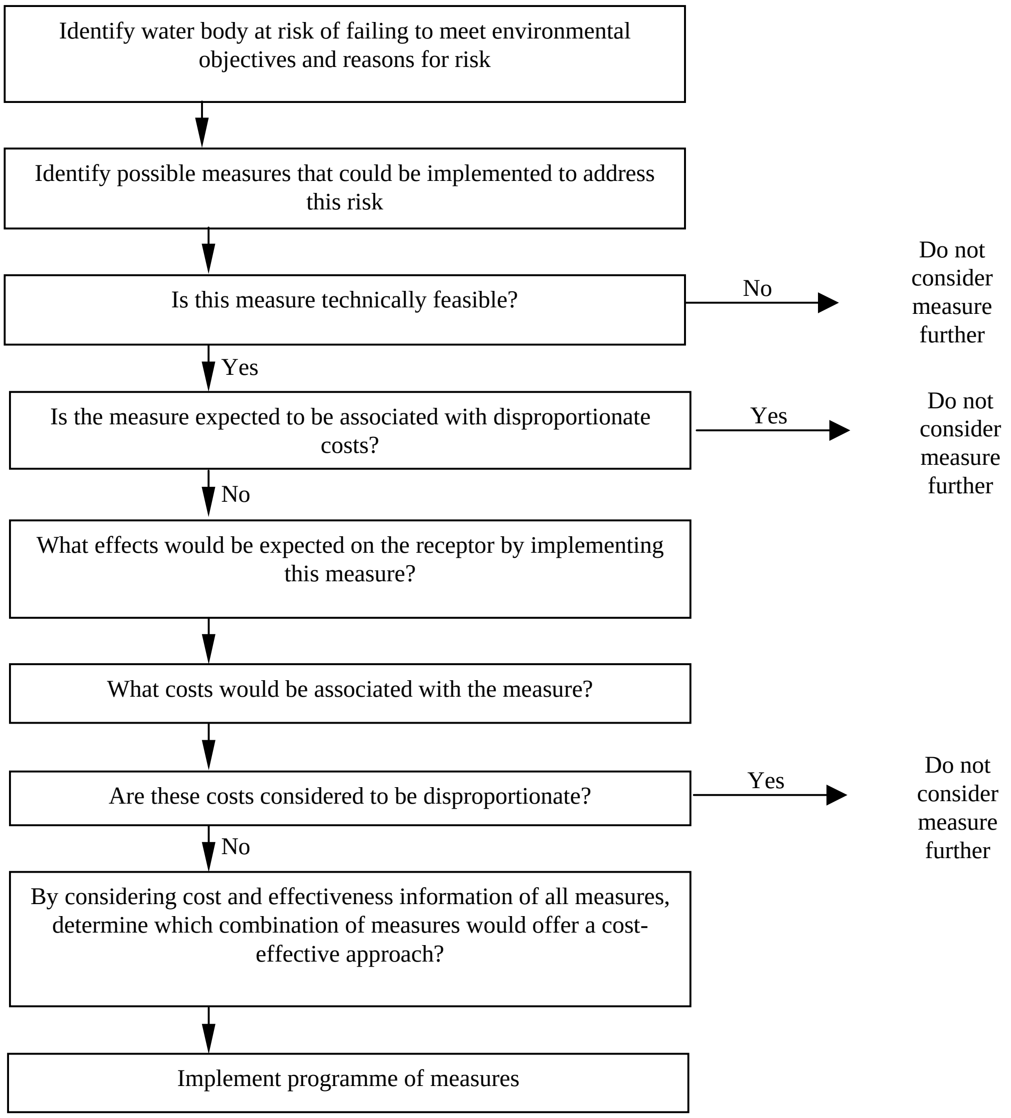
chemical or quantitative status, cost for a percentage move towards good status, etc.).

In any of these cases, there are a number of elements of a measure that could indicate disproportionate costs, suggesting that it may not be possible or desirable to work through a full cost-effectiveness analysis.

- A measure that requires excavation of the subsoil over a large area is likely to be associated with high costs. Therefore, there would need to be significant benefits (including the benefits of not requiring other measures) to prevent the measure being disproportionately costly.
- A measure that requires the treatment of large volumes of groundwater per hectare remediated.
- A measure that requires the cessation of a large number of public water supply abstractions.

On the other hand, a measure may be less likely to be associated with disproportionate cost where the measure impacts on a sensitive receptor, for example a drinking water supply, Site of Special Scientific Interest, or Natura 2000 site.

Figure 7.1 Decision Framework for Assessing Cost Effectiveness and Disproportionate Cost



7.1.1 Alternative Approaches

The approach set out above and described in more detail in the following text is one of a number of possible ways in which to approach the cost-effectiveness analysis. This is a research report rather than a policy document, and therefore the competent authorities will consider the most appropriate form of analysis to meet their needs and legislative requirements. One important alternative is set out in the research report for DEFRA Water Directorate and led by Risk and Policy Analysts (RPA) Limited (RPA, 2004). The RPA report proposes an approach that starts with a national and river basin level cost-effectiveness analysis and moves to a cost-benefit analysis to assess disproportionate cost. This differs by including a national level assessment and delaying the consideration of disproportionate cost. It also differs by defining disproportionate in terms of costs and benefits, whereas this report considers a number of alternative approaches and the approach set out in this report does not go as far as valuing the benefits associated with required improvements in water status. However, many of the same issues are considered as part of the cost analysis in this report.

7.2 Categorisation of Measures

It will be possible to characterise measures in a number of different ways, depending on the technical and regulatory changes that they require, the impacts that they are designed to have, and the effects that they have on different sectors of the economy, environment and society. The technical and socio-economic features of the potential measures will have impacts on both their cost and their effectiveness, and will also be relevant in informing decisions on technical, administrative and political feasibility. Therefore, the first stage in assessing cost-effectiveness highlights the main features of the possible measures that could be used to achieve environmental objectives. This could be done using a proforma as suggested in Table 7.1, which would build on the information stated in Table 3.2 and would summarise the main features of each measure.

Table 7.1 Proforma for characterising a potential measure

Question		Comments
What receptor pressures does it aim to affect?	• Chemical status ⇒ Which chemicals? • Quantitative status	
Over what geographic scale is the impact to the receptor?	• Local, Regional or National ?	
What will the measure involve?	**CHEMICAL** • Reducing the concentration of contaminant entering the groundwater body from diffuse or point sources; • Improving the recharge; • Increasing the through-flow; and/or • Increasing chemical degradation rates. **QUANTITATIVE** • Reduction in abstraction • Increase in recharge	
Over what timeframe will the measure be required?	• Single period (up to one year) • Short term (2012 to 2015 i.e. 1 - 3 years) • Medium term (2015 to 2027 i.e. 3 – 15 years) • Long term/ indefinite (> 15 years)	Single period is likely to be relevant to some point source contamination.

Question		Comments
Which sectors will be directly affected?	• Agricultural producers • Water supply and treatment companies • Sewerage and drainage companies • Local Authorities • Regulators (EA, SEPA and EHS) • Industry • Other landowners • Households • Other sectors	
What actions will this sector be required to take?	• What actions? • Over what time frame?	
What will be the costs of undertaking action?	• Set-up costs • Running costs • Indirect costs • Induced changes, where incentives change decisions on production processes or products • Spin-off benefits to other sectors or the environment	
Which sectors will bear the costs?	• Will the sectors taking action bear the costs? • Will costs be passed on, and to whom? • Is this the most appropriate/ equitable/ sensible allocation of cost?	
Are the sectors taking action responsible for the pollution?	• Yes, through a well-established and recognised link • Yes, but without a clear degree of recognition • No • Not known	
What administration or regulation will be required?	• Office-based administration • Monitoring	
How feasible is this administration or regulation in terms of those regulating and those regulated?	• Is the sector relatively homogenous? • Is it already regulated on similar issues?	
What effects will be expected on other sectors or the environment?	• Costs to industries not required to take action • Social costs • Environmental costs	
Has this measure been implemented elsewhere?	• Where? • With what effect?	

7.3 Assessing Cost Effectiveness of Measures

7.3.1 Importance of cost-effectiveness

The second stage of assessment considers the costs and effectiveness of each of the measures considered as having potential for improving groundwater status. This will need to be carried out for each measure individually, although it will be useful to record the information gathered in summary tables for all potential measures.

7.3.2 Assessing effectiveness

The effectiveness of a particular measure will be determined by the extent to which it addresses risk to chemical or quantitative status. This should also reflect the effectiveness of measures implemented to meet requirements for surface water quality and ecological considerations. The assessment is expected to draw heavily on the methods developed in the earlier parts of this report to consider how area specific recovery factors will affect the effectiveness of the measure.

Although there is significant uncertainty associated with the effects of any programme of measures on groundwater recovery, assessment of cost-effectiveness will require at least an estimate of likely effects. In order to reflect the uncertainty, it may be relevant to record an upper and lower estimate in addition to the central estimate. This will prove useful in considering the potential range of cost-effectiveness of particular measures.

The assessment may be a tiered process from initial estimate through to more quantitative estimations (analytical solutions or numerical modelling) of impacts. The methodologies developed for the detailed assessment of timescale extensions and less stringent objectives (Section 6) should be used to assess the effectiveness of a programme of measures measure where appropriate.

Measures affecting chemical status

It is likely that the effect of a particular measure on contaminant concentration will be neither immediate nor uniform, but that there will be an expected profile of concentration over time. Therefore, it is necessary to estimate concentrations under each programme of measures for each cycle of the WFD and the time at which it may be reasonably expected to achieve the environmental objectives. It may also be necessary to consider the geographic scale of the impact. Table 7.2 provides a proforma that could be used to record this information.

Measures affecting quantitative status

Measures affecting quantitative status will follow a similar approach to that for chemical status. As for chemical status, it will be necessary to consider the effects over time and the geographic spread of impacts. Table 7.2 will also be suitable for assessing the effectiveness of measures affecting quantitative status. Figures included in Table 7.2 are illustrative only.

Table 7.2 Proforma for recording information on effectiveness of potential measures

Groundwater Body	Measure	Contaminant or quantitative status impacted	Estimate timescale to achieve env. objectives	Estimate of conc. achieved by 2027	Comment on geographic coverage
GWB1	Control on fertiliser application	Nitrate	2050	70 mg/l	Conc. evenly distributed throughout groundwater body
GWB2	Control on fertliliser application	Nitrate	2015	30 mg/l	Fast response limestone aquifer
GWB3	Control on pesticide application	Pesticides	2025	0.1 mg/l	Key target areas

Assuming a nitrate good status threshold in the groundwater body of 50 mg/l, application for less stringent environmental objectives would be required for GWB1.

Assuming a pesticide good status threshold of 0.1 mg/l then a timescale extension would be required for GWB3.

7.3.3 Assessing Cost

There are a number of costs associated with any measure, and these costs will not only differ in their magnitude, but also the time at which they occur and the groups who are required to bear them. The costs fall broadly into set-up costs (i.e. capital expenditure), running costs (including operating costs and administrative costs), non-water indirect costs, and social costs.

- Set-up costs are those immediate costs associated with installing the technology (e.g. costs of drilling a borehole for increasing abstraction) or making changes to industrial practice (e.g. changing discharge for industrial effluent).

- Administrative costs are those required on an ongoing basis to undertake the measure. These could include maintenance requirements, costs of regulatory compliance, and costs to those monitoring compliance. These latter costs are likely to depend on the number of people affected and the sectors in which they operate, and estimates will draw on information recorded in the first proforma.

- Non-water indirect costs are costs to the environment associated with implementing the measure. These may occur where the changes in practice in response to the measure have other environmental implications. This could be emissions of pollutants to air due to increased energy requirements to operate a measure, or could be unintended changes caused by substitution of practices in response to restrictions.

- Social costs consider the broader costs of implementing a particular measure. This makes explicit which groups are required to bear the direct costs of implementing a measure and which groups bear indirect costs. This helps to highlight whether the groups causing the impact and the groups bearing the costs are the same, in order that this information can be used to assess social equity. It also helps to highlight where particular groups are expected to face costs that would prove fundamentally damaging to their business and would force organisations to close down.

There may also be benefits (negative costs) that occur beyond reducing the impact of a particular contaminant or improving quantitative status. In particular, one measure may have effects on more than one element of good status. Indeed, recent research (Aftab and Hanley, 2004) suggests that there may be advantages to considering dual effects in designing cost-effective instruments. Even where a measure affects only one element of good status, there may be other benefits, for example through reduced clean-up costs for other users, or a reduction in other non-water pollutants with associated environmental benefits. These should also be included in the assessment where appropriate.

In order to assess the overall cost of a possible measure, Table 7.3 could be used to provide summary information on the different types of cost. The table includes illustrative costs for three possible measures; however, these measures are not proposed or recommended.

Table 7.3 Proforma for recording information on cost of potential measures

		Direct costs		Indirect costs	
Ground-water body	**Measures**	**Set-up (capital) costs**	**Running costs**	**Non-water environmental costs**	**Social costs**
GWB1	Control on fertiliser application	Distribution of information to farmers- £50k Compensation to farmers	Monitoring (requires one full-time officer) Farmers reduce yield by an estimated 25% Reduction in water treatment costs by £Xm.	Change in energy required for treatment and processing of harvest	Increase in food production costs and costs to consumer. Increase in taxation or other source of funding for compensation.
GWB2	Control on fertiliser	Distribution of information to farmers- £50k Compensation to farmers	Monitoring (requires one full-time officer) Farmers reduce yield by an estimated 40% Reduction in water treatment costs by £Ym.	Change in energy required for treatment and processing of harvest	Increase in food production costs and costs to consumer. Increase in taxation or other source of funding for compensation.
GWB3	Control on pesticide application	Distribution of information to farmers- £50k	Monitoring Reduced yield Reduction in water treatment costs by £Zm.	Change in energy required for treatment and processing of harvest	Increase in food production costs and costs to consumer. Increase in taxation or other source of funding for compensation.

Financial information should be presented where available, with a range included to indicate uncertainty. However, although it may be relatively straightforward to provide a financial estimate of the direct costs (set-up and administrative costs) of a measure, it is likely to be more difficult to make quantitative estimates of the indirect costs. This is particularly true because the importance of an indirect cost will depend in part on social and political priorities. It may be that a lower social cost to one group is less politically acceptable than a higher social cost to another group, perhaps because of the sensitivity of that group or the number of individuals affected, and therefore it may be too crude to combine information based only on financial costs. It is one of the limits of cost-effectiveness analysis that there is limited scope to include non-financial estimates of costs within the analysis. Therefore, it will be important to consider indirect costs at a qualitative level in order to qualify any quantitative estimate made later in the analysis.

Calculating net present costs

Where financial estimates are made, it may be relevant to discount future costs to provide a net present cost. This is particularly likely for administrative and indirect costs, which could be expected to occur years into the future. The present value of a cost in the future is considered to be lower than the present value of a cost incurred immediately. This is based on the premise that if an organisation was required to meet a cost of £x at some point in the future, it would be possible for them to invest less than £x now and accrue interest before meeting the cost. It is also assumed that given uncertainty in life, individuals and organisations would prefer to meet costs and benefits in the present.

In order to calculate net present costs, costs associated with each time period (t) are discounted by dividing by $(1+r)^t$, where r is the rate of time preference (often taken to be the interest rate). This generates the present cost for the costs faced in each time period. Summing these over time provides a single value for the net present cost.

$$\textit{Net present costs} = \sum_{t=0}^{n} \frac{\cos ts_t}{(1+r)^t}$$

where the project runs from now (t = 0) to some point in the future (t = n), and r is the rate of time preference (the discount rate).

The UK Treasury Green Book suggests a discount rate of 3.5% to reflect the rate of time preference for public investment projects. Using this rate, the formula to calculate net present costs in the assessments presented here is as follows:

$$\textit{Net present costs} = \sum_{t=0}^{n} \frac{\cos ts_t}{(1.035)^t}$$

7.3.4 Combining cost and effectiveness information

Each measure will be associated with different costs and effectiveness. Table 7.4 provides a proforma for recording information on cost and effectiveness together, in order that a decision can be taken on overall cost-effectiveness. For many of the measures, costs and effectiveness will be estimated as a range, within which there is a central estimate. This reporting as a range is desirable due to the inherent uncertainty in the estimations. As before, information included in this table is for illustration only.

Table 7.4 Proforma for combining cost and effectiveness information

Measures	Cost			Effectiveness		
	Low	Central Estimate	High	Low	Central Estimate	High
Reduction of nitrogen fertiliser application to 140kg/ha	£2.34m	£4.67m	£5.60m	2030	2050	2070

It is expected that in many cases it will not be sufficient to implement only one measure, but that working towards environmental objectives will require a combination of measures. Each of these measures will be associated with a particular cost and effectiveness if implemented on its own. However, in combination with other measures it is possible that this relationship between costs and effectiveness could change. Therefore, in considering the most cost-effective combination of measures, the relationship between different measures will need to be considered.

- Two (or more) measures may complement each other, so that the effectiveness of implementing both is greater than the sum of the effectiveness of implementing them separately. For example, increasing abstraction to encourage through-flow could be combined with changes in land use to reduce nitrate concentrations in the groundwater.
- Two (or more) measures may complement each other so that the cost associated with implementing both is less than the cost associated with implementing them separately. For example, 'Whole Farm Planning' combined with reduction in the application of animal manures.
- Two (or more) measures may be independent of each other, so that the costs and effectiveness of the combination is equal to the sum of the individual values.
- Two (or more) measures may conflict, so that the effectiveness of implementing both is less than the sum of the effectiveness of implementing them separately. However, this would not necessarily rule out implementing them both.
- Two (or more) measures may conflict so that the cost of implementing both is greater than the cost of implementing them separately.

7.4 Dealing with Uncertainty

Much of the method for assessing costs and effectiveness outlined above assumes that there is information available and that there is confidence in that information. However, it has been recognised throughout this report, and specifically outlined in Sections 5.6 and 6.2.6, that there is significant uncertainty associated with the effects and timescales. Therefore, it may be relevant to consider this uncertainty in assessing the most cost-effective Programme of Measures. There are a number of possible ways of considering uncertainty in cost-effectiveness analysis. Of these, two are particularly relevant to the assessment of groundwater recovery, and are briefly outlined below. Both of them rely on quantified information even where the degree of confidence in the numbers is low. Indeed they are considering the case in which the quantified information is not well informed. Therefore, it may only be possible to use particular elements of the sensitivity analyses where some of the information is qualitative.

Partial Sensitivity Analysis

Partial sensitivity analysis considers the impact on the costs or effectiveness of changing one of the parameters. For example, this could consider changes in the cost of administering the programme if the number of organisations regulated increased, changes in the social costs if farms became unprofitable, or changes in the discount rate used to calculate net present costs.

The method for assessing cost-effectiveness outlined in this section relies on form of partial sensitivity analysis to calculate net present costs where the time taken for a measure to be effective is uncertain. This is shown in the representative examples below.

In addition, other partial sensitivity analyses could be carried out by varying any of the other assumptions made for calculating the cost and effectiveness of measures. This could include changes in the direct costs, indirect costs, time over which the measure is effective or degree to which the measure is effective by 2015.

Worst-case and Best-case Scenario Analysis

Worst-case and best-case scenario analysis considers the extremes of the range of cost and effectiveness associated with a particular measure. Most of the measures considered will have a range of possible cost and effectiveness reflecting the uncertainty of the impacts. Worst-case scenario analysis considers the most pessimistic predictions of effectiveness and the highest predictions of costs, while best-case scenario analysis reflects the most optimistic estimates of effectiveness and the lowest estimates of cost.

This reflects the ‘hedging’ and ‘flexing’ approaches undertaken in some work on cost-effectiveness for England and Wales. ‘Hedging’ combines low estimates of effectiveness with low estimates of cost, while ‘flexing’ combines high estimates of effectiveness with high estimates of cost.

The worst-case and best-case scenario analyses are not developed in the representative examples below, but may be appropriate in some situations where there is suitable quantitative information.

7.5 Representative Examples

7.5.1 Introduction

Representative examples showing the application of the disproportionate cost decision tree and the cost effectiveness matrices to different types of combinations of measures are presented below. The types of combinations of measures include consideration of the following circumstances:

- Diffuse pollution by nitrates and pesticides from arable agriculture.
- Point source pollution leading to the degradation of groundwater dependent surface waters and terrestrial ecosystems in a urban context.
- Rebounding groundwater levels in former deep mining areas.

7.5.2 Diffuse Pollution by Nitrates

Response options are considered to reduce the application of nitrogen to agricultural land. Two example responses or programmes of measures are presented in the proforma in **Table 7.5**.

Table 7.5 Potential measures to reduce diffuse pollution by nitrates

Question	Response 1: Reducing application of nitrogen based fertilisers to 140kg/ha	Response 2: Prohibiting application of nitrogen based fertilisers
What receptor pressures does it aim to affect?	Chemical status- concentration of nitrate in groundwater in the groundwater body.	
Over what geographic area?	Groundwater body extends over 100,000ha, with agriculture prevalent across the area.	
What will the measure involve?	Reducing application of nitrate fertilisers to agricultural land in the groundwater body from current optimal rate of 180kg/ha to 140kg/ha. The measure is expected to affect 30,000ha of agricultural land.	Prohibiting application of nitrate fertilisers to agricultural land in the groundwater body from current optimal rate of 180kg/ha. The measure is expected to affect 30,000ha of agricultural land.
Over what timeframe will the measure be required?	The measure is likely to be permanent, with the impact on the groundwater taking some time	
Which sectors will be directly affected?	Farmers will be directly affected. Both arable and livestock farmers could be affected by the measure, depending on the use of nitrate fertilisers in this area. Water companies could see benefit in reduced treatment costs for public water supply.	
What actions will this sector be required to take?	Farmers will have to reduce application of fertilisers to 140kg/ha (compared to an optimal rate of 180kg/ha).	Farmers will have to stop application of fertilisers (compared to an optimal rate of 180kg/ha).

Question	Response 1: Reducing application of nitrogen based fertilisers to 140kg/ha	Response 2: Prohibiting application of nitrogen based fertilisers
What will be the costs of taking action?	This is expected to reduce yield of grain crops per hectare from 8 tonnes/ha to 6 tonnes/ha. Based on a wheat price of £80/t, this could reduce farm incomes by £160/ha, or 25%. However, there could also be reduced costs associated with reduced application of fertiliser. With fertiliser costs of £1.20/tonne (35pence/kg nitrogen), this could save £4.80/ha. Therefore, there would be a net cost to the farmer of £155/ha, or 24% of revenue. These costs would be expected to recur every year.	It is expected that farmers will reduce their production of cereal crops in the area. The expected reduction of grain yield without applying any fertiliser (from 8t/ha to 3t/ha) is not expected to be economical for any of the farmers in the affected area.
Which sectors will bear the costs?	It is expected that, assuming no transfer payments, the agricultural producers would be expected to bear the costs.	
Are the sectors taking action responsible for the pollution?	Agricultural fertilisers are responsible for some of the nitrate pollution of groundwater bodies, and the relationship has been clearly established. However, the extent to which other types of pollution may contribute to nitrate contamination is not well known.	
What administration or regulation will be required?	The programme would require some administration to ensure that farmers were aware of the new restrictions (set-up cost) and to monitor their applications (ongoing costs).	The programme would require some administration to ensure that farmers were aware of the new restrictions (set-up cost) and to monitor their applications (ongoing costs).
How feasible is this administration or regulation in terms of those regulating and those regulated?	The sector is relatively homogenous in terms of nitrate fertiliser use and value of farm outputs.	
What effects will be expected on other sectors or the environment?	Reduction of nitrate application to land could be expected to reduce concentrations of nitrates in surface waters. Reduced grain yields could increase grain prices for consumers (bakeries, distilleries, livestock farmers, etc) if grain yields fall over a significant area. As custodians of the landscape, changes in agricultural land practice could be expected to change the image of the area.	Reduction of nitrate application to land could be expected to reduce concentrations of nitrates in surface waters. Reduced grain yields could increase grain prices for consumers (bakeries, distilleries, livestock farmers, etc) if grain yields fall over a significant area. As custodians of the landscape, changes in agricultural land practice could be expected to change the image of the area. Limiting agricultural production over such a large area could be expected to increase insolvency of farmers in the area. This could have high social costs within agriculture and the rural economy more generally.
Has this measure been implemented elsewhere?		

Decision on Disproportionate Cost

At this stage there would appear to be high costs associated with the first response option but also high effectiveness, and therefore it is not appropriate to disregard this option without further consideration of cost-effectiveness.

However, with respect to the second response option there would appear to be extremely high costs associated with reduction of agricultural production in the area. In this example, we assume in this example that the social costs in an area dependent on the rural economy would prove to be socially unacceptable, and therefore the measure is considered to be disproportionately expensive.

Effectiveness of potential measures

The extent to which reducing applications of nitrate fertilisers will reduce nitrate concentrations in the receptor will be crucial to indicate whether the WFD objectives can be met in the timescales specified. The effectiveness is considered both in terms of the time taken to meet environmental objectives (in this example the objective is assumed to be 50mg/l), and the estimate of the concentration that could be achieved within WFD timescales. This is shown in Table 7.6 below.

Table 7.6 Effectiveness of potential measures to reduce diffuse pollution by nitrates

Measure	Contaminant or quantitative status impacted	Estimate timescale to achieve environmental objectives	Estimate of conc. achieved by:		Comment on geographic coverage
			2015	2027	
Reduction of nitrogen fertiliser application to 140kg/ha	Nitrate	2050	80 mg/l	70 mg/l	Concentration evenly distributed throughout groundwater body.

Costs of potential measures

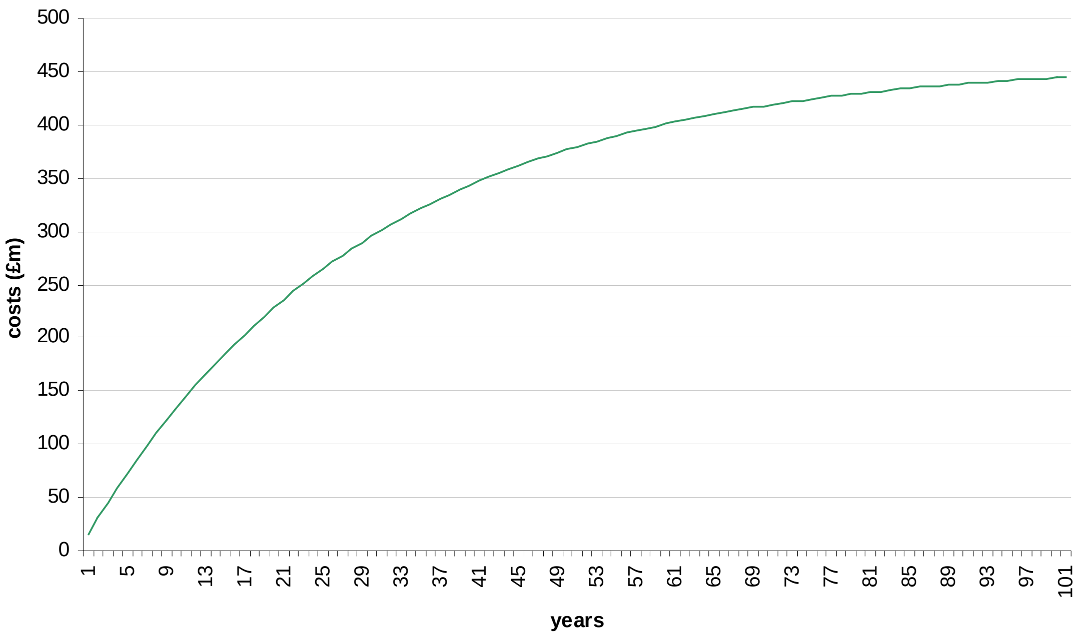
The characterisation of the potential measures in Table 7.5 indicates some of the direct and indirect costs associated with reducing fertiliser application. These costs are summarised in Table 7.7. The costs are quantified where possible, but it is unlikely to be feasible to quantify all of the costs identified.

Table 7.7 Costs of potential measures to reduce diffuse pollution by nitrates

Measure	Direct costs		Indirect costs	
	Costs of administering measure	Costs to those taking action	Non-water environmental costs	Social costs
Reduction of nitrogen fertiliser application to 140kg/ha	Disseminating information to farmers- included in monitoring applications Cost of monitoring fertiliser applications- £20,000/year	Costs to farmers of reduced yields- £155/ha. Some costs may be avoided by moving cereal growing outside groundwater body	None	Reduced profit for agricultural sector could adversely affect economy of rural areas

The measure is expected to be implemented permanently, so that the costs are ongoing. The net present cost associated with different timescales is shown in Figure 7.2 below (this considers monitoring costs and costs to farmers over 100,000ha, but does not include other indirect costs). For example, if costs are considered over 10 years, the net present cost is £144.6 m. Over 38 years (from 2012 to 2050) the net present cost is £339.0 m. Over the longer time periods, the rate of growth of the net present cost slows.

Figure 7.2 Illustration of net present costs over different timescales



Summary and Discussion

In this example, only one possible measure is assessed, since the alternative was considered to be disproportionately expensive. However, this is illustrative, and in reality there are expected to be other options. This could include reducing nitrate pollution from other sources or combining reduction of nitrate pollution from agriculture with other measures affecting farming.

Table 7.8 summarises the costs and effectiveness of reducing application of nitrate fertilisers to 140kg/ha. This shows that even within the shortest timescale considered feasible, the measure would not be effective by 2027. Therefore, it will be necessary to apply for a less stringent objective for this pollutant and groundwater body. The central estimate of concentrations that could be achieved by 2015 is 80mg/l.

Table 7.8 Summary of costs and effectiveness of potential measures to reduce diffuse pollution by nitrates

Measures	Cost			Effectiveness (1)			Effectiveness (2)		
	Low cost	Central estimate	High cost	Short time scale	Central estimate	Long time scale	High effect	Central estimate	Low effect
Reduction of nitrogen fertiliser application to 140kg/ha	£2.34m	£4.67m	£5.60m	2030	2050	2070	70	80	90

Effectiveness (1): Expected date by which environmental objectives are achieved
Effectiveness (2): Expected concentration (mg/l) achieved by 2015

7.5.3 Point Source Pollution in an Urban Context

The remediation of an extensive hydrocarbon based plume is suggested as an example point source pollution leading to the degradation of groundwater dependent surface waters and terrestrial ecosystems in an urban context. Two potential responses or programmes of measures are presented in Table 7.9.

Table 7.9 Potential measures for the remediation of a hydrocarbon plume

Question	Response 1: Pump and Treat of Hydrocarbon Contamination	Response 2: In Situ Bioremediation of hydrocarbon plume
What does it aim to affect?	Hydrocarbon contamination affecting chemical status	
Over what geographic area?	Over whole area of plume (100ha)	Over whole area of plume (100ha)
What will the measure involve?	Installation of boreholes and the pumping of hydrocarbon contaminated groundwater to a carbon treatment facility. Discharge of treated groundwater to a surface water course.	Insitu bioremediation of a groundwater plume using suitable technologies.
Over what timeframe will the measure be required?	It is expected that the remediation will take between one and five years.	The measure is expected to be required for between 10 and 20 years.
Which sectors will be directly affected?	Industry, Regulator	Industry, Regulator
What actions will this sector be required to take?	Active remediation and monitoring of the contamination	Active remediation and monitoring of the contamination

Question	Response 1: Pump and Treat of Hydrocarbon Contamination	Response 2: In Situ Bioremediation of hydrocarbon plume
What will be the costs of taking action?	There will be capital and operating costs, plus costs to monitor the treatment. However, there could be reduced costs to the water companies if the pollution is currently affecting water supplies.	There will be capital and operating costs, plus costs to monitor the treatment. However, there could be reduced costs to the water companies if the pollution is currently affecting water supplies.
Which sectors will bear the costs?	Industry	Industry
Are the sectors taking action responsible for the pollution?	Appropriate organisations.	Appropriate organisations.
What administration or regulation will be required?	There will be initial capital costs estimated at £100,000/ha, with running costs of £50,000/year. Monitoring of the system will also be required.	There will be initial capital costs estimated at £50,000/ha, with running costs of £10,000/year. Monitoring of the system will also be required.
How feasible is this administration or regulation in terms of those regulating and those regulated?	Administration will be relatively simple since the measure is carried out by a small group.	Administration will be relatively simple since the measure is carried out by a small group.
What effects will be expected on other sectors or the environment?	Monitoring implemented by appropriate organisations as required by regulator.	Monitoring implemented by appropriate organisations as required by regulator.
Has this measure been implemented elsewhere?	Yes – known and available technology	Yes – known and available technology

Decision on Disproportionate Cost

These proposed measures are associated with relatively well-defined costs which do not appear at this stage to be disproportionate in comparison to expected effectiveness.

Effectiveness of potential measures

The two potential measures differ in the time taken to achieve the environmental objectives, and therefore in the concentrations that could be achieved within WFD timescales. The effectiveness of each measure is summarised in Table 7.10. The assessment of effectiveness presented here assumes a WFD target concentration for hydrocarbon of 0.1 mg/l.

Table 7.10 Effectiveness of potential measures for the remediation of a hydrocarbon plume

Measure	Contaminant or quantitative status impacted	Estimate WFD timescale to achieve environmental objectives	Estimate of conc. achieved by: 2015	Estimate of conc. achieved by: 2027	Comment on geographic coverage
Pump and Treat	Hydrocarbon	2015	0.1 mg/l	0.1 mg/l	Hydrocarbon plume from specific source impacting on specific sensitive receptor
Bioremed-iation	Hydrocarbon	2027	20 mg/l	0.1 mg/l	

Costs of potential measures

The costs of the potential measures are summarised in Table 7.11. In this case, all the costs are expected to fall on those administering the measure. However, there may be indirect benefits, for example the pollution is currently being removed from a drinking water supply by the water company responsible for abstraction.

Table 7.11 Costs of potential measures for the remediation of a hydrocarbon plume

	Direct costs		Indirect costs	
Measure	**Costs to those administering measure**	**Costs to those taking action**	**Non-water environmental costs (or benefits)**	**Social costs (or benefits)**
Pump and Treat	Capital cost- £100k/ha Running costs- £50k/year for 1-5 years Monitoring costs- £50k/year for 1-5 years	No additional costs		No costs anticipated
In-situ bioremediation	Capital cost- £50k/ha Monitoring and Running costs- £10k/year for 10-20 years	No additional costs		No costs anticipated

Assuming a large 100 Ha plume, the first measure proposed is expected to have high capital and running costs over a relatively short period (1-5 years) which will meet the 2015 timescale, whereas bioremediation is expected to have lower costs over a longer period (10-20 years) but require at least a timescale extension. The net present cost calculations are used to assess the sensitivity of the cost estimates to the time taken for the measure to be effective. For the pump and treat alternative, the central time estimate is taken as 3 years, with a range of 1-5 years. For the bioremediation alternative, the central estimate is 15 years, with a range of 10-20 years.

Summary and Discussion

Table 7.12 combines cost and effectiveness information calculated above into a summary table. The effectiveness of the proposed measures is shown in terms of both concentration and time taken to achieve environmental objectives.

Table 7.12 Summary of costs and effectiveness of potential measures for the remediation of a hydrocarbon plume

Measures	Cost			Effectiveness (1)			Effectiveness (2)		
	Low cost	Central estimate	High cost	Short time scale	Central estimate	Long time scale	High effect	Central estimate	Low effect
Pump and Treat	£10.1m	£10.3m	£10.5m	2010	2015	2020	0.08	0.1	1.02
In-situ bioremediation	£5.08m	£5.12m	£5.14m	2020	2027	2040	16	20	28

Effectiveness (1): Expected date by which environmental objectives are achieved
Effectiveness (2): Expected concentration (mg/l) achieved by 2015

In conjunction with the assessment made in preceding tables and text, the summary table indicates that while the 'pump and treat' option is most effective in the immediate future, and would be expected to be effective by 2015, costs are much greater than for the alternative option. Bioremediation would be expected to have lower costs within the range of timescales considered, but would not be expected to be effective until 2027. Therefore, in order to justify use of this option, it would be necessary to argue that pumping the water would be disproportionately expensive (in one of the ways outlined in Section 7.4 above). The likelihood of this argument being accepted as reasonable would depend not only on the costs and effectiveness of the alternatives, but also on the sensitivity of the receptor. Use of bioremediation would also require application for a time extension in meeting the environmental objectives. As the range of effectiveness indicates that bioremediation may only be effective beyond 2027, the competent authority may also wish to consider applying for a less stringent objective.

7.5.4 Rebounding Groundwater Levels in Former Deep Mining Areas

Rebounding groundwater levels in mining areas, leading to the resurgence of acid minewaters often characterised by elevated iron and manganese concentrations, has generally resulted in very site specific engineering and pumping options being developed. Rebounding minewater can become a problem when rising minewater levels result in surface or groundwater receptors being impacted. Where possible passive engineering structures can be employed to control the minewater and direct it to passive or active treatment options. Two potential responses or programmes of measures are presented in Table 7.13.

Table 7.13 Potential measures to treat rebounding groundwater levels in former deep mining areas

Question	Response 1: Pump and Treat	Response 2: Engineering Measures
What does it aim to affect?	Control of contaminated groundwater to protect sensitive receptors.	
Over what geographic area?	Over the extent of the mine workings – say 100 Ha	
What will the measure involve?	Pumping groundwater from mining adits to a treatment plant to maintain water levels below that at which groundwater contamination of surface water receptors occurs	Interception and diversion of minewaters into aeration/ reedbed treatment systems established adjacent to each adit discharge. Treated water is fed back into affected watercourses.
Over what timeframe will the measure be required?	Long term/indefinite	Long term/indefinite
Which sectors will be directly affected?	Coal Authority. Coal Mining company, where available. May be the regional development agency.	
What actions will this sector be required to take?	The measure will require installation of pumps. It is assumed that treatment facilities are already available to receive water removed from mines.	Measures will require construction of engineering works to divert water and the construction of treatment systems.
What will be the costs of taking action?	The costs are expected to be limited to installing pumps.	Costs limited to the extent of the engineering measures and the maintenance of the reed bed system.
Which sectors will bear the costs?	Coal mining company – where available - or local and regional development agencies.	Coal mining company – where available - or local and regional development agencies.
Are the sectors taking action responsible for the pollution?	Not necessarily due to the historical nature of the pollution	
What administration or regulation will be required?	Regular monitoring of contract. It is possible that a body may need to be set up to manage the remediation	Regular monitoring of contract. It is possible that a body may need to be set up to manage the remediation.
	Capital costs could be in the order of £100k to £1M per scheme	Capital costs could be in the order of £100k to £1M per scheme
How feasible is this administration or regulation in terms of those regulating and those regulated?	Feasible	Feasible
What effects will be expected on other sectors or the environment?	If schemes are not implemented severe environmental degradation within a catchment can occur.	If schemes are not implemented severe environmental degradation within a catchment can occur.
Has the measure been implemented elsewhere?	Yes – technology available	Yes – technology available

Decision on disproportionate cost

The actual costs are normally scheme specific. Decisions will be guided on the technically feasible argument. Schemes indicated in Table 7.13 have been employed in the UK and are not considered disproportionate in cost.

Effectiveness of potential measures

The assessment of effectiveness included here differs from the other examples, since it could be addressing threats to the surface water environment in addition to existing pollution. The treatment systems are likely to require long timescales and therefore the groundwater bodies are likely to require the implementation of less stringent environmental objectives. A measure is considered effective if it meets the less stringent objectives and prevents deterioration of status.

Table 7.14 Effectiveness of potential measures to treat rebounding groundwater levels in former deep mining areas

Measure	Contaminant or quantitative status impacted	Estimate WFD timescale to achieve environmental objectives	Estimate of conc. achieved by:		Comment on geographic coverage
			2015	2027	
Pump and Treat	Acid Mine Drainage	Indefinite	N/A	N/A	Acid mine drainage from specific mine adit system.
Engineering Measures	Acid Mine Drainage	Indefinite	N/A	N/A	

Table 7.15 Costs of potential measures to treat rebounding groundwater levels in former deep mining areas

Measure	Direct costs		Indirect costs	
	Costs to those administering measure	Costs to those taking action	Non-water environmental costs	Social costs
Pump and Treat	Monitoring by and advice from regulator	Installation costs- £200,000 Running costs- £50,000/year Treatment costs- £50,000/year	Reduction in water treatment by water company	Increased taxation if implemented by regional development authority
Engineering Measure	Monitoring by and advice from regulator	Installation costs- £500,000 Running costs- £10,000/year Treatment costs- £50,000/year	Reduction in water treatment by water company	Increased taxation if implemented by regional development authority

Based on a discount rate of 3.5%, the costs of the measure over the first ten years are expected to be £1.03m. For twenty years, the net present costs are expected to be £1.62m.

Table 7.16 Summary of costs and effectiveness of potential measures to treat rebounding groundwater levels in former deep mining areas

Measures	Cost			Effectiveness		
	Low	Best guess	High	Low	Best guess	High
Pump and Treat	£14.8m	£23.8m	£32.8m			
Engineering Measure	£5.08m	£5.11m	£5.14m			

Summary and Discussion

Technology is available to control and treat the minewaters though this treatment is generally required over timescales longer than those available in the implementation of the WFD. Therefore it will be necessary to define and justify less stringent objectives. Effectiveness will be case specific.

Summary

Assessment of costs and effectiveness is required for two elements of establishing a programme of measures:

– Assessment of whether a measure is associated with **disproportionate cost**, in order that such measures can be excluded from programmes of measures; and

– Assessment of the **cost-effectiveness** of measures that are both technically feasible and not disproportionately expensive, in order that the programme of measures consists of the most cost-effective combination of measures.

However, assessment of the costs of measures is difficult because of **uncertainty**. This uncertainty may relate to the direct costs, indirect costs, or the effectiveness of potential measures. There may be particular uncertainty relating to the effectiveness of groundwater measures since there may be greater uncertainty about the fate and behaviour of chemical contaminants, and the factors affecting contaminant migration and transport through overlying strata and the groundwater body to other receptors. It may be possible to reduce some of this uncertainty through increased investigation or improved data collection, although this will also be associated with costs.

Measures associated with disproportionate cost will be excluded from potential combinations of measures, and it will be necessary to indicate disproportionate cost to the European Commission where technically feasible measures are not implemented and where this leads to requirements for either a timescale extension or less stringent objective.

The cost-effectiveness of measures can be assessed by considering the range of likely costs, the expected impact on concentrations of contaminants or quantitative status by 2015, and the timescale thought to be required to meet WFD environmental objectives. This will be used to assess possible options to include in a programme of measures, so that environmental objectives can be met in the most cost-effective manner.

8. Conclusions and Recommendations

A **framework** for the assessment process has been proposed. This identifies the assessment requirements from initial characterisation, through further characterisation to the submission and revision of the river basin management plans.

A **basic assessment** is suggested for the initial characterisation reports which will, through categorisation primarily based on expert opinion, identify those groundwater bodies likely to require timescale extensions or less stringent objectives. This basic assessment uses a risk scoring matrix system to categorise the groundwater bodies.

For the further characterisation and revision of the river basin management plans **detailed assessments** are proposed which will provide a numerical estimation of the times to achieve good environmental status (recovery times) and less stringent objectives, where required. The detailed assessments will consist of **three tiers** of calculation.

Tier 1 would be a broad groundwater body scale calculation; Tier 2 is a spreadsheet based flushing cell (chemical) or aquifer response calculation and Tier 3 is a distributed numerical model.

The cost-effectiveness of measures can be assessed by considering the range of likely costs, the expected impact on concentrations of contaminants or quantitative status by 2015, and the timescale thought to be required to meet WFD environmental objectives. This will be used to assess possible options to include in a programme of measures, so that environmental objectives can be met in the most cost-effective manner.

Further data acquisition, in particular monitoring of the groundwater bodies considered at risk, is required for the detailed technical assessment. The cost effective assessment of the programme of measures also requires more detailed consideration. This work will be conducted during the further characterisation phase prior to the publishing of the first river basin management plan.

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10. 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)
Derogation	Where the Environmental Objectives in Article 4 are not met and the failing to meet these conditions fall outside the provision of paragraphs 6 and 7.
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 chemical status	The chemical status of a body of groundwater which meets all the conditions set out in table 2.3.2 of Annex V.
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.
Hazardous substances	Substances or groups of substances that are toxic, persistent and liable to bio-accumulate; and other substances or groups of substances which give rise to an equivalent level of concern.
Less stringent objectives	In cases where a body of water is so affected by human activity such that it may be unfeasible or unreasonably expensive to achieve good status, less stringent environmental objectives may be set on the basis of appropriate, evident and transparent criteria, and all practicable steps should be taken to prevent any further deterioration of the status of waters. (further information Article 4.5)
Lower objectives	See Less Stringent Objectives.
Measure	A process implemented with the purpose of achieving ‘Good Status’.
Pollutant	Any substance liable to cause pollution, in particular those listed in Annex VIII.
Pollution	The direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on

	aquatic ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment
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.
Significant and Upward Trend	Means any statistically significant increase of concentration of a pollutant as compared to concentrations measured at the start of the monitoring programme referred to in Article 8 of Directive 2000/60/EC, taking into consideration quality standards and threshold values.
Stress	A ***'stress'*** is normally identified through monitoring (e.g. water levels or water quality).
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.
Timescale extensions	Allowed by Article 4.4 for the purposes of phased achievements of the objectives for bodies of water, provided that no further deterioration occurs in the status of the affected body of water and when a number of conditions (see Article) are met.
Tool	A '***tool***' is an approach, algorithm or model that evaluates the groundwater recovery.
Trend reversal objective	Objectives with the aim of reversing any identified significant and sustained upward trend in the concentration of any pollutant. Measures to achieve trend reversal shall be implemented in accordance with paragraphs 2, 4 and 5 of Article 17, taking into account the applicable standards set out in relevant Community legislation, subject to the application of paragraphs 6 and 7 and without prejudice to paragraph 8. In the absence of other criteria trend reversal shall take as its starting point a maximum of 75% of the level of the quality standards set out in existing Community legislation applicable to groundwater.

Appendix A
Project Consultees

1 Pages

Project Consultees Proposed for Review of this Document

- British Geological Survey (BGS)
- Environment Agency (EA) Head Office
- Environment Agency Land Air and Water Science Group
- Environment and Heritage Service (EHS) Northern Ireland / GSNI
- Environmental Protection Agency (Ireland) (EPA)
- Geological Survey of Ireland (GSI)
- UKTAG
- Scottish Environmental Protection Agency (SEPA)

Appendix B
Flushing Model
2 Pages

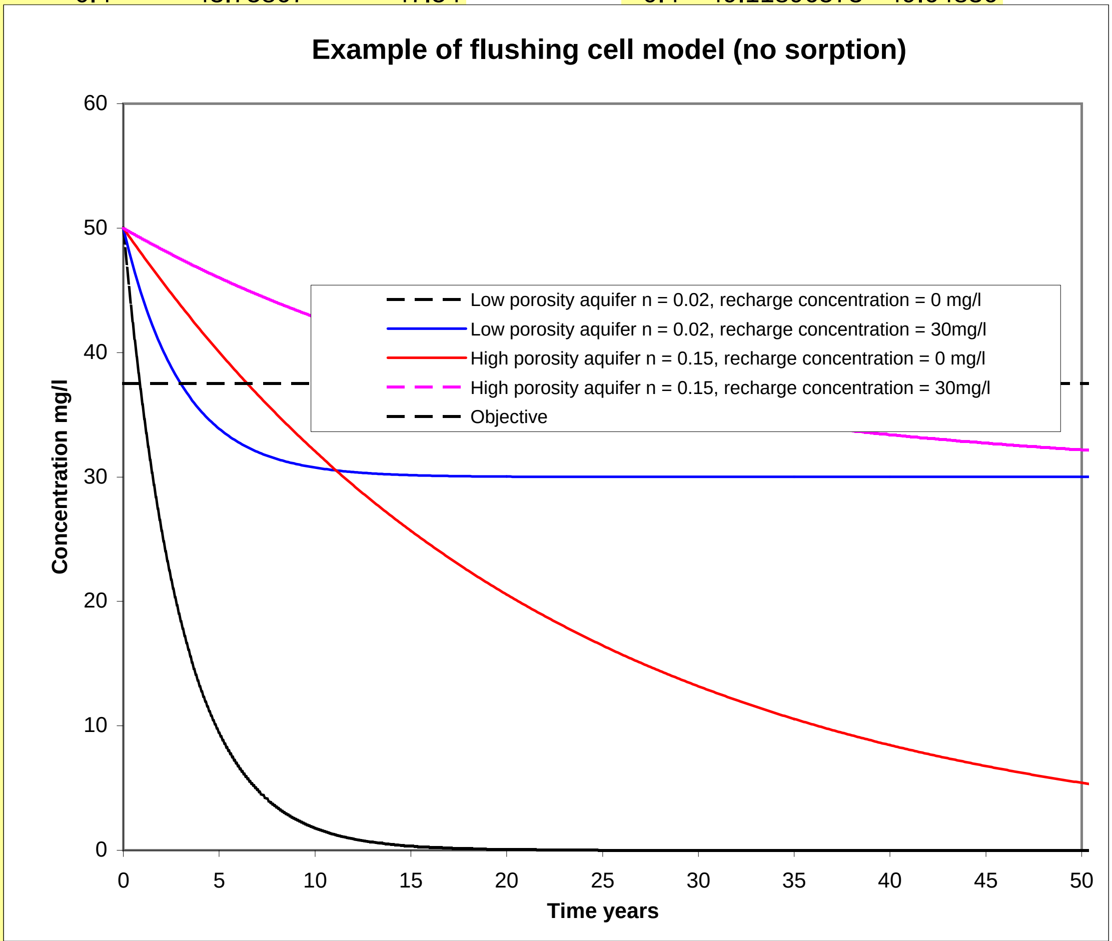
Appendix B

light blue	data entry	Model assumes that outflow = recharge
yellow	calculated	Flushing only by recharge

Current nitrate concentration	50	mg/l		Low porosi
Objective concentration	37.5	mg/l		Low porosi
		Aquifer residence time (years)		High poros
Low porosity aquifer (limestone)	0.02	3		High poros
High porosity aquifer (sandstone)	0.15	23		

Aquifer area	200	km2	Objective	
Aquifer thickness	30	m	0	37.5
Recharge	0.2	m/year	100	37.5
Recharge nitrate concentration	30	mg/l		
Time step	0.1	year		

Time	Low porosity aquifer Nitrate concentration Rech conc = 0	Rech conc = 20	High porosity aquifer Time	Nitrate concentration Rech conc = 0	Rech conc = 20
years	mg/l	mg/l	years	mg/l	mg/l
0	50	50	0	50	50
0.1	48.36081	49.35	0.1	49.77827087	49.9115
0.2	46.77535	48.73	0.2	49.55752502	49.8234
0.3	45.24187	48.13	0.3	49.33775809	49.73569
0.4	43.75867	47.54	0.4	49.11896573	49.64836



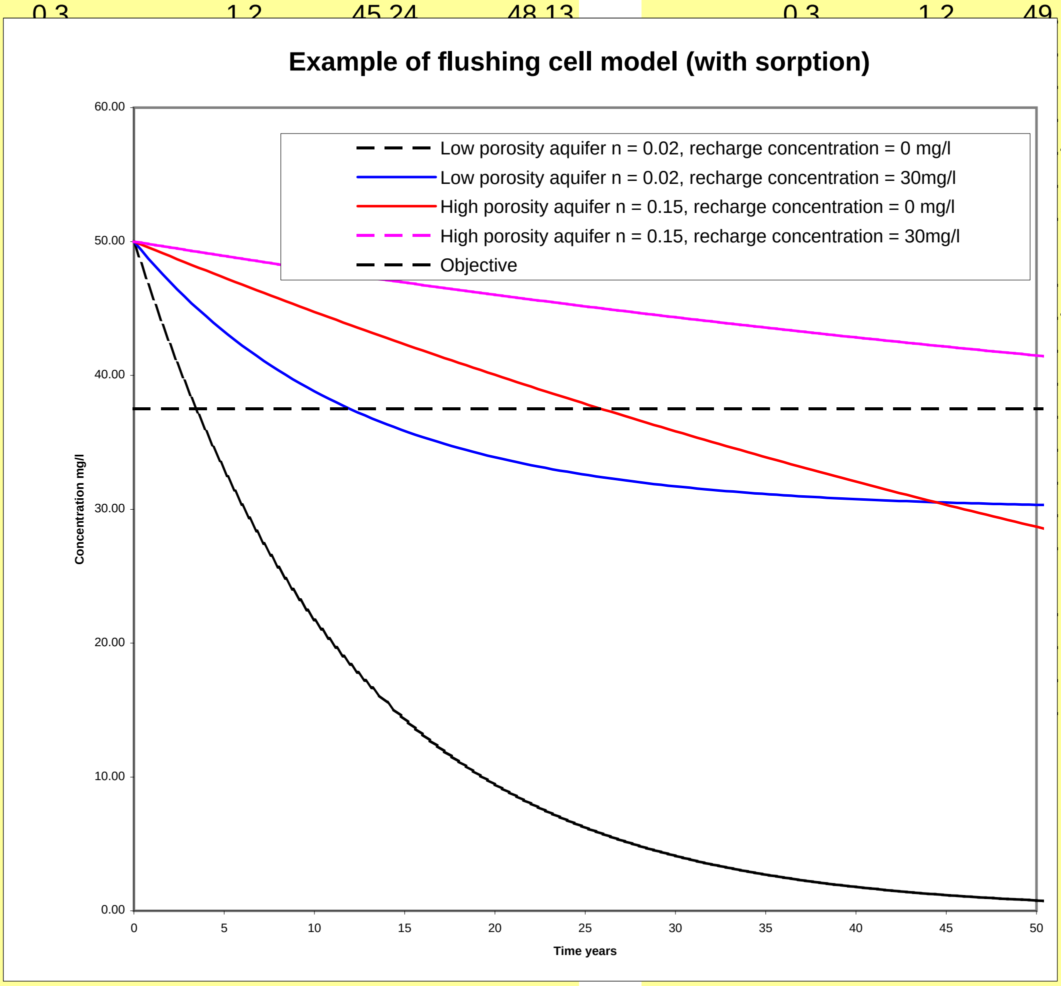
3.3	16.64355	36.78	3.3	43.1790895	47.27725
3.4	16.09791	36.56	3.4	42.98760827	47.2008
3.5	15.57016	36.35	3.5	42.79697617	47.12469
3.6	15.05971	36.14	3.6	42.60718945	47.04892

Appendix B

light blue	data entry	Model assumes that outflow = recharge
yellow	calculated	Flushing only by recharge

Current nitrate concentration	50	mg/l			
Objective concentration	37.5	mg/l			
		Aquifer residence time (years)			
Low porosity aquifer (limestone)	0.02	3			
High porosity aquifer (sandstone)	0.15	23			
Aquifer area	200	km2			
Aquifer thickness	30	m			
Recharge	0.2	m/ye	Objective		
Recharge nitrate concentration	30	mg/l		0	37.5
Time step	0.1	year		100	37.5
Retardation factor	4				

Time		**Low porosity aquifer** Nitrate concentration		**High porosity aquifer** Time	Retarded Time	Nitrate concentration	
		Rech conc =	Rech conc = 20			Rech conc	Rech conc
years	years	mg/l	mg/l	years		mg/l	mg/l
0	0	50.00	50.00	0	0	50	50
0.1	0.4	48.36	49.35	0.1	0.4	49.78	49.91
0.2	0.8	46.78	48.73	0.2	0.8	49.56	49.82
0.3	1.2	45.24	48.13	0.3	1.2	49.34	49.74
						12	49.65
						90	49.56
						68	49.47
						47	49.39
						25	49.30
						04	49.22
						83	49.13
						61	49.05
						40	48.96
						19	48.88
						98	48.80
						78	48.71
						57	48.63
						36	48.55
						16	48.47
						95	48.38
						75	48.30
						54	48.22
						34	48.14
						14	48.06
						94	47.98
						74	47.90
						54	47.82
						35	47.74
						15	47.66
						95	47.59
						76	47.51
						56	47.43
						37	47.35
3.3	13.2	16.64	36.78	3.3	13.2	43.18	47.28
3.4	13.6	16.10	36.56	3.4	13.6	42.99	47.20
3.5	14	15.57	36.35	3.5	14	42.80	47.12



Appendix C
Summary of Soil Leaching Models

2 Pages

Entec

Table E.1 Assessment of Existing Soil Leaching Models – Diffuse Contamination

Assessment Criteria	MACRO/MACRO DB	SWAT	POPPIE	NITCAT	NEAP-N	ANNA	MAGPIE
Reference	Jarvis, 1994. Jarvis et al., 1996, 1997	Brown and Hollis, 1996.	Environment Agency, 2000.	Lord, 1992.	Anthony et al, 1996	Oakes and Clark, 1994.	Lord and Anthony, 2000.
Activity for which the Tool was developed.	Leaching of pesticides to groundwater	Leaching of pesticides to groundwater	Leaching of Pesticides to groundwater.	Field scale nitrogen leaching	Catchment scale nitrogen leaching.	Leaching of nitrates to groundwater and transport of nitrate to abstraction point.	Leaching of Nitrates to groundwater.
Description	Preferential flow model, with two flow domains. Uses the Richards eqn (micropores) and convection/dispersion eqn (macropores).	Broad scale semi-empirical model with simpler inputs based on link to the HOST classifications.	GIS GUI tool which uses Meta-MACRO or SWAT for soil zone and then a simple approach for unsaturated aquifer.	N loss based on coefficients from field experiments	Based on leaching coefficients from past studies for maxm potential N loss for landuse, HER and soil type.	Physical based tool attempts to reproduce the turnover, leaching and mixing processes. Transient model	GIS based decision support meta-model system which uses a range of soil leaching models (NEAP-N, NITCAT) to predict nitrate leaching.
Limitations		Empirically derived from few field based experiments.	Does not include dual porosity or bypass flow.	Calibrated for lighter texture soils, requires accurate information on soil profile	Not calibrated for subtle changes in landuse. Assumptions on management practices	Determines change in nitrate conc. in abstracted groundwater for a step change in input conc.	Predicts a drainage volume and nitrate concentration.
Validation		Included with POPPIE and validated against broad HOST classes.	Deemed satisfactory by authors of POPPIE methodology.	Modelled NSA areas and compared to monitoring	Modelled NSA areas and compared to monitoring	Modelled NSAs (Oakes and Munro, 1998)	Agreement with measured nitrate concentrations and flows in rivers

Ease of operation	MACRO DB uses database of soil properties	with POPPIE	Data generally available and many GIS layers already set up.		Uses long-term MORECS data and soil water field capacities. Annual timesteps.	Not known	Data set up in GIS. Could provide nitrate source term

Table E.2 Assessment of Existing Soil Leaching Models – Point Source Contamination

Assessment Criteria	ConSim/LandSim	P20 Methodology and Spreadsheet	RAM	RBCA (Risk Based Corrective Action) Tool Kit
Reference	Environment Agency, 1999,2002a	Environment Agency, 1999 and 2001.	ESI, 2001.	Groundwater Services Inc., 1998 for USEPA
Activity for which the Tool was developed.	Quantifying risks to groundwater from contaminated land and landfill respectively.	Tiered assessment to quantify risks to receptors from soil leaching and groundwater transport.	Quantifying risks to receptors from contaminated land and groundwater.	Analytical fate and transport models for air, groundwater and soil exposure pathways in the US regulatory context.
Description	Probabilistic software designed to enumerate source terms as well as contaminant fate in the unsaturated aquifer.	Excel spreadsheet based estimates concentrations at a receptor from a known source.	Uses P20 algorithms. Has been adapted (RAM) to allow prediction at specific time slices.	'deterministic' model to calculate both risk levels and/or back-calculate cleanup standards.
Validation of predictions with site monitoring data.	Some validation against site specific data.	Validated. Whittaker et al., 2001	Agreement within validation tests undertaken for EA.	Validated. Whittaker et al., 2001
Ease of operation in terms of effort to produce required outputs	Data generally available, but site specific tool only.	Good ease of operation.	Good ease of operation.	Good ease of operation.
Ability for probabilistic calculations	Yes – Monte Carlo approach included.	No.	Using Crystal ball software.	No.