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A Framework for the Assessment of Groundwater - Dependent Terrestrial Ecosystems under the Water Framework Directive

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI
Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

Environmental Protection Agency

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A Framework for the Assessment of Groundwater-Dependent Terrestrial Ecosystems under the Water Framework Directive

Environmental Research Centre Report

Prepared for the Environmental Protection Agency

Authors:

Garrett Kilroy, Fiona Dunne, Jim Ryan, Áine O'Connor, Donal Daly, Matt Craig, Catherine Coxon, Paul Johnston and Henning Moe

ENVIRONMENTAL PROTECTION AGENCY

An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
E-mail: info@epa.ie Website: www.epa.ie

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Details of Project Partners

Garrett Kilroy
Department of Geology
School of Natural Sciences
Trinity College Dublin
Dublin 2
Ireland

E-mail: garrettkilroy@gmail.com

Fiona Dunne
Ecological Consultant
20 Mount Symon Crescent
Clonsilla
Dublin 15
Ireland

E-mail: fiona.dunne@imagine.ie

Jim Ryan
National Parks and Wildlife Service
7 Ely Place
Dublin 2
Ireland

Tel.: +353 1 8882000
E-mail: jim_ryan@environ.ie

Áine O'Connor
National Parks and Wildlife Service
7 Ely Place
Dublin 2
Ireland

Tel.: +353 1 8882000
E-mail: aine_o'connor@environ.ie

Donal Daly
Hydrometric & Groundwater Section
Environmental Protection Agency
McCumiskey House
Richview
Dublin 14
Ireland

Tel.: +353 1 2680100
E-mail: d.daly@epa.ie

Matt Craig
Hydrometric & Groundwater Section
Environmental Protection Agency
McCumiskey House
Richview
Dublin 14
Ireland

Tel.: +353 1 2680100
E-mail: m.craig@epa.ie

Catherine Coxon
Department of Geology
School of Natural Sciences
Trinity College Dublin
Dublin 2
Ireland

Tel.: +353 1 8962235
E-mail: cecoxon@tcd.ie

Paul Johnston
Department of Civil, Structural and
Environment Engineering
Trinity College Dublin
Dublin 2
Ireland

Tel.: +353 1 8961372
E-mail: pjhnston@tcd.ie

Henning Moe
CDM Consultants
O'Connell Bridge House
Dublin 2
Ireland

Tel.: +353 1 6722700
E-mail: MoeH@cdm.com

Table of Contents

Executive Summary

1 Introduction

The Environmental Protection Agency (EPA) established this project to develop a decision-making framework for the management of groundwater-dependent terrestrial ecosystems (GWDTEs) at risk of ‘significant damage’, as required by the European Water Framework Directive (WFD), in collaboration with the National Parks and Wildlife Service (NPWS). The principal aims of this project were:

- To identify the locations of groundwater-dependent habitats and species within a selection of candidate Special Areas of Conservation (cSACs) by undertaking a desk survey of available data and subsequently to generate a GIS map of the location of GWDTEs in SACs.

- To support the WFD Groundwater Working Group and NPWS staff in their attempts to assess groundwater dependency, sensitivity and significant damage to GWDTEs by developing a framework for their assessment and integration into river basin management plans.

2 Mapping of GWDTEs

In total, 64 GWDTEs in SACs were mapped. Of the 48 GWDTEs identified as being ‘at risk’ under the WFD, 11 required mapping. An additional site, Castletaylor Complex was added to this list by the NPWS and mapped, as it was deemed to be an at-risk site. Thirty-six sites from a second additional list of SACs (not identified as being ‘at risk’) that have GWDTEs as their main qualifying interests were also mapped. In addition, the locations of 16 *Vertigo* sites were compiled and mapped from information supplied by Dr Evelyn Moorkens. Further work is required to better define boundaries of GWDTEs where multiple types exist within a SAC. Coastal ecosystems, such as machairs and dune slacks, were not examined.

3 Development of Indicator Species

The development of indicator species is at a very early stage. Some preliminary species have been identified for fens, but this type of work needs to be rolled out for all Annexed GWDTE habitats. All indicator species need to be field verified and correlated with hydrogeological parameters. Ellenberg values for vegetation communities provided some indication of expected environmental conditions for the studied habitats. It would be desirable, however, to develop and field verify baseline Ellenberg values for all GWDTEs and relate these to corresponding hydrogeological values.

4 Developing a Conceptual Framework for Managing GWDTEs

A simple water supply mechanism classification based on geo-hydrological setting was developed and applied to Irish SAC habitats. This classification system formed the basis for the development of a conceptual framework for assessing the groundwater dependency of different wetland types. Variability in groundwater level, groundwater chemistry (degree of mineralisation) and relative groundwater contribution were identified as key metrics of environmental supporting conditions for GWDTEs. The proposed conceptual framework was subsequently tested against three case studies of contrasting SAC groundwater-dependent wetland types (Pollardstown Fen, Clara Bog and Caranavoodaun Turlough). Water supply mechanisms were investigated and the key environmental supporting conditions (hydrogeological and hydrochemical characteristics) required to maintain these habitats in a favourable condition were examined. An initial assessment was carried out to ascertain whether or not the wetlands are significantly damaged due to anthropogenic pressures on the associated groundwater body.

Progress has been made in establishing the principles of the conceptual framework and in examining the data requirements to apply this framework to the three contrasting groundwater-dependent wetland case studies. The conceptual framework can provide a useful basis for developing individual site conceptual models and in assisting in the development of programmes of monitoring and of measures. However, further testing is required on other wetland types using hydrogeological and ecological field data.

5 Assessment of GWDTEs in the River Basin Management Plans

Given the lack of baseline data for the full range of Irish GWDTEs, greater emphasis should be given to developing our understanding of the relationships between hydrogeological and ecological characteristics. In the future this will facilitate more intelligent and cost-effective monitoring and allow for more effective measures to be put in place. For this reason, it is recommended that a small number of GWDTEs, representative of the main wetland types in Ireland, are chosen for monitoring in the first river basin cycle to address these knowledge gaps. A prioritisation approach to identify candidate GWDTEs for monitoring in the first river basin management cycle is presented in Chapter 9. This approach should be adopted in consultation with relevant staff in the NPWS and in the EPA. Chapter 9 also provides a flow chart on how the assessment of GWDTEs can be integrated into the river basin management planning cycle. The emphasis is on developing an understanding of the relationships between hydrogeology and ecology within the context of groundwater body classification and river basin management.

6 Recommendations for Future Work on GWDTEs

More baseline field ecological data are required to accurately map and characterise these GWDTEs and, in tandem, the hydrogeological characteristics should be described, encompassing in both cases the natural variation. Existing and new data should be used to test and refine the proposed conceptual framework. Thresholds of significance to measure change in ecological and hydrogeological parameters are required to prioritise sites for monitoring and programmes of measures. In particular, thresholds are required for defining receptor sensitivity to particular pressures and subsequent quantification of significant damage. The original WFD Article 5 risk assessment for GWDTEs will need to be revisited by the River Basin Districts based on the conceptual framework outlined above. In particular, the catchment areas need to be re-examined to ensure that they accurately delineate the contributing area to the dependent wetland.

It is envisaged that the establishment of a GWDTE monitoring programme will provide useful data (ecological and hydrogeological) that will contribute to the refinement of the conceptual framework and to improving understanding of the structure and functioning of GWDTEs and their management. Monitoring methodologies will evolve and can be modified as the programme progresses. In parallel, further research on the environmental supporting conditions of the full range of GWDTEs should be supported.

1 Introduction

1.1 Background and Project Aims

The Environmental Protection Agency (EPA) established this project to develop a decision-making framework for the management of groundwater-dependent terrestrial ecosystems (GWDTEs) at risk of 'significant damage', as required by the European Water Framework Directive (WFD), in collaboration with the National Parks and Wildlife Service (NPWS). The WFD (2000/60/EC) requires the assessment of terrestrial ecosystems that depend directly on groundwater as part of the classification of groundwater bodies (Annex V). If chemical or quantitative pressures on a groundwater body result in 'significant damage' to a GWDTE, the groundwater body will be classified as being at 'poor status' and require mitigation measures. The WFD groundwater working group (GW-WG) was set up in Ireland as a subgroup of the National Technical Coordination Group (NTCG) which co-ordinates technical aspects of WFD implementation. The membership of the GW-WG comprises representatives from a range of organisations including the EPA, the Geological Survey of Ireland, River Basin Districts (RBDs), together with consultants and academics involved in groundwater management and research. The main role of the GW-WG is to address the technical aspects of WFD implementation concerning groundwater. The steering group for this project was derived from members of the GW-WG. The Groundwater Task Team (GWTT) of UKTAG (the Technical Advisory Group for WFD implementation in the UK) of which the Republic of Ireland is a member has developed common guidance for the UK and Ireland on the application of classification tests for groundwater bodies including a test for significant damage to GWDTEs.

Within this background the principal aims of this project were:

- To identify the locations of groundwater-dependent habitats and species within a selection of candidate Special Areas of Conservation (cSACs) by undertaking a desk survey of available data and subsequently to generate a GIS map of the location of GWDTEs in SACs.

- To support the WFD Groundwater Working Group and NPWS staff in their attempts to assess groundwater dependency, sensitivity and significant damage to GWDTEs by developing a framework for their assessment and integration into river basin management plans.

1.2 GWDTEs and the WFD

Groundwater-dependent terrestrial ecosystems are defined here as habitats/species that are dependent on groundwater to maintain the environmental supporting conditions required to sustain that habitat and/or species. Groundwater may provide either a direct input, such as in turloughs, fens and petrifying springs or, alternatively, the groundwater may have an indirect influence in maintaining high and stable water levels within the habitat, such as with raised bogs.

Groundwater bodies are subject to a range of pressures which can result in significant damage to GWDTEs depending on the susceptibility of the pathway and the sensitivity of the receptor. Figure 1.1 provides a conceptual visualisation of a riverine wetland and raised bog ecosystem subject to a range of pressures and the hydrogeological context within which these wetlands are situated (source: http://www.wfdvisual.com).

Groundwater-dependent terrestrial ecosystems within SACs designated under the European Habitats Directive (92/43/EEC) have been the main priority of work on groundwater-dependent wetlands under the WFD to date. The reason for this connection is due to Articles 5 and 6 of the WFD which respectively required a characterisation of the pressures and impacts on Europe's RBDs and the preparation of a Register of Protected Areas (RPA) including SACs (EPA and RBDs, 2005). Research funded by the EPA has provided the basis for identifying water-dependent habitats and species in nature conservation

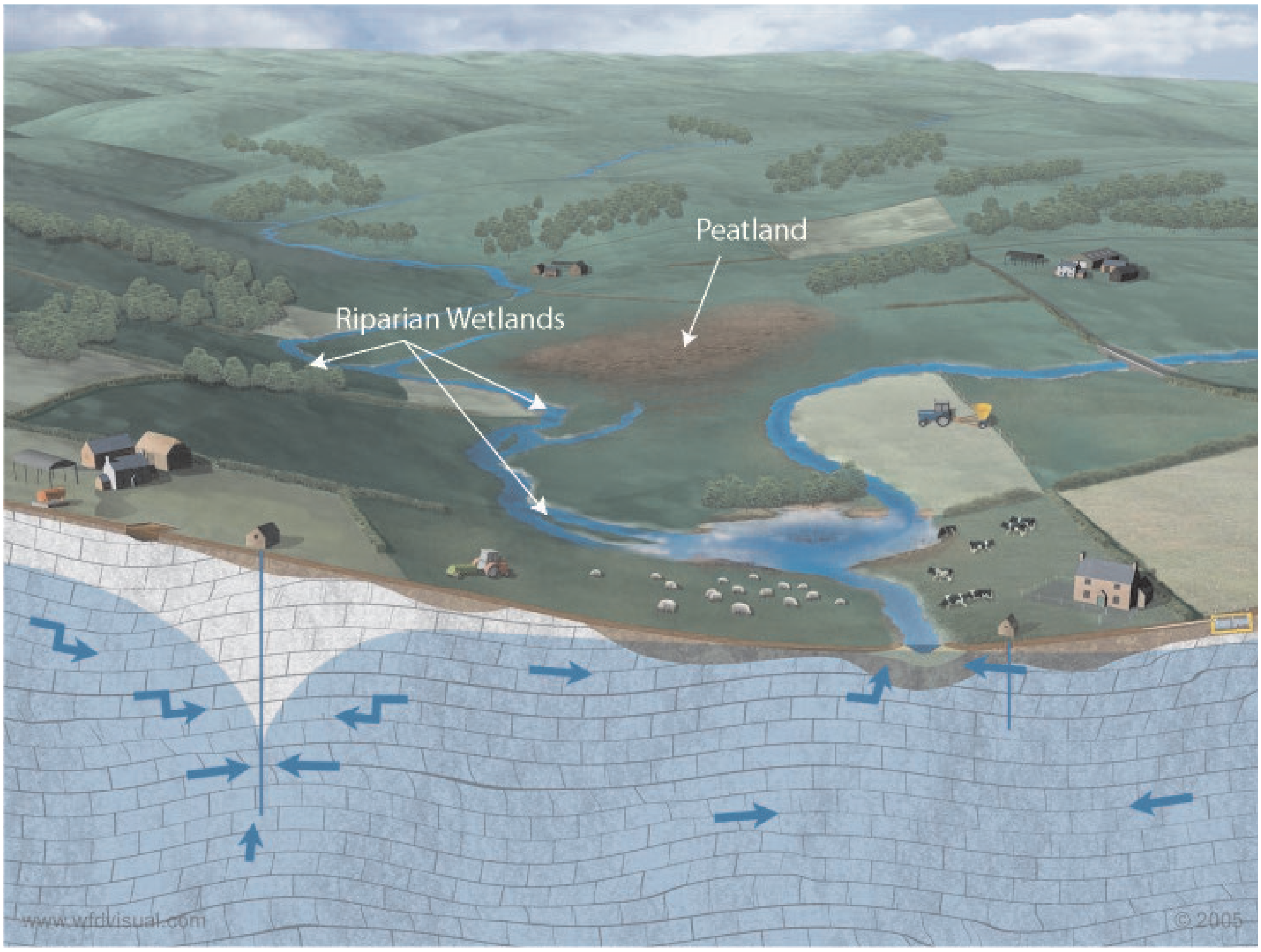

Figure 1.1. General context for a riparian and raised bog ecosystem within its groundwater context (source http://www.wfdvisual.com).

designated areas (O'Riain *et al*., 2005). Table 1.1 identifies the habitats listed under Annex I and the species listed under Annex II of the Habitats Directive that are GWDTEs. Under the Habitats Directive, these Annex I habitats and Annex II species require protection by designating SACs and, where they are the principal reason for designation of a SAC, are known as the qualifying interest for the SAC.

1.3 Characterisation of Ireland's RBDs and GWDTEs

Ireland's RBDs have been characterised and the waterbodies (surface and groundwater) within each assessed to establish if they were at risk of failing to meet their objectives under the WFD. This characterisation and assessment process, required by Article 5 of the WFD, was completed in 2004 and submitted to the European Commission in 2005 (EPA and RBDs, 2005). Details of the methodologies used for this risk assessment are available at http://www.wfdireland.ie.

The characterisation process for groundwater adopted the Source–Pathway–Receptor Model and involved carrying out a risk assessment of all available pressure information on groundwater bodies. The qualifying interests of SACs were assessed for their groundwater dependency and their catchment areas delineated, thus creating some 266 groundwater bodies which contained groundwater-dependent ecosystems in the Republic of Ireland. These GWDTEs were then assessed for similar risk tests as per normal groundwater bodies and some 48 were identified as being at risk. The approach described for Article 5 was robust enough where large groundwater bodies were

Table 1.1. List of Habitats Directive Annex I habitats and Annex II species that are groundwater-dependent terrestrial ecosystems.

EU habitat/ species code	EU Annex I Habitat (*indicates priority habitat)	EU Annex II Species
2190	Humid dune slacks	
21A0	Machairs (*in Ireland)	
3180	*Turloughs	
7220	*Petrifying springs with tufa formation (*Cratoneurion*)	
7210	*Calcareous fens with *Cladium mariscus* and species of *Caricion davallianae*	
7230	Alkaline fens	
7140	Transition mires and quaking bogs	
7110	*Active raised bogs (lagg and high bog)	
7120	Degraded raised bogs still capable of natural regeneration	
7130	Blanket bog (*if active bog) flushes	
91D0	*Bog woodland	
91E0	*Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-padion*, *Alnion incanae*, *Salicion albae*)	
6430	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	
3270	Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation	
4010	Northern Atlantic wet heaths with *Erica tetralix* flushes	
1393		*Drepanocladus vernicosus*
1528		*Saxifraga hirculus*
1013		*Vertigo geyeri*
1014		*Vertigo angustior*
1016		*Vertigo moulinsiana*

Note: The following habitats are not considered in any detail in this report, a strategic decision based on prioritisation of GWDTE habitats by the NPWS: 6430 Hydrophilous tall herb fringe communities and 3270 Rivers with muddy banks.

concerned and where information on the Source–Pathway–Receptor elements was available.

However, there were limitations concerning GWDTEs. In particular, the groundwater pathways to the wetland were generally poorly understood and the available pressure data were at too large a resolution to relate to the often local impacts affecting GWDTEs. Specific impact information was also often unavailable concerning GWDTEs and the location of GWDTEs within a SAC was often undefined. This project was established to address these information deficits, to improve understanding of these ecosystems, and to develop a longer-term framework for managing and assessing GWDTEs.

As part of the overall WFD process to classify groundwater body status, the purpose of this framework is to help determine whether or not the anthropogenic impacts on a groundwater body cause significant damage to a GWDTE.

1.4 Structure of the Report

The report comprises ten chapters. Chapters 1 and 2 provide an introduction to the aims of the project and the institutional and legislative context of the research. Chapter 3 summarises the work carried out to identify and map the GWDTEs. Chapter 4 examines potential ecological and hydrogeological indicators of GWDTEs. Chapter 5 introduces the conceptual framework for assessing GWDTEs with the context of available various water supply mechanisms and typologies. Chapter 6 examines this conceptual framework from the perspective of the sensitivity of the receptor. Chapter 7 examines the importance of understanding the pathways from the sources of pressures to the target receptors. In Chapter 8 the conceptual framework is trialled using three contrasting wetlands (fen, turlough and raised bog) to examine its practical application. Chapter 9 deals with the monitoring and management of GWDTEs under the WFD and their integration within the river basin management plans, and, finally, Chapter 10 provides the main conclusions of this project and some recommendations for further study.

2 Context of Study

2.1 Introduction

The main policy drivers for this study are the WFD and the European Habitats Directive. Both directives require the assessment and management of wetland habitats. The EPA is a designated competent authority for the WFD and the NPWS is a designated competent authority for the Habitats Directive. The focus of the WFD is on the groundwater body and associated dependent wetland, whereas the focus of the Habitats Directive is on the habitat and species of the wetland itself. However, given the close linkages in terms of monitoring requirements and objective setting, there are obvious benefits in a collaborative approach to implementing the overlapping elements of these directives. This chapter sets out the boundaries of this project and a number of the background contexts associated with this research.

2.2 Project Boundaries

Much of the literature concerning wetlands (classification, typology and water supply mechanisms, etc.) focuses on the broadest range of wetland types or the 'universe of wetlands'. However, the context for this project is specifically GWDTEs as defined in the WFD and their relationship with the quantitative and chemical status of associated groundwater bodies, as defined in Annex V, Sections 2.1.2 and 2.3.2 of the WFD (see Fig. 2.1).

Water-dependent habitats and in particular GWDTEs have been identified during the characterisation process of Article 5 and through the preparation of the RPA through Article 6 of the WFD. In practice, due to significant knowledge gaps, this limits this study to GWDTEs in SACs already identified as being 'at risk' through the WFD Article 5 risk assessments, together with some unimpacted 'reference' GWDTEs (also in SACs). Coastal GWDTEs were not examined in this study. Future work in this area can be expanded to include more GWDTE types as the base of knowledge improves.

2.3 GWDTE and WFD Objectives

Objectives under the WFD include the requirement that anthropogenic pressures on groundwater bodies shall not result in any 'significant damage' to groundwater-dependent terrestrial ecosystems. The ecology of groundwater-dependent wetlands is fundamentally reliant on the supporting hydrogeology. Therefore, hydrogeological damage in these wetlands is frequently reflected in corresponding changes in that

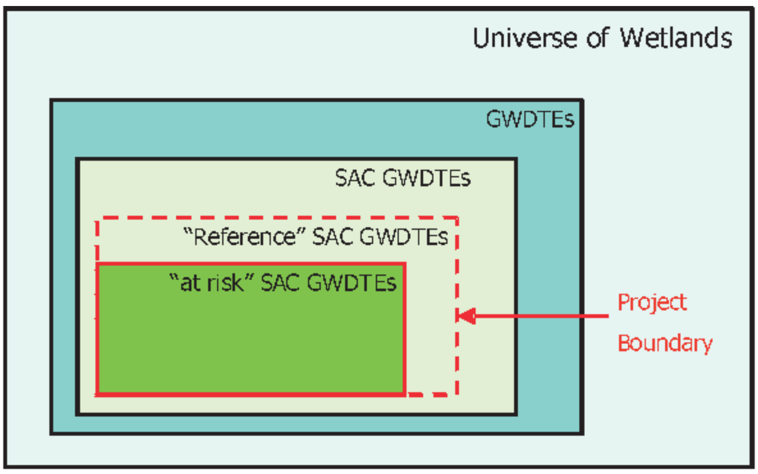

Figure 2.1. The project is limited in scope to Special Area of Conservation groundwater-dependent terrestrial ecosystems (SAC GWDTEs) which were identified as being 'at risk' with some unimpacted 'reference' SAC GWDTEs.

ecology. Understanding the eco-hydrogeological connectivity and environmental supporting conditions is basic to the management of these wetlands under the WFD.

The objectives of the WFD include achieving both good ecological and chemical status for surface waters and good chemical and quantitative status for groundwater. Less explicit, but no less important, are the objectives for wetlands. Good groundwater chemical status is set out in Annex V (Section 2.3.2) under Article 2 (25) and includes preventing a significant deterioration of the ecological or chemical quality of associated surface waters, or any significant damage to terrestrial ecosystems which depend directly on groundwater (GWDTEs). Similarly good groundwater quantitative status is set out in Annex V (Section 2.1.2) under Article 2 (28) and includes preventing a significant deterioration in the status of associated surface waters or GWDTEs. Therefore, a fundamental requirement for the effective management of GWDTEs will be the identification of key hydrogeological and ecological indicators of significant damage.

In addition to these objectives, the WFD also requires that objectives for protected areas under other legislation must also be achieved (e.g. Favourable Conservation Status under the Habitats Directive).

The consequences of downgrading a groundwater body to poor status for whatever reason are significant. It will require the relevant competent authority to ensure that mitigation measures are put in place to address the pressures that are resulting in the poor status. These measures may include, for example, actions to reduce nutrient inputs to groundwater or actions to address changes in groundwater level. Therefore, improved understanding of these complex systems is required to support these important management decisions.

2.4 Guidance for the GWDTE Classification Tests

The Groundwater Task Team of UKTAG, comprising groundwater specialists from the UK and Ireland, has developed guidance on, *inter alia*, the definition of significant damage and the GWDTE aspects required for groundwater body classification. These guidance documents are available for download at the UKTAG website (http://www.wfduk.org). In summary, the UKTAG guidance requires a screening exercise to confirm that there is in fact a physical linkage between an ecosystem and the associated groundwater body. The screening exercise is based on criteria such as ecological indicator communities, proximity to pressures, site condition reports and the hydrogeological context. A starting point for this classification is the establishment of key environmental supporting conditions which are required to maintain dependent communities in a favourable state.

Environmental threshold values (e.g. flow, level, chemistry) are required to apply the classification tests. The guidance proposes the higher of either:

- the upper limit of natural background for the groundwater body; or
- a relevant surface water quality standard.

The UKTAG guidance acknowledges that the linkage between conditions at monitoring points in a groundwater body and conditions within a specific GWDTE identified as being at risk will often be uncertain. Therefore, threshold values may need to be precautionary. It is also acknowledged that unlike for other groundwater body classification tests, the GWDTE tests will often require detailed and site-specific knowledge.

3 Identification and Mapping of Groundwater-Dependent Terrestrial Ecosystems and Special Areas of Conservation

3.1 Background

As part of the requirements of the WFD, there is a need to identify the location of GWDTEs so that monitoring and mitigation measures can be undertaken to ensure that the GWDTEs are not significantly damaged. Groundwater-dependent terrestrial ecosystems may be found within a larger ecosystem that is not necessarily groundwater dependent, so that mapping of the GWDTE boundaries may be necessary in order to correctly establish the groundwater catchment and flow paths to the GWDTE. Initially, during this first river basin cycle, GWDTEs within SACs are being prioritised (see Chapter 9). The focus is initially on SACs where the GWDTE is a qualifying interest for the SAC (see Table 1.1).

An initial list was compiled of 48 SACs, with GWDTEs as qualifying interests, where a preliminary risk assessment under the WFD had identified the GWDTE as 'at risk' or 'possibly at risk' during the characterisation process. For the majority of the SACs on the list, primarily turloughs and raised bogs, the SAC boundary was also taken as the GWDTE boundary and so no additional mapping was required for these sites. Out of this list, however, 11 sites required identification of the location(s) of the GWDTE(s) within the SAC and subsequent mapping of those GWDTE(s). Castletaylor Complex was subsequently included in this list as it was deemed by the NPWS to be at risk. Some SACs may have multiple individual sites of a single GWDTE type (e.g. alkaline fen) or a SAC may have a number of different types of GWDTE (e.g. alkaline fen, *Cladium* fen and petrifying spring). This mapping exercise was completed in December 2006 and is documented in *GWDTE Mapping Report No. 1* (Dunne, 2006).

A second subsequent list was drawn up of over 100 SACs that have GWDTEs as their main qualifying interests. Out of this extensive list there was a subset of 36 large, complex SAC sites that also required mapping of the GWDTEs within the SAC. For the remainder of the SACs, the SAC boundary has been taken as the GWDTE boundary. This mapping exercise was completed in February 2007 and is documented in *GWDTE Mapping Report No. 2* (Dunne, 2007).

Within these lists of SAC sites that required GWDTE mapping, work was prioritised based on receptor sensitivity to groundwater quality and groundwater level (see Chapter 9), with SACs having the most sensitive GWDTEs as qualifying interests reviewed first (i.e. scoring 1 (extremely sensitive) or 2 (highly sensitive) for groundwater quality and/or level).

3.2 Methods for Identifying and Mapping GWDTEs in the Selected SACs

A review of NPWS files was undertaken for the selected sites (mentioned above) to identify locations of the GWDTEs. Principal data sources included:

- Field survey notes from NPWS Natural Heritage Area (NHA) files
- Habitat maps from NPWS SAC management plans (where available)
- Goodwillie (1992) *Turloughs over 10 ha. Vegetation Survey and Evaluation.* A report to the NPWS
- Southern Water Global and Jennings O'Donovan and Partners (1997) *An Investigation of the Flooding Problems of the Gort–Ardrahan Area of South Galway.* Final report to the Office of Public Works
- NPWS Rare Flora Databases for data on *Saxifraga hirculus* and *Drepanocladus vernicosus*
- Foss (2007) *Study of the Extent and Conservation Status of Springs, Fens and Flushes in Ireland.* An internal report to the NPWS

- Locations of *Vertigo* spp. habitat were complied from information supplied by Dr Evelyn Moorkens (personal communication, 2007)
- Expert knowledge of NPWS research staff.

Once the GWDTE location was identified, an approximate boundary around it was drawn using the NPWS GeoBrowser system – a software application for viewing of mapping, aerial photography and SAC boundary data layers. A grid reference was obtained from the centre of the GWDTE polygon on GeoBrowser and an image of the GWDTE was created, printed and saved as a JPEG file. Where a SAC had a large number of discrete GWDTEs, for example alkaline fens around Lough Corrib, a schematic map was also created, showing the relative locations of the GWDTEs within the whole SAC. This methodology is described in detail in Dunne (2006, 2007).

In the case of the GWDTE species – *Saxifraga hirculus*, *Drepanocladus vernicosus* – their location is given as a grid reference (point data) rather than a polygon. At certain sites, petrifying springs were also mapped as grid references rather than polygons, depending on the data source. Single grid references are not ideal, as the boundaries of the GWDTE that support the GWDTE species (for example, the flush supporting *Saxifraga hirculus*) cannot be elucidated from a single grid reference. Attempts were made to outline GWDTE boundaries on GeoBrowser maps and aerial photographs but there was not enough information to do this accurately. Field mapping of these GWDTEs will be required in the future.

Map information on the location and extent of the GWDTE habitat for *Vertigo* spp. – *Vertigo geyeri*, *V. moulinsiana* and *V. angustior* – were supplied by Dr Evelyn Moorkens (personal communication, 2007). The data were supplied as PDFs of aerial photographs of sites, with the boundaries of the *Vertigo* habitat outlined and categorised into optimal, suboptimal and unsuitable habitat, together with respective grid references. Where grid references were not supplied, they were obtained from the NPWS GeoBrowser.

Once the GWDTEs had been identified and mapped, the data were forwarded to CDM, working on behalf of the Eastern RBD for digitising and incorporation into a GIS. This mapping exercise was relatively crude and was focused on the physical location of the GWDTE based on data made available by the NPWS and constrained by the time frame of this project. The GWDTE location boundaries mapped do not include a buffer zone or zone of contribution. The mapping exercise focused solely on delineating a boundary around the GWDTE. Detailed mapping of GWDTEs, such as noting groundwater discharges and plant communities, was not undertaken during this project.

3.3 Outputs

In total, GWDTEs in 64 SACs were reviewed for mapping:

- Groundwater-dependent terrestrial ecosystems in the initial 11 sites were identified and mapped on GeoBrowser as outlined above. An additional site, Castletaylor Complex, was added to this list by the NPWS and mapped, as it was deemed to be an at-risk site. This was based on reports of development immediately adjacent to this oligotrophic turlough.
- Thirty-six sites from a second additional list of SACs that have GWDTEs as their main qualifying interests were also mapped.
- Locations of 16 *Vertigo* sites were compiled and mapped from information supplied by Dr Evelyn Moorkens.

3.4 Future Mapping

Outstanding mapping (files that were not examined during the course of this project) includes bog woodland in Lough Oughter SAC, transition mire and quaking bog in River Finn SAC and the locations of three *Vertigo* sites at Carrowmore Dunes SAC, Ben Bulben, Gleniff and Glenade SAC and Slieve Tooey/Tormore/Loughros Beg SAC. Further work is required to elucidate more accurately the locations and extent of petrifying springs, transition mires and quaking bogs, alkaline fens and *Cladium* fens. Ideally, this would involve discussions with NPWS staff expert in these habitats and/or familiar with these sites. For some sites, additional field survey data may be needed, however, before any further clarification of the locations/extents of GWDTEs can be achieved:

- Within the NPWS NHA files, the principal data source used in this project for mapping GWDTEs within large SACs, certain habitats are often noted together – for example fens may be mapped and described together with wet grassland/flush/reed bed/marsh. This is a particular problem for alkaline fen along lake shores such as Lough Carra/Mask and Lough Corrib.
- *Cladium* fen and *Cladium* swamp habitat are often not sufficiently described within the file data to discriminate between the two habitats. The former is an Annex I habitat and a GWDTE.
- Transition mires that occur within other extensive habitats such as blanket bog are rarely described or mapped, for example Glenamoy Bog Complex SAC.

The shortcomings of the mapping exercise are also discussed in *GWDTE Mapping Report No. 2* (Dunne, 2007). Further work is also required to determine the boundaries of the GWDTEs supporting the Annex II species *Saxifraga hirculus* and *Drepanocladus vernicosus* (see Section 3.2). Coastal GWDTEs such as machair and dune slacks were not mapped as part of this contract. This was a decision taken by the NPWS in order to prioritise work. Recent surveys and conservation assessments of coastal habitats by the NPWS may produce maps that will inform future work in identifying the location and extent of coastal GWDTEs such as machair and dune slacks.

4 Developing Ecological and Hydrogeological Indicators for Groundwater-Dependent Terrestrial Ecosystems

4.1 Introduction

An essential requirement in the assessment of GWDTEs is criteria so that the status of these sites can be determined and any changes to status over time identified. The WFD specifically requires the prevention of ‘significant damage’ and the Habitats Directive requires the achievement of ‘favourable condition’. In effect, what are required are indicators which reflect the ecological and hydrogeological condition of each site. This chapter examines this issue and proposes some indicators to assess GWDTEs.

4.2 Defining Significant Damage in GWDTEs

As part of the Common Implementation Strategy (CIS) for the WFD a guidance document on wetlands has been prepared by a European working group to elaborate a common understanding of the WFD requirements regarding wetlands and to identify their role in its implementation (EC, 2003). Wetland ecosystems will play a key role both in terms of specific WFD objectives and in appropriate circumstances in terms of the programmes of measures to meet broader objectives through wetland creation and enhancement (e.g. for pollution abatement and flood protection). However, there is little specific CIS guidance on the definition of significant damage for GWDTEs and the integration of their assessment in the river basin planning management process.

The Environment Agency for England and Wales (EA) has trialled a methodology to assess significant damage (Miller and Hulme, 2006). This GIS-based approach uses national data sets and therefore is limited to providing a national-scale assessment. Modifications of the assessment criteria for local evidence are planned through a series of workshops between EA staff and Conservation Agency staff. An NS-SHARE study has progressed definition of the ecological requirements of water-dependent habitats and provides a valuable catalogue of key requirements (Curtis *et al.*, 2006). However, limited specific data were highlighted in this report as a major knowledge gap. More recently, Hinsby *et al.* (2008) have developed some groundwater threshold values for coastal groundwater-dependent ecosystems.

It is clear that greater understanding of the relationships between pressures on groundwater and impacts on wetland habitats and species is required in order to better define significant damage. This will only be achieved through the assessment of existing data and collection of new data from a range of representative GWDTEs. Essential to this work will be the identification of key indicators of site condition at different GWDTEs. Indicators are required to represent both the ecological and hydrogeological conditions of each site. Thresholds of significance can than be developed for these key indicators.

4.3 Developing Indicator Species to Monitor Impacts on GWDTEs

Indicator species are species whose status (presence, absence and abundance) allows an assessment of environmental conditions in a habitat. Therefore, a set of indicator species could potentially be used for investigating the linkages between the vegetation and the controlling hydrogeology. Some species will indicate the occurrence of specific environmental conditions which, in turn, could be correlated with groundwater influence and therefore the likelihood of changes in the groundwater regime. One of the aims of this project was to develop a set of groundwater condition indicator species for GWDTEs but this aim has not been realised within the contract time frame.

There is little available information on actual indicator species for groundwater pressures in GWDTEs in Ireland, partly due to the absence of systematic site survey data such as species lists, relevés, etc., and corresponding environmental data. Development of a monitoring programme for GWDTEs is likely to contribute to actual environmental measurements from which a set of indicator species for GWDTE conditions can be derived. The NPWS is currently compiling a list of typical plant species for the following GWDTEs that are Annex I habitats: alkaline fen, *Cladium* fen and petrifying springs, based on conservation assessments of a number of sites. These species lists will indicate the typical species complement of each habitat considered to be in 'good conservation status' (Peter Foss, personal communication, 2007). Since these habitats are highly dependent on groundwater, some of the typical species may prove to be useful indicator species of groundwater conditions in the habitat. If this work was carried out systematically for all Annex I GWDTE habitats, it could provide a useful tool.

Scientists at Staatsbosbeheer in The Netherlands have compiled lists of groundwater indicator plant species for various fen and transition mire communities with regard to water regime, pH and trophic status (Jalink and Janssen 1995; Jalink 1996) – which could be used as a starting point for developing a set of groundwater indicator species for the Irish context. Other useful data sets include those of the British National Vegetation Classification (Rodwell, 1991), which lists synoptic tables of relevés from many habitats and sub-communities. A number of comprehensive phyto-sociological studies of certain Irish habitat types can also provide characteristic species data together with limited corresponding environmental data. Such studies include those of fens by Ó'Críodáin and Doyle (1994, 1997) and wet woodland by Kelly and Iremonger (1997). A current monitoring programme in Pollardstown Fen is also providing data that can contribute to developing a set of indicator species (Katherine Duff, Natura Environmental Consultants, personal communication, 2007).

4.3.1 Ellenberg indicator values

Ellenberg (1988) defined a set of indicator values for the vascular plants of central Europe, indicating their 'ecological behaviour' in relation to environmental conditions such as soil moisture (F), soil/water pH (R), nitrogen/soil fertility (N), light (L), salinity (S), temperature (T) and continentality (K). For each variable there is a scale, e.g. moisture (F), ranging from 1 to 12, dry to wet. Species with wide amplitude tend to fall in the middle of the scale, while more specialised species occur at either end of the scale (i.e. those with a preference for dry conditions or those of aquatic conditions). Therefore, information provided by the occurrence of a plant species can infer particular environmental conditions.

These Ellenberg values have been widely used by ecologists and are now generally accepted as having a good correlation with actual observed environmental variables. Hill *et al.* (1999) took Ellenberg's list and adapted it for the British flora, which, owing to its more oceanic climate and reduced flora relative to central Europe, would have certain species with a wider amplitude or a different ecological requirement than on the continent. It is this revised set of indicator values that is used in this report. Three Ellenberg values in particular may capture the elements of the conceptual framework and hence groundwater dependence/ sensitivity of the GWDTE (Table 4.1):

1. Ellenberg moisture (F) – groundwater level
2. Ellenberg pH (R) – relative groundwater contribution, alkalinity
3. Ellenberg nitrogen (N) – nutrients.

Ellenberg values may be used in a number of different ways:

- Within species list data, it is useful to look at subsets of species: species characteristic of (or differential for) different sub-communities may indicate environmental variation and possibly be used as indicator species from which Ellenberg values can be applied.
- One application of Ellenberg values is using them to obtain a mean value for a vegetation sample (relevé) or a vegetation community. This can show where groundwater influence is strongest within a site. These within-site differences are useful when monitoring an individual site and can be based upon species presence/absence, relative frequency or cover.
- Ellenberg values can also be obtained on a whole-site basis by averaging the values from all

Table 4.1. Ellenberg indicator values for moisture (F), nitrogen (N), and pH (R) (taken from Hill *et al.*, 1999).

Indicator value	F – Moisture	R – Reaction	N – Nitrogen
1	Indicator of extreme dryness, restricted to soils that often dry out for some time	Indicator of extreme acidity, never found on weakly acidic or basic soils	Indicator of extremely infertile sites
2	Between 1 and 3	Between 1 and 3	Between 1 and 3
3	Dry site indicator, more often found on dry ground than in moist places	Acidity indicator, mainly on acidic soils but exceptionally also on nearly neutral ones	Indicator of more or less infertile sites
4	Between 3 and 5	Between 3 and 5	Between 3 and 5
5	Moist site indicator, mainly on fresh soils of average dampness	Indicator of moderately acidic soils, only occasionally found on very acidic or on neutral to basic soils	Indicator of sites of intermediate fertility
6	Between 5 and 7	Between 5 and 7	Between 5 and 7
7	Dampness indicator, mainly on constantly moist or damp but not on wet soils	Indicator of weakly acidic to weakly basic conditions; never found on very acidic soils	Plant often found in richly fertile places
8	Between 7 and 9	Between 7 and 9	Between 7 and 9
9	Wet site indicator, often on water-saturated, badly aerated soils	Indicator of basic reaction, always found on calcareous or other high pH soils	Indicator of extremely rich situations, such as cattle resting places or near polluted rivers
10	Indicator of shallow-water sites that may lack standing water for extensive periods	N/A	N/A
11	Plant rooting under water but at least for a time exposed above or plant floating on the surface	N/A	N/A
12	Submerged plant, permanently or almost constantly under water	N/A	N/A
~	Indicator for periodical moistening		
=	Indicator for flooding		

communities within a site. This mean value for all communities in a site indicates the relative groundwater influence between sites, allowing for a comparison between sites. Weightings can be used to prioritise one site over another – for example Tynan *et al.* (2007) calculated the Ellenberg N value for plant communities within turloughs and used the percentage area of oligotrophic communities within each turlough as a weighting to rank each turlough site.

4.4 Hydrogeological Indicators

The hydrogeological monitoring requirements of GWDTEs will be determined by the nature and extent of the groundwater dependency of each wetland. The conceptual framework and GWDTE typology described in Chapter 5 will assist in the initial stages in developing a monitoring programme. Ultimately, a detailed site assessment, including site visits, is required to construct individual conceptual models properly and to elucidate an effective GWDTE monitoring programme.

Table 4.2 presents examples of hydrogeological attributes that can be used to measure the environmental supporting conditions of GWDTEs. The attributes listed in Table 4.2 should not be examined in isolation but should be assessed in parallel with the

Table 4.2. Measurable hydrogeological attributes for conceptual framework elements.

Element	Measurable attribute
Variability in groundwater level	Groundwater level
Relative groundwater contribution	Water balance Groundwater quality Spring flows
Chemistry	Groundwater quality Groundwater fluxes (flow+concentration)

ecological indicators listed above. A groundwater balance will be essential in nearly all cases as this will determine the relative importance of groundwater flows and therefore fluxes (of nutrients for example) to the wetland. Lloyd and Tellam (1995) emphasise three-dimensional groundwater head distribution as the key hydrogeological parameter for wetland studies.

The hydrogeological attributes are examined in more detail in the conceptual framework in Chapter 5 and in the case studies presented in Chapter 8.

5 A Conceptual Framework for Groundwater-Dependent Terrestrial Ecosystems

5.1 Introduction

The objective of this chapter is to develop a conceptual framework for assessing GWDTEs within the overall context of the Source–Pathway–Receptor Model. There is a scale issue associated with this type of assessment due to the fact that the wetlands can often be very small in contrast to the contributing groundwater body, which can be very large. For this proposed conceptual framework the focus is on the wetland scale and the immediate groundwater discharging to the wetland.

This chapter evolved from discussions within the project steering group during the course of the project. Output from the chapter together with the case studies described in Chapter 8 were subsequently published in the Proceedings of the 35th Congress of the International Association of Hydrogeologists (IAH) (Kilroy *et al.*, 2007).

5.2 Geo-Hydrological Setting

As a starting point a simple GWDTE typology is proposed here based on water supply mechanisms and geo-hydrological setting. There have been several water supply mechanisms proposed for wetlands (e.g. in the UK: Wheeler and Shaw (2000), and Heathwaite *et al.* (2006); in the USA: Clairain (2002); and in Canada: Warner and Rubec (1997)). Of most relevance to Irish wetlands is the proposal by Wheeler and Shaw (2000), which subsequently formed the basis for the Heathwaite *et al.* (2006) study (and that of Krause *et al.,* 2008), and proposes the WETMECs or Wetland Water Supply Mechanism approach. One of the difficulties in using WETMECs in Ireland is their complexity and that the nine main types encompass all wetlands, whereas Irish GWDTEs either fall into a subset of WETMECs or are not sufficiently described by WETMECs. Since WETMECs are largely based on data from the East Anglia region of the UK, there is no clear home for some of the more important Irish ecosystems such as turloughs and raised bogs.

The proposal here is to begin with a very simple water supply mechanism typology, which can be readily applied to all Irish GWDTEs. Sub-types can be then be developed as required. This typology focuses on the general geo-hydrological setting within which the wetland is situated. Local water supply mechanisms will need to be dealt with on a site-by-site basis. However, the aspiration here is to achieve a simple classification for regional management of these wetlands. Using schematics based on Lloyd and Tellam (1995), the two basic water supply mechanisms are defined below and represented in Fig. 5.1.

1. **Type A:**
   Groundwater Discharge Zone Wetlands

In this case the wetlands and any associated open surface water represent the main groundwater discharge zone. These wetlands include fens, flushes in wet heaths and blanket bogs, transition mires and quaking bogs, and petrifying springs. Criteria have yet to be developed for subdivisions of Type A wetlands, but could potentially be based on changes in groundwater level and/or relative groundwater contribution at the wetland-scale (Fig. 5.2).

2. **Type B:**
   Groundwater Flow-Through Depression Wetlands

The wetland is situated in a depression within the regional groundwater flow aquifer system. These wetlands include turloughs and raised bogs. Based on discussions of the project steering group, further subdivisions can be made in Type B wetlands based on the degree of changes in groundwater level. A proposed subdivision is turloughs and raised bogs. Further subdivisions can be developed where knowledge of the flow systems is available (e.g. ERTDI Turloughs Project; Tynan *et al.*, 2007).

Figure 5.2 presents a schematic of a basic water supply mechanism typology for Irish GWDTEs based

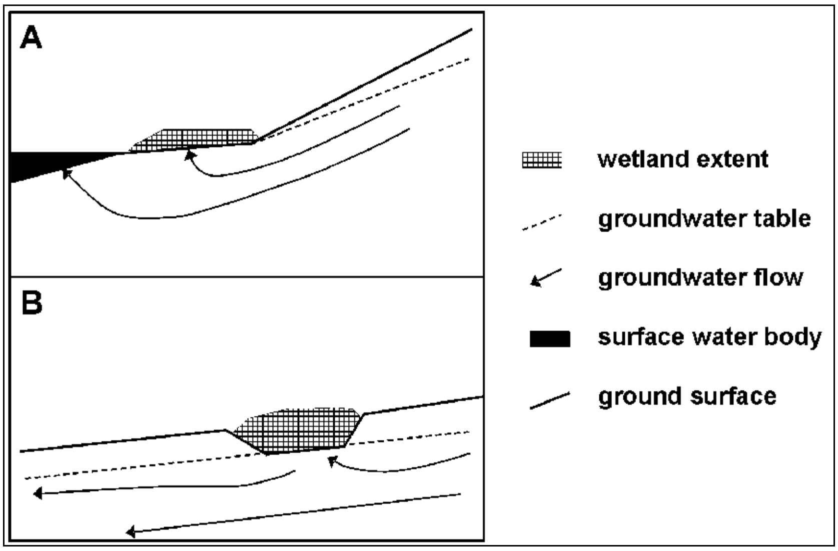

Figure 5.1. Two water supply mechanisms for application to Irish groundwater-dependent terrestrial ecosystems. Type A: Groundwater Discharge Zone Wetlands. Type B: Groundwater Flow-Through Depression Wetlands. After Lloyd and Tellam (1995).

on geo-hydrological setting and degree of changes in groundwater level. The typology can be refined and further developed as fundamental gaps in knowledge are filled.

Certain habitats may have a Type A or a Type B water supply mechanism depending on the site (Table 5.1).

The importance of understanding the water supply mechanisms to GWDTEs cannot be understated. They provide knowledge on where to monitor and what to monitor. Figures 5.1 and 5.2 form the basis for the development of a conceptual framework model for assessing GWDTEs under the WFD described in Section 5.3.

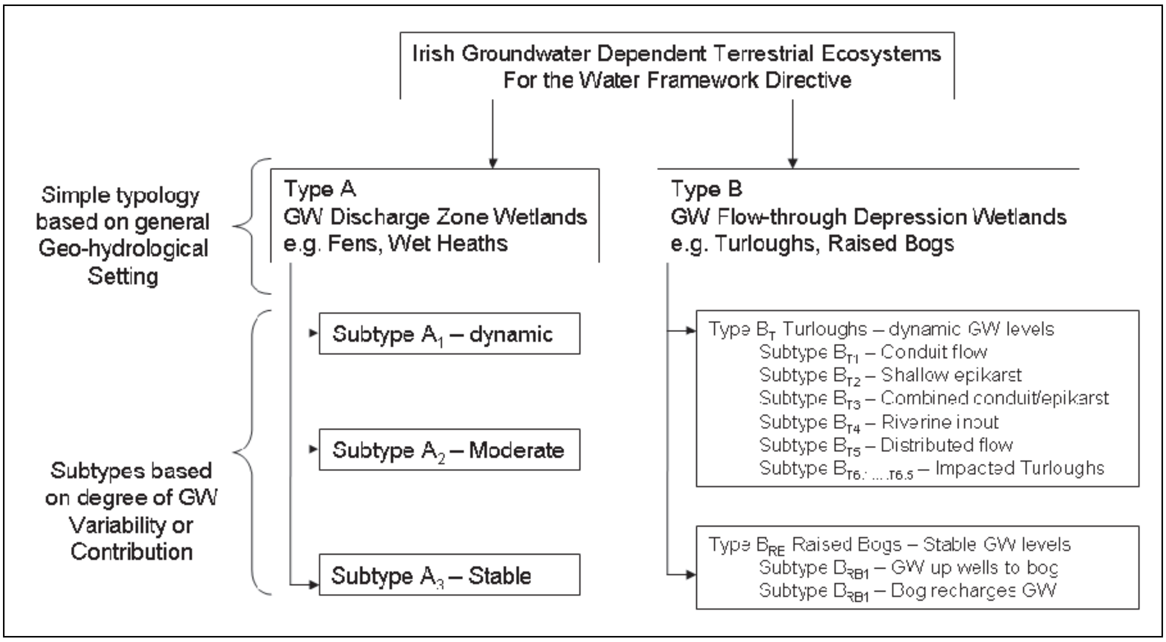

Figure 5.2. Basic water supply typology for Irish groundwater-dependent terrestrial ecosystems based on geo-hydrological setting and degree of groundwater-level variability.

Table 5.1. Water supply mechanisms for each groundwater-dependent terrestrial ecosystem. Type A, Groundwater Discharge Zone Wetlands; Type B, Groundwater Flow-Through Depression Wetlands.

EU Annex I Habitat (*indicates priority habitat)	Type
Transition mires and quaking bogs	A
*Bog woodland	A
*Calcareous fens with *Cladium mariscus* and species of *Caricion davallianae*	A
*Petrifying springs with tufa formation (*Cratoneurion*)	A
Alkaline fens	A
Northern Atlantic wet heaths with *Erica tetralix* (flushes)	A
Blanket bog (*if active bog) (flushes)	A
Dunes with *Salix repens* spp. *argentea* (*Salicion arenariae*)	A
Humid dune slacks	A
*Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-padion*, *Alnion incanae*, *Salicion albae*)	A
Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	A
Degraded raised bogs still capable of natural regeneration	A/B
*Active raised bogs	A/B
Machairs (*in Ireland)	B/A
*Turloughs	B

In order to try to further refine the water supply mechanisms, a number of characteristics of the GWDTEs were examined to see if sub-types of the water supply mechanisms A and B, particularly sub-types of Type A (Discharge Wetlands), could be constructed (Table 5.2).

5.3 A Conceptual Framework For Assessing the Environmental Supporting Conditions of GWDTEs

The development of sound conceptual models for different GWDTEs is an essential starting point for understanding and managing these wetlands. Subsequent monitoring will help validate or modify these conceptual models so that they become refined during the WFD river basin management cycles. The environmental supporting conditions of different GWDTEs will include quantifiable metrics such as groundwater flow, groundwater level and chemical flux. However, there are few detailed studies in Ireland that relate these metrics to quantifiable ecological responses in the GWDTEs and further research is required to identify the most appropriate controlling factors in each GWDTE. The few studies that do exist will be essential for guiding the development of conceptual models for the first WFD river basin management cycle.

A conceptual framework for the understanding of the environmental supporting conditions of GWDTEs under the WFD and Groundwater Directive is presented in Fig. 5.3. The objective is to provide a conceptual framework for locating in three-dimensional space groundwater-dependent wetlands relative to ecological/hydrogeological criteria that can be measured in the field. Individual models may be required for particular wetlands. The three axes aim to incorporate the main hydrogeological and hydrochemical environmental supporting conditions required by GWDTEs for their assessment under these directives, namely:

1. Groundwater contribution: proportion of water contributing arising from groundwater

2. Groundwater level: variability of groundwater level

3. Groundwater chemistry: e.g. degree of mineralisation of groundwater discharging to wetland.

Table 5.2. Characterisation of groundwater-dependent terrestrial ecosystems, based on expert judgement of steering group.

GWDTE	Groundwater discharge	Groundwater contribution	Degree of mineralisation	Groundwater level	Rate of groundwater flow	Other
Petrifying springs	Direct	High	High	Minimum threshold Required	Important	Note some springs may naturally dry up, whereas others will have perennial flow
Alkaline fen	Direct	High	High	Absolute water level important		
***Cladium* fen**	Direct	High	High	Absolute water level important		
Transition mires	Direct	Mixed groundwater and rainwater input	Low–moderate	Stable		Groundwater level supports rainwater lens Groundwater supports high, stable water level in habitat Need to maintain regional groundwater flow and level
Bog woodland on raised bog	Indirect	Not groundwater dependent except in context of regional groundwater supporting the overall raised bog				
Bog woodland on transition mire	Direct	Small but vital contribution	Low–moderate			Groundwater supports surface water
Raised bog (high bog)	Indirect	Regional groundwater supports water level in bog				
Raised bog (lagg)	Direct	Mixed water contribution – groundwater, surface water and bog water				Groundwater contribution vital
Turloughs	Direct	High	Moderate–high	Dynamic groundwater fluctuations (level, timing, frequency)		Significant inundation range and duration
Machairs	Direct	High	Moderate–high	Moderate groundwater fluctuations		

The relative groundwater contribution to the wetland (x-axis) can be calculated by carrying out a water balance. Even in GWDTEs where the relative contribution of groundwater may be small, such as bog woodland or transition mire, it can nevertheless be a critical input that maintains the habitat. In the case of transition mires, for example, a change in relative groundwater contribution could drive the ecosystems towards fen (increase) or bog (decrease).

The changes of groundwater level (y-axis) can be partly measured through changes in water table and

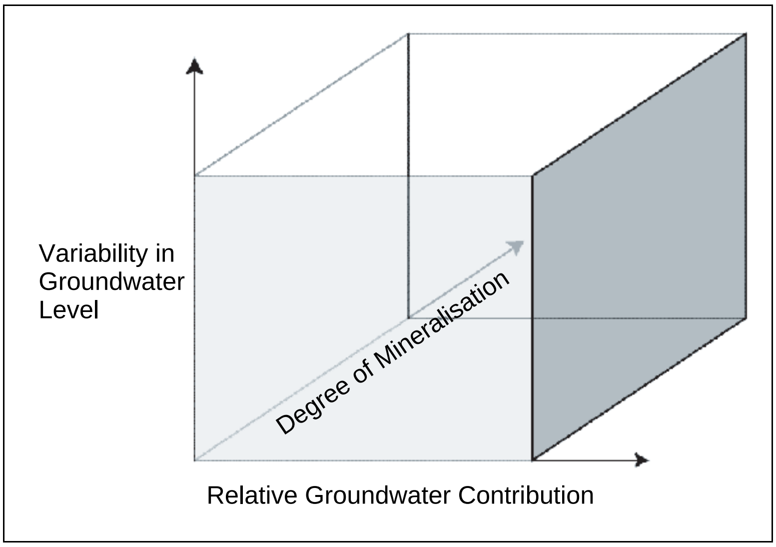

Figure 5.3. A proposed conceptual framework for the assessment of different groundwater-dependent wetlands for the Water Framework Directive. The location of a particular wetland within this cube will be determined by its environmental supporting conditions in terms of relative groundwater contribution, variability in groundwater levels and groundwater chemical composition (see also Table 5.3).

expressed as a coefficient of variation[1]. Groundwater-dependent terrestrial ecosystem habitats will vary in terms of their required groundwater level range and periodicity. Certain habitats require a constant water level to maintain the habitat. At the other extreme, habitats such as turloughs have a dynamic water regime in both space and time – water levels change quite quickly, the length of time that the habitat remains inundated can also vary, as can the frequency of these events. Other GWDTE habitats may tolerate small fluctuations in the water level. Habitats such as some petrifying springs may have a minimum threshold value. As well as a direct influence of groundwater on GWDTEs, for some GWDTEs such as raised bogs, for example, groundwater has a critical support function in maintaining water levels.

The chemistry (z-axis) of the groundwater discharging to a wetland in part determines the chemical conditions needed to maintain a habitat in a favourable condition. The alkalinity and nutrient parameters also reflect the relative contribution of groundwater (Table 5.3). Regional groundwater tends to have a relatively high base status and to be relatively nutrient poor when compared with surface waters, so GWDTEs are typically relatively basic and relatively oligotrophic ecosystems. In this conceptual framework, chemistry (z-axis) is taken to be primarily degree of mineralisation. Nutrients are not considered for this axis but will be discussed in the context of the sensitivity of GWDTEs to changes in groundwater quality (see Chapter 6).

The location of a GWDTE habitat within this cube can inform the key monitoring and management issues for different groundwater-dependent wetland types by highlighting important environmental supporting conditions for the GWDTE.

There is scope for refining this framework. In particular, the axis concerning groundwater chemistry (z-axis) requires further consideration. For this axis it was difficult to agree on a universal attribute that would apply in all cases. Degree of mineralisation was chosen for the application of the case study wetlands in Chapter 8. However, it is likely that in some instances other chemical descriptors (e.g. nitrate, phosphate, redox potential) may be more appropriate.

1. To compare different sites, or areas within a single site, the coefficient of variation should be measured from points with similar characteristics, such as depth to water table.

Table 5.3. Environmental characteristics of groundwater-dependent terrestrial ecosystems.

EU Annex I Habitat	Variability in groundwater level	Degree of mineralisation (alkalinity)	Relative groundwater contribution
Transition mires and quaking bogs	Constant	Low–moderate	Low–moderate
***Bog woodland**	Constant	Low–high	Low
Calcareous fens with *Cladium mariscus* and species of *Caricion davallianae	Constant–moderate	High	High
***Petrifying springs with tufa formation (*Cratoneurion*)**	Constant–moderate	High	High
Alkaline fens	Constant–moderate	High	High
Degraded raised bogs still capable of natural regeneration	Constant–moderate	Low–high	Low–high
Northern Atlantic wet heaths with Erica tetralix (flushes)	Constant–moderate	Low–high	
***Active raised bogs (lagg)**	Constant–moderate	Moderate–high	Low–high
Blanket bog (*if active bog) (flushes)	Constant–moderate	Low–high	
Machairs (*in Ireland)	Moderate–dynamic	Moderate–high	High
Dunes with *Salix repens* spp. *argentea* (*Salicion arenariae*)	Dynamic	Moderate	
Humid dune slacks	Dynamic	Moderate	
***Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-padion*, *Alnion incanae*, *Salicion albae*)[1]**	Dynamic	Moderate–high	Low–moderate
Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	Dynamic	Moderate–high	
***Turloughs**	Dynamic	High	High

[1]Alluvial forests along river banks and flood plains, vegetation of muddy banks and tall herb communities also receive significant inputs from surface water, which influences their alkalinity and nutrients. Therefore they are less sensitive to changes in groundwater chemistry.

5.4 Validating the Conceptual Framework

The three principal environmental variables that were considered for the conceptual framework for GWDTEs were:

1. Relative groundwater contribution
2. Variability in groundwater level
3. Degree of mineralisation.

To verify the conceptual framework, these three attributes have to be measured in real terms during a monitoring programme. The conceptual framework was examined using available data from three contrasting wetlands (fen, raised bog and turlough).

These case studies are presented in Chapter 8.

6 Addressing Receptor Sensitivity within the Conceptual Framework

6.1 Introduction

This chapter is based on discussion papers prepared by the NPWS and subsequent discussions with the steering group and the authors of this report.

6.2 Receptor Sensitivity

The sensitivity of a GWDTE habitat operates on a number of different scales. The whole GWDTE has a sensitivity to groundwater pressures itself (landscape and wetland scale). Within a GWDTE, certain habitats or species will be inherently more sensitive than others (sub-wetland scale). The sensitivity of the different groundwater-dependent elements (habitats and species) within the GWDTE is influenced by pathway factors within the wetland, such as location within the GWDTE, e.g. close to groundwater discharge point, position along margin of GWDTE, depth of soils/peat. *Cladium* fen, for example, is a nutrient-poor habitat and so is sensitive to nutrient enrichment. The pathway of nutrients in groundwater to the *Cladium* fen can limit this sensitivity somewhat, as groundwater discharging through peat will allow nitrate to be attenuated *via* denitrification of the nitrate by soil micro-organisms. *Cladium* fen is often found downslope from the groundwater discharge zone and so the groundwater has a longer flow path to *Cladium* fen habitat than, for example, to alkaline fen which is more commonly associated with the immediate vicinity of the discharge zone. This chapter considers pathways within the GWDTE as a factor of receptor sensitivity. The pathway of groundwater through the catchment is considered in Chapter 7.

6.3 Assessment of GWDTE Sensitivity

Chapter 5 presented a conceptual framework for describing key characteristics of GWDTEs (see Fig. 5.3). In this chapter the validity of that conceptual framework is tested using expert judgement to place Habitats Directive Annex I habitats within the framework. By placing the habitats within the framework, the sensitivity of these habitats to groundwater pressures can be illustrated.

Twelve of the groundwater-dependent habitats listed have been placed within the conceptual framework (Table 6.1). It was decided not to apply the model to the habitat "depressions on peat substrates of the

Table 6.1. Twelve habitats from Annex I of the Habitats Directive that have been tested within the proposed groundwater-dependent terrestrial ecosystem conceptual framework.

EU Annex I Habitat (*indicates a priority habitat)
Transition mires and quaking bogs
*Bog woodland
*Calcareous fens with *Cladium mariscus* and species of *Caricion davallianae*
*Petrifying springs with tufa formation (*Cratoneurion*)
Alkaline fens
*Active raised bogs (ombrotrophic/high bog)
*Active raised bogs (lagg)
Active blanket bog
Flushes in active blanket bog and Northern Atlantic wet heaths with *Erica tetralix*
Machairs (*in Ireland)
*Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-padion*, *Alnion incanae*, *Salicion albae*)
Turloughs

Rhynchosporion", as it is generally found within other bog and heath habitats and will not be monitored for WFD purposes. We have also omitted "degraded raised bogs still capable of natural regeneration", as this is a damaged habitat which has the objective of restoration to the priority habitat 'active raised bog'; therefore the hydrogeological objectives for active raised bog apply.

Owing to the difficulty of creating a three-dimensional framework, the application of the framework to the habitats is presented as a series of one-dimensional figures (Figs 6.1–6.3). Sensitivity to changes in the nutrient status of the groundwater is also considered in this chapter (Fig. 6.4).

There are three types of Alluvial Woodland presented in these diagrams. Type 1 is found on coarse gravel deposits adjacent to the permanent river channel and has a high summer water level. Type 2 is typically dry in summer. Type 3 is associated with springs/ seepages that flow throughout all/most of the year and are often found at the edge of the flood plain where the alluvial deposits meet bedrock/subsoils.

One of the difficulties in applying the conceptual framework was interpretation of the three axes of the conceptual framework. For example, groundwater level can influence ecology in a number of different ways, and these may not be captured by the coefficient of variation alone.

For the purposes of this test, the following interpretation of the conceptual framework axes were used:

- X-axis – Relative groundwater contribution
- Y-axis – Sensitivity to changes in groundwater level
- Z-axis – Sensitivity to changes in groundwater chemistry.

These titles were considered broad enough to capture the full range of mechanisms by which groundwater influences GWDTE ecology.

6.3.1 Relative groundwater contribution

The relative groundwater contribution has been taken to represent the percentage of the water in the habitat that comes from groundwater. This can be highly variable both within sites and among sites of the same habitat type. For this reason, many of the habitats are broadly distributed along this axis (Fig. 6.1). Groundwater-dependent terrestrial ecosystems with high relative groundwater contribution, often 100%, include petrifying springs, fens, machairs and turloughs, with no riverine inputs. Groundwater-dependent terrestrial ecosystems with low or no direct groundwater contribution include bogs and certain types of bog woodland and alluvial woodland. Groundwater-dependent terrestrial ecosystems that show a large range in groundwater contribution, that varies with each individual site, are habitats such as transition mires, flushes and turloughs with riverine inputs.

6.3.2 Sensitivity to changes in groundwater level

The sensitivity to changes in groundwater level (Fig. 6.2) can also vary within sites and among sites of the same habitat type. Changes in groundwater level can influence an ecosystem's ecology through a number of mechanisms:

- **Water depth.** Increasing or decreasing the water level in the habitat will change the organisms (particularly primary producers) that can occur there.
- **Rate of flow.** For some habitats, such as petrifying springs, there is a minimum flow rate of groundwater to the habitat necessary in order for tufa to deposit.
- **Rate of change.** It is unclear whether this is a factor or not, but if the rate of change in water level could be increased, some organisms might not cope with the increased dynamism.
- **Timing of change.** The precise timing of a change in water level can be critical, e.g. in turloughs flooding in late summer/early autumn will allow insects with aquatic eggs and larvae to deposit eggs into the flood water.

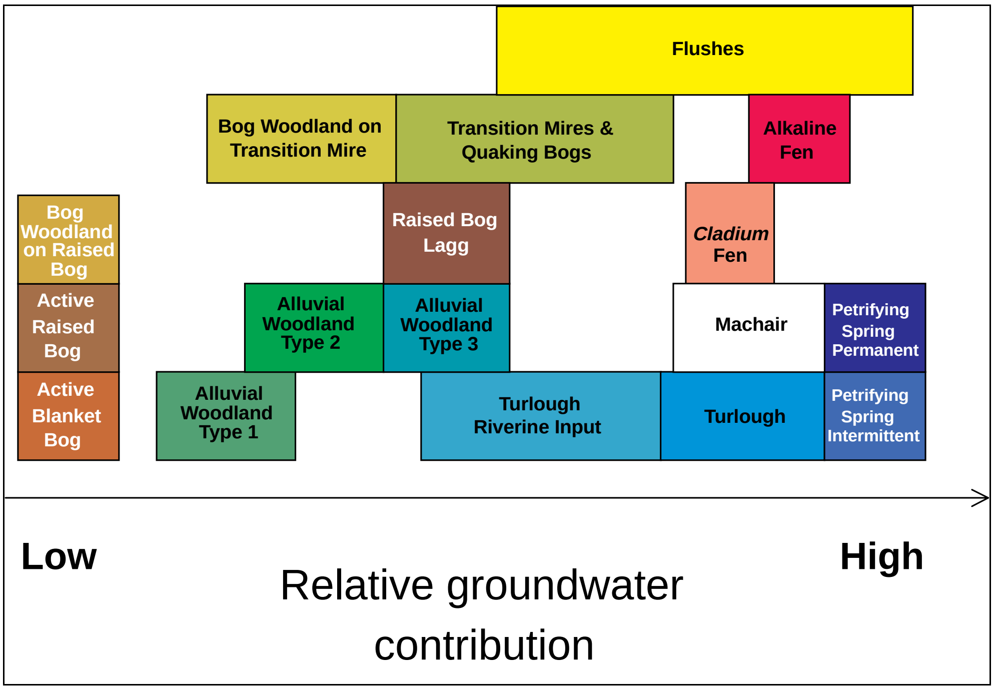

Figure 6.1. Illustration of the relative groundwater contribution (ranging from low to high) of a number of groundwater-dependent terrestrial ecosystems. This is a single axis graph (x-axis). There is no y-axis and habitats are arranged vertically for clarity only.

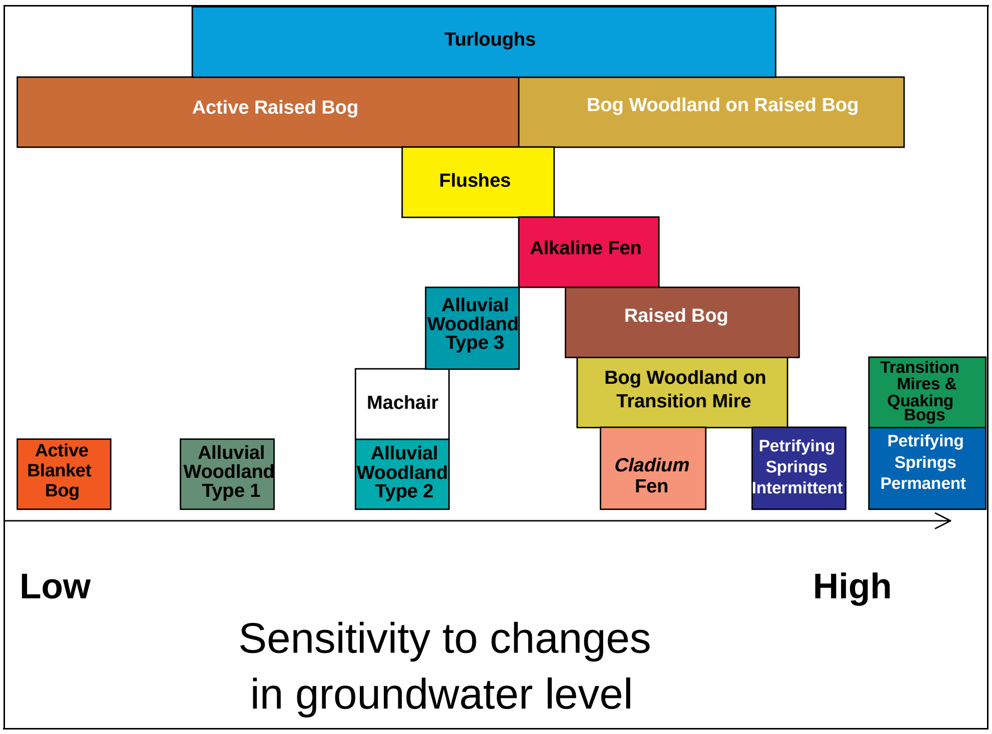

Figure 6.2. Illustration of the sensitivity to changes in groundwater level (ranging from low to high) of a number of groundwater-dependent terrestrial ecosystems. This is a single axis graph (x-axis). There is no y-axis and habitats are arranged vertically for clarity only.

- **Duration of change.** Some organisms will tolerate short-term flooding, but will be eliminated by prolonged flooding (e.g. some tree species). Other species (e.g. aquatic invertebrates in turloughs) will require a minimum flood duration.

- **Frequency of change.** Generally this will be how often a habitat floods or dries out on an annual (or sometimes longer) timescale.

- **Support function.** In many GWDTE habitats, groundwater from the aquifer may not directly discharge into the habitat but is essential in ensuring a high water level, e.g. raised bogs.

Habitats most sensitive to changes in groundwater level are those located on the right-hand side of Fig. 6.2, such as petrifying springs, alkaline and *Cladium* fens and transition mires. These are habitats that require a stable water regime and may have a high relative groundwater contribution. Habitats showing a range in sensitivities to groundwater level are those such as turloughs that have a dynamic water regime or those such as raised bogs may have an indirect input of groundwater. Habitats least sensitive to changes in groundwater level are bogs and alluvial woodland types, which have a low relative contribution of groundwater and/or a dynamic water regime.

6.3.3 Sensitivity to changes in groundwater chemistry

Those habitats to which groundwater does not discharge directly, i.e. where groundwater represents 0% of the water in the habitat, are not sensitive to changes in groundwater chemistry, such as active blanket bog, active raised bog (other than the lagg zones), bog woodland on raised bog and certain types of alluvial woodland. For other habitats, however, their sensitivity to changes in groundwater may be very complex. In assessing this, it was necessary to consider each habitat's sensitivity to changes in concentrations of both mineral requirements (e.g. calcium and associated alkalinity and pH) (Fig. 6.3) and nutrients (N and P) (Fig. 6.4). Habitats most sensitive to changes in groundwater nutrient concentrations are those with direct inputs of groundwater and are low productivity systems. The sensitivity to changes in groundwater chemistry is largely based upon receptor sensitivity, incorporating aspects of the pathway susceptibility within the habitat.

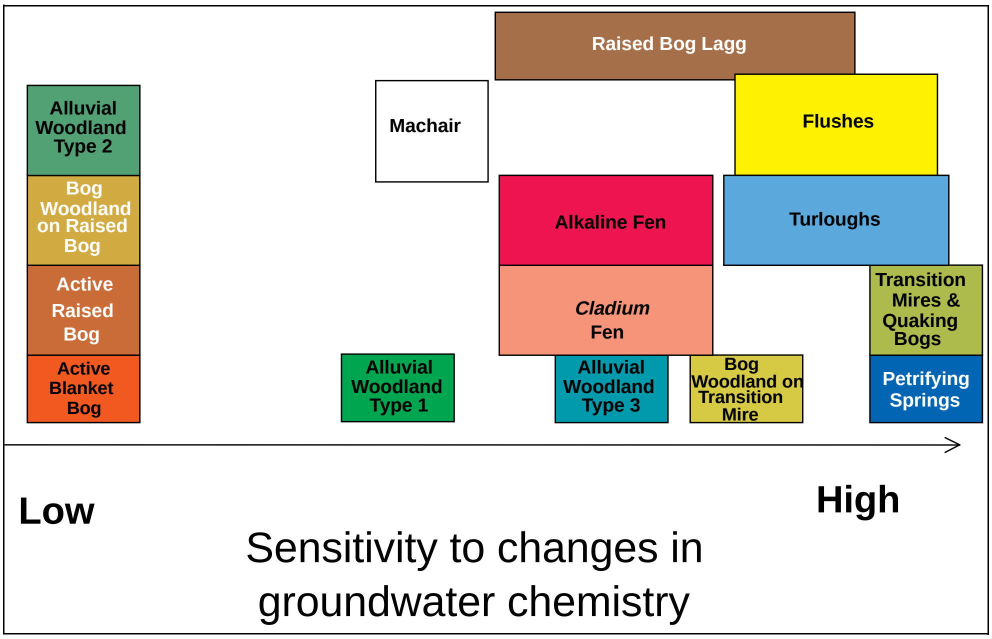

Figure 6.3. Illustration of the sensitivity to changes in groundwater chemistry (ranging from low to high) of a number of groundwater-dependent terrestrial ecosystems. This is a single axis graph (x-axis). There is no y-axis and habitats are arranged vertically for clarity only.

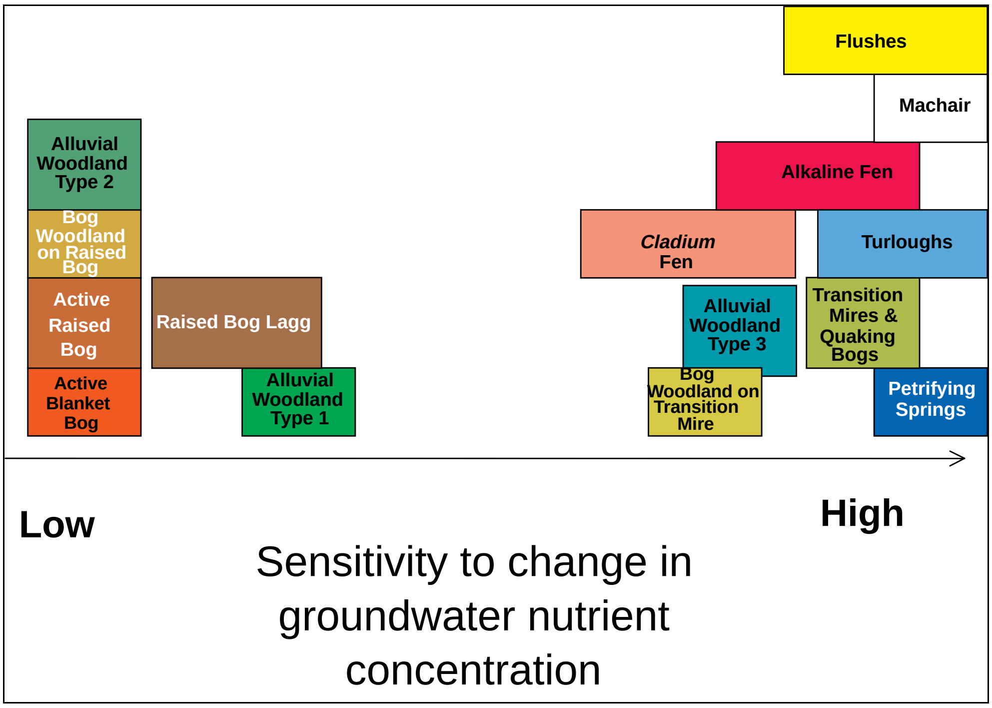

Figure 6.4 Sensitivity to changes in groundwater nutrients (ranging from low to high) of a number of groundwater-dependent terrestrial ecosystems. This is a single axis graph (x-axis). There is no (y-axis) and habitats are arranged vertically for clarity only.

Pathway susceptibility is discussed further in Chapter 7.

6.4 Conclusions

Application of the conceptual framework for the various environmental supporting conditions (groundwater level, contribution and chemistry) and consideration of the habitat's sensitivity to changes in these attributes illustrate the relative sensitivities of the GWDTE habitats.

The conceptual framework broadly facilitates the differentiation between differing sensitivities between different GWDTEs. However, the assessment also illustrates the complexity which is often present within these wetlands. A wetland may have a number of habitats with a range of sensitivities to different environmental supporting conditions. A means to address this issue is to identify the most sensitive element within each habitat and to use this for assessment using the conceptual framework.

7 Addressing the Pathway within the Conceptual Framework

7.1 Introduction

Much of modern management of environmental hazards is based on the Source–Pathway–Receptor Model. It has formed the basis for much of water management in Ireland for many years, e.g. groundwater protection schemes and contaminated land assessment. The risk concept in essence is quite simple (see Fig. 7.1).

The magnitude of risk depends on all three elements. For example:

1. If there are no pressures, there is no risk to receptors, even if there is a pathway and/or the receptor is sensitive.

2. If there is a significant thickness of low permeability subsoil (i.e. the vulnerability is low), even if there are significant pressures, the 'susceptibility' of groundwater is low and therefore the risk to receptor is low.

3. If the receptor is particularly resilient (i.e. is less sensitive), such as calcareous lakes with a buffering capacity to acidification, then the risk is diminished.

All three elements must be considered in each assessment because the nature of either element may determine the predominance of one element of the model. Phosphate, for example, typically has low mobility in soils and normally follows an overland pathway to surface waters except in situations where there are thin permeable soils and in the karstic environments. Nitrate, in contrast, is very mobile through soils and will typically follow the underground route to groundwater and then on to surface waters.

The pathway to the receptor is of particular interest to this study. The implications for designating a groundwater body are significant. The programmes of measures required to address a particular issue may be costly and potentially limit or even restrict certain activities in the contributing area. Therefore great care must be taken to ensure that there is a good understanding of the sensitivity of the receptor to particular pressures and on the nature and extent of the pathway from the pressure to the receptor.

7.2 Application of the Source–Pathway–Receptor Approach in the WFD

The application of geoscientific information, particularly hydrogeological data, in the implementation of the WFD in Ireland is comprehensively dealt with by Daly (2004). Much of this section is derived from this publication. The purpose of this section is to provide the WFD context for examining the pathway element.

7.2.1 Environmental characterisation and risk assessment

In implementing the WFD, risk assessment (for the Article 5 Characterisation of river basins) allows

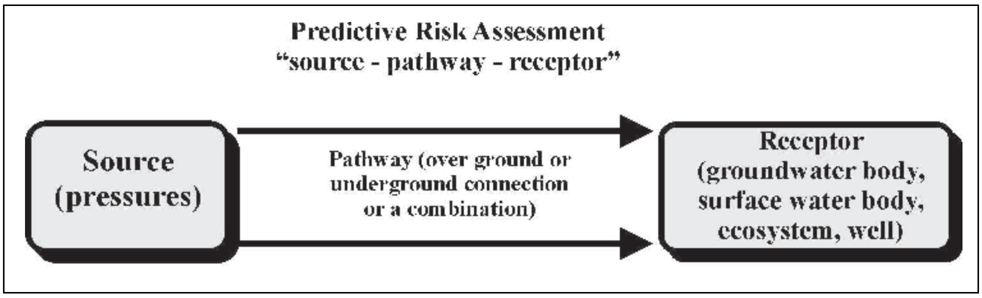

Figure 7.1. Source–Pathway–Receptor Model for managing risks to surface and groundwaters.

environmental problems to be identified, monitoring programmes to be designed, and appropriate cost-effective protection and improvement measures to be formulated and implemented. The basic unit of risk assessment is the 'waterbody' or, in the case of groundwater, the 'groundwater body', which is defined in the Directive as "*a distinct volume of groundwater within an aquifer or aquifers*". The output of the risk assessment is a list of waterbodies, including groundwater bodies, considered to be 'at risk' of failing to meet the environmental objectives of the Directive. The risk assessment approach is summarised in Fig. 7.2.

In previous applications of the Source–Pathway–Receptor approach (such as for groundwater protection schemes), typically the receptor involved was the groundwater itself as a drinking water resource. The risk assessment approach for the WFD is broader in that:

- The receptors that must be considered are not just groundwater and drinking water abstraction points, but also groundwater-dependent river and lakes and GWDTEs (see Fig. 7.3), and

- The geological pathway includes, potentially, both vertical and horizontal components to the receptors (see Fig. 7.4).

7.2.2 *Pathway susceptibility for different pressures*

In undertaking the risk assessment, taking account of the pathway is required to enable:

- Provision of the link between pressures and receptors

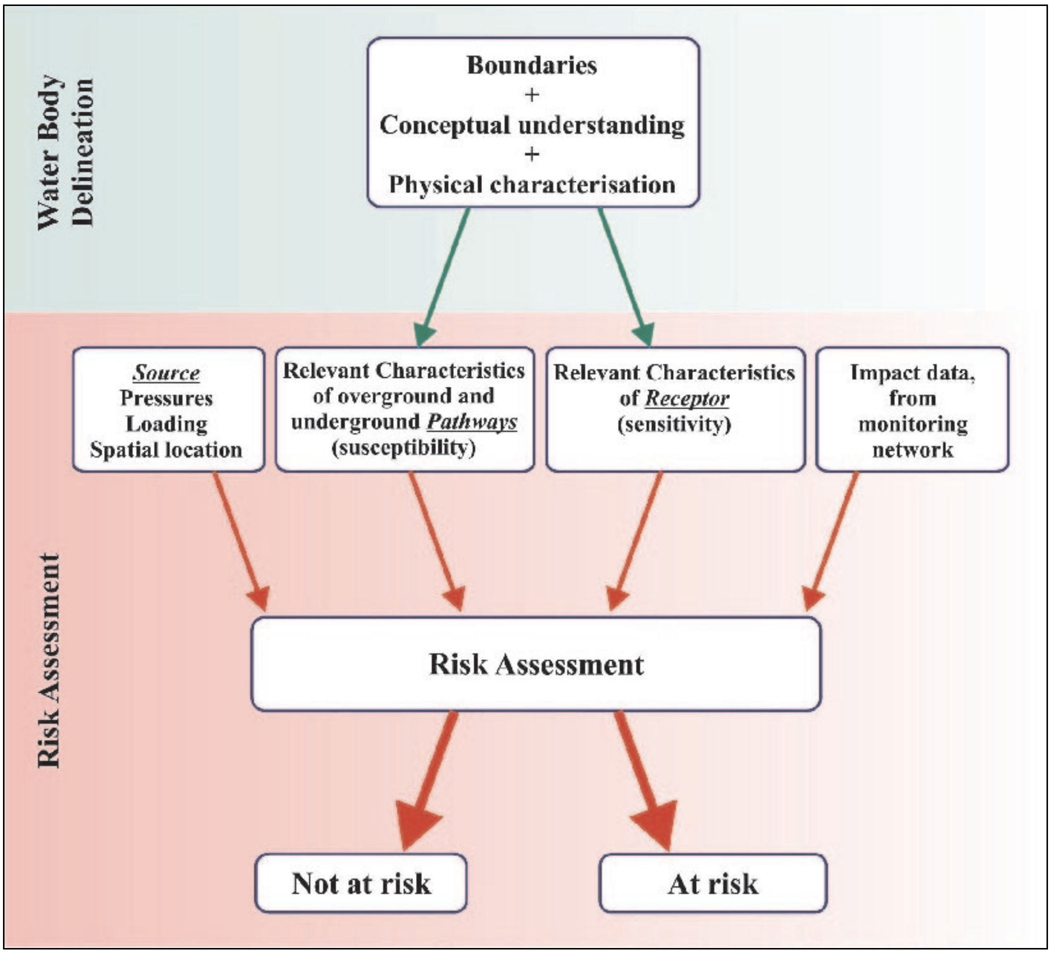

Figure 7.2. Summary of Water Framework Directive (WFD) risk assessment approach (adapted from WFD Groundwater Working Group, 2004).

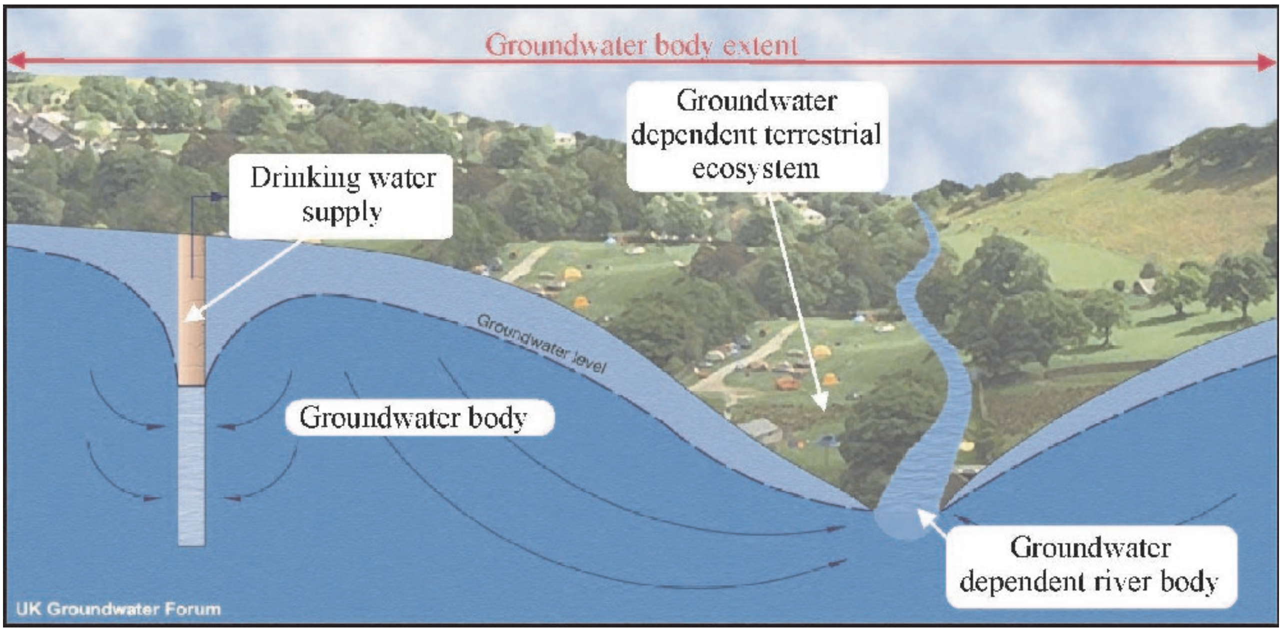

Figure 7.3. Diagrammatic illustration of a groundwater body showing the range of receptors that must be considered (adapted from NERC (Natural Environment Research Council), 1998).

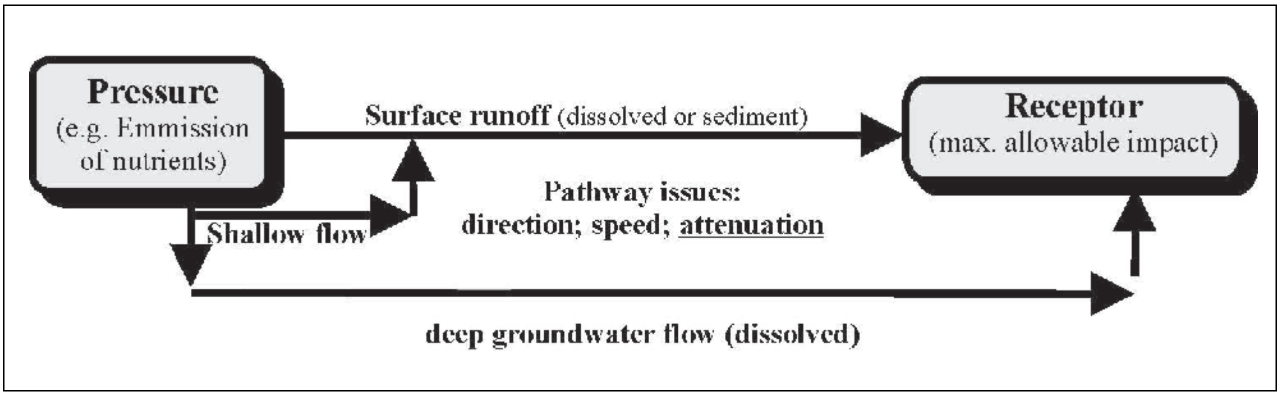

Figure 7.4. Pressure–Pathway–Receptor Model for implementation of the Water Framework Directive (Daly, 2004).

- Prediction of the likelihood of impact, where monitoring is inadequate
- A description and understanding of 'why' there could be/has been an impact
- Monitoring data to be assessed
- Monitoring networks to be designed, and
- Responses to the risk and appropriate measures to be implemented.

Pathway susceptibility is a measure of the degree of attenuation between source and receptor. It is a measure of the ability of the pathway to reduce the impact of a pressure, in terms of time to reach the receptor, pollutant load reaching the receptor, pollutant concentration level in the receptor, and duration of the pollution event. Typically, this requires the compilation and characterisation of relevant elements, such as soils, subsoils, aquifers, vulnerability and the classification of pathway information for the main pollutant types (e.g. the pathway susceptibility for nitrate and phosphate will differ).

7.3 Importance of Pathway Susceptibility to GWDTEs

The importance of understanding the pathway for pressures to reach a GWDTE cannot be underestimated. This understanding is required not only to confidently identity the source of the problem but also in the development of appropriate measures to tackle different issues. Closely linked to the pathway is the water supply mechanisms discussed in Chapter 5. They differ in that whereas the water supply mechanism focuses on the transmission of water from area of recharge to the wetland, the pathway focuses on the contaminant of concern and the nature and extent of its transport from source to receptor. It is equally important to understand both to allow for the effective management of GWDTEs.

8 Application of the Conceptual Framework to Three Contrasting Wetland Case Studies

8.1 Introduction

Three contrasting wetlands typical of the Irish environment (Pollardstown Fen, Caranavoodaun Turlough and Clara Bog) are examined in this chapter as a basis for developing a conceptual framework for managing groundwater-dependent wetlands. All three wetlands have been previously studied intensively, the water supply mechanisms are reasonably well understood and all contain priority habitats in Annex I of the Habitats Directive. Pollardstown Fen is a SAC located in Co. Kildare and situated in a sand and gravel aquifer. Caranavoodaun Turlough is wholly groundwater fed and is within a larger SAC complex located in Co. Galway and situated in a Carboniferous Limestone karst aquifer. Clara Bog is a SAC located in Co. Offaly and situated in a glacial till basin underlain by a poorly productive Carboniferous Limestone aquifer.

The relative position of the three study wetlands in this conceptual framework will be determined by their key environmental supporting conditions (see Fig. 5.3). Ideally a detailed assessment is required using available data from these groundwater-dependent wetlands to test this conceptual framework and provide a basis for their monitoring and management.

In this study, where data were available, each wetland was examined for each of the characteristics of the conceptual framework:

- The relative contribution of groundwater to the wetland
- The variability in changes of groundwater level
- The degree of mineralisation discharging to the wetland.

The locations of all three case study sites are presented in Fig. 8.1.

8.2 Pollardstown Fen

8.2.1 Geo-hydrological setting and dependent ecosystem characteristics

Pollardstown Fen is a SAC extending over 2.35 km^2, located on the northern boundary of the Curragh Aquifer (a Pleistocene fluvioglacial sand and gravel aquifer) in Co. Kildare. Groundwater from this aquifer largely maintains this wetland *via* a series of springs and seepage zones (Kuczynska, 2006). It is the largest spring-fed fen in Ireland, with approximately 40 springs providing a continuous supply of calcium-rich groundwater to the fen. These springs are located mainly at the margins of the fen, along distinct seepage areas. It is this continuous input of groundwater that maintains the fen and prevents succession to a more ombrotrophic system, ultimately developing into a raised bog.

Pollardstown Fen is designated as a SAC owing to the occurrence of a number of Annex I habitats – alkaline fen, *Cladium* fen* and petrifying springs* (*denotes priority habitats under the EU Habitats Directive) – and Annex II species (NPWS, 2007a). The three species of whorl snail *Vertigo angustior*, *V. geyeri* and *V. moulinsiana* (all Annex II species) occur in the fen, the only known Irish site where they occur together.

Some of the most sensitive receptors to groundwater pressures in the fen are petrifying springs with tufa and the snail *Vertigo geyeri*. Petrifying springs need a permanent groundwater contribution. In order for tufa to form, the discharging groundwater needs to be saturated with calcium. Given that discharge of groundwater is directly at the spring, it is also vulnerable to increases in the nutrient concentrations within that groundwater. *Vertigo geyeri* requires a stable set of environmental conditions and is extremely vulnerable to even small changes in groundwater level. It requires a certain humidity level that is determined by the proximity of the snail habitat to water, usually within 5 cm of that water (Kuczynska, 2006). Given its small

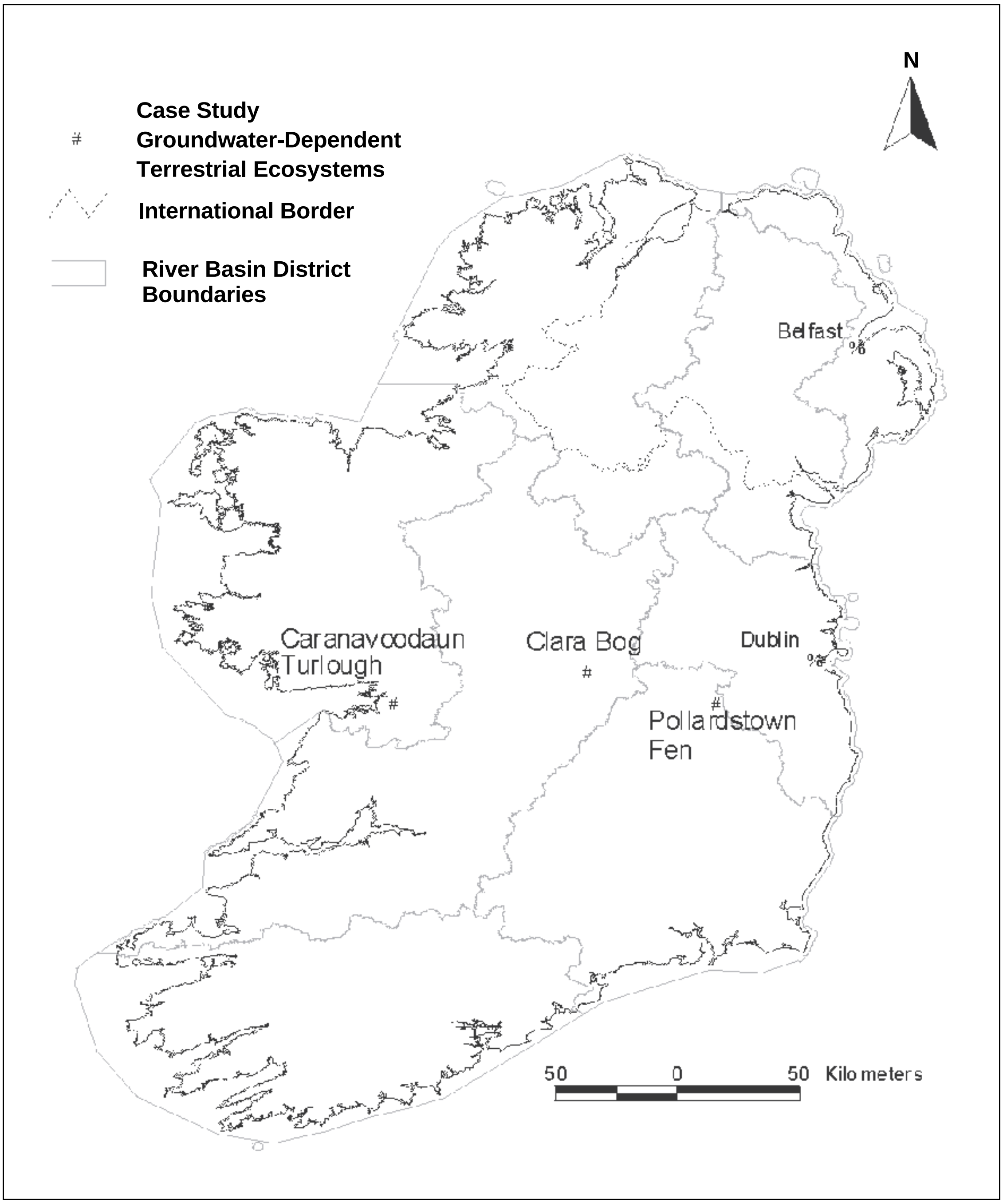

Figure 8.1. Location of the three case study wetlands to test the conceptual framework.

size, the snail has limited mobility within the fen should its environment become less favourable.

Within Pollardstown Fen, certain areas are more sensitive to changes in groundwater level and contribution than other areas. One of the most sensitive areas, known as Site A, is located along a series of seepages at the southern fen margin. This area has been the focus of a monitoring programme by Kildare County Council to detect possible impacts on the fen, following recent construction of a motorway close to the fen.

8.2.2 *Environmental supporting conditions*

The main pathway of groundwater flow to the fen is along flow lines through the sand and gravel aquifer from south to north. Some data were examined to explore the y-axis of the conceptual framework (groundwater level) in a more quantitative way as it might apply to Pollardstown Fen. Borehole MB 30 was used as it is located on the groundwater divide south of Pollardstown Fen. Therefore, changes in level at this borehole will also result in a change in the groundwater contribution being delivered to the wetland. Figure 8.2 presents the time series for MB 30.

To the south of MB 30 a motorway has been constructed which involved extensive dewatering during the construction phase. The relative contribution of groundwater to the wetland is significant, with the majority of water supply being provided by the Curragh Aquifer.

Table 8.1 presents the groundwater variability calculations for borehole MB 30. Coefficients of variation (CVs), expressed as percentages ((mean/SD) × 100), were used to express groundwater-level variability as a single value. From these data it is clear that careful consideration must be taken when choosing a time series to average and calculate CVs. Knowledge of local activities or natural hydrological events in the wetland catchment will be essential to ensure any anomalous measures of variability are avoided. It is also clear from Table 8.2 that CVs should be calculated from as long a time series as possible to account for between-year variation.

Groundwater that supplies Pollardstown Fen *via* springs and seepage lines is alkaline and extremely calcareous with mean hardness values up to 500 mg/l $CaCO_3$ (Reynolds, 2003). This supersaturated water results in the deposition of calcium carbonate tufa (petrifying springs, a priority habitat).

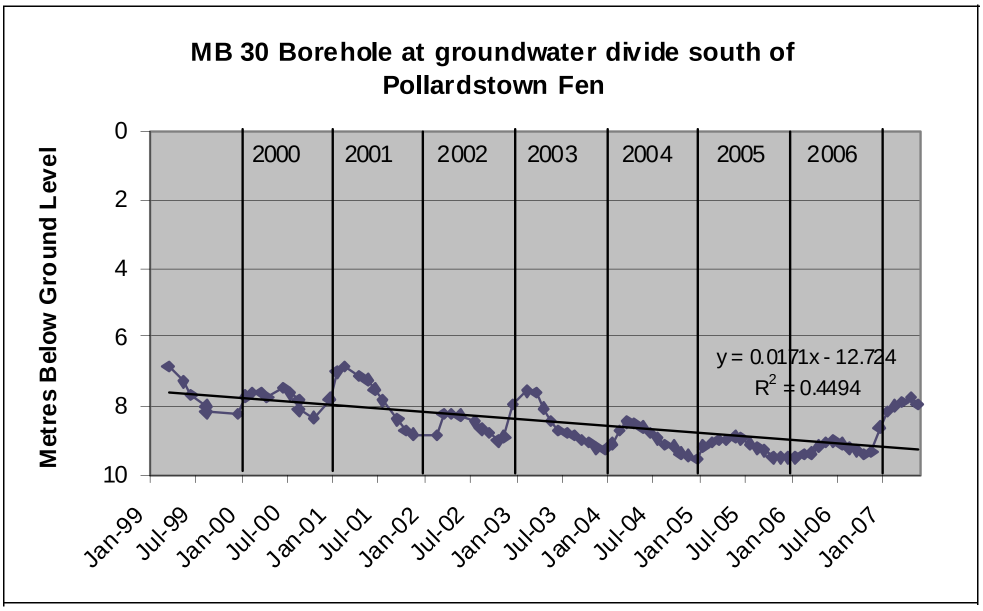

Figure 8.2. Temporal series of groundwater levels (metres below ground) at borehole MB 30 located at the groundwater divide south of Pollardstown Fen.

Table 8.1. Calculations of variability of groundwater levels at MB 30 based on data from Fig. 8.2 expressed as coefficient of variation percentages.

	2000	2001	2002	2003	2004	2005	2006	2000–2006
Average depth below ground level (m)	7.78	7.72	8.53	8.59	8.98	9.17	9.21	8.52
Standard deviation (m)	0.26	0.75	0.35	0.60	0.36	0.23	0.24	0.71
Coefficient of variation (%)	3.4	9.7	4.1	7.0	4.1	2.5	2.6	8.4

Table 8.2. Indicator properties attributed to the vegetation.

Index	Applies to:	Scale
Wetland Ranking Score (WRS)	Higher and lower plants	1: Wet 16: Dry
WRS indicator quality	Higher and lower plants	0: Good indicator 1: Bad indicator
Ellenberg F	Higher plants only	1: Dry 12: Wet
Ellenberg N	Higher plants only	1: Infertile 9: Fertile
Ellenberg R	Higher plants only	1: Base-poor 9: Base-rich

8.2.3 Vegetation monitoring in Pollardstown Fen

The data presented in this section were supplied by Natura Environmental Consultants from the draft 2006 monitoring report for Pollardstown Fen.

The fen vegetation is monitored by a number of permanent quadrats (PQs). The *Vertigo geyeri* populations are monitored in a series of transects, where the vegetation is also monitored in intensive quadrats (IQs).

The plant assemblage reflects soil wetness conditions. A chosen index of soil wetness is the Wetland Ranking Score (WRS), compiled for the Pollardstown Fen monitoring project, calculated based on higher plants and lower plants (mosses, liverworts and charophytes) but excluding plants perceived to be adapted to a wide range of soil wetness conditions (high ecological amplitude). All WRS calculations are based on tweaked WRS values weighted for abundance, i.e. a species scoring, for example, 4 has twice the effect of a species scoring 2 (Table 8.2).

Plant species cover abundance data were collected from all the quadrats and these data were used to calculate the wetness index (WRS) value for each quadrat and it was compared with the WRS values since 2001 to see if there have been significant changes. Significant changes in the 'wetness' of the vegetation were assessed by means of Levels of Acceptable Change (LAC) which were determined from the wWRS (weighted WRS) scores.

8.2.3.1 Permanent quadrat monitoring results

Over the range of PQs sampled, 17 relevés decreased in WRS, indicating wetter soil conditions between 2005 and 2006 while 10 relevés increased, indicating drier soil conditions.

Permanent quadrat 10 is located in an area where there is known to be upwelling water supplying the fen surface. It is the only PQ where all relevés have a general upward trend in WRS, indicating drying (Table 8.3).

In areas where there is not currently known to be upwelling, there are some relevés which show a

Table 8.3. Wetland Ranking Score (WRS) values for permanent quadrat 10 from 1998 to 2005, showing an increase in the WRS values, indicating a drying out of the vegetation.

PQ10	1998	1999	2000	2001	2002	2003	2004	2005
10.1	10.57	10.17		10.95	10.28	10.81	11.27	11.61
10.2	10.68	10.32		10.69	10.20	11.23	10.99	11.21
10.3	12.19	11.75		12.16	12.05	12.77	12.75	12.73
10.4	10.13	10.08		10.30	10.26	10.35	10.51	10.76
10.5	10.69	10.24		10.09	10.42	10.82	10.56	10.58

PQ10, permanent quadrat 10.

continuing upward trend indicating drying over the monitoring period, but equally some are stable, some indicate increasing soil wetness and some are more erratic without a consistent trend emerging. In general, the relevés with higher WRS values tend to fluctuate more widely and more erratically than those with lower WRS values.

8.2.3.2 *Intensive quadrat monitoring*

Plant species cover data were collected from all the IQs on Transects A, C, D and E. Five of the six quadrats at Site A continued the trend of becoming drier relative to 2005. Transect E is also on the south side of the fen and one of its two quadrats showed a decrease in wetness while the other had no significant change. On the north side of the fen at Transect C, three of the six quadrats became wetter, while at Transect D four of the six quadrats became wetter.

The wetness index (WRS) results indicate that the vegetation of Site A continued the overall trend of becoming dryer since monitoring began in 2002 (Table 8.4). The WRS values continued to exceed the limits of the levels of acceptable change within four of the six quadrats.

8.2.3.3 *Changes in plant species in intensive quadrats through the monitoring period*

Vegetation indices provide us with information on trends in increasing wetness or dryness in the vegetation. Looking at the flora to see which individual species are changing may lead to a better understanding of why the vegetation is changing. Abundance of indicator species was noted at the beginning of monitoring (2000), at the time of road construction (2003) and most recently (2006) and changes (percentage increase or decrease) are calculated. There is not an obvious uniform trend within the species. Some 'wet' species have declined since 2003, such as *Drepanocladus revolvens* and *Juncus subnodulosus*, some 'wet' species have increased since 2003, such as *Scorpidium scorpidiodes*. Some 'wet' species have increased overall since 2000, such as *Triglochin palustris* and *Cirsium dissectum*. Other 'wet' species have remained fairly constant since 2000, such as *Galium uliginosum* and *Schoenus nigricans*. Perhaps most noticeably, the moss *Cratoneuron commutatum* (which is associated with calcareous seepage springs) has decreased dramatically since 2003. In addition, there has been an overall increase in the frequency of grasses since 2000, including *Festuca rubra*, *Holcus lanatus* and *Molinia caerulea*, which suggests a drying effect.

8.2.4 *Sensitivity of receptor and implications for the WFD*

It is clear that a pressure on the groundwater body is resulting in a lowering of the groundwater levels in the aquifer feeding the fen and so the environmental supporting conditions of the most sensitive receptors in the fen are not being met. Droughts induced by climate change and construction of the motorway south of the fen may be amongst the contributing factors. This is also resulting in a lowering of the groundwater levels at the fen and thus drying out of the seepage zones along the fen margin which are critical for supporting the fen habitats and species, particularly petrifying springs and *Vertigo geyeri*. The fen is highly sensitive to changes in groundwater level, with impacts likely to the most sensitive species where there is a change in groundwater contribution of 5% or greater (Kuczynska,

Table 8.4. Weighted Wetland Ranking Score (WRS) results for quadrats within Transect A (2002–2006) indicating drying out of vegetation.

	Weighted WRS score averages				
	2002	**2003**	**2004**	**2005**	**2006**
BQ1	9.29	8.99	9.42	9.87	
BQ2	9.22	9.28	9.88	9.79	10.81
BQ3	9.29	9.79	10.67	10.44	10.16
BQ4	10.14	10.23	11.02	11.08	11.29
BQ5	9.08	8.57	9.12	8.95	9.20
BQ6	9.48	10.53	10.63	10.11	9.76

2006). Monitoring programmes have detected declines in *Vertigo geyeri* populations and changes in the vegetation, including a cessation of tufa formation in some places, as a result of changes in groundwater level variability. For this reason, the groundwater body containing Pollardstown Fen would likely be classified as being at poor status under the WFD because there is significant damage to a GWDTE. Consequently, corrective action is required through a programme of measures in the WFD river basin management plans.

8.3 Caranavoodaun Turlough

8.3.1 Geo-hydrological setting and dependent ecosystem characteristics

Caranavoodaun Turlough is approximately 0.31 km^2 in size when flooded and is part of the Castletaylor Complex SAC located in Co. Galway and situated in a Carboniferous Limestone karst aquifer. It is surrounded by hazel woodland and limestone heath and has a shallow basin containing areas of exposed limestone (O'Connor *et al.*, 2004), including a swallow hole by which it empties and fills. Caranavoodaun Turlough is entirely groundwater fed and this groundwater input is dominated by shallow epikarst flow in the top 2–5 m in the karst limestone. Castletaylor Complex SAC consists of two parts: (a) Caranavoodaun Turlough, a shallow basin at the north-western end of the site, and (b) a mix of woodland, grassland, limestone pavement and scrub.

The interest of the site lies partly in the diversity of habitats within a small area. There are five Annex I habitats present within the site, including the turlough habitat, a priority habitat listed under Annex I of the EU Habitats Directive. The site also shows the transition from wetland to surrounding habitats. Caranavoodaun Turlough itself is considered a good example of an extremely oligotrophic and calcareous turlough that is relatively undamaged.

8.3.2 Overview of the ecology of Caranavoodaun Turlough

This section provides a summary of the ecology at Caranavoodaun Turlough and is derived from data provided by Roger Goodwillie's (1992) turlough study, Southern Water Global and Jennings O'Donovan and Partners (1997) Gort flooding study, the NPWS (2007b) SAC site synopsis, and Tynan *et al.* (2007).

Caranavoodaun Turlough lies in a relatively shallow basin that rises more steeply on the northern edge than on its southern side. There is a slight rise in the centre of the turlough, where flooded limestone pavement and scrub can be found. The eastern limit of the turlough is defined by scattered rocks. A wall crosses the turlough from east to west. The turlough is lightly grazed by cattle. The upper turlough levels support buckthorn and hawthorn scrub, while in the basin there is extensive fen vegetation and marl ponds. A permanent pool occurs at the centre of the basin, from which a channel runs southward to a swallow hole. Another swallow hole is located at the western end of the turlough. There is considerable marl deposition within the turlough and also some peat accumulation.

Goodwillie (1992) described the vegetation of turloughs over 10 ha and included the vegetation of Caranavoodaun Turlough in his study. He devised 32 plant communities of turlough basins and grouped them according to position in the basin (coded 1–12, 1 being highest from turlough floor, 12 being open lake) and in terms of their trophic status (coded A–D, A eutrophic, B mesotrophic, C oligotrophic calcareous, and D oligotrophic peat). Caranavoodaun Turlough supports nine of these plant communities (Table 8.5).

The turlough vegetation is predominantly fen (proportion of turlough vegetation 0.64) and aquatic plant communities (proportion of turlough vegetation 0.33), with drier plant communities making up only a small proportion of the vegetation (0.03). Sedge fen, Community 5D, covers over half the turlough area. There are also two distinct patches of *Schoenus* fen, Community 4D, the largest of which is located along the eastern side of the turlough. This *Schoenus* vegetation gives way to scrub communities above the turlough. The north-western side has a band of tall herb vegetation, Community 3A. Marl pond vegetation, Community 9C, occupies the low ground, extending to the southern swallow hole, where there is also a band of species-poor *Potentilla reptans* vegetation, Community 5B.

Table 8.5. Plant communities of Caranavoodaun Turlough, as recorded by Goodwillie (1992).

Plant community name	Characteristic species	Plant community code	Area (ha)
Tall herb	*Phalaris arundinacea, Filipendula ulmaria, Festuca arundinacea, Vicia cracca, Lysimachia vulgaris, Thalictrum flavum, Iris pseudacorus*	3A	0.6
Sedge heath	*Deschampsia cespitosa, Molinia caerulea, Carex panicea, Carex hostiana, Danthonia decumbens, Nardus stricta, Plantago maritima, Festuca arundinacea*	3B	0.2
***Schoenus* fen**	*Schoenus nigricans, Molinia caerulea, Achillea ptarmica, Cirsium dissectum, Parnassia palustris*	4D	1.0
***Potentilla fruticosa/Frangula* scrub**	*Potentilla fruticosa, Frangula alnus, Rubus caesius, Solanum dulcamara, Polygonum amphibium*	4W	0.2
***Potentilla reptans* (species poor)**	*Potentilla reptans, Carex nigra, Carex flacca, Trifolium repens, Lotus corniculatus, Rumex crispus, Filipendula ulmaria, Viola persicifolia*	5B	0.7
Sedge fen	*Carex hostiana, Carex panicea, Succisa pratensis, Potentilla erecta, Molinia caerulea, Briza media, Schoenus nigricans*	5D	13.8
Temporary pond	*Glyceria fluitans, Agrostis stolonifera, Ranunculus trichophyllus, Myosotis scorpioides, Rorippa amphibia, Apium inundatum, Eleocharis palustris, Polygonum hydropiper, Polygonum minus*	9A	0.1
Marl pond	*Juncus articulatus, J. bulbosus, Baldellia ranunculoides, Eleocharis multicaulis, Littorella uniflora, Potamogeton coloratus, P. gramineus, Carex lepidocarpa, Scirpus fluitans*	9C	7.8
Open water	*Potamogeton natans, P. crispus, P. berchtoldii, Myriophyllum spicatum, Nuphar lutea*	12	0.1

8.3.3 Environmental supporting conditions

Depth of flooding from the base of the turlough is typically 1 m but can extend to 1.5 m. The turlough can empty and fill rapidly *via* its swallow hole as evident from Fig. 8.3. Caranavoodaun Turlough exhibits much greater variability in groundwater levels than Pollardstown Fen and based on the data in Fig. 8.3 reports a CV of 66%.

Plant (and animal) communities of turloughs have to be adapted to withstand various periods of inundation, either through persistence *in situ* during the flooded phase or by having the ability to rapidly recolonise after the water level subsides. Location of plant communities in a turlough basin have been shown to be correlated with flooding duration, in particular minimum and maximum flood durations (Tynan *et al.*, 2007).

The flood regime of Caranavoodaun is reflected in the relative 'wetness' of the vegetation as indicated by the Ellenberg value for F (moisture) of over 8 (Table 8.6). Ellenberg values of 5–7 are generally indicators of moist-damp soils but not wet soils. Values above 8 are wet site indicators, with 10 indicating shallow water sites that may lack standing water for extensive periods.

Only Communities 9A, temporary pond, and 9C, marl pond, have high F values of 9 and 10, respectively (Table 8.7), reflecting the duration of the presence of open water for much of the year in the case of the temporary pond 9A and also reflecting the wetness of the marl substrate in the case of 9C. The driest community is 3B sedge heath (Ellenberg F value of 6) which occurs on an area of higher ground and is likely inundated for the least amount of time.

The inflowing groundwater is a hard limestone water. Following flooding, turlough waters lose carbon dioxide and increase in pH, becoming supersaturated with calcium carbonate and forming a characteristic calcite deposit on the turlough floor. The trophic status of the temporary waterbodies in turloughs has received little attention to date but is the subject of a current study on nutrient and algal dynamics in turlough waters. Total

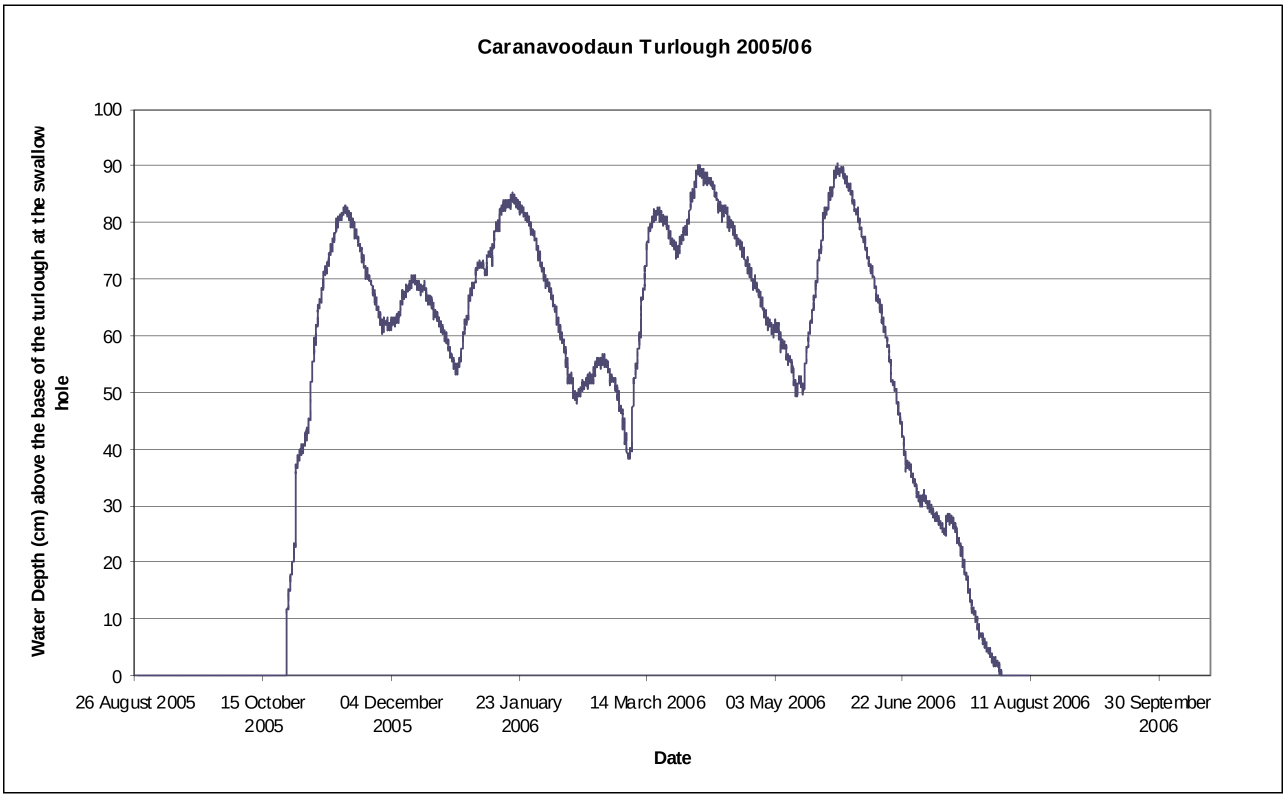

Figure 8.3. Temporal series of water depth (cm) above the base of the turlough at the swallow hole, which empties and fills with groundwater from the surrounding karst limestone aquifer.

Table 8.6. Average Ellenberg Indices for moisture (F) for plant communities of Caranavoodaun Turlough. Average values were calculated by averaging the F value for each characteristic species of each plant community. These community values were then weighted by the proportion of that community within the turlough and an average site F value obtained.

Goodwillie community	Mean Ellenberg F value based on character species for the plant communities	Weighted by proportion
3A	7.7	0.154286
3B	7.1	0.07125
4D	7.8	0.312
5B	6.1	0.18375
5D	7.4	4.234286
9A	9.1	0
9C	10.2	3.27111
Average site F value	**7.9**	**8.23**

phosphorus (TP) concentrations in Caranavoodaun Turlough in the 2006–2007 flooding season (October to April) ranged from 6 to 12 µg/l (mean 10 µg/l), placing it at the upper boundary of the oligotrophic category according to the OECD (1982) criteria for lakes (H.C. Pereira, personal communication, 2007). This mean TP concentration falls in the bottom 23% of TP values in the 22 turloughs surveyed in this year – thus the site is at the more nutrient-sensitive end of the range. Chlorophyll *a* concentrations ranged from 0.7 to

Table 8.7. Average Ellenberg Indices for nitrogen (N) for plant communities of Caranavoodaun Turlough. Community values were calculated by averaging the N value for each set of characteristic species that occurred in >10% of Goodwillie's sites. These community values were then weighted by the proportion of that community within the turlough and an average site N value obtained.

Goodwillie community	Ellenberg N	Weighted by proportion
3A	5.3	0.131259
3B	3.6	0.029385
4D	2.5	0.10209
5B	4.4	0.127273
5D	2.8	1.590692
9A	5.8	0.023821
9C	3.5	1.14275
Site average weighted		3.15

2 µg/l, falling in the bottom 27% of the 22 sites surveyed (H.C. Pereira, personal communication, 2007).

Using the plant community data from Goodwillie (1992), Tynan *et al.* (2007) in their turlough study calculated the Ellenberg Index for N for a number of turloughs including Caranavoodaun. They obtained an average N value for the site of 3.15 (Table 8.7). Ellenberg N values of less then 4 indicate infertile sites (Hill *et al*., 1999); therefore Caranavoodaun is an oligotrophic system. The most nutrient-poor communities were sedge fen (5D), *Schoenus* fen (4D) and marl pond (9C), communities that make up most of the turlough vegetation. Tall herb (3A) and temporary pond (9A) were the most nutrient-rich communities and these only account for a small proportion of the turlough vegetation. It would be expected that Caranavoodaun would be naturally ultra-oligotrophic due to its hydrology (shallow epikarst flow). The relatively high proportion of oligotrophic plant communities (i.e. low Ellenberg value for N) within the basin (0.94) also indicates that Caranavoodaun is extremely sensitive to nutrient inputs.

8.3.4 Sensitivity of receptor and implications for the WFD

By definition, turloughs are dependent on groundwater, relying on groundwater to flood the turlough annually. Both the quality of groundwater and the levels and frequency of flooding by groundwater influence the ecology of a turlough. Karst groundwater environments, where turloughs typically occur, have been identified as particularly vulnerable to pollution and can result in contaminants, such as phosphorus, being rapidly transmitted from groundwater to surface water ecosystems *via* springs (Kilroy and Coxon, 2005).

A rating system (1–3) for turlough nutrient status has been devised (WFD guidance document *Risk to Turloughs from Phosphate* available at http://www.wfdireland.ie) based on the percentage area of oligotrophic plant communities in the turlough. Turloughs rated 1 had the highest percentage area of oligotrophic plant communities (>50%) and are extremely sensitive to groundwater quality. Turloughs rated 3 are least sensitive to changes in groundwater quality, having <25% oligotrophic plant communities. Caranavoodaun Turlough was rated 1 in this classification, for both its natural and current trophic sensitivity. This assessment is consistent with the Ellenberg N values and water chemistry data presented in the previous section.

Given that Caranavoodaun Turlough has a naturally oligotrophic status, anthropogenic nutrient inputs would have a damaging effect on the turlough ecology. Therefore, whilst not currently damaged, Caranavoodaun Turlough has been classified as 'at risk' and will require measures for the contributing groundwater body under the WFD to prevent any future damage.

8.4 Clara Bog

8.4.1 Geo-hydrological setting and dependent ecosystem characteristics

Clara Bog is located in Co. Offaly and is the largest remaining example of a true midlands sub-type raised bog. It is underlain by a poorly productive Carboniferous Limestone aquifer (Daly *et al.*, 1994). Above this is a layer of glacial till of varying thickness within the basin. This till layer is overlain by a layer of lacustrine clay, again of varying thickness. In places, a thin layer of lake marl has been deposited over the clay. Before the development of ombrotrophic peat, the basin went through a fen phase and this layer of minerotrophic fen peat can be found below the ombrotrophic peat mass. The greatest peat depth is 12 m. Clara Bog is regarded as one of the most important raised bogs in the country, with well-developed hummock hollow complexes and one of the few remaining soak systems, as well as a number of rare species. Clara Bog is 665 ha in total, inclusive of cutaway sections. It was designated a nature reserve in 1986 (465 ha) and subsequently has been designated a SAC for the presence of active raised bog and bog woodland habitats, both priority habitats under the EU's Habitats Directive.

Clara Bog has suffered much damage – a third of the bog has been lost to peat cutting, a road built in the 18th century bisects the bog into Clara East and Clara West and an extensive network of drains was installed in the 1980s. More recently, a programme of research has been undertaken on Clara Bog and restoration measures implemented to offset some of the damage. The bog remains threatened, however, by turf cutting on its southern margins, particularly where the groundwater table has been lowered. In the 1990s, this resulted in severe subsidence on Clara Bog West.

8.4.2 Environmental supporting conditions

Hydraulic conductivity in the acrotelm for Clara Bog has been measured as typically >25 m/day and for the catotelm as low as 10^{-5} m/day (Daly *et al.*, 1994). Hydraulic conductivity measurements and potentiometric mapping indicate that the bog is relatively independent of the regional groundwater flow system. However, at the fringes of the bog (lagg zone) there is evidence of mixing of upwelling groundwater flow and surface water run-off from the bog. Groundwater plays two distinct roles in Clara Bog. Firstly, the regional groundwater has a support function for the whole raised bog, even though it may not directly influence the plant communities. Secondly, the lagg zone is where the vegetation is directly influenced by groundwater upwelling.

8.4.3 Overview of the ecology of Clara Bog

The vegetation of Clara Bog has been described in detail by Kelly and Schouten (2002) in their studies on Irish raised bogs. There are three main areas from where the vegetation has been described – the high bog, the soaks and the lagg/cutaway. Plant communities have been given local names according to their dominant or characteristic species, differentiated on the basis of differential species into sub-community, variants, sub-variants and associations, the latter based on dominant species. Where a number of plant communities occur with similar abiotic factors, they have been grouped into ecotopes. The high bog comprises the dome of ombrotrophic peat. It is composed of two layers – the acrotelm, or living surface layer, and the catotelm, the mass of peat below. In an intact raised bog system, the ombrotrophic peat is removed from the influence of groundwater and receives all its inputs from precipitation. The soak systems in Clara have been shown to be rheotrophic and dependent on the lateral movement of water through the acrotelm. The regional groundwater, however, is vital in maintaining high water levels in these soak systems and in the whole bog.

Kelly and Schouten (2002) identified 15 plant communities (as well as a number of variants and sociations) of the cutaway and lagg margins of Clara and Raheen Bogs. Certain of these communities can be considered as relict lagg vegetation and the species composition reflects the influence of groundwater. The cutaway/lagg plant communities have been grouped into five ecotopes based on degree of groundwater influence and wetness. Analysis of hydrochemistry from studies on Clara Bog, particularly the variables conductivity, calcium (Ca) and pH showed a clear variation between plant communities and resulted in three groupings:

1. Communities of cutaways – low pH, low Ca, low conductivity (wet and dry types)

2. Intermediate communities – high pH, intermediate conductivity and Ca (wet and dry types)

3. Lagg communities – high pH, high conductivity, high Ca (an indication of groundwater) but variable water table.

Communities in grouping 3 would form the core of the lagg vegetation. However, the hydrological conditions are not typical of intact lagg, so the question remains whether they formed part of the original lagg or are derived from peat cut to groundwater level.

Lagg zones are a component of intact raised bogs and comprise a band of poor fen encircling the bog dome. This lagg zone receives water both from groundwater and surface run-off from the bog. It is this mixing of water that results in a mesotrophic, poor fen habitat. The relative contribution of the groundwater to a lagg zone plant community is reflected in its hydrochemistry and the plant species complement. Today, there are no raised bogs in Ireland with intact lagg vegetation. Pockets of relict lagg communities have been identified around the margin of Clara Bog, principally along its northern edge. Since extensive turf cutting has taken place along the margins of Clara Bog, the relict lagg communities are found in mosaic with plant communities of cutaway.

8.4.4 Subsidence in Clara Bog

An intact raised bog has a convex peat dome. Where damage results in increased water loss, the peat, which is over 95% water, can shrink (subsidence). In extreme cases, this leads to the development of a concave shape. Such a process has occurred at Clara Bog over a period of several hundred years. In the 1990s the rate of subsidence accelerated sharply on Clara Bog West. Given the rapidity and scale of subsidence (with a decrease of over 1 m at the southern margin and over 25 cm up to 600 m into the bog), it was suspected that a lowering of groundwater levels had caused the subsidence rather than other typical local causes of subsidence such as fire or surface drains. Investigations showed that on the southern margin deep drains in the mineral soil, installed to facilitate turf cutting on Clara Bog, have lowered the groundwater table. This lowering of the groundwater table resulted in loss of water from the catotelm into underlying mineral layers. A chain of events was initiated, with the peat mass compressing from the base of the catotelm and hence subsidence was observed at the surface (Fig. 8.4) (ten Heggeler *et al.*, 2004).

The consequence of such subsidence is a change in water flow patterns across the acrotelm, which threatens the viability of the western soak and Shanley's Lough. The soaks are important ecological features of Clara Bog, dependent on lateral flow of water through the acrotelm. Other impacts of subsidence include increases in slopes and shorter flow paths, both of which influence the plant communities and ecology of the high bog.

8.4.5 Sensitivity of receptor and implications for the WFD

Subsidence in the 1990s due to turf-cutting drainage has had a major impact on Clara Bog West and it is estimated that where the bog surface gradient is more than 0.3 m/100 m the acrotelm becomes damaged and the bog has not been functioning properly either hydrologically or ecologically in these areas (Daly *et al.*, 1994). Geological and hydrogeological studies indicate that the bog is relatively independent of the regional hydrology because of the low hydraulic conductivity of the deeper peat layers (catotelm). However, in the longer term, compaction of the basal peat layers could occur if the regional groundwater levels drop significantly (Schouten, 2002).

The high bog relies on regional groundwater to support high water tables in the bog. Deepening of drains to groundwater level along the southern margin of Clara Bog resulted in loss of water from the base of the catotelm into its underlying mineral layers. The subsequent shrinkage of the peat mass has implications for the physical structure of the high bog (change from convex to concave shape) and hence an alteration in the surface flows of water. This has implications for (a) the rheotrophic soak systems,

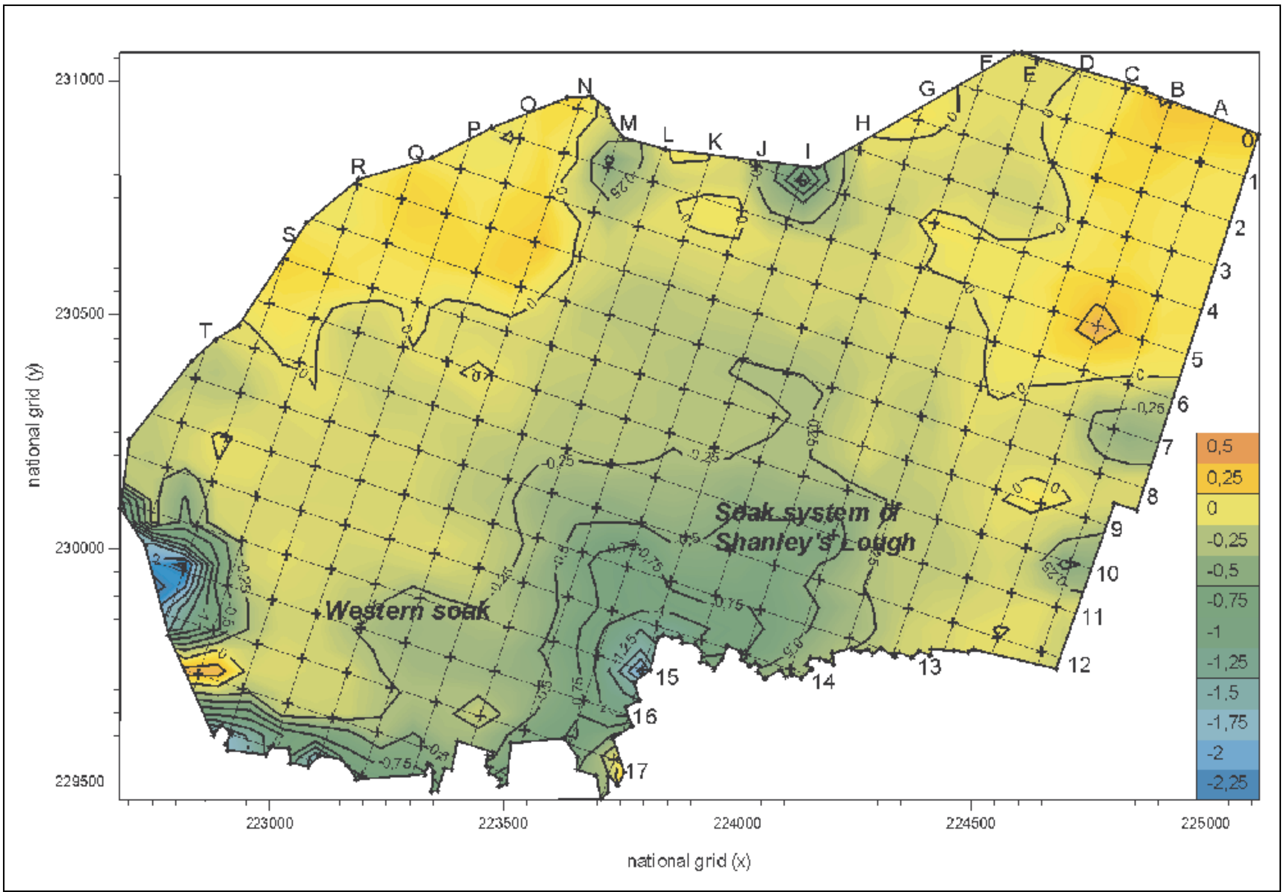

Figure 8.4. Subsidence (m) between 1991 and 2002 with co-ordinates of the national and the local grid. The values >1.50 m in the south and south-west are caused by two grid points, which lay on the bog in 1991 and in the cutaway in 2002 (from ten Heggeler *et al.*, 2004).

which rely on water inputs from surface flows and now have these flow paths threatened, and (b) plant communities of the high bog that rely on long flow paths and a relatively stable water table to maintain their ecology.

The lagg zone depends strongly on groundwater and can be significantly impacted by surrounding hydrological conditions. For example, the lagg zone north of the bog, which is bordered by permeable esker deposits, has been impacted by arterial drainage of the River Brosna to the north. Lowering of the river water level resulted in increased groundwater flow to the river and away from the lagg zone.

Under the WFD, whilst the surrounding groundwater body may not be contributing significantly to the water supply of the bog, measures may be required to ensure that its supporting function is not impaired and remedial measures for the lagg zones will be required. Detailed topographic surveys of the bog will be required to monitor the ongoing subsidence issue.

8.5 Discussion and Conclusions

The proposed conceptual framework for assessing the environmental supporting conditions of GWDTEs is being developed and tested using data from the three study wetlands. Based on the available data, the relative environmental supporting conditions for specific habitats of the three study wetlands are presented in Fig. 8.5.

The location of these habitats within the conceptual framework highlights their key hydrogeological and hydrochemical conditions and thus informs monitoring and management priorities. For example, Caranavoodaun Turlough requires much greater variability in groundwater levels than the other two

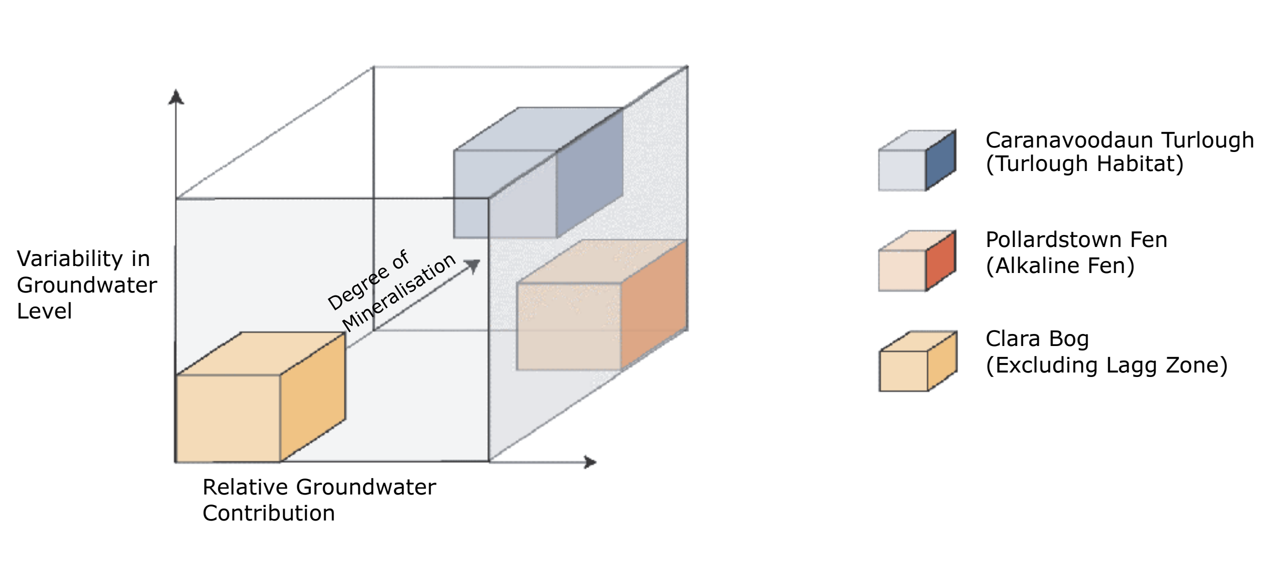

Figure 8.5. A proposed conceptual framework indicating the main environmental supporting conditions for specific habitats in the three groundwater-dependent terrestrial ecosystem case studies.

habitats, which require more stable groundwater level conditions. Pollardstown Fen needs a significant groundwater contribution, stable levels and groundwater quality that is base-rich to ensure that the alkaline fen characteristics are maintained. The high bog element of Clara Bog has the lowest overall groundwater contribution; however, regional groundwater still has a role in supporting water levels within the bog. The lagg zone element of this habitat will require much greater direct groundwater inputs.

The environmental supporting conditions required by different GWDTEs will dictate different monitoring and management strategies. The hydrogeological monitoring of raised bogs may focus particularly on the lagg zones that fringe the bogs whereas fens are more directly dependent on groundwater and require monitoring along the flow lines to the supply points. The hydrogeological monitoring needs of turloughs will vary depending on the degree and nature of karstification, the presence of epikarst and connectivity to surface water sources. Monitoring will need to take into account the complexity of each wetland, thereby providing key indicators of the habitat's sensitivity to groundwater inputs. In parallel, ecological indicators need further development and correlation with these hydrogeological indicators.

Progress has been made to develop assessment approaches that specifically address the requirements of the WFD; Rodríquez-Rodríquez and Benavente (2007) used a hydro-morphological and water balance approach for wetlands in Southern Spain and Dahl *et al.* (2007) have developed a groundwater–surface water interaction typology for riparian wetlands in Denmark. Hinsby *et al.* (2008) have also developed chemical threshold values in groundwaters related to ecological criteria in some coastal groundwater-dependent ecosystems. Different wetland types will require different assessment and monitoring approaches. However, common to all will be the necessity to identify the key environmental supporting conditions required to maintain these habitats in a favourable condition.

Further work is needed to characterise significant damage in different GWDTE types due to different pressures in the contributing groundwater body. In particular, it is necessary to identify relevant sensitive species within each wetland type and their relationship with the corresponding hydrogeological and hydrochemical characteristics. The development of groundwater threshold values which relate to ecological criteria for different wetland types will be essential for future classification of groundwater bodies and to ensure protection of dependent ecosystems. A significant monitoring effort will be required to develop understanding of the relevant pathways for water and contaminants to GWDTEs during the early stages of the WFD river basin planning process. As knowledge gaps are addressed and understanding of groundwater–surface water interactions improves this monitoring effort may be reduced. Progress has been made concerning the integration of wetlands into the WFD implementation process; however, further work is needed to improve understanding of the relationship between the biotic and the hydrogeological/hydrochemical characteristics of GWDTEs.

9 Monitoring and Assessment of Groundwater-Dependent Terrestrial Ecosystems

9.1 Introduction

Detailed monitoring data are only available for a few GWDTEs, mainly as a result of research projects or planning issues. These sites, such as those described in the case studies, provide a basis for informing the location of monitoring sites in other less well studied sites. For the first river basin management plan, it is recommended that the key aims of the GWDTE monitoring programme are to:

- Improve understanding of GWDTEs through the detailed monitoring of a limited number of representative wetland types, including impacted and pristine sites
- Refine the conceptual framework model to allow for more general roll-out of GWDTE monitoring in subsequent river basin cycles
- Develop key indicators of significant damage for the most groundwater-dependent wetland types.

9.2 Approach to Prioritisation of Sites for GWDTE Monitoring

This section is based on advice from the NPWS and the UK TAG guidance documents.

Because of limited time and resources available, the first objective is to prioritise sites for assessment based on available data. Prioritisation will be based upon:

- Significance of a site with respect to its conservation designation (initially SACs with GWDTEs as qualifying interests (QIs))
- Within the SACs, sites will be further prioritised using the following:
    - Site condition – consideration of known damage or potential for damage where groundwater quantity or quality may be a factor
    - Outcome of the Article 5 risk assessment results of the groundwater body
- Receptor sensitivity – sensitivity of the habitat or species to pressures on groundwater quality and/or quantity:
    - Sensitive receptors within the GWDTE may be further prioritised based on pathways, e.g. vulnerable springs on the margin of a fen, distance from groundwater discharge point, attenuation of pollutants *via* soils and vegetation.

9.2.1 Prioritisation based on conservation designation

Initially, work will concentrate on SACs because of their international importance and the mandatory requirement that their water requirements are met during the implementation of the WFD. A similar requirement applies to the Special Protection Areas (SPAs) but work on these cannot commence until their QIs are formally identified. Work on NHAs and Non-SAC Nature Reserves will begin when designation of these networks is further advanced and the necessary information on their QIs becomes available. Within SACs, sites can be further prioritised.

9.2.2 Prioritisation based on site condition

Sites can be prioritised based on the SAC site condition. Unfortunately there is very little baseline or monitoring information currently available on which to base such decisions. In future when such information becomes available it will allow prioritisation to occur along the lines outlined in Table 9.1. For SACs, where such information is available and where they are reported to be in unfavourable conservation status or unfavourable condition, there may be some indication as to whether the recorded damage could be related to groundwater factors. Such sites should be prioritised for assessment. Those sites where damage caused by groundwater-related factors is known should be used as calibration sites for testing methodologies developed during the project and an appropriate programme of measures instigated to offset damage.

Table 9.1. Prioritisation for significant damage assessments for Republic of Ireland (where information on the condition of groundwater-dependent terrestrial ecosystems in designated sites is available).

Conservation designation	Priority ranking			
	Damaged (cause unknown)	Maybe damaged (cause unknown)	Not damaged (groundwater dependent & groundwater pressures)	Not damaged (water source unknown, groundwater pressures)
International SAC or SPA	1	2	3	4
NHA or Nature Reserve	5	6	7	8

SAC, Special Area of Conservation; SPA, Special Protection Area; NHA, Natural Heritage Area.

Those sites that are definitely not damaged, based upon ecologists' expert opinion and/or monitoring and where no groundwater pressures have been identified, should not be further assessed at this stage unless they are being assessed as reference sites.

9.2.3 *Prioritisation based on risk assessment to the groundwater body*

As stated above, the number of sites where condition information is available is very limited and at the present time a more useful approach is to prioritise GWDTE SACs based on the risk assessments for their associated groundwater body. To date, a total of 48 GWDTE SACs have been identified in groundwater bodies considered to be 'at risk or 'possibly at risk'. These sites can be further prioritised by looking more closely at the intensity, location and nature of the risk, the presence of a pathway and its ability to transmit the pressure to the receptor and the receptor sensitivity to the particular pressure.

9.2.4 *Prioritisation based on receptor sensitivity*

A desktop analysis of the QIs of each SAC has been undertaken for groundwater dependency (using an agreed list of groundwater-dependent habitat and species indicators). This list contains 272 SACs. This list of QIs can be further reduced based on the sensitivity of each QI to groundwater-related impacts, which reduces the number of SACs to 184. These can be further prioritised based on relative sensitivities between the remaining QIs (Table 9.2).

For those SAC GWDTEs with several QIs the most sensitive will be used to determine their priority for assessment. In relation to those QIs which have a range of possible sensitivities (e.g. low–high) it is essential that at least some with potentially high sensitivities are assessed. It is essential that examples of all GWDTE priority habitats are included. Ideally, for completeness, it would be desirable that all QIs with at least moderate sensitivity were present in the sites assessed.

9.3 Summary of Prioritisation for Monitoring

To summarise the above sections, sites will be shortlisted on the following hierarchical basis:

1. SACs with GWDTE or species, further prioritised based on:
    2. Site condition and risk assessment results, and further prioritised based on:
        3. Sensitivity of their QIs (habitats or species) to changes in groundwater quantity or quality.

Therefore, a list of sites for a monitoring programme will be drawn up based upon:

- All SAC sites connected to groundwater bodies which are considered to be at risk or probably at risk (48 sites)
- Any SAC sites considered by the NPWS to be damaged by groundwater-related problems will be included.

To establish reference conditions, good-quality SAC sites connected to groundwater bodies not at risk should be considered; these can be prioritised based on the groundwater sensitivity of their QIs (habitats or species), starting with those given the highest rating for sensitivity to changes in groundwater quantity or quality. Sites selected on the hierarchical basis

Table 9.2. Ranking for groundwater-dependent terrestrial ecosystem EU Annex I Habitats and Annex II Species according to their sensitivity to changes in groundwater level and groundwater quality, where 1 = most sensitive, 4 = least sensitive. Ranking based on expert judgement (National Parks and Wildlife Service) (*indicates priority habitat).

EU habitat/ species code	Priority ranking groundwater level	Priority ranking groundwater quality	EU Annex I habitat/Annex II species name
2190	1	1	Humid dune slacks
21A0	1	1	Machairs (*in Ireland)
7220	1	1	*Petrifying springs with tufa formation (*Cratoneurion*)
1013	1	1	*Vertigo geyeri*
1393	1	1	*Drepanocladus vernicosus*
1528	1	1	*Saxifraga hirculus*
7210	1	2	*Calcareous fens with *Cladium mariscus* and species of *Caricion davallianae*
7230	1	2	Alkaline fens
8310	1	2	Caves not open to the public
7140	1	3	Transition mires and quaking bogs
91D0	1	4	*Bog woodland
7110	1–4	2–4	*Active raised bogs
7120	1–4	2–4	Degraded raised bogs still capable of natural regeneration
7130	1–4	2–4	Blanket bog (*if active bog) (flushes)
3180	2	1	*Turloughs
1014	2	2	*Vertigo angustior*
1016	2	2	*Vertigo moulinsiana*
91E0	3	2–4	*Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-padion*, *Alnion incanae*, *Salicion albae*)
6430	3	3	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels
3270	3	4	Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation
4010	4	2	Northern Atlantic wet heaths with *Erica tetralix* (flushes)

outlined in 1 to 3 above should try to include examples of all priority GWDTE habitats.

9.4 Site Management

The impacts of local site management may need to be separated out from groundwater influences on the site. Local site damage in a GWDTE that is a SAC, for example inappropriate burning, grazing or on-site drainage, is dealt with under the terms of the Habitats Directive, not the WFD.

9.5 Approach for Monitoring and Assessing GWDTEs for First River Basin Plans

A prescribed approach to monitoring is not possible or desirable for GWDTEs because differences can be so great between and within different wetland types. The conceptual framework should be used to identify the key environmental supporting conditions, which can be used to inform the initial monitoring programme. Intensive monitoring will likely be required initially but once the main environmental supporting conditions and key indicator species are identified and a conceptual model developed, the monitoring effort should reduce.

Given the lack of baseline data for the full range of Irish GWDTEs, there would be little merit in establishing a comprehensive GWDTE monitoring programme at this stage. It would be prohibitively expensive and run the danger of collecting spurious data. Greater emphasis should be given to developing our understanding of the relationships between hydrogeological and ecological characteristics. For this reason, it is recommended that a small number of GWDTEs, representative of the main wetland types in Ireland, are chosen for monitoring in the first river basin cycle. An overall approach for assessing GWDTEs is presented in Fig. 9.1. A key element of this approach is a detailed evaluation of each site to identify its environmental supporting conditions within the conceptual framework described in Chapter 5, which can then be used to develop appropriate monitoring programmes. This will facilitate more intelligent and cost-effective monitoring and allow for more effective measures to be put in place.

The emphasis is on developing understanding of the relationships between hydrogeology and ecology within the context of groundwater body classification and river basin management. The prioritisation approach presented above should be adopted for each RBD and, in discussion with relevant staff in the NPWS and EPA, candidate sites should be identified for monitoring in the first river basin management plans.

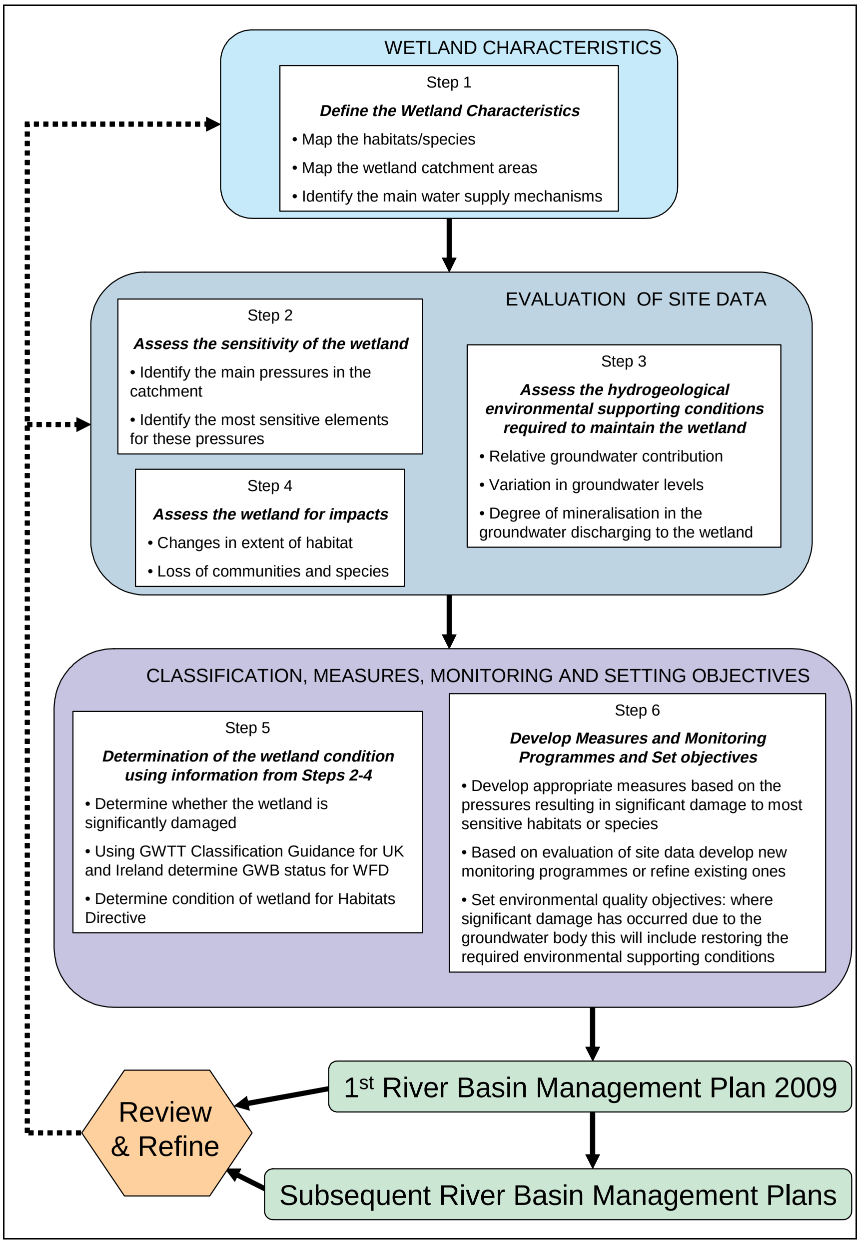

Figure 9.1. Overall strategy for assessing groundwater-dependent terrestrial ecosystems under the Water Framework Directive.

10 Conclusions and Recommendations

10.1 Conclusions

This project attempted to map groundwater-dependent habitats and species within a selection of SACs and to develop and test a conceptual framework for the assessment of GWDTEs for the WFD. Forty-eight GWDTEs were mapped during the project and the locations of 16 *Vertigo* sites were also compiled. Further mapping is required for SACs that were not prioritised during this project, particularly coastal ecosystems. Further work is required to clarify or confirm the location of certain GWDTEs such as transition mires, for example, and this may require new field mapping data. The mapping exercise was relatively crude and refinement of the GWDTE locations mapped to include buffer zones and zones of contribution would be desirable. Intensive within-site mapping would also be desirable in the future, for example to identify the most sensitive receptors within the GWDTE, and would inform understanding and management of the habitat.

Progress has been made in establishing the principles of the conceptual framework and in examining the data requirements to apply this framework to contrasting groundwater-dependent wetland case studies. Scale was identified as a key factor when developing a conceptual framework for GWDTEs. Three examples of contrasting wetland types in Ireland (raised bog, fen and turlough) were examined to determine their environmental supporting conditions. Water supply mechanisms were investigated and the hydrogeological and hydrochemical characteristics required to maintain these habitats in a favourable condition were also examined. Variability in groundwater level, groundwater chemistry (degree of mineralisation) and relative groundwater contribution were identified as key metrics of environmental supporting conditions for GWDTEs. An initial assessment was carried out to ascertain whether the wetlands are significantly damaged due to anthropogenic pressures on the associated groundwater body. The proposed conceptual framework can provide a useful basis for developing individual site conceptual models and in assisting in the development of programmes of monitoring and of measures. However, further demonstration testing is required on other wetland types using hydrogeological and ecological field data.

Given the lack of baseline data for the full range of Irish GWDTEs, it is recommended that a small number of GWDTEs, representative of the main wetland types in Ireland, are chosen for monitoring in the first river basin cycle. This will facilitate the development of understanding of the relationships between hydrogeology and ecology within the context of groundwater body classification and river basin management for different GWDTE types. As knowledge improves the monitoring programme can be broadened to include a wider number of wetland types. Candidate GWDTEs should be identified for monitoring in the first river basin management cycle through adopting the prioritisation approach presented in Chapter 9 and in discussion with relevant staff in the NPWS and the EPA for each RBD.

10.2 Recommendations

On a general note, significant benefits can clearly be accrued through the collaboration between ecologists and hydrogeologists, allowing a more holistic understanding of GWDTEs. Further efforts are needed to bridge the gap between the two disciplines, particularly with respect to developing a common understanding on terminology and issues of scale (landscape, wetland, habitat, micro-habitat). However, the experience from this project is that these issues are not insurmountable and that a continued interdisciplinary approach is essential for progress in developing GWDTE understanding.

The sections overleaf provide the details of the main recommendations for further work on GWDTEs concerning baseline data issues, assessment issues and research priorities.

10.2.1 Baseline data issues

Much further work is required on locating the boundaries of GWDTEs. Verification is also required on the sites delineated during this project. A significant number of GWDTEs in SACs are outstanding (e.g. coastal sites were not assessed). Only a limited assessment of actual hydrogeological data was achieved within the scope of the project. More detailed assessment of these data is required to refine the conceptual framework and better link with ecological indicators. More baseline field ecological data are required to accurately map and characterise these GWDTEs and, in tandem, the hydrogeological characteristics should be described, encompassing in both cases the natural variation of the GWDTE types. The development of indicator species is at a very early stage. Some preliminary species have been identified for fens, but this type of work needs to be rolled out for all Annexed GWDTE habitats. All indicator species need to be field verified and correlated with hydrogeological parameters. Ellenberg values for vegetation communities provided some indication of expected environmental conditions for the studied habitats. It would be desirable, however, to develop and field verify baseline Ellenberg values for all GWDTEs and relate these to corresponding hydrogeological values.

10.2.2 Assessment issues

The conceptual framework provides a starting point for the development of the ecological and hydrogeological assessment of GWDTEs; however, individual conceptual models will need to be developed for each wetland and verified with field data. It is envisaged that the establishment of a GWDTE monitoring programme will provide useful data (ecological and hydrogeological) that will contribute to the understanding of the structure and functioning of GWDTEs and their management. Monitoring methodologies will evolve and can be modified as the programme progresses.

Thresholds of significance to measure change in ecological and hydrogeological parameters are required to prioritise sites for monitoring and programmes of measures. In particular, thresholds are required for defining receptor sensitivity to particular pressures and subsequent quantification of significant damage.

The original Article 5 risk assessment for GWDTEs will need to be revisited by the RBDs based on the conceptual framework and GWDTE location mapping outlined above. In particular, the catchment areas need to be re-examined to ensure that they accurately delineate the contributing area to the dependent wetland.

10.2.3 Research priorities

Integrated research combining the disciplines of hydrogeology, hydrology and the ecological sciences should be encouraged to develop our understanding of the environmental supporting conditions of groundwater-dependent ecosystems. The new Groundwater Directive (2006/118/EC) provides a legislative basis for this research by stating in Article 20:

"*Research should be conducted in order to provide better criteria for ensuring groundwater ecosystem quality and protection. Where necessary, the findings obtained should be taken into account when implementing or revising this Directive. Such research, as well as dissemination of knowledge, experience and research findings, needs to be encouraged and funded*".

Therefore, it is recommended that, in parallel with progressing the baseline and assessment issues described above, research is undertaken to identify and characterise the environmental supporting conditions of the full range of GWDTEs.

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An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

National Development Plan 2007 - 2013

The EPA's Environmental Research Centre (ERC) was established as a centre of excellence under the National Development Plan (NDP) to build capacity in environmental data handling, modelling, assessment and guidance. The objective of the ERC is to allow for a more structured approach to environmental research, through the development of advanced innovative techniques and systems to address priority environmental issues and thereby support environmentally sustainable development.

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

ENVIRONMENTAL PROTECTION AGENCY
PO Box 3000, Johnstown Castle Estate, Co. Wexford, Ireland
t 053 916 0600 f 053 916 0699
LoCall 1890 33 55 99
e info@epa.ie w http://www.epa.ie

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government