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Evaluating the Influence of Groundwater Pressures on Groundwater-Dependent Wetlands

STRIVE

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2007-2013

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Environmental Protection Agency

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EPA STRIVE Programme 2007–2013

Evaluating the Influence of Groundwater Pressures on Groundwater-Dependent Wetlands

Environmental Supporting Conditions for Groundwater-Dependent Terrestrial Ecosystems

(2011-W-DS-5)

STRIVE Report

Prepared for the Environmental Protection Agency

by

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The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary[1]

This 8-month desk study aims to contribute to the development of chemical and quantitative status tests for groundwater-dependent terrestrial ecosystems (GWDTEs) within the context of groundwater body (GWB) classification under the Water Framework Directive (WFD) and associated Groundwater Directive. These tests must be applied to all GWBs at risk of failing to meet WFD objectives owing to GWB pressures on GWDTEs. To assist in the development of the GWDTE test in Ireland the following project objectives were identified:

- Review relevant EU and national legislation and GWDTE research activities;
- Develop an enhanced understanding of GWDTE ecohydrogeology;
- Determine groundwater nutrient threshold values for GWDTEs;
- Determine methodologies for assessing quantitative pressures on GWDTEs;
- Summarise key knowledge gaps and provide recommendations for progressing test development; and
- Incorporate the views of the wider scientific community via individual and group meetings and workshops.

Twenty-one ecosystems on the WFD Register of Protected Areas (Annex I habitats under the Habitats Directive) were identified by Irish National Parks and Wildlife Service (NPWS) as directly dependent on groundwater.[2] This project focuses on a subset of 11 terrestrial habitat types that are considered to be the most groundwater dependent, namely:

1. Alkaline fens (Natura 2000 code 7230);
2. Species-rich *Cladium* fen (7210);
3. Petrifying springs (7220);
4. Transition mire (quaking bog) (7140);
5. Active raised bog (7110);
6. Turloughs (3180);
7. Flushes in blanket bog (7130);
8. Wet heath (4010);
9. Alluvial forests (91EO);
10. Machair (21AO); and
11. Humid dune slacks (2190).

Chapter 1 provides an overview of current legislation and policy affecting GWDTEs and highlights knowledge gaps relating to development of the GWDTE tests. GWDTE ecohydrogeological models (Chapter 2) were developed within the Source–Pathway–Receptor framework and comprise a descriptive summary table and a cross-section schematic diagram for each GWDTE type. The sources of pressure in this context are abstraction/drainage and nutrient inputs from groundwater. The models capture the dominant pathways of water movement from the GWB into the GWDTE and describe potential ecological responses to changes in groundwater quality and quantity.

The development of the chemical status test, and in particular the determination of groundwater nutrient threshold values (TVs) for GWDTEs, was the main focus of this project (Chapter 3). GWDTE TVs are concentrations of nitrate and/or phosphate within the GWB, the exceedance of which may exert a negative effect on GWDTE ecology, and which therefore trigger further site investigations. A predetermined

1. Metadata and data sets associated with this report can be found on the EPA SAFER website at: http://erc.epa.ie/safer/iso19115/displayISO19115.jsp?isoID=289.
2. EPA, 2005. A*rticle 5: The Characterisation and Analysis of Ireland's River Basin Districts – Summary Report on the Characterisation and Analysis of Ireland's River Basins*. Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland.

methodology developed by the UK WFD Technical Advisory Group (TAG) Wetlands Task Team was applied to the Irish situation. This involved the following process:

1. Identification of GWDTEs with potentially hydrogeologically linked drinking water and/or groundwater quality monitoring points;
2. Ecological assessment via desk study of GWDTEs and grouping of sites into good and poor ecological condition categories; and
3. Comparison of groundwater nutrient concentrations among these ecological condition groupings.

National spatial data sets for each of the 11 GWDTE types under investigation were obtained from the NPWS and the Irish Environmental Protection Agency (EPA). The Steering Group made a decision to develop TVs for only calcareous fens, including both alkaline fens and species-rich *Cladium* fens, because of data availability issues. The focus was on determining a nitrate (NO_3) TV given the low numbers of groundwater quality monitoring points with phosphate data potentially linked to the fens.

Forty-two calcareous fens were identified as being in good ecological condition; however, ecological condition assessments for 29 of these sites were assigned a low confidence owing to a lack of recent, site-specific information. The main data limitation was the lack of an agreed poor ecological condition category, which prevented the application of the comparative UK TAG approach. Due to the data problems, the report does not recommend a nitrate TV for calcareous fens, but proposes several options to the EPA:

1. Adopt a TV of 15 mg/l NO_3 for calcareous fens in Ireland. This value is the average of the 75th percentile of the good ecological grouping, including all levels of confidence in the ecological assessments, and the 75th percentile of the good ecological grouping, excluding sites with a low confidence in their ecological assessments;
2. Adopt the UK TV for oligotrophic fens with petrifying springs, which is problematic because of the potential differences in vegetation composition between Ireland the UK; or
3. Defer TV determination until further investigations are carried out.

The report recommends that setting a TV for calcareous fens is deferred until further investigations are carried out (Option 3). In the short term, all 44 fen sites with potentially linked groundwater quality monitoring points should be surveyed to confirm the presence, extent and ecological condition of alkaline fen and species-rich *Cladium* fen habitats, as defined under the EU Habitats Directive. A list of calcareous fens sites in poor ecological condition (if they exist) should be compiled as a matter of urgency. In the longer term, baseline ecological surveys of all alkaline fens and species-rich *Cladium* fens recorded in the national data sets are needed in order to confirm their presence, extent and ecological condition. Nitrogen and phosphorus data should then be collated from the drinking water and/or groundwater quality monitoring network, or collected from dedicated sampling boreholes, for sites ranging from near pristine to heavily impacted conditions. The aim of future work should be to generate a reliable data set for TV development using the UK TAG approach.

With reference to the quantitative status tests (Chapter 4), the project proposes an example of the type of matrix that might be developed in order to incorporate groundwater body flow regime into the quantitative pressure risk assessment process for GWDTEs. Options are also proposed for conducting site-specific quantitative status investigations following risk assessments. The approaches involve targeted groundwater-level surveys of either Irish vegetation communities similar to the most groundwater-dependent British National Vegetation Classification categories or within sites representative of good and poor ecological conditions. Each approach for site-specific investigations requires long-term groundwater-level data in order to understand the sensitivities to seasonal and multi-annual variations in rainfall, recharge and groundwater levels.

Finally, primary knowledge gaps and key recommendations are summarised in Chapter 5. The main knowledge gaps hindering the development of chemical and quantitative status tests for GWDTEs in Ireland are:

- The lack of reliable information on the spatial extent of some groundwater-dependent Annex I habitat types (e.g. alkaline fens) within Special Area of Conservation (SAC) complexes;
- The lack of site-specific conservation status assessments;
- Low numbers of groundwater quality monitoring points with phosphate data potentially linked to GWDTEs; and
- The lack of extensive monitoring of groundwater level and/or flow both within GWDTEs and their associated zones of groundwater contribution (ZOCs).

The key recommendations are that the EPA and NPWS agree on a priority list of GWDTE types for determining groundwater nutrient TVs and groundwater-level standards for the next River Basin Cycle. Where necessary, baseline surveys are recommended to confirm the presence, extent and current ecological condition of the selected GWDTE types with SAC/SPA[3] status. Groundwater nutrient and level and/or flow data should be collected for a subset of sites ranging from near pristine to heavily impacted conditions. These data should then be used to determine TVs and groundwater-level/flow standards for GWDTEs.

3. SPA, Special Protection Area.

1 Introduction

1.1 WFD Objectives for GWDTEs

The European Union (EU) Water Framework Directive (WFD) (2000/60/EC) is the primary European legislative driver of this project. The Directive was transposed into Irish law in 2003 by the European Communities (Water Policy) Regulations, 2003 (S.I. No. 722 of 2003), which declared the Environmental Protection Agency (EPA) as central to its implementation in co-operation with local authorities and the Department of Environment, Heritage and Local Government[1]. The WFD promotes the integrated management of surface waters and groundwater and requires the protection of groundwater in terms of its environmental value in addition to its protection as an important resource (Daly, 2009). River basin management is the core of WFD implementation and focuses on interrelationships among significant elements of the hydrological network, of which wetlands are recognised as an integral part. The WFD clearly identifies the protection of the water needs of wetlands as part of its purpose in Article 1(a) (EC, 2003b). Specifically, the framework must protect, inter alia, the water requirements of terrestrial ecosystems and wetlands depending directly on aquatic ecosystems. Although the WFD includes general environmental objectives relating to Protected Areas (e.g. Special Areas of Conservation (SACs)), there are no specific WFD environmental objectives for wetlands, and their protection is afforded indirectly via their associated waterbodies (ground and surface) (EC, 2003b). Groundwater-dependent terrestrial ecosystems (GWDTEs) are terrestrial ecosystems that depend directly on groundwater bodies (GWBs) and constitute one of five wetland types identified by the WFD, the remainder of which are associated with surface waterbodies (EC, 2003a). The WFD aims to establish a framework for attaining good status in all waters by 2015. The WFD's objectives of achieving good groundwater quantitative status (Annex V.2.1.2) and good groundwater chemical status (Annex V.2.3.2) require that, among other things, the groundwater needs of terrestrial ecosystems that depend directly on bodies of groundwater be protected, and, where necessary, restored to the extent needed to avoid or remedy significant damage to such ecosystems (Schutten et al., 2011). These provisions protect dependent terrestrial ecosystems from significant damage resulting from a reduction in the water table or from groundwater pollution, but not from other sources of damage (EC, 2003b). For instance, under the current chemical and quantitative assessment tests relating to GWDTEs, good status of the GWB is upheld where GWDTE ecology is damaged but where evidence indicates that the GWB is not the source of the damage.

1. Now the Department of the Environment, Community and Local Government.

For groundwater quantitative status (Annex V.2.1.2), the WFD requires that:

> "*the level of groundwater is not subject to anthropogenic alterations such as would result in any significant damage to terrestrial ecosystems which depend directly on the groundwater body*".

For groundwater chemical status (Annex V.2.3.2), good status requires that the concentrations of pollutants:

> "*are not such as would result in failure to achieve the environmental objectives specified under Article 4 for associated surface waters nor any significant diminution of the ecological or chemical quality of such bodies nor in any significant damage to terrestrial ecosystems which depend directly on the groundwater body*".

1.2 GWB Classification and GWDTEs

The first River Basin Cycle of the WFD (2003–2009) comprised three main phases (Hunter Williams et al., 2009):

1. The 'Initial Characterisation' (IC) phase (2001–2005);
2. The 'Further Characterisation' (FC) phase (2005–2009); and

3. The interim classification of GWBs (2008).

The IC phase involved physical and risk characterisation of GWBs (EPA, 2005). GWBs, which are the key groundwater management unit, are a distinct volume of groundwater within an aquifer or aquifers (EC, 2003a). In Ireland, bedrock aquifers were delineated using mapped bedrock geology and hydrogeological information (WFD Working Group on Groundwater, 2004b). GWBs were ultimately delineated based on aquifer flow regimes, geological boundaries and boundaries based on flow systems and flow lines. Unlike many other EU countries, Ireland has delineated GWBs for GWDTEs that are at risk of failing to meet the environmental objectives of the WFD. These GWDTE GWBs have followed the delineation rules relating to aquifer flow regimes and geological boundaries, but have focused on boundaries relating to the flow systems and flow lines of the GWDTE catchment. GWBs are delineated to a finer scale than in other EU countries owing to the complex pattern of Irish geology. The presence of GWDTEs was a significant factor during the subdivision of some GWBs. Geographical Information Systems (GIS)-based risk characterisation assessed the risks to the chemical and quantitative status of the GWBs (WFD Working Group on Groundwater, 2005a). The FC phase involved more detailed study of aspects of groundwater quality and quantity identified as lacking adequate information during the IC phase, e.g. groundwater abstraction pressures. Finally, the interim chemical and quantitative status classification of GWBs was finalised in 2009 using key principles outlined in *Guidance on Groundwater Status and Trends Assessment* (EC, 2009).

Status assessments were required for GWBs that were identified as being at risk during the IC phase as part of Article 5 Risk Assessment (Craig and Daly, 2010). Both chemical and quantitative status must be classified as either good or poor. GWBs not at risk are automatically classified as good. The overall framework for GWB status assessment (classification) is presented in Fig. 1.1. A GWB is designated as poor if any of the classification tests is failed. The main aim of the quantitative status assessment is to ensure a balance between abstraction and recharge of groundwater. Quantitative assessment involved four tests related to saline intrusion, water balance and assessments of effects of groundwater abstraction on surface waters and GWDTEs (Fig. 1.1). The chemical status assessments are significantly more complex than the quantitative assessments and the Groundwater Directive (2006/118/EC) was brought into effect to clarify the criteria for good chemical status. This new legislation was transposed into Irish law in 2010 by the European Communities Environmental Objectives (Groundwater) Regulations, 2010 (S.I. No. 9 of 2010), with the original Groundwater Directive (80/68/EEC) due to be repealed and fully replaced by 2013. Chemical assessment involves a series of five tests related to saline intrusion, drinking water, a general quality test and assessments of effects of groundwater pollutants on surface waters and GWDTEs (Fig. 1.1). The Groundwater Directive also demands the determination of threshold values (TVs) as part of the GWDTE chemical status test. TV exceedance should prompt further investigation to determine whether good status conditions have been met.

In 2004, 132 GWBs were identified as containing one or more GWDTEs with SAC status under the Habitats Directive (92/43/EEC), and were the subject of a suite of risk assessments (WFD Working Group on Groundwater, 2004b) as part of the WFD Article V Characterisation and Risk Assessment of River Basin Districts (RBDs) (WFD Working Group on Groundwater, 2005a) This process identified 48 GWBs at risk of failing to meet WFD objectives owing to potential damage to GWDTEs. Twenty-three were at risk from abstraction and/or arterial drainage, 19 were at risk from diffuse sources of phosphorus, five were at risk from both abstraction and diffuse phosphorus and one was identified as at risk from point sources of phosphorus.

The first River Basin Management Plan (RBMP) (http://www.wfdireland.ie) reported on GWB status at the end of the first River Basin Cycle (2009), where GWBs were classified as being of either good or poor status following risk assessment. The interim GWB classification identified 0.5% of all Irish GWBs as having poor quantitative status, whereas 14.7% of GWBs were identified as having poor chemical status (Daly, 2009). The majority of the poor chemical status

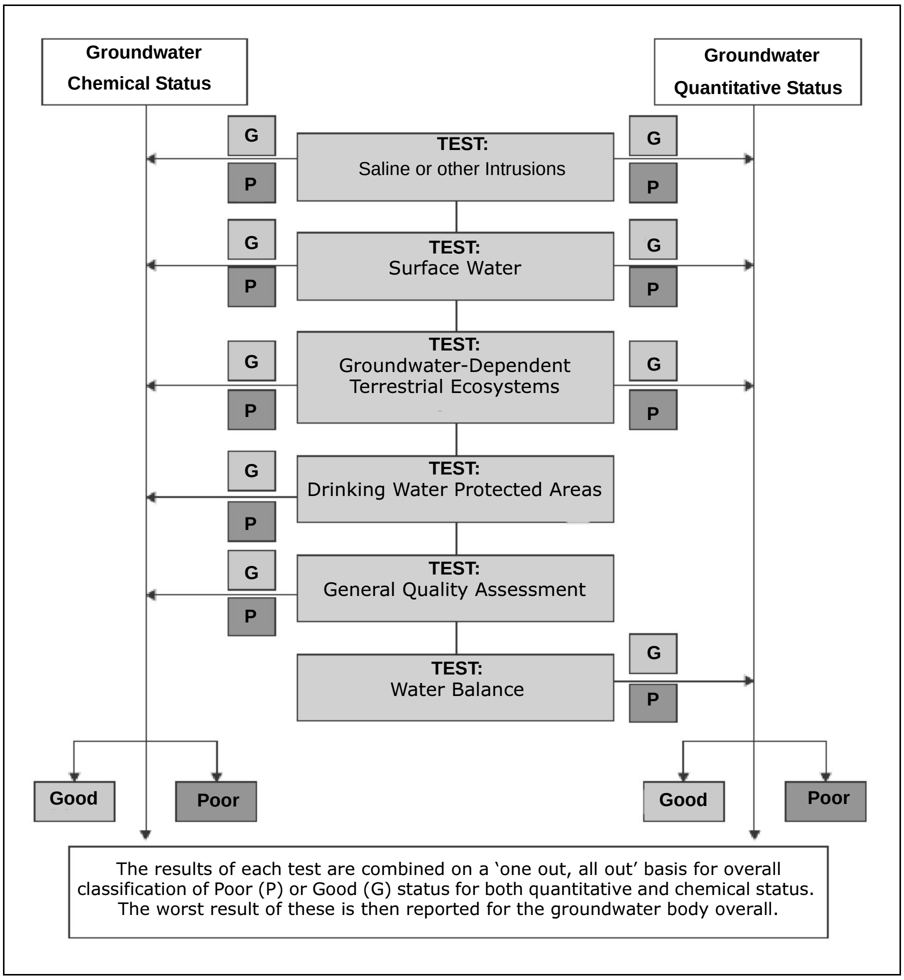

Figure 1.1. Framework for groundwater body status assessment (classification) (EC, 2008).

GWBs relate to impact on surface waters, principally owing to ecologically significant concentrations of phosphate determined via the surface water test (Fig. 1.1). Two of the four poor quantitative status GWBs are related to GWDTEs. The current frameworks for chemical and quantitative status tests for GWDTEs are presented in Tables 1.1 and 1.2, respectively (Craig and Daly, 2010).

The interim outputs from the chemical and quantitative status tests for GWDTEs must be considered with caution as the data available to assess significant GWB-mediated damage to GWDTEs were flagged as inadequate during the classification process, and, consequently, the status tests were undertaken for a very limited number of GWDTEs (Mayes and Codling, 2009).

The result from the chemical status tests (Table 1.1) that no GWBs are of poor status owing to chemical pressures from groundwater on GWDTEs is because the chemical status test was not applied to any GWDTEs at risk from chemical pressures, rather than the lack of nutrient pressure on GWDTEs. The lack of TVs for GWDTEs was a major limiting factor for application of the chemical status test to GWDTEs. Similarly, the quantitative status test was only applied to two of the 23 GWDTEs identified as being at risk from quantitative pressures owing to a lack of information. This situation will need to be remedied for the next RBMP, due in 2015. Information on the environmental supporting conditions (flow, level and chemistry), needed to maintain GWDTEs in a favourable state, is a prerequisite for status assessments (Daly, 2009).

Table 1.1. Current chemical status test for groundwater-dependent terrestrial ecosystems (GWDTEs) within the context of groundwater body (GWB) classification (after Daly, 2009; Craig and Daly, 2010).

Key concept	Status is determined through a combination of GWDTE assessments to determine ecological damage and an assessment of chemical inputs from GWBs into GWDTEs. The test is designed to determine whether the contribution from groundwater quality to GWDTEs and consequent impact on GWDTE ecology is sufficient to threaten the WFD objectives for these associated GWDTEs.
Threshold values	An appropriate percentage of a prescribed standard; however, to date, no specific standards have been derived for GWDTEs. Wetland quality standards or action values adjusted by dilution and, where appropriate, attenuation factors.
Criteria for poor chemical status	**Low confidence:** Ecology of GWDTE damaged, and further investigation indicates that groundwater loading greater than loading required to breach wetland trigger action value/concentration. **High confidence:** Ecology of GWDTE damaged, and further investigation indicates that groundwater loading greater than loading required to breach wetland trigger action value/concentration AND detailed site-specific studies identify and quantify direct connection between groundwater and GWDTE.
Result of interim classification	Zero GWBs associated with GWDTEs of poor status owing to groundwater pollution.

WFD, Water Framework Directive.

Table 1.2. Current quantitative status test for groundwater-dependent terrestrial ecosystems (GWDTEs) within the context of groundwater body (GWB) classification (after Daly 2009; Craig and Daly, 2010).

Key concept	Status is determined through determination of ecological damage at the GWDTE, and then assessment of the impact of groundwater abstraction on GWDTE ecology. The test is designed to assess whether groundwater abstractions reduce the contribution from groundwater (in terms of water level or groundwater flow) to GWDTEs and if the consequent impact on GWDTE ecology is sufficient to threaten the WFD objectives for these associated GWDTEs.
Action values	Wetland flow and/or water level standards (or action values). Only developed for Pollardstown Fen, Co. Kildare.
Criteria for poor quantitative status	**Low Confidence:** Ecology of GWDTE damaged, and further investigation indicates that groundwater abstractions are impacting on the wetland. **High Confidence:** Ecology of GWDTE damaged, and further investigation indicates that groundwater abstractions are impacting on the wetland AND detailed site-specific studies identify and quantify direct connection between groundwater and GWDTE.
Result of interim classification	Two GWBs of poor status, due to impact of lowering of groundwater levels on Pollardstown Fen, Co. Kildare.

WFD, Water Framework Directive.

1.3 GWDTEs and Links with the Habitats Directive

The WFD focuses on the inter-linkage between the GWB and the GWDTE, whereas the Habitats Directive requires a more holistic conservation assessment based on the range, area, structures and functions and threats to and future prospects of the habitat. Recent EU guidance has clarified the linkage between the Habitats Directive and the WFD (EC, 2011). The Habitats Directive (92/43/EEC) was transposed into Irish law in the European Union (Natural Habitats) Regulations, 1997, which have since been amended three times, fully replaced by S.I. 477 of 2011. This Directive placed an obligation on EU Member States to establish the Natura 2000 network of important ecological sites made up of Special Protection Areas (SPAs), established under the Birds Directive (79/409/EEC), and SACs established under the Habitats Directive itself. Annex I habitats require special conservation measures. Priority habitats, designated with an asterisk, are those Annex I habitats that require particular protection because their global distribution largely falls within the EU and they are in danger of disappearance (NPWS, 2008).

GWDTEs designated for conservation under the Habitats Directive have been the main priority of work on groundwater–dependent wetlands to date (Kilroy et al., 2009). However, WFD Common Implementation Strategy (CIS) guidance encourages the assessment of significant damage to other ecologically important GWDTEs outside the Natura network (EC, 2003b). This brings GWDTEs designated as Natural Heritage Areas (NHAs) under national legislation, namely the Wildlife Act, 1976 and the Wildlife (Amendment) Act, 2000, within the remit of the WFD.

WFD CIS guidance provides a synopsis of the most important WFD provisions for wetlands. The two obligations relevant to GWDTEs are:

A. Obligation to achieve good groundwater status (Article 4.1(b) (i & ii) as defined in Annex V 2.1.2 and 2.3.2). Member States must control and remedy anthropogenic alterations to groundwater quality and water levels to ensure that such alterations are not causing, or will not cause, significant damage to GWDTEs.

B. Member States must fulfil obligations, as requested specifically under the Habitats Directive, to take protective or restorative action in the management of wetlands that are included in the Register of Protected Areas following Annex IV (v) (EC, 2003b).

In the absence of a clear WFD definition, EU CIS guidance suggests interpretation of the term ‘significant damage’, primarily with respect to the ecological quality of terrestrial ecosystems that depend on the inter-linkage with groundwater (EC, 2003b; Schutten et al., 2011). Guidance also promotes the use of the Natura 2000 network established under the Habitats Directive to identify dependent terrestrial systems that are of sufficient conservation importance that damage to them could legitimately be described as 'significant'. In Ireland and the UK, significant damage to a GWDTE is equivalent to unfavourable conservation status under the Habitats Directive (UK TAG, 2012).

Obligation B sets out an explicit requirement to link the objectives of nature conservation legislation and the objective of good groundwater status (Kilroy et al., 2005). Obligation B forges a tight link between Article 6 of the Habitats Directive, which demands understanding of the ecological requirements of habitats and species in order to develop and implement conservation measures (Irvine, 2009), and Articles 6 and 8 of the WFD. Article 6 of the WFD required Member States to create a Register of Protected Areas by 2004 to include all surface water, groundwater and GWDTEs designated for conservation under other EU legislation. The Irish Register of Protected Areas includes SACs, SPAs, NHAs and all salmonid waters designated under the European Communities (Quality of Salmonid Waters) Regulations 1988 (S.I. No. 293, 1988) (EPA, 2005). In Ireland, the initial chemical and quantitative risk assessments and status tests were only applied to GWDTEs designated as SACs and formally identified as Protected Areas under Regulation 8 of S.I. No. 722 of 2003 (Craig and Daly, 2010). Article 6 of the WFD links the objectives of nature conservation legislation and objectives of good water status for the WFD. A programme of measures aiming to achieve good groundwater status, including the prevention of significant damage to GWDTEs, will assist in the achievement of favourable conservation status (FCS) under the Habitats Directive (Kilroy et al., 2005). The conservation status of habitats and species is assessed and reported every 6 years at a national level and the next report is due in 2013. The National Parks and Wildlife Service (NPWS), which is the national competent authority for the Habitats Directive, assesses the conservation status for individual habitats at site level, where monitoring is being conducted, and these data inform the national assessments. Where possible, the overarching site-specific objective to either ‘maintain’ or ‘restore’ is based on the current conservation status. Currently, however, many GWDTEs designated as SACs lack a site-specific conservation status assessment and defined conservation objectives. In order to meet Obligations A and B for wetlands as noted in WFD CIS guidance, there needs to be a co-ordinated strategy, driven by site-specific conservation objectives and management plans, between the EPA and the NPWS.

1.4 GWDTE Ecohydrogeology

Assessing the conservation status of habitats under the Habitats Directive requires, inter alia, an assessment of habitat structures and functions. The terms 'structure' and 'function' are not defined in the Habitats Directive and require careful interpretation in the context of conservation assessment, as ecosystem structure (i.e. system components) and function (i.e. system dynamics) are essentially artificial concepts, incorporating many aspects of ecosystems (Jaeger Miehls et al., 2009). Structural characteristics of wetlands include physical habitat conditions and species. Functional characteristics involve nutrient cycling, decomposition and photosynthesis (Sutton-Grier et al., 2010). Assessing the structures and functions of hydrologically dynamic GWDTE habitats is extremely challenging, particularly given that the ecohydrogeology of different GWDTE types is poorly understood. For surface waters, the issue of how to assess ecological damage under the WFD is tackled by relating ecological quality to a baseline or reference state under minimal human influence (Solimini et al., 2006). This reference condition approach or ecological status assessments do not explicitly apply to GWDTEs; however, identifying GWB-mediated reductions in ecological quality is the key to assessing significant damage to GWDTEs arising from pressures on groundwater. An improved understanding of the ecohydrogeology of different GWDTE types is important for informing future assessments of the nature of groundwater dependency associated with different GWDTE types/sites and for identifying ecological indicators of significant damage arising from groundwater.

1.5 Project Objectives

The overall project aim was to inform the development of chemical and quantitative status tests for GWDTEs, within the context of GWB classification, based on an improved understanding of associated ecohydrogeology. The project was primarily concerned with Obligation A of the WFD CIS guidance (EC, 2003b), as discussed in Section 1.3.

The specific objectives of the project were to:

1. **Review relevant EU and national legislation and GWDTE research activities**
   The project literature report aimed to provide an overview of current legislation and policy affecting GWDTEs and to highlight knowledge gaps relating to development of a GWDTE test.

2. **Develop an enhanced understanding of GWDTE ecohydrogeology**
   This aspect of the project aimed to improve understanding of the important pathways of water movement from the GWB to the GWDTE and ecological responses within the GWDTE to quantitative and chemical pressures. This aspect of the project identified the nature of the groundwater dependency of each GWDTE type and informs assessments of their structural and functional characteristics. Documenting potential ecological responses to GWB-derived pressures helps to identify suitable indicators of significant damage to GWDTEs for future work. Information derived by the project on groundwater flow pathways to GWDTEs enhances understanding of the links between nutrient pressures, groundwater quality and GWDTE ecology.

3. **Determine groundwater nutrient TVs for GWDTEs**
   This objective was the main focus of the project. This involves applying a predetermined methodology for determining TVs, developed by the UK WFD Technical Advisory Group (TAG) Wetlands Task Team, to the Irish situation. This objective addresses the requirement for TVs for the GWDTE chemical status test.

4. **Determine methodologies for assessing quantitative pressures on GWDTEs**
   This aspect of the project reviewed the current quantitative GWDTE risk assessment and provides recommendations for conducting site-specific investigations of quantitative pressures.

5. **Summarise key knowledge gaps and recommendations for progressing test development.**

2 Conceptual Understanding of GWDTE Ecohydrogeology

2.1 GWDTE Types

Twenty-one ecosystems on the WFD Register of Protected Areas (Annex I habitats under the Habitats Directive) were identified by the NPWS as directly dependent on groundwater (EPA, 2005). This project focused on a subset of 11 terrestrial GWDTE types that are considered to be the most groundwater dependent (Table 2.1). Global distributions of species-rich *Cladium* fen (Natura 2000 code 7210), Petrifying springs (7220), Active raised bog (7110), Turloughs (3180), Machair (21AO) and Alluvial forests (91EO) are largely restricted to the EU zone and are therefore a top priority for conservation under the Habitats Directive. Table 2.1 provides the Natura 2000 codes, Irish habitat codes (Fossitt, 2000) and project codes.

2.2 Purpose of Conceptual GWDTE Ecohydrogeological Models

Conceptual understanding of GWDTE ecohydrogeology and associated groundwater systems is central to implementation of the WFD and the Groundwater Directive (EC, 2009). Chemical and quantitative status tests for GWDTEs require an understanding of the interactions between the GWDTE and the GWB, and also of properties such as wetland deposits and basal substrata within and adjacent to GWDTEs. The purpose of the models is to provide a user-friendly summary of the key hydrogeological characteristics of 11 selected GWDTE types occurring in Ireland, and potential ecological responses to chemical and quantitative pressures. The outputs, which should be viewed as working hypotheses, will aid co-operation between wetland ecologists and hydrogeologists by highlighting where the focus needs to be when establishing links between the GWDTE and GWB and when assessing GWB-mediated significant damage during future site-specific investigations.

2.3 Format of Conceptual GWDTE Ecohydrogeological Models

The conceptual models were developed within the Source–Pathway–Receptor framework and build on previous work by Kilroy et al. (2008), which described

Table 2.1. List of groundwater-dependent terrestrial ecosystem types under investigation by this project. Note: Natura 2000 codes and titles are as they appear in the Habitats Directive.

Annex I habitat type	Natura 2000 code	Fossitt habitat code	Project code
Alkaline fen	7230	PF1	AKF
Calcareous fen with *Cladium mariscus* and *Carex davalliana	7210	PF1	CLF
***Petrifying springs with tufa formation (*Cratoneurion*)**	7220	FP1	PTS
Transition mire (quaking bogs)	7140	PF3	TNM
***Active raised bog**	7110	PB1	ARB
***Turloughs**	3180	FL6	TUR
Blanket bog (*if active) (FLUSHES ONLY)**	7130	PB3	BBF
Northern Atlantic wet heaths with *Erica tetralix* (FLUSHES ONLY)**	4010	HH3	WTH
Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior	91EO	WN4	ALF
Machair (*in Ireland)	21AO	CD6	MAC
Humid dune slacks	2190	CD5	HDS

*Indicates a priority habitat for conservation. Fossitt habitat codes are as they appear in Fossitt (2000).
**Identifies Annex I habitat types where the focus is on flushed areas only.

the broad hydrogeological framework for GWDTEs. The models are presented as a combination of a descriptive summary table and a cross-section schematic diagram for each GWDTE type. The sources of pressure in this context are abstraction/drainage and nutrient inputs from the GWB. The models capture the important pathways of water transport into each generalised GWDTE type, taking account of both GWB scale and GWB–GWDTE interface processes, both of which strongly influence the ecological roles of groundwater (Bertrand et al., 2011). The models also capture the potential GWDTE (receptor) ecological responses to changes in groundwater level (and/or flow) and chemistry. For this aspect of the project, a broad-scale rather than a fine-scale, site-specific approach was adopted. Two GWDTE types are presented in one conceptual model in cases where they often occur in association with each other.

2.3.1 Descriptive table

Table 2.2 presents a description of the elements of the descriptive table for each conceptual model. Elements 1–7 describe the key hydrogeological characteristics of

Table 2.2. Description of the information (including a schematic cross-section diagram) that is presented for each groundwater-dependent terrestrial ecosystem (GWDTE) type.

Element no.	Element name	Description
1	Landscape situation	A description of the typical topographical situation in which each GWDTE type occurs.
2	Dominant substrata	Details of the main substrata types, including wetland substrata and basal substrata (subsoils (unconsolidated deposits)/bedrock).
3	GWB flow regime	Proportion of GWDTE catchments associated with karstic, poorly productive, fissured and intergranular groundwater body (GWB) flow regimes.
4	Dominant water inputs	Identifies major and minor inputs selected from groundwater flow (shallow and/or deep); discrete fault/conduit flow; overland flow; interflow; riverine floodwater; lake floodwater; precipitation. Groundwater contribution is described as High, Moderate or Low relative to the other inputs.
5	Groundwater supply mechanisms	Description of key groundwater supply mechanisms and, where appropriate, associated generic groundwater supply mechanisms (WETMECs) after Wheeler et al. (2009).
6	Groundwater hydrochemistry	Background hydrochemistry (i.e. alkalinity and base status) of groundwater inflows.
7	Temporal variation in water level within GWDTE	Description of seasonal variation (i.e. summer versus winter) of water level within the GWDTE (or shorter-term variation where relevant).
8	Ecological responses in GWDTE to changes in groundwater level and/or flow	**Changes to GWDTE groundwater supply mechanisms** Critical potential effects of reduced groundwater level/flow on groundwater supply mechanisms to GWDTE. **Ecological responses to changes in groundwater supply mechanisms** Potential ecological responses following changes to GWDTE groundwater supply mechanisms.
9	Ecological responses in GWDTE to changes in groundwater chemistry	**Nitrogen and phosphorus limitation in GWDTE** Statement regarding the nature of nutrient limitation in GWDTE. Relates to understanding of whether nitrogen and/or phosphorus limit vegetation growth in GWDTE. **Groundwater supply mechanisms and nutrient attenuation** Capacity of groundwater supply mechanisms to attenuate nutrients. **Ecological responses to increased nutrients** Potential ecological responses to increased nutrient input from groundwater.

each GWDTE type. Elements 1 and 2 describe the typical topographical and landscape setting and associated substrates, respectively. Element 3 (GWB flow regime) describes the GWB-scale flow regimes associated with each GWDTE type. In Ireland, GWB flow regimes have been classified for the WFD as karstic, poorly productive, fissured or intergranular (WFD Working Group on Groundwater, 2004b; Daly, 2009). The GWB flow regime characteristics associated with each GWDTE type provide information on flow paths and nutrient transport pathways (Table 2.3). Element 4 (Dominant water inputs) describes the main pathways of water transport to the GWDTEs. Element 5 (Groundwater supply mechanisms) provides more detail on the groundwater supply mechanisms using, where appropriate, WETMEC[2] terminology presented in Wheeler et al. (2009). This element captures GWB–GWDTE interface processes. Element 6 describes the background groundwater hydrochemistry, with emphasis on alkalinity as calcium carbonate deposition can exert a significant ecological effect on GWDTEs. Element 7 describes the typical temporal variation of water level associated with each GWDTE type as a key habitat characteristic and ecological driver. Elements 8 and 9 describe the potential responses to changes in groundwater level/flow and chemistry, respectively. The specific effects of a reduction in groundwater level in the GWB on groundwater supply mechanisms and subsequent ecological responses are documented. GWDTE nutrient limitation and the potential for nutrient attenuation (denitrification and phosphorus sorption) associated with different groundwater supply mechanisms are also considered.

2. WETMEC, WETland water supply MEChanisms.

2.3.2 Schematic cross-section diagram

The diagrams illustrate the typical topography (slope, basin or flat ground), wetland and basal substrates, GWB flow regime, dominant water inputs, and groundwater supply mechanisms associated with each GWDTE type. These directly relate to Elements 1, 2, 3, 4 and 5 of the descriptive tables, respectively. The wetland substrates are shown using different symbols. The typical GWB flow regime is noted on the diagram using text in cases where there is a reasonable degree

Table 2.3. Relevant characteristics of groundwater body (GWB) flow regimes and implications for pollutant transport (WFD Working Group on Groundwater, 2004b).

GWB flow regime/ Aquifer classes	Relevant characteristics	Implication
Karstic **Rk, Rkc, Rkd, Lk**	• Variable to high transmissivity, low effective porosity and solutionally enlarged permeability, often with rapid throughput • Potentially long flow paths, except where flow is limited by extent or shape of GWB • High velocities, point recharge and minimal nutrient attenuation	Pollutants can reach receptor quickly
Fissured **Rf, Lm**	• Moderate to high transmissivity and low effective porosity • Generally long flow paths through fissures, except where flow is limited by extent or shape of GWB • High/Moderate transmissivity, long underground flow paths	Low surface drainage density
Poorly productive **Ll, Pl, Pu**	• Low transmissivity and very low effective porosity. Generally short shallow flow paths	High surface drainage density
Intergranular **Rg, Lg**	• High intergranular permeability and high effective porosity • Potentially long flow paths, often limited by extent or shape of GWB • High transmissivities	Mobility of nitrate but not phosphate

R, Regionally important aquifer; L, Locally important aquifer; P, Poor aquifer; k, Karstified bedrock; c, Conduit flow; d, Diffuse flow; f, Fissured bedrock; m, Moderately productive; l, Local zones; u, Unproductive; g, Sand & gravel.

of certainty regarding this aspect. The directions of flow associated with major and minor water inputs are shown using different coloured arrows. Major inputs are shown using relatively thicker arrows than those for minor inputs. Groundwater supply mechanisms at the GWDTE–GWB interface are shown using short blue arrows. Springs are shown using a thick arrow reflecting the greater quantity of flows relative to groundwater seepages, which are shown using a thinner, broken blue arrow. Potentially associated WETMECs (Wheeler et al., 2009) are noted using text (see Section 2.3.3).

2.3.3 *Use of water supply mechanism terminology (WETMECs)*

As mentioned, the models use WETMEC terminology, where appropriate, to describe the main groundwater supply mechanisms of each GWDTE type. WETMECs summarise how wetlands function hydrologically and are essentially conceptual units that describe the supply and distribution of water in wetlands (Wheeler et al., 2009). WETMECs were developed as part of the interdisciplinary Wetland Framework project conducted as a partnership between the Wetland Research Group at the University of Sheffield, the UK Environment Agency, Natural England and the Countryside Council for Wales (Wheeler et al., 2009). The project aimed to improve understanding of wetland hydrological and vegetation processes, and impacts of pressures such as groundwater abstraction and quality, in order to enable the Environment Agency to achieve conservation objectives for wetlands. The Wetland Framework exclusively examines bogs, fens and some swamps. Ecohydrogeological data from over 1,500 vegetation types spanning over 200 wetlands throughout England and Wales were analysed in order to identify the main water supply mechanisms (Wheeler et al., 2009). There has not been a similar, broad-scale wetland study in Ireland to date; however, the information relating to fens and bogs should be broadly applicable to the Irish situation.

WETMECs take particular account of the impact of top-layer effects in the supply and distribution of water within wetlands and can form an ‘add-on’ to wider conceptual hydrogeological models (Whiteman et al., 2009). Cluster analysis identified 20 WETMECs, which are essentially hydrological categories. Eleven of these (WETMECs 7–17) deal with connections between the wetland and groundwater (Appendix 1). It must be borne in mind that:

- WETMECs often gradually merge with each other;
- Outputs from a ‘bottom–up’ approach based on field data are being applied to a ‘top–down’ approach to GWDTE categorisation;
- WETMECs were determined from ecohydrogeological information collected from fens and bogs in the UK and may not cover all mechanisms associated with GWDTEs occurring in Ireland; and
- That WETMECs may support several plant communities, owing to management factors and other non-hydrogeological drivers.

An additional WETMEC 21 is proposed by the present project to describe discrete karst/conduit flow input, which is characteristic of some Irish wetlands and not covered in Wheeler et al. (2009).

2.4 Calcareous Fens (7230 and *7210); Fossitt Habitat Code (PF1)

Alkaline fen (7230) and *Calcareous fen with *Cladium mariscus* and *Carex davalliana* (7210) often occur together at a site. Both are considered calcareous fens under the Habitats Directive (EC, 2007). The vegetation of 7230 is typically dominated by rushes, small/medium sedges, patchy stands of tussock forming sedges and reedbeds and a broad range of bryophytes (Fossitt, 2000). 7210 is a specific type of species-rich *Cladium* fen that often occurs down slope of 7230. 7210 is typically wetter (but drier than species-poor *Cladium* fen) and more calcareous and oligotrophic than 7230 (Curtis et al., 2009). Habitat drying and herbage removal reduces the competitive ability of *Cladium mariscus* and increases species diversity (Meredith, 1985). 7210 typically occurs as a transition zone between 7230 and species-poor *Cladium* fen swamp. Petrifying springs with *Cratoneurion* (7220) often occur within calcareous fens (see Section 2.5).

Landscape situation	Topogenous basins
Dominant substrata associated with GWDTE	Wetland substrates: Loosely consolidated fen peat overlying marl deposits (Wheeler et al., 2009). Basal substrata: Typically layer of limestone till underlain by limestone bedrock. Till can be thick and can be the only source of calcium-rich waters to Irish fens (Áine O'Connor, NPWS, personal communication, 2012).
GWB flow regime	65% = Karstic, 29% = Poorly Productive, 4% = Fissured and 2% = Intergranular (based on spatial join between 'Alkaline fen' and 'Alkaline fen, Cladium fen' and 'Alkaline fen, transition mire' polygons in the GWDTE SAC layer and GWB layer, see Section 3.2.1).
Dominant water inputs	**Major:** Groundwater (shallow and deep). **Minor:** Precipitation, overland flow and interflow at fen margins. The groundwater contribution is high.
Groundwater supply mechanisms	Discrete springs, particularly at fen margins, and diffuse seepages either at the fen margins or upwards through shallow till and peats (Harding, 1993; Johansen et al., 2011). WETMECs 10, 11, 13 and 17.
Groundwater background hydrochemistry	Highly alkaline and base rich (Fossitt, 2000).
Temporal variation in water level within GWDTE	Low fluctuations in groundwater level. Groundwater level is relatively lower in summer than winter owing to higher rates of evapotranspiration and lower amounts of precipitation.
Ecological responses in GWDTE to changes in groundwater level and/or flow	**Changes to GWDTE groundwater supply mechanisms** Loss of or reduced flow at springs and reduced seepage quantities and rates. **Ecological responses to changes in groundwater supply mechanisms** Disruption of marl precipitation and breakdown of associated phosphate fixing processes at springs resulting in loss of specialised species (Fojt, 1994; Bertrand et al., 2011); aeration of peat resulting in decomposition, shrinkage and release of nutrients (Fojt, 1994), owing to mineralisation of organic matter; acidification of substrates as rainfall infills pore spaces (Johansen, 2011); dominant *Sphagnum* can indicate a shift to ombrotrophic conditions (Bertrand et al., 2011) resulting from acidification linked to drying out (Sefferova Stanova et al., 2008); loss of species-rich vegetation communities characterised by low productivity, calcareous conditions and generally high water table levels owing to alteration of the competitive balance of the community dominants and subsequent replacement of fine vegetation structure with coarse grasses and larger herbs (scrub encroachment) (Harding, 1993; Fojt, 1994); loss of high conservation value (HCV) species requiring wet (e.g. *Vertigo geyeri*) (Kuczńyska and Moorkens, 2010) and/or low nutrient conditions and/or calcareous conditions; replacement of *Scorpidium scorpioides* with *Calliergonella cuspidata* (Kooijman and Bakker, 1995).
Ecological responses in GWDTE to changes in groundwater chemistry	**Nitrogen and phosphorus limitation in GWDTE** Fen vegetation can be both nitrogen and phosphorus limited (Kooijman and Bakker, 1995; Verhoeven et al., 1996; Pauli et al., 2002). **Groundwater supply mechanisms and nutrient attenuation** Little chance for nutrient attenuation at springs; Seepage through shallow till and peats provides opportunity for nutrient attenuation. **Ecological responses to increased nutrients** Algal blooms evident at springs; shift in occurrence and abundance of moss species and macrophytes in the short term (Bertrand et al., 2011), decrease in species richness of low productivity, HCV *Caricion davallianae* vegetation communities owing to increased dominance of high potential growth rate species, e.g. Common Reed (Pauli et al., 2002).

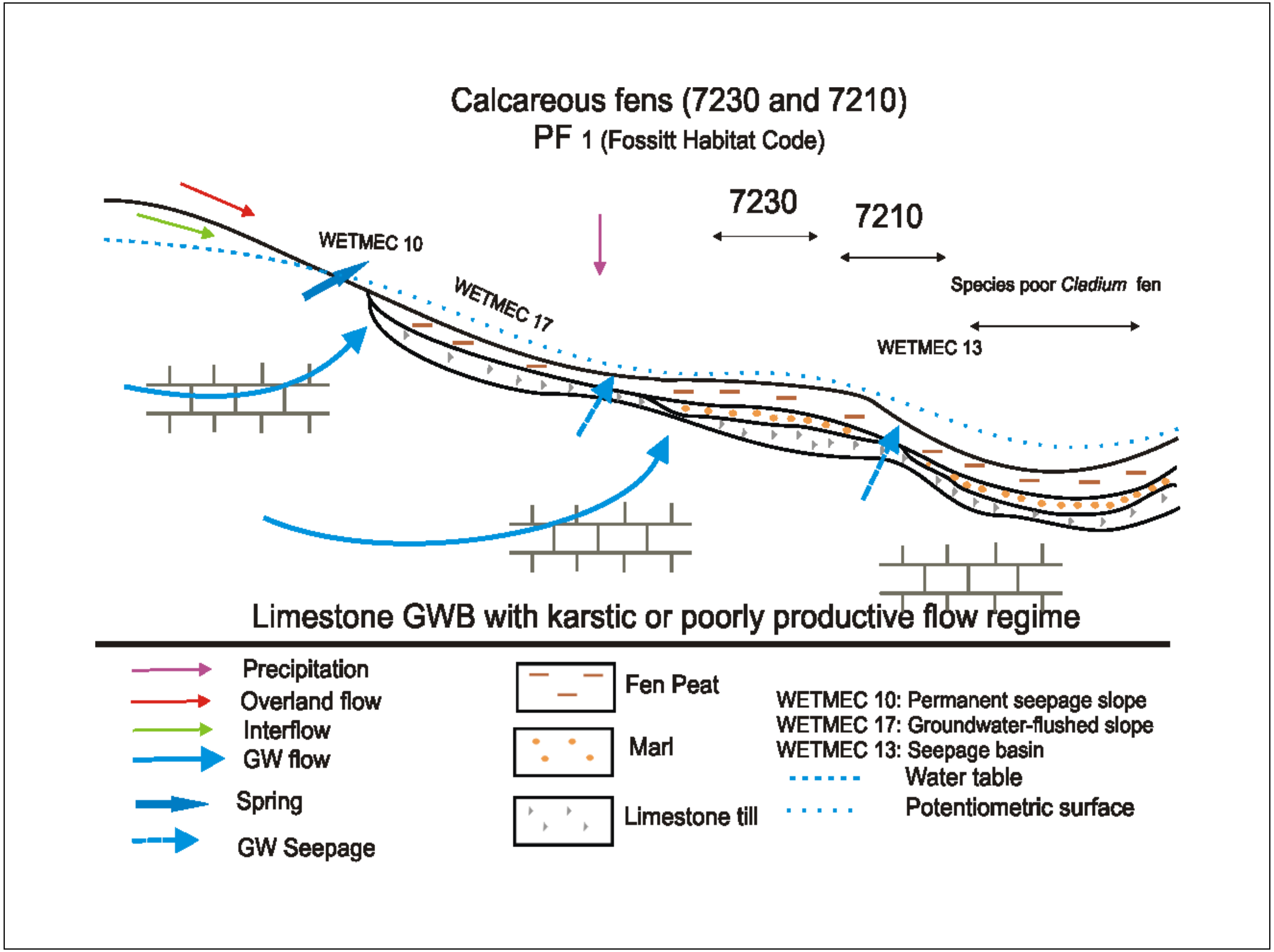

Figure 2.1. Schematic cross-section for Alkaline fen (7230) and Calcareous fen with *Cladium mariscus* and *Carex davalliana (7210).**

2.5 *Petrifying Springs with Tufa Formation (*Cratoneurion*) (7220); Fossitt Habitat Code (FP1)

Under the Habitats Directive, petrifying springs are defined by the occurrence of *Cratoneurion* vegetation with tufa formation rather than the occurrence of spring hydrogeological characteristics. Bryophytes dominate the habitat (Heery, 1993) and moss species such as *Palustriella commutata*, *Cratoneuron filicinum* and *Eucladium verticillatum* are characteristic of tufa formation (Curtis et al., 2009). Calcium carbonate precipitation (tufa formation) is driven by both physical and biological processes (Ford and Pedley, 1996).

Landscape situation	A wide range of landscape settings, from coastal areas to woodland habitats (Curtis et al., 2006). Groundwater is fundamental for the development of both (1) perched springline tufas (solegenous) (Fig. 2.2) and (2) paludal tufas (topogenous) (Fig. 2.3).
Dominant substrata associated with GWDTE	Wetland substrata: Dominated by tufa; peat occurs in some situations. Basal substrata: Various, thought to be generally associated with limestone bedrock or lime-rich unconsolidated deposits (Melinda Lyons, TCD, personal communication, 2012).
GWB flow regime	Spatial extent information is currently inadequate for relating to GWB flow regime using spatial analysis in GIS.
Dominant water inputs	**Major**: Shallow groundwater. The groundwater contribution is high.
Groundwater supply mechanisms	*Cratoneurion* vegetation may be associated with calcareous springs with either permanent or periodic flow (Bertrand et al., 2012). In Ireland, petrifying springs appear to be typically associated with permanent flow conditions (Melinda Lyons, TCD, personal communication, 2012). Type 1. Perched springline tufas typically develop from multiple or single point spring discharges. The discharges arise downgradient of recharge areas, following water seepage down to an impervious layer below the aquifer, and subsequent gravity-driven flow to ground surface. Water flows down the topographic gradient after discharging and the tufas generally form lobate, fan-shaped mound morphologies on hill slopes (Pedley et al., 2003). Type 2. Paludal tufas develop predominantly in low-lying terrain, with an elevated water table (Pentecost, 1995). Paludal tufas, consisting of isolated calcium carbonate build-ups around vegetation (Pentecost and Viles, 1994), are associated with slower, more diffuse water seepage than perched springline tufas (Pedley et al., 2003).
Groundwater hydrochemistry	High alkalinity. Tufa active growth is limited primarily by the availability of calcium carbonate in solution (Pedley et al., 2003).
Temporal variation in water level within GWDTE	In Ireland, petrifying springs appear to have permanent flow (Melinda Lyons, TCD, personal communication, 2012).
Ecological responses in GWDTE to changes in groundwater level and/or flow	**Changes to GWDTE groundwater supply mechanisms** Cessation of point discharge, reduced flow velocity at springs, shift from permanent flow to periodic flow, extended droughts associated with periodic flow, reduced seepage quantities and rates. **Ecological responses to changes in groundwater supply mechanisms** Interruption or cessation of tufa formation resulting in shifts in occurrence and abundance of characteristic moss species such as *Palustriella commutata, Cratoneuron filicinum* and *Eucladium verticillatum*, loss of drought-sensitive species, e.g. *Cratoneuron filicinum, Vertigo geyeri.*
Ecological responses in GWDTE to changes in groundwater chemistry	**Nitrogen and phosphorus limitation in GWDTE** Poorly understood, may be nitrogen and/or phosphorus limited. Calcite precipitation may negatively influence phosphorus availability as calcite can adsorb phosphorus (Boyer and Wheeler, 1989). **Groundwater supply mechanisms and nutrient attenuation** Potentially greater chance for nutrient attenuation associated with paludal tufas than perched springline tufas. Waterlogging associated with paludal conditions may promote denitrification (Patrick and Mahaptra, 1968). **Ecological responses to increased nutrients** Algal blooms evident at springs; shift in occurrence and abundance of nutrient-sensitive moss species and macrophytes in the short-term (Bertrand et al., 2011).

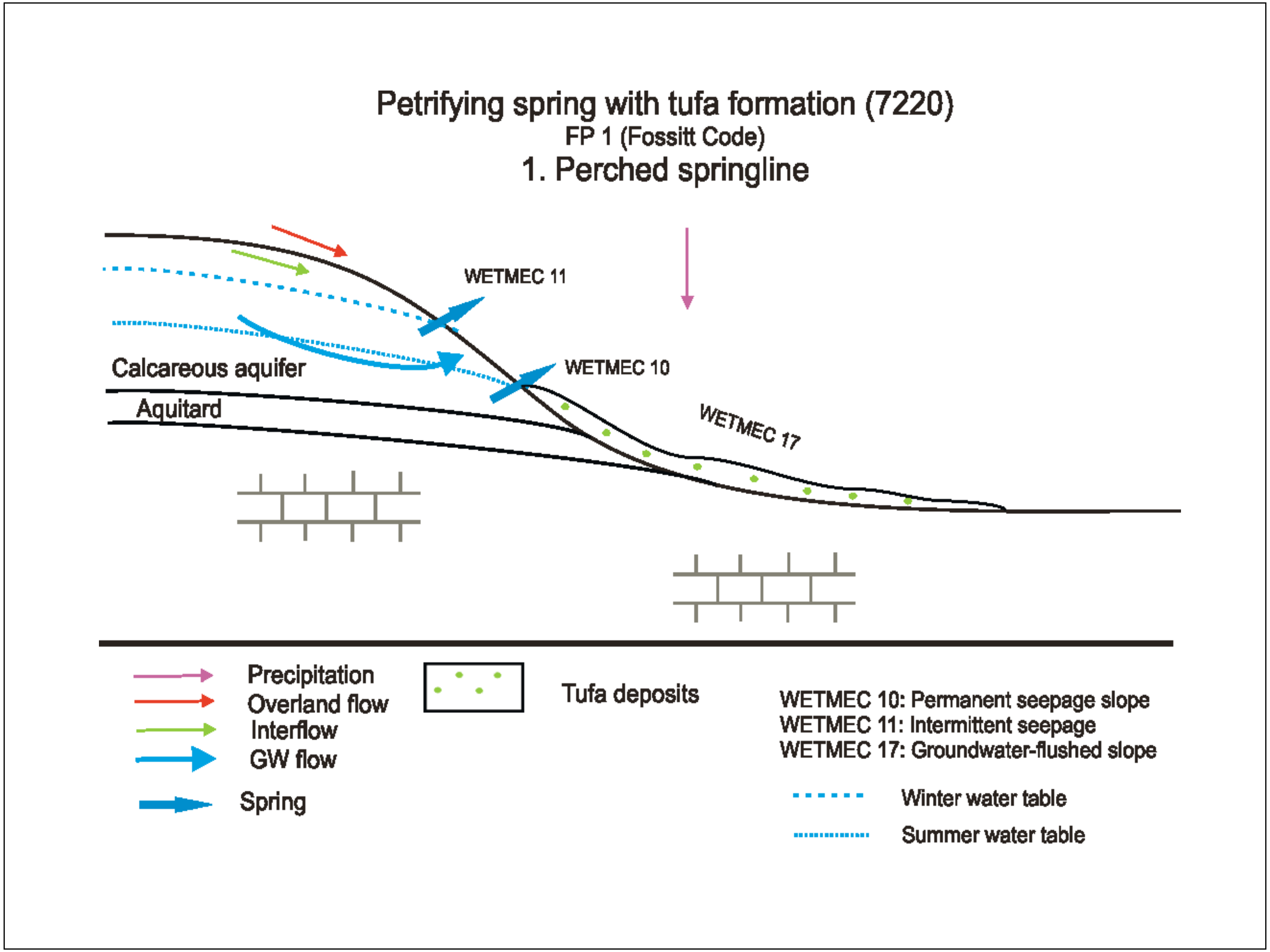

Figure 2.2. Schematic cross-section for *Petrifying springs with tufa formation (*Cratoneurion*) (7220); Type 1. Perched springline.

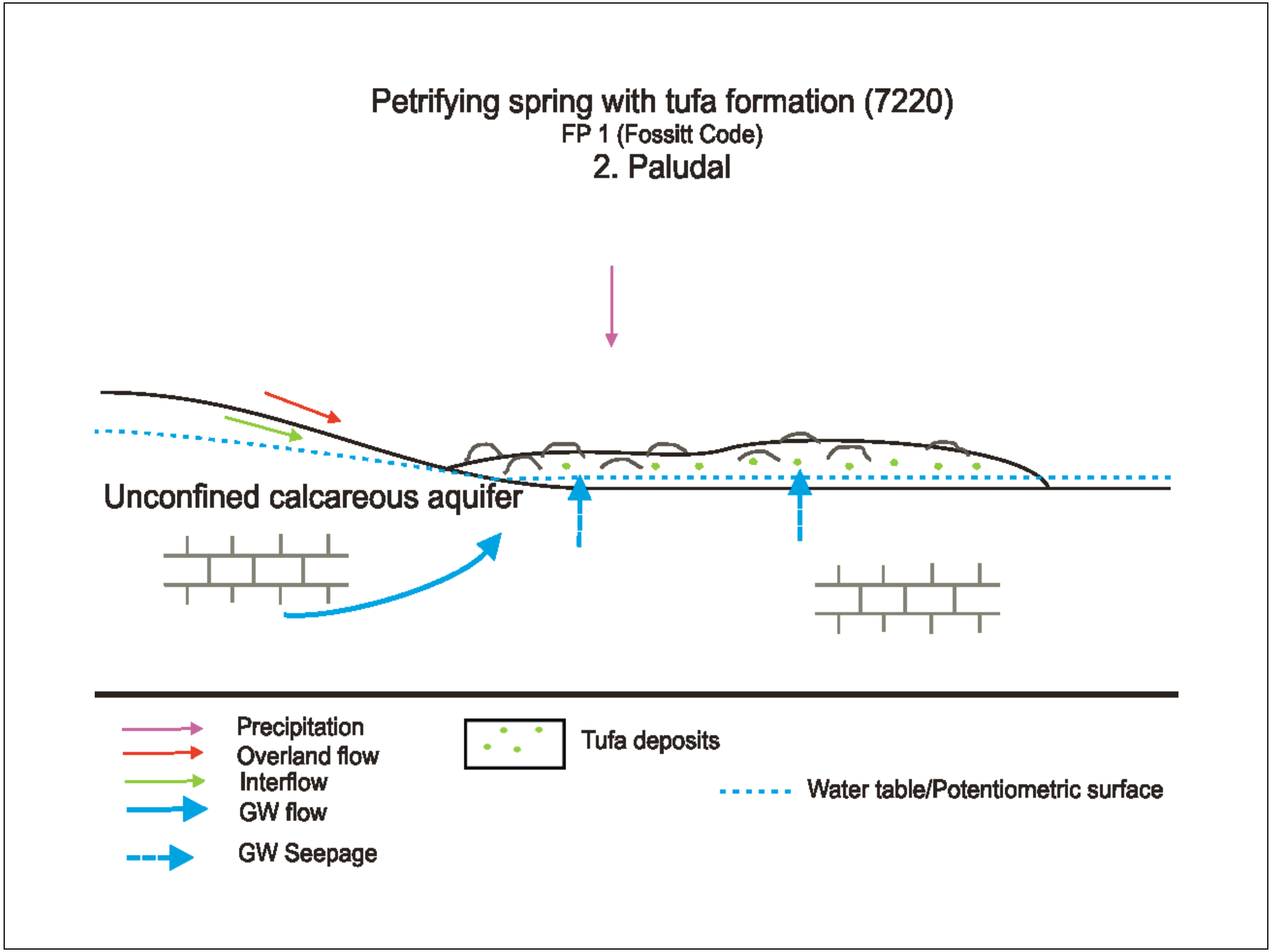

Figure 2.3. Schematic cross-section for *Petrifying springs with tufa formation (*Cratoneurion*) (7220); Type 2. Paludal.

2.6 Transition Mire (Quaking Bogs) (7140); Fossitt Habitat Code (PF3)

A transition mire is a peat-forming habitat that develops in very wet groundwater- and/or surface-water-fed basins, and has characteristics intermediate between bog and fen (EC, 2007). Transition mires are frequently associated with open waters, where their floating mats of vegetation give rise to the term 'quaking bog'. A constantly high water table is characteristic (Wheeler et al., 2009). The habitat is very varied structurally; the best-developed examples have large, bog moss-dominated hummocks separated by hollows of more minerotrophic species. Transition mires and quaking bog with significant groundwater inputs are the focus in the context of this project.

Landscape situation	Wettest parts of raised bog, blanket bog or fen and at transition areas of open water (Fossitt, 2000). Transition mires (quaking bogs) may reflect the actual succession from fen to bog.
Dominant substrata associated with GWDTE	Wetland substrates: Saturated, spongy or quaking peat (Fossitt, 2000) often underlain by lake muds (Wheeler et al., 2009). Basal substratum: Calcareous and non-calcareous subsoils and bedrock (Curtis et al., 2009).
GWB flow regime	Uncertain
Dominant water inputs	Very variable among sites. **Major:** Typically shallow groundwater and precipitation. Overland flow and throughflow from adjacent hills may be only input in some cases (Curtis et al., 2009). The groundwater contribution is low to moderate.
Groundwater supply mechanisms	Very variable among sites. High degree of uncertainty with regards to nature of connection to groundwater. May be minor, local groundwater outflow into basin from sand lenses in till subsoils. Magnitude, and in some cases direction, of any water exchange with mineral aquifer is uncertain (if connected some basins may recharge the aquifer). Groundwater inflows typically not obvious (Wheeler et al., 2009). Similar to WETMEC 3: Buoyant weakly minerotrophic surfaces (transition bogs). Other WETMECs are likely to be present.
Groundwater hydrochemistry	Broad ranges of alkalinity and base status (Curtis et al., 2009).
Temporal variation in water level within GWDTE	Minor temporal fluctuations in water level. Water level is thought to remain close to peat surface all year.
Ecological responses in GWDTE to changes in groundwater level and/or flow	**Changes to GWDTE groundwater supply mechanisms** Where the water level is directly determined by the aquifer water table, abstraction pressures may result in lowering of water table. **Ecological responses to changes in groundwater supply mechanisms** Vegetation rafts are vertically mobile to some extent. Where the water level is directly determined by the aquifer water table, the ecological response may be determined by the degree of water-level reduction that can be accommodated by vegetation rafts before significant drying occurs (Wheeler et al., 2009). Succession to a coarser, drier vegetation type (Wheeler et al., 2009).
Ecological responses in GWDTE to changes in groundwater chemistry	**Nitrogen and phosphorus limitation in GWDTE** Nutrient limitation within transition mire (quaking bog) is poorly understood. **Groundwater supply mechanisms and nutrient attenuation** Mineral subsoils, where present, afford some nutrient attenuation capacity. **Ecological responses to increased nutrients** Taller, more productive sward, with reduced species diversity (Wheeler et al., 2009).

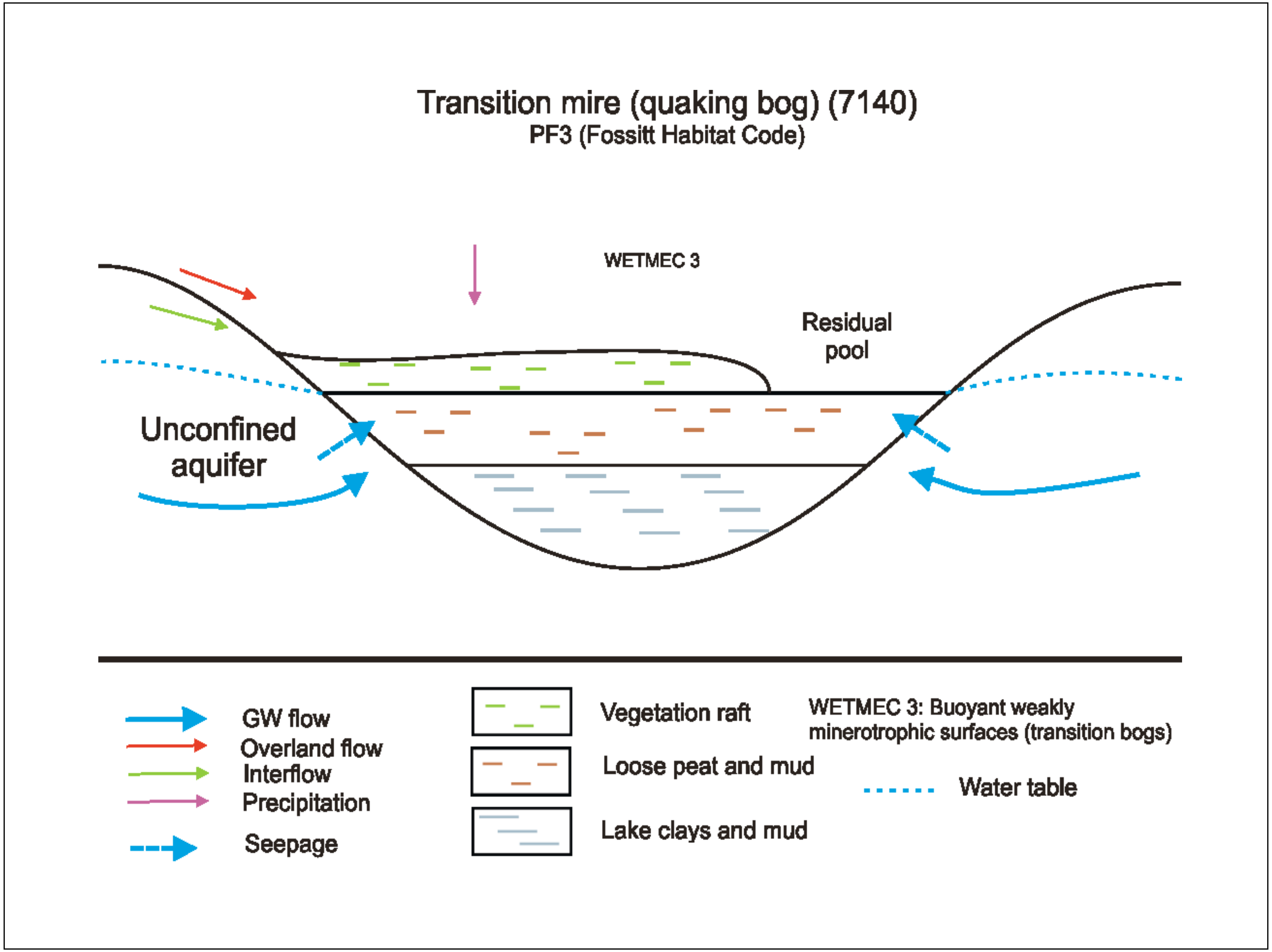

Figure 2.4. Schematic cross-section for Transition mire (quaking bogs) (7140).

2.7 *Active Raised Bogs (including lagg zone) (7110); Fossitt Habitat Code (PB1)

Very few active raised bog sites in Ireland have intact lagg zones (Jim Ryan, NPWS, personal communication, 2012).

Landscape situation	Topogenous basins in central lowlands of Ireland (Fossitt, 2000).
Dominant substrata associated with GWDTE	Wetland substrates: The central bog zone consists of peat in varying stages of decomposition and compaction. Marginal areas consist of very loose peat, at least near surface. Pools often present (Wheeler et al., 2009). Basal substratum: Glacial till deposits of varying permeability and low permeability lacustrine clay sediments, thinning towards the margins.
GWB flow regime	34% = Karstic, 60% = Poorly Productive, 4% = Fissured and 2% = Intergranular (based on spatial join between site boundaries, as determined by the Raised Bog Restoration and Monitoring Projects (see Section 3.2.1) and the national GWB flow regime data set).
Dominant water inputs	**Major:** Precipitation, groundwater (shallow and deep). **Minor:** Overland flow and interflow at margins/lagg zones. The direct groundwater contribution is low.
Groundwater supply mechanisms	Recent research suggests that groundwater hydrostatic pressures can be essential for maintaining the topography and high water table in the high bog of Irish raised bogs. This contradicts the paradigm that the central areas of raised bogs are isolated from regional groundwater flows. Consequently, raised bogs in Ireland are considered as GWDTEs under the WFD even though groundwater does not come into direct contact with the high bog vegetation (Regan and Johnston, 2010b). The lagg zone of raised bogs receives groundwater via seepage, surface flow and interflow (horizontal flow of water in a very shallow saturated surface layer) and acrotelm flow (Schouten, 2002). There may be seepage from peat into underlying till (Flynn, 1993). The lagg zone is similar to WETMEC 15 (fed by groundwater supply from marginal seepages, and in some cases by upflow).
Groundwater hydrochemistry	Typically alkaline and base rich (Shane Regan, TCD, personal communication, 2012)
Temporal variation in water level within GWDTE	Minor fluctuations.
Ecological responses in GWDTE to changes in groundwater level and/or flow	**Changes to GWDTE groundwater supply mechanisms** Water table drawdown is associated with steep marginal edges, where dome is truncated by peat extraction (Wheeler et al., 2009). A lowering of regional groundwater level, induced by local drainage or abstraction, may reduce hydrostatic pressure within the bog and result in both vertical water losses in the main bog body and increased lateral seepage at the bog margins. **Ecological responses to changes in groundwater supply mechanisms** Peat subsidence and shrinkage of main peat profile, or catotelm (Regan and Johnston, 2010a).
Ecological responses in GWDTE to changes in groundwater chemistry	**Nitrogen and phosphorus limitation in GWDTE** The high bog is ombrotrophic and highly nutrient limited whereas the lagg zone is relatively more nutrient enriched as it receives nutrient inputs from various sources, including groundwater. **Groundwater supply mechanisms and nutrient attenuation** Seepage through till and clay sediments provides an opportunity for nutrient attenuation. **Ecological responses to increased nutrients** Increased groundwater nutrients are most likely to have a direct impact on the ecology (species richness and abundances) of lagg zones but are unlikely to negatively affect the high bog.

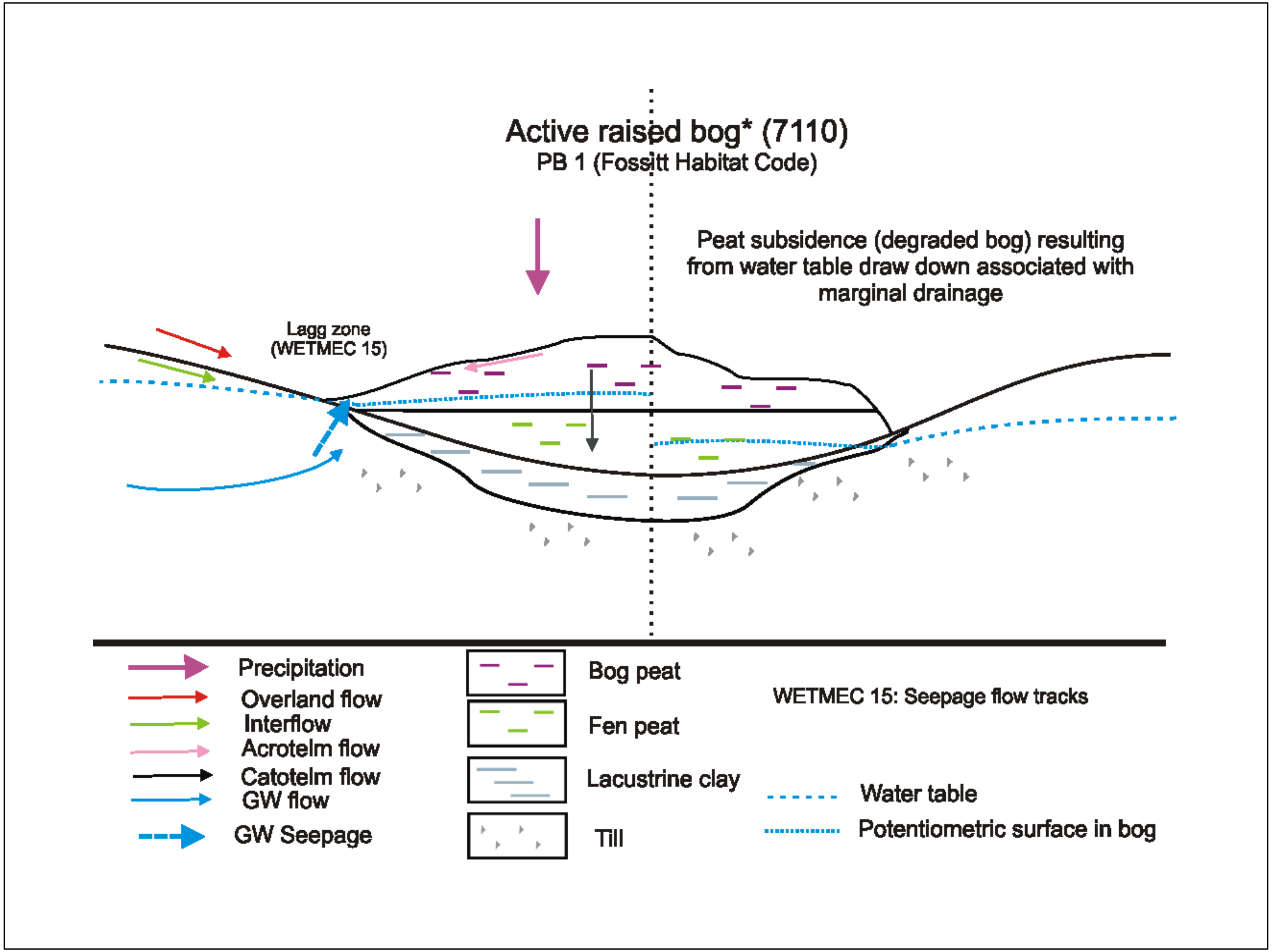

Figure 2.5. Schematic cross-section for *Active raised bogs (including lagg zone) (7110).

2.8. *Turloughs (3180); Fossitt Habitat Code (FL6)

Landscape situation	Topogenous basins.
Dominant substrata associated with GWDTE	Wetland substrata: Carbonate-rich peats or organic soils, often overlying marl, or mineral soils (Coxon, 1987b).
GWB flow regime	Karstic (turbulent flow in conduit or solutionally widened fissures, diffuse flow in fine fractures). 88% = Karstic, 9% = Poorly productive, 2% = Fissured and 1% = Intergranular (based on spatial join between confirmed turloughs in the Turlough Database (Mayes, 2008) see Section 3.2.1).
Dominant water inputs	**Major:** Groundwater (shallow and deep); discrete conduit flow. **Minor**: Precipitation, potential for overland flow and interflow at some turlough margins. A small minority of turloughs receive riverine inputs (Coxon, 1986, p. 60). The groundwater contribution is high.
Groundwater supply mechanisms	Primarily intermittent springs and estavelles, with highly variable flow velocities, and seepages at margins of low-permeability floor deposits. Strong evidence for a surge-tank model (characterised by predominance of estavelles) has been found in turloughs in the Gort Lowlands, where there is no outflow during filling periods and little inflow during recession periods (Gill, 2010; Naughton, 2011). Only two of 22 sites displayed strong hydrological evidence of a flow-through model, where groundwater inflow and outflow occur independently, and potentially simultaneously, at distinct springs and swallow holes (Naughton, 2011). Preliminary hydrochemical evidence suggests that 17 of 22 sites are rapidly flushed waterbodies (Cunha Pereira et al., 2010). It is thought that most turloughs are a complex combination of both surge-tank and flow-through functioning (Naughton, 2011). WETMECs 11 and 21.
Groundwater hydrochemistry	Turlough floodwaters are highly alkaline (112–234 mg/l $CaCO_3$) (Cunha Pereira et al., 2010).
Temporal variation in water level within GWDTE	Turloughs typically present extensive surface flooding during winter months, which drains to residual pools during summer months. They present a continuum of water-level fluctuations, however, the extremes of which are a single, annual flood event and an extremely flashy hydrological regime, with numerous flood events throughout a calendar year (Naughton, 2011).
Ecological responses in GWDTE to changes in groundwater level and/or flow	**Changes to GWDTE groundwater supply mechanisms** Loss of or reduced flow at springs and reduced seepage quantities resulting in shorter hydro-periods and reduction in flood extent. **Ecological responses to changes in groundwater supply mechanisms** Loss of or reduced extent of plant communities and species defined by a narrow and/or extended flood duration range; interruption of invertebrate life cycles; loss of turlough area indicated by reduced extent of *Cinclidotus fontinaloides* at upper elevations; encroachment of scrub at margins; interruption of calcium carbonate precipitation and deposition processes and subsequent shifts in occurrence and abundance of plant species requiring calcareous soil conditions; reversion of diverse mosaics of wetland vegetation communities to semi-natural grassland and loss of rare aquatic invertebrate species (e.g. *Graptodytes bilineatus, Agabus labiatus*) following potential complete cessation of flooding.
Ecological responses in GWDTE to changes in groundwater chemistry	**Nitrogen and phosphorus limitation in GWDTE** Phytoplankton biomass in turlough floodwaters is phosphorus limited (Cunha Pereira et al., 2010). **Groundwater supply mechanisms and nutrient attenuation** Springs provide little chance for nutrient attenuation at the turlough–GWB interface. **Ecological responses to increased nutrients** Increased phytoplankton biomass and potential algal blooms in floodwaters (Cunha Pereira, 2011), increase in occurrences and abundances of the macroinvertebrate orders Diptera and Ostracoda (Porst, 2009).

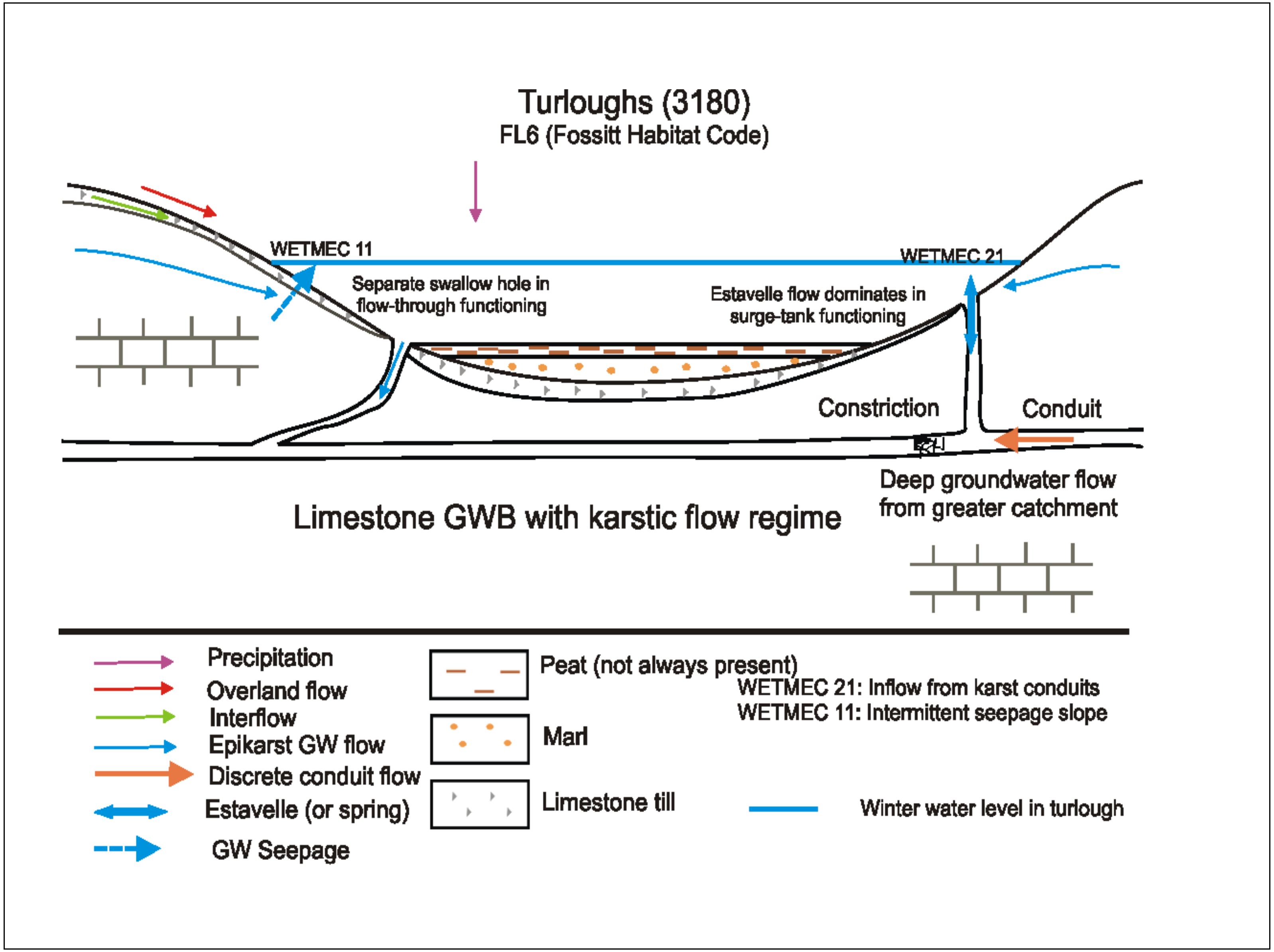

Figure 2.6. Schematic cross-section for *Turloughs (3180).

2.9 Flushes in Blanket Bog (7130) and Wet Heath (4010); Fossitt Habitat Codes (7130 and 4010, respectively)

Wet heath often forms mosaics with blanket bog. Wet heath is characterised by abundant *Calluna vulgaris*, *Erica tetralix*, *Molinia caerulea* and sedges. Blanket bog has a relatively higher cover of *Sphagnum* mosses and *Eriophorum vaginatum*. Wet heath and blanket bog are differentiated from each other by presence/absence and relative abundance of the aforementioned species and peat depth. Wet heath occurs on areas of relatively shallower peat (0.3–0.8 m depth) than blanket bog, where peat depths can range from 0.8 m to greater than 5 m (Fossitt, 2000). Flushes occur in mosaic with both habitat types.

Landscape situation	Both wet heath and blanket bog flushes often occur on sloping ground in uplands and lowlands of western Ireland (Fossitt, 2000), typically downslope of springs, where climatic conditions maintain a high water table (Averis, 2003).
Dominant substrata associated with GWDTE	Wetland substrates: Both wet heath and blanket bog flushes occur on peat of varying, often shallow, depths. Basal substratum: Both wet heath and blanket bog flushes are often underlain by a poorly permeable aquitard (Wheeler et al., 2009) overlying acidic subsoils and bedrock (Curtis et al., 2005).
GWB flow regime	Poorly productive, locally important aquifers (Jim Ryan, NPWS, personal communication, 2012).
Dominant water inputs	**Major**: Shallow groundwater flow; precipitation. The groundwater contribution is moderate to high.
Groundwater supply mechanisms	Discrete spring inflow or diffuse groundwater seepage. Potentially associated WETMECs are WETMEC 10: Permanent seepage slope; WETMEC 11: Intermittent seepage slope; and WETMEC 17: Groundwater flushed slopes
Groundwater hydrochemistry	Variable base status and alkalinity (Ray Flynn, QUB, personal communication, 2012).
Temporal variation in water level within GWDTE	Low fluctuations, groundwater flushes may experience periods of drought during summer months.
Ecological responses in GWDTE to changes in groundwater level and/or flow	**Changes to GWDTE groundwater supply mechanisms** Loss or reduced flow at springs and seepage zones. **Ecological responses to changes in groundwater supply mechanisms** Differ between flushes in wet heath and blanket bog owing to differences in species composition. Extent of flush may be reduced or lost completely owing to prolonged periods of drought. Greatly reduced cover of *Sphagnum* mosses in blanket bog flushes; increase in abundance of *Calluna vulgaris* in both.
Ecological responses in GWDTE to changes in groundwater chemistry	**Nitrogen and phosphorus limitation in GWDTE** Evidence suggests that blanket bog mires are principally phosphorus limited (Beltman et al., 1996). **Groundwater supply mechanisms and nutrient attenuation** Little chance for nutrient attenuation at springs. Movement through peat downslope may attenuate nutrients. **Ecological responses to increased nutrients** Increased vegetation biomass in response to phosphorus (Beltman et al., 1996).

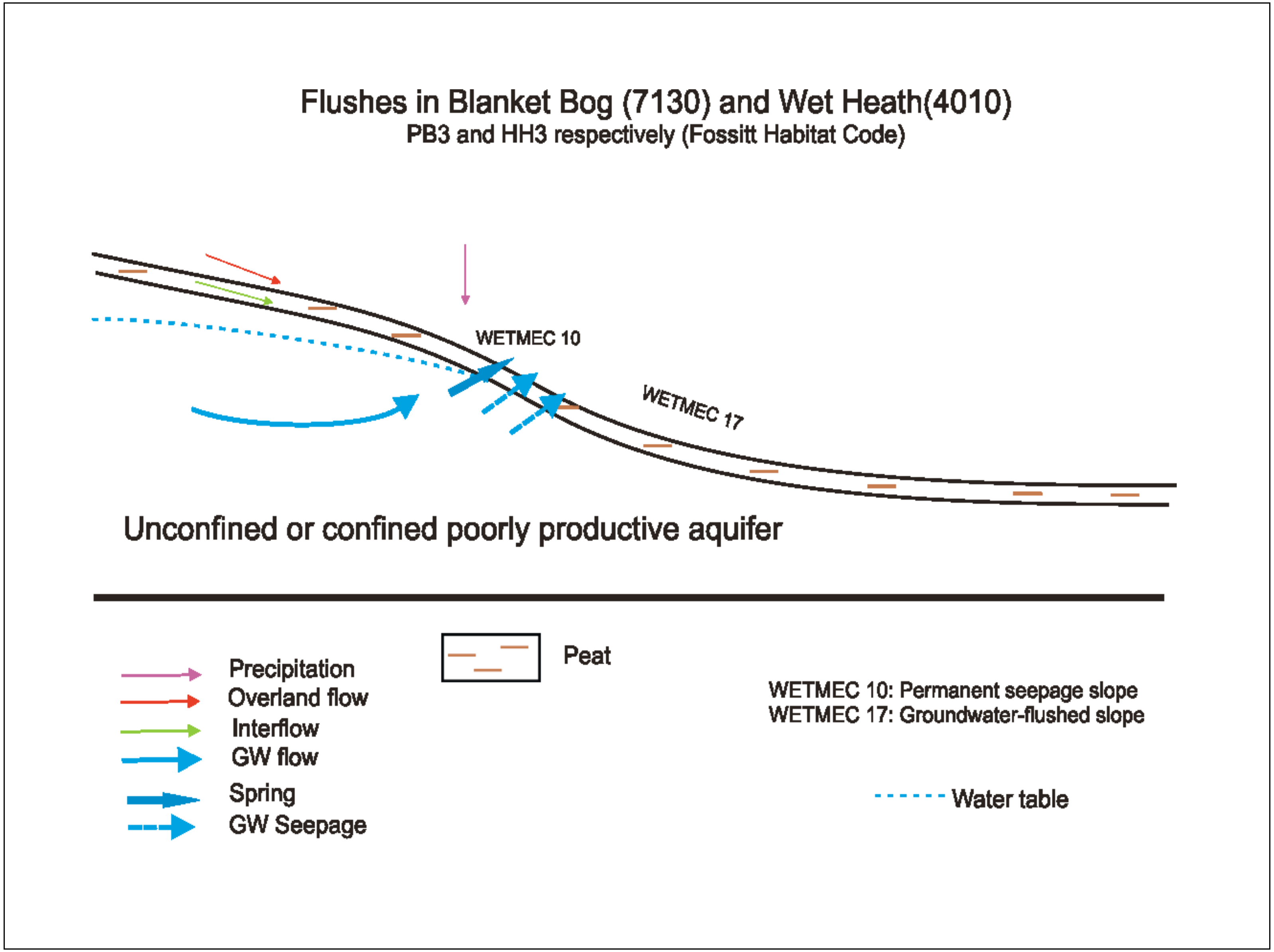

Figure 2.7. Schematic cross-section for Flushes in blanket bog (7130) and Wet heath (4010).

2.10 *Alluvial Forests with *Alnus glutinosa* and *Fraxinus excelsior* (91EO); Fossitt Habitat Code (WN4)

Alluvial forests comprise any woodland on alluvial deposits subjected to intermittent flooding by a stream, river or lake (Curtis et al., 2009). 91EO is dominated by *Alnus glutinosa*, *Salix* spp., *Quercus robur* and *Fraxinus excelsior* (Curtis et al., 2009). Flooding may occur annually or at intervals of several years but the inundation determines the vegetation in either scenario. There are six types of alluvial woodland in Ireland (John Cross, NPWS, personal communication, 2012). The most relevant in this context is the type occurring around springs or seepages associated with rivers and lakes. This type corresponds to Types 3a and 3b as classified by the National Survey of Native Woodlands (Perrin et al., 2008). Two sub-types are considered here (Wheeler et al., 2009; Jim Ryan, NPWS, personal communication, 2012):

- Type 1: Floodplain slope; and
- Type 2: Floodplain bottom.

Landscape situation	Around spring and seepage areas associated with rivers and lakes (John Cross, NPWS, personal communication, 2012).
Dominant substrata associated with GWDTE	Poorly drained alluvial soils. Type 1 is associated with silty alluvial deposits, whereas Type 2 is associated with coarse gravel deposits which may or may not be overlain with alluvium. Typical basal substrata unknown.
GWB flow regime	Uncertain for spring/seepage-fed woodlands.
Dominant water inputs	**Major:** Springs, seepages, riverine and lake surface waters. **Minor:** Overland flow, interflow and precipitation. The groundwater contribution is moderate to high.
Groundwater supply mechanisms	Type1: Springs and seepages; WETMEC 10: Permanent seepage slope. Type 2: Seepages; WETMEC 7: Groundwater floodplain (bottom). There is likely to be complex exchange between surface water and groundwater, both above and below ground, in Type 2.
Groundwater hydrochemistry	Uncertain
Temporal variation in water level within GWDTE	Moderately dynamic; strongly dependent on nature of riverine and lake water inputs.
Ecological responses in GWDTE to changes in groundwater level and/or flow	**Changes to GWDTE groundwater supply mechanisms** Reduced or loss of spring flow; reduced seepage rates and quantities. **Ecological responses to changes in groundwater supply mechanisms** Dependent on the nature of groundwater dependency, frequency of inundation from adjacent rivers or lakes and soil type (John Cross, NPWS, personal communication, 2012). Potential loss of wetland specialists such as tussock sedges. Increase in abundances of *Iris* spp., *Alnus glutinosa*, *Equisetum fluviatile*, *Salix cinerea*, *Carex* spp. as indicators of desiccation (John Cross, NPWS, personal communication, 2012).
Ecological responses in GWDTE to changes in groundwater chemistry	**Nitrogen and phosphorus limitation in GWDTE** Type 2 is unlikely to be nutrient limited owing to nutrient inputs from adjacent rivers or lakes. Type 1 may be relatively more nutrient limited than Type 2 owing to the greater distance from flood waters where nutrients will be supplied principally from groundwater (Jim Ryan, NPWS, personal communication, 2012). Type 2 is considered relatively more sensitive to enrichment from groundwater than Type 1. **Groundwater supply mechanisms and nutrient attenuation** Seepages through fine silt alluvial deposits provide greater chance for denitrification (Pinay et al., 2000) and phosphorus sorption than coarse gravel deposits (Bruland and Richardson, 2004). **Ecological responses to increased nutrients** Indicators of nutrient enrichment are *Sambus nigra*, *Urtica dioica*, *Galium aparine*, *Anthriscus sylvestris*, *Heracleum sphondylium* (John Cross, NPWS, personal communication, 2012).

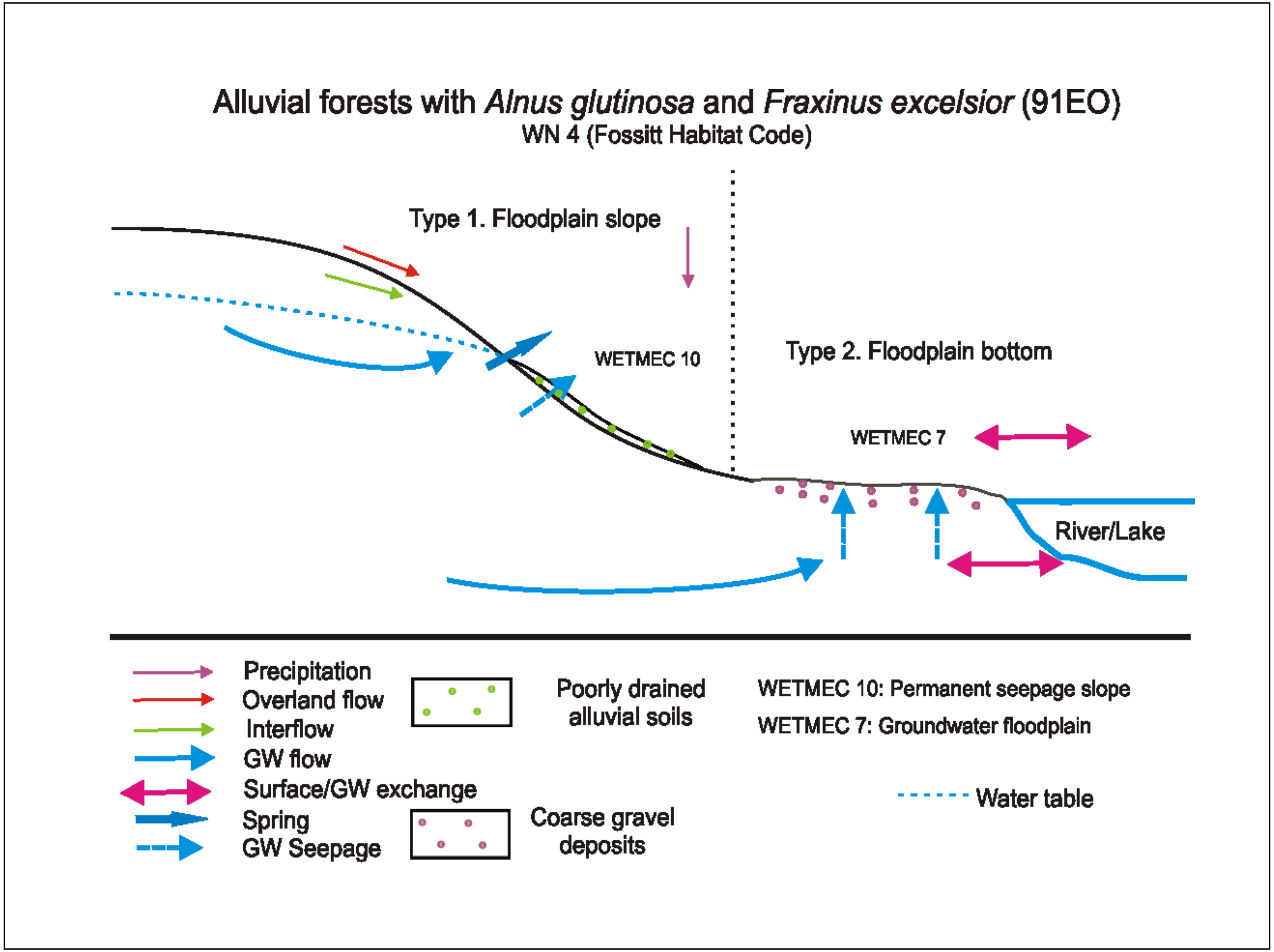

Figure 2.8. Schematic cross-section for *Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (91EO).

2.11 Humid Dune Slacks (2190) and Machair (21AO) (*in Ireland); Fossitt Habitat Codes (CD5 and CD6, respectively)

Humid dune slacks: Wet or moist hollows between dune ridges (NPWS, 2008).

Machair: Coastal semi-natural grassy plains where disturbed sands are gradually eroded by wind down to the water table (Fossitt, 2000). Shifting wet and dry patches and dune grassland vegetation types characterise machair (Curtis, 1991).

Both GWDTE types are typically associated with a small, sandy GWB underlain by a larger poorly productive aquifer, where groundwater flow and fluctuations are mainly dependent on the local topographic catchment (Áine O'Connor, NPWS, personal communication, 2012). Neither humid dune slacks nor machair are thought to be significantly connected to GWBs delineated for the WFD.

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Landscape situation	*Humid dune slacks*: Topogenous basins. *Machair*: Flat or hummocky mature coastal sand plains behind coastal dune ridges (Curtis et al., 2009).
Dominant substrata associated with GWDTE	*Humid dune slacks*: Sandy soils underlain by a low permeability layer (NPWS, 2008). *Machair*: Free-draining calcareous sands with shallow peaty patches (Curtis et al., 2009).
GWB flow regime	Uncertain, associated regional groundwater flow is likely to be poorly productive.
Dominant water inputs	*Humid dune slacks*: **Major:** Groundwater (shallow). **Minor:** Precipitation, potential brackish water intrusion. *Machair*: **Major:** Groundwater (shallow). **Minor:** Lake water at machair fringes, precipitation. The groundwater contribution for dune slacks is high and moderate for machair.
Groundwater supply mechanisms	Diffuse seepage. *Humid dune slacks:* Variant of WETMEC 12: Fluctuating seepage basin. *Machair*: Variant of WETMEC 12: Fluctuating seepage basins where shifting hollows provide an expression of the local water table.
Groundwater hydrochemistry	Base rich and calcareous for both humid dune slacks and machair. Dune slack hydrochemistry may be affected by saline intrusion.
Temporal variation in water level within GWDTE	Seasonally dynamic. Water level relatively higher in winter than summer. Typical annual range of fluctuation is c.1 m (Curtis et al., 2009).
Ecological responses in GWDTE to changes in groundwater level and/or flow	**Changes to GWDTE groundwater supply mechanisms** Groundwater level may fall below critical 1-m-below-surface threshold, extended drought during summer months, reduced flood extent and duration in winter months (Davy et al., 2006). **Ecological responses to changes in groundwater supply mechanisms** Potential loss of hydrophilic species.
Ecological responses in GWDTE to changes in groundwater chemistry	**Nitrogen and phosphorus limitation in GWDTE** A primary nitrogen and secondary phosphorus limitation is reported for dune slacks (e.g. Lammerts and Grootjans, 1997). The nature of nutrient limitation in machair is uncertain but a similar scenario to dune slacks is likely owing to high rates of nitrogen leaching from associated sandy soils. **Groundwater supply mechanisms and nutrient attenuation** Highly permeable, free-draining substrates provide little chance for phosphorus sorption or denitrification of wastewater nutrients from coastal developments. **Ecological responses to increased nutrients** Late successional and fast-growing species (e.g. *Calamagrostis epigejos*, *Molinia caerulea*) may invade and out-compete low productivity species (Bakker et al., 2005).

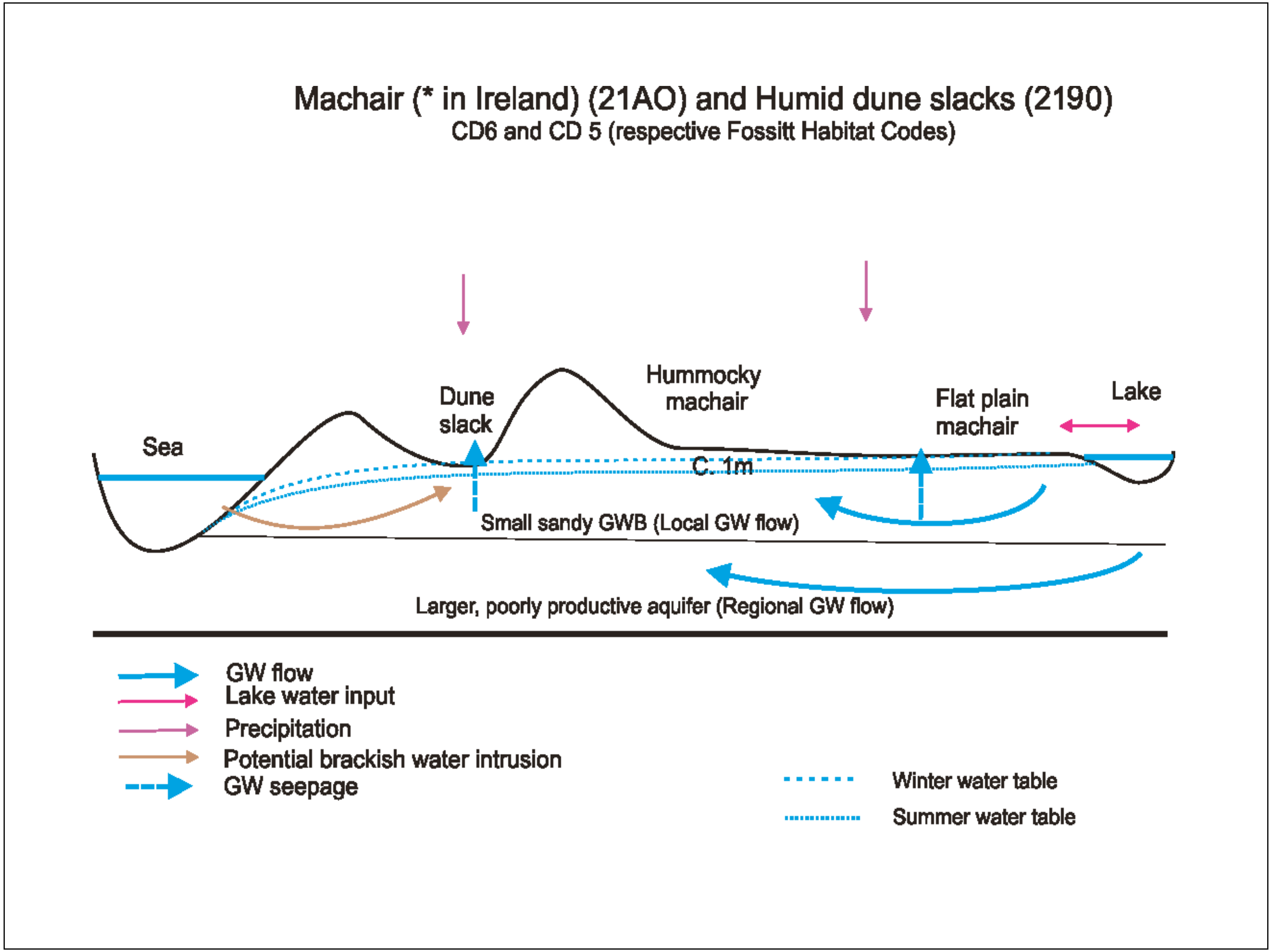

Figure 2.9. Schematic cross-section for Humid dune slacks (2190) and Machair (21AO) (*in Ireland). See Davy et al. (2006) for a more detailed diagram.

3 Determination of Groundwater Nutrient Threshold Values for GWDTEs in Ireland

3.1 Introduction

3.1.1 Development of GWDTE threshold values

Groundwater chemical TVs are a key first step in the GWB chemical status assessment process (UK TAG, 2012). Where groundwater body nutrient concentrations are greater than a GWDTE TV, there is a risk of significant damage to the GWDTE ecology that depends on this groundwater. The existence of a damaged Natura 2000 GWDTE combined with exceedance of TVs at relevant monitoring points within an associated GWB triggers further site investigation (UK TAG, 2012). GWB chemical status assessment comprises a series of five tests related to saline intrusion, drinking water, a general quality test and assessments of effects of groundwater pollutants on surface waters and GWDTEs (Fig. 1.1). The TV for each status test must be appropriate to the receptor being considered for that test, e.g. a GWDTE type (Craig and Daly, 2010). For the GWDTE chemical status test, status is determined through a combination of GWDTE assessments to determine the magnitude of the ecological damage, the societal importance of the GWDTE and an assessment of the magnitude of chemical inputs from GWBs that reach and impact upon the GWDTEs (Craig and Daly, 2010). Good chemical status is met where:

- No groundwater-dependent wetlands are identified as significantly damaged;
- One or more wetlands is identified as significantly damaged but there is high confidence that no relevant TV is breached; or
- Further investigation has concluded, based on agreement of the relevant lines of evidence, that the damage to the wetlands is not significant or that nitrate from groundwater is not making a significant contribution to it (draft UK TAG Regulatory Standards stakeholder consultation, 2012).

If the TV is exceeded at a monitoring point in the GWB, further investigations will consider the site-specific dilution and attenuation factors and the groundwater contribution to the GWDTE (Craig and Daly, 2010). Site-specific dilution and attenuation factors are necessary owing to differences in aquifer type, soil and subsoil types and hydraulic connectivity with the wetland, among other things. Dilution and attenuation factors will depend on the GWDTE/GWB interactions and the position of the monitoring points relative to the receptor (Blum et al., 2009).

3.1.2 The risk to GWDTEs from groundwater nutrients

In relation to GWDTEs, TVs are only required for those pollutants that are considered to exert a negative impact in those wetlands, primarily phosphate, nitrate and ammonium (Craig and Daly, 2010). Vegetation diversity is of general conservation interest in wetlands, having implications for, inter alia, aquatic invertebrate and bird diversity, and nitrogen- or phosphorus-limited plant growth creates conditions for high botanical diversity, with plant species adapted to low nitrogen or phosphorus availability capable of maximising nutrient use (Verhoeven et al., 1996). The vegetation of different GWDTE types may be limited, or co-limited, by nitrogen or phosphorus (see Sections 2.4–2.11); however, understanding of the nature of nutrient limitation in different GWDTE types is generally poor. A distinct aquatic phase distinguishes turloughs from other GWDTE types. The understanding of vegetation nutrient limitation in turloughs is weak; however, algal development in turlough floodwaters is limited by phosphorus (Cunha Pereira et al., 2010), thereby dictating the determination of a relevant phosphate TV.

The main pathways of contaminant flow to GWDTEs are overland flow, interflow, shallow groundwater flow, deep groundwater flow, and discrete fault/conduit flow (Archbold et al., 2010). The critical groundwater dependency of GWDTEs suggests that groundwater flows are an essential component of flow and potentially transfer pollutants to GWDTEs; however, the nature and extent of groundwater dependency and vulnerability to the ingression of pollutants vary among GWDTE types. In Ireland, groundwater vulnerability is determined mainly according to subsoil (Quaternary deposit) thickness and permeability, properties that influence pollutant attenuation processes (Misstear and Brown, 2008). GWDTEs occurring in areas with thin or absent subsoils, e.g. turloughs, are particularly vulnerable to nutrient enrichment from groundwater. Nutrient attenuation at the GWDTE/GWB interface and the nature of nutrient limitation associated with each GWDTE type will determine the impact of groundwater nutrients on GWDTE ecology. During RBMP1, 132 GWBs were identified as containing one or more GWDTEs and were the subject of a suite of risk assessments (WFD Working Group on Groundwater, 2004b) as part of the WFD Article V Characterisation and Risk Assessment (2005). The predominant GWDTE types dealt with in the 2004/2005 risk assessment work were alkaline and *Cladium* fens, active raised bog, petrifying springs and turloughs. For GWDTE types other than turloughs, risk categories were adjusted using available groundwater data (WFD Working Group on Groundwater, 2004b). Generally, only molybdate reactive phosphorus (MRP) data were available for groundwater, in which case river criteria were applied. Predicted risk categories for turloughs were adjusted using available within-turlough and groundwater impact data (WFD Working Group on Groundwater, 2004b). Screening values for within-turlough data were based on Organisation for Economic Co-operation and Development (OECD) trophic standards for lakes (OECD, 1982). Screening values for groundwater data were based on the Phosphorus Regulations' standards for MRP in lakes.

3.1.3 UK TAG methodology for determining TVs for GWDTEs

GWDTE chemical groundwater TVs were developed in the UK using three sources of information (UK TAG, 2012), namely:

1. Correlation between GWDTE condition and chemistry data from hydrogeologically linked groundwater bodies across the UK;
2. Site-specific investigations; and
3. Other published databases and literature.

The data analysis involved the comparison of groundwater nitrate and phosphate data among GWDTEs in good or poor ecological condition. This process identified groundwater quality monitoring boreholes within 2 km of groundwater-dependent Natura 2000 sites and evaluated hydrogeological linkages between the monitoring points and GWDTEs. For each site, the 6-yearly, or 3-yearly if 6-yearly were not available, mean groundwater chemical concentrations were calculated from 2000–2005 data (the data used for groundwater body classification in the first RBMPs).

In the UK, the condition of each GWDTE was measured using the relevant Joint Nature Conservation Committee (JNCC) Common Standards for Monitoring (JNCC, 2004) carried out by the nature conservation organisations. Sites of favourable conservation status were deemed to be in good ecological condition. In this case, any input from groundwater is not **currently** causing significant damage to the wetland. Poor ecological condition sites were taken as sites in unfavourable conservation status and those showing evidence of a nutrient impact. In this case, groundwater **could** be causing significant damage to the wetland, although other pressures may be the source of the damage (UK TAG, 2012).

Sites were assigned to good and poor ecological groups based upon the ecological condition information. A set of rules was developed to identify at which concentration the TV should lie, using the three data sources (UK TAG, 2012), namely:

1. Empirical correlation between wetland condition and chemistry data for hydrogeologically linked GWBs;
2. Site-specific investigations; and
3. Other published databases and literature.

Two of the rules state that the TVs should lie above the mean and ideally above the 75th percentile for sites in good condition and below the mean and preferably below the 25th percentile for sites in poor condition. The UK TAG used logistic regression to evaluate the initial TV by showing the probability that a GWDTE at a given nitrate concentration would be in good or poor condition. This analysis increased the confidence of the whole of the UK TAG and conservation organisations in the outcome of the TV work (UK TAG, 2012).

3.2 Methods

The methodology used in this study involved the following sequence of steps:

1. Collation of spatial data sets for the range of GWDTE types under investigation;
2. Identification of groundwater monitoring points that are potentially hydrogeologically linked to each GWDTE type, with a view to selecting GWDTE types for which sufficient data are available to merit further analysis;
3. Identification of groundwater monitoring points where there is a moderate or high confidence that groundwater is representative of water feeding a selected GWDTE;
4. Assessment of the ecological condition for sites that contain selected GWDTE types and that are hydrogeologically linked (high/moderate confidence) to groundwater monitoring points;
5. Numerical derivation of TVs; and
6. Comparison of UK GWDTE TVs with those proposed for Ireland.

3.2.1 Collation of spatial GWDTE data sets

Nine national and four county data sets were available to the project. Their sources and accompanying reports are presented in Tables 3.1 and 3.2. The majority of the spatial data sets comprise polygons delineating site boundaries, with the exception of the Turlough Database and the National Spring, Fen and Flush Survey (NSFFS) data set.

The GWDTE SAC database was obtained via the EPA and presents the spatial location information for

Table 3.1. National data sets, their sources and accompanying reports used during the project.

National spatial data set	GWDTE types[1]	Point/Polygon	Data source/Accompanying report	Date range
National Spring, Fen and Flush Survey Database	AKF, CLF, PTS, TNM	Point	Foss (2007)	2006 to present (updates ongoing)
GWDTE SAC Database	AKF, CLF, TNM, PTS, ARB, ALF, TUR, MAC	Polygon	Kilroy et al. (2008)	2006–2008
Derived Irish Peat Map	ARB	Polygon	Connolly and Holden (2009)	2000–2006
Raised Bog Restoration Project	ARB	Polygon	Kelly et al. (1995)	1994–2003
Raised Bog Monitoring Project	ARB	Polygon	Valverde et al. (2005)	2004–2005
Blanket Bog NHAs	WTH, TNM	Polygon	Barron and Perrin (2010)	2004–2010
Turlough Database Consolidation Project	TUR	Point	Mayes (2008)	2007–2008
National Survey of Native Woodlands	ALF	Polygon	Perrin et al. (2008)	2003–2008
Coastal Monitoring Project	MAC, HDS	Polygon	Ryle et al. (2009)	2004–2006

[1]See Table 2.1 for GWDTE type descriptions.
GWDTE, Groundwater-dependent terrestrial ecosystem; SAC, Special Area of Conservation; NHA, Natural Heritage Area.

Table 3.2. County data sets, their sources and accompanying reports used during the project.

County spatial data set	GWDTE types	Point/Polygon	Data source/Accompanying report	Date range
Co. Sligo Wetlands Survey	Broad range of wetland types	Polygon	Wilson (2009)	2008–2009
Co. Louth Wetlands Survey	Broad range of wetland types	Polygon	Foss et al. (2011a)	2011
Co. Monaghan Wetlands Survey	Broad range of wetland types	Polygon	Foss et al. (2011b)	2011
Co. Monaghan Fen Survey	Broad range of fen types	Polygon	Foss and Crushell (2011)	2007–2008

GWDTE, Groundwater-dependent terrestrial ecosystem.

GWDTEs occurring within at-risk SAC complexes (Kilroy et al., 2008). This file was cross-referenced with the NPWS SAC data set to identify additional SAC sites designated for calcareous fens that did not require more detailed mapping as part of the Kilroy et al. (2008) project. Spatial data sets generated from recent county wetland surveys were also requested from the Heritage Officers in counties Louth, Sligo and Monaghan. Further detailed descriptions of the nature of the data sets and caveats, as noted in the accompanying reports, are presented in Appendix 2. The project found several problems with the spatial data sets for each of the GWDTE categories and they are described per GWDTE category in the following sections.

3.2.1.1 *Alkaline fens, species-rich* Cladium *fens, petrifying springs, transition mires and wet heath*

The NSFFS and GWDTE SAC data sets provide information on a range of GWDTE types and are the only source of information for Alkaline fens (7230), species-rich *Cladium* fens (7210) and Petrifying springs (7220). In the NSFFS data set, more than one GWDTE is often assigned to a point and consequently the site counts for each type are not independent of each other. There are currently grid reference inaccuracies and uncertainty in relation to the extent of GWDTE types within the vicinity of each point. This data set was compiled as a precursor to a field survey, which has not taken place to date.

Polygons in the GWDTE SAC database designated for alkaline fen are also often co-designated for *Cladium* fen and transition mire and the extent of each type within polygons is uncertain. Kilroy et al. (2008) noted that *Cladium* fen and *Cladium* swamp were not sufficiently described within the NPWS file data to discriminate between the two habitat types. This is still the case and much of the area mapped as *Cladium* fen may not be the high conservation value species-rich *Cladium* fen (7210). The GWDTE SAC data set provided improved GWDTE spatial extent information for SAC complexes; however, this information was generated via a desk study and many sites remain to be ground-truthed. There was little overlap between the points and polygons designated for calcareous fens in the NSFFS data set and the GWDTE SAC data set, respectively, further highlighting the need for a dedicated fen field survey. There was also little overlap between the points and polygons in the respective data sets for petrifying springs.

A current PhD project (Melinda Lyons, Trinity College Dublin) is investigating the hydroecology of petrifying springs in Ireland and will improve the spatial information for this GWDTE type, although it should be noted that this research focuses on sites of high ecological quality so is unlikely to provide a database for comparison of sites in good versus poor ecological condition. The transition mires mapped within the GWDTE SAC database also do not coincide with points in the NSFFS database or the Blanket Bog NHA data set. The latter data set, although desk-study based, is considered the most reliable source of information for transition mires, wet heath and flushes.

3.2.1.2 Active raised bogs

Information for active raised bog features in four data sets, namely the GWDTE SAC database, the Derived Irish Peat Map, and the Raised Bog Monitoring and Restoration Project data sets. A small proportion of sites mapped for active raised bog in the GWDTE SAC data set do not occur in either of the Raised Bog Monitoring or Restoration data sets. Approximately 85% of the raised bog extent as mapped in the Derived Irish Peat Map is undesignated and consequently site counts were based on the Raised Bog Monitoring or Restoration data sets, which focus on designated sites. Prior to the site counts, site sub-polygons were merged to create a discrete site boundary for each raised bog site.

3.2.1.3 Turloughs

Turloughs are one of the most commonly occurring GWDTE types, with 256 confirmed sites. An ongoing project titled *Assessing the Conservation Status of Turloughs* (Kimberley, 2011) has delimited site boundaries for 22 of these sites. The NPWS Turlough Database consists of points rather than polygons. The polygons for the 22 turloughs have not been added to this data set as yet.

3.2.1.4 Alluvial forests

Alluvial forests are also commonly occurring Natura 2000 sites; however, many sites are associated with riverine and surface waters and the extent of the groundwater dependency of each site is uncertain.

3.2.1.5 Machair and humid dune slacks

Finally, the Coastal Monitoring Project data set provides detailed information for machair and dune slacks. In the case of machair, site sub-polygons were merged to create a site boundary for each Coastal Monitoring Project Site. This was not done for dune slacks as this data set consisted of mostly disjointed polygons. Individual polygons represent discrete, often small areas of dune slack.

3.2.2 Assessing potential hydrogeological links between GWDTEs and groundwater monitoring boreholes

This section clarifies how this study identified groundwater monitoring points for which a moderate or high confidence exists that this groundwater is feeding an associated GWDTE. This work was conducted in close co-operation with Matthew Craig of the EPA's Hydrometric and Groundwater Section.

Point data sets of the drinking water quality and groundwater quality monitoring networks were obtained from the EPA. The drinking water quality monitoring network for groundwaters does not include phosphate, so only nitrate data were used. The groundwater quality monitoring network has a lower density than the drinking water quality monitoring network but includes both nitrate and phosphate data.

Initial spatial queries identified the number of monitoring points occurring within 5 km of sites of each GWDTE type. A 5-km cut-off was used rather than the 2-km cut-off of the UK approach as low numbers of monitoring points were within 2 km of Irish GWDTEs.

A more rigorous evaluation of the linkages between monitoring points and GWDTEs was conducted using a series of steps as outlined below:

1. The location of the monitoring point in relation to the GWDTE polygon was described as upgradient, downgradient, parallel or uncertain, using tracing information where available;

2. The distance between the monitoring point and the GWDTE was measured and noted as either less than 2 km or between 2 and 5 km; and

3. Co-occurrence of the GWDTE and monitoring points within the same groundwater bodies and aquifers was noted.

GWDTE/Monitoring point pairings were considered **unsuitable** where the GWDTE and monitoring point:

- Occurred in different GWB types (e.g. where flow is unlikely between a poorly productive bedrock and karstic bedrock);

- Where the GWDTE was greater than 2 km from the monitoring point in a poorly productive GWB with short flow paths; or

- Where both were separated by a significant surface water body.

This resulted in a level of confidence (high/moderate/low) of the probability that the groundwater at the monitoring point is feeding a particular GWDTE.

3.2.3 Rationale behind the selection of calcareous fens for determination of TVs

3.2.3.1 Review of spatial data sets and site numbers for each GWDTE type

Site counts were used to determine the relative abundance or rarity of the 11 GWDTE types in Ireland (Table 3.3) in order to prioritise types for TV development. The Steering Group made a decision to only use those types with sufficient data and which were not already part of other research projects.

Table 3.4 describes how many groundwater monitoring points are associated with each GWDTE type. The majority of GWDTE types lacked a sufficient number of reasonably close monitoring points to justify further the development of TVs. Calcareous fens, active raised bog, turloughs, alluvial forests and dune slacks had potentially sufficient data points. However, the ongoing project titled *Assessing the Conservation Status of Turloughs* (Kimberley, 2011) aims to propose TVs relevant to turloughs and it was therefore decided to focus on the remaining GWDTE types as part of the project reported here. The groundwater dependency of active raised bogs, alluvial forests and dune slacks is an ongoing source of debate. Recent findings suggest that groundwater provides a vital supporting function for active raised bogs (Regan and Johnston, 2010b); however, these findings are based on investigations of Clara Bog and evaluating groundwater contributions to a broader range of raised bog sites was considered too complex for this short-term project. Many of the alluvial forests are fed primarily by surface waters and further work is needed to identify the most groundwater-dependent alluvial forest sites. Finally, dune slacks were not selected for further work as they are generally thought to be fed by small sandy deposits overlying larger, poorly productive GWBs. The sandy deposits are often localised in nature and are not substantial enough to satisfy the requirements for delineating a GWB. Therefore their status does not arise in terms of WFD reporting and classification.

Taking these considerations into account the Steering Group decided to focus on applying the UK TAG methodology to calcareous fens, including both alkaline fens and *Cladium* fens, which have a high groundwater dependency and occur extensively throughout Ireland. The focus was on determining a nitrate TV given the low numbers of associated groundwater monitoring points with phosphate data.

Further TV development for calcareous fens used the GWDTE SAC database. The initial screening phase identified 55 fens with potentially hydrogeologically linked drinking water and groundwater monitoring points and information on the ecological condition of these sites was collated (Section 3.2.4). In many cases there were pseudo-replication issues, where often fens had two or more potentially linked monitoring points.

3.2.4 Ecological condition assessments

Following the compilation of a provisional site list of calcareous fens with hydrogeologically linked monitoring points, NPWS SAC files, conservation reports and expert personnel were consulted in order to collate information on the ecological condition (good or poor) of the sites. An overall ecological condition was determined using this variety of sources and a level of confidence (high/moderate/low) was assigned to the ecological condition assessment because many Irish GWDTEs lack a site-specific standardised conservation assessment. The UK TAG approach did not assign a level of confidence to the ecological assessments because standardised conservation assessments were available for the UK GWDTEs.

3.2.4.1 Ecological condition assessments

Of the original list of 55 alkaline fens, NPWS and Julian Reynolds (TCD, personal communication, 2012) identified nine sites as ecosystems other than calcareous fens (being rather swamp/lakeshore fen, base-flushed cutovers, brackish wetland, field pond or non-calcareous fen) and these sites were excluded from further data analysis. Two sites were noted as extensively damaged by drainage rather than nutrient enrichment and were also removed from the list.

An output summary of the ecological information for the final list of 44 calcareous fen sites is presented in Table 3.5 and in the working spreadsheet

Table 3.3. Site numbers for each groundwater-dependent terrestrial ecosystem (GWDTE) type as recorded in the available national data sets. See Appendix 2 for more information on basis of site number counts.

National spatial data set	GWDTE types[1]	Site numbers
National Spring, Fen and Flush Survey Database	AKF	228 (often more than one GWDTE type assigned to an individual point)
	CLF	105 (often more than one GWDTE type assigned to an individual point)
	PTS	87 (often more than one GWDTE type assigned to an individual point)
	TNM	137 (often more than one GWDTE type assigned to an individual point)
GWDTE SAC Database	AKF and/or CLF	111 polygons across 26 SACs
	TNM	3 polygons across 3 SACs
	PTS	14 polygons across 6 SACs
	ARB	5 polygons across 5 SACs
	ALF	2 polygons representing 2 SACs
	TUR	32 polygons across 12 SACs
	MAC	1 polygon representing 1 SAC
Derived Irish Peat Map	ARB	Merged generalised polygon for raised bog, much of this area is undesignated and not active raised bog
Raised Bog Restoration Project and Raised Bog Monitoring Project	ARB	136 (polygons represent individual SACs or NHAs) Raised Bog Restoration Project: 87 sites Raised Bog Monitoring project: 49 sites
Blanket Bog NHAs	WTH	48 (confirmed Annex I Habitat)
	TNM	50 (confirmed Annex I Habitat)
	BBF	461 (fens and flushes/flushed areas, unconfirmed and area uncertain)
Turlough Database Consolidation Project	TUR	483 (227 need to be ground-truthed)
National Survey of Native Woodlands	ALF	191 polygons total, SAC and non-SAC, 88 polygons across 31 SACs
Coastal Monitoring Project	MAC	61 discrete machair Coastal Monitoring Project Sites across 30 NPWS sites
	HDS	311 disjointed polygons (72 Coastal Monitoring Project Sites) across 50 NPWS sites

[1]See Table 2.1 for GWDTE type descriptions.
SAC, Special Area of Conservation; NHA, Natural Heritage Area; NPWS, National Parks and Wildlife Service.

Table 3.4. Site numbers for each groundwater-dependent terrestrial ecosystem (GWDTE) type as recorded in the available national data sets.

National spatial data set	GWDTE types[1]	Site numbers	No. of sites within 5 km of drinking water monitoring point (ground or spring)	No. of sites within 5 km of groundwater quality monitoring points	Availability and quality of conservation assessment (CA) information associated with each data set
GWDTE SAC Database	AKF and CLF	110 across 26 SACs	71	21	No CA information generated by mapping project. Overall CA information for discrete SAC sites and SAC complexes is available from Natura 2000 Standard Data Forms
	TNM	3 across 3 SACs	2	2	
	PTS	14 across 6 SACs	10	5	
	ARB	2 of 2 SACs	5	2	
	ALF	2 of 2 SACs	2	2	
	TUR	32 across 12 SACs	29	15	
	MAC	1 of 1 SAC	0	0	
Raised Bog Restoration Project and Raised Bog Monitoring Project	ARB	136 (polygons represent individual SACs or NHAs)	101	29	Detailed sub-habitat maps and conservation assessments for each raised bog site
Blanket Bog NHAs	WTH	48 (confirmed Annex I Habitat)	24	5	Detailed habitat maps but lacking conservation assessment information
	TNM	50 (Confirmed Annex I Habitat)	18	0	Detailed habitat maps but lacking conservation assessment information
Turlough Database Consolidation Project	TUR	256 (ground-truthed turloughs)	206	108	Comprehensive compilation of general site information. No conservation assessment information in attribute table but directed towards sources of information
National Survey of Native Woodlands	ALF	191 (total number of polygons, SAC and non-SAC)	100	52	Detailed conservation assessment information available in the NSNW project database
Coastal Monitoring Project	MAC	61 discrete machair Coastal Monitoring Project Sites across 30 NPWS sites	19	6	Detailed conservation assessment information available in Coastal Monitoring Project database
	HDS	311 disjointed polygons across 49 NPWS sites	99	24	Detailed conservation assessment information available in Coastal Monitoring Project database

[1]See Table 2.1 for GWDTE type descriptions.
SAC, Special Area of Conservation; NHA, Natural Heritage Area; NSNW, National Survey of Native Woodlands; NPWS, National Parks and Wildlife Service.

Table 3.5. Summary of ecological condition information for 44 calcareous fen sites with potentially hydrogeologically linked drinking water and/or groundwater quality monitoring points.

Ecological condition assessment (confidence level)	Number of calcareous fen sites
Good (high and moderate confidence)	13
Good (low confidence)	29
Sites with disputed ecological condition	2

EPA_GWDTE_TV_ExcelFiles_2012.xls[3]. The NSFFS data set was cross-referenced with the calcareous fen polygons with potentially hydrogeologically linked monitoring points, and conservation value assessments were noted where available.

In Ireland, many of the calcareous fens identified as linked to monitoring points occurred within large SAC complexes and lacked a polygon-specific conservation assessment. Forty-two of the 44 sites were identified as in good ecological condition (Table 3.5). Ecological assessments based on both Natura 2000 Standard Data forms and expert judgement from personnel familiar with the sites were assigned a high or moderate confidence level. Ecological assessments purely based on Natura 2000 Standard Data forms (for the whole SAC complex) were assigned a lower confidence. Thirteen of the 42 sites are in good ecological condition with high or moderate confidence, with the remaining 29 sites in good ecological condition but with a lower confidence (**note, although a lower confidence is assigned there is no evidence to suggest that these 29 sites are in poor ecological condition**). The remaining two sites, Scragh Bog, Co. Westmeath, and Pollardstown Fen, Co. Kildare, had conflicting ecological condition assessments from various sources and were excluded from further data analysis. Following the ecological condition assessment, the monitoring points potentially linked to each calcareous fen GWDTE were re-examined in order to identify the most suitable monitoring point(s) to use. A mean value was calculated in cases where more than one monitoring point was potentially linked to a GWDTE with a moderate or high confidence.

3.2.5 Data analysis

It was intended to analyse the data according to statistical protocol in UK TAG (2012). These analyses are based on comparisons of nutrient concentrations among calcareous fens in good and poor ecological condition. Critically, there was a lack of a poor ecological condition category, which prevented a relative comparison with the good ecological condition Irish fens. The analysis was therefore restricted to simpler summary statistics, presented as tables and box plots.

The lack of a poor ecological condition category of Irish calcareous fens prompted exploration of the possibility of using nitrate data for poor ecological condition oligotrophic fens with petrifying springs (oligotrophic fens for short) in the UK for the determination of a TV. In the UK, TVs were generated for altitude subcategories for each GWDTE type as a strong positive correlation was found between GWDTE altitude and groundwater nitrate concentrations, with the majority of low nitrate concentrations found above 175 mAOD[4]. The respective TVs for low altitude and mid-altitude oligotrophic fens in the UK are 20 mg/l NO_3 and 4 mg/l NO_3. All Irish fens in good ecological condition had an altitude less than 175 mAOD and were considered comparable with low altitude oligotrophic fens in the UK. Oligotrophic fens are considered to be similar to Irish calcareous fens although they are not classified according to the same criteria as used in Ireland. UK GWDTE classification is largely based on the British National Vegetation Classification (NVC), whereas Irish GWDTEs are classified according to criteria for Annex I habitats as outlined in the Habitats Directive Interpretation Manual (EC, 2007). If there were clear differences between lowland calcareous fens in good ecological condition in Ireland and in poor ecological condition in the UK this would at least provide a range within which to propose a provisional TV for Irish calcareous fens pending further investigation. Data normality of good ecological condition Irish calcareous fens (N = 42) and poor ecological condition low altitude UK fens (N = 12) was

3. http://www.erc.epa.ie/safer/

4. mAOD, metres Above Ordnance Datum.

checked using the Shapiro–Wilks test (N < 50) prior to and post transformation. The non-parametric Mann–Whitney *U* test and the Kruskal–Wallis test were used to compare nitrate concentrations among both groupings as transformation did not yield an approximately normal distribution for the Irish fen group. Data analyses were carried out using SPSS version 16.0.

3.3 Results

A frequency distribution of nitrate concentrations in groundwater linked to Irish fens in good ecological condition is presented in Fig. 3.1, while a frequency distribution, taking into account the confidence in the ecological condition, is presented in Fig. 3.2. Summary statistics for nitrate concentrations in groundwater linked to Irish calcareous fens and UK oligotrophic fens with tufa-forming springs are presented in Table 3.6 and accompanying box plots are presented in Fig. 3.3. Summary statistics for phosphate concentrations in groundwater linked to Irish calcareous fens (N = 4) are also presented in Table 3.6.

A bimodal distribution is evident in Fig. 3.1. However, when the data are grouped according to confidence in the ecological condition assessments (Fig. 3.2), all sites associated with monitoring points where groundwater nitrate concentrations are in excess of 20 mg/l NO_3 are in good ecological condition but have a low confidence in the ecological condition assessment and are exclusive to the Askeaton Fen SAC Complex.

Nitrate concentrations in groundwater linked to good ecological condition Irish calcareous fens were compared with data from UK fens in good and poor ecological condition (Fig. 3.3). All of the 42 Irish fens in good ecological condition had an altitude less than 175 mAOD, which was equivalent to low altitude fens in the UK. The range of nitrate concentrations in groundwater linked to low altitude oligotrophic fens in good ecological condition in the UK is much broader than the range for Irish calcareous fens in good ecological condition, both including and excluding the sites with a low confidence in their ecological assessments.

There was no significant difference in nitrate concentrations between good ecological condition Irish calcareous fens and poor ecological condition low altitude oligotrophic fens in the UK (Mann–Whitney $U = 161$, $P > 0.05$; Kruskal–Wallis $H = 3.595$, $P > 0.05$). Because there was no significant difference between Irish good condition calcareous fens and UK poor condition oligotrophic fens (low altitude) it was not considered appropriate to undertake any further statistical work aimed at finding a TV placed appropriately between the Irish sites in good condition and UK sites in poor condition. The range of nitrate concentrations for Irish calcareous fens in good ecological condition is similar to the range for UK mid-altitude oligotrophic fens in poor ecological condition.

The lack of a poor ecological grouping prevents the use of a comparative approach for determining a scientifically robust nitrate TV for Irish calcareous fens. An alternative approach is to use the limited Irish data for good ecological condition calcareous fens to determine a TV. Not taking into account the confidence in ecological condition assessments and following the UK TAG approach, the nitrate TV should lie above 12 mg/l NO_3 or 21.6 mg/l NO_3 as the mean and 75th percentile, respectively, of the good ecological grouping. The lack of confidence in the ecological condition assessments should be taken into account, however, especially as fens associated with relatively higher concentrations of groundwater nitrate have low confidence in their ecological condition assessments. Therefore there is no clear justification for excluding the low confidence ecological assessments from the data set nor is it acceptable to overlook the significance of the bimodal distribution of the nitrate data for the fens with a low confidence in their ecological assessment.

The UK did not set a TV for phosphate as there was no clear difference in phosphate concentrations between good and poor ecological condition sites. Further research on the impact of phosphate pressures in wetlands is required prior to further attempts to determine TVs for GWDTEs (UK TAG, 2012). The current groundwater quality monitoring network in Ireland is not sufficiently extensive to determine phosphate TVs for Irish calcareous fens.

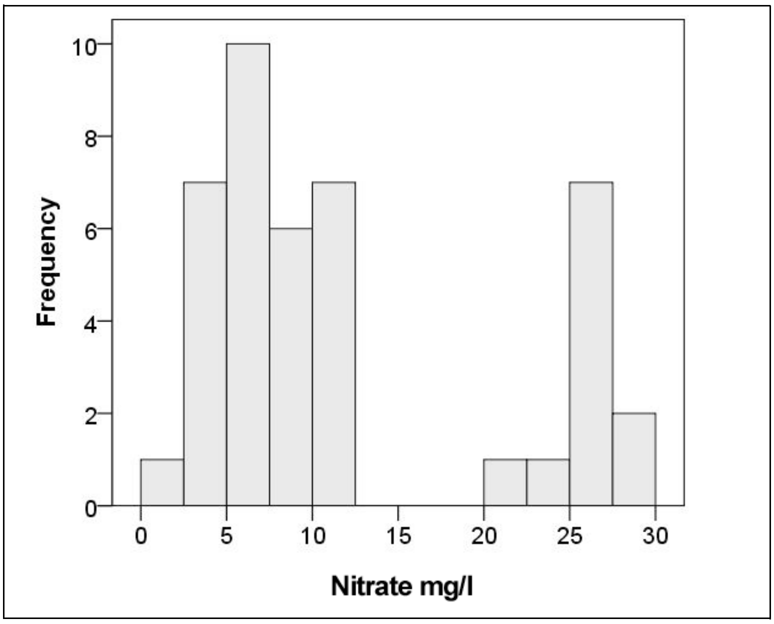

Figure 3.1. Frequency distribution of nitrate concentrations in groundwater linked to Irish fens in good ecological condition.

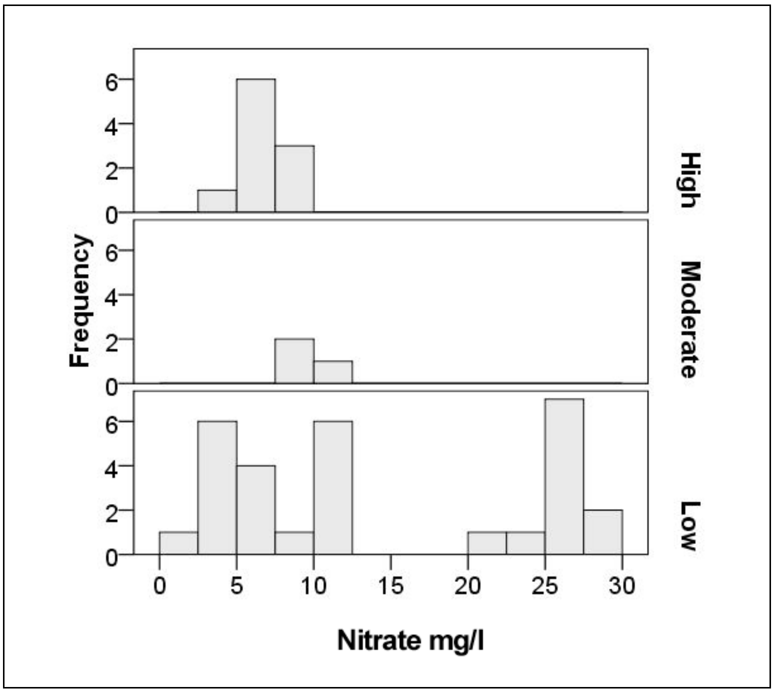

Figure 3.2. Frequency distribution of nitrate concentrations in groundwater linked to Irish fens in good ecological condition (separated according to level of confidence in the ecological condition assessment).

Table 3.6. Summary statistics of nitrate and phosphate concentrations in groundwater linked to Irish fens in good ecological condition.

Ecological condition	Hydrochemical variable	Mean	Median	SD	Minimum	Maximum	25th percentile	75th percentile
Irish good (high/moderate/low confidence) (N = 42)	NO_3 mg/l (N = 42)	12.0	7.9	8.7	1.5	27.9	5.9	21.6
	MRP mg/l (N = 4)	0.017	0.014	0.008	0.012	0.029	n/a	0.025
Irish good (high/moderate confidence) (N = 13)	NO_3 mg/l (N = 13)	7.1	7.2	1.8	4.2	11.6	5.9	8.1
	MRP mg/l (N = 1; 0.029)	n/a	n/a	n/a	n/a	n/a	n/a	n/a
UK good (low altitude)	NO_3 mg/l (N = 17)	20.2	19.6	20.4	0.3	69.7	2.6	28.9
UK poor (low altitude)	NO_3 mg/l (N = 12)	36.7	31.7	36.4	0.3	111.8	2.6	69.1
UK good (mid-altitude)	NO_3 mg/l (N = 13)	3.4	3.4	2.4	0.9	9.6	1.4	4.4
UK poor (mid-altitude)	NO_3 mg/l (N = 4)	18.3	20.9	13.9	0.4	31.1	3.9	30.2

NO_3, nitrate; SD, standard deviation; MRP, molybdate reactive phosphorus.

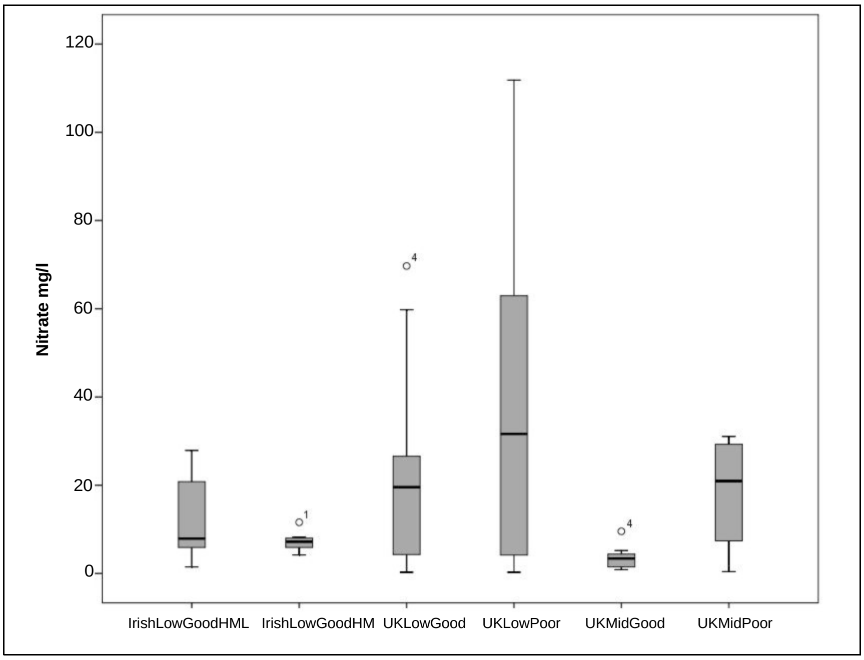

Figure 3.3. Nitrate concentrations in groundwater linked to low altitude (<175 mAOD) Irish calcareous fens in good ecological condition including low confidence assessments (N = 42) and excluding low confidence assessments (N = 13). Confidence in ecological assessments: H, High; M, Moderate; L, Low. Nitrate concentrations in groundwater linked to UK low altitude (<175 mAOD) oligotrophic fens with tufa-forming springs in good (N = 17) and poor ecological condition (N = 12) and mid-altitude (>175 mAOD) oligotrophic fens with tufa-forming springs in good (N = 13) and poor ecological condition (N = 4). The bottom and top of each grey box are the 25th and 75th percentiles, respectively.

3.4 Discussion and Recommendations

3.4.1 Discussion of options for determining a nitrate TV for calcareous fens

TVs in the context of the GWDTE chemical status test are concentrations of nitrate that trigger site investigations to determine if the groundwater has contributed to the ecology of the GWDTE being significantly damaged. TVs relevant to a range of Irish GWDTE types must be determined by the end of 2013; however, it is clear from the above data analysis that the currently available data for Irish calcareous fens are insufficient to allow final TVs for nitrate or phosphate using the UK TAG approach to be proposed at this stage. Three potential alternative approaches to setting an Irish nitrate TV for GWBs containing calcareous fens are proposed below.

1. **Adopt a TV of 15 mg/l NO_3 for calcareous fens in Ireland**
   The average of the 75th percentile of the good ecological grouping including all levels of confidence in the ecological assessments and the 75th percentile of the good ecological grouping excluding sites with a low confidence in their ecological assessments is 15 mg/l NO_3. This value lies above the mean for Irish calcareous fens in good ecological condition (all levels of confidence in ecological assessments) and above the maximum for Irish calcareous fens in good ecological condition (excluding low confidence sites) (Table 3.6). The proposed TV represents a compromise based on best available information. The main benefit of proposing an interim TV based on limited Irish data is that the data are relevant to the Irish context. This TV can be reviewed during each River Basin Cycle.

2. **Adopt the nitrate TV for oligotrophic fens with tufa-forming springs in the UK**
   This is an option; however, the use of UK data is questionable in light of the differences in GWDTE typology and conservation assessment information between Ireland and the UK. As mentioned in Section 3.2.5, GWDTE types in Ireland are groundwater-dependent Annex I habitats under the Habitats Directive, whereas in the UK GWDTE types are primarily classified according to the ecology of British NVC categories. In a review of the ecological requirements of water-dependent habitats under the Habitats Directive, Curtis et al. (2009) state that the species composition of Irish alkaline fens is the classic *Schoenetum nigricantis* described by Ó Críodáin and Doyle (1994, 1997) which equates with the NVC category of M13 *Schoenus nigricans–Juncus subnodulosus.* The authors note that a wider view of the alkaline fen habitat (Habitats Directive Code 7230) has been taken in the UK, which also includes the NVC categories M9 and M10. The present study of calcareous fens in Ireland also encompasses calcareous fens with *Cladium mariscus* and species of *Carex davalliana* (Habitats Directive Code 7210). The understanding of the species composition of this habitat type as it occurs in Ireland is weak and the sites used in the present study are generally thought to be most similar to the S2 *Cladium mariscus* swamp NVC category. In the UK, however, the species composition is relatively well understood and eight NVC categories are considered to be associated with this habitat. UK TAG guidance outlines the associations between the UK GWDTE categories and NVC categories (UK TAG, 2012). The broad range of NVC categories that may be associated with UK oligotrophic fens also supports the assertion that there are significant differences in vegetation composition and, consequently, ecological responses to nitrate inputs from groundwater between the two fen categories. There is a high degree of uncertainty therefore as to whether the Irish calcareous fens investigated in the present study are directly comparable with the UK oligotrophic fen category.

   In addition, it is suspected that lowland oligotrophic fens in the UK are under relatively more intense land-use pressure than the Irish lowland calcareous fens given the much broader range of nitrate concentrations associated with the UK lowland oligotrophic fens. Irrespective of potential differences between the ecology of Irish calcareous fens and UK oligotrophic fens, recent site-specific conservation assessments were not available for the majority of Irish calcareous fen sites used in this study and the reliability of ecological condition information is inferior to that of the UK.

3. **Defer determination of a TV until further investigations are carried out**
   Given the uncertainties outlined above, the third option is that no Irish TV should be set until further investigations are completed. It is appreciated that the setting of a TV cannot await the completion of detailed site investigations but important information might be gained relatively rapidly from site walk-overs as outlined below.

This study recommends that the third option is adopted and a future work programme for determining reliable TVs for Irish calcareous fens is outlined below.

3.4.2 Future work programme for determining TVs for calcareous fens in Ireland

- In the short term, a dedicated survey of the Askeaton Fen SAC Complex fens is imperative in order to confirm the ecological condition of these sites (which are currently classed as good condition with low confidence, and which have significantly higher nitrate values than the good condition, high/moderate confidence sites). Ideally, however, all 44 fens with potentially linked monitoring points should be surveyed as assurance is needed that the 44 sites contain alkaline fens and/or *Cladium* fen habitats as determined under the Habitats Directive. These surveys need not be expensive or excessively time consuming and a 1- or 2-day walk-over survey by an ecologist and hydrogeologist could identify sites that are currently in poor ecological condition. As a minimum, these surveys should describe the presence/absence of vegetation indicative of alkaline fens/species-rich *Cladium* fens, the hydrogeological setting, within-site and surrounding land use and evidence of ecological impact, particularly from groundwater.

- The determination of a final TV is dependent on the identification of Irish calcareous fen sites in poor ecological condition, for which associated groundwater quality data are available or can be obtained. The lack of Irish sites agreed as being in poor ecological condition was a major limiting factor to the present data analysis so it is important that a list of such sites (if they exist) should be compiled as a matter of urgency. Groundwater quality data could be collected specifically for these sites, thereby facilitating the essential comparative approach. The current Irish groundwater monitoring point network is not extensive enough to determine a phosphate TV for calcareous fens. Even if the network was as extensive as the drinking water monitoring point network, the process for determining a phosphate TV would be limited by the reliability of ecological condition information. In lieu of analysis of samples collected from the drinking water monitoring point network for phosphate, dedicated sampling of groundwater inputs to calcareous fens in good and poor ecological condition is required. Fens may be limited by nitrogen and/or phosphorus (Kooijman and Bakker, 1995; Verhoeven et al., 1996; Pauli et al., 2002), and the fact that many Irish calcareous fens are associated with karstic flow regimes (see Section 2.4) emphasises the importance of determining a phosphate TV for calcareous fens in the future.

- In the longer term, the main priority for future work is to confirm the presence and extent of alkaline fens and species-rich *Cladium* fens within SAC complexes. The NSFFS Database and the GWDTE SAC database were compiled via desk studies and follow-up baseline field surveys are required to improve the reliability of the data sets. It must be noted that there is no definitive vegetation classification for alkaline fens or species-rich *Cladium* fens in Ireland; however, a broad-scale baseline vegetation survey based on criteria outlined in the Habitats Directive Interpretation Manual (EC, 2007) and other relevant literature would provide sufficient information to identify the presence of these habitat types.

- As a minimum, baseline surveys of alkaline fens or species-rich *Cladium* fen sites should collect information on the hydrogeological setting, within-site and surrounding land use, locations of groundwater seepages and springs, and any evidence of nutrient enrichment and/or desiccation.

- Groundwater nitrogen and phosphorus data should then be collated from the groundwater monitoring network, or collected from installed boreholes for a subset of sites representative of the natural variation of Irish calcareous fens and ranging from near pristine to heavily impacted conditions.

An important lesson learned from this project is that the collation of information on the ecological condition of GWDTEs should precede the investigation of hydrogeological connections between groundwater monitoring points and GWDTEs during the TV development process in Ireland. Following the completion of future basic survey work, some consideration needs to be given to the possibility of determining TVs for calcareous fens, and possibly other GWDTE types, occurring in different areas. Owing to large variation around the mean nitrate or phosphate concentrations, UK TAG examined factors affecting the relationship between groundwater nutrient concentrations and wetland condition. Altitude was found to exert a significant effect on groundwater nitrate concentrations for a range of wetland categories, including oligotrophic fens and wetlands with tufa-forming springs. It is not clear whether the same relationship will prevail in Ireland, and the effects of geological differences, effective rainfall, wetland altitude, dominant land use and annual groundwater recharge on the relationship between groundwater nutrient concentrations and wetland condition should be examined statistically.

3.4.3 Potential for determining groundwater nutrient TVs for other GWDTE types in Ireland

The prioritisation of GWDTE types for determining groundwater nutrient TVs should be driven by the strategy for the next River Basin Cycle. Alkaline and *Cladium* fens, active raised bog, petrifying springs and turloughs were the predominant GWDTE types dealt with in the 2004/2005 risk assessment work. The site boundaries of these GWDTE types should be mapped to enable the development of TVs for them. The spatial information for groundwater-dependent transition mire, flushes in blanket bog and wet heath, and alluvial forests will need to be improved if they are to be included in future GWDTE assessments. Determining chemical TVs for active raised bog should not be a priority, given that groundwater does not come into direct contact with the main bog area and that there are only three sites in Ireland with intact lagg zones. It is likely that the priority list for determining groundwater nutrient TVs will include alkaline fens, species-rich *Cladium* fens, petrifying springs, alluvial forest, turloughs and machair, all of which are designated as priority habitats under the Habitats Directive with the exception of alkaline fens.

As noted above, the most groundwater-dependent alluvial forest sites will need to be identified prior to efforts to determine relevant TVs. Ongoing NPWS projects should provide improved spatial information for alluvial forests and petrifying springs. Turlough floodwaters are phosphorus limited and 108 of 256 turloughs are within 5 km of a groundwater monitoring point, which suggests that the TV proposed by the project *Assessing the Conservation Status of Turloughs* (Kimberley, 2011) could be tested using this data set. It is likely that machair could feature in the next risk assessments give its high priority status for conservation under the Habitats Directive. Table 3.7 presents a national site number estimate for each GWDTE type and an assessment of the currently available ecological/conservation assessment information. This table should be cross-referenced with the more detailed review of available data sets in Appendix 2.

Table 3.7. Estimate of national site numbers for each groundwater-dependent terrestrial ecosystem type and assessment of currently available conservation assessment information (cf. with Appendix 2).

Annex I habitat type	Natura 2000 code	Site number estimate	Nature of ecological condition information
Alkaline fen	7230	150–250	A field survey to confirm the location and spatial extent of fens in the National Spring, Fen and Flush Database would allow for use of the site-specific information conservation assessment information in the database.
Calcareous fen with *Cladium mariscus* and *Carex davalliana	7210	50–100	As above.
***Petrifying springs with tufa formation (*Cratoneurion*)**	7220	50–100	Site-specific information on the bryophyte ecology of petrifying springs is being generated by an ongoing PhD project in TCD.
Transition mire (quaking bogs)	7140	~50	Lack of site-specific conservation assessments.
***Active raised bog**	7110	~150	Site-specific conservation assessments available.
***Turloughs**	3180	250–400	Ground-truthing of a number of potential turlough sites is required and ecological information of varying forms and standards available for ~100 sites. Standard conservation assessments for 22 turloughs will be available by 2013.
Blanket bog (*if active) (FLUSHES ONLY)**	7130	~400	Lack of site-specific conservation assessments.
Northern Atlantic wet heaths with *Erica tetralix* (FLUSHES ONLY)**	4010	~50	Lack of site-specific conservation assessments.
Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior	91EO	100–200	Vegetation descriptions available but sites lack conservation assessments.
Machair (*in Ireland)	21AO	~60	Site-specific conservation assessments available.
Humid dune slacks	2190	~70	Site-specific conservation assessments available.

4 Methodologies for Assessing Quantitative Pressures on GWDTEs

4.1 Quantitative Pressures on GWDTEs

Quantitative pressures include both catchment-scale and local abstraction and drainage. The quantitative status of GWBs must be assessed for the WFD and a quantitative status test (Fig. 1.1) must be applied to those GWDTEs at risk from abstraction or drainage pressures. The current quantitative risk assessment process for GWDTEs uses a combination of potential impact from catchment-scale and local abstraction/ drainage pressures and evidence of groundwater-level decline to identify sites (WFD Working Group on Groundwater, 2004a):

- At significant risk (1a);
- Probably at risk (1b);
- Not at significant risk (low confidence) (2a); and
- Not at significant risk (high confidence) (2b).

Twenty-three GWBs associated with GWDTEs were determined as being at risk from quantitative pressures during the first River Basin Cycle; however, the subsequent quantitative test for GWDTEs was only applied to two sites owing to a lack of information. This chapter reviews the current quantitative risk assessment process and proposes recommendations for site-specific investigations of quantitative pressures.

4.2 Including Aquifer Characteristics in the Impact Potential Assessment Process for GWDTEs

The current Impact Potential Matrix for catchment-scale abstraction pressures (WFD Working Group on Groundwater, 2004a) does not take aquifer class or groundwater flow regime into account even though these factors influence the certainty of zone of groundwater contribution (ZOC), recharge and specific yield estimations, and the impact of abstractions on the GWB. The national aquifer map identifies 11 aquifer classes, which were grouped into four groundwater flow regime types (see Table 2.3):

1. Karstic;
2. Fissured;
3. Poorly productive; and
4. Intergranular.

The certainty of specific yield estimation, ZOC delineation and recharge estimation is lowest in karstic flow regimes owing to their extreme heterogeneity. Variation in hydrograph character among three groundwater-level monitoring points in close proximity to one another within a highly karstified sub-catchment of the Nore River Basin highlights the complexity of karst systems (Tedd et al., 2012). GWB flow regime also affects the susceptibility of the GWB to groundwater abstractions. For example, differences in specific yield mean that the same groundwater abstractions as percentages of recharge would cause a much bigger water-level drop in fractured aquifers than in sand and gravel aquifers, since the latter have large intergranular storage available. The assessments of the relative impact of groundwater abstraction thresholds should therefore be more conservative for GWDTEs occurring within karstic and fissured flow regimes than for intergranular flow regimes. Poorly productive bedrock aquifers are also likely to be more sensitive to groundwater abstractions than extensive sand and gravel aquifers. For the next River Basin Cycle, some consideration should be given to developing a matrix for assessing the potential impact of different abstraction thresholds on different aquifer classes, or the more generalised flow regimes, occurring within GWDTE ZOCs.

The further development of such a matrix should be preceded by an assessment of the aquifer classes typically occurring within the ZOCs of calcareous fens, turloughs, petrifying springs, machair and groundwater-dependent alluvial forests as a priority.

Table 4.1. Example of the type of matrix that might be developed in order to incorporate groundwater body (GWB) flow regime into the quantitative pressure risk assessment process for groundwater-dependent terrestrial ecosystem (GWDTEs).

	Impact of abstraction on GWB flow regime (aquifer classes*)			
	Karstic (Rkc, Rkd)	**Fissured (Rf, Lm)**	**Poorly productive**	**Intergranular (Rg, Lg)**
GWB abstraction as a % of recharge in ZOC of GWDTE				
>20%	High	High	High	High
10–20%	High	Moderate	Moderate	Moderate
5–10%	High	Moderate	Moderate	Low
<5%	Moderate	Moderate	Low	Low

Rkc, Regionally Important Karstified Bedrock Aquifer (conduit flow); Rkd, Regionally Important Karstified Bedrock Aquifer (diffuse flow); Rf, Regionally Important Fissured Bedrock Aquifer; Lm, Locally Important Bedrock Aquifer, Generally Moderately Productive; Rg, Regionally Important Sand/Gravel Aquifer; Lg, Locally Important Sand Gravel Aquifer. ZOC, zone of groundwater contribution.

Table 4.1 presents an example of the type of matrix that might be developed following assessments of aquifer classes occurring within GWDTE ZOCs.

4.3 Review of GWDTE Sensitivity in the Quantitative Risk Assessment

The impact potential of abstraction on the GWDTE types could then be assessed by combining the impact of abstraction on the GWB with the GWDTE sensitivities to changes in groundwater quantity. The current Impact Potential Matrix for assessing the impact of abstraction on GWDTEs does not include an extreme GWDTE sensitivity category (WFD Working Group on Groundwater, 2004a) even though numerous GWDTEs are determined as having an extreme sensitivity to changes in groundwater quantity (WFD Working Group on Groundwater, 2005b). The authors of the this report suggest that this matrix is revised to include an extreme sensitivity category. The current matrix (Table C2 – WFD Working Group on Groundwater, 2004a) for assessing the impact of local abstraction and arterial drainage on GWDTEs should also be revised to include an extreme 'GWDTE sensitivity to changes in groundwater quantity' category. This matrix should also be amended to include the statement "*within a 100 m distance that can influence the ZOC*" rather than "*within 100 m of boundary*" as a downgradient drain or abstraction may change the position of the ZOC boundary.

4.4 Site-Specific Investigations for Quantitative Status Classification Following Risk Assessment

Groundwater quantitative status classification requires site-specific investigation of GWDTEs identified as being at risk from quantitative pressures. A seven-step process for groundwater classification, as defined by UK TAG (UK TAG, 2007), requires the determination of relevant environmental supporting conditions needed within the GWDTE to maintain dependent plant communities in a favourable state, using a combination of published sources, relevant monitoring data and/or expert judgement (Whiteman et al., 2010). In the UK, the environmental supporting conditions for the most groundwater-dependent plant communities were defined with reference to WETMECs (Wheeler et al., 2009; Whiteman et al., 2009) and UK ecohydrological guidelines that define generic environmental supporting conditions for plant communities for specific habitats. At a given site, the departure from defined environmental supporting conditions was assessed based on available data and the driver of the departure was analysed. Hurcott and Podmore Pools are presented as a case study for groundwater quantity classification in Whiteman et al. (2009). The most groundwater-dependent plant communities at this site were identified as W5 *Alnus glutinosa–Carex paniculata* and W6 *Alnus glutinosa–Urtica dioica*. The suggested quantitative environmental supporting conditions were to maintain the within-site water level within the range 5–45 cm below ground level in the summer. Site assessments determined that groundwater levels within the W5 and W6 plant communities were between 0 and 4 m below ground level and the environmental supporting conditions were therefore not met at some areas of the site. Modelling results indicated that a major reduction in abstraction would be needed to trigger a sufficient rise in groundwater level to meet the required environmental supporting conditions and the quantitative status for this site was therefore classified as poor with high confidence.

The UK site-specific investigations rely heavily on the British NVC and related ecohydrological guidelines and WETMECs information. The NVC is based on numerical cluster analysis of vegetation data generated via an extensive field survey across a wide variety of habitat types. The NVC has become the standard vegetation classification used in Britain and is sometimes used in Ireland (Smith et al., 2011). Caution is urged when comparing Irish vegetation with NVC classes owing to the biogeographical and land-use differences between Ireland and the UK (Smith et al., 2011). However, such caution should not preclude comparisons that may be useful for assessing the environmental supporting conditions of GWDTEs. If UK ecohydrological guidelines and WETMEC information are to be applied to the Irish situation, an assessment of the occurrence of the most groundwater-dependent NVC communities within Irish GWDTE types will be necessary. Curtis et al. (2009) list NVC classes potentially associated with a range of GWDTE types. A targeted survey of the occurrence of similar vegetation communities within, for example, a range of calcareous fen sites, followed by a groundwater-level survey would allow for the comparison of environmental supporting conditions between the UK and Ireland.

The Irish National Biodiversity Data Centre is currently analysing data within the National Vegetation Database in order to progress the development of a national vegetation classification for Ireland. Such a classification is unlikely to be available for the next River Basin Cycle; however, when it is available, this vegetation classification will eventually facilitate the development of ecohydrological guidelines specific to the Irish context.

An alternative option is to conduct a targeted groundwater-level survey, taking into account both within-site water levels and groundwater levels in the ZOCs, within a representative sample of Irish calcareous fen sites at favourable and unfavourable conservation status. Such a targeted survey would identify the groundwater-level range required to maintain calcareous fens in good ecological condition, i.e. the required environmental supporting conditions. It must be emphasised that long-term groundwater-level data would need to be collected in order to understand the sensitivities to seasonal and multi-annual variations in rainfall, recharge and groundwater level. If environmental supporting conditions are not met at a site, the proportion of departure arising from anthropogenic pressures should be assessed using groundwater modelling techniques (Whiteman et al., 2009) based on a site-specific conceptual understanding of the hydraulic linkages between the GWDTE and the GWB.

Different GWDTE types present different challenges for determining the environmental supporting conditions required to maintain sites in a favourable conservation status. Groundwater flow and/or level characteristics should be considered where appropriate. Both flow and level should be assessed for petrifying springs and groundwater-dependent flushes in blanket bog and wet heath associated with a discrete spring discharge. For all other types, the focus should be on assessing the groundwater level, both within the wetland and the associated ZOC, particularly during the summer months.

5 Summary of Knowledge Gaps and Recommendations

This research project was undertaken to inform the development of chemical and quantitative status tests for GWDTEs within the context of GWB classification. During the first River Basin Cycle, tests were not applied to all GWDTEs identified as being at risk from chemical and quantitative GWB pressures owing to a lack of data and this situation needs to be rectified for the second River Basin Cycle. With regard to the chemical status test, exceedance of a TV at a monitoring point that is hydrogeologically linked to the GWDTE triggers further site-specific investigations to determine if groundwater is causing significant damage to the wetland. As a priority, the project attempted to determine groundwater nutrient TVs for Irish GWDTEs using a predetermined methodology developed by the UK WFD TAG Wetlands Task Team. The method was applied to existing GWDTE spatial data sets, groundwater nutrient data collated from the drinking water and/or groundwater quality monitoring network and best available information on GWDTE ecological condition. Data limitations prevented the determination of scientifically robust TVs for Irish calcareous fens and data limitations are also likely to compromise future efforts to determine TVs for other GWDTE types. There is also currently no dedicated extensive monitoring of groundwater quality, level and/or flow within GWDTEs and their associated ZOCs. Specific knowledge gaps and recommendations for addressing these gaps are presented below.

5.1 Knowledge Gaps and Related Recommendations

5.1.1 Spatial extent of groundwater-dependent Annex I habitat types within SACs

Reliable information on the spatial extent of groundwater-dependent Annex I habitat types is a prerequisite for developing the GWDTE chemical and quantitative status tests for GWB classification. There is uncertainty with regard to alkaline fen and calcareous fen with *Cladium mariscus* and *Carex davalliana* designations in the GWDTE SAC database. Petrifying springs have poor quality spatial extent information but the current NPWS-supported PhD project in TCD will improve the quality of this information. Not all transition mire (quaking bog), flushes in blanket bog and wet heath and alluvial forests are groundwater-dependent and the degree of groundwater dependence for sites of these GWDTE types is not currently recorded in national data sets. The boundaries of turloughs designated as SACs or occurring within SAC complexes are often not mapped.

The priorities for improving the spatial extent information for Annex I habitat types within special areas of conservation should be to:

- Conduct baseline surveys of alkaline fen and calcareous fen with *Cladium mariscus* and *Carex davalliana* sites, as recorded in the GWDTE SAC database, to confirm the Annex I habitat designations;
- Map the boundaries of confirmed turloughs as recorded in the Turlough Database (Mayes, 2008); and
- Identify the most groundwater-dependent transition mire (quaking bog), flushes in blanket bog and wet heath and alluvial forests and update currently available data sets accordingly (see Section 3.2.1).

5.1.2 Conservation assessment information for Annex I habitat types within SAC complexes

The quality of conservation assessment information for SAC complexes compromised the attempts to apply the UK TAG methodology for determining groundwater nutrient TVs for calcareous fens. The methodology requires site-specific conservation assessments and there is currently uncertainty with regard to the ecological condition of many calcareous fen sites. Future attempts to apply the methodology to other GWDTE types are likely to be hindered by a similar lack of information regarding ecological condition. Extensive information on the conservation status of petrifying springs, turloughs and groundwater-dependent transition mire (quaking bog), flushes in blanket bog/wet heath and alluvial forests is currently lacking. Current projects on petrifying springs and turloughs will provide improved conservation assessment information for the next River Basin Cycle.

5.1.3 Further investigations required to determine TVs for Irish calcareous fens (cf. Section 3.4.2)

- A dedicated survey of the Askeaton Fen SAC Complex fens is imperative in order to confirm the ecological condition of these sites (which are currently classed as good condition with low confidence, and which have significantly higher nitrate values than the good condition, high/moderate confidence sites). Ideally, however, all 44 fens with potentially linked monitoring points should be surveyed as assurance is needed that the 44 sites contain alkaline fens and/or *Cladium* fens as determined under the Habitats Directive. As a minimum, these surveys should describe the presence/absence of vegetation indicative of the Annex I habitat types, the hydrogeological setting, within-site and surrounding land use and evidence of ecological impact, particularly from groundwater.

- The lack of Irish sites agreed as being in poor ecological condition was a major limiting factor to the present data analysis so it is important that a list of such sites (if they exist) should be compiled as a matter of urgency. Groundwater nitrogen and phosphorus data could be collected specifically for these sites, thereby facilitating the essential comparative approach.

- In the longer term, the main priority for future work is to confirm the presence and extent of alkaline fens and species-rich *Cladium* fens within all SAC sites. The NSFFS Database and the GWDTE SAC Database were compiled via desk study, and follow-up baseline field surveys are required to improve the reliability of the data sets. It must be noted that there is no definitive vegetation classification for alkaline fens or species-rich *Cladium* fens in Ireland; however, a broad-scale baseline vegetation survey based on criteria outlined in the Habitats Directive Interpretation Manual (EC, 2007).

- As a minimum, baseline surveys of alkaline fen/species-rich *Cladium* fen sites should collect information on hydrogeological setting, within-site and surrounding land use, locations of groundwater seepages and springs, and any evidence of nutrient enrichment and/or desiccation.

- Groundwater nitrogen and phosphorus data should then be collated from the groundwater monitoring network, or collected from installed boreholes, for a subset of sites representative of the natural variation of Irish calcareous fens, ranging from pristine to heavily impacted conditions.

5.1.4 Quantitative status assessments

Aquifer classes are currently not taken into account when assessing the impact of different abstraction thresholds on GWDTEs even though differences in aquifer characteristics influence ZOC, recharge and specific yield estimations and the impact of groundwater abstraction thresholds. The current risk assessment process should be revised to factor in aquifer classes, based on an improved understanding of the aquifer classes occurring within the ZOCs of GWDTE types identified as a high priority for risk assessment for the next River Basin Cycle. A more fundamental problem is the lack of extensive monitoring of groundwater level or flow within GWDTEs in Ireland. Targeted groundwater-level surveys of either Irish vegetation communities similar to the most groundwater-dependent British NVC categories or within sites representative of good and poor ecological conditions are recommended. It must be borne in mind that site-specific investigations require long-term groundwater-level data in order to understand the sensitivities to seasonal and multi-annual variations in rainfall, recharge and groundwater level.

5.1.5 Ecohydrological guidelines for Irish groundwater-dependent vegetation communities

Assessing the environmental supporting conditions of Irish GWDTEs is limited by a lack of evidence-based information on the groundwater level, flow and chemistry required to maintain the ecosystems in a favourable conservation status. GWDTE sites often lack vegetation maps and this compromises the application of UK TAG guidance on assessing groundwater-mediated significant damage to GWDTEs, which is heavily based on vegetation classes, to the Irish context. The prioritisation of work to address this knowledge gap should be driven by the NPWS/EPA strategy for dealing with GWDTEs as part of the next River Basin Cycle. This strategy should identify priority GWDTE types and sites for risk assessment and drive dedicated field surveys and the development of ecohydrological guidelines for Irish groundwater-dependent vegetation communities.

5.1.6 Research on links between GWDTEs and GWBs

There is a need to extend the scientific knowledge of the hydraulic linkages between the GWB and GWDTE for different GWDTE types situated in contrasting hydrogeological settings and of the level of nutrient attenuation between the GWB and discharge on-site.

The priority for addressing this research gap should be to conduct walk-over surveys of a range of priority GWDTE sites, encompassing a co-operative approach by ecologists and hydrogeologists. A framework for cost-effective, collaborative survey work has been developed in the UK (Whiteman et al., 2009) and this framework should be adopted for the Irish survey work. These surveys should target sites already identified as being at risk from qualitative and/or quantitative pressures and would also inform the development of the GWDTE chemical and quantitative status test. Such survey work would develop specific research questions that could be addressed by university-based or consultant research professionals.

5.2 Overall Recommendations

A clear strategy for co-ordinating the WFD and Habitats Directive objectives for water-dependent habitats should be developed by both the NPWS and the EPA. The main aim of this strategy should be to prioritise work for the next River Basin Cycle.

For the next River Basin Cycle, a structure for recording detailed notes on the rationale behind decisions relating to GWDTE risk assessment and chemical and quantitative status tests should be agreed between the NPWS and the EPA. The database of water-dependent Annex I habitat sites developed by O'Riain et al. (2005) could be used to document the information. In the short term, improving the accuracy and reliability of the spatial information for priority GWDTE types and sites should be the main priority for future work.

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Acronyms

CA	Conservation assessment
CIS	Common Implementation Strategy
EPA	Environmental Protection Agency
EU	European Union
FC	Further Characterisation
FCS	Favourable conservation status
GIS	Geographical Information Systems
GWB	Groundwater body
GWDTE	Groundwater-dependent terrestrial ecosystem
HCV	High conservation value
IC	Initial Characterisation
JNCC	Joint Nature Conservation Council
MRP	Molybdate reactive phosphorus
NHA	Natural Heritage Area
NO_3	Nitrate
NPWS	National Parks and Wildlife Service
NSFFS	National Spring, Fen and Flush Survey
NSNW	National Survey of Native Woodlands
NVC	National Vegetation Classification
QUB	Queen's University Belfast
RBD	River Basin District
RBMP	River Basin Management Plan
SAC	Special Area of Conservation
SPA	Special Protection Area
TAG	Technical Advisory Group
TCD	Trinity College Dublin
TV	Threshold value
WETMEC	WETland water supply MEChanisms
WFD	Water Framework Directive
ZOC	Zone of groundwater contribution

Glossary

Aquifer	A subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater (EC, 2003a).
Aquitard	A zone of low hydraulic conductivity/permeability adjacent to an aquifer.
Basin	Hollows in the landscape of variable size.
Bottom	A range of topogenous (impeded drainage) situations (basins, flats, floodplains and troughs).
Floodplain	More or less flat valley-bottom surfaces alongside relatively mature watercourses and episodically flooded by these.
Flush	Groundwater flushes and flushed surfaces are surfaces upon an aquitard located below a spring or seepage line, and irrigated primarily by surface or near-surface flow of water derived from groundwater outflow upslope of them.
Groundwater	Water in, or sourced from, an aquifer.
Groundwater outflow	Groundwater-sourced surface water.
Paludal	Of or relating to a swamp or marsh.
Percolation	Used to refer to diffuse water flow through a typically topogenous wetland deposit.
Seepage	Groundwater seepage is considered to be groundwater outflow from a mineral aquifer to the surface of a wetland (cf. Flush).
Soligenous	Literally 'made by soil'; here used to refer to wetness induced primarily by water sourced from mineral deposits adjoining a wetland. Little impedence to outflow.
Spring	Discrete focus of groundwater outflow onto the ground surface, usually with visible water flow; may occur as an area of enhanced outflow within a more diffuse seepage system.
Sump	Small shallow depression within wetland.
Topogenous	High water levels are maintained primarily by topographical constraints upon the drainage of water inputs.
Flow tracks	Distinct, linear zones of focused surface or near-surface water flow within wetlands.
Trough	Elongate, mostly valley-bottom situations that are neither valley heads nor floodplains.
Valleyside	Soligenous (little impedence to outflow) wetlands developed along a valley slope.
Valleyhead	Soligenous (little impedence to outflow) wetlands developed near headwaters and upper reaches of valleys.
Water table	Free groundwater surface at which the pressure equals atmospheric pressure. This loosely corresponds to the boundary between the unsaturated and saturated zones.

Appendix 1 WETMEC Descriptions

Table A1.1. WETMEC descriptions.

WETMEC (Wheeler et al., 2009)	Description
WETMEC 3	Buoyant weakly minerotrophic surfaces (transition bogs).
WETMEC 7 – Groundwater floodplain	Floodplains of groundwater-fed watercourses with flat topography. Often complex alluvial sequence with only shallow peat. Water supply and relationship to river and aquifer mostly uncertain. Springs and seepages mostly absent. Surface flooding not known, possibly infrequent.
WETMEC 8 – Groundwater-fed bottoms with aquitard	Trough or basin, usually on quite deep peat upon aquitard; if on floodplain, usually isolated from river. Water table often below solid surface. Often marginal springs/seepages. Distinguished from WETMEC 16 by topography and deeper peat. Water supply to much of surface may be dominated by precipitation in places. Water level may be episodically at, above or near surface, but water table in wetland may fall well below groundwater table at margins. Typically no surface flooding.
WETMEC 9 – Groundwater-fed bottoms	Similar to WETMEC 8 but no aquitard and marginal springs/seepages often less evident. Water level may be episodically at, above or near surface, but is often low and more or less in equilibrium with wetland water table. Typically no surface flooding.
WETMECs 10–17 – WETMEC Macro-Group: Groundwater-fed surfaces	This macro-grouping of WETMECs includes systems where there is permanent or episodic groundwater outflow at, or very close to the surface. Groundwater outflow of WETMECs 7–9 rarely reaches the surface of the wetland.
WETMEC 10 – Permanent seepage slopes	Summer wet surface, usually sloping and shallow peat; springs/seepages usually visible, over permeable substratum. Water table at or immediately below outflow. Localised strong seepage is characterised by small strong springs, often corresponding to variations in basal material (locally high potassium). Diffuse seepage takes the form of elongated seepages, often forming a valleyside zone.
WETMEC 11 – Intermittent & part-drained seepage	Similar to WETMEC 10 but water table well below surface in summer or year round; also more often on flat surfaces or in sumps. Low water levels may be due to low aquifer water tables and/or to a low permeability top-layer deposit.
WETMEC 12 – Fluctuating seepage basin	Small shallow sumps with strongly fluctuating water table. Effectively represents a WETMEC 11 mechanism within a shallow depression, where topography permits the accumulation of water, which can sometimes persist year round.
WETMEC 13: Seepage percolation basin	Groundwater-fed basins, typically with buoyant surface and a transmissive surface layer, often with a quite strong outflow from the basin. Low permeability deposits may constrain groundwater upflow and confine outflow to basin margins. Typically occurs in basins, floodplain margins and sometimes in small depressions in valley heads. Springs and seepages often visible around periphery, or aquifer head at or above wetland surface. Wet for much of the year.
WETMEC 14: Seepage percolation troughs	Peat-filled troughs, generally flat to gently sloping, fed by groundwater outflow directly from underlying deposits or flanking slopes. Soft or quaking (rarely buoyant) surfaces in groundwater-fed valley heads and troughs. More flopping than WETMEC 13.

Table A1.1 *contd*

WETMEC (Wheeler et al. 2009)	Description
WETMEC 15: Seepage flow tracks	Water flow tracks, mostly narrow and unstable, sourced primarily by groundwater outflow but sometimes with a surface run-off component. Groundwater-fed flow paths in mires, often embedded in WETMEC 14 but occasionally alone. Unconsolidated watery surface.
WETMEC 16: Groundwater-flushed bottoms	Broadly analogous to WETMEC 14, differing primarily in being underlain by a continuous, extensive aquitard, so that groundwater outflows occur mainly at margin and flow laterally, and having thinner peat. Marginal springs/seepages often evident.
WETMEC 17: Groundwater-flushed slopes	Groundwater-flushed slopes with thin peat over aquitard, below springs or narrow seepage line. Analogous to WETMECs 10 and 11, differing primarily in being underlain by a continuous aquitard, so that groundwater outflows occur primarily along the top edge as a seepage and flow downslope.
WETMEC 21: Inflow from karst conduits	

Appendix 2

Table A2.1. Detailed descriptions of data sets, data management notes and caveats.

National spatial data set*	Data management/Site no. count notes	Database description	Caveats
National Spring, Fen and Flush Survey Database **NPWS data set** **Geodatabase layer name: NSFFS.shp** **Original layer name: Fen_complete.shp**	Site counts based on 'Confirme_1' field. Numerous GWDTE types are assigned to one point and counts were based on exported attribute table in MS Excel. GWDTE types need to be separated out into individual fields to allow for accurate counts in ArcGIS.	This project involved the compilation of a list of all known fen sites in Ireland and the classification of these according to fen type. Foss (2007) used the fen habitats recognised in the EU Habitats Directive to classify fen types. However, two additional types not included in the Directive were added: Poor fen type and Non-calcareous spring type. This desk study compiled data held within the NPWS, from external NGO and expert sources. The list of publications, reports and surveys consulted and the full list of consulted data sets can be found in Appendices 1 and 4, respectively, of Foss (2007).	Although the project provided co-ordinates for each habitat site record, the accuracy of the location is uncertain in cases. Further surveys will improve this accuracy which will involve refinement of the habitat distribution map and therefore range. In the absence of a national fen survey, the list of sites should not be regarded as definitive. At any given site it was not always possible to determine the presence of a particular fen type with any confidence. Where more than one fen type occurred at a site, there was often uncertainty about the occurrence of other fen types. Thirty-three per cent of site records have noted uncertainty over the presence of one or more fen types, 13% have no fen extent information, while 75% have only estimated extents. Extent information was not estimated from polygons.
GWDTE SAC Database **EPA data set** **Geodatabase layer name: GWDTEs_SACs.shp** **Original layer name: GWDTE_April2008.shp**	Site counts based on 'GWDTE' field.	This data set was generated to improve the spatial location information for GWDTEs occurring within 'at-risk' SAC complexes.	
Derived Irish Peat Map (not included in geodatabase)	Raster data set converted to polygon data set by Sarah Kimberley. Approximately 85% of the raised bog extent is undesignated and would most likely lack sufficient ecological information. Spatial queries with groundwater monitoring points used the Raised Bog 1 and 2 shapefiles which focus on designated sites.	The Derived Irish Peat Map Version 2 (DIPMV2) is an updated version of the Derived Irish Peat Map (DIPM). The DIPM was derived from the peatland Map of Ireland, CORINE Land Cover Database (CORINE) 1990 and the General Soil Map of Ireland. The DIPMV2 was derived, using the same rules-based decision tree methodology, using CORINE 2000 and the Indicative Soil Map of Ireland. The producer, user and overall accuracies are 88%, 91% and 85%, respectively.	A spatial filter model was developed to screen out peat soil areas less than 7 ha until more accurate information becomes available. As with DIPMV1, fens were also excluded from this mapping exercise owing to their very limited extent. The total extent of peat soils in Ireland (20.6%) is likely to be higher given these omissions.

Table A2.1 *contd*

National spatial data set	Data management/Site no. count notes	Database description	Caveats
Raised Bog Restoration Project Database **NPWS data set** **Geodatabase layer name: RaisedBog1.shp** **Original layer name: 7110_7120_intactrb_surv_indesign_othersurv.shp**	NHAs and SACs in this file. Mapped area consists of individual polygons and lacks an overall site boundary. Can use NHA/SAC boundaries or merge polygons to create site boundary. In some cases the NHA/SAC extends well beyond the mapped area of raised bog. Best to create boundary for mapped area. Individual polygons for each site were merged to create a site boundary which was used for the site counts and spatial queries with groundwater monitoring points.	These surveys involved vegetation mapping at the ecotope level, as described by Kelly et al. (1995). Active raised bog habitat consists of two ecotopes (central and sub-central) and active peat-forming flushes. Bog woodland habitat (91D0), on raised bog, is also deemed part of active raised bog habitat as it also actively forms peat. Degraded raised bog habitat consists of marginal, sub-marginal and facebank ecotopes. All the records provided by these surveys are limited to designated sites (i.e. NHAs or SACs). A very small amount of active raised bog habitat is considered to be outside designated sites.	There is no overlap with NPWS Raised Bog Database 2.
Raised Bog Monitoring Project Database **NPWS data set** **Geodatabase layer name: RaisedBog2.shp** **Original layer name: 7110_7120_intactrb_surv_indesign_rbmp2005.shp**	NHAs and SACs in this file. Mapped area consists of individual polygons and lacks an overall site boundary. Can use NHA/SAC boundaries or merge polygons to create site boundary. In some cases, the NHA/SAC extends well beyond the mapped area of raised bog. Best to create boundary for mapped area. Individual polygons for each site were merged to create a site boundary which was used for the site counts and spatial queries with groundwater monitoring points.	This project aimed to monitor the conservation status of raised bog habitats included in Annex I of the Council Directive 92/43/ECC. A total of 48 of designated sites that represent the habitat's range were selected for this purpose based mainly on the original sites investigated by Kelly et al. (1995). These sites were resurveyed using similar methods and the vegetation descriptions and maps of Kelly et al. (1995) were used as a baseline to identify changes that occurred in the intervening period. The main outcomes of the project were individual site's habitat and overall habitat conservation status assessments, as well as detailed impacts and habitat (i.e. ecotopes) maps. This data set includes all the raised bog habitats digitised as part of this project. Habitats were mapped at ecotope level according to the Kelly et al. (1995) description. Active raised bog habitat (7110) includes sub-central and central ecotopes; Degraded raised bog habitat (7120) includes marginal, sub-marginal and facebank ecotopes. Flushes were mapped independently as active forming (habitat 7110) or inactive peat forming (habitat 7120). Bog woodland habitat was also mapped independently (habitat 91D0). This data set provides a reliable conservation status assessment for each site.	Photographic data and landownership details to be added. There is no overlap with NPWS Raised Bog Database 1.

Table A2.1 ***contd***

National spatial data set	Data management/Site no. count notes	Database description	Caveats
Blanket Bog NHAs Database **NPWS data set** **Geodatabase layer name:** **BlanketBog.shp** **Original layer name:** **Blanket_Bog_NHA_polygons_Edited_2011.shp**	Polygons labelled as Fens and Flushes, Flushed areas, Quaking mires and Wet heath in 'HABIT2004' field were initially exported from the data set by Sarah Kimberley. Eighty NHA blanket bogs have flushes and/or wet heath. Annex_C1 field identifies polygons for which there is a reasonably high level of confidence that the habitat recorded corresponds to the Annex 1 habitat type and the area for the polygon can be taken to indicate the amount of habitat occurring. Polygons identified in Annex_C1 field were used for site counts and spatial queries for WTH and TNM. Flush counts were based on 'Fens and Flushes', 'Flushed areas' in field HABIT2004	This project was commissioned to review and amend GIS mapping for blanket bog NHA sites. The original GIS mapping was conducted as part of the 'Survey and evaluation of blanket bogs for proposal as NHAs' (Derwin et al., 2004) for the NPWS. The main objectives were to clean the spatial data set, to allocate Fossitt and Annex 1 habitat codes to each feature and to calculate the area of each Annex 1 feature.	Eighty-six dystrophic lake polygons contain large areas of terrestrial habitat and a further 48 do not contain a visible waterbody. Discrepancies occur between the habitats indicated, based on 6-inch maps, and what appears on the 2005 aerial photographs. Caution is advised when determining the area of particular habitats.
NPWS Turlough Database **NPWS data set** **Geodatabase layer name:** **Turloughs.shp** **Original layer name:** **Turloughs_Consolidated_Final_point.shp**	Site counts based on 'Truthed' field. Two hundred and twenty-seven sites have not been ground-truthed or there are queries relating to the ground-truthing.	This database was generated via desk study to document the national turlough resource and to identify and remedy inaccuracies, omissions and duplicate listings in existing databases. Existing turlough databases were cross-checked and amalgamated. Published and unpublished sources were consulted in order to identify previously undocumented sites and orthophotography was queried to identify new and possible/probable turloughs.	Many sites are flagged as requiring ground-truthing to confirm the presence of characteristic turlough features.
National Survey of Native Woodlands Database **NPWS data set** **Geodatabase layer name:** **NSNW.shp** **Original layer name:** **NSNW_Woodland_Habitats_2010.shp**	Polygons labelled as 91E0, 91E0 / - and 91E0/91A0 in field 'H_EU_CODE' were used for site counts. Individual polygons were used for spatial queries with groundwater monitoring points.	This data set was generated as part of the National Survey of Native Woodlands in Ireland. A total of 1,217 woodland sites across the Republic of Ireland were surveyed during 2003–2007. The data set holds polygon data for the National Survey of Native Woodlands sites digitised in 2010 by BEC Consultants. Habitats types are assigned to survey areas using both EU Habitats Directive codes and Fossitt (2000) codes.	The habitat classes represent habitat type in a broad sense. Habitat Indicator Classes were assigned a modified version of codes presented in *A Guide to Habitats in Ireland* (Fossitt, 2000) and users are requested to consult this publication for class descriptions.

Table A2.1 *contd*

National spatial data set	Data management/Site no. count notes	Database description	Caveats
Coastal Monitoring Project Database **NPWS data set** **Geodatabase layer name: CoastalSites.shp** **Original layer name: Coastal_Monitoring_Project_2004_2006.shp**	Polygons identified as machair and humid dune slacks in 'CMP_NAME' field were used for site counts. Site sub-polygons for machair were merged to create a single site boundary and these boundaries were used for site counts.	All known sites for sand dunes in Ireland were visited and assessed during 2004, 2005 and 2006 for the purpose of updating an existing inventory of sand dune systems (Curtis, 1991), producing habitat maps and assessing the conservation status of sites within the context of the EU Habitats Directive. Habitat types are assigned to survey areas, using both EU Habitats Directive Annex 1 codes as well as habitat codes established for the purposes of the project.	Although the present file is cleaned of topology errors, it must be noted that due to preceding processing steps (separate incongruent files have apparently been merged/clipped in the creation of the file submitted to the NPWS) this file is not free from errors, especially when examined on a large scale.
Co. Sligo Wetlands Survey **County data set** **Geodatabase layer name: SligoWetlands.shp** **Original layer name: complete_wetland_habitats.shp**	Consult site assessment table in MS Access database 2009 for detailed site information. Use this data set for spatial queries rather than Sligo_Wetlands_2008_1.shp. Also consult Wilson et al. (2010). Wetlands 2010 data set requested from Heritage Officer, no response received.	The Sligo wetlands survey MS Access database identified sites that contain Habitats Directive Annex 1 habitats (site_eu-Habitat_types_present table). Not all of these sites are present in the Sligo Wetlands 2008 1 data set. Additional sites containing Annex 1 habitats were exported from the Sligo Inventory Layer. The 2009 data set builds on information generated from the Sligo Wetlands 2008 survey. This database was populated with data on a further 40 undesignated wetlands following field visits and a review of information made available since 2008.	No metadata with GIS files.
Co. Louth Wetlands Survey **County data set** **Geodatabase layer name: LouthWetlands.shp** **Original layer name: LWS 2011 Site Boundaries**	Consult LWS 2011 Polygon Habitats.shp and LWS_Survey_Database_Site_Summary.xls for more detailed site information. Many sites are not GWDTEs.	Boundaries of wetland sites surveyed during the Louth Wetlands Survey 2011. The LWS 2011 Polygon Habitats layer contains Fossit 2000 habitat boundaries within surveyed sites.	No metadata with GIS files. Additional database is in FileMaker Pro format.
Co. Monaghan Wetlands Survey **County data set** **Geodatabase layer name: MonaghanWetlands.shp** **Original layer name: MWM Site Boundaries 2011**	Very broad range of wetland types. The Monaghan Fen Survey data set should suffice.	The data set was produced during the Co. Monaghan Wetland Map project 2010 and updated following completion of the Monaghan Wetland Survey 2011. The data set shows the boundaries of wetland sites identified during the project. This version is a 2011 revision of the original file and includes sites surveyed during the Co. Monaghan Wetland Survey 2011 (Foss et al., 2011b)	Be aware of potential overlap with Monaghan_Fens_2007_2008.shp and Monaghan_Turloughs.shp. MWM Polygon Habitats 2011 contains many more polygons than MWM Site Boundaries 2011. Most additional polygons seem to be an unknown wetland type.

Table A2.1 ***contd***

National spatial data set	Data management/Site no. count notes	Database description	Caveats
Co. Monaghan Fen Survey County data set Geodatabase layer name: MonaghanFens.shp Original layer name: MFS1_and_MFS2_All_ Survey_Sites_Boundaries.shp	Consult MFS1_and_MFS2_All_ Survey_Sites_Boundaries.shp for more detailed site information.	Extent of all sites surveyed in detail during Monaghan Fen Survey I (2007) and Monaghan Fen Survey II (2008).	Database information in FileMaker Pro format.

*Contact Dr Naomi Kingston, NPWS, for copies of data sets.
NPWS, National Parks and Wildlife Service; NSFFS, National Spring, Fen and Flush Survey; GWDTE, Groundwater-dependent terrestrial ecosystem; GIS, Geographical Information Systems; EU, European Union; NGO, Non-Governmental Organisation; NHA, Natural Heritage Area; SAC, Special Area of Conservation; WTH, Northern Atlantic wet heaths with *Erica tetralix* (FLUSHES ONLY)**; TNM, Transition mire (quaking bogs); MWM, Monaghan Wetlands Map.

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 príomhnithe 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, Pobal agus Rialtais Áitiúil.

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;
- scardadh dramhuisce.

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.

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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