Environmental RTDI Programme 2000-2006

WATER FRAMEWORK DIRECTIVE

Development of a Methodology for the Characterisation of a Karstic Groundwater Body with Particular Emphasis on the Linkage with Associated Ecosystems such as Turlough Ecosystems

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Synthesis Report

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Prepared for the Environmental Protection Agency

by

Department of Civil, Structural and Environmental Engineering,

Trinity College Dublin

Authors:

Suzanne Tynan, Michael Gill and Paul Johnston

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

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
LoCall: 1890 33 55 99
Email: info@epa.ie Website: www.epa.ie

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WATER QUALITY

The Water Quality Section of the Environmental Research Technological Development and Innovation (ERTDI) Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in this area. The reports in this series are intended as contributions to the necessary debate on water quality and the environment.

ENVIRONMENTAL RTDI PROGRAMME 2000-2006

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This project, although a desk study has involved significant fieldwork, particularly on the hydrological aspects. Many have contributed to the results, not all of whom can be included in a synthesis report but grateful acknowledgement is made to those who have undertaken these contributions: Dr Catherine Coxon, Department of Geology and Dr David Drew, Department of Geography of Trinity College, Dr Michael Gormally, Dr Micheline Sheehy-Skeffington and the turlough research group at the National University of Ireland Galway, and Dr Steve Waldren and his students from the Department of Botany at Trinity College. Many hydrological data were collected during the Gort Flood Study following the floods of the 1990s and acknowledgement is made to the Office of Public Works (OPW)—Mr Tony Smyth, Chief Engineer—which carried out this work and to which two of the present authors contributed.

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Details of Project Partners

Michael Gill,
Department of Civil, Structural and Environmental Engineering,
Trinity College Dublin,
Dublin 2

Paul Johnston,
Department of Civil, Structural and Environmental Engineering,
Trinity College Dublin,
Dublin 2
Tel. +353 1 896 1372
E-mail: pjhston@tcd.ie

Suzanne Tynan,
Department of Civil, Structural and Environmental Engineering,
Trinity College Dublin,
Dublin 2

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1. INTRODUCTION

1.1 Introduction

Turloughs are an integral and characteristic part of the Irish landscape and as such almost form part of our cultural identity. There has long been curiosity as to how turloughs 'work' hydrologically and ecologically and there has been an engagement in sporadic research and investigation over many years. It has been the advent of the Water Framework Directive, in particular, that has now focused attention on precisely how they function and to what degree they are susceptible to environmental impact. Thus, this desk study has drawn on many people's work in an attempt to synthesize a form of classification or typology.

From the Irish etymology of the word, turloughs may be broadly defined as groundwater dependent, seasonally inundated wetlands in karst. In Ireland, they are the most characteristic wetlands occurring in association with groundwater bodies in karst. Their characteristic occurrence may be attributed to a combination of the karstified limestone geology and geomorphology with an appropriate hydrological regime (i.e. sufficient rainfall).

Nationally, this occurrence is manifest in the west, mainly in counties Donegal to Clare. As such, turloughs have a characteristic hydrology which drives a corresponding ecology, particularly vegetation and invertebrate communities. It is this unique hydroecology which has resulted in many turloughs being designated as Special Areas of Conservation (SACs). It is the aim of this study to analyse that hydrology and to propose a methodology of relating hydrological indicators to appropriate measures of the ecology, based on whatever data were available from a variety of sources.

1.2 Turloughs within the Water Framework Directive and Associated Legislation

Turloughs, as the most characteristic of karst wetlands in Ireland, are at a unique interface between surface water and groundwater hydrological systems. As a seasonal phenomenon, under inundation, turloughs have a free, open water surface but the wetland they represent is groundwater-fed. Thus, the turlough usually occurs within the groundwater body which feeds it and in this context, the free water surface in the turlough may be regarded as the 'surface expression of the groundwater table'.

Consequently, in the context of the Water Framework Directive (2000/60/EC) (WFD), turloughs fall into the category of terrestrial ecosystems which depend directly on bodies of groundwater. Groundwater Dependant Terrestrial Ecosystems (GWDTEs) include ecosystems which are located in areas where the water table is at or near the surface of the ground (Wetlands Horizontal Guidance, 2003). Thus, GWDTEs are given specific protection under the purposes of the directive. The need to understand the linkage between the GWDTE and the groundwater upon which it depends is an integral part of the Directive.

There is a very large number of turlough GWDTEs in Ireland. For the first characterisation and pressures and impact analysis phase (due to be carried out by 2004) being carried out under the Irish implementation of the Directive, only GWDTEs which are defined as Protected Areas under Article 6 of the Directive, and which, in addition, are designated under the European Union (EU) Habitats Directive (92/43/EEC) or the Birds Directive (79/409/EEC) are included.

1.3 Project Objectives and Results

1.3.1 Objectives

The objectives of this desk study were to:

- Develop a risk assessment framework for groundwater dependant habitats in Ireland, with particular reference to turloughs.
- Identify and assess the qualitative and quantitative pressures leading to identification of risk of impact of such pressures (*e.g.* nutrients, physical disturbance of karst aquifers) Designated protected areas would be considered as a priority and high risk areas would be given a more in-depth investigation.
- Examine the response of turlough ecosystems to hydrological inputs using appropriate methodologies to enable potential impacts to be addressed.

1.3.2 Results

The results of this project substantially exceed the initial objectives. From the legislation, it is clear that a vital step in delivering WFD obligations towards turloughs is to determine the groundwater related needs of sites, to the extent required:

- To devise appropriate standards and objectives
- To decide if there is a significant risk of failing to achieve these water related standards and objectives
- To take measures to address any such significant risk.

The project has contributed significantly towards all of the crucial elements in delivering WFD obligations towards turloughs, including:

- Quantitative determination of the relationships between water quantity and chemistry *i.e.* hydrological indicators, and turlough ecology, including relationships between:
  - Turlough flood duration and vegetation community zoning;
  - Turlough outflow characteristics as described by the hydrological indicator, flood stage recession, Ellenberg plant wetness indices, and vegetation composition;
  - Turlough trophic status and karstic flow system as described by the hydrological indicator flood stage recession.
- A set of key turlough characteristics was defined by coupling the quantitative relationships above with qualitative relationships relating invertebrate communities and turlough flood regime.
- Assessment of current and potential pressures and their predicted impact, to be used in both initial and further characterisation stages
- Development of an indicative typology for turloughs, dividing them into two broad groups, based on a combination of vegetation trophic status, karst flow system and the hydrological indicator stage recession. This typology forms the basis for a turlough catchment delineation methodology, thus defining the area over which risk assessment for the turlough must be carried out.
- Development of a risk based approach for analysis of pressures on turlough receptors.
- An assessment of work which will need to be undertaken under to facilitate the implementation of the further

characterisation phase and on-going cycles of WFD implementation.

All of the above were used in conjunction with expertise from other members of the Ground Water Working Group Turloughs Sub-Committee (Turloughs Working Group) to devise a risk assessment procedure for assessing the risk of an individual turloughs failing to achieve its Article 4 objectives. Development of the risk assessment procedure included the setting of standards and objectives for turloughs.

The risk assessment procedure is published as a Risk Assessment Sheet and accompanying Guidance on its implementation. The procedure is sufficiently detailed to be used at both initial and further characterisation stages where sufficient supporting data are available.

There is a contribution of additional data to the body of turlough data by turlough water level monitoring and topographic levelling.

The project set up an informal network of turloughs researchers and initiated interdisciplinary idea and data sharing.

This group of co-operating scientists subsequently became the core of the WFD Co-Ordination Group, Groundwater Working Group Turloughs Sub-Committee which developed the risk assessment procedures and guidance for turloughs.

2. TURLOUGHS

2.1 Definition

An agreed (GSI Turlough Working Group, 2004) formal definition of a turlough is a **topographic depression in karst which is intermittently inundated on an annual basis, mainly from groundwater, and which has a substrate and/or ecological communities characteristic of wetlands.**

This definition was developed to take account of the fact that a turlough is an integrated hydro-ecological entity, and not simply a hydrological entity. A relationship exists between the water quality, the flooding regime, the morphology and substrate of the turlough, and the composition and distribution of its plant and animal communities, which are adapted to survive fluctuating hydrological conditions. Turloughs exhibit a range of hydrological, morphological and substrate parameters that are associated with a characteristic range of ecologies.

Previous definitions have focused on single aspects of the turlough, generally focussing on the water regime and/or geomorphological characteristics. Each of those definitions defines a set of waterbodies as turloughs, though these sets will not overlap completely. In essence, the occurrence of flooding is a function of the climatic regime, of the hydrological functioning of the turloughs and the karstic limestone system of which they are an integrated part. Western Ireland, where almost all turloughs occur, has high rainfall, on average 1,000 mm per annum. The predominantly seasonal pattern of flooding observed in turloughs results from high rainfall in winter, and less rainfall, with higher evapotranspiration, in summer. Turloughs within the same climatic environment have different patterns of seasonal flooding due to differences in their hydrological functioning, specifically their capacity for filling and emptying. A small number of upland turloughs have been reported to have short-term filling and emptying (Williams, 1964), in response to individual rainfall events, even in summer. These reported turloughs all occur on the Burren plateau. The majority of lowland turloughs flood seasonally, filling sometime in September/October and emptying (apart from residual pools) in the April to June period. The speed of filling and emptying varies among turloughs, as does the modality of increase and decrease in water levels during the flooded period. Analysis of rainfall data for the Gort area of county Galway (Johnston and Peach, 1999), where turloughs are associated with conduit flow type hydrology, showed that intensive flooding was always associated with high winter rainfall amounts, specifically when cumulative rainfall during the December through January period exceeded 550 mm. A proportion of turloughs retains some permanent water in summer. Others will have small area(s) of water (residual pools) which will dry out only in years when rainfall is very low.

2.2 Inventory of Turlough Sites

A number of disparate lists of turlough sites exist. These have been collated by various institutions and for studies in various disciplines with a variety of different objectives.

For the purposes of this study four digital databases, available in GIS and spreadsheet format were created and an ArcView (GIS) project compiled to facilitate viewing, overlay and query of these databases in a single visual environment.

2.2.1 TCD Project Turloughs Database

This database is available in Arcview (GIS) shape format (TCDTurloughs.shp), for spatial viewing and querying, and Excel spreadsheet format (TCDturloughs.xls).

It is comprised of 128 turlough sites which are listed in Coxon, (1986), Goodwillie, R. (1992), and Regan, E., and O'Connor, A. (2003) aquatic and terrestrial beetle sampling lists and Southern Water Global (1996). These sources have been listed because they include the most detailed sources of information on various aspects of turloughs, and in many cases overlap so that the site is included in more than one of the lists and therefore more than one type of data (hydrology, morphology, substrate, composition and distribution of plant and invertebrate ecologies, *etc.*) exists for that turlough site. The database can be used to identify and access the data available for a given site from each of the sources. The locations and names of the turloughs have been validated and cross-checked across the individual databases and the data are reliable.

Other databases used in compilation of the TCD database were those of the Geological Survey of Ireland (Karst Database) and the SAC/SPA database of the National Parks and Wildlife Service (NPWS).

Figure 2.1 below shows the distribution of turloughs listed in the TCD Project Turloughs Database and the Geological Survey of Ireland (GSI) Karst (Turloughs) database.

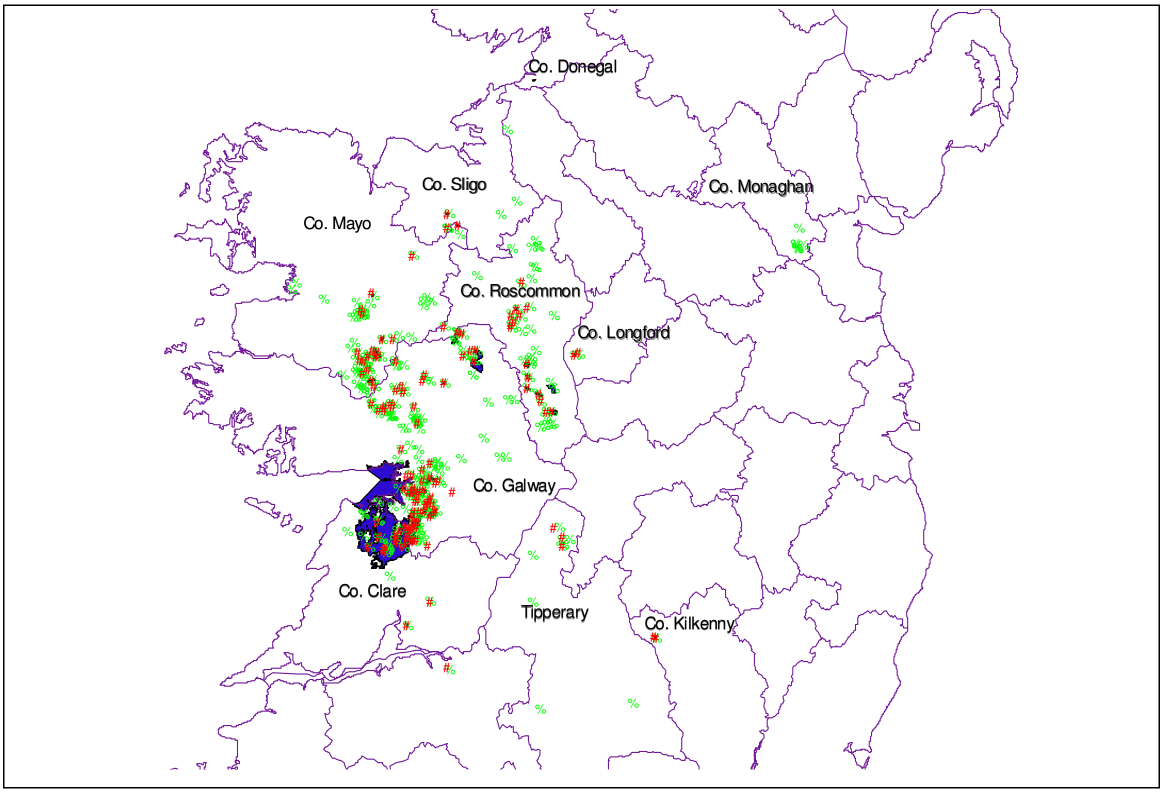


Figure 2.1 Distribution of turloughs listed in the TCD Project Turloughs Database and the Geological Survey of Ireland (GSI) Karst (Turloughs) database

2.2.2 ArcView Turloughs Project

An ArcView project (turloughs.apr) has been compiled. This allows access to all GIS based data, using ArcView pre-loaded in one environment.

It is available for viewing, spatial and database query. Other GIS based data can be added to the project by the user to facilitate analysis. O.S. 1:50,000 scale raster maps were sourced from the EPA and used during the project. They provide a useful topographic base for the data.

It is comprised of the TCD project database, the Geological Survey of the Ireland (GSI) Karst (Turloughs) database, the Turlough Special Areas of Conservation (SACs) database and the Turlough Special Protection Areas (SPAs) database.

Figure 2.2 below shows all the database turlough, SAC and SPA locations displayed and an associated database table open for viewing and query in the ArcView Turloughs Project.

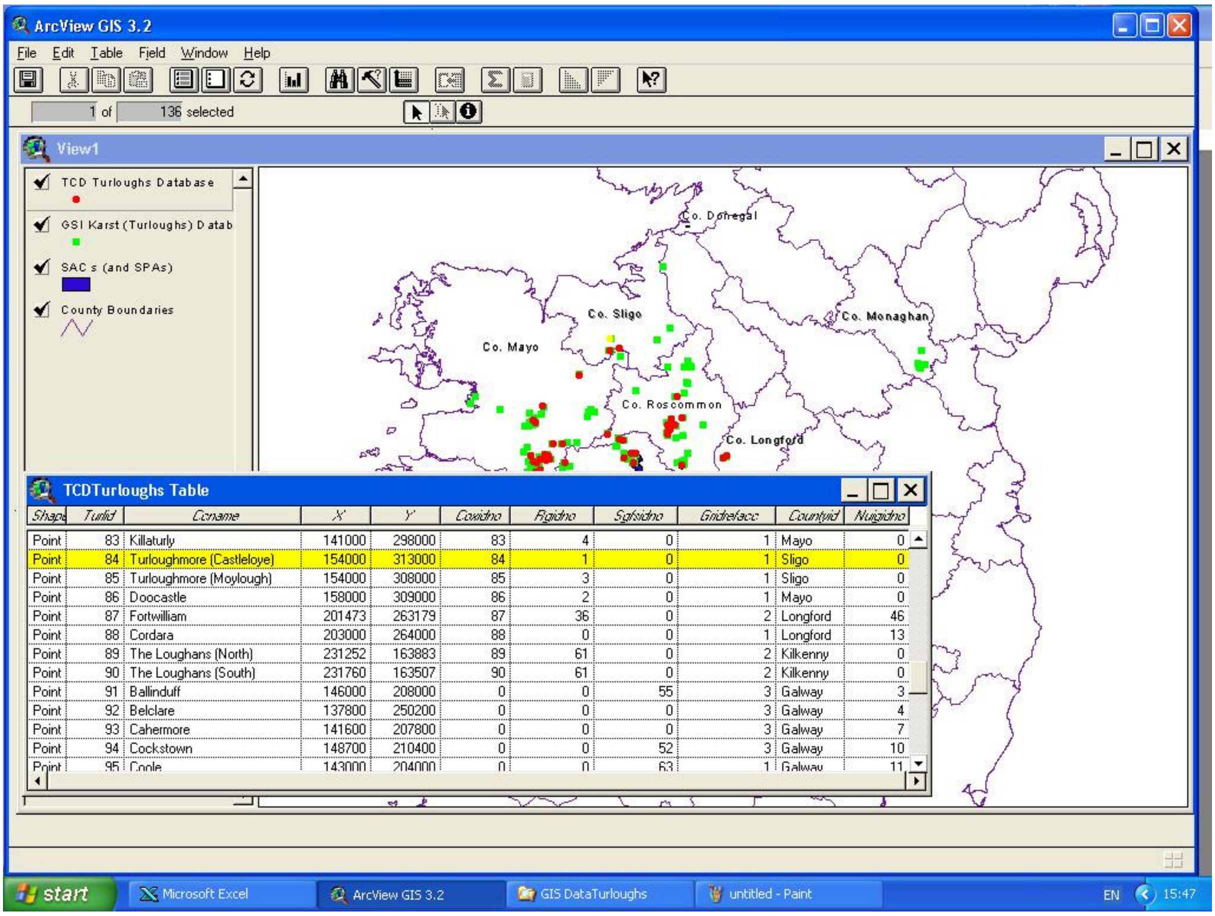


Figure 2.2 ArcView Turloughs Project (turloughs.apr) open for view and query

The individual GIS data files, in shape file format, can be viewed or converted for viewing in a large number of proprietary GIS systems.

A comprehensive listing of references and data resources relevant to turloughs has been compiled in under the project. It includes both published information and unpublished data. It is reasonably comprehensive although there may be omissions and work on turloughs is continuing.

2.3 Pattern of Turlough Distribution

The most extensive work on the pattern of turlough distribution has been carried out by Coxon (1986). Ninety sites were located which correspond to her criteria above (Coxon, C. (1987(b))) and, in addition, are <10 ha in area and undrained. Various sources were used, primarily the 1:10,560 Ordnance Survey maps of the area of Ireland underlain by carboniferous limestone. (These sites are all included in the TCD turlough database). She considers that since turloughs of less than 10 ha only occur in the areas with the 90 larger ones. These turloughs represent a reasonable picture of the spatial distribution of turloughs (Coxon, 1987a). In addition, work by Coxon (1987b) on the relationship between the area of the turloughs and other characteristics of the turloughs identified, no significant link between turlough area and other turlough characteristics. The sites, which have been identified in this project and from the GSI Karst (Turloughs) database, bear out this assertion. The additional sites occur predominantly in the same areas as the Coxon sites.

Coxon studied the distribution of turloughs with respect to solid geology, surrounding topography and drift cover. The work indicated that the majority of turloughs occur on well-bedded, pure grey calcarenite, lithologically if not stratigraphically similar to the Burren limestone. At this time, no consistent bedrock mapping was available for the whole area in which turloughs are located, and so assumptions were made about the lithological similarity of inconsistently named geological formations and lithologies. These well-bedded, pure limestones are susceptible to karstification, thus favouring the development of turloughs.

Surrounding topography tends to consist of gently undulating, glacial depositional landscapes. The limited drift information suggests that in addition to the lithological control, turloughs occur in areas where drift is relatively thin and permeable. Structure was thought by Coxon to play a role in control on glaciation, with which turlough orientation does seem to be related, but not directly on turlough location.

Coxon's sites were compared with the GSI Rock Unit Groups raster mapping in a GIS environment. This mapping was prepared to facilitate implementation of the WFD, specifically ground water body delineation. The 1,200 geological formations and members defined within the Republic of Ireland have been reduced to 27 *Rock Unit Groups*. These have been defined within a stratigraphic framework based on what are understood to be important differences between rock units/ rock unit groups in terms of groundwater flow properties, including:

- Limestone purity and susceptibility to karstification;
- Bedding presence or absence and its influence on the prevalence of jointing;
- Degree of deformation and its impact on flow properties (*e.g.*, older rocks have been deformed many times since their formation, so lack pore spaces and connected fracture networks).

With the exception of two turloughs, all of the TCD project database 128 turloughs sites are located on the Dinantian pure bedded limestone rock unit group (this includes Coxon's 90 sites). The bedding planes and purity of this limestone render it susceptible to karstification. Of the two turloughs which do not occur on the Dinantian pure bedded limestone, one Sluggary Pool (turlid 80) occurs on the Dinantian pure unbedded limestone, but close to a fault zone, which may have made it more susceptible to the formation of epikarst found at that site (Taly Hunter-Williams, G.S.I., pers. comm). The second Ballynakill (Hanrahan's lough) (turlid 94) crosses the boundary between Dinantian Lower impure limestones and Dinantian (early) sandstones, shales and limestones. This site is also in a faulted area and its catchment may occur in the Dinantian (early) limestones, there is also a possibility that this is not actually a turlough, but may be closer in character to a seasonal lake.

This validates Coxon's assumption that all the sites occur on lithologically similar bedrock with similar bedding characteristics. It also indicates that turloughs occur on areas with similar susceptibility to karstification. The definition of a rock unit/rock unit group based on what are understood to be important differences between rock units/ rock unit groups in terms of groundwater flow properties, as detailed above, and the occurrence of all of the Coxon sites on one rock unit group, confirms that the properties of the bedrock which control hydrology are key in the development of turloughs.

These interrelated properties consists of, the degree of limestone purity, prevalence of bedding and fracturing, and degree of karstification.

2.4 Vulnerability of Turloughs as Elements of a Karst System

The karstic systems of which turloughs form part have a number of characteristics which render their hydrology very sensitive to anthropogenic pressures. Their sensitivity is such that a relatively slight stress at some point in the hydrology of the karst system may cause a disproportionately large response (Drew, D. and Hotzl, H., 1999). The interdependence of hydrology and ecology guarantees that any changes to the hydrology will impact on the ecology.

These characteristics include the following:

- The presence of potentially interconnected conduit and diffuse flow systems, and of flow in an epikarst zone, where these flow systems result in extremely high flow rates high relative to other g/w flow systems with flow velocities ranging from 90-250m/hr (European Commission, COST 65 1995) reducing possibilities for attenuation of pollutants, and facilitate easy movement of pollutants through the interconnected system.
- Surface and groundwater flow are strongly interrelated and water can move rapidly from one to the other and through the interconnected groundwater flow system. This aspect of vulnerability is pronounced in the case of the Irish karst in which the turloughs are located. The common definition for a karstic area is the absence of surface water, with virtually all excess precipitation quickly converted to groundwater recharge and discharging primarily from springs. In many turlough areas, autogenic surface waters occur, not simply allogenic waters generated on non-karst strata. This surface drainage may result from the presence of a high water table, a superficial covering of low permeability deposits or from an immature karst groundwater. Thus, surface water contaminants may enter groundwater via sinking streams and surface and groundwater become part of an interchangeable system (Coxon, C. and Drew, D., 1998).
- Changes in direction of flow of groundwater and surface water may occur in response to changing hydraulic head within the system.

- Catchments (contributing area to a turlough) can change rapidly in response to changes in water level height (hydraulic head).
- Responses of flow system characteristics *e.g.* flood duration in turloughs, to changes in recharge patterns or quantity, are very rapid.
- Point recharge of substances (pollutants) directly to groundwater can occur, as well as via sinking surface waters. Turloughs may act as points of direct recharge with respect to the flow system and the turloughs downstream in the flow system.
- Upland karsts are frequently associated with very thin / absent soil cover.

2.5 Existing Classification Schemes

A number of workers have attempted to classify turloughs. These classifications reflect the discipline of the workers and their particular interest in the turlough system and are generally based on a single aspect of the turlough system. Hydrological classifications include Coxon, C. E. and Drew, D. P. 1998(b), Coxon (1986) and Williams (1964 (in Coxon (1986)) and include factors such as speed, duration, seasonality, and routes of filling and emptying, and degree of contribution to and from surface and groundwater.

Botanical classifications include Praeger (1932) which refers to zonation of plant species. Work on aquatic and terrestrial beetles by Regan and O'Connor (2003) respectively result in statistical groupings with potential links to site nutrient status and duration and speed of filling and emptying. More qualitative systems include that of Reynolds (pers. comm) which associates changing invertebrate communities with changing water chemistry across an east-west gradient in the Galway and Clare areas.

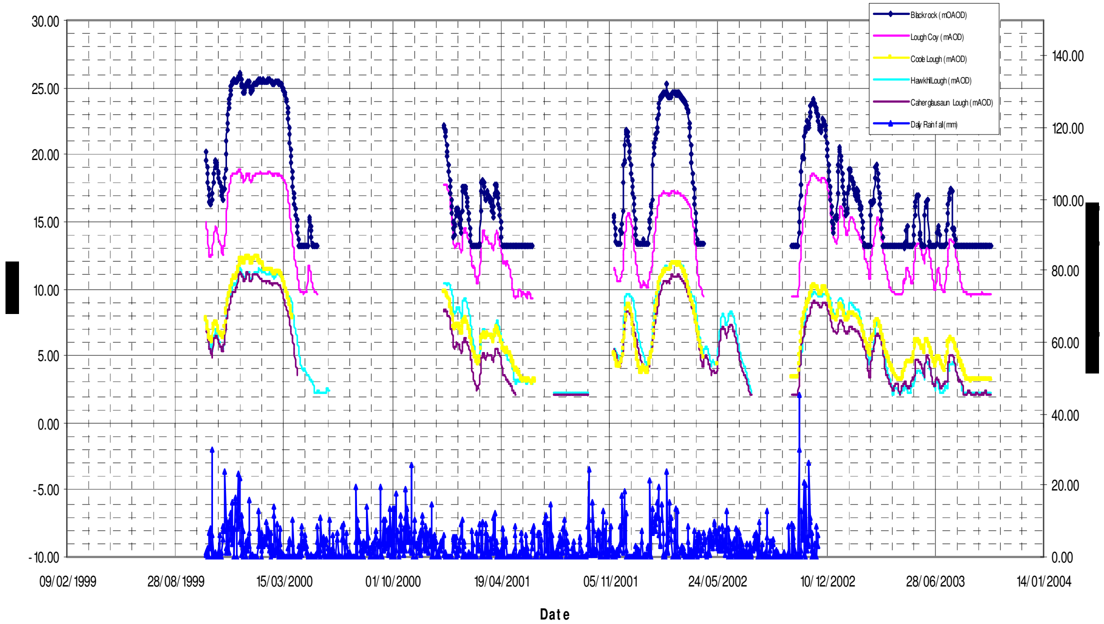


Figure 2.3 Hydrological response of turloughs

Photos illustrate changes in water level from winter to summer at a turlough site in south Galway.

January 2002

June 2002

Classifications which take into account more than one aspect of the turlough systems are those of Coxon (1986) and Goodwillie (2003). Coxon (1986) takes into account of a number of turlough characteristics and groups turloughs on the basis of combined morphology, deposits, vegetation and duration of flooding using multivariate statistics. Goodwillie (2003) identifies zones of vegetation, with respect to qualitative measures of site nutrient status, wetness, substrate, and land use. In most cases, the authors were hampered by a lack of quantitative data on one or more characteristics of the turlough.

Broadly, the hydrological classification of turloughs is based on the rapidity of response which, in turn is based on the underlying nature of the karstification. Those turloughs fed by conduit systems and often linked together in series usually respond very rapidly (within hours or days) to rainfall (Figure 2.3) whereas those fed by shallow, more diffuse 'epikarst' fissuring responds much more slowly, in general. Combinations of these systems can also occur together with external surface water inputs, for example, from an inflowing surface water stream. There are clearly particular implications for the associate hydroecology.

An indicative classification scheme for turloughs, developed as part of this project, which take account of the turlough as an integrated hydro-ecological entity is discussed in greater detail in Chapter 3.

3. STUDY OF THE ECO-HYDROLOGY OF TURLOUGHS

3.1 Introduction

3.1.1 Objectives

The objective of this study of the eco-hydrology of turloughs was to:

- Identify hydrological indicators for the turlough hydrological regime which can be related to ecological parameters, in order to understand better the relationship between the hydrology and the ecology of turloughs.
- Identify the key ecological and hydrological characteristics of turloughs.
- Based on these identified relationships and key characteristics, to identify pressures which impact or could potentially impact on the hydro-ecology of the turloughs.
- Develop an indicative typology for turloughs, which has relevance to the assessment of pressures and impacts.
- Previous work has focussed on analysis of hydrology for the purposes better understanding this facet of turloughs, and on ecological studies for the purposes of understanding that facet of turloughs, any study of the relationship between ecology and hydrology being based on qualitative estimates of, or surrogate measures for, hydrology.

The exceptions to this approach are work carried out by Coxon (Coxon, 1986) and by Goodwillie (Goodwillie, 2003). These studies addressed the relationship between flooding regime and vegetation but were restricted by a lack of detailed hydrological data.

3.1.2 Data Availability

3.1.2.1 Data Used

To achieve the objectives outlined above, large datasets for each of the ecological and hydrological characteristics of turloughs, which span a large number of turloughs and a long period of time, are required. In the inevitable absence of such data, the most suitable datasets were chosen. These are the datasets which cover the widest range of turlough variety, for the longest periods of time, for any given turlough characteristic. The main data sources are indicated in the following Table 3.1.

Table 3.1 Sources of data for turlough hydroecology

Hydrology and Hydrogeology	Water Chemistry	Morphology and Substrate	Plant Ecology	Aquatic Invertebrates (water beetles)	Terrestrial Invertebrates (terrestrial beetles)
Coxon, C. (1986)	NUIG Monitoring (O'Connor, A., Regan, E.)	Coxon, C. (1986)	Goodwillie, R. (1992)	NUIG Monitoring (O'Connor, A.)	NUIG Monitoring (Regan. E.)
Drew, D. (1984)		Goodwillie, R. (1992)	MacGowran, B.A. (1985)		
Drew, D. (1985)		MacGowran, B.A. (1985)	NPWS, Turlough SACs data		
Southern Water Global (1996, 1997)					
TCD Turloughs Monitoring (Johnston, P.)					

Within these datasets, with the exception of hydrological data, the data are for only one year of monitoring. In addition, the year of monitoring for one characteristic is almost always not coincident with monitoring for any other characteristic. The set of turloughs which have been monitored for a given characteristic frequently does not coincide with the set monitored for another characteristic. To supplement these large datasets, where it exists, data on characteristics of individual or groups of turloughs were drawn from other data sources. These are referenced in the report.

3.2 Relationships between Plant Ecology and Turlough Hydrology

3.2.1 Plant Ecology and Flooding Regime

3.2.1.1 Flooding Effects on Plants

The flooding regime of turloughs is variable, within an overall seasonal pattern. The majority of lowland turloughs floods seasonally, filling sometime in September/October and emptying (apart from any permanent water or residual pools that may remain) in the April to June period. The speed of filling and emptying varies among turloughs, as does the modality of increase and decrease in water levels during the flooded period, indicates that some turloughs fill in response to flooding, but remain full until they empty in spring, whereas others may fill, then partially empty more than once before emptying in spring / early summer. A small number of turloughs on the Burren plateau are reported to have short term filling and emptying (in response to individual rainfall events) in summer. A proportion of turloughs retain some permanent water in summer. Others will have small area(s) of water (residual pools) which will dry out only in years when rainfall is very low.

Flooding affects plants mainly through the interruption of gaseous exchange. Additional impacts are the accumulation in soils of toxic substances that are caused by anaerobic metabolism of plants or bacteria and changes in soil structure. Certain plants have developed adaptations to survive these conditions and as such, are termed wetland species. Adaptations include morphological/physiological changes and timing of important life cycle events. Specific adaptations (Goodwillie, 2003) include:

- Annual plants reduction in oxygen demanded by seed dormancy and completion of their life cycle within a short time period;
- Perennial plants ability to change from aerobic to anaerobic respiration, withstand root death or develop *aerenchyma* so as to allow oxygen to reach the roots;
- Fully aquatic plants frequently have a connection between the atmosphere and roots which persists during the winter flooding period through their dead stems.

Flooding affects vegetation by favouring those plants which have developed these adaptations and thus have a competitive advantage. The vegetation of previously dry areas will change upon flooding by shifting the competitive balance towards wetland species (Nillson *et al*., 1991, cited in Caffarra, 2002). The variable and unpredictable nature of flooding in turloughs provides particular challenges for wetland plants.

3.2.1.2 Turlough Vegetation

Goodwillie (2003) gives a general description of turlough vegetation composition and distribution based on study of in excess of 90 turloughs. Turloughs typically have open, species poor assemblages of plants, including only those which can withstand flooding *in situ* and those which can colonise quickly after it has passed. Goodwillie describes a regular zonation of vegetation "*from the surrounding grassland or woodland through various sedge and grass communities to something wet, either exposed mud or marl, fen or grassland with a few aquatic species poking through it".*

A few species occur from the edge of the turlough almost to its base. Other species are less tolerant to changing water regime and are restricted to definite zones. There are no plant species restricted to turloughs in Ireland, as far as is known, but some become more common there than elsewhere (Goodwillie, 2003).

3.2.1.3 Studies of Relationship between Turlough Vegetation and Flood Regime

The relationship between flood regime and vegetation composition and distribution has been addressed by various workers. A lack of measured hydrological information on flood regime resulted in a dependence on qualitative estimates of, or surrogate measures for, hydrological parameters of the flood regime, in almost all cases. The most frequently used surrogate is depth in the basin, taken to equate with flood duration.

Praeger, (1932) identifies three ecological zones in three turloughs studied in Clare and east Galway (Caherglassaun, turlough south of Garryland wood and turlough close to Tirneevin chapel). These are defined from top to bottom of the turlough by, the upper limit of the moss *Cinclidotus fontinaloides* on rocks, the lower limit of bushes, and the upper limit of the moss *Fontinalis antipyretica*. They occur in the same relative sequence, though at different absolute height and distance to one another, across the turloughs studied. These are equated to increasing periods of flood duration based on assumptions about the tolerance of these species to flooding. Coxon, (1987) suggests that the relationship between the moss zones described by Praeger may also be related to flood frequency, and that the relationship with flood regime may be complicated by competition between the mosses as described in Allott, (1976).

Caffarra, (2003) identified a well-defined vegetation zonation along the topographic gradient of the basin of the two turloughs studied, Coole and Knockaunroe. Gradient is assumed by Caffarra to equate with flood duration. The change along the gradient involved both species composition and richness, with a species poor community adapted to withstand what is assumed to be prolonged flooding in the lower zones and species rich communities less affected by flooding in the upper zones.

Lynn and Waldren, (2003a) report a morphological and associated physiological variation in populations of *Ranunculus repens* in Hawkhill turlough. This species can occur across the whole turlough basin, traversing the boundary between drier grassland habitats and the wetter base of the turlough. Leaf dissection was found to increase with depth in the basin. Depth in the basin was assumed to correlate with susceptibility to inundation, specifically duration of inundation. Lynn and Waldren, (2003b) also identified distinctive zone up the topographic gradient of the Hawkhill turlough basin, with an emergent aquatic community occupying the deepest zone, ephemerals on the open mud above this, followed by a damp grassland community, and a drier grassland community occupying the upper elevations.

Goodwillie, (1992) surveyed 61 turloughs and subsequently added to this number during the Gort Flood Studies project (Southern Water Global, 1997). He identified 32 communities and a zonation with depth in the basin within these communities. These communities were classified in a series of 1 to 12 vegetation divisions encountered with increasing depth. A division of plant communities generally appears in the same order of elevation relative to the other divisions, but not at the same absolute height. Goodwillie believes that the divisions are related broadly to depth of submergence and that coverage by water is the main controlling factor in vegetation and has the largest part to play in its zonation. In 1995 and 1997, topographic spot heights were recorded for noticeable plant species in six turloughs (*e.g.* Upper zone, top of *Veronica serpyllifolia, Elymus repens*) (Goodwillie, 2003). For the purposes of this work, it was assumed that the maximum flood period that vegetation can survive dictates the species composition. The flood period (in days) and the release dates at these locations were worked out from Gort Flood Studies hydrographic and personal records. Goodwillie reports a relatively good association between vegetation position and the flooding regime as measured by flood period and release date, in that the same plant communities in different sites experienced the same flood conditions.

3.2.1.4 Hydroecology

A number of hydrological indicators were identified to compare with various aspects of turlough vegetation. These are flood duration, flood recession, 'residence time' in the turlough and response time. Based on available data, the hydrological indicators which have the best relationship with aspects of the vegetation ecology are duration of inundation and hydrograph recession gradient.

3.2.2 Flood Duration and Vegetation Distribution

The relationship between flood duration and vegetation distribution is investigated by comparing the topographic height occurrence of the communities identified by Roger Goodwillie (Goodwillie, 1992) and flood duration across four turloughs, Caherglassaun, Coy, Skealoghan and Termon South.

3.2.2.1 Flood Duration

The duration of flooding at any given height can be read from an exceedance curve. At any height on the exceedance curve, the percentage of time for which the flood is at or exceeds that height can be obtained.

3.2.2.2. Calculation

Exceedance curves were constructed for Caherglassaun, Coy, Skealoghan and Termon South turloughs. The following exceedance calculation (Fetter, 1994) was used to create the percentage exceedance values:
% Exceedance at height (h) =(descending rank position of (ascending value flood stage (h))/total no. of values +1)*100

3.2.2.3. Flood Duration (exceedance) Graphs

The percentage exceedance values are plotted on a graph of percentage exceedance time at height (h) (x-axis) *vs.* height (y axis).

3.2.2.4. Data

Various lengths of flood stage record were used to construct the exceedance curves for different turloughs.

Coy: Curve constructed from three full hydrological years of stage data (a hydrological year consists of data from 1 October year 1, to 30 September year 2), compiled from daily data collected during the period 23/10/1999 to 2/10/2003 (Source Paul Johnston, Trinity College).

Caherglassaun: Curve constructed from three full hydrological years of daily stage data compiled from data collected during the period 23/10/1999 to 8/10/2003. (Source Paul Johnston, Trinity College).

Skealoghan: Curve constructed from two full hydrological years of approximately weekly stage data collected during the period 1/10/2001 to 30/9/2003. (Source James Moran, NUI Galway).

Termon: Curve constructed from one hydrological year of stage data. Hourly stage data were collected during the period 12/02/1996 to 29/09/1996 (Source Southern Water Global, Gort Flood Studies project) Based on these, data were interpolated for the period 01/10/1995 to 11/02/1996, to create a full year of data. The period of data collected does not include data from October – January and it is possible that water levels during this period were higher than those recorded after this period. The distribution of values used in the exceedance curve may therefore not include the highest values which actually occurred and therefore may underestimate the proportion of time that higher levels in the turlough are flooded, and correspondingly overestimate the proportion of time that lower levels in the turlough are flooded.

All the stage data are expressed in metres O D. Malin.

3.2.2.5. Height Ranges of Vegetation Communities

The topographic height range across which each Goodwillie plant community occurs in each turlough was recorded (See Appendix 1, 1. Summary of Goodwillie, (1992) Vegetation Survey, for details of Goodwillie's vegetation mapping). MacGowran (1985) carried out phytosociological mapping of 16 turloughs. The Goodwillie mapping was chosen for comparison with hydrological indicators because of the large number of turloughs mapped, which resulted in the greatest overlap between available vegetation and hydrological data. In addition, Goodwillie modified the classical phytosociological communities to reflect better the distribution and composition of the plant ecology observed in the turlough environment.

A topographic survey of each turlough was carried out using a Trimble GPS level, accurate to a minimum of 2 cm (in x, y, and z directions) and registered to the national grid. Height is recorded in m O.D. by registration to a local benchmark from the 1:10, 560 O.S. map series. It was not possible to level areas which were under water at the time of survey (August-October 2002). Each of these turloughs retained some water through the driest period of this year.

Vegetation community maps from Goodwillie, (1992) were digitised in AutoCAD and registered to the national grid. Each topographic survey was overlaid on the relevant vegetation community map. See Appendix 1, 2 Goodwillie Vegetation Maps with Topographic Detail (m O.D. Malin) for maps.

Figure 3.1 below shows topography overalid on Goodwillie vegetation communities for Skealoghan turlough.

For each turlough, the topographic height range (*i.e.* the minimum and maximum height) of each of the communities occurring in that turlough was recorded.

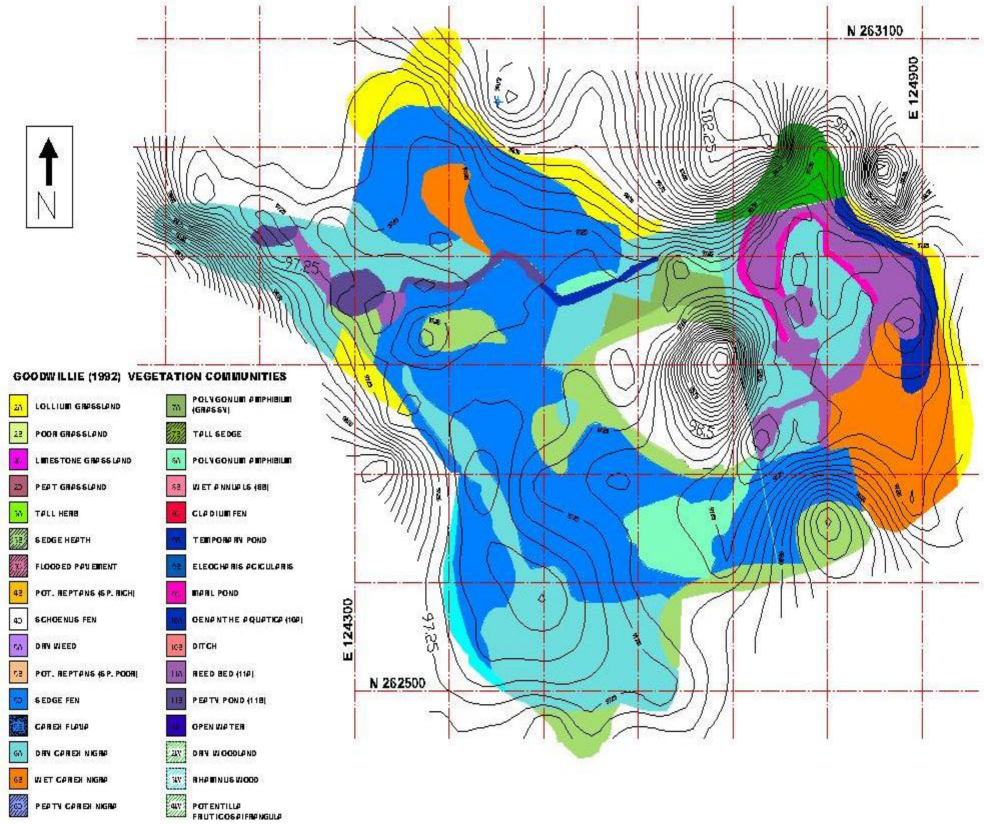


Figure 3.1 **Skealoghan, Goodwillie (1992) vegetation communities and topographic contours (m O.D.. Malin)**

3.2.2.6 Integration of Flood Duration and Height Ranges of Vegetation Communities

The height range of each community occurring in the turlough is plotted onto the flood duration (exceedance) graph for each turlough. The data are provided in the final report (Appendices 1, 3 Combined Flood Duration (Exceedance) curves and Vegetation Range Graphs). Figure 3.2 below is the combined community height range-flood duration graph for Skealoghan turlough.

Plant communities occurring in each of the four turloughs are tabulated. The four turloughs include 25 of the 32 Goodwillie communities. See Table 3.2 for the occurrence of Goodwillie communities in studied turloughs.

Plant communities which occur in two or more of the four turloughs are tabulated. This comprises 15 communities. For each turlough, the maximum flood duration each of these communities is subjected to be recorded from the combined Flood duration (exceedance) curve/Vegetation Range Graph. That is, the percentage exceedance time for the minimum height at which the community occurs is recorded. Similarly, for each turlough, the minimum flood duration that each of these communities is subject to be recorded from the combined Flood duration (exceedance) curve/Vegetation Range Graph. That is, the percentage exceedance time for the maximum height at which the community occurs is recorded. See Table 3.3, below. The combined range of flood duration *i.e.* the minimum to maximum flood duration encountered across all four turloughs for each community is recorded and similarly for turloughs Caherglassaun and Coy combined and Skealoghan and Termon combined (Table 3.4). In the case of the results for combined turloughs (all or Skealoghan/Termon), due to the uncertainty in the data, the ranges are those from Skealoghan, except where there is no Skealoghan data.

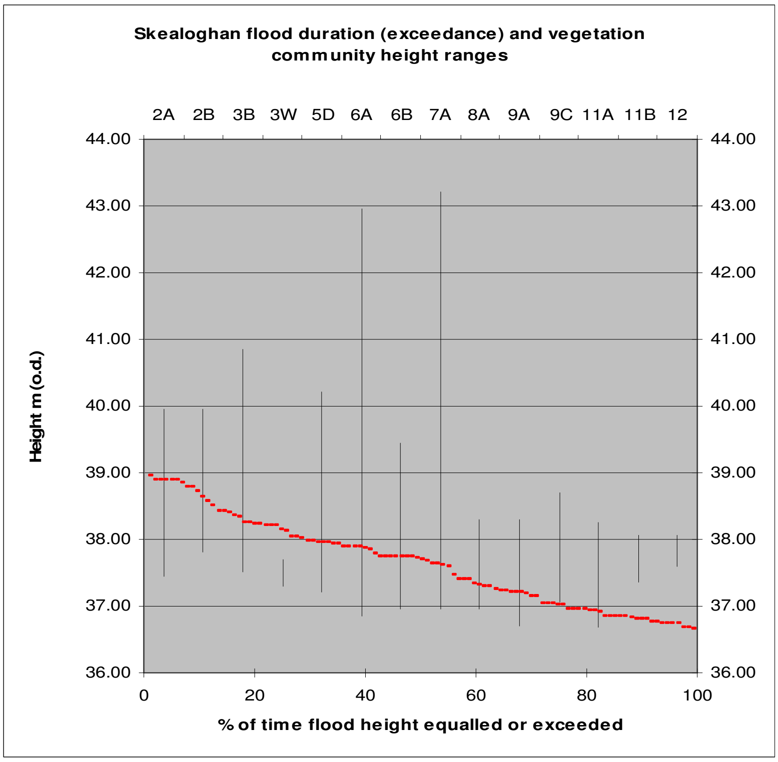


Figure 3.2 Combined community height range-flood duration graph for Skealoghan turlough

Plant communities occurring in each of the four turloughs were tabulated. The four turloughs include 25 of the 32 Goodwillie communities (Table 3.2).

Plant communities which occur in two or more of the four turloughs are tabulated. This comprises 15 communities. For each turlough, the maximum flood duration each of these communities is subjected to be recorded from the combined Flood duration (exceedance) curve/Vegetation Range Graph. That is, the percentage exceedance time for the minimum height at which the community occurs is recorded. Similarly, for each turlough, the minimum flood duration that each of these communities is subject to be recorded from the combined Flood duration (exceedance) curve/Vegetation Range graph. That is, the percentage exceedance time for the maximum height at which the community occurs is recorded. See Table 3.3, below. The combined range of flood duration, *i.e.* the minimum to maximum flood duration encountered across all four turloughs for each community, is recorded and similarly for turloughs Caherglassaun and Coy combined and Skealoghan and Termon combined (Table 3.4). In the case of the results for combined turloughs (all or Skealoghan/Termon), due to the uncertainty in the data, the ranges are those from Skealoghan, except where there is no Skealoghan data.

3.2.2.7 Results

Table 3.2 Occurrence of Goodwillie communities in studied turloughs

Turlough		Caherglassaun	Coy	Skealoghan	Termon
Goodwillie (1992) community		**Presence of community**			
2A	*Lolium* grassland	x	x	x	
2B	Poor grassland	x	x	x	x
2C	Limestone grassland	x			
2D	Peat grassland				
2W	Dry Woodland				
3A	Tall herb	x			x
3B	Sedge heath			x	
3C	Flooded pavement	x			x
3W	*Rhamnus* wood	x	x	x	x
4B	*Potentilla reptans* (sp. rich)	x	x		
4D	*Schoenus* fen				
4W	*Potentilla fruticosa/frangula*				
5A	Dry weed	x			
5B	*Potentilla reptans* (sp. poor)	x			
5D	Sedge fen			x	x
5E	*Carex flavia*				
6A	Dry *Carex nigra*		x	x	x
6B	Wet *Carex nigra*			x	x
6D	Peaty *Carex nigra*				
7A	*Polygonum amphibium* (grassy)	x		x	

7B	Tall sedge				x
8A	*Polygonum amphibium*			x	x
8B	Wet annuals	x			
8C	*Cladium* fen				x
9A	Temporary pond			x	x
9B	*Eleocharis acicularis*	x	x		
9C	Marl pond			x	x
10A	*Oenanthe aquatica*				
10B	Ditch				
11A	Reed bed			x	x
11B	Peaty pond			x	
12	Open water	x		x	x

Table 3.3 Minimum and maximum flood duration of Goodwillie communities for individual turloughs

Turlough		**Caherglassaun**		**Coy**		**Skealoghan**		**Termon**	
		% flood duration (of time) for community							
Goodwillie (1992) community		**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**
2A	*Lolium* grassland	54.0	0.0	24.0	0.0	55.6	0.0		
2B	Poor grassland	19.0	0.0	26.5	0.0	40.0	0.0	0.6	0.0
3A	Tall herb	100.0	23.0					100.0	23.0
3C	Flooded pavement	63.0	0.0					100.0	0.1
3W	*Rhamnus* wood	59.0	0.0	17.0	1.0	69.0	0.0	100.0	54.0
4B	*Potentilla reptans* (sp. rich)	100.0	0.0	33.0	17.0				
5D	Sedge fen					68.0	0.0	100.0	0.0
6A	Dry *Carex nigra*			43.0	0.4	83.0	18.0	83.0	0.0
6B	Wet *Carex nigra*					100.0	0.0	100.0	0.0
7A	*Polygonum amphibium* (grassy)	100.0	52.0			76.0	0.0		
8A	*Polygonum amphibium*					76.0	17.0	100.0	100.0
9A	Temporary pond					96.0	17.0	100.0	0.0
9C	Marl pond					72.0	9.0	100.0	20.0
11A	Reed bed					98.0	17.0	100.0	100.0
12	Open water	63.0	45.0			54.0	26.0	100.0	100.0

Table 3.4 Flood duration ranges of Goodwillie communities across turlough combinations

Turlough		Caherglassaun and Coy	Skealoghan and Termon	All four turloughs
Goodwillie (1992) community		**Range of % flood duration (of time) for community**		
2A	*Lolium* grassland	0-54	0-55	0-56
2B	Poor grassland	0-26	0-40	0-40
3A	Tall herb	23-100	23-100	23-100
3C	Flooded pavement	0-63	0.1-100	0.1-100
3W	*Rhamnus* wood	0-59	0-69	0-69
4B	*Potentilla reptans* (sp. rich)	0-100		0-100
5D	Sedge fen		0-68	0-68
6A	Dry *Carex nigra*	0.4-43	18-83	0.4-83
6B	Wet *Carex nigra*		0-100	0-100
7A	*Polygonum amphibium* (grassy)	52-100	0-76	0-100
8A	*Polygonum amphibium*		17-76	17-76
9A	Temporary pond		17-96	17-96
9C	Marl pond		9.0-72	9.0-72
11A	Reed bed		17-98	17-98
12	Open water	45-63	26-54	26-63

3.2.2.8 Conclusions

The flood duration range results for the four turloughs suggest that four broad groups can be identified, within the limitations of the small number of turloughs studied, and the potential inaccuracies associated with the data.

Table 3.5 Group 1

Community	Flood duration range all four turloughs
2A *Lolium* grassland	0-56%
2B Poor grassland	0-40%
3W *Rhamnus* wood	0-69%
5D Sedge fen	0-68%
6A Dry *Carex nigra*	0.4-83%

These communities appear, both from their maximum and minimum flood duration values in individual turloughs and from their combined range in all four turloughs, to be constrained in their distribution by a maximum flooding duration value. The results suggest that they can occur at a position within the turlough basin which undergoes flooding from approximately 0% of the time, up to a defined maximum flood length and cannot tolerate being flooded for any greater percentage of time within a given year. This indicates that they are constrained to specific height ranges within the basin, which undergo this duration of flooding or less. The different maximum flood durations at which these communities are observed is in line with Goodwillie's divisional numbering system, that is, according to Goodwillie's observations, communities in division 2 are found at a relatively higher position than the community in division 3, and so on. The maximum flood duration observed for each community increases according to its divisional number, and therefore its maximum depth of occurrence within the basin. However, these communities divisions do not appear to have an upper boundary relating to a (minimum) flood duration, and are found at a range of common flood durations above the specific community maximum, and do not appear to have an upper boundary as defined by Goodwillie. It is possible that in these communities have the possibility of occurring under a wider range of flood conditions than Goodwillie's divisions would suggest, but that some other factor, such as competition restricts their distribution in general. This methodology does not take account of the area of a given community occurring at a specific height, it is possible that only small areas of the overall community occur across this wider range.

Table 3.6 Group 2

Communities	Flood duration range all four turloughs
8A *Polygonum amphibium*	17-76%
9A Temporary pond	17-96%
9C Marl pond	9.0-72%
11A Reed bed	17-98%
12 Open water	26-63%

These communities appear, both from their maximum and minimum flood duration values in individual turloughs and from their combined range in all four turloughs, to be constrained in their distribution by a minimum flooding duration value. The results suggest that they can occur at a height position within the turlough basin which undergoes flooding from a defined minimum to some longer duration within a given year. This indicates that they can only occur within the specific height ranges within the basin which undergo this duration or longer of flooding. The maximum flood duration seems to be close to 100% for 9A and 11A, but less than this for 8A and 9C and 12. In the case of 12, Open water, it would be expected that this community would tolerate 100% coverage by water, as it is noted as occurring in deeper areas of permanent water. Data from Termon, where 100% duration is recorded, would suggest that such is the case. Including these, data would extend the duration range to 26% to 100%. The duration ranges associated with these communities are consistent with their general habitat in terms of persistence of water, as described by Goodwillie. All of these communities are from the four lowest divisions observed by Goodwillie. (Division 10 does not occur in this dataset). That indicates that Goodwillie expects them to occur in the lowest part of the basin, which he associates with longer flood durations. This is consistent with these results. However, within this group, there is no clear pattern in terms of relative height that can be associated with flood duration. As with the previous group, it is possible that in these communities have the possibility of occurring under a wider range of flood conditions than Goodwillie's divisions would suggest, but that some other factor, such as competition restricts their distribution in general. This methodology does not take account of the area of a given community occurring at a specific height, it is possible that only small areas of the overall community occur across this wider range.

Table 3.7 Group 3

Communities	Flood duration range all four turloughs
3A Tall herb	23-100%
4B *Potentilla reptans* (sp. rich)	17-100%
6B Wet *Carex nigra*	0-100%
7A *Polygonum amphibium* (grassy)	0-100%

This group consists of communities which occur across a very wide range of flood duration conditions. In the case of 6B and 7A, these can be found at all flood durations. 4B and 3A occur under slightly more restricted duration conditions, and could potentially be included in Group 2. However, they occur under a wider range of conditions than the other members of that group. All of these communities are noted by Goodwillie as occurring across a considerable height range. There is no obvious relationship between Goodwillie's divisions and the flood duration range of these communities.

Table 3.8 Group 4

Community	Flood duration range all four turloughs
3C Flooded pavement	0.1-100

This group consists of one community, 3C, which is a distinct physical habitat, rather than a plant community. Goodwillie notes that it can host widely different vegetation depending on the position of the rock within the basin. As such, its occurrence is not associated with any specific flood duration, but can occur at all levels and so has a duration range of 0% to 100%.

In addition to the emergence of a number of groups, there appears to be a pattern in terms of the range of durations associated with specific communities in different turloughs. Table 3.4 shows the flood duration ranges for each community for turloughs Caherglassaun and Coy combined, Skealoghan and Termon combined, and for all four turloughs combined. From this small dataset, it appears that Coy and Caherglassaun combined, show in each case an equal or smaller range of flood duration for each community, than Skealoghan and Termon combined. The provisos relating to the Termon data are not relevant here, as the comparison is with the size of the range, not the absolute values, of duration. A possible reason for this is that Caherglassaun and Coy are responding to a different pattern of flooding than Skealoghan and Coy. Caherglassaun and Coy turloughs are located in hydrological systems which are dominated by conduit flow, whereas Skealoghan and Coy are located in hydrological systems which are dominated by epikarstic flow. These two systems seem to be associated respectively with potentially multi-modal flooding events during the year, and uni-modal flood events. Multi-modal flood events consist of periodic rises and drops in flood level during the flooded period, in response to recharge events associated with rainfall. This means that the duration of flooding in a turlough with this type of regime may be composed at certain height levels of a number of discrete flood events, rather than one continuous flood event. This situation would potentially provide a more stressful environment for plants and possibly restrict their occurrence to locations within a narrower flood duration band, in order to minimise the level of uncertainty in the continuity of that flood duration.

It is not possible to see whether the vegetation community distribution occurring in the year mapped by Goodwillie is a response to short or long-term flood duration patterns. Longer-term hydrological data would need to be available for comparison with community distribution, as well as hydrological data for the year directly preceding the growing season. Goodwillie, (2003) considers that the vegetation composition is in a state of constant adjustment to the previous flood event, while response times of up to 20 years are assumed for other wetland habitats.

With respect to wet grasslands, Gowing, (1998) states that "*there is no firm guide as to the length of time it may take a grassland community to achieve near-equilibrium with respect to the water regime; in practice, we use 20 years"*.

These groupings illustrate quantitatively the relationship between vegetation distribution pattern and flood regime, which has been assumed or only qualitatively described in previous studies.

This methodology is data intensive, however extending this methodology to other turloughs would validate or change the conclusions reached here and verify whether these observations can be extended across a larger number of turloughs. It could potentially provide significant insights into the relationship between flood regime and vegetation ecology. This would require topographic survey of turlough sites as well as a minimum of one year's continuous hydrological monitoring, and carried out so as to result in a high degree of certainty regarding relative topographic heights of vegetation and hydrological stage. It potentially requires re-mapping of site vegetation, in order to provide contemporaneous hydrological and vegetation information in order to assess whether vegetation distribution is related to long-term flood regime or to the flood regime in the season immediately preceding a given growing season.

3.2.3 Flood Recession and Vegetation Wetness Index

The relationship between flood recession in twelve turloughs and a vegetation wetness index is evaluated. Substrate was found to be a factor in the relationship.

3.2.3.1 Flood Recession

A recession constant for the falling limb of the stage recession for each turlough was calculated. The falling limb recession (recession) for turloughs is well defined, both in cases where there is a single annual recession and where there are multiple recessions. The recessions approach, or have a straight-line form, and are very consistent across the data periods available for each turlough. For this reason, a single recession line is considered to represent accurately the recession characteristics. A recession constant was calculated using the following methodology:

- The longest straight-line recession available was chosen. This is important in choosing the recession. This does not include the very base of the hydrograph in instances where there is a very low slope section at the base of the recession. This area of the hydrograph is considered to relate to residual water ponded below the turlough outflow zone and not representative of the dominant turlough outflow characteristics.
- Decreases in water level here are probably related to evaporation and seepage:
    - A plot of: log10 stage (time +1) *(y-axis) vs.* log10 stage (time) *(x-axis)* is constructed.
    - A best-fit linear regression line of the form:
    - y = ax + b is fitted to the data. The r^2 value must be > 0.8 to indicate a good linear recession. This was achieved in all cases.
    - The recession constant is the anti-log of slope value a.

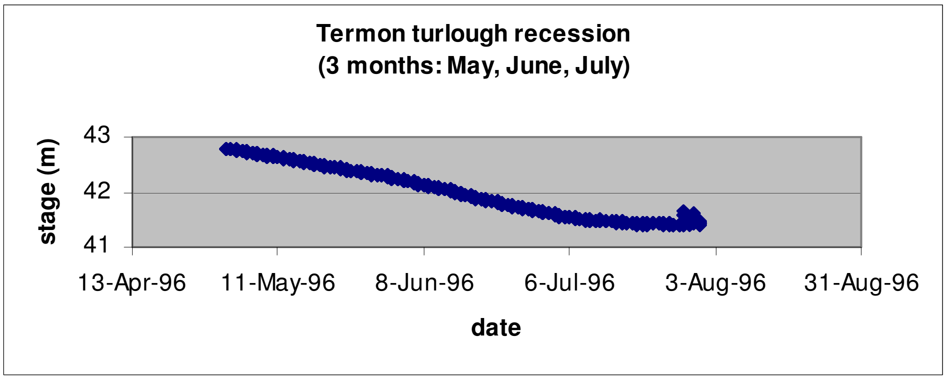
A summary of the stage data used to construct the stage recession for each turlough and the recession plots for each turlough are listed in an appendix to the main report.

3.2.3.2. Turlough Stage Recessions

Recession as used in surface water catchments, is a hydrological indicator for a catchment response to rainfall inputs. It can be described as an indicator of an integrated response to the head of water within the reservoir (catchment) and the characteristics of outflow from the reservoir. This is analogous to the representation of flow of water from a tank reservoir, which can be described in terms of the head of water within the tank and the outflow characteristics of the tank including its morphology.

Applying this conceptual model to the turlough, the turlough can be treated as a tank, with a head of water in the turlough (turlough stage) and outflow characteristics comprised of two components, the physical outflow aperture(s) of the turlough tank and the flow characteristics of the receiving environment. In the tank system there is a constant relationship between the head of water in the tank and rate of discharge from the tank outflow. This is complicated in the case of the turlough by the interaction of the receiving environment. Intuitively, a receiving environment - in this case the karstic system - with a relatively low storage capacity, will become filled with water and retard the rate of outflow from the turlough tank. A system with higher storage is less likely to become backed up with water and therefore will have less of a retarding impact on rate of outflow from the turlough tank. In using this conceptual model, the recession constant is an indicator of this integrated response to turlough recharge and therefore represents both the discharge rate associated with the head component in the turlough tank and the outflow characteristics of the turlough.

A low recession constant represents a slow rate of recession, while a high recession constant represents a fast rate of recession. Figure 3.3 below shows two turloughs hydrographs with very different recession rates over a three-month period. Termon South has a slow rate, shallow sloping recession curve, and an associated low recession constant of 10. Coy in contrast has a fast rate, steeply sloping recession curve, with associated high recession constant of 10.8, and a number of flood and recession events occur over the three-month period.



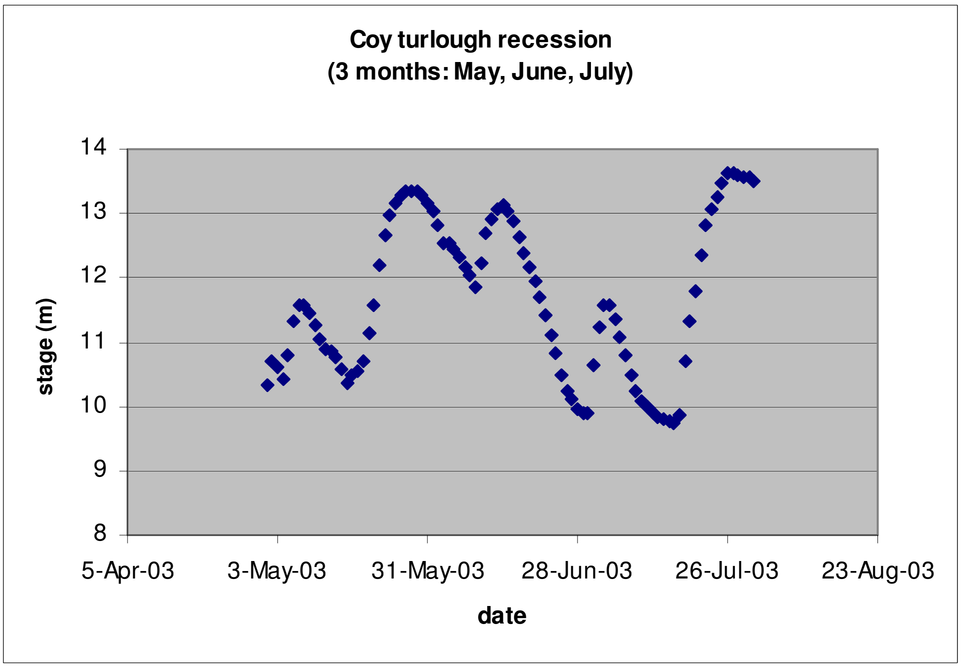


Figure 3.3 Contrasting recession rates at Termon South and Coy

3.2.3.3. Dominant Vegetation Scheme and Associated Degree of Wetness

A turlough vegetation dominance scheme,, based on Goodwillie's mapping, was devised by Eugenie Regan and James Moran, NUIG (pers. comm.). Goodwillie's communities (excluding woodland communities) are amalgamated into three vegetation types, comprising grassland, sedge and aquatic community types. These types are generally associated in with increasing habitat wetness. This approach is consistent with the generally observed relationship between various wetland species and wetness (Euliss, N.H. *et al.*, 2004, Wierda, A. *et al.*, 1997). Dominance is based on the relative proportions of each of the vegetation types.

Dominance by a certain type is therefore associated with a relative degree of turlough wetness. The types are composed of Goodwillie vegetation communities.

The types are combined, (slightly modified from the original scheme), to allow for a continuum of wetness associated co-dominant types.

Table 3.9 Vegetation dominant grouping

Community	Type
2A-3C	Grass (G)
4B-7B	Sedge (S) 7A-polygonum amphibium (grassy) included here even though grass
8A-12	Aquatic (A)

Table 3.10 Vegetation dominance and karst type

Vegetation Dominance Type	Type number	Degree of wetness
G Dominated	1	Dry
GS Co-Dominated	2	↓
S Dominated	3	
GSA Co-Dominated	4	
SA Co-Dominated	5	
A Dominated	6	Wet

The dominant vegetation type for each turlough is arrived at by summing the area of communities which comprise each of the grass, sedge and aquatic types, to arrive at a proportion of area occupied by each of these types in the turlough.

The dominance type is based on a proportion of area rule:

- 2:1:1 dominance of one type area over the other two, gives that type single dominance;
- 2:1 and 2:1 dominance of two type areas over one, and no clear (2:1) dominance between these two type areas results in two type co- dominance;
- No 2:1 dominance of any type area over another, gives a three-type co-dominance.

In order to validate the Moran, Regan approach for turloughs, *i.e.* that the Goodwillie communities can be assigned to vegetation types which have a relationship with wetness, Ellenberg moisture scores were calculated for each community. Ellenberg defined a set of indicator values for the vascular plants of central Europe. These indicator values were adopted for British conditions (Hill, M. O. *et al.,* 1999) which are considered to be appropriate for use in Ireland. The basis of indicator values is the realised ecological niche, that is, that plants have a certain range of tolerance of site parameters, including moisture.

Ellenberg moisture (F) indices were identified (where they existed) for each of the indicator species for each Goodwillie community. An average Ellenberg score was calculated for each Goodwillie division - according to Goodwillie's observations, communities in division 2 are found at a relatively higher position than the community in division 3, and so on, and are considered by Goodwillie to be associated with increasing duration of flooding. For example the characteristic species in division 11 (comprising 11A and 11B) have an average Ellenberg score of 10, which indicates shallow water sites that may lack standing water for extensive periods. A measure of the relationship between Goodwillie's divisions and moisture as indicated by the Ellenberg scores was obtained by regressing the division number against its average Ellenberg score. See Figure 3.4 below.

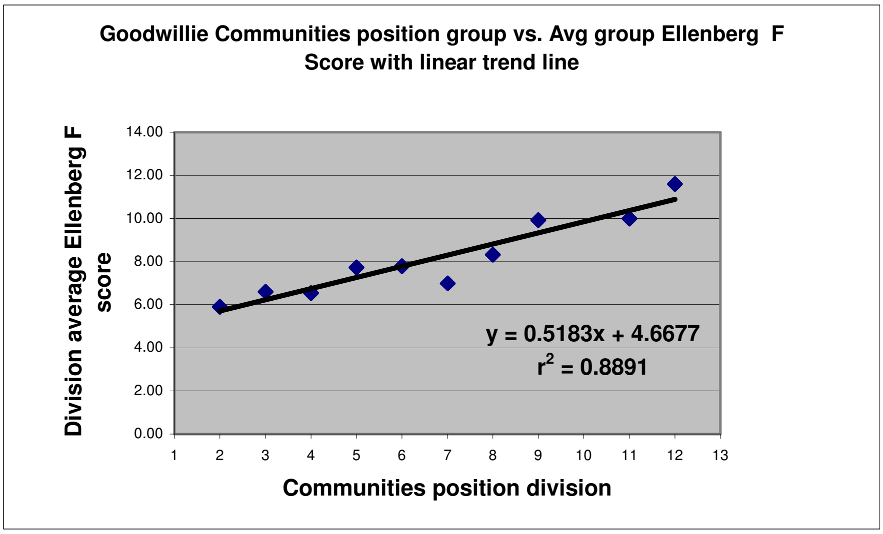


Figure 3.4 Scatter plot of Ellenberg F scores *vs.* Goodwillie vegetation division with best-fit linear regression line

A significant linear relationship exists between the two parameters (r^2 = 0.89). An exponential regression yields a slightly more significant relationship (r^2 = 0.9). It is therefore possible to assume that Goodwillie's ascending division numbers, observed with increasing relative depth in the turlough, are indicative of increasing moisture conditions, as reflected by the average Ellenberg index of the characteristic plant species.

An average Ellenberg index for the characteristic species in the communities comprising each vegetation type was calculated. The indices are as follows:

Table 3.11 Vegetation communities and Ellenberg scores

Vegetation types	Goodwillie community numbers	Average Ellenberg (F) score	Definition of Ellenberg indicator values
Grass	2A-3C	6	Between 5 and 7 (5: Moist-site indicator, mainly on fresh soils of average dampness)
Sedge	4B-7B	7	Dampness indicator, mainly on constantly moist or damp, but not on wet soils
Aquatic	8A-12	10	Indicator of shallow water sites that may lack standing water for extensive periods

The indices show an increasing trend with vegetation type progression from grass, through sedge, to aquatic species, which is consistent with the degree of wetness scale proposed by Moran and Regan.

3.2.3.4. Grouping Communities in Successive Divisions into Vegetation Types, Associated with Increasing Moisture is therefore a Valid Approach for Turlough Vegetation.

Dominance categories were calculated as follows for 11 turloughs. The areas occupied by each community in each turlough were provided by National Parks and Wildlife Service (NPWS).

Comparison of dominant vegetation (wetness) type, recession, substrate and maximum stage

Dominant vegetation type and recession constant of each turlough were tabulated, as well as substrate and maximum recorded stage above the base of the turlough.

Table 3.12 Dominant vegetation (wetness) type classification

Turlough	Vegetation type area proportions					
	Grass	Sedge	Aquatic	Total area (ha)	Dominance category	Category number
Coy	0.25	0.34	0.42	36.5	GSA	4
Rahasane	0.14	0.53	0.327	274	SA	5
Knockaunroe	0.05	0.39	0.57	42.50	SA	5
Termon	0.02	0.26	0.7	38	A	6
Tullynafrankagh	0.19	0.34	0.47	16	SA	5
Carranavoodaun	0.03	0.64	0.33	24.5	SA	5
Hawkhill	0.79	0.15	0.06	7.5	G	1
Skealoghan	0.16	0.71	0.13	29.10	S	3
Coole	0.25	0.58	0.17	188.6	S	3
Caherglassaun	0.15	0.53	0.31	41.60	SA	5
Blackrock	0.43	0.56	0.12	40.2	GS	2

Table 3.13 Turlough Dominant vegetation (wetness) type, recession, substrate and maximum stage

Turlough	Recession constant	Max. stage m (O.D.)	Min. stage m (O.D.)	Maximum stage above base of turlough (cm)	Dominance Category	Category Number
Rahassane	8.89	19.48	16.51	297	SA	5
Knockaunroe	9.76	30.59	25.43	516	SA	5
Termon	10	22.61	20.69	192	A	6
Tullynafrankagh	10.01	21.025	19.89	116	SA	5
Carranavoodaun	10.02	24.67	23.66	101	SA	5
Skealoghan	10.72	38.96	36.66	230	S	3

Turlough	**Recession constant**	**Max. stage m (O.D.)**	**Min. stage m (O.D.)**	**Maximum stage above base of turlough (cm)**	**Dominance Category**	**Category Number**
Coy	10.8	18.96	9.28	968	GSA	4
Caherglassaun	11.28	11.16	2.03	913	SA	5
Coole	11.19	12.39	2.9	949	S	3
Blackrock	11.67	26.02	13.03	1299	GS	2
Hawkhill	10.25	9.23	5.16	407	G	1

3.2.3.4. Results

The recession constants were plotted against the vegetation category number for each turlough and a measure of association between the two parameters calculated by applying linear regression. The purpose was to test the hypothesis that an association exists between the recession constant, which is an indicator of the emptying characteristics of the turlough and the dominant vegetation, expressed in terms of its association with habitat wetness. A relatively low degree of linear association is evident (r^2 = 0.48).

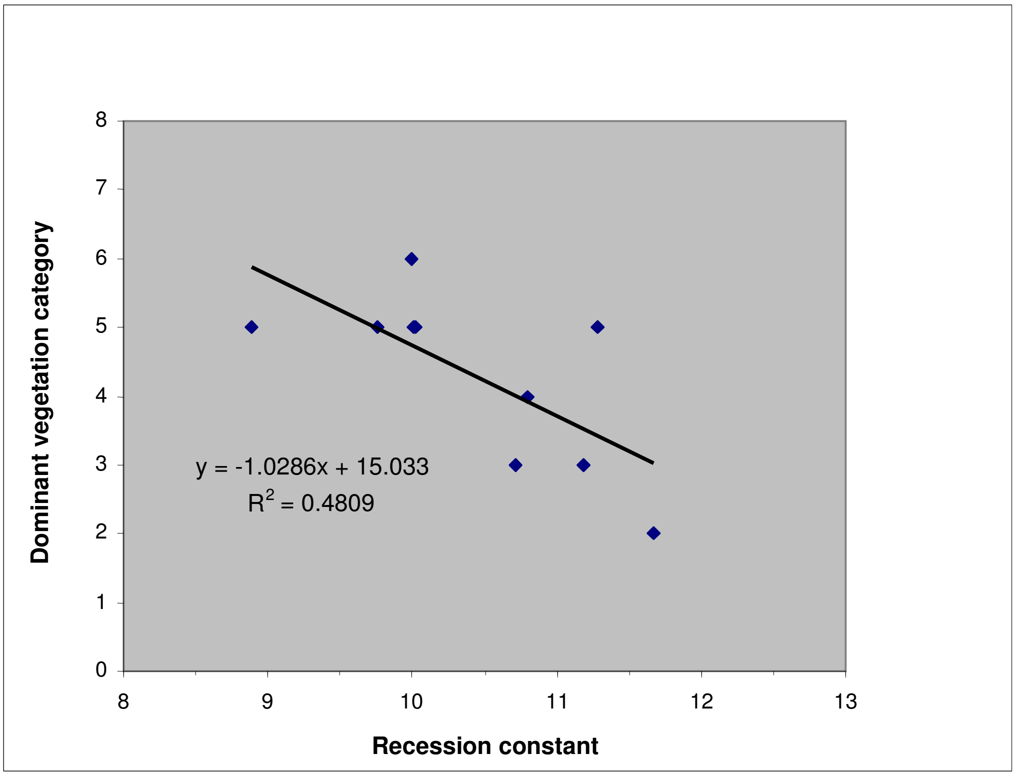


Figure 3.5 Dominant vegetation category vs. recession constant

There are two anomalous turloughs according to the plot above. These are Termon (recession constant 10, vegetation category 6) and Caherglassaun (recession constant 11.28, vegetation category 5). In both cases, the dominant vegetation category is higher (that is, the vegetation signifies a greater degree of wetness) than expected, based on the recession constant, if a relationship between recession constant and dominant vegetation (wetness) category is assumed and based on the pattern observed in the rest of the data in the data plot.

The overall spread of data in the plot indicates that as the recession constant decreases, that is, the turlough rate of emptying decreases, the vegetation tends towards being dominated by wet vegetation categories (*e.g.* Knockaunroe, with the lowest recession constant 9.76, is dominated by sedge-aquatic species). Equally as the recession constant increases, that is the rate of emptying increases, the vegetation tends towards being dominated by dry vegetation categories (*e.g.* Blackrock, recession constant 11.67, is dominated by grass-sedge species). A review of the characteristics of these two turloughs was carried out in order to ascertain whether they differed in some way from the other turloughs, with a focus on substrate and water persistence. Both turloughs have a substrate (surface layer of deposit) dominated by marl. Coxon (1986) records the two substrates present in Termon as marl and brown, peaty marl and the single substrate present in Caherglassaun as marl. None of the other turloughs studied are as dominated by marl substrate, having marl in combination with other substrate types as recorded by Coxon (1986) or Southern Water Global (1997). A possible reason for a change in vegetation towards a wetter type is the ability of marl to impeded drainage and to hold water later into the dry season than other substrates. This could allow the persistence of plants requiring greater wetness, in areas whose flood regime would under other substrate conditions support plants associated with drier conditions.

The vegetation categories of these two turloughs are adjusted to be in a drier category than they actually are (Termon changes from category 6, aquatic to 5, sedge aquatic and Caherglassaun from category 5, sedge aquatic to 3, sedge). In other words, a prediction of what the dominant vegetation category would be with a non-marl substrate, and the regression plotted again.

The resulting regression below, shows a significant relationship between dominant vegetation category and recession constant, with an r^2 value of 0.8, when the influence of substrate (or some other turlough characteristic is removed).

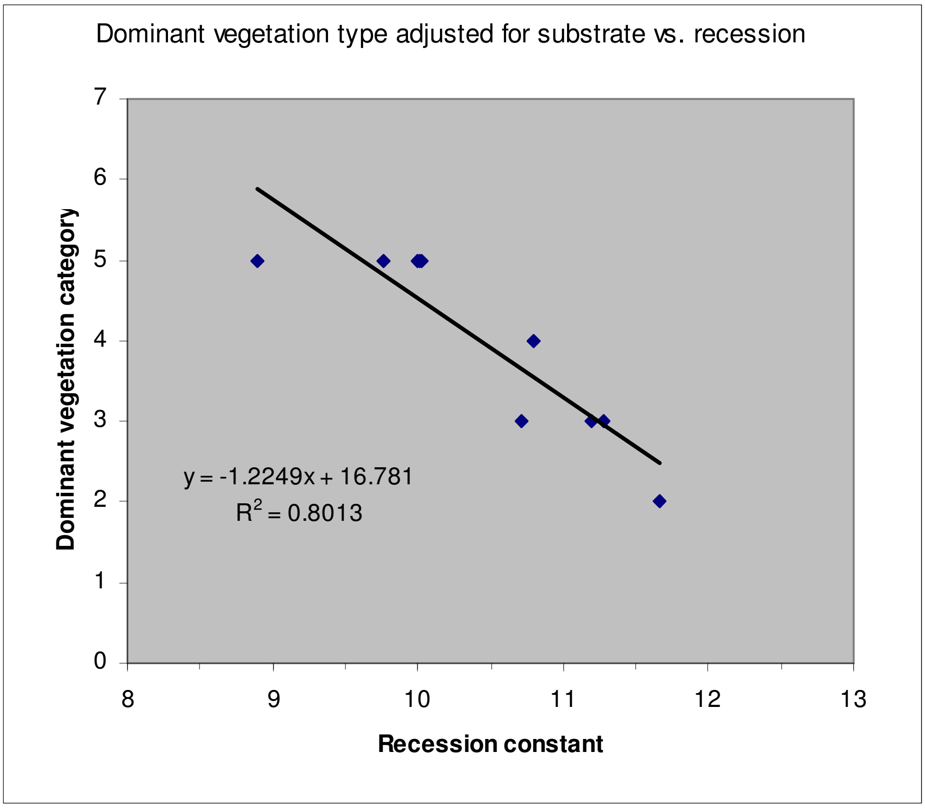


Figure 3.6 Dominant vegetation type adjusted for substrate *vs.* turlough recession constant

There are other features of the two turloughs that may be causing their anomalously wet vegetation. Caherglassaun has a small permanent lake, which is subject to tidal fluctuation, and is the only turlough in which this is known to occur. According to Goodwillie (1992), this promotes the growth of a larger area of *Eleocharis* species than would otherwise occur. *Eleocharis* species comprise community 9B, which is a wet vegetation type, and this would cause an increase in the relative area of wet type vegetation, potentially changing the vegetation category to a wetter one than would occur in non – tidally influenced turloughs. Termon is described by Goodwillie as a hybrid lake/turlough, due to the presence of a permanent calcareous lake. However, in the turloughs studied, the presence of permanent water does not appear to have a relationship with either the recession constant or the vegetation category. It is likely that the presence of persistent water, either large lake type bodies (Termon, Tullynafrankagh, Coole, Coy, Caherglassaun), or pools (Skealoghan, Knockaunroe, Carranavoodaun) is related to the turlough morphology and /or the presence of surface water inflow. In many turloughs, the main path(s) of egress of water from the turlough (swallow hole, estavelle or more diffuse outflow systems) is located topographically above the base of the turlough. Therefore, any water remaining in the turlough below this point can empty only by evaporation and/or seepage, both extremely slow processes, resulting in a large number of turloughs retaining water throughout the year, or drying only in very dry conditions. There are also a small number of turloughs which have surface water inflows, which result in permanent water (Rahassane, Blackrock, and Coole). The location of the path or path(s) of egress may be related to historical substrate deposition. Hawkhill turlough was originally included in the dominance categorisation, but was subsequently excluded from the regression analysis. It has an anomalously low vegetation category (1, that is grassland dominated) in comparison to its recession constant (10.25). Investigation of references to the turlough vegetation reveal that this turlough has been seriously modified by agricultural management, with more than half of the more natural turlough vegetation replaced by managed agricultural grassland (probably recorded as community 2A). The vegetation category is therefore skewed towards grassland, agricultural management rather than flood regime dominating the turlough vegetation characteristics.

3.2.3.5. Conclusions

The recession constant does have a significant relationship with the composition of vegetation turlough vegetation, but this relationship is probably mitigated by the presence of a substrate which impedes drainage. The relationship between substrate characteristics and vegetation is well documented. It appears that in the case of the two anomalous turloughs, the influence of the marl substrate on vegetation type is sufficient to dominate to a degree, the relationship between outflow characteristics of the turlough (as measured by the recession constant) and vegetation type, categorised according to wetness affinity. Alternatively, there are some characteristics of the turloughs, apart from substrate) which are dominating the vegetation response to outflow characteristics in these two cases. In the case of Hawkhill turlough, agricultural management has impacted severely on the turlough management, dominating the vegetation response.

The recession constant is therefore a useful hydrological indicator in defining the relationship between dominant vegetation category and the outflow characteristics (specifically rate of emptying) for turloughs.

These analyses illustrate quantitatively a relationship between plant composition and turlough flood regime.

3.2.4 Relationship between Turlough Trophic Status and Karstic Flow System, and the Influence of Anthropogenic Inputs

3.2.4.1 Trophic Status and Vegetation and Invertebrates

The trophic status of a habitat influences both flora and fauna. The Ellenberg indicator values for the vascular plants of central Europe, the basis of which is the idea that plants have a certain range of tolerance of site parameters uses this relationship to create an index for site fertility (broadly equivalent to trophic status), based on the occurrence of certain indicator species which are indicative of the degree of N enrichment of the site. With respect to turloughs Goodwillie bases his lateral categorisation of plant communities on trophic status, dividing them into four categories on this basis: A eutrophic, B mesotrophic and C and D, calcareous and peaty oligotrophic respectively Composition of invertebrate populations in turloughs have also been observed to be influenced by the nutrient status of the site

3.2.4.2 Elements of Trophic Status

Trophic status in turloughs is composed of two interacting elements, the trophic status of the water and that of the substrate. In wetlands, there is interchange of nutrients between the soils and water, phosphate is adsorbed onto soils particles from the water column, and a similar situation exists for nitrogen. (Brinkman, R. and van Diepen, C.A., 1990). There exists therefore a dynamic equilibrium between the soil and water. Turlough water, from ground and surface water sources bring sediment and dissolved nutrients into the turlough basin, Goodwillie (2003) notes that the proportion trapped, the mechanism and how it is moderated by soil and water pH is poorly understood.

Substrates in turloughs are variable, with a wider range than would be expected in a normal wetland habitat. They include, peat, marl and soils derived from glacial till. Unfortunately, practically no information exists on nutrient levels in turlough water. Turloughs are however characterised by high pH (ranging 8-8.4 in turloughs measured by Coxon, 1986). They are also characterised by high alkalinity. Turlough waters are high in $CaCo_3$ and the more calcium present, the fewer nutrients are held in a form which is available to plants. This results in some turloughs having ultra-oligotrophic conditions.

Which of the two elements, water or substrate, dominates trophic status is not known. It is possible that substrate has a greater influence than water chemistry, as most vegetation growth occurs during the period when least water remains in the turlough. However, the interchange of nutrients between water and soils must also be taken into account.

3.2.4.3 Investigation of Relationship between Turlough Trophic Status and Karstic Flow Environment, and the Influence of Anthropogenic Inputs.

The relationship between turlough trophic status and the karstic flow system of the turlough is investigated, since the interdependence of vegetation, invertebrate ecology and water and substrate trophic status is evidenced by previous work, as described above. Stage recession constants were also included in the analysis, to assess their affinity as a hydrological indicator of the karstic flow environment. The influence of anthropogenic impacts on this relationship is also assessed.

3.2.5 Methodology

3.2.5.1 Karstic Flow System

An assessment was made of the type of karst and associated flow occurring in the area around each of the studied turloughs, that is, the area estimated to be its catchment and the immediate area to which the turlough contributes flow. This was based on a review of all the available hydrological data, including published data and unpublished monitoring data. A large number of turloughs occur in the area investigated by the Gort Flood Studies project (GFS) (Southern Water Global, 1997), which investigated the nature of the karstic environment and associated flow characteristics and pathways. The GFS conceptual model for categorisation of karst and its associated flow characteristics has been used here to describe the karstic environment of turloughs within the area studied by the GFS, and also to describe the karstic environment of turloughs outside this area, where it is comparable.

The GFS categorisation is as follows comprising:

3.2.5.2 Epikarst Flow Systems

- ***Shallow epikarst*:** Groundwater flows in the upper 2-5 m, in karst characterised by fluted clints , grikes, small deflation structures, solution opened joints and fissures and bedding plane karst. Development often occurs over large areas and is as a result of direct recharge.
- ***Deep epikarst*:** Normally generated in the top 10-15 m, groundwater flow is in larger conduits, collapses at high level, areas of broken limestone, zones of solution opened fissures and joints and bedding

plane karst. Development is over smaller areas than shallow epikarst and is often route specific. Very large flows are supported.

These systems are considered to be relatively modern, likely to be post glacial or younger.

3.2.5.3. Deep Karst Flow Systems

- ***Conduit flow systems:*** Flow is in major conduit/cave systems at depths of up to 45 m bgl, often several meters in diameter, and representing linear flow routes. In the area around Gort, they developed in response to hydrological or base level conditions which no longer exists and are remnants of an older, much larger regime which is masked by erosion and covered by glacial deposits. They can carry very large flows.
- ***Fracture/conduit (Conduit type) flow systems***: Flow is at depth in smaller more distributed fractures and/or conduits, but which can be represented by the idea of a single conduit. These systems can carry minor to very large flows. They seem to be structurally/lithologically controlled.

3.2.5.4 Stage Recession Constants

The stage recession constants calculated as described above are included in the analysis. The recession is taken to be a hydrological indicator of flood regime, as evidenced by its relationship with plant composition as described above, and is assumed conceptually to reflect the outflow characteristics of the turlough, and to a lesser extent the head of water in the turlough.

3.2.5.5 Trophic Status

The measure of trophic status of a turlough is based on a classification of trophic sensitivity of turloughs by NPWS based on terrestrial plant communities, as mapped and classified by Roger Goodwillie (Goodwillie, 1992, Southern Water Global, 1997 and NPWS, 2004). Trophic sensitivity as described by this classification is comparable to trophic status as it is based on Ellenberg N indicator values for plants, the N score for a site relating to the occurrence of plants which are indicative of the general fertility of the site. Ellenberg Fertility Scores were assigned to each turlough vegetation community, by averaging the Ellenberg Fertility Scores for the characteristic species.

The turloughs were then categorised and ranked according to the proportional area of communities with low Ellenberg Scores (< 4), *i.e.* the proportional area of low productivity, nutrient sensitive plant communities. A score of four or less indicates that a site is in the range of intermediate fertility to extreme infertility (Hill *et al.*, 1999). The turloughs were classified as having high, medium or low trophic sensitivity, respectively > 50%, 29-49% or < 29% proportional area of communities with Ellenberg scores < 4. It is important to note that while there are relatively eutrophic turloughs within the turlough trophic range, in comparison to other ecosystems, the whole turlough trophic range falls into the ultra- oligotrophic to meso-trophic classes.

3.2.5.6 Significant Recorded Impacts

A number of turloughs have been assessed by the Ecological sub-group of the Turloughs Working Group, and the degree to which they are impacted has been described qualitatively. The data apply only to the immediate turlough basin and not the catchment, and is not completely consistent, as the impacts recorded reflect the focus of the visiting ecologist. An evaluation was made of what constitutes a significant impact and this information included in the analysis.

3.2.5.7 Analysis

Data were tabulated and comparison was made between the karstic flow system surrounding a turlough, the recession constant and trophic status, for the eleven turloughs for which all of these data were available, as well as the presence of any known anthropogenic impacts, and the degree of linear association assessed.

Based on the results of this comparison, a further comparison was made of fifteen turloughs for which information on two of either the recession constant, karstic flow system, and/or trophic status was available. In total, twenty five turloughs were analysed. The data for eleven turloughs for which recession constants, karstic flow system and trophic status information were tabulated. See Table 3.14 below.

Table 3.14 Recession constants, karstic flow system and trophic status information for eleven turloughs

Turlough name	Current Trophic status	Recession constant	Karstic flow system (and river/overland inputs)	Karstic flow system index	Source data on which classification is based	Significant recorded Impacts
Rahassane	3	8.89	Shallow Epikarst, river inputs	1	GFS (Southern Water Global (1997)), Coxon, C. and Drew, D.P. (1986)	Arterial drainage, river inputs channelled through turlough and drained to sea
Knockaunroe	1	9.76	Shallow Epikarst	1	Drew, D.P. (1995)	
Termon South	1	10	Shallow Epikarst	1	GFS, TCD monitoring	
Tullynafrankagh	1	10.01	Shallow Epikarst	1	GFS, TCD monitoring	
Carranavoodaun	1	10.02	Shallow Epikarst	1	GFS, TCD monitoring	
Hawkhill	3	10.25	Shallow Epikarst, Deep Epikarst conduit, Overland flow at high stage from Coole	2	GFS, TCD monitoring	Land –use management has impacted heavily on vegetation composition
Skealoghan	1	10.72	Shallow Epikarst, possibly some zones of greater flow	1	Coxon, C. (1986), Coxon, C. and Drew, D.P. (1986). Moran, J. NUIG monitoring	
Coy	3	10.8	Fracture/conduit (conduit type)	2	GFS, TCD monitoring	
Caherglassaun	3	11.28	Deep Epikarst conduit, conduit, Overland flow at high stage	2	GFS, TCD monitoring	Parts intensively managed, vegetation changes

Turlough name	Current Trophic status	Recession constant	Karstic flow system (and river/overland inputs)	Karstic flow system index	Source data on which classification is based	Significant recorded Impacts
Coole	3	11.19	Deep Epikarst conduit, Overland flow at high stage, river inputs	2	GFS, TCD monitoring	
Blackrock	3	11.67	Fracture/conduit (conduit type)	2	GFS, TCD monitoring	Enrichment from abattoir, slurry spreading fertiliser

A strong association between the value of the recession constant and karstic flow system, and with both of these and trophic status is obvious from the tabulated data.

The karstic flow system surrounding the turlough was indexed as 1 or 2. Index 1 indicates a flow system comprising shallow epikarst. Index 2 indicates a flow system comprising conduit, conduit/fracture (conduit type) and or/ Deep epikarst conduit flow. These are all systems which are generally route specific and which are capable of carrying large volumes of flow.

To confirm the relationships obvious above, a number of scatter plots were created and the degree of linear association between each factor assessed.

3.2.5.8 Relationship between Karstic Flow System and Turlough Stage Recession

A scatter plot of stage recession constant versus karstic flow system index (Figure 3. 7) shows that the recession constant varies almost continuously across the range 8.89 (Rahassane) to 11.67 (Coole), and is associated with two slightly overlapping groups of karstic flow system index (FSI). KFSI 1 (shallow epikarst) is associated with recession constants in the range 8.89 to 10.72, whereas KFSI 2 (comprising conduit, conduit/fracture (conduit type) and/ or deep epikarst conduit flow) is associated with recession constants in the range 10.25 to 11.67 that is respectively with lower and higher recession constants. A moderate r^2 value of 0.57 describes the significance of a best-fit linear regression line imposed on the data.

In order to improve the correlation, Hawkhill turlough was removed from the analysis. Hawkhill is anomalous in terms of a number of its characteristics. It has a low recession value, indicating slow emptying, but fills and empties according to the pattern of nearby turloughs Coy, Blackrock and Coole which have much higher recession values. It is assumed to be in an epikarst region, though this is not certain, but appears to have flow characteristics similar to Coy, Blackrock and Coole which are proven to be situated in a conduit karst flow system. Removing Hawkhill improves the linear correlation between recession constant and KFSI (Figure 3.7). A more significant r^2 value of 0.68 describes the fit of the linear regression line imposed on the data.

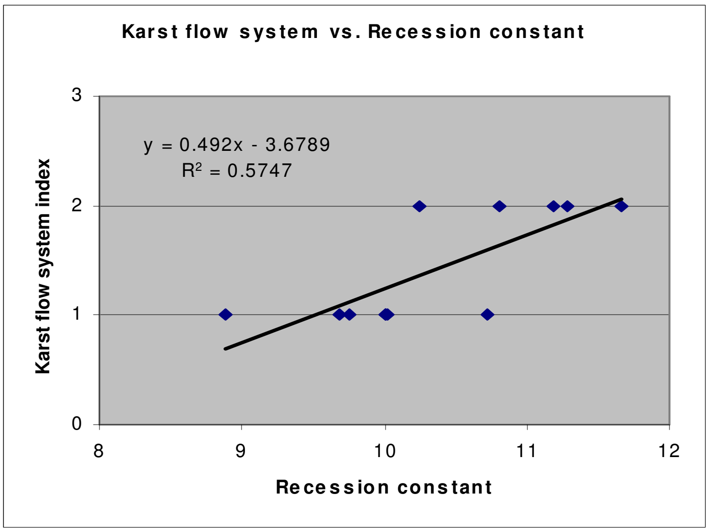


Figure 3. 7 **Scatter plot with regression line of stage recession constant versus karstic flow system index**

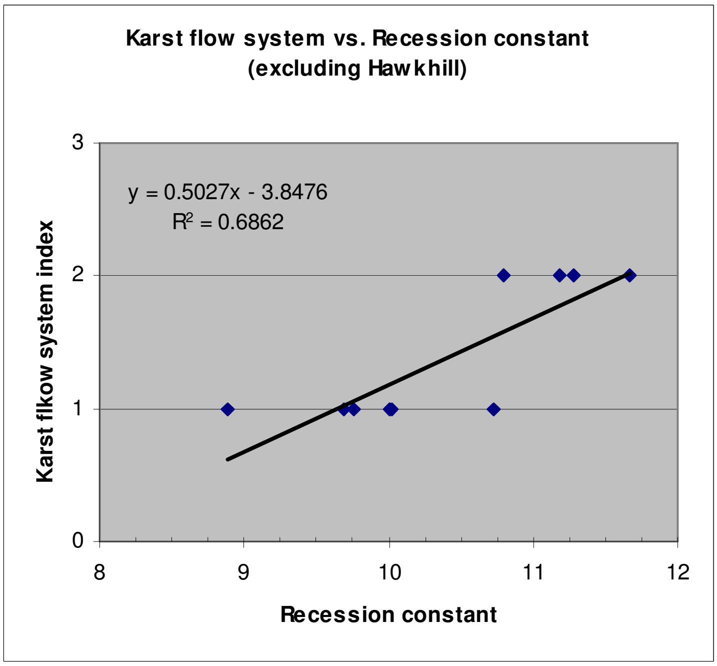


Figure 3.8 **Scatter plot with regression line of stage recession constant versus karstic flow system index (excluding Hawkhill)**

A conceptual model of the karstic flow system surrounding turloughs, based on the flow system data examined and these associations is as follows. Flow systems surrounding turloughs can be divided into three broad groups.

3.2.6 Shallow Epikarst Flow Systems

These are comprised of shallow epikarst comparable to that described by the GFS. That is, groundwater flows in the upper 2-5 m, in karst characterised by fluted clints , grikes, small deflation structures, solution opened joints and fissures and bedding plane karst. Development often occurs over large areas and is as a result of direct recharge. They are low storage systems, which support low volumes of flow. Flow is in a relatively dispersed system, is unconfined, and effectively a discontinuous water table exist. Water appearing in a turlough is effectively a reflection of this water table surface, flow is generally across the turlough, driven by the hydraulic gradient of the water table. Stage recessions from turloughs in this system are relatively slow. This is due to the low storage capacity of the receiving system, which impedes outflow, and the fact that the turlough is in effect emptying into a full system. When the water table drops in summer below the level of any turlough in such a system, water will only remain in the turlough at a level below the main egress points for flow, and this water level will be disconnected from the water table. Recharge to these systems is direct via the epikarst and relatively local, probably from within the local topographic catchment.

3.2.7 Conduit or Conduit Type Flow Systems

These are comprised of deep conduit, conduit/fracture (conduit type) and or/ deep epikarst conduit flow. These systems are high storage systems, which can support large volumes of flow. Flow is in discrete, though interconnected pathways, with confined and unconfined conditions depending on the volume of water in the system. Turloughs receive water via these discrete systems when sufficient volume of flow exists in the system, at sufficient hydraulic head to be forced into the turlough. Stage recession from turloughs in such flow systems is relatively rapid. The large storage capacity of the system allows rapid discharge from a turlough, once the hydraulic head has dropped in response to dropping water levels in the conduit system.

Recharge to these systems can be from connected shallow epikarst, indirect recharge from losing and/or sinking streams or indirect recharge from surface waters generated on non-karstic aquifers and which sink in the karstic catchment. A combination of all three frequently occurs in a conduit/conduit type flow system. Recharge to a turlough flow system may occur at some distance, travelling along the interconnected conduit /conduit type networks at potentially high velocities, velocities ranging from 90-250m/hr have been recorded in karstic systems (European Commission, COST 65 1995).

3.2.8 Combined Shallow Epikarst, Conduit/conduit Type Flow Systems

Shallow epikarst flow will frequently exist in continuity laterally and vertically with conduit /conduit type flow systems. Depending on the proportion of the different flow system present the response will be closer to that of either of the two systems. It is probable that a small proportion of conduit/conduit type flow can dominate the response, causing the system and any associated turloughs to behave as if in a conduit/conduit type system, due to the proportionally larger storage associated with this flow system type. Stage recession constants could be expected to be in the mid to high range for turlough situated in these flow systems, that is, stage recession will be moderate to fast.

The stage recession rate, as measured by the recession constant, is predominantly an indicator of the outflow characteristics of the turlough and the receiving karstic flow system, with an element relating to head of water in the turlough. As it correlates so significantly with the overall karstic flow environment of the turlough, as to both the catchment flow system and the immediate receiving flow system, it allows the assumption that the catchment and immediate receiving flow systems are generally comparable. This allows the cautious use of stage recession constant as a hydrological indicator for the overall karstic flow environment of the turlough.

3.2.9 Relationship between Karstic Flow System, Recession and Trophic Status

An association between trophic status and karstic flow system index, is visible from the tabulated data. The significance of this association is assessed by creating scatter plots and by assessing linear correlation between the two factors. From the scatter plot, it is clear that increasing trophic status is associated with a change from KFSI 1 to KFSI 2 which is from shallow epikarst to conduit flow system type. See Figure 3.9.

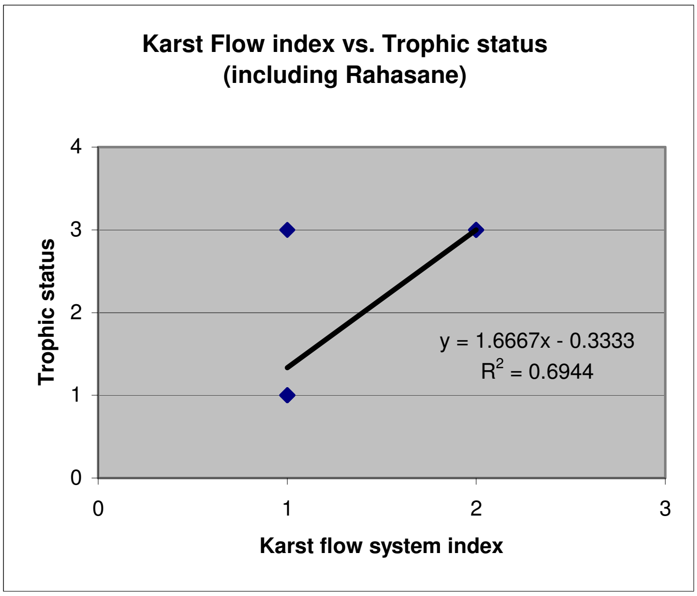


Figure 3.9 Turlough trophic status and karst flow index

A moderately significant linear association exists, the best-fit regression line having an r^2 value of 0.69. Rahasane turlough is an anomalous value in this association, having a trophic status of 3, associated with a KFSI of 1.

To improve the correlation, Rahasane was removed from the calculations. See Figure 3.10 below.

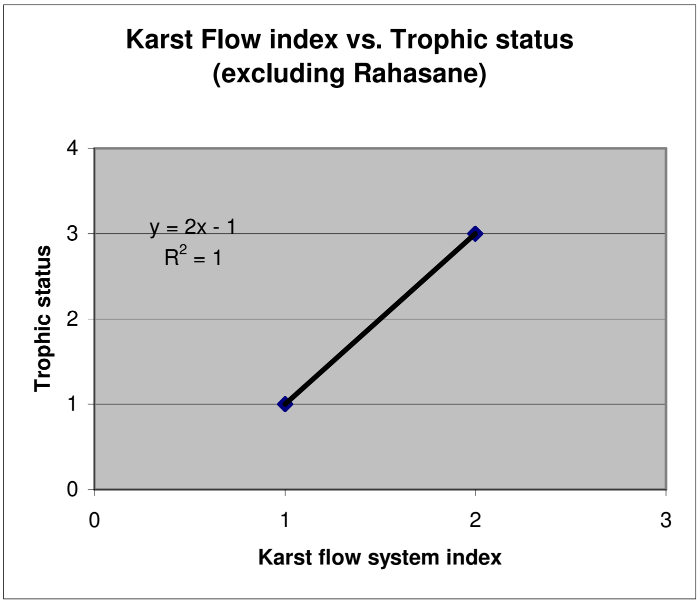


Figure 3.10 Trophic status and karst flow index, excluding Rahasane riverine turlough

The resulting (albeit constrained) correlation indicates a significant relationship between KFSI and trophic status, the best-fit regression line having a perfect fit r^2 value of 1. That is, turloughs with a trophic status of 1 (ultra oligotrophic) are associated with KFSI 1, that is shallow epikarst flow systems, while turloughs with a trophic status of 3 (relatively eutrophic) are associated with KFSI 2, that is conduit/conduit type flow systems.

In order to explore this relationship further, data were tabulated for a further 15 turloughs for which trophic status and information on the karstic flow system was available. See Table 3.15 below.

Table 3.15 Trophic status and karstic flow system data for 14 turloughs, karstic flow system and recession data for one turlough

Turlough name	Current Trophic status	Recession constant	Karstic flow system (and river/ overland inputs)	Karstic flow system index	Source data on which classification is based	Significant Recorded Impacts
Levally West		9.69	Shallow Epikarst	1	TCD monitoring, GFS	
Ballylea River Turlough	3		Conduit, Fracture/conduit (conduit type)	2	GFS	
Garryland	3		Deep Epikarst conduit, Overland flow at high stage	2	GFS	
Lough Doo	3		Deep Epikarst conduit, Overland flow at high stage	2	GFS	

Newtown	2		Deep Epikarst conduit, Overland flow at high stage	2	GFS	
Ballinduff	2		Shallow Epikarst, also distributed g/w flow from sandy gravels and gravelly tills	1	GFS	Soil excavation, limited land reclamation
Lough Mannagh	1		Shallow Epikarst	1	GFS	
Roo West	1		Shallow Epikarst	1	GFS	
Tulla	2		Shallow Epikarst, very rapid epikarst flows, ?some deep epikarst	1	GFS	
Lough Allenaun	3		Shallow Epikarst	1	GFS, Drew D. (pers. comm.)	Very extensively reclaimed (basin has been scraped out), probable enrichment from
Fingall	1		Shallow Epikarst	1	GFS	
Ballindereen	1		Shallow Epikarst	1	GFS	
Kilglassan	3		Shallow Epikarst	1	Coxon, C. (1986), Coxon, C. and, Drew D.D D.P. (1986).	Enrichment from dairy farm - intensively managed steep slopes of turlough.
Ardkill	3		Shallow Epikarst	1	Coxon, C. (1986), Coxon, C. and , Drew D D.P. (1986).	Enrichment from 2 intensive dairy farms in topographical catchment
Greaghans	3		Shallow Epikarst	1	Coxon, C. (1986), Coxon, C. and , Drew D D.P. (1986).	Heavily enriched. Badly managed farmyard (floods) and intensive dairy farms.

The significance of the association between trophic There is a low level of association between the two status and karstic flow system index visible from the additional tabulated data are assessed by creating scatter plots and assessing linear correlation between the two factors for all of the 25 turloughs. There is a low level of association between the two factors, the best-fit regression line having an r value of 0.35. See Figure 3.11.

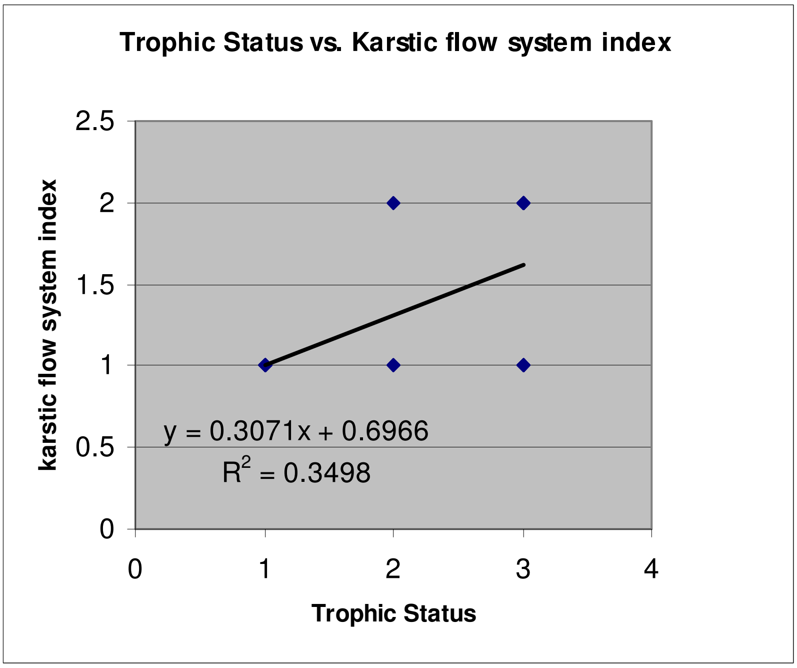


Figure 3.11 Turlough trophic status and karst flow index

Analysis showed that the data which do not conform to the established pattern falls into two categories, those turloughs which have significant recorded impacts, which could be expected to impact on the trophic status of the turlough, and a number of additional turloughs, which have riverine inputs or other factors which may influence the trophic status of the turlough.

Those turloughs which have significant recorded impacts were removed from the analysis. These are Rahasane, Hawkhill, Lough Allenaun, Kilglassan, Ardkill and Greaghans turloughs. Rahasane also has riverine inputs. The scatter plot and linear correlation for the reduced dataset show a very significant association between trophic status and KFSI. See Figure 3.12.

Figure 3.12 Trophic status and karst flow index for unimpacted turloughs

The best-fit regression line has an r^2 value of 0.84, which signifies a very significant linear correlation between trophic status and KFSI, with trophic status increasing from 1 to 3, with a change in KFSI from 1 to 2. That is, oligotrophic status is associated with KFSI 1 which indicates a flow system comprising shallow epikarst, while relatively eutrophic status is associated with KFSI 2, which indicates a flow system comprising conduit, conduit/fracture (conduit type) and or/ Deep epikarst conduit flow. It is important to note that while there are relatively eutrophic turloughs within the turlough trophic range, in comparison to other ecosystems, the whole turlough trophic range falls into the ultra-oligotrophic to mesotrophic classes.

There are only a small number of turloughs (3) within our dataset of 25 turloughs which have a trophic status of 2. All of these fall into the category of having some other potential factor apart from direct anthropogenic impact, which may influence their trophic status. It is therefore more difficult to make inferences about these turloughs. These turloughs include Ballinduff which has a shallow epikarst flow system (KFS1) and which has some recorded impacts, but it is also noted as receiving substantial flow from sands, gravels and sandy tills. Such deposits would be expected to increase the trophic status of water flowing through them. Water from sandy till deposits also contributes to Coy and Blackrock turloughs, these turloughs have a trophic status of 3, which can be associated with conduit/conduit type flow. Tulla turlough appears to be located in a shallow epikarst flow system (KFS1), but there are possibly links between the epikarst and a conduit/fracture flow system, which would be expected to increase the trophic status from 1, towards higher trophic status. Newtown turlough has a trophic status of 2, but appears to be located in a conduit dominated flow system, which is difficult to explain without additional data.

3.2.4.5 Conclusions

The strong relationship between trophic status and flow system type has potentially interconnected causes.

Conduit/conduit type flow systems as described above in the three broad groups of karstic flow system, and which are strongly associated with relatively high trophic status, are high-storage systems, capable of transmitting large volumes of flow. They are composed of discrete pathways with high interconnectivity. In the area studied by the Gort Flood Studies, interconnected conduit/conduit type flow networks were identified which run for tens of kilometres. These flow networks interact with surface waters via connected shallow epikarst, swallow holes, turloughs and springs. The catchment area for the waters contributing to a turlough is therefore potentially very large, and ground and surface waters are connected, thus providing potentially large opportunity for accumulating nutrient load. High volumes of water can move through these high storage flow systems at periods of high stage, potentially at high velocity (as is reflected by the high stage recession rates in turloughs in such systems).

This would be expected to result in a high cumulative mass loading of nutrients to the turlough, resulting in a relatively high trophic status. In addition, the transport of sediments and consequently particulate phosphorus would be favoured by the presence of conduit flow. Although most of the loading would be expected to occur during high flow winter months, when only aquatic plants are growing, and the mechanism by which water and soil chemistries interact is poorly understood, there is definitely is interchange of nutrients between the soils and water. In general, in wetlands, phosphate is adsorbed onto soil particles from the water column, and a similar situation exists for nitrogen. (Brinkman, R. and van Diepen, C.A., 1990) This interaction may be most important in spring/early summer, during the last major flood recession before the growing season.

This relationship with high trophic status holds equally for turloughs with riverine inputs. Rivers will have relatively large catchments, and the potential for accumulating high nutrient load, as well as potentially high flow volumes, moving at high velocity. This would be expected to result in a high cumulative mass loading of nutrients to the turlough, resulting in a relatively high trophic status.

Shallow epikarst systems as described above in the three broad groups of karstic flow system, and which are strongly associated with low trophic status, are low storage systems, capable of supporting low flow volumes relative to conduit/conduit type systems. Flow is in a relatively dispersed system, is unconfined, and effectively a discontinuous water table exist. Water appearing in a turlough is effectively a reflection of this water table surface. Recharge to such systems is relatively local, and the catchment is most likely defined by the local topographic catchment. The small area of catchment, relative to conduit/conduit type flow systems provides relatively little opportunity for accumulating nutrient load. Combined with lower volume and rates of flow through the system (the later reflected by the low stage recession rates in turloughs) this probably results in a low cumulative mass loading of nutrients to the turlough, resulting in a low trophic status.

3.3 Indicative Turlough Typology

An indicative turlough typology has been developed. This is based on the understanding developed above of the karstic flow systems within which turloughs occur (and stage recession as a hydrological indicator of same), and their relationship with turlough tropic status. This indicative typology comprises five main types of 'natural' turlough/turlough environments, that is to say those which have not undergone anthropogenic impacts. Two of these types (Types 1 and 2) contain the majority of turloughs studied, and based on the relatively large sample of turloughs studied, this proportion is probably true for the turlough population. The sixth type is anthropogenically impacted turloughs.

3.3.1 Non-anthropogenically impacted turlough types

- **Type 1:** Conduit/conduit type flow system turloughs, with relatively high trophic status.

These turloughs are situated in conduit/conduit type flow systems as described above in the three broad groups of karstic flow system. The hydrological indicator stage recession, will probably have values in the range 10.25 to 11.67, a higher recession constant in this range will give greater confidence in the presence of this flow system type. Trophic status as defined by NPWS will be high, generally having a value of 3, but may occasionally be 2. Examples include:

- **Type 2:** Shallow epikarst type flow system turloughs, with low trophic status

These turloughs are situated in shallow epikarst flow systems as described above in the three broad groups of karstic flow system. The hydrological indicator stage recession, will probably have values in the range 8.89 to 10.72, a lower recession constant in this range will give greater confidence in the presence of this flow system type. Trophic status as defined by NPWS will be low, generally having a value of 1.

- **Type 3:** Combined conduit/conduit type, shallow epikarst type flow system turloughs, with relatively high trophic status

These turloughs have flow occurring from and to both shallow, low volume, low flow epikarst and are also connected to a conduit/conduit type flow network, possibly via the epikarst. The conduit/conduit flow appears in general to dominate the trophic status response of the turlough. Examples include Tulla (trophic status 2), which according to the GFS appears to be located in a shallow epikarst flow system (KFS1), which possibly has links with a conduit/fracture flow system, and Hawkhill turloughs. Hawkhill (trophic status 3), has both shallow epikarst, and deep epikarst conduit flow components to its flow system. Insufficient stage recession data are available to assess the likely recession constant for these turloughs.

- **Type 4:** Turloughs with riverine input, with high trophic status

These are a small number of turloughs which have inflow, and in some cases also outflow, via rivers. The karstic flow system may be any of shallow epikarst, conduit/conduit type flow or a combination of both. In the case of turloughs situated in shallow epikarst flow systems , a low stage recession constant, as is typical of such systems can be expected, and a high trophic status. For example Rahasane turlough is situated in a shallow epikarst system, has a low stage recession constant of 8.89 and a trophic status of 3. In the case of combination or conduit/conduit type flow system turloughs, with typically high stage recession rates, a high trophic status will be caused by the conduit flow component as well as by the riverine input. Coole turlough is an example.

- **Type 5:** Turloughs receiving distributed flow from certain types of sediment

These are a small number of turloughs which receive distributed flow from sediments whose composition will increase the nutrient load of waters flowing through them in addition to having inputs from any of shallow epikarst, conduit/conduit type flow or a combination of both. Tropic status may be moderate/high *i.e.* 2 or possibly 3 in the case of shallow epikarst turloughs. Conduit/conduit type or combination flow system turloughs will have a high trophic status caused by the conduit flow component as well as any influence of the water from such sediments.

These turloughs include Ballinduff which is situated in a shallow epikarst flow system, but is also noted as receiving substantial flow from sands, gravels and sandy tills. Such deposits would be expected to increase the trophic status of water flowing through them. Water from sandy till deposits also contributes to Coy and Blackrock turloughs, these turloughs have a trophic status of 3, and are situated in conduit/conduit type flow systems.

3.3.2 Anthropogenically impacted turlough type

- **Type 6:** Turloughs with (significant) anthropogenic inputs

These are a large number of turloughs of types 1 to 5, which have an additional anthropogenic nutrient loading on their natural – non-impacted trophic status. Where the loading is sufficient it will increase the natural trophic status. In the case of turloughs having a naturally high trophic status of 3, the impact will not be discernible unless the pressure can be identified. Impacts on turloughs with lower trophic status, a change from the expected type trophic status will be evident. Examples of the former include Blackrock and Caherglassaun turloughs, the latter include Kilglassan and Ardkill turloughs.

3.4 Turlough Catchment Delineation Methodology

For the purposes of assessing pressures and impacts on turloughs, a methodology for turlough catchment delineation was developed. This is based on the above conceptual model of karstic flow systems surrounding turloughs and the relationships and their relationship with turlough tropic status.

This comprises two elements:

1. Identifying the catchment type
2. Methods for delineating the catchment area.

These are outlined in section 4.3.2 and 4.3.3 of Guidance on the Assessment of Pressures and Impacts on *Groundwater Dependant Terrestrial Ecosystems Risk Assessment Sheet GWDTERA2a – Turloughs*. This document was written as part of this project and is included in the main report but is not included in this synthesis report.

3.5 Turlough Invertebrate Populations

3.5.1 Invertebrates

Although turlough faunas may be sparse and unpredictable, they appear to be inhabited by a characteristic set of invertebrate species. (Reynolds J, 1999, Reynolds *et al.,* 1998). Many of these species are opportunists widespread elsewhere and most turlough species are also to be found in small ponds. There are however rarities which appear to be restricted to in Ireland to turloughs, these include *Tanymastix stagnalis* and the rare glacial relict *Eurycerus glacialis* (Reynolds, 2003). Species which occur in turloughs are all well adapted to the special nature of their environment, with strategies including production of resting stage, resistance to desiccation or an amphibious lifestyle (Reynolds, 1999). Spatial distribution of species varies across the distribution of turloughs. In a study of turloughs in the Gort area, Reynolds (1999) found an increase in species diversity from east to north, which he attributed to a move away from turloughs whose source of water is in the Slieve Aughtys, or to an increase in the diversity of habitats within a turlough basin.

3.5.2 Aquatic Beetles

Aquatic beetle assemblages in Ireland were analysed by Foster *et al.,* (1992), eleven assemblages were identified. One of these was an assemblage whose typical habitat is the turlough. The sites with the greatest diversity recorded were some of the turlough sites. Typical turlough beetles include species which are rare or unknown elsewhere in Ireland and Great Britain. Work carried out by Eugenie Regan and Aine O'Connor at NUIG (2003) involved the analysis of the distribution of water beetles in 27 turloughs. Aquatic beetles can occur in both semi- permanent and permanent water. Cluster analysis and ordination techniques were applied to the data. Five groups were identified from these combined analyses. See Figure 3.13 below. The groups fall into two categories, groups comprising wetland / turlough specialists and groups comprising more ubiquitous species which also occur in other habitats. The groups were compared with various turlough characteristics. The characteristics which are most important in determining which group occurs in a turlough are wetness, specifically summer wetness, and the occurrence of detritus, which is associated with the nutrient status of the turlough.

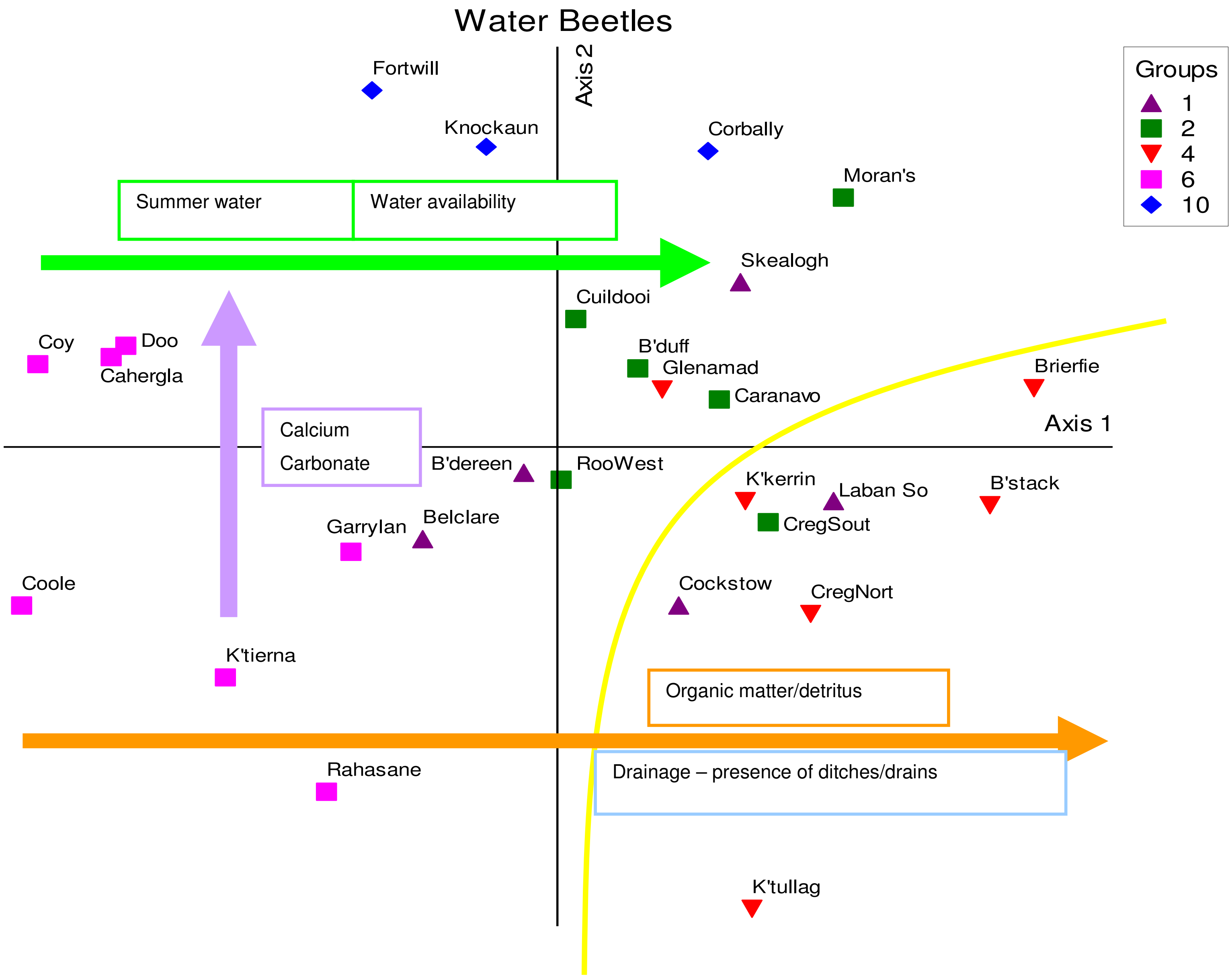
3.5.3 Terrestrial Beetles

The distribution of terrestrial beetle in turloughs was studied by Eugenie O'Regan NUIG (2003).

Terrestrial beetles occur in the area of a turlough which is periodically flooded but not in open water. Cluster analysis identified two main groupings according to their wetland fidelity, that to say is wetland specialist beetles and agricultural generalists. The most important turlough characteristics in terms of the occurrence of either group are:

- Soil wetness, particularly availability of summer water, which is determined by a combination of substrate characteristics and flood regime. Flood duration is thought to be an important factor.
- Surrounding habitat, specifically the degree of disturbance of the surrounding habitat and how close it is in composition to natural turlough vegetation.
- Vegetation structure – this is related to vegetation composition, which itself is influenced among other factors by flood regime and trophic status.

Figure 3.13 NMS ordination results wit overlay of five cluster analysis groups and vectors (Regan, 2003)



The turloughs under the yellow line are the most modified – they all have ditches and drains and one suspects that all suffer from enrichment as a result of fertilisation of the topographical catchment.

Both Groups 1 and 2 have pond and ditch, euryoecious species associated with vegetation and/or detritus and/or filamentous algae

Group 1 has species associated with stagnant water, vegetation and detritus and eutrophic conditions.

Group 2 has somewhat similar species but possibly associated with less stagnant, less permanent and more muddy conditions

Both Groups 3 and 4 have the turlough species – associated with seasonal water, fens etc
Group 3 has species associated with clear, base rich water – and possibly more permanent conditions than Group 4. Also has the rarer species – most interesting group for aquatic Coleoptera

Group 4 like 3 but possible more muddy conditions.

Group 5 has species that are associated with less vegetation, less permanent water, 'faster' water and are fairly ubiquitous.

4. Key Characteristics of Turloughs

Vegetation community distribution and composition have been shown above to be related to flood regime, as described quantitatively by duration and recession respectively. Flood duration at a particular level in the turlough is also related to turlough morphology. This is in addition to qualitative relationships between flood duration, depth and release date and vegetation described in the literature.

Turlough trophic status, comprising the interacting elements of water and substrate trophic status is related to the distribution and composition of vegetation communities. Trophic status has been shown to relate to the flood regime of the turlough as described by the recession and to the hydrological setting of the turlough, of which recession is an indicator.

Invertebrate population distribution and composition have been related to turlough nutrient status, and qualitatively to wetness of the substrate and flood duration.

In terms of the combined ecologies described above the key characteristics of turloughs which influence their composition and distribution are:

- Flood regime which can be described by the hydrological indicators recession and duration, and potentially by flood depth and release date.
- Substrate, including substrate trophic status, permeability and water retention characteristics.
- Morphology, including position of egress points/areas and potentially slope steepness.
- Trophic status, comprising water chemistry and substrate characteristics.

Risk Assessment

The whole strategy for risk assessment has been developed for groundwater and GWDTE by the Geological Survey of Ireland under the various working groups for the Water Framework Directive (2001). The pressures which are the basis for risk assessment are related, in the case of turloughs, to water quantity (usually drainage issues) and quality related to agriculture and other point sources. In the latter case, the key controlling factor is the catchment (zone of contribution) of the turlough and its delineation. A full analysis of pressures and the risk assessment for turloughs was included in the final report of this project. It is not included here, as the outcome has already been released in the form of a guidance document under the Water Framework Directive by the Geological Survey and the EPA.

5. Conclusions

A principal outcome of this work is the gathering and collation of available data relating to turlough hydrogeology and its incorporation into an accessible database.

The second outcome has been to establish the feasibility of defining hydrological indicators (*i.e.* recession constants and frequency-duration parameters) which can be used to relate the turlough hydrology to corresponding ecological indicators – the first time such a hydroecological analysis has been done for these karst systems. On the basis of the available data, good correlations were achieved between species communities (as represented by an integrated Ellenberg wetness index) and duration of inundation. For example, Polygonum amphibium, characteristic of some turloughs, appears to occur over narrow ranges (1m) in elevation but requires flooding some 60% of the time. Dominant vegetation types as defined in this study also show good correlation with recession constant. The latter can vary dramatically between turloughs and thus may be good indicators of vegetation communities to be expected. However, it is in the definition of these ecological indicators that there remain significant gaps in available data. Often ecological measurements are made as one-off studies and there is little scope to relate these to measures of time-dependency.

However, particularly on the basis of defined trophic status as indicated by NPWS and the comprehensive vegetation surveys done by Roger Goodwillie, there is a strong indication from this study that such ecological parameters *can* be developed and thus risk assessment for turloughs put on a sounder footing.

Finally, a hydroecological typology, mainly on the basis of hydrological response, has been developed under which turloughs can be classified for such risk assessment. Short-term hydrological measurements may be sufficient to undertake such classification. Nevertheless, there remain significant shortages of data (hydrological, ecological and water quality) in order to validate these tentative relationships.

Based on available data, hydrological parameters have been defined, particularly recession constant and frequency-duration curve gradient for water depth which have potential for characterising the hydroecology of karst systems. Karst 'type' may also be a broad indicator but as the karst type is also defined hydrologically, this has less potential than deriving indicators from direct hydrological measurement.

A key conclusion is that there *are* hydrological measures (such as water level recession constants) which can be related to corresponding ecological community indicators, thus facilitating the further identification of measures for risk assessment. As groundwater dependent terrestrial ecosystems (GWDTE), turloughs, as wetlands, are assessed under the EU Water Framework Directive. This tentative step in understanding the hydroecological linkage is essential in the assessment of risk (of 'damage') under the WFD. It is clear also from this study that there is no such entity as a 'standard' turlough: different levels of karstification will produce different hydro-ecological responses and, therefore, different susceptibilities to anthropogenic influences. At present, the likely principal sources of such effects are agricultural pressures, forestry practice and wastewater disposal systems.

The methodology outlined in this study enables the turlough ecology to be expected from a given measured hydrological regime. Significant deviation from the expected ecology/trophic status is likely to be attributable to anthropogenic influences.

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7. ACRONYMS AND NOTATION

BGL	**Below Ground Level**
$CaCo_3$	**Calcium Carbonate**
EEC	**European Economic Communities**
ERTDI	**Environmental Research Technological Development and Innovation**
EU	**European Union**
FSI	**Flow System Index**
GIS	**Geographic Information System**
GSI	**Geological Survey of Ireland**
GFS	**Gort Flood Studies**
GIS	**Geographic(al) Information System**
GPS	**Global Positioning System**
GWDTE	**Groundwater Dependant Terrestrial Ecosystem**
GWDTERA	**Groundwater Dependant Terrestrial Ecosystems Risk Assessment**
KFSI	**Karstic Flow System index**
m O.D.	**metres above Ordnance Datum**
NMS	
NPWS	**National Parks and Wildlife Service**
NUIG	**National University of Ireland - Galway**
O.S.	**Ordinance Survey**
OPW	**Office of Public Works**
per. comm.	**Personal Communication**
SAC	**Special Area(s) of Conservation**
SPA	**Special Protection Area**
TCD	**Trinity College Dublin**
Turlid	**Turlough Identification Number**

Appendix 1

Turlough Database

Each site has been assigned a location, an internal database turlough identification number (turlid), its own identification number from the original source, and a measure of the accuracy of the location.

Coxon (1986) includes predominantly hydrological and morphological data for 90 turloughs sites which adhere to the definition above (Coxon, C., (1987b)) and in addition are < 10 ha in area and undrained. Substrate and vegetation were also investigated. Sites from Goodwillie, (1992), which includes vegetation-mapping data, are a subset of the Coxon sites, and include in addition one site described by Coxon as drained. Topography, substrate and qualitative hydrological data are included in Goodwillie's report. Turlough sites were identified from among wetland sites listed in the Gort Flood Studies project (Southern Water Global, 1997), which includes predominantly hydrological, with some vegetation and invertebrate data.

These overlap in some instances with the previous sources and include additional sites, including sites less than 10 ha. Sites studied by Regan E. and O'Connor, A. (2003), for their beetle fauna, including limited water sampling, are a subset of the former sites and include additional sites.

The table below lists all of the sites included in the project database.

Table A-1 Turloughs listed in TCD projects database

Turlid	Ccname	X	Y	Cox id no	RG id no	SGF id no	Grid ref acc	NUIG id no	County
1	Rahasane	148000	220000	1	42	0	2	37	Galway
2	Dunkellin	145000	219000	2	0	0	1	0	Galway
3	Killora	151000	219000	3	0	0	1	0	Galway
4	Aggard	150000	218000	4	0	26	1	0	Galway
5	Tonroe	141000	221000	5	0	0	1	0	Galway
6	Turloughnacashla	139000	221000	6	0	0	1	0	Galway
7	Pollnakirka	145000	223000	7	0	0	1	0	Galway
8	Willmount	148000	225000	8	0	0	1	0	Galway
9	Caranavoodaun	145314	215421	9	43	21	2	8	Galway
10	Kiltiernan	143602	214621	10	45	25	2	23	Galway
11	Ballinderreen	140000	215000	11	44	13	1	2	Galway
12	Blackrock (Peterswell)	150000	208000	12	46	53	2	35	Galway
13	Caherglassaun	141235	206225	13	47	62	2	6	Galway
14	Garryland	141556	203812	14	48	67	2	20	Galway
15	Newtown Lough	142787	202556	15	49	65	1	33	Galway
16	Lough Mannagh	140336	201630	16	50	68	1	0	Galway
17	Termon Lough	140971	197249	17	51	88	2	0	Galway
18	Kiltullagh	137000	230000	18	41	0	1	24	Galway
19	Turloughmore (Clare River)	143000	239000	19	0	0	1	0	Galway
20	Turloughour	142000	245000	20	0	0	1	0	Galway
21	Fearagha	134000	245000	21	35	0	1	0	Galway
22	Turlough Monaghan	133000	246000	22	34	0	1	0	Galway
23	Bredagh	131000	245000	23	0	0	1	0	Galway
24	Kilcoona	131000	244000	24	0	0	1	0	Galway
25	Turloughcor	129000	244000	25	0	0	1	0	Galway
26	Ballyconlaught	126000	246000	26	0	0	1	0	Galway
27	Turlough O'Gall	135000	251000	27	32	0	1	0	Galway
28	Turloughnaroyey	138000	250000	28	0	0	1	0	Galway
29	Killower	137000	252000	29	0	0	1	0	Galway
30	Beagh	146000	256000	30	0	0	1	0	Galway
31	Garrauns	145000	254000	31	0	0	1	0	Galway
32	Shrule	127000	252000	32	31	0	1	40	Mayo
33	Lough Nakill	126000	254000	33	0	0	1	0	Mayo
34	Turloughmore (Fountainhill)	123000	257000	34	0	0	1	0	Mayo
35	Turloughagurkall	123372	260971	35	0	0	3	0	Mayo
36	Turlough Faugh	125000	258000	36	0	0	1	0	Mayo
37	Turloughosheheen	121000	264000	37	0	0	1	0	Mayo
38	Skealoghan	124737	262878	38	28	0	2	41	Mayo
39	Caheravoostia	126528	264681	39	26	0	2	0	Mayo
40	Ardkill	127490	262382	40	29	0	2	0	Mayo
41	Kilglassan	128000	264000	41	25	0	1	0	Mayo
42	Greghans	128944	262708	42	27	0	2	0	Mayo
43	Rathbaun	135000	261000	43	30	0	1	0	Galway
44	Pollelamagur Lough	130000	269000	44	22000	0	1	0	Mayo
45	Scardaun	134000	269000	45	24	0	1	0	Mayo
46	Ballyglass	123000	278000	46	7	0	1	0	Mayo
47	Slishmeen	122000	279000	47	6	0	1	0	Mayo

Turlid	Ccname	X	Y	Cox id no	RG id no	SGF id no	Grid ref acc	NUIG id no	County
48	Pollaghard	126000	285000	48	5000	0	1	0	Mayo
49	Tur Lough	153000	273000	49	15000	0	1	0	Roscommon
50	Levally Lough	152913	253456	50	22	0	2	0	Galway
51	Coolcam	158000	271000	51	16	0	1	0	Roscommon
52	Croaghill	159631	270711	52	17	0	2	16	Galway
53	Turlough Boyouna	160000	263000	53	19	0	1	0	Galway
54	Ballinastack	165000	265000	54	18	0	1	1	Galway
55	Glenamaddy	164000	261000	55	20	0	1	21	Galway
56	Kilkerrin	163000	265000	56	21	0	1	22	Galway
57	Mantua	182000	289000	57	0	0	1	0	Roscommon
58	Corbally	184000	280000	58	8	0	1	12	Roscommon
59	Castleplunket	178000	277000	59	10	0	1	0	Roscommon
60	Mullygollan	179803	279400	60	9	0	2	0	Roscommon
61	Brierfield	181000	277000	61	11	0	1	5	Roscommon
62	Carrowreagh	179000	275000	62	12	0	1	0	Roscommon
63	Rathnalulleagh	178000	274000	63	13	0	1	0	Roscommon
64	Ballinturly (Newtown)	178000	273000	64	14	0	1	34	Roscommon
65	Ballinturly (Castlestrange)	184000	260000	65	37	0	1	0	Roscommon
66	Lisduff	184163	255350	66	38	0	2	0	Roscommon
67	Lough Croan	188161	249393	67	39	0	2	29	Roscommon
68	Cuileenirwan Lough	189000	247000	68	0	0	1	0	Roscommon
69	Feacle Lough	191000	243000	69	40	0	1	47	Roscommon
70	Corkip Lough	193000	243000	70	0	0	1	0	Roscommon
71	Turloughmore (Burren)	135000	200000	71	53	76	1	44	Clare
72	Castle Lough	135000	198000	72	55	77	1	0	Clare
73	Knockaunroe	131000	194000	73	57	0	2	25	Clare
74	Lough Aleenaun	124932	195380	74	56	0	2	0	Clare
75	Carran	129000	199000	75	54	0	1	9	Clare
76	Turloughnagullaun	128000	204000	76	52	0	1	0	Clare
77	Lough Gash	139208	167823	77	58	0	2	0	Clare
78	Turloughmore (Derrybeg)	148000	176000	78	0	0	1	0	Clare
79	Loughmore Common	154000	153000	79	59	0	1	0	Limerick
80	Sluggary Pool	194000	202000	80	0	0	1	0	Tipperary
81	Liskeenan	197000	199000	81	60	0	1	0	Tipperary
82	Ballingarry	197000	196000	82	0	0	1	0	Tipperary
83	Killaturly	141000	298000	83	4	0	1	0	Mayo
84	Turloughmore (Castleloye)	154000	313000	84	1	0	1	0	Sligo
85	Turloughmore (Moylough)	154000	308000	85	3	0	1	0	Sligo
86	Doocastle	158000	309000	86	2	0	1	0	Mayo
87	Fortwilliam	201473	263179	87	36	0	2	46	Longford
88	Cordara	203000	264000	88	0	0	1	13	Longford
89	The Loughans (North)	231252	163883	89	61	0	2	0	Kilkenny
90	The Loughans (South)	231760	163507	90	61	0	2	0	Kilkenny
91	Ballinduff	146000	208000	0	0	55	3	3	Galway
92	Belclare	137800	250200	0	0	0	3	4	Galway
93	Cahermore	141600	207800	0	0	0	3	7	Galway
94	Cockstown	148700	210400	0	0	52	3	10	Galway
95	Coole	143000	204000	0	0	63	1	11	Galway
96	Cregaclare North	148200	213000	0	0	30	3	14	Galway

Turlid	Ccname	X	Y	Cox id no	RG id no	SGF id no	Grid ref acc	NUIG id no	County
97	Cregaclare South	147600	211600	0	0	31	3	15	Galway
98	Cuildooish	141400	215900	0	0	14	3	17	Galway
99	Doo Lough	142300	204300	0	0	0	3	18	Galway
100	Frenchpark	141300	214900	0	0	17	3	19	Galway
101	Hawkhill	141100	202300	0	0	66	3	45	Galway
102	Laban North	146400	210900	0	0	51	3	26	Galway
103	Laban South	146500	210200	0	0	96	3	27	Galway
104	Lough Coy	149000	207500	0	0	56	3	28	Galway
105	Lough Gealain	131300	194700	0	0	0	3	30	Clare
106	Lydacan	143700	207800	0	0	43	3	31	Galway
107	Moran's Turlough	121600	261400	0	0	0	3	32	Mayo
108	Poulroe	137500	195700	0	0	83	3	36	Clare
109	Roo East	139600	201900	0	0	61	3	38	Galway
110	Roo West	138600	202400	0	0	60	3	39	Galway
111	Treed Turlough	130600	194700	0	0	0	3	42	Clare
112	Tulla	136600	201600	0	0	59	3	43	Clare
113	Lough Bunny	139000	197000	0	0	81	2	0	Clare
115	Tullnafrankagh Lough	143300	215300	0	0	20	2	0	Galway
116	Owenbristy East	143100	211900	0	0	38	2	0	Galway
117	Ownebristy West	142500	211800	0	0	38	2	0	Galway
118	Brackloon Lough	143000	212600	0	0	37	1	0	Galway
120	Skaghard (Travaun)	135000	197000	0	0	78	1	0	Clare
121	Kilmacduagh	140000	200000	0	0	72	1	0	Galway
122	Ballinderreen Loughs	138400	216000	0	0	4	2	0	Galway
124	Lough Fingal	141700	215000	0	0	18	2	0	Galway
126	Ballynakill (Hanrahan's Lough)	147000	196000	0	0	94	1	0	Galway
127	Ballylee River	148000	206000	0	0	57	1	0	Galway
128	Kilchreest Marshes	156000	215000	0	0	33	1	0	Galway
130	Termon South	142000	198000	0	0	91	1	0	Galway
133	Ballyboy	142700	198000	0	0	90	1	0	Galway
134	Lough Skaerdeen	139000	199000	0	0	95	1	0	Clare
136	Four Roads Turlough	184123	251376	0	381	0	2	0	Roscommon