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 (2002-W-DS-8-M1)

Final Report

2007

Prepared for the Environmental Protection Agency

by

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ACKNOWLEDGEMENTS

This report has been prepared as part of the Environmental Research Technological Development and Innovation (ERTDI) Programme under the Productive Sector Operational Programme, 2000-2006. This programme is financed by the Irish Government under the National Development Plan 2000-2006. It is administered on behalf of the Department of the Environment, Heritage and Local Government by the Environmental Protection Agency (EPA) which has the statutory function of co-ordinating and promoting environmental research.

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.

Although a desk study, this project has involved significant fieldwork, particularly on the hydrological aspects. Many have contributed to the results, not all of which can be included in a synthesis report but grateful acknowledgement is made to those who have undertaken these contributions : Dr Catherine Coxon, Dept of Geology and Dr David Drew, Dept of Geography of Trinity College, Dr Michael Gormally, Dr Micheline Sheehy-Skeffington and the turlough research group in the National University of Ireland Galway, and Dr Steve Waldren and his students from the Department of Botany at Trinity College. Much hydrological data was collected during the Gort Flood Study following the floods of the 1990s and acknowledgement is made to the OPW (Mr Tony Smyth, Chief Engineer) who carried out this work and to which two of the present authors contributed. The Geological Survey of Ireland, particularly Donal Daly, contributed much to the hydrogeological understanding of turloughs and are a repository of much available information through their karst database. Latterly hydrological work was also carried out in connection with an analysis of environmental impact of roads by Komex Ltd and P.J.Tobin Consulting Engineers in Counties Clare and Galway and that experience has also been drawn upon. The considerable experience of the ecologists within Duchas (now National Parks and Wildlife Service (NPWS, Dept of the Environment) and their consultants, particularly Dr Roger Goodwillie, has been a great support in the project. Finally, the patience and support of the EPA officers, F. Clinton, A.Wemaere and B.Donlon is fully appreciated and acknowledged.

WATER QUALITY

The Water Quality Section of the Environmental RTDI Programme addresses the need for research in Ireland to inform policy makers 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.

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1 Introduction

1.1 Background

Karstic groundwater bodies have particular characteristics with respect to hydrological flow regime and thus, so do the terrestrial ecosystems associated with them. The hydrology is characterized by relatively high groundwater velocities and relatively low porosities but flows are concentrated in solutional fissures or groups of fissures. Those ecosystems associated with karst and typically having protected status under the Water Framework (EU,2000) and Habitats (EU 1992) Directives are unique to Ireland in their defined form as 'turloughs'. Turloughs have characteristic hydrological dynamics which give rise to their peculiar vegetation and fauna.

A turlough is currently defined as '*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'*

The aim of this desk study has been to gather the available information and data involving turloughs and their associated karst hydrogeology (as 'karst flow systems') and firstly to analyze possible relationships between the limited ecological information and effective hydrological indicators. The second and ultimate objective was to define a risk-based methodology for turloughs to suit the requirements of the Water Framework Directive (WFD) in the assessment of pressures and impacts for groundwater bodies. It should be noted that under the definition above (agreed over the duration of this project) that turloughs are classified as groundwater and their open water surfaces during seasonal inundation are regarded as 'surface expressions of a groundwater table'. This logic has specific implications in terms of pressures and impacts under the Water Framework Directive, in contrast to regarding turloughs as temporary surface waters. The development of this logical framework took some time under the discussion meetings of the Working Groups of the Water Framework Directive but the outcome in terms of a specific Risk Assessment Document is included as a key outcome of this Desk Study.

1.2 Turloughs within the Water Framework Directive and Associated Legislation

1.2.1 Turloughs as Ground Water Dependent Ecosystems (GWDTE)

In the context of the Water Framework Directive (EU,2000) turloughs fall into the category of terrestrial ecosystems that 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). In addition, they occur where groundwater discharges to the surface or to the rooting zone of the vegetation is in sufficient quantity to determine the ecological potential of the site (Groundwater Working Group, 2001). Thus GWDTEs are, by definition, wetland ecosystems. Turloughs are included in the category of highly groundwater dependant ecosystems, which also includes fens, in particular rich fens and flushes, springs, marl lakes and dune slacks (Groundwater Working Group, 2001).

The purposes of the directive as stated in Article 1 are:

> "to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which, inter alia:
>
> *"(a) prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems;*

Thus GWDTEs are given specific protection under the purposes of the directive.

1.2.2 Environmental Objectives

A series of environmental objectives are set out in Article 4 of the WFD. The objectives in relation to groundwater are the most relevant for GWDTEs such as turloughs. The environmental objectives for groundwater apply to groundwater bodies identified within aquifers.

1.2.2.1 Groundwater Bodies

The WFD defines a body of groundwater as *" a distinct volume of groundwater within an aquifer or aquifers"*. According to the Irish Groundwater Working Group (2001) interpretation, the concept of "Groundwater Bodies" embraces:

- Groundwater that can provide for the abstraction of significant quantities of water (i.e. the groundwater which can and should be managed to ensure sustainable, balanced and equitable water use); and
- Groundwater which is in continuity with ecosystems and can place then at risk, either through the transmission of pollution or by unsustainable abstraction that reduces baseflows (i.e. the groundwater which can and should be managed to prevent environmental impacts on surface ecosystems).

Under the aquifer categories defined in *Groundwater Protection Schemes* (DELG/EPA/GSI, 1999), which will be the starting point for delineation of groundwater bodies by the Geological Survey of Ireland, all Irish bedrock units are defined as aquifers, therefore the all bedrock units have become elements of one or more groundwater bodies.

1.2.2.2 Environmental Objectives for Turloughs

The environmental objectives for groundwater (Article 4) relevant to GWDTEs, including turloughs, are the achievement of:

> *"good groundwater status at the latest 15 years after the date of entry into force of this Directive, in accordance with the provisions laid down in Annex V"*

Groundwater status is described in terms of both quantitative and chemical status in Annex V. Good groundwater quantitative status Annex V [2.1.2] requires *inter alia* that:

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

Good groundwater chemical status Annex V [2.3.2] requires that the concentration of pollutants *inter alia*:

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

These provisions protect groundwater dependant terrestrial ecosystems from significant adverse impacts resulting from changes in water quantity or from groundwater pollution.

1.2.2.3 Turlough GWDTEs to which Objectives Apply

There are 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 EU Habitats Directive (EU,1992) or the Birds Directive (EU,1979) are included. This is in accordance with the Horizontal Guidance on Wetlands (2003) which states may use their own nationally developed criteria for identifying "*those* *dependant terrestrial ecosystems which they believe are of sufficient importance that damage to them, as a result of anthropogenic groundwater alterations, could legitimately be described as 'significant'*".

Article 6, *Register of Protected Areas*, defines protected areas as those areas lying within each river basin district which have been designated as requiring special protection under specific Community legislation for the protection of their surface water and groundwater or for the conservation of habitats and species directly depending on water. These include Protected Areas designated under legislation listed in Annex IV, which includes the Habitats and Birds Directives. Under Article 4, member states must achieve compliance (by 2015) with any standards and objectives under which the individual protected areas have been established. In addition where more than one objective exists for a water body, the most stringent must be applied.

Turloughs are designated as priority habitats under the Habitats Directive. The most significant standard for sites designated under this directive is the achievement of favourable Conservation Status for the designated feature of interest, in the case of turloughs, as priority habitats, this consists of the whole area of the turlough habitat. In the case of turloughs, the standards which have been developed in order to achieve this status include standards both for the turlough waters and for contributing ground and surface waters. In addition the groundwaters contributing to the turlough will be expected to meet the any other relevant environmental objectives pertaining to groundwater.

It is hoped that in the next phase of work (after 2004) additional turloughs will be subject to the characterisation procedure. This could occur either by additional sites being designated as SPAs under the Habitat's Directive or by the extension of the type of designated sites to be subject to the characterisation procedure.

1.2.3 Characterisation Process and Risk Assessment

The achievement of the enviromental objectives is implemented through a phased process, River Basin Management Plan, carried out for each of the River Basin Districts into which the member state is divided.

Article 5, *Characteristics of the river basin district, review of the environmental impact of human activity and economic analysis of water use,* sets out what must be undertaken in this phased process, River Basin Management Plan. For each river basin district it includes:

> *"-an analysis of its characteristics,*
>
> *-a review of the impact of human activity on the status of surface waters and on groundwater, in accordance with the specifications of Annexe II."*

The specific requirements for groundwaters, and therefore by association for GWDTEs , including turloughs, are listed in Annex II. These are a phased process consisting of:

> *An Initial characterisation of all groundwater bodies to …assess the degree to which they are at risk of failing to meet the objectives for each groundwater body under Article 4.*

and

> *Further characterisation, following this initial characterisation…, of those groundwater bodies or groups of bodies which have been identified as being at risk in order to establish a more precise assessment of the significance of such risk and identification of any measures to be required under Article 11*."

The process therefore consists of an initial characterisation of each groundwater body and its associated GWDTEs, which includes an assessment of pressures and impacts, in order to assess their risk of failing to achieve their environmental objectives, as outlined above for turloughs. This followed by a more detailed phase of characterisation, of those water bodies/groups of water bodies which have been identified as being at risk.

A programme of measures must be established in order to achieve the objectives stated under Article 4, which in the current case for Turloughs subject to characterisation, consists of the achievement of objectives defined under the Habitats Directive.

1.3 Project Objectives

1.3.1 Objectives

The objectives of this desk study were to:

- Develop a risk assessment framework for groundwater dependent 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.

2 Turloughs

2.1 Definition

A turlough is defined as:

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 these definitions defines a set of waterbodies as turloughs, though these sets will not overlap completely. These include:

Coxon, C. (1987(b)) defined what constituted a turlough based on hydrological criteria, that is:

- The area must flood seasonally, *i.e.* it must consist of open water for part of the year, and must be dry (except for any small residual pools occupying a small % of the area) for part of the year, and to a minimum depth of 0.5m and;
- There must be evidence of emptying to groundwater, which generally means that there must be no surface water outlet.

Coxon (1986) also includes a list of other author's definitions, both from technical and non-technical literature, of turloughs. Some examples include:

King (1965, from Coxon,1986): *" As of those places called turloughs, quasi terreni lacus, or land-lakes, they answer the name very well, being lakes one part of the year of considerable depth, and level smooth fields the rest. There holes are in there, out of which the water rises in winter, and retires again in summer…."*

Scannell (1972): *"Turloughs, periodic lakes, occur as solution hollows on the Carboniferous Limestone".*

Drew (1976): *"A characteristic landform of this area of western Ireland is the turlough or intermittent lake…typically they consist of a shallow depression up to 25m deep with well defined bounding slopes and an overall oval shape. The floor is commonly flat, and occupies an area of between 0.5 to 3.0km^2. There is a sharp break of slope between floor and sides. True turloughs are invariably bedrock hollows, and not simply declivities in the glacial drift, although there may be very little relief between their base and the level of the surrounding lowlands".*

Other definitions include:

The Karst Working Group (2005) convened as a working group under the Water Framework Directive by the Geological Survey of Ireland suggested:

"Seasonal lake found in the lowland karsts of western Ireland. They often fill and empty via estavelles".

MacGowran, B.A. (1985):
"A turlough is a depression in limestone areas which is covered mostly with small perennial vegetation, and which floods in winter after wet weather. There is a basic pattern of winter flooding and summer drying, the main flooding starting in October or November".

Goodwillie, R. (2003): *"A working definition of a turloughs is that the winter size must be twice the summer size if permanent water is present".*

Reynolds, J. (pers comm.) *"…part of a continuum from field ponds through to permanent lakes"*

The development of a definition which views turloughs as integrated hydro-ecological entities is consistent with the requirements of the Water Framework Directive. It draws in part upon these existing definitions, the inputs of the Turloughs Working Group, and on the on results of work carried out for this project.

The turlough definition emphasises the input to turloughs *mainly from groundwater,* there will also be some surface water run-off in the turlough basin, particularly where there are overlying deposits. In addition a minority of turloughs have surface water streams running into them, which sink within the turlough area, thus there is no surface water output from the turlough. Of 60 undrained turloughs studied by Coxon (1986), only 3 function in this way. 5 have permanent internal springs and sinks and between 40 and 50 appear to flood via estavelles or temporary springs within the turlough, in other words, have input almost exclusively from groundwater.

The occurrence of flooding is a function of the climatic regime and 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 1000 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. Similarly derived landforms in Yugoslavia (poljes), are glacial hollows on Carboniferous limestone, but do not flood for periods of many years due to a different climatic regime, in addition to a thick layer of sediments on the basin floor (Coxon, 1986). 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 Co. 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 550mm.

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.

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. The most extensive lists of existing data are contained in the following work:

-Coxon, C. E. (1986);

-Goodwillie, R. (1992);

-O'Connor, A. and Regan, E., Ecosystem Research Group, NUI Galway sampling lists;

-Ecosystem Research Group, NUI Galway references database;

-Geological Survey of Ireland, Karst Database.

-Southern Water Global, (1996);

- National Special Areas of Conservation (SACs) and Special Protection Areas for birds (SPAs) databases, National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government (NPWS).

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.

i) 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), O'Connor, A. and Regan, E. (2003) aquatic and terrestrial beetle sampling lists and Southern Water Global (1996). These sources have been included 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 is reliable.

Each site has been assigned a location, an internal database turlough identification number (turlid), its 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. (1987(b))) and in addition are <10 ha in area and undrained. Substrate and vegetation were also investigated. Sites from Goodwillie (1992), which include 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 O'Connor, A. and

Regan, E. (2003) for their beetle fauna, including limited water sampling, are a subset of the former sites but include additional sites. Table 2.1 below lists all of the sites included in the project database.

Table 2.1 Turloughs listed in TCD projects database

Abbreviations : Turlid :Turlough identification number X,Y : easting and northing, Irish National Grid
Cox id : Coxon identification number RG : Goodwillie identification number
SGF id : Southern Water Global identification number
Grid ref acc : Grid reference accuracy, 1 least (~km), 3 most (100m) accurate
NUIG id no. : NUIGalway (O'Connor and Regan) identification number

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
36	Turlough Faugh	125000	258000	36	0	0	1	0	Mayo
37	Turloughosheheen	121000	264000	37	0	0	1	0	Mayo

Turlid	Ccname	X	Y	Cox id no	RG id no	SGF id no	Grid ref acc	NUIG id no	County
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
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

Turlid	Ccname	X	Y	Cox id no	RG id no	SGF id no	Grid ref acc	NUIG id no	County
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
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

Turlid	Ccname	X	Y	Cox id no	RG id no	SGF id no	Grid ref acc	NUIG id no	County
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
35	Turloughagurkall	123372	260971	35	0	0	3	0	Mayo

ii) Geological Survey of Ireland (GSI) Karst (Turloughs) database.

This database is available in Arcview shape (GIS) format (gsikarstturls.shp), for spatial viewing and querying, and Excel spreadsheet format (gsikarstturlsdec04.xls).

Turlough sites were selected from the GSI karst database. This database currently (December 2004) comprises 285 turlough sites. The database is currently under review for the purposes of validating site locations and adding in the sites listed in the Ecosystem Research Group, NUI Galway references database. This latter database includes sites referenced in the literature, but not yet validated by field work. The information included in the TCD Project Turlough Database will also integrated. When complete and validated, it will provide the most extensive database of turloughs. Currently 98% of the turloughs in the TCD turloughs database are included the GSI Karst (Turloughs) database. However there are small differences in the locational information, since the dgree of accuracy varies between databses. Consequently, the position of a turlough will frequently be slightly offset from the same turlough in the other database, when displayed in the GIS environment.

The database includes locational information, a measure of the accuracy of the location, information on the source of the location and in most instances the lithology and/or stratigraphy on which it is located.

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.

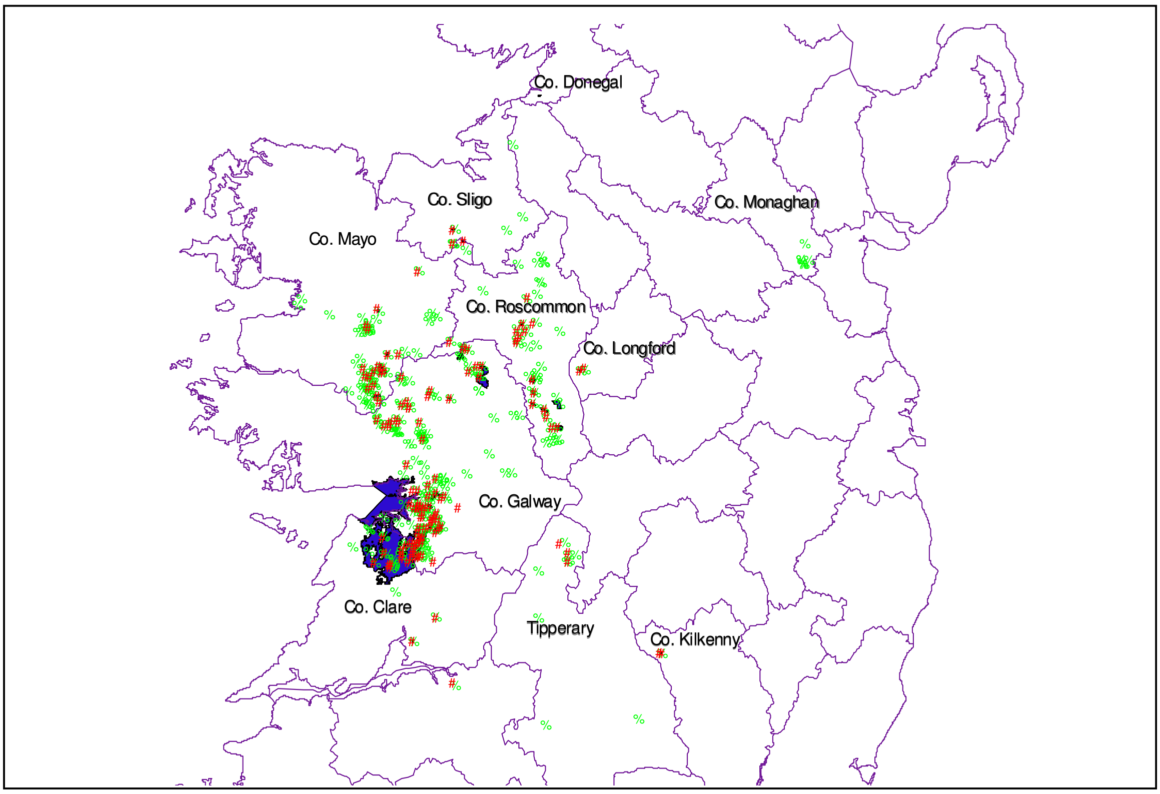


Figure 2.1 Distribution of turloughs listed in the TCD Project Turloughs Database and the Geological Survey of Ireland (GSI) Karst (Turloughs) database

iii) Turlough Special Areas of Conservation (SACs) database

This database is available in Arcview shape (GIS) format (sacturlfinal.shp), for spatial viewing and querying and in Excel spread sheet format (sacturlfinal.xls).

The database was compiled from turlough SAC site information provided by the NPWS in GIS format. It comprises 43 SAC areas, a number of which are SAC complexes. A complex includes more than one designated turlough site within their area, and may also include other areas of conservation value, which are not turloughs. The 43 SAC areas include 70 individual turloughs.

The database includes location, SAC code, name and county information for each SAC area.

Annex III of the Habitats Directive indicates that all occurrences of Annex I habitats (which includes turloughs). In reality guidance from Europe suggests that a "representative sample" of 20 to 60% of the resource (i.e. Annex I habitat), should be designated. In the case of priority habitats (as are turloughs), the proportion should be closer to 60% (Aine O'Connor, NPWS pers.comm.). Seventy turloughs have been designated as SACs. This represent approximately approx. 25% of the potential 285 turloughs listed in the current Geological Survey of Ireland Karst Database. It is possible that further turloughs may be designated as SACs in the future. Also, additional turloughs are likely to be designated as Natural Heritage Areas (NHAs) under the Wildlife (Amendment) Act, 2000 (Jim Ryan, NPWS pers. comm.).

This database is therefore subject to change and will need to be updated in line with new NPWS designations.

iv) Turlough Special Protection Areas (SPAs) database

This database is available in Arcview shape (GIS) format (spaturlfinal.shp) for spatial viewing and querying and in Excel spread sheet format in - <TurloughSACsSPAslistTrophicImpacttablesGuidance110205.xls>, Table 2).

The database was compiled from turlough SPA site information provided by the NPWS in GIS format. It comprises 2 SPA areas, the SPAs coded 4107 (Coole-Garryland) and SPA 4089 (Rahasane), which are currently SPAs. Both of these turlough sites are also designated as SACs, but have different boundaries. SPAs coded 4138 (Ballinturly), 4139 (L. Croan) and 4140 (Four Roads) are not currently SPAs, but have been proposed and digital boundaries are not yet available from NPWS. Information on both the designated and proposed sites is included in the spreadsheet TurloughSACsSPAslistTrophicImpacttablesGuidance110205.xls, Table 2.

The database and spreadsheet include location, SPA code, name and county information for each SAC area.

Lists of turlough SPAs and SACs are given as part of Appendix 3, within the Risk Guidance document.

v) ArcView Turloughs Project

An ArcView project (turloughs.apr) has been compiled. This allows access to all the 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. Ordnance Survey 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 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.

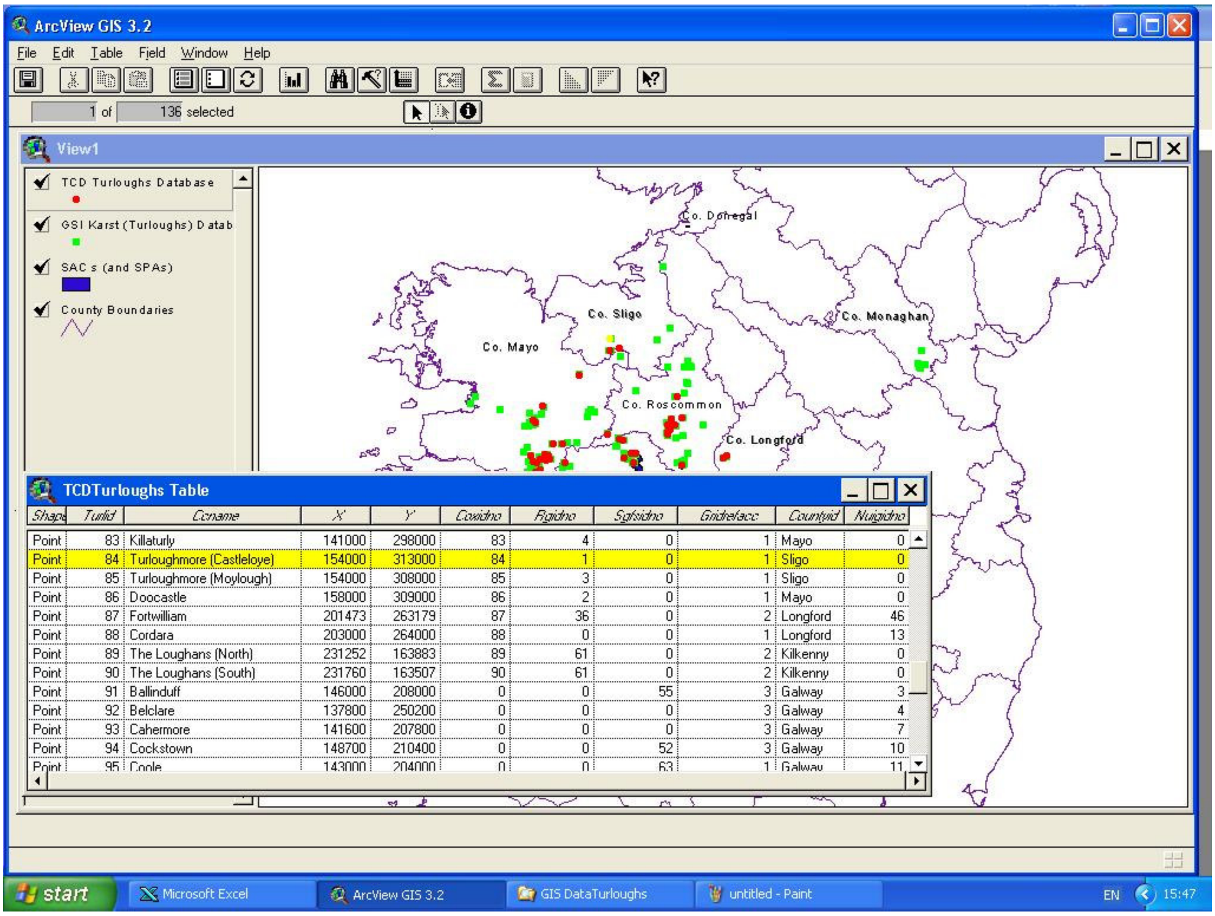


Figure 2.2 ArcView Turloughs Project (turloughs.apr) open for view and query

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

2.3 Turloughs Data and Information Resources

A comprehensive listing of references and data resources relevant to turloughs has been compiled in Appendix 3 *Data and Information Resources*. It includes both published information and unpublished data. It is reasonably exhaustive, however there may be omissions and work on turloughs is on-going.

2.4 Distribution of Turloughs

The GSI Karst (Turloughs) database currently includes 285 turloughs occurring in these counties and in Counties Cork, Leitrim, Monaghan and Longford. The project database contains 128 turloughs located in Counties Clare, Galway, Kilkenny, Limerick, Longford, Mayo, Sligo and Tipperary. As can be seen from Table 2.2 below based on the GSI Karst (turloughs) database, the turloughs are concentrated in Counties Galway, Mayo, Roscommon and Clare in ascending order. Table 2.3 based on the project turlough database shows the same pattern of turlough distribution –

Table 2.2 Turlough Distribution (GSI karst database)

County	Number
Clare	26
Cork	2
Galway	121
Kilkenny	1
Leitrim	1
Limerick	1
Longford	2
Mayo	62
Monaghan	7
Roscommon	48
Sligo	5
Tipperary	9

Table 2.3 : Turlough distribution (Project database)

County	Number
Clare	15
Galway	67
Kilkenny	2
Limerick	1
Longford	2
Mayo	19
Roscommon	17
Sligo	2
Tipperary	3

2.5 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 10ha 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 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 1200 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 on the basis of 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 Coxons 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 suscepible to the formation of epi-karst 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.

2.6 Vulnerabilty of Turloughs as elements of a Karst System

A turlough is defined as:

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.

In the context of the WFD turloughs fall into the category of terrestrial ecosystems that depend directly on bodies of groundwater. GWDTEs are, by definition, wetland ecosystems. Turloughs are included in the category of highly groundwater dependant ecosystems (Groundwater Working Group, 2001). Both of these definitions arise from the fact that turloughs form an integrated part of the karstic system in which they occur.

The karstic systems of which turloughs form a part have a number of characteristics that 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 presence of potentially interconnected conduit and diffuse flow systems, and of flow in an epikarst zone. 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 inter-related 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).
- Response 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.

In terms of assessing the impact of pressures upon turloughs, these characteristics contribute to:
- Potentially high and rapid impact of pressures;
- Difficulty of assessing the area contributing to the turlough (the catchment) and within which pressures must be identified and assessed;
- Difficulty in assessing the pathway via which pressures are transmitted to the turlough;

These issues are addressed in Sections 3.3: Indicative Turlough Typology, 3.4: Turlough Catchment Delineation, and Section 4: Risk assessment.

2.7 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 O'Connor and Regan (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, Clare area.

Classifications which take into account more that 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 are hampered by a lack of quantitative data on one or more characteristics of the turlough.

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 detail in Chapter 3.

2.8 Multidisciplinary co-operation

In addition to the project team and partners, 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. These individuals contributed data and ideas. They are the following:

Individual	***Organisation***
Dr Deirdre Lynn	National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government
Donal Daly	Groundwater Division, Geological Survey of Ireland
Jim Ryan	National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government
Dr Julian Reynolds	Dept. of Zoology, Trinity College, Dublin
Dr Roger Goodwillie	Consultant Ecologist
Dr Stephen Waldren	Dept. of Botany, Trinity College, Dublin
Sarah Kimberley	Dept. of Botany, Trinity College, Dublin

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 of 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

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 time period 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 'type', for the longest periods of time, for any given turlough characteristic. The main data sources are the following:

Table 2.4 : Turlough eco-hydrology - Data sources

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. Also, the year of monitoring for one characteristic is almost always not co-incident with monitoring for any other characteristic. The set of turloughs which 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 was drawn from other data sources. These are referenced in the report.

Available Data and reference listing

In addition to the data used and references cited in this project, a comprehensive listing of turlough related data sources and references was compiled. See Appendix 3 *Data and Information Resources*.

3.1.3 Issues and limitations

The main issues and limitations in terms of data are the following:

- A lack of spatially and temporally co-incident data on the different turlough characteristics.
- Lack of long-run plant ecological (plant and invertebrate) mapping or monitoring.
- Lack of long-run hydrological data for a large number of turloughs and no data for over half.
- Sporadic data on invertebrate populations.
- An almost complete absence of water chemistry measurements (all existing measurements, with the exception of one turlough, are single samples from one year, data which is of extremely limited value).
- A complete absence of any type of data for a large proportion of turloughs.

These data limitations restricts analysis of relationships between different turlough characteristics and inhibits analysis of trends and of impact of pressures.

Due to these data constraints the work has focussed therefore on analysis of relationships between ecological and hydrological characteristics of turloughs (eco-hydrology) for which quantitative or semi-quantitative results could be achieved. Some aspects of turlough ecology have therefore not been addressed.

Issues which have not been addressed due to a lack of suitable data are:

- Relationships between bird life and other turlough characteristics. Limited data on distribution and habits of breeding and overwintering birds exists.
- Flora and Fauna of cave systems and their relationship to karstic flooding. There is extremely limited data on existing cave flora and fauna.

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 flood 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, that is 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 mophological/physiological changes and timing of important life cycle events. Specific adaptations (Goodwillie, 2003) include:

- Annual plants reduction in oxygen demand 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 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 provide 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 commoner 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 have 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 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 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. (See Appendix 1, 1. Summary of Goodwillie (1992) Vegetation Survey, for details). These commmunities 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.

Selected hydrological indicators: residence and response time

A number of hydrological indicators were chosen to compare with various aspects of turlough vegetation. Intuitively, the hydrological measures which are likely to affect vegetation type (species communities) in a turlough wetland will include the length of time that a species is likely to be under water (over an annual cycle), the timing of inundation during the growth cycle and the frequency with which inundation occurs within an annual cycle. One recognized parameter used in environmental engineering which integrates some of these measures is so-called 'residence time' which equates to the volume, V, of the inundated wetland divided by the flow rate, Q, which fills it. In naturally functioning wetlands, residence time is difficult to define as the flow rate, either on filling or emptying (often through the same inlet/oulet), is variable and the volume filled in any one season can also vary – turloughs are not 'steady state' systems. Thus, 'residence time' will vary with topographic elevation and the duration of water cover at any particular elevation will differ from year to year under fluctuating climatic conditions. Relating depth of water to duration of inundation at that depth provides an indicator of this variable residence time in an integrated way. The so-called frequency-duration curve for water level can be determined from readily measured time series records of water level in a turlough. The curve becomes a characteristic indicator of residence time.

As a hydrological system, a turlough is a 'reservoir' which is filled and emptied in response to rainfall. A turlough may be represented, therefore, as a linear hydrological system, under which S=K.Q where S represents the hydrogeological storage ('field porosity' or specific yield of the groundwater body) which is supplying the turlough and K is the recession constant determined from the hydrograph recession characteristic of a given turlough. The measured recession in a turlough is that of water level naturally decreasing during periods of little or no rainfall. A topographic survey of a turlough will result in a contour map or digital terrain model for the 'reservoir' from which a relationship between depth and volume can be determined. The depth-volume curve becomes a hydrogeomorphic characteristic of the turlough. When combined with a recorded water level time series, a discharge can be determined for discrete time intervals along the recession (dV/dt : change in volume/time interval). The recession constant is determined from either the discharge curve or the stage (water level) curve on recession. The recession constant is a well established criterion in hydrology, as a characteristic parameter for representing the flow behaviour of the system and, therefore, as an indicator of response time. A steep recession curve indicates a relatively fast response time to a rainfall input and the converse applies for a 'flatter' recession.

Thus, hydrological measures of duration of inundation, or 'flood duration', represented by the frequency-duration curve, derived from the turlough water level records, and the turlough response time, represented by the recession constant, were selected as the key hydrological indicators to be related to corresponding ecological indicators, such as Ellenburg wetness indices for species communities. These pragmatic hydrological measures, determinable from available data (much of which was collected during the study) incorporate concepts of residence time and respsonse time for a turlough. Indeed, the hydrological indicators which emerged as having the best relationship with aspects of the vegetation ecology are flood duration 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.

i) 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.

Calculation

Exceedance curves were constructed for Caherglassaun, Coy, Skealoghan and Termon South turloughs. The following exceedance calculation (Fetter, 1994) was used to create the % exceedance values:

% Exceedance at height (h) = (descending rank position of (ascending value flood stage (h))/total no. of values +1)*100

Flood duration (Exceedance) graphs

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

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- 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- 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- 30/9/2003. James Moran, NUI Galway.

Termon: Curve constructed from one hydrological year of stage data. Hourly stage data was collected during the period 12/02/1996-29/09/1996 (Source Southern Water Global, Gort Flood Studies project) Based on this data was interpolated for the period 01/10/1995-11/02/1996, 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 that 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 is expressed in m O.D. Malin.

ii) 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, the Goodwillie modified the classical phytosociological communities to better reflect the distribution and composition of the plant ecology observed in the turlough environment.

Methodology

A topographic survey of each turlough was carried out using a Trimble GPS level, accurate to a minimum of 20cm (in x, y and z directions) and registered to the national grid. Height is recorded in m. O.D. by registration to a local bench mark 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 overlaid on Goodwillie vegetation communities for Skealoghan turlough.

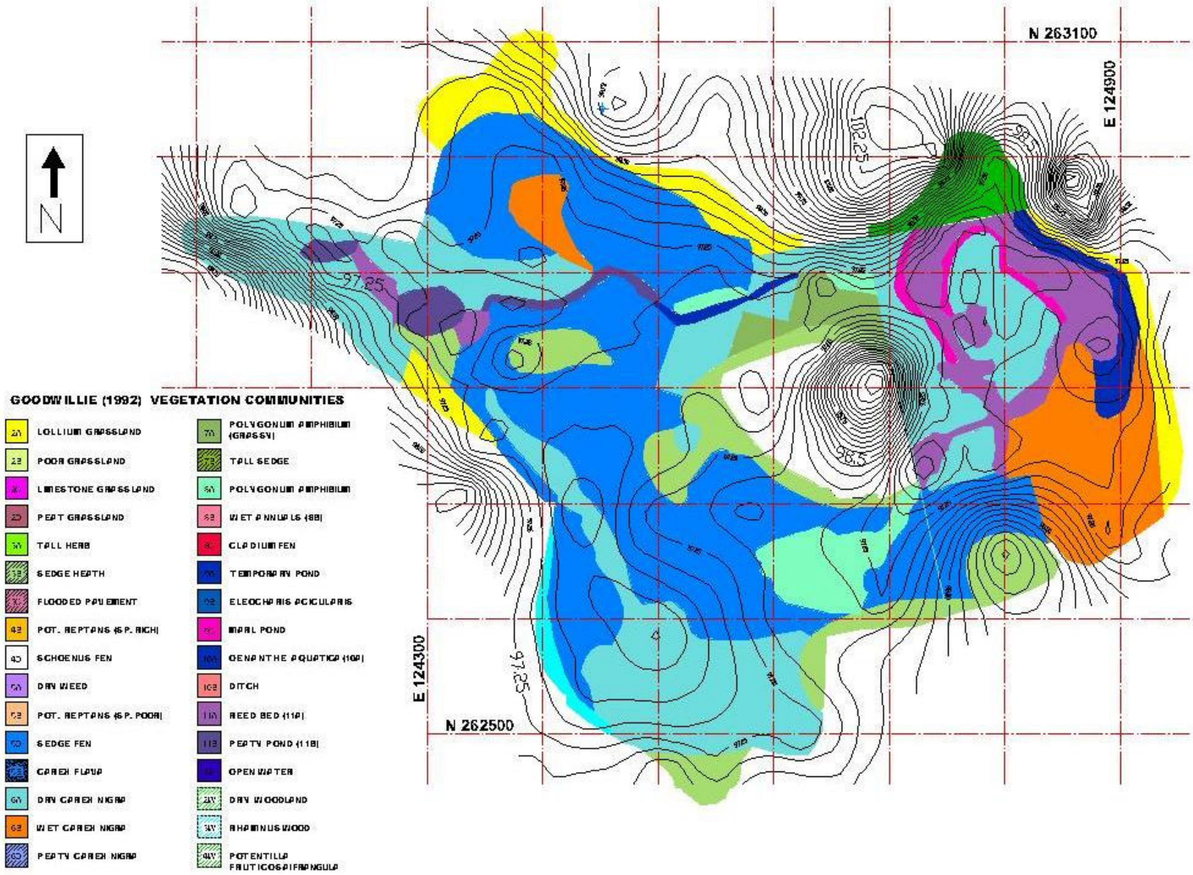


Fig 3.1 Skealoghan, Goodwillie (1992) vegetation communities and topographic contours (m O.D. Malin)

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.

iii) 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. (See Appendix 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.

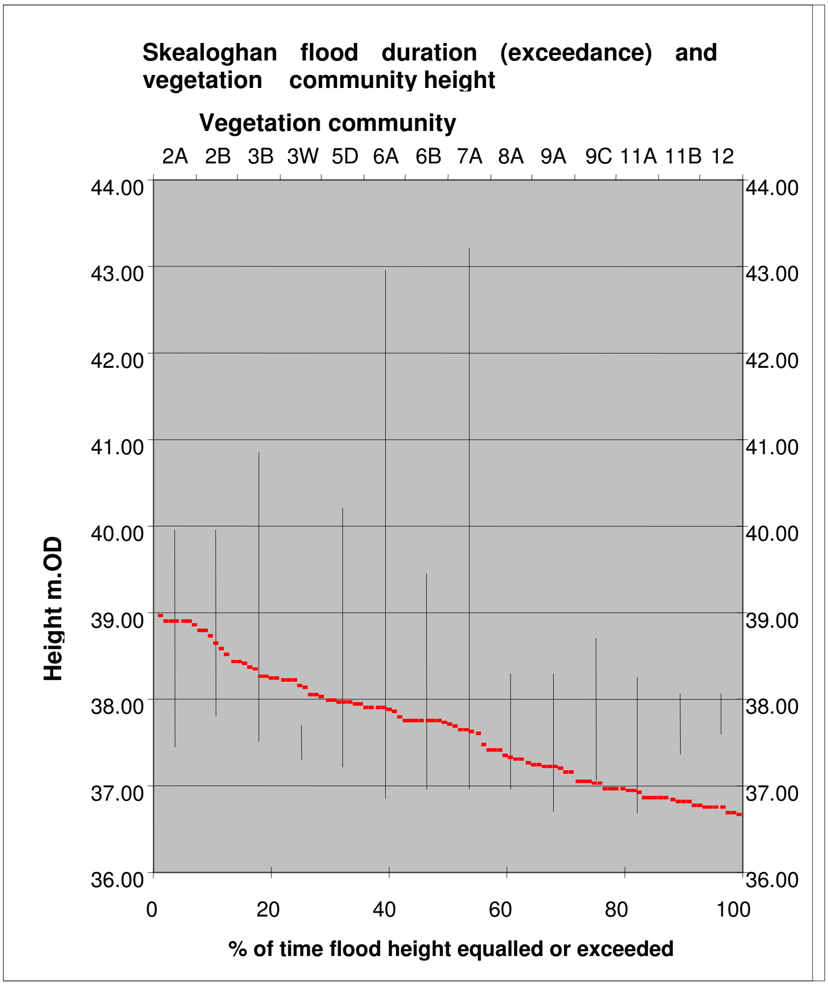


Figure 3.2 Combined community height range-flood duration graph for Skealoghan turlough

In the case of Termon turlough, the topographic survey, to which the vegetation is referenced, was carried out by this project, whereas the hydrological survey was carried out under the Gort Flood Studies projects (Southern Water Global). It is not certain whether these are both referenced to the same base level, and there is therefore some uncertainty about the relationship between flood duration at a given height and vegetation occurrence heights.

Plant communities occurring in each of the four turloughs are tabulated . The four turloughs include 25 of the 32 Goodwillie communities - see Table 3.1 : Occurrence of Goodwillie communities in studied turloughs, below.

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 is recorded from the combined Flood duration (exceedance) curve/Vegetation Range Graph. That is, the % exceedance time for the minimum height at which the community occurs is recorded. Similarily, for each turlough, the minimum flood duration to which each of these communities is subject is 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. The data is given in Table 3.2: Minimum and maximum flood duration of Goodwillie communities for individual turloughs, 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. The results are given in Table 3.3, Flood duration ranges of Goodwillie communities across turlough combinations. 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.

iv) Results

Table 3.1 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	Pot. 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 3.2 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 3.3 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

v) 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. Group 1 is shown in table 3.4.

Table 3.4 Combined Goodwillie vegetation communities : 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 approx. 0% of the time, up to a defined maximum flood length and cannot tolerate being flooded for any greater % 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.

A second group of vegetation communities is given in Table 3.5

Table 3.5 Combined Goodwillie vegetation communities : 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 this is the case. Including this data would extend the duration range to 26-100%. 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 doesn't occur in this dataset). That is 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, but it is possible that only small areas of the overall community occur across this wider range.

A third grouping of vegetation communities is given in Table 3.6

Table 3.6 Combined Goodwillie vegetation communities : group3

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, the 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.

A final fourth grouping of vegetation communities has a single type as shown in Table 3.7

Table 3.7 Combined Goodwillie vegetation communities : 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 0-100%.

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 3.3 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 consists 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 preceeding 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 et al (1998) state 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 years 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.

i) 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 accurately represent 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:

  $\log_{10}$ stage (time +1) *(y-axis)* vs. $\log_{10}$ stage (time) *(x-axis)*

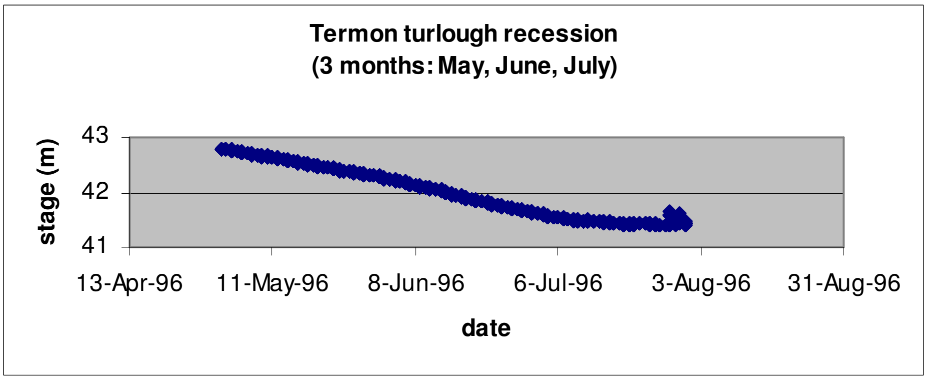
  is constructed.
- A best-fit linear regression line of the form:

  $y = ax + b$

  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 Appendix 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 discharge characteristics of the tank. 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. 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.



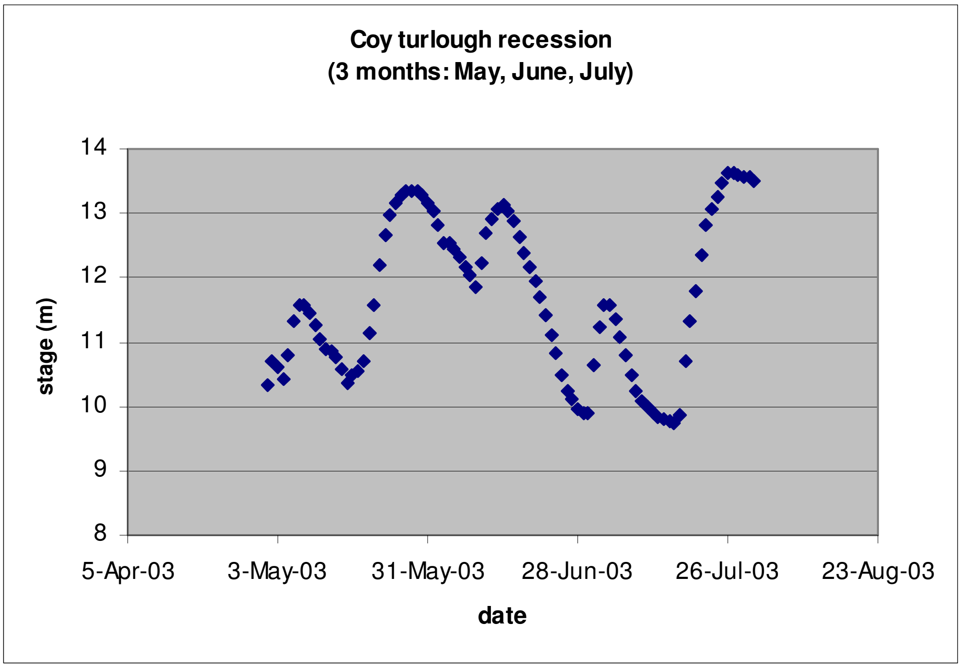


Figure 3.3 Contrasting recession rates at Termon South and Coy.

ii) 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, NUI Galway (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 as shown in Table 3.8:

Table 3.8 Dominant vegetation types in grouped Goodwillie communities

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

The types are combined, (slightly modified from the original scheme), to allow for a continuum of wetness associated co-dominant types as shown in Table 3.9:

Table 3.9 Dominant vegetation types and associated relative wetness

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 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.

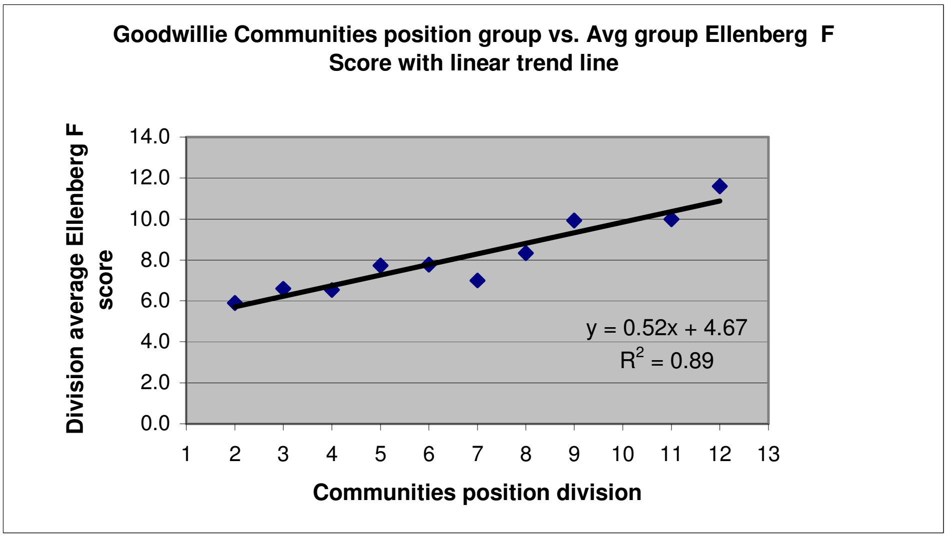


Figure 3.4 Scatter plot of Ellenberg F scores vs. Goodwillie vegetation division with best-fit linear regression line

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 shown in Table 3.10:

Table 3.10 Indices for characteristic vegetation species groups

Vegetation types	Goodwillie commmunity 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. 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 shown in Table 3.11 for 11 turloughs. The areas occupied by each community in each turlough were provided by NPWS.

Table 3.11 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
Rahassane	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

iii) 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, as shown in Table 3.12.

Table 3.12 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
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

iv) 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 ($r^2 = 0.48$).

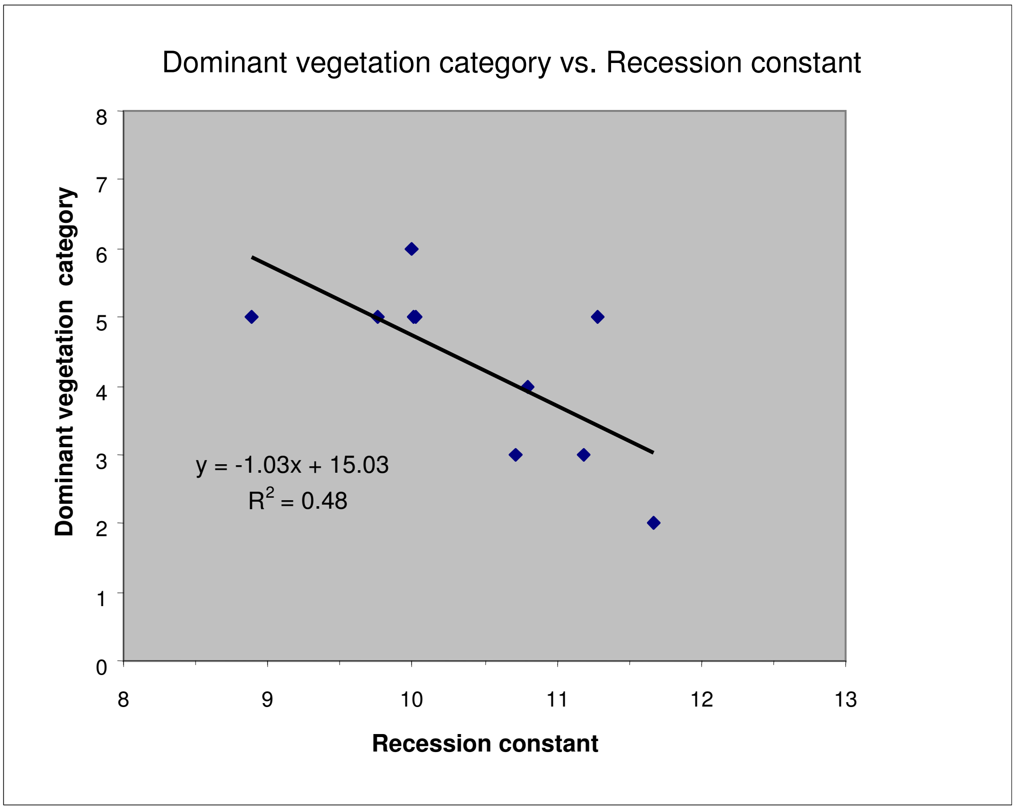


Figure 3.5 : Dominant vegetation relative to turlough recession constant

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.)

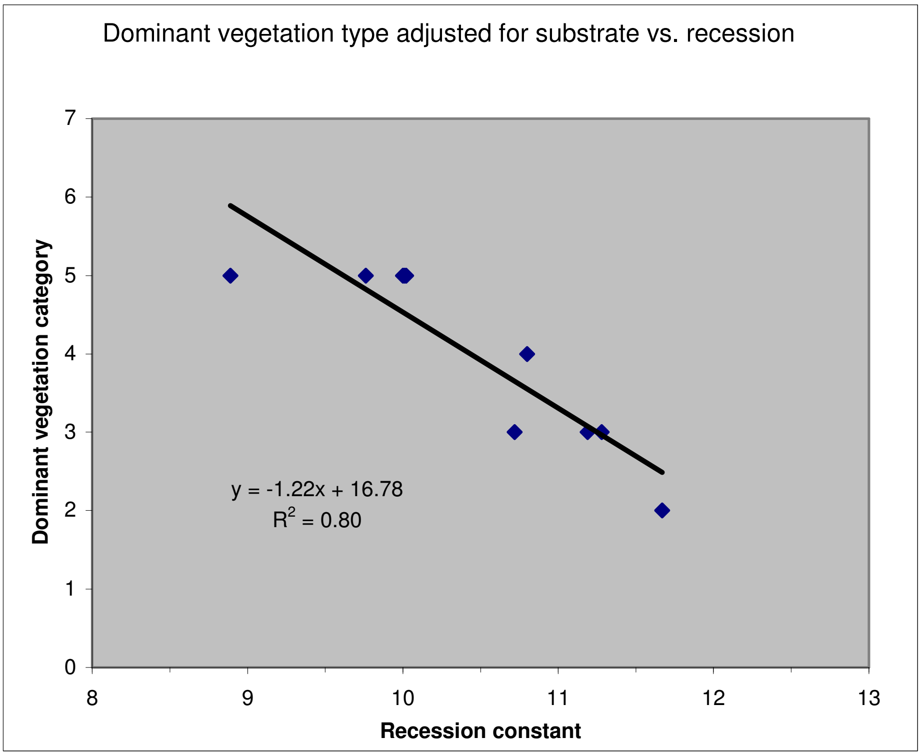


Figure 3.6 Dominant vegetation type adjusted for substrate against turlough recession constant

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* sp. 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, 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.

v) 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, 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

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 less 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.

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.

3.2.4.2 Methodology

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:

- Epikarst flow systems, comprising:

  -*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 large 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

- Deep karst flow systems, comprising:

  -*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.

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.

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 4 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.

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 applies 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.

Analysis

Data was 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 this data was 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.

3.2.4.3 Results

The data for eleven turloughs for which recession constants, karstic flow system and trophic status information were tabulated - see Table 3.13 below.

Table 3.13 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 channelised through turlough and drained to sea
Knockaunroe	1	9.76	Shallow Epikarst	1	Drew, D. (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. UCG 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
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 abbatoir, slurry spreading fertilizer

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.

Relationship between Karstic flow system and turlough stage recession

A scatter plot of stage recession constant versus karstic flow system index (Fig. 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 10.25-11.67, 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.

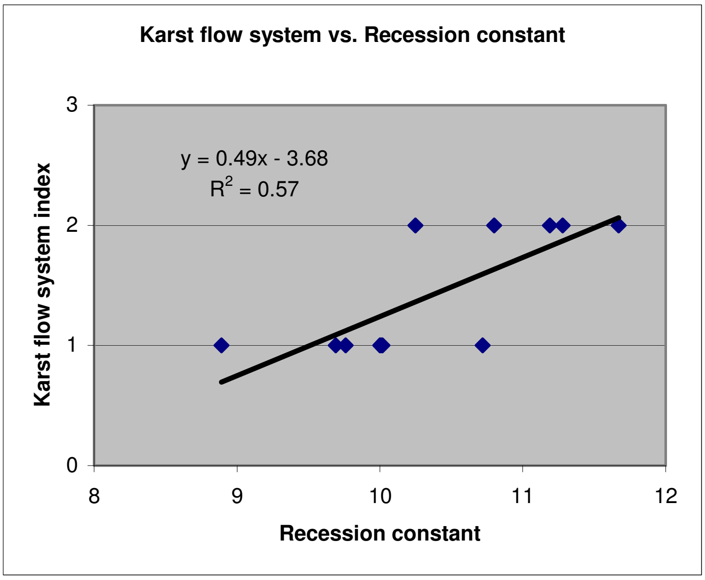


Figure 3.7 Scatter plot with regression line of stage recession constant versus karstic flow system index

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 (Fig. 3.8). A more significant r^2 value of 0.68 describes the fit of the linear regression line imposed on the data.

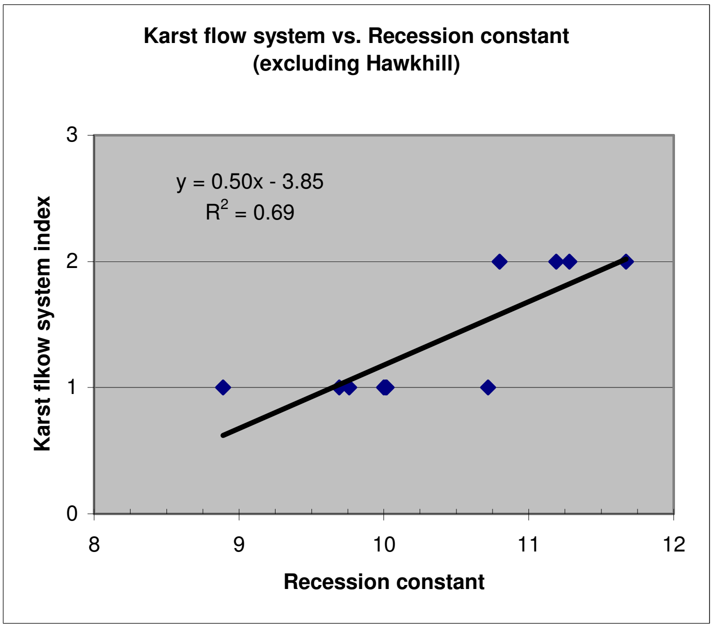


Figure 3.8 Scatter plot with regression line of stage recession constant versus karstic flow system index (excluding Hawkhill)

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.

i) 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.

ii) Conduit/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).

iii) 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. The fact that it correlates so significantly with the overall karstic flow environment of the turlough, that is both the catchment flow system and the immediate receiving flow system, 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.

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, that is from shallow epikarst to conduit flow system type - see Figure 3.9 below.

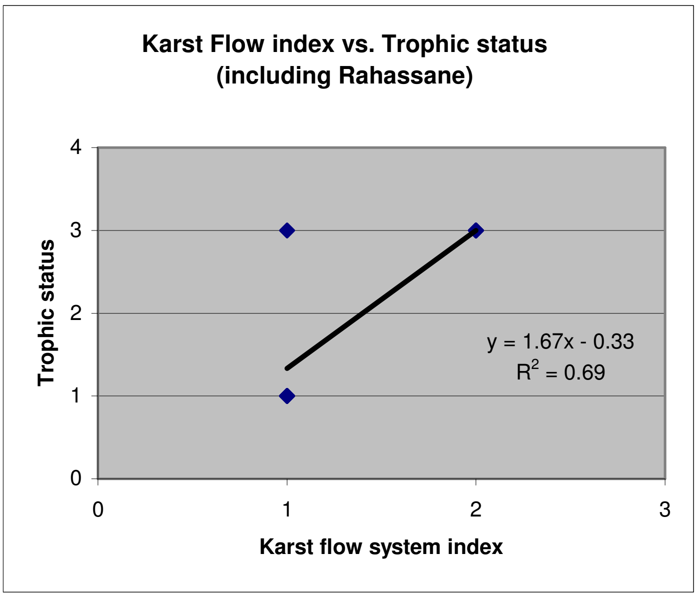


Fig 3.9 Karst flow index against turlough trophic status

A moderately significant linear association exists, the best-fit regression line having an r^2 value of 0.69. Rahassane turlough is an anomalous value in this association, having a trophic status of 3, associated with a KFSI of 1. To improve the correlation Rahassane was removed from the calculations.

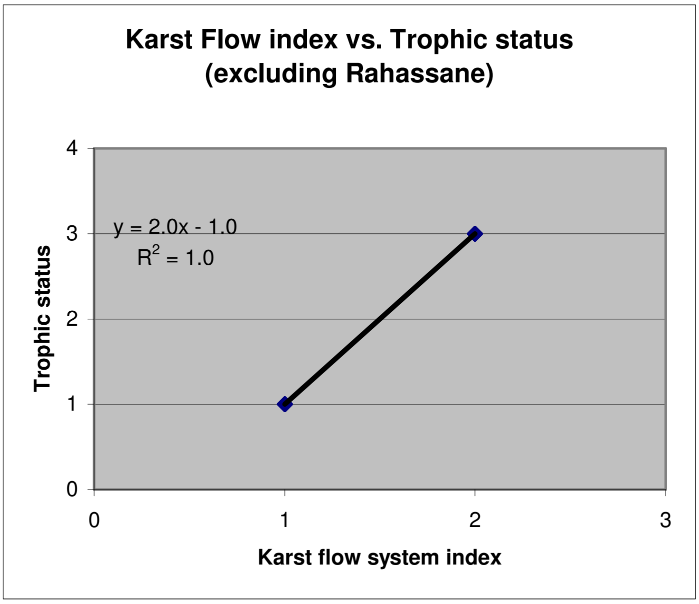


Fig 3.10 Karst flow index against turlough trophic status (river flow excluded)

Albeit with few sample points, the resulting correlation indicates a significant relationship between KFSI and trophic status, the best-fit regression line, inevitably here, 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 was tabulated for a further 15 turloughs for which trophic status and information on the karstic flow system was available - see Table 3.14 below

Table 3.14 Trophic staus and karstic flow system data for fourteen 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, D. Drew pers.comm.	Very extensively reclaimed (basin has been scraped out), probable enrichment from heavy fertilisation.
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.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.P. (1986).	Enrichment from 2 intensive dairy farms in topographical catchment
Greaghans	3		Shallow Epikarst	1	Coxon, C. (1986), Coxon, C. and Drew, D.P. (1986).	Heavily enriched. Badly managed farmyard (floods) and intensive dairy farms.

The significance of the association between trophic status and karstic flow system index visible from the additional tabulated data is 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^2 value of 0.35 - see Fig 3.11.

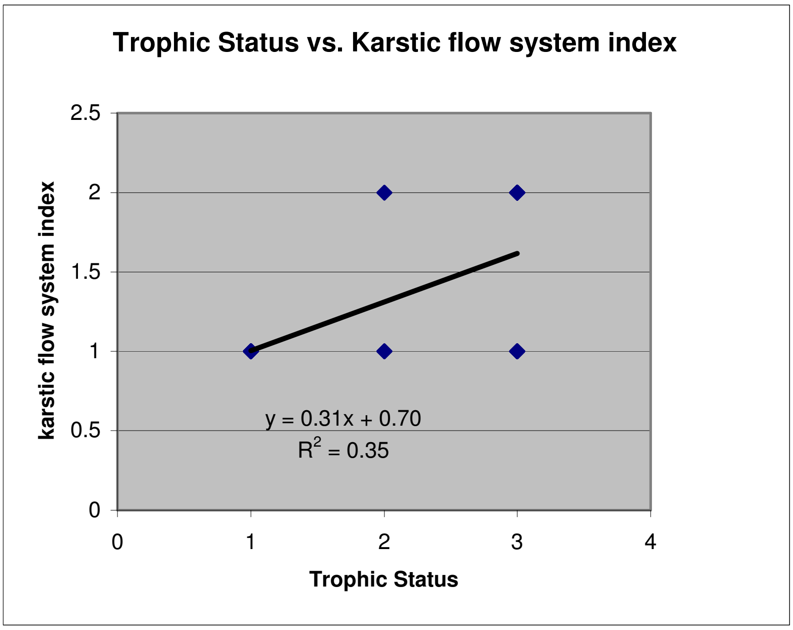


Fig 3.11 Trophic staus against karst flow index

The data was examined. The data that does not conform to the pattern established 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: Rahassane, Hawkhill, Lough Allenaun, Kilglassan, Ardkill and Greaghans turloughs. Rahassane 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 Fig. 3.12

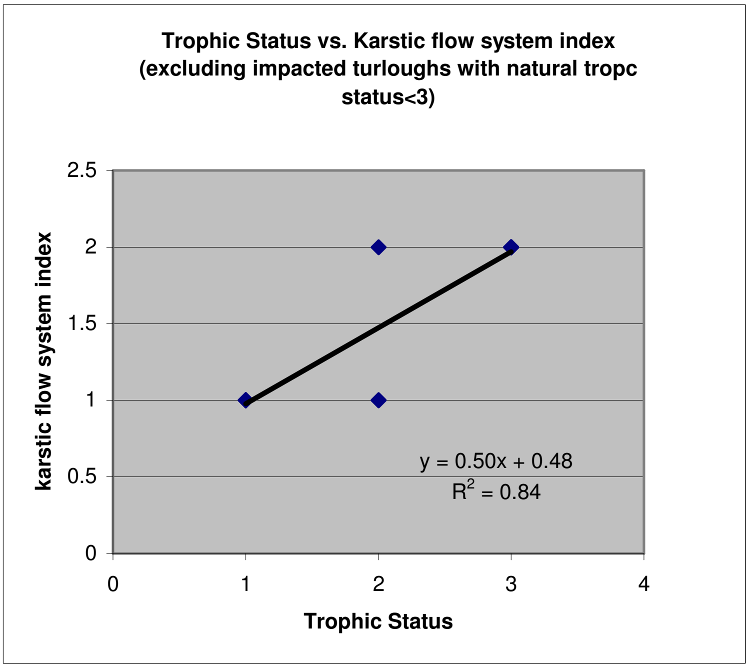


Fig. 3.12 Turlough trophic status against karst flow index excluding impacted turlough

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 meso trophic 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 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.

3.2.4.4 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 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.

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 10.25-11.67, 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 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 is 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 Rahassane 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.

Anthropogenically impacted turlough type :

- Type 6: Turloughs with 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:
i) Identifying the catchment type
ii) 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*. See Appendix 3.

3.5 Turlough Invertebrate Populations

Invertebrates

Although turlough faunas may be sparse and unpreditable, they appear to be inhabited by a characteristic set of invertebrate species. (Reynolds J, 2000, 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 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 dessication 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.

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 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.

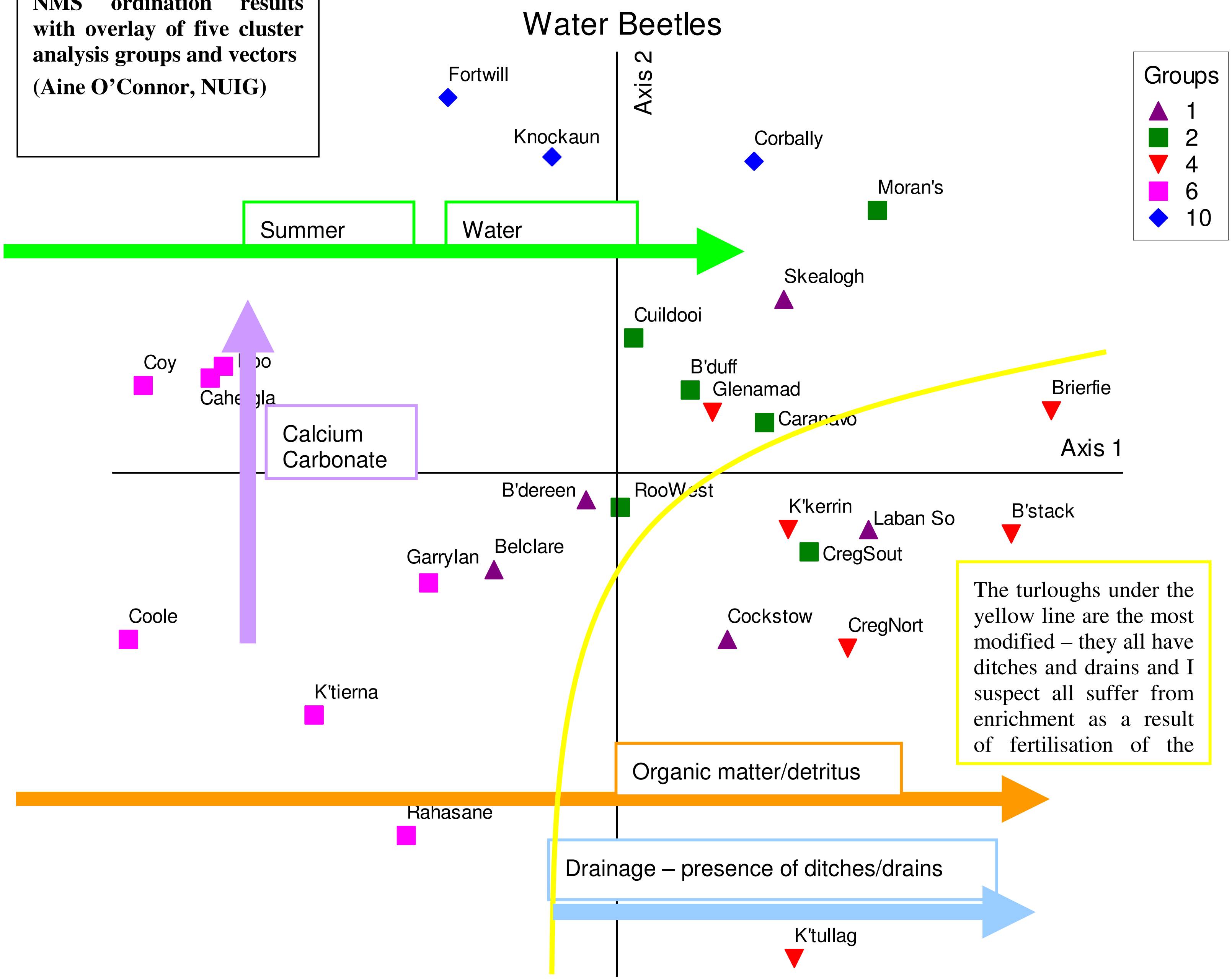
Terrestrial Beetles

The distribution of terrestrial beetle in turloughs was studied by Eugenie O'Regan at 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 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.

Both Groups 1 & 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 & 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.

Figure 3.13
NMS ordination results with overlay of five cluster analysis groups and vectors (Aine O'Connor, NUIG)



3.6 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 has 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.

4 Risk Assessment

Risks or 'threats' to the functioning of a turlough as a wetland (GWDTE) may be described in terms of 'pressures' (ie potential hazards), the susceptibility of the pathway and potential impacts on the receptor, ie the turlough ecology. In the case of turloughs as karstic features, the pathway susceptibility is usually high, although the catchment area is often difficult in practice to define. However, the hydrological behaviour of a turlough, as described earlier in terms of recession constants and duration of inundation, can be a surrogate indicator of potential risk to a turlough ecology.

4.1 Pressures

Wetland Horizonal Guidance (IMPRESS) states that in identifying pressures for the purposes of the Water Framework Directive, risk from current pressures must be asssessed, but that the potential impact of future pressures should also be understood. Thus pressures which are not current should be identified, in the context of a potentially changing policy framework.

Pressures are identified as events or situation which may cause damage or impact under specific circumstances. Impacts resulting from pressures are therefore a function of both the source of pressure, the pathway by which the pressure arrives at the turlough, and the sensitivity of the turlough to the pressure.

Pressures which impact on the turlough can have sources within the turlough basin itself, and/or in the turlough wider catchment. The extent of the turlough catchment and the pathways via which pressures reach a turlough are dependant on the type karstic flow system within which the turlough is situated. Shallow epikarst type flow systems tend to have relatively local catchments, as described above. Conduit/conduit type, or combined flow systems will have potentially large catchments, with the possibility of pressures at distance impacting on the turlough. The delineation of catchments within which pressures may result in impact to the turlough is complicated by the issues of partially contributing catchments, which contribute a proportion (but not all) of their flow to another catchment under specific stage conditions. The pathway via which pressures are transferred is also potentially discrete, with rapid travel times.

Pressures which impact on turloughs can be grouped in to two main groups as follows:

Group I

Pressure: Changes in spatial and temporal pattern, location and magnitude of recharge in t he catchment and within the turlough.

Sources : Drainage: arterial and small scale local; Abstractions; Flood control measures; Land-use management; Urban and infrastructural development.

Climate change, resulting in more intense rainfall events and increased winter rainfall in western/north western Ireland (Sweeney et al, 2003);

Impacts: Change in flood regime, resulting in changes to the composition and distribution of turlough plant species. Potential hydrological indicators of changes in flood regime include flood duration curves. Activities associated with the source of this pressure can also increase the vulnerability of a turlough to other pressures such as nutrient loading by opening new and more rapid physical pathways for pollutant transfer. Changes in recharge may also increase the loading of pollutants/nutreints to a turlough by decreasing flow volumes and consequent dilution and dispersion or by increasing flow volumes and associated loading.

Group II

Pressure: Nutrient loading (phosphorus and nitrogen). Turloughs are phosphate limited systems, but may also be nitrogen limited. Research is ongoing to understand the role on nitrogen in turlough ecosystems.

Sources : Land-use practises: Agricultural land-spreading of organic and non-organic fertilisers, farmyard run-off; Forestry, fertilizers and nutrients associated with sediment loss due forest practise; Construction on peatlands, resulting in mobilisation of sediment and associated nutrients; Municipal, industrial and local (septic-tank) waste discharges;

Impacts Impacts will include changes in composition of plant and faunal ecologies as a result in changes to the overall trophic status of the turlough. Nutrient inputs influences the species composition and productivity. Invertebrate species are impacted directly by nutrient status and indirectly by plant structure. Over-wintering and breeding bird populations may also be impacted by changes in vegetation compositon and structure.

In addition, landuse management has direct impacts on turlough ecology. Grazing has direct impacts on plant and faunal species, through impact on vegetation composition and structure and on substrate structure. These factors will also cause changes to fauna. The circumstances in which grazing has a negative or positive impact are not well understood, certain patterns and intensities levels of grazing can have a positive impact on plant species composition and diversity.

4.2 Risk Assessment Guidance

4.2.1 Purpose of Risk Assessment Guidance

The purpose of the Risk Assessment Guidance is to provide a procedure for assessment of the risk of a turlough failing to meet its environmental objectives. The Guidance, which arose out of the work reported here, consists of:

- A Guidance Document and Summary Risk Assessment Sheet which provide information on how to carry out the assessment of risks to turloughs from phosphate (and associated sediment loading) entitled *WFD Pressures and Impact Methodology Guidance on Groundwater Risk Assessment Sheet GWDTE2a - Risk to Turloughs from Phosphate* is included in Appendix 3. It is designed to be used during the initial characterisation phase, where appropriate data exists, to assess the impact of pressures on a turlough and thus to indicate the degree of risk of a turlough failing to meet standards and objectives contained within the risk assessment. It includes a characterisation of the turlough and its catchment as a precursor to assessing pressure-impact relationships. It is also sufficiently detailed to be appropriate for use during the further characterisation phase, but using more detailed data.

- A Guidance Document and Summary Risk Assessment Sheet which provide information on how to carry out the assessment of risks to turloughs from abstraction entitled *WFD Pressures and Impact Methodology Guidance on Groundwater Risk Assessment Sheet GWDTERA2a - Risk to Groundwater Dependant Terrestrial Ecosystems from Abstraction* is alo included in Appendix 3. This is a more generalised risk assessment used for all GWDTEs. It is designed to be used during the initial characterisation phase.

4.3 Risk Assessment Approach and Scope

4.3.1 Risk Assessment Approach

The risk assessment approach adopted for turloughs is consistent with the approach being used in other areas of the WFD in Ireland. It uses the basic risk analysis model of:

The risk assessment approach for turloughs sits within the larger groundwater characterisation framework, which starts with the delineation of water bodies and the identification of any associated Ground Water Dependant Terrestrial Ecosystems (GWDTEs). The risk approach outlined below and illusratated in Figure 4.1 and Table 4.1, is that adopted under the UK Technical Advisory Group (TAG) Guidance, and has been adapted for turlough risk assessment. This approach is consistent with other risk assessment procedures undertaken for other ground water related risk assessments in Ireland.

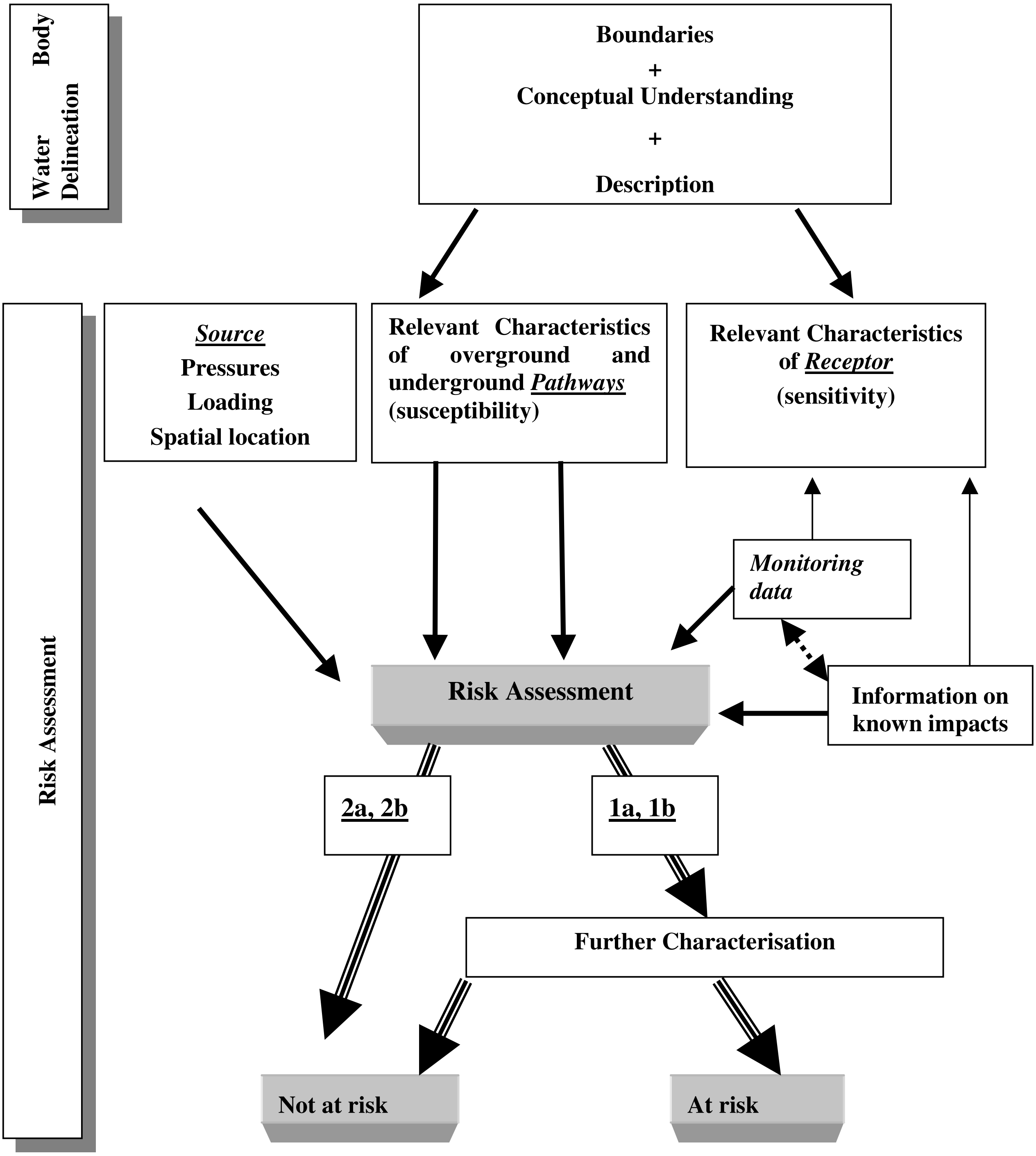


Figure 4.1 Summary of risk assessment approach (from UK TAG Guidance)

The risk assessment procedure takes the form of a risk matrix. This approach has been used successfully in other areas of groundwater protection in Ireland, specifically in the development of groundwater protection schemes (Department of the Environment and Local Government *et al.*,1999). The assessment procedure combines predictive risk assessment and knowledge of actual impacts. The predictive risk assessment is based on an assessment of the relationship between source (pressure), pathway and receptor (turlough). The resultant predictive risk category arising from this process can then be modified by existing data on known impacts. The risk assessment categories that result from the procedure are as follows (Table 4.1):

Table 4.1 Risk Categories Resulting from Assessment Procedure

WFD Risk Category	Reporting Category
1. Water bodies at risk of failing to achieve an environmental objective	**(1.a) Water bodies at significant risk** *Note: Identifies water bodies for which consideration of appropriate measures can start as soon as practical*
	(1.b) Water bodies probably at significant risk but for which further information will be needed to make sure this view is correct *Note: Focus for more detailed risk assessments (including, where necessary, further characterisation) aimed at determining whether or not the water bodies in this category are at significant risk in time for the publication of the interim overview of significant water management issues in 2007*
2. Water bodies not at risk of failing to achieve an environmental objective	**(2.a & 2.b) Water bodies not at significant risk on the basis of available information** **(2.a) Water bodies for which confidence in the available information being comprehensive and reliable is low** *Note: Work on these water bodies will be focused on appropriately improving the quality of information on pressures and their likely environmental effects in time for the second pressures and impact analysis due to be completed in 2013*
	(2.b) Water bodies for which confidence in the available information being comprehensive and reliable is high *Note: Review for the next pressures and impacts analysis report in 2013 to identify any significant changes in the situation*

Each risk category has actions arising from that designation. In addition to the actions outlined in the chart above, turlough which are designated as being in the 1a or 1b *at risk* categories will have their catchments designated as new water bodies.

4.3.2 Risk Assessment Scope

4.3.2.1 Protected Areas

Only turloughs which are designated under the Habitats (92/43/EEC) or the Birds Directive (79/409/EEC) as Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) are subject to the risk assessment procedure. As such they are designated as Protected Areas under Article 5 of the WFD.

4.3.2.2 Environmental Objectives

This particular risk assessment (GWDTE2a) is designed to achieve the combined objectives of the WFD and HD in terms of water quality. In accordance with Article 5, the objectives for SACS and SPAs are the attainment of objectives and standards set out under the Habitats (92/43/EEC) or the Birds Directive (79/409/EEC). The most important of these is the achievement of Favourable Conservation Status. The standards which the turlough waters and contributing ground and surface waters will be required to met in order to achieve Good Conservation Status, have been devised in consultation with the National Parks and Wildlife Service (NPWS) (who form part of the GWWG Turloughs Sub-Committee) and who are the competent authority with respect to the Habitats and Birds Directives. In general terms the environmental objectives for groundwaters require the protection of dependant terrestrial ecosystems from *significant damage.* Impairment of conservation objectives could be regarded as constituting significant damage (Horizontal Guidance on Wetlands, 2003). This requirement may be effective in protecting turlough GWDTEs which are not designated under the Habitats or Birds directive, but are considered to have national or local conservation value. Additional turloughs are likely to be designated as Natural Heritage Areas (NHAs) under the Wildlife (Amendment) Act, 2000 (Jim Ryan, NPWS, pers. comm.). In addition Article 6 of the WFD would not preclude such nationally designated sites from being included in the register of protected sites, which would ensure that they would be subject to the WFD Characterisation procedure.

The risk assessment is designed to assess risk to both the SAC and SPA elements of the site in one procedure, although impacts on the SPA are difficult to predict due to a lack of baseline data. No specific reference is made to birds, but the attainment of good conservation status for the turlough habitat as a whole will ensure that the site will remain at favourable conservation status for birds also. It is also acknowledged that high P values may in fact result in an increase in bird numbers (Aine O'Connor, NPWS pers. comm.) at a turlough site. The aim is to provide a conservation balance, which results in the attainment of good conservation status for the widest range of ecologies.

4.3.3 Pressures

4.3.3.1 Pressures Assessed

Pressures which are included in the current risk assessment procedure are diffuse low mobility, inorganic phosphorus (PO_4), and abstraction.

Abstraction

The procedure for assessment of risk from abstraction is common for all GWDTEs. Abstraction pressure consisting of general abstraction in the catchment area/and or from wells in the immediate vicinity of the GWDTEs (turloughs) boundary or by arterial drainage is assessed. The carrying out of arterial drainage is not current policy, however it has occurred in the past and caused significant changes to turlough morphology and hydrology. For the purposes of any further characterisation, a more turlough specific risk assessment procedure will need to be carried out in order to more accurately assess the significance of abstraction related pressures.

Other Pressures

Other pressures do exist, as outlined in the *WFD Pressures and Impact Methodology Guidance on Groundwater Risk Assessment Sheet GWDTE2a - Risk to Turloughs from Phosphate*, but their significance is difficult to assess, due to a lack of data and/or understanding of the pressure impact relationship. IMPRESS Guidance for the Analysis of Pressures and Impacts in accordance with the WFD states that a key requirement of the impacts and pressures analysis will be to identify future activities in the RBD which may put at risk the achievement of WFD objectives. Specifically that:

The analysis of pressures and impacts must identify:

-Existing pressures and impacts (identified in 2004) likely to be causing the status of water to be lower than good;

-How pressures would be likely to develop prior to 20015, in ways which would cause a failure to achieve good status if appropriate programmes of measure were not designated and implemented.

The IMPRESS Guidance recognises that the initial characterisation process (deadline 2004) may rely heavily on existing data, but it also emphasises the need for Member States to ensure that this can be refined and supplemented during the river basin planning cycle(s) which follow. This should allow for work to be carried out to develop a better understanding of the pressure impact relationship for pressures not included in this assessment and for filling of data gaps.

4.3.3.2 Pressure Location

The area to be included in the risk analysis is the catchment of the turlough. The predictive risk assessment refers only to risk from pressures occurring within the turlough catchment, and not to pressures occurring within the actual turlough basin (the boundaries of which are defined by NPWS, based on work carried out by Goodwillie (1992, and subsequent unpublished work for NPWS). Turloughs over 10ha: Vegetation survey and evaluation. A report for the National Parks and Wildlife Service and the Office of Public Works., and which in the case of SAC/SPA complexes, will be different from the boundary of the full complex). Pressures confined to the turlough basin are regulated by the National Parks and Wildlife Service (NPWS) under the Habitats Directive. Policy instruments complementary to the Habitats Directive, and which can aid in the regulation of these pressures include, the Rural Environmental Protection Schemes, Farm Management Plans and co-operation with other government agencies. Adjustments to the predictive risk category based on available impact data can be based on data from inside the turlough, or from the catchment. In the first case by comparing turlough water Total P values with set thresholds, and for the catchment by comparing groundwater MRP values with set thresholds.

4.4 Guidance Documents

The risk assessment procedure for *WFD Pressures and Impact Methodology Guidance on Groundwater Risk Assessment Sheet GWDTE2a - Risk to Turloughs from Phosphate* was developed by the WFD Co-Ordination Group, Groundwater Working Group- Turloughs Sub-Committee, listed in the guidance document.

The risk assessment procedure for *WFD Pressures and Impact Methodology Guidance on Groundwater Risk Assessment Sheet - Risk to Groundwater Dependant Terrestrial Ecosystems from Abstraction* was developed by the WFD Co-ordination Group, Groundwater Working Group.

These guidance documents are given in Appendix 3.

5 Further Work

For the purposes of further characterisation, a more turlough specific risk assessment procedure will need to be developed in order to more accurately assess the significance of abstraction related pressures.

Other pressures do exist, as outlined in the guidance and in section 4, but their significance is difficult to assess, due to a lack of data and/or understanding of the pressure impact relationship. Guidance for the Analysis of Pressures and Impacts in accordance with the WFD (IMPRESS) document states that a key requirement of the impacts and pressures analysis will be to identify future activities in the RBD which may put at risk the achievement of WFD objectives. Specifically that:

The analysis of pressures and impacts must identify:

- *Existing pressures and impacts (identified in 2004) likely to be causing the status of water to be lower than good;*
- *How pressures would be likely to develop prior to 2015, in ways which would cause a failure to achieve good status if appropriate programmes of measure were not designated and implemented.*

The IMPRESS Guidance recognises that the initial characterisation process may rely heavily on existing data, but it also emphasises the need for Member States to ensure that this can be refined and supplemented during the river basin planning cycle(s) which follow. This should allow for work to be carried out to develop a better understanding of the pressure-impact relationship for pressures not included in this assessment and for filling of data gaps. Determination of 'catchment areas' for turloughs remains a key component in determining pressures and impacts. While these are currently evaluated using topographic data often with individual knowledge of hydrogeological conditions, it is well known that hydrological catchment areas may well not conform the topographical determination.

5.1.1 Issues and limitations

The main issues and limitations in terms of data are the following:

- A lack of spatially and temporally co-incident data on the different turlough characteristics.
- Lack of long-run plant ecological (plant and invertebrate) mapping or monitoring.
- Lack of long-run hydrological data for a large number of turloughs and no data for over half of protected sites.
- Sporadic data on invertebrate populations.
- An almost complete absence of water chemistry measurements (all existing measurements, with the exception of one turlough, are single,'grab' samples from one year, data which is of extremely limited value).
- A complete absence of any type of data for a large proportion of turloughs.

These data limitations restricts analysis of relationships between different turlough characteristics and inhibits analysis of trends and of impact of pressures.

Specific work: Extending the work on the relationship between flood duration and the distribution of vegetation communites, using the methodology described in section 3.2.2 is clearly needed for the purposes of validation of the reported realtionships. Flood depth-duration related to vegetation distribution applied to other turloughs would confirm or, indeed, may change the conclusions reached in this report. 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. It potentially requires re-mapping of site vegetation , in order to provide contemporaneous hydrological and vegetation information.

More importantly, given the nature of the karstic fissure systems in which turloughs occur, the determination of catchment areas is likely to lead to a new basis for evaluation, based on the hydrological response of a given system rather than (or combined with) the topographical/hydrogeological determination as currently practised. Re-interpreation of turlough hydrological responses is required with this objective ib mind.

6 Conclusions

To reiterate, the objectives of this desk study were to:

- Develop a risk assessment framework for groundwater dependent 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.

6.1 *Results*

The results of this project succeeded in developing a risk-based framework for groundwater dependent habitats as exemplified by turloughs in karst systems. The risk-based assessment is dependent upon catchment area to the turlough and the pressures represented by landuse on that catchment area and mainly involve nutrient levels (N and P), and suspended sediment loads. The impact is represented by ecological requirements, which, in turn, have been related to hydrological indicators by the work of this study. While the correlation between hydrology and ecology has been made, the assessment of 'damage', or ecological risk, as a result of *changes* to the hydrology, could not be directly determined for lack of available data.

Specifically, under 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
- Decide if there is a significant risk of failing to achieve these water related standards and objectives
- Take measures to address any such significant risk.

It was not the objective of this work to establish such standards but to provide a methodology under which the relevant risks could be determined and, eventually, through which unacceptable impacts could be determined. In this sense, 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 were 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 and 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 as represented by the risk assessment guidance presented in this report.
- 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 is available.
- 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.

6.2 *Analysis of outcomes*

A principal outcome of this work has been the gathering and collation of available data relating to turlough hydrogeology and its incorporation into an accessible data base. The second outcome has been to establish the feasibility of defining hydrological indicators (ie 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 allocated species communities (as represented by an integrated Ellenberg wetness index) and duration of inundation at a particular turlough level/water depth. 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 for the turlough hydrograph of stage. 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. Nevertheless, particularly on the basis of defined trophic status, as indicated by NPWS and the comprehensive vegetation surveys done by Goodwillie, there is a strong indication from this study that such ecological parameters *can* be developed (as indicated by the species communities developed here) and thus risk assessment for turloughs put on a scientific basis. 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 of stage time series 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.

On the basis of 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. Steep recessions and quick response times indicate more eutrophic conditions. 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. In short, the recession constant correlates well with trophic status and the related Ellenburg index : eutrophic conditions have recession constants above 10 as measured here and relate to Ellenburg indices for drier species communities.

A key conclusion is that hydrological measures (such as water level recession constants) have been identified 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 a determination of 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 anthropegenic influences. The precise measure of 'significant' requires a better understanding of ecological response.

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APPENDIX 1

MAPS OF TURLOUGH VEGETATION (GOODWILLIE) SUPERPOSED ON TOPOGRAPHIC SURVEYS

and

FLOOD INUNDATION FREQUENCY CURVES

Summary of Goodwillie (1992) Vegetation Survey (of turloughs over 10ha)

Introduction

Goodwillie surveyed 61 turloughs, resulting in the identification of a total of 32 recognisable vegetation communities. Communites from among this set of 32 are distributed and repeated across these 61 turloughs.

Plant communities Approach

The work concentrated on the identification of plant communities. The purpose of the study was to discover both the flora and the habitat variation of the turloughs, and plant communities are better indicators of habitat variation than the presence or absence of individual species. This approach involved the identification of distinct communities or grouping of species which are repeated in different turloughs, presumably under the same habitat conditions. Identification of communities is based on the presence of indicator or characteristic species which grow under a narrow range of habitat conditions. These less widely occurring species can be distinguished from ubiquitous species which occur from top to bottom of the turlough. These ubiquitous species along with the fact that communities appear to merge gradually into one another can make plant communities difficult to identify.

Methodology

The one-year time frame of the survey did not allow for the traditional phytosociological approach of identifying communities by ordering mechanically a mass of releves into those that most resemble one another. Therefore, at the outset, a conspectus of possible communities was drawn up from the literature. These possible communities were checked at the beginning of the field survey, modified to fit with the existing vegetation and some more were added.

This process resulted in the identification of 32 recognisable vegetation units. The majority are based on phytosociological communities, but some are defined more by their physiognomy, e.g. flooded limestone pavement, tall sedge stands, or by certain conditions of land management e.g. *Lolium* grassland (artificially re-seeded)

These communities were used in further field survey, and with the aid of aerial photographs (1972), to record variation within each turlough and to map the vegetation pattern. In addition information on qualitative hydrology, morphology, substrate, man-induce modification and presence of wintering birds and/or breeding waders was recorded. Goodwillie (1992) includes descriptions of each community, along with as lists of the characteristic species used to identify vegetation communities and species occurring in the communities.

The 32 communities are divided into a series of one to twelve vegetation divisions, generally occurring in the same relative positions, with increasing depth in the turlough basin. The communities are numbered according to their division. At any level, the communities were roughly split according to their trophic status. A – eutrophic, B - less enriched and often less managed types, C – oligotrophic calcareous, D and E – peaty types and W – those containing woody species. At certain levels there seem to be gaps in the eutrophic-oligotrophic range and no appropriate community was recognised. See table below for communities and their relative positions and trophic status.

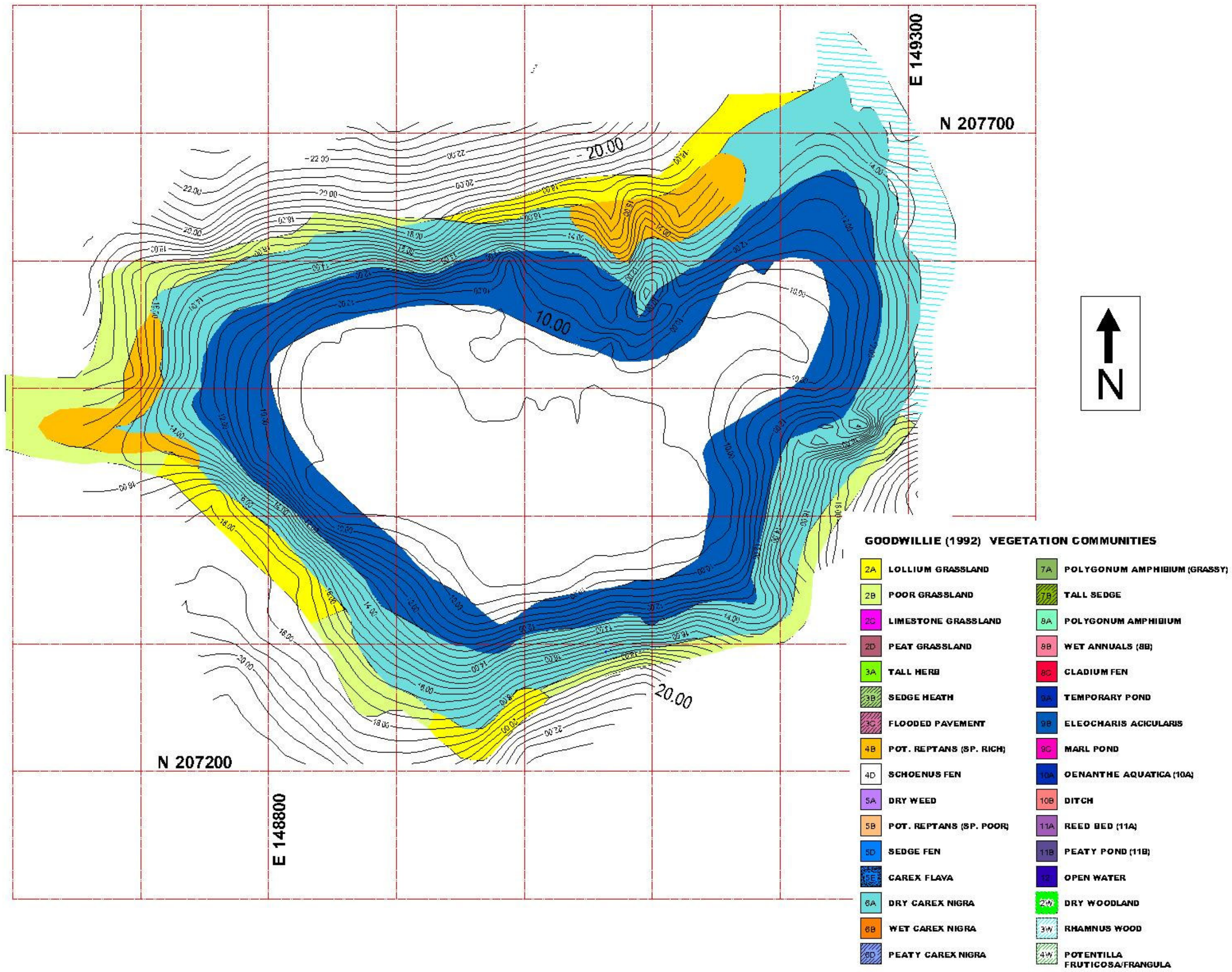
Goodwillie (1992) vegetation communities recorded in turloughs

Increasing depth in turlough basin 2-12, trophic status A-D. Woodlands are recorded as a separate division

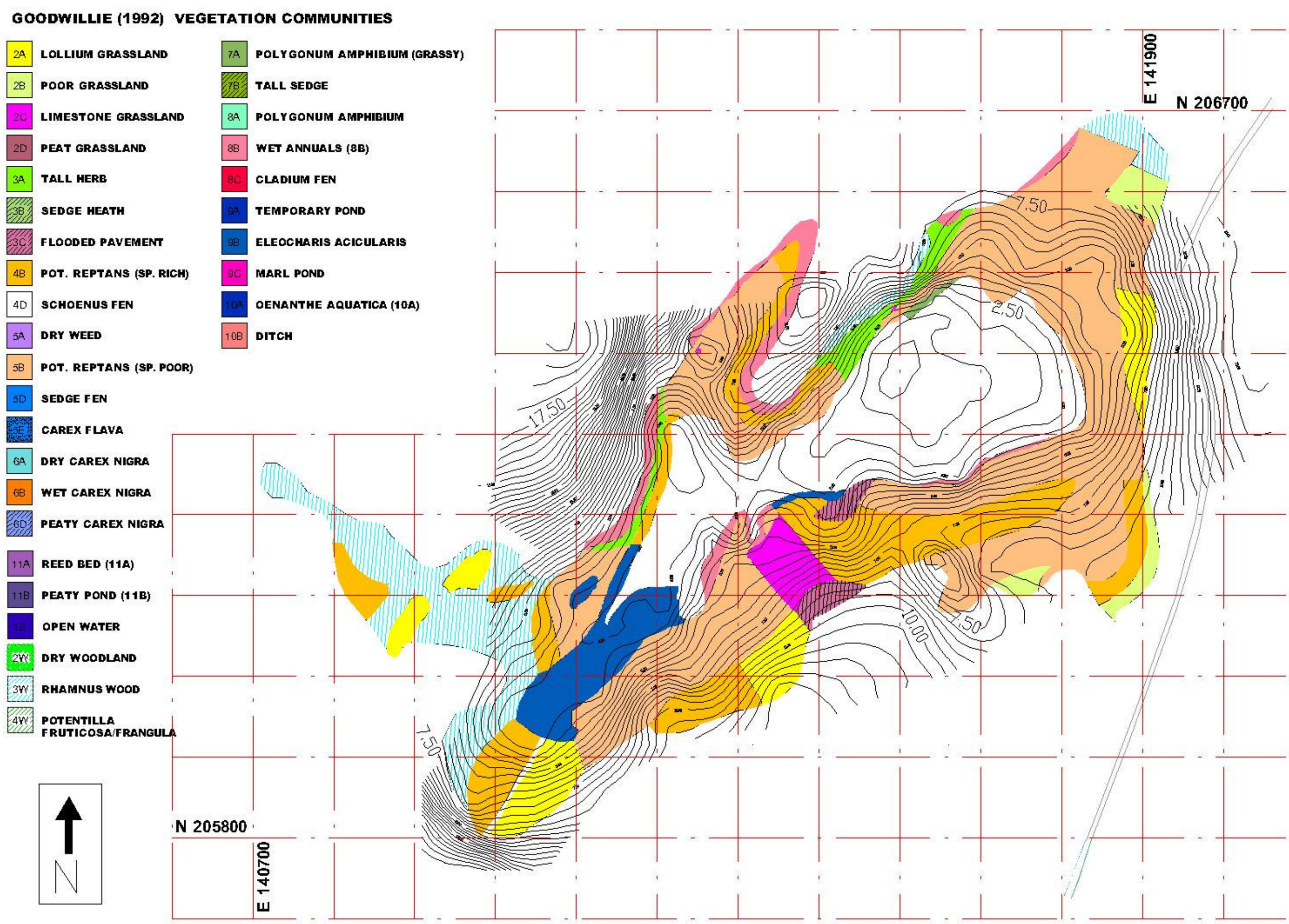
Eutrophic		**Mesotrophic**		**Oligotrophic**						**Woodland**	
				Calcareous		*Peaty*					
2A	Lolium grassland	2B	Poor grassland	2C	Limestone grassland	2D	Peat grassland			2W	Dry Woodland
3A	Tall herb	3B	Sedge heath	3C	Flooded pavement					3W	Rhamnus wood
		4B	Potentilla reptans (sp. rich)			4D	Schoenus fen			4W	Potentilla fruticosa/Frangul
5A	Dry weed	5B	Pot. reptans (sp. poor)			5D	Sedge fen	5E	Carex flavia		
6A	Dry Carex Nigra	6B	Wet Carex Nigra			6D	Peaty Carex nigra				
7A	Polygonum amphibium (grassy)	7B	Tall sedge								
8A	Polygonum amphibium	8B	Wet annuals	8C	Cladium fen						
9A	Temporary pond	9B	Eleocharis acicularis	9C	Marl pond						
10A	Oenanthe aquatica	10B	Ditch								
11A	Reed bed	11B	Peaty pond								
12	Open water										

Goodwillie Vegetation Maps with Topographic Detail

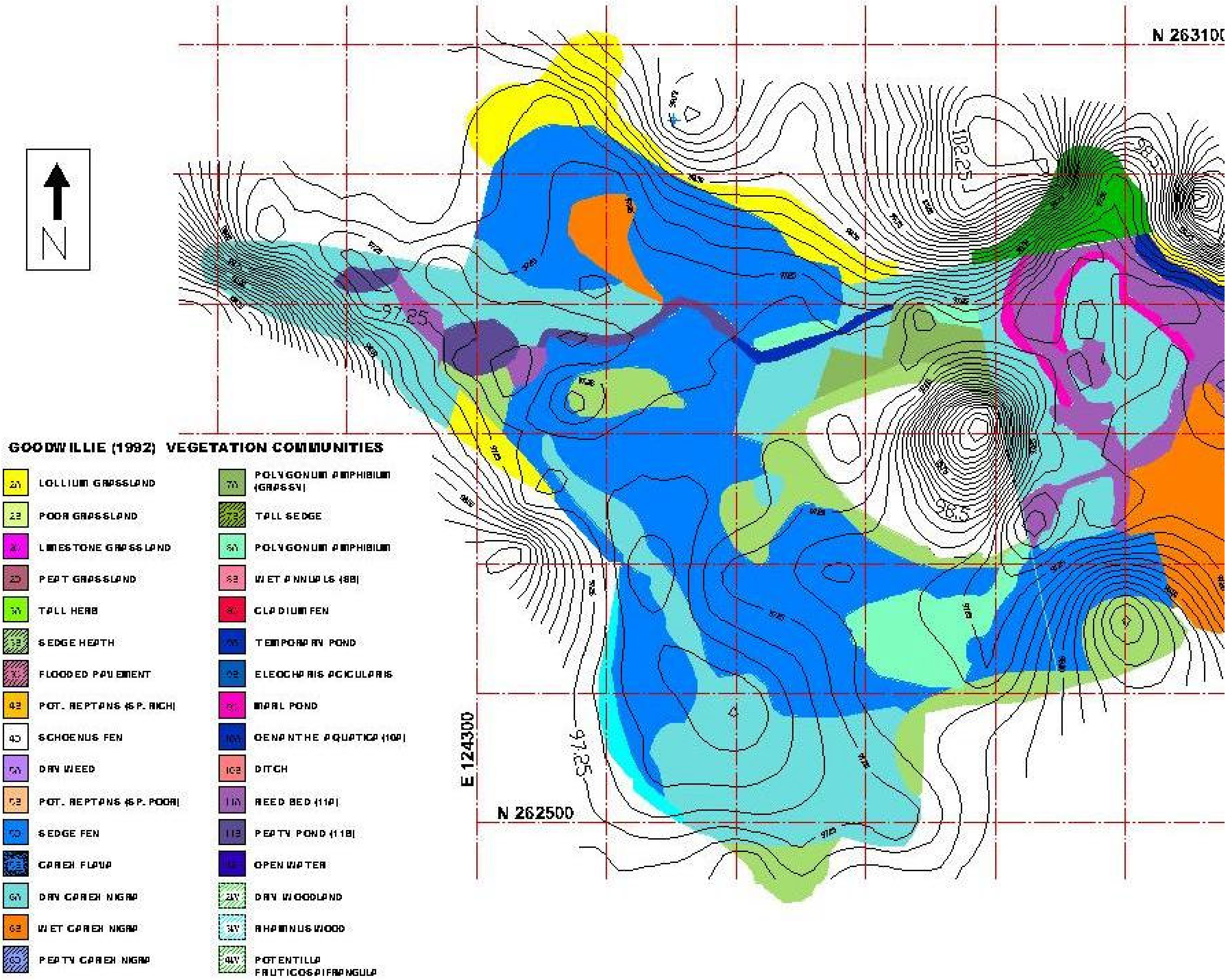
(elevations in metres O.D. Malin)



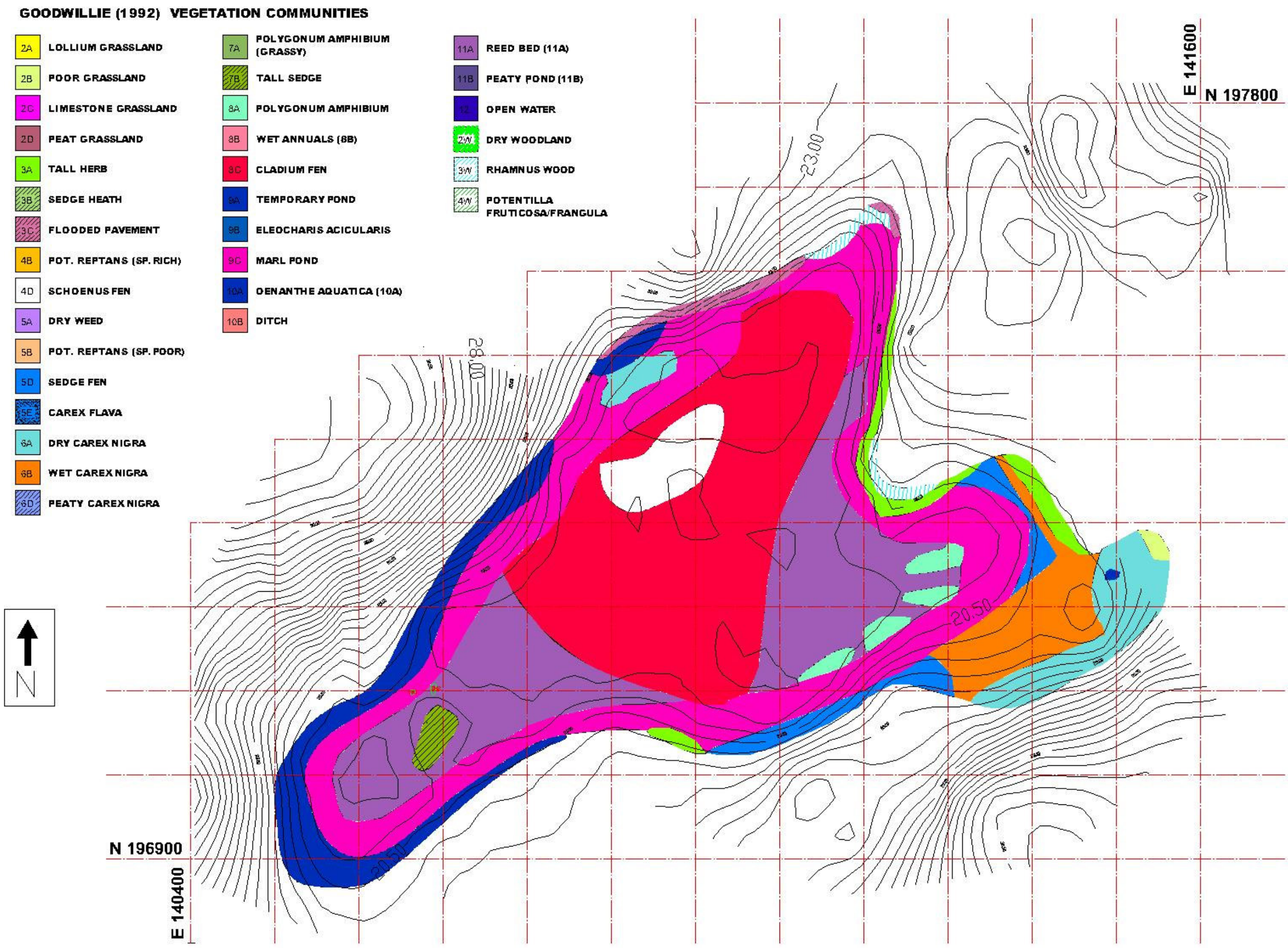
Lough Coy Goodwillie (1992) vegetation communities and topographic contours (m O.D. Malin)



Caherglassaun Goodwillie (1992) vegetation communities and topographic contours (m O.D. Malin)

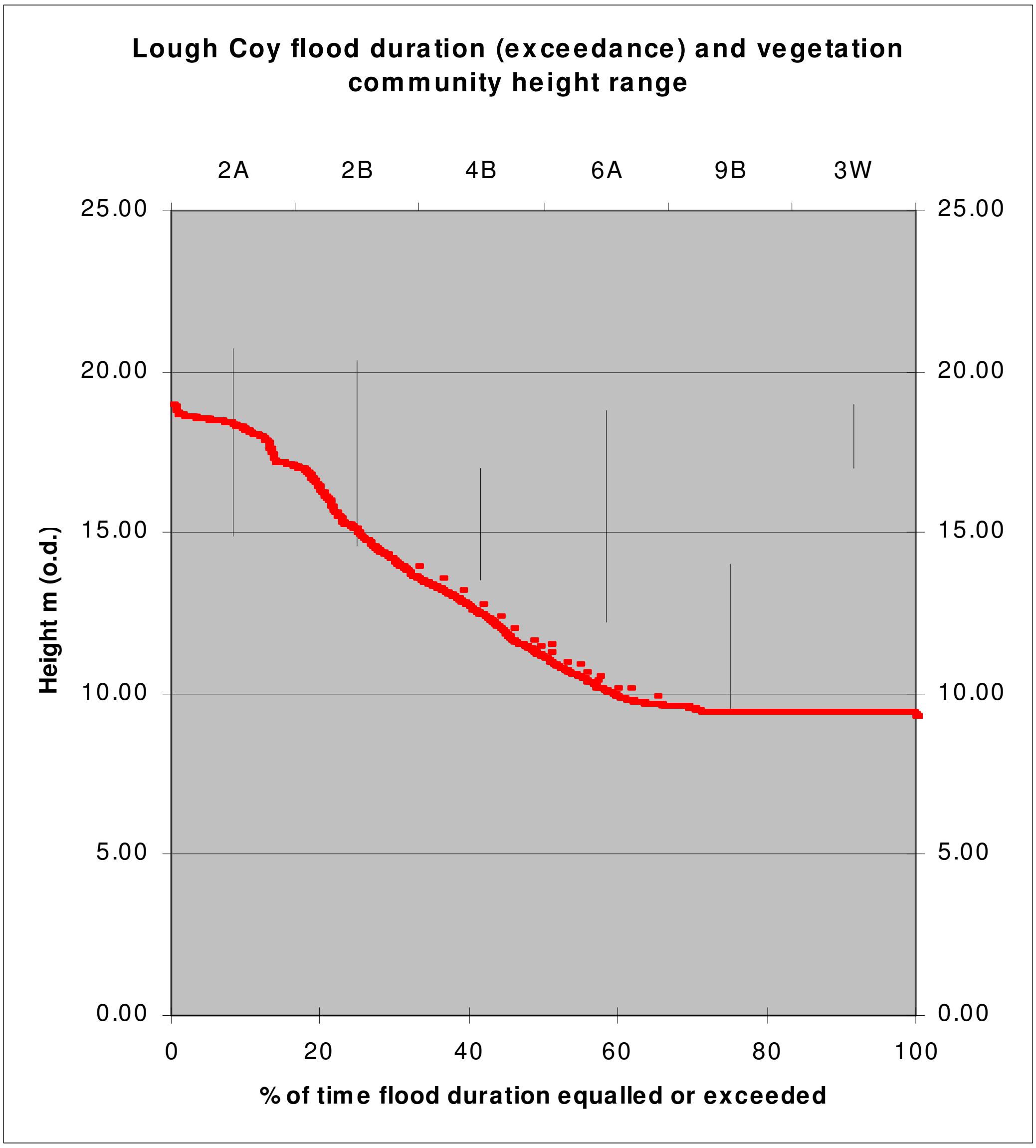


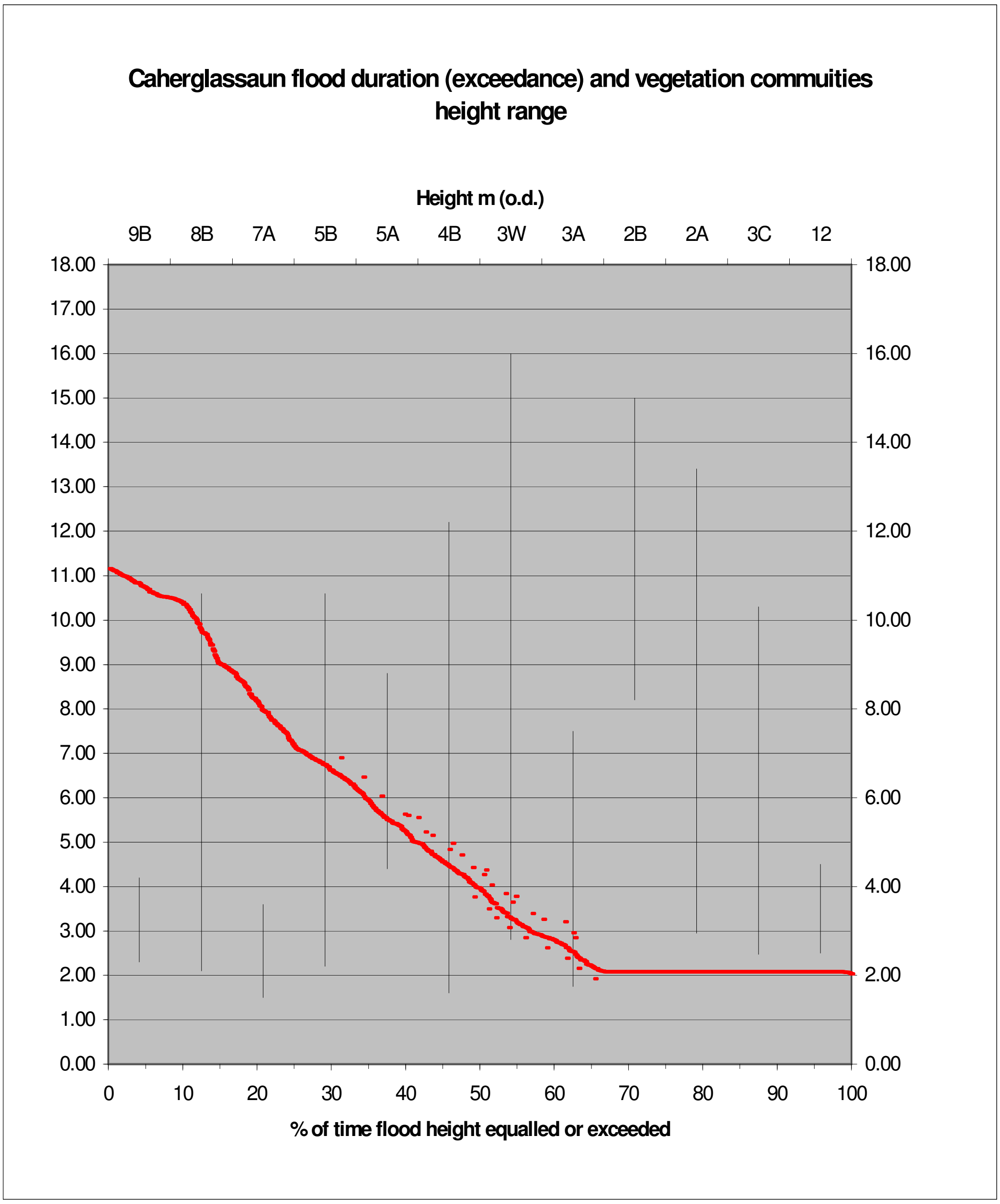
Skealoghan Goodwillie (1992) vegetation communities and topographic contours (m O.D. Malin)



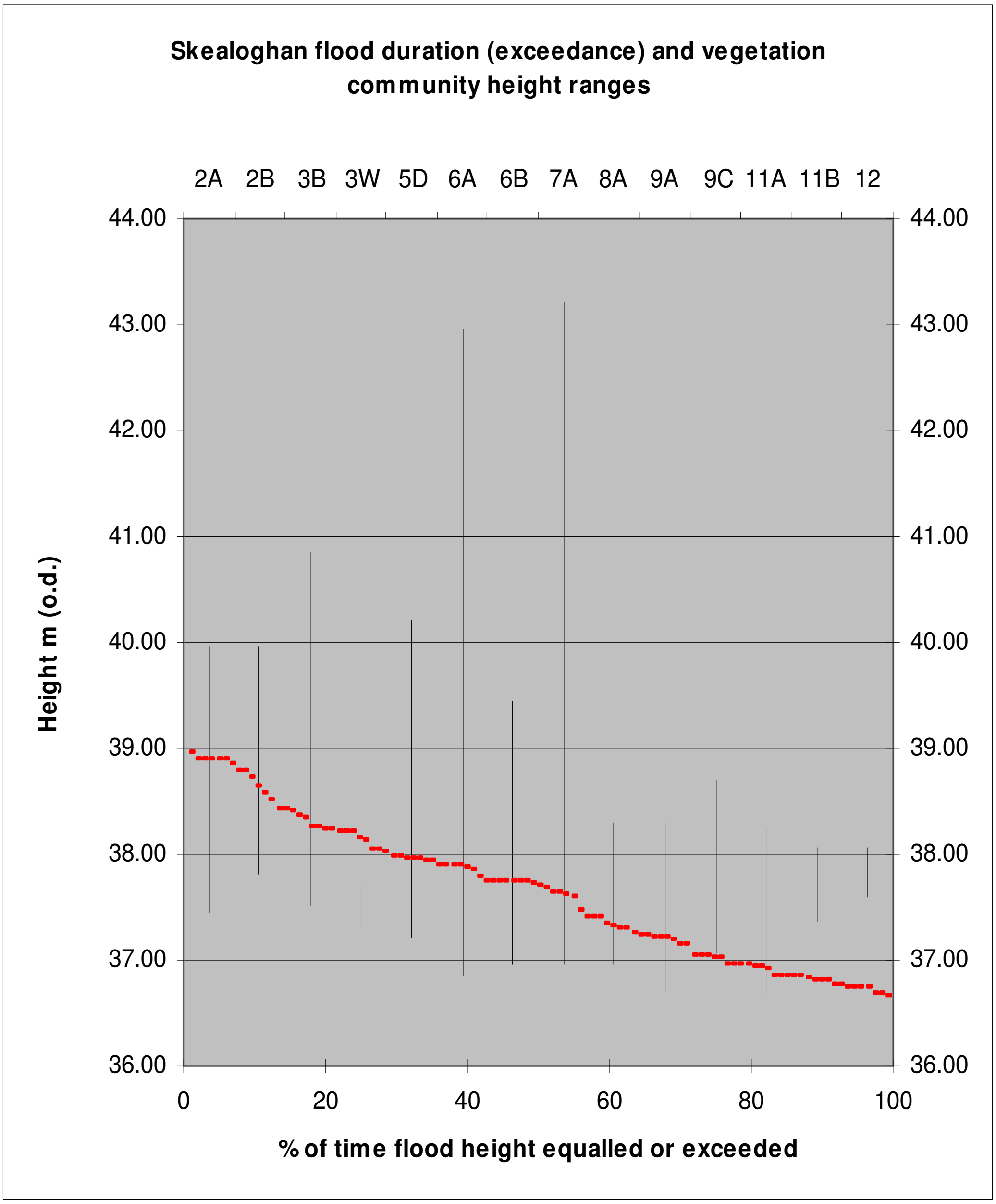
Termon South Goodwillie (1992) vegetation communities and topographic contours (m O.D. Malin)

Combined Flood Duration (Exceedance) curves and Vegetation Range Graphs

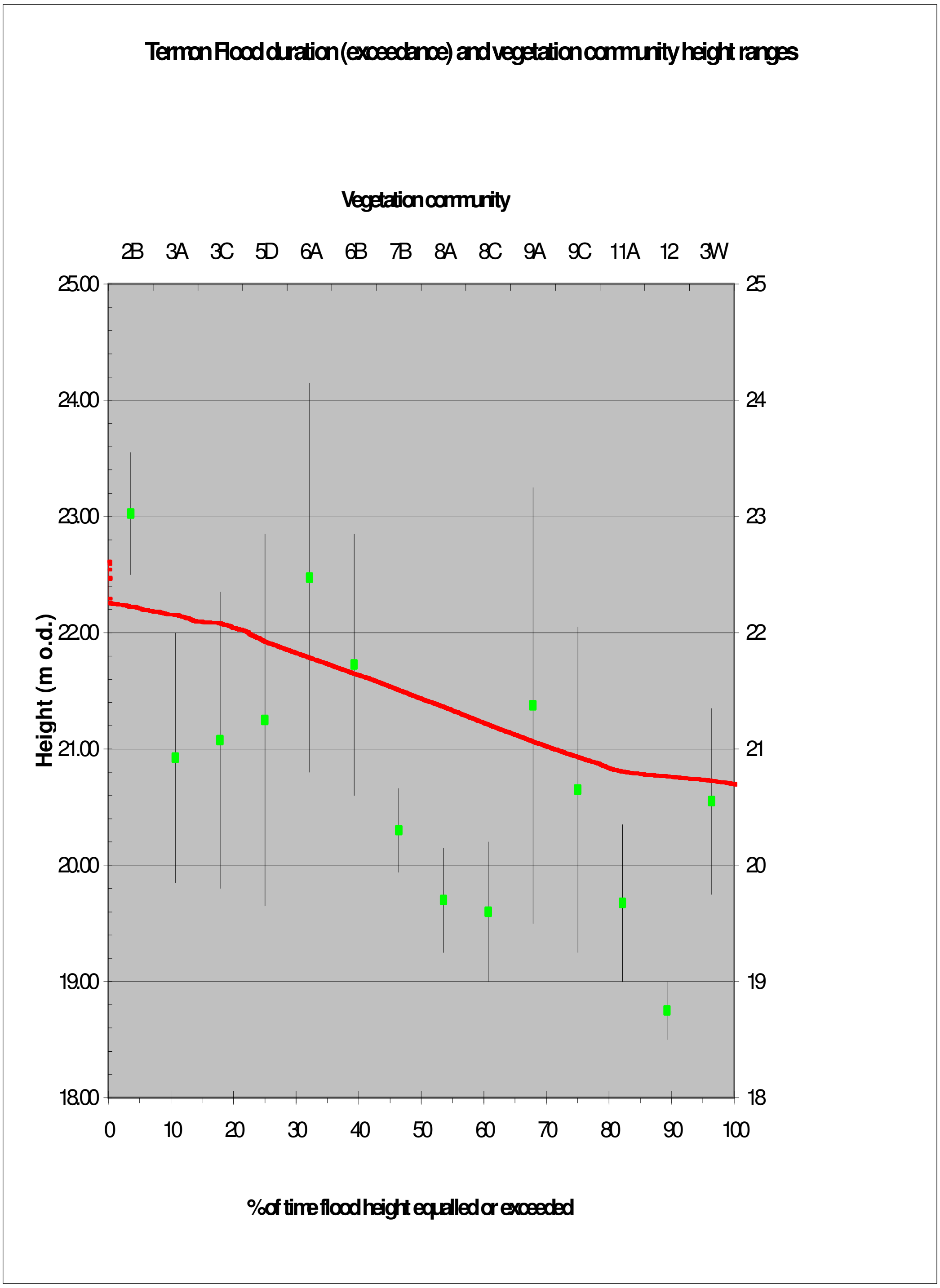




Caherglassaun flood duration (exceedance) and vegetation commuities height range
Height m (o.d.)
9B
8B
7A
5B
5A
4B
3W
3A
2B
2A
3C
12
18.00
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
10
20
30
40
50
60
70
80
90
100
% of time flood height equalled or exceeded



Skealoghan flood duration (exceedance) and vegetation community height ranges
2A 2B 3B 3W 5D 6A 6B 7A 8A 9A 9C 11A 11B 12
44.00
43.00
42.00
41.00
40.00
39.00
38.00
37.00
36.00
Height m (o.d.)
0 20 40 60 80 100
% of time flood height equalled or exceeded



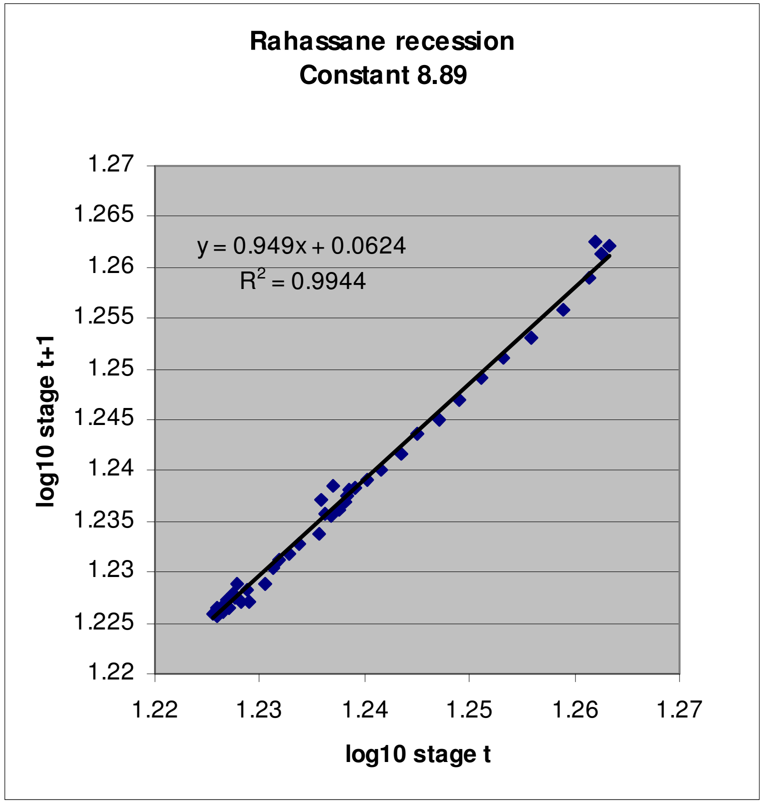
Termon Flood duration (exceedance) and vegetation community height ranges
Vegetation community
2B 3A 3C 5D 6A 6B 7B 8A 8C 9A 9C 11A 12 3W
Height (m o.d.)
25.00 24.00 23.00 22.00 21.00 20.00 19.00 18.00
25 24 23 22 21 20 19 18
0 10 20 30 40 50 60 70 80 90 100
% of time flood height equalled or exceeded

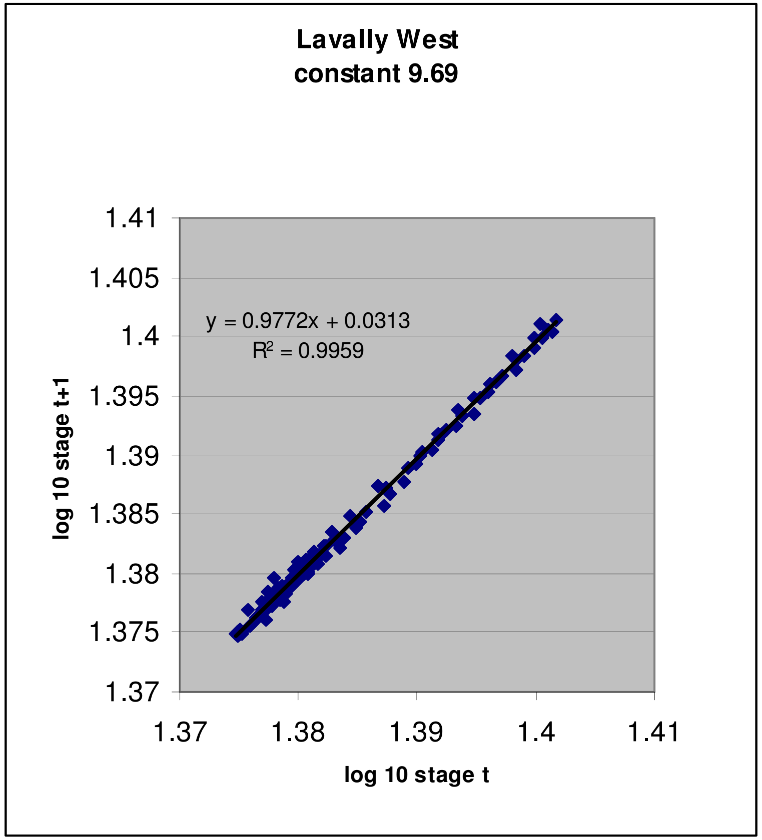
APPENDIX 2

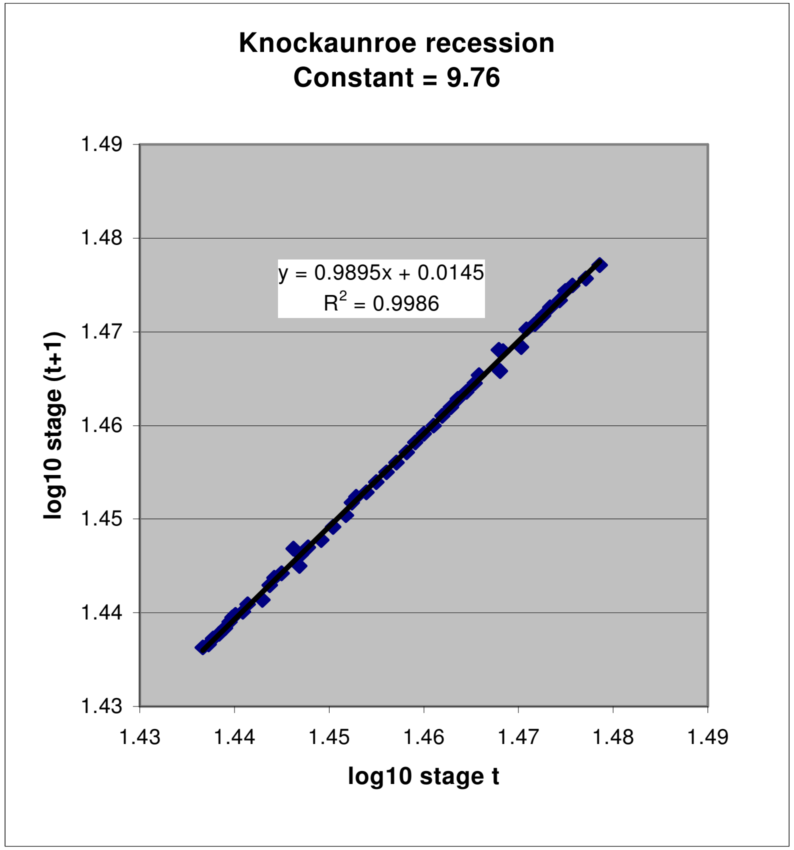
SUMMARY OF TURLOUGH STAGE AND RECESSION DAT

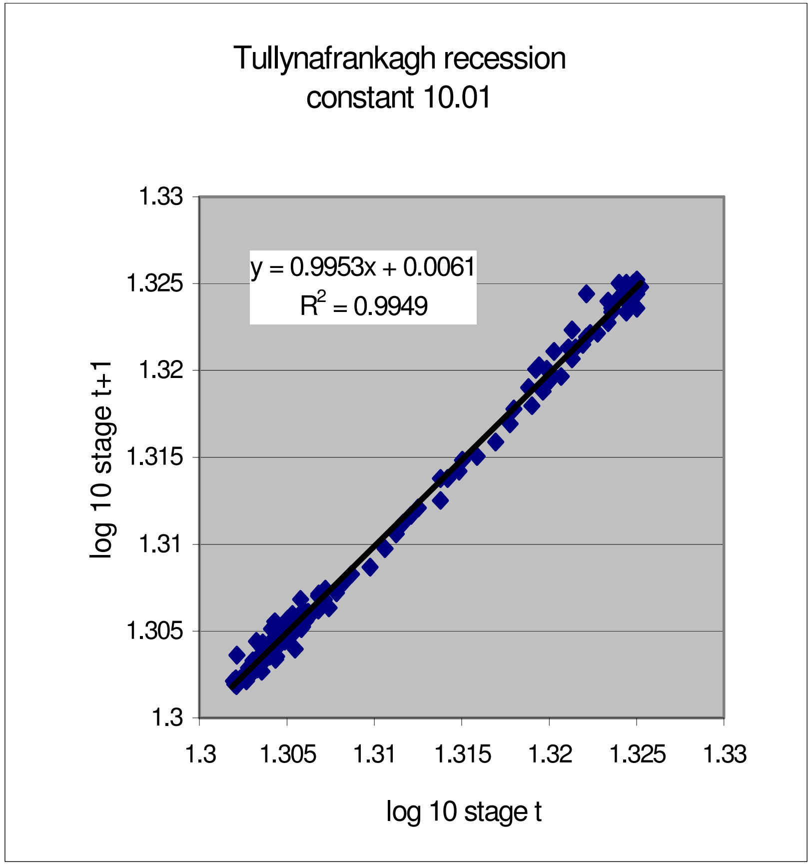
Summary of stage and recession data

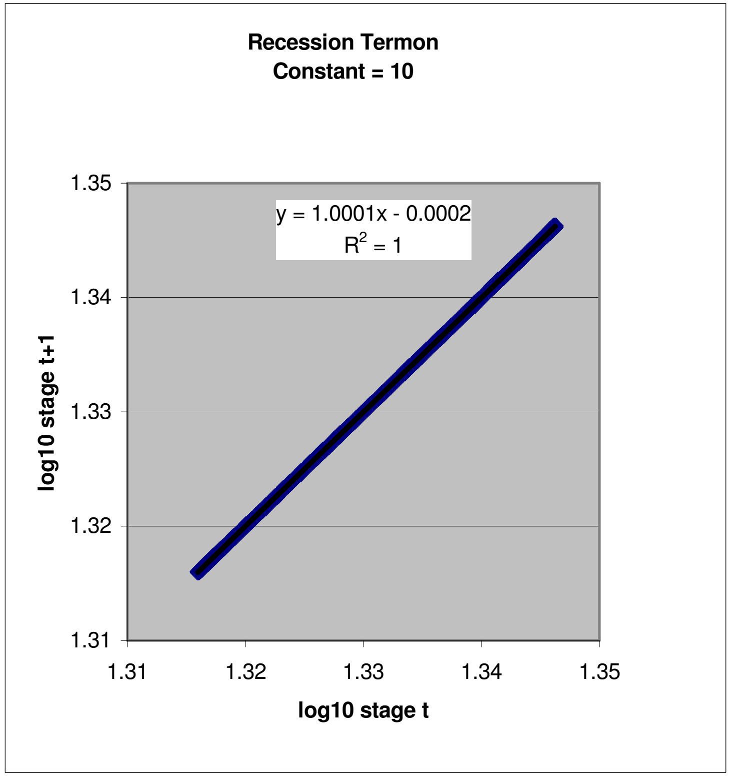
Turlough	recession constant	max. stage m (o.d.)	min. stage m (o.d.)	maximum stage (cm)	stage data	recession dates	Data source (stage, recession)
Rahassane	8.89	19.48	16.51	297	1/9/'71-31/1/'01 daily	20/3/1984-9/5/1982	OPW
Lavally West	9.69	25.22	23.697	152	15/3/'02-16/8/'02	15/3/'02-22/5/'02	Johnston, P. (TCD)
Knockaunroe	9.76	30.59	25.43	516	24/1/'92-31/7/'96 daily (with gaps)	05/04/1995-25/05/1995	Drew, D. (1995)
Termon	10	22.61	20.69	192	12/02/1996-29/09/1996 daily	15/04/1990-20/07/1996	Southern Water Global (1997)
Tullynafrankagh	10.01	21.025	19.89	116	18/2/'02-4/8/'02 quarter hourly	19/3/'02-17/4/'02	Johnston, P. (TCD)
Carranavoodaun	10.02	24.67	23.66	101	9/10/'03-7/9/'04 hourly	12/02/2004-09/03/2004	Johnston, P. (TCD)
Hawkhill	10.25	9.23	5.16	407	18/2/'02-4/8/'02 quarter hourly	10/04/2002-27/04/2002	Johnston, P. (TCD)
Skealoghan	10.72	38.96	36.66	230	22/05/01-18/05/04 approx.weekly	26/03/2002-23/4/2002	Moran, J. (NUIG)
Coy	10.8	18.96	9.28	968	23/10/'99-8/10/'03 daily large gaps summer	16/03/2002 - 9/04/2002	Johnston, P. (TCD)
Coole	11.19	12.39	2.9	949	1/10/ '03- 30/9/'04 hourly	21/03/2002-26/04/2002	Johnston, P. (TCD)
Caherglassaun	11.28	11.16	2.03	913	23/10/'99-'8/10/03 daily large gaps summer	21/03/2002-26/04/2002	Johnston, P. (TCD)
Blackrock	11.67	26.02	13.03	1299	3/1/'01-8/10/'03 daily large gaps summer	04/01/2001-23/01/2001	Johnston, P. (TCD)


Rahassane recession
Constant 8.89
y = 0.949x + 0.0624
R2 = 0.9944
log10 stage t+1
log10 stage t
1.27
1.265
1.26
1.255
1.25
1.245
1.24
1.235
1.23
1.225
1.22
1.22
1.23
1.24
1.25
1.26
1.27

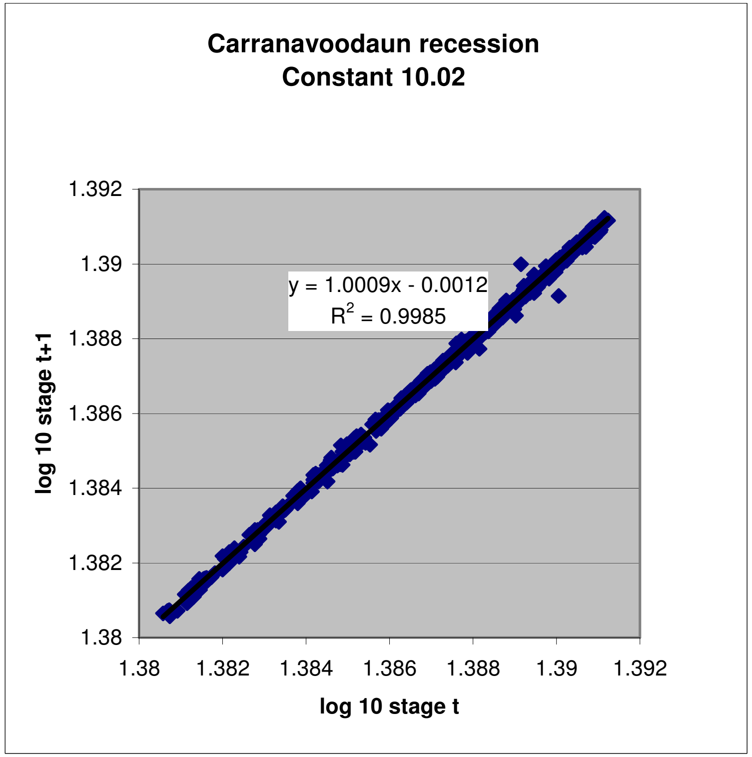

Lavally West
constant 9.69
y = 0.9772x + 0.0313
R2 = 0.9959
log 10 stage t+1
log 10 stage t
1.41
1.405
1.4
1.395
1.39
1.385
1.38
1.375
1.37
1.37
1.38
1.39
1.4
1.41


Knockaunroe recession
Constant = 9.76
y = 0.9895x + 0.0145
R2 = 0.9986
1.49
1.48
1.47
1.46
1.45
1.44
1.43
log10 stage (t+1)
1.43
1.44
1.45
1.46
1.47
1.48
1.49
log10 stage t

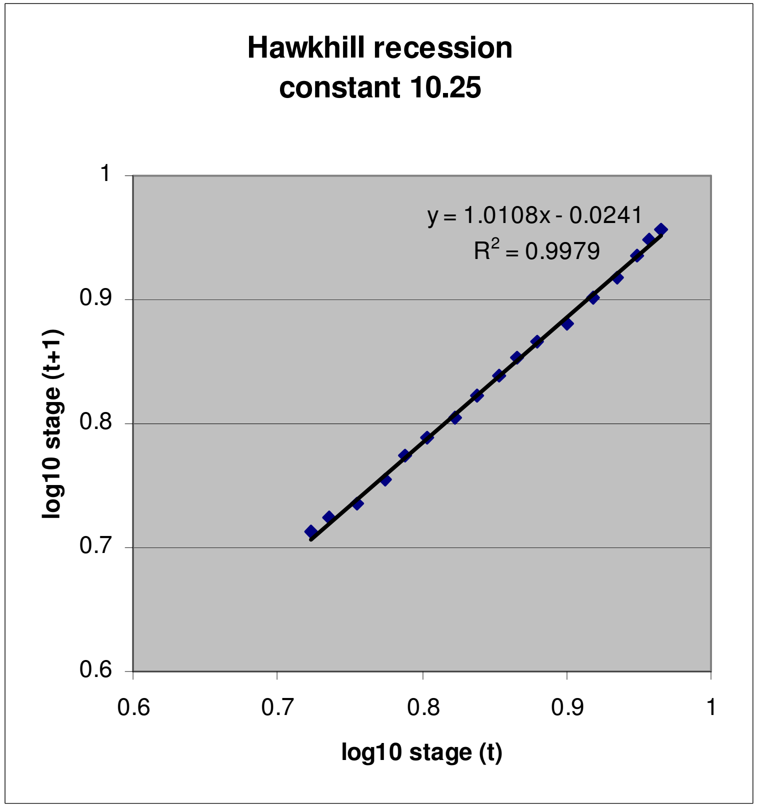

Tullynafrankagh recession
constant 10.01
y = 0.9953x + 0.0061
R2 = 0.9949
1.33
1.325
1.32
1.315
1.31
1.305
1.3
log 10 stage t+1
1.3
1.305
1.31
1.315
1.32
1.325
1.33
log 10 stage t

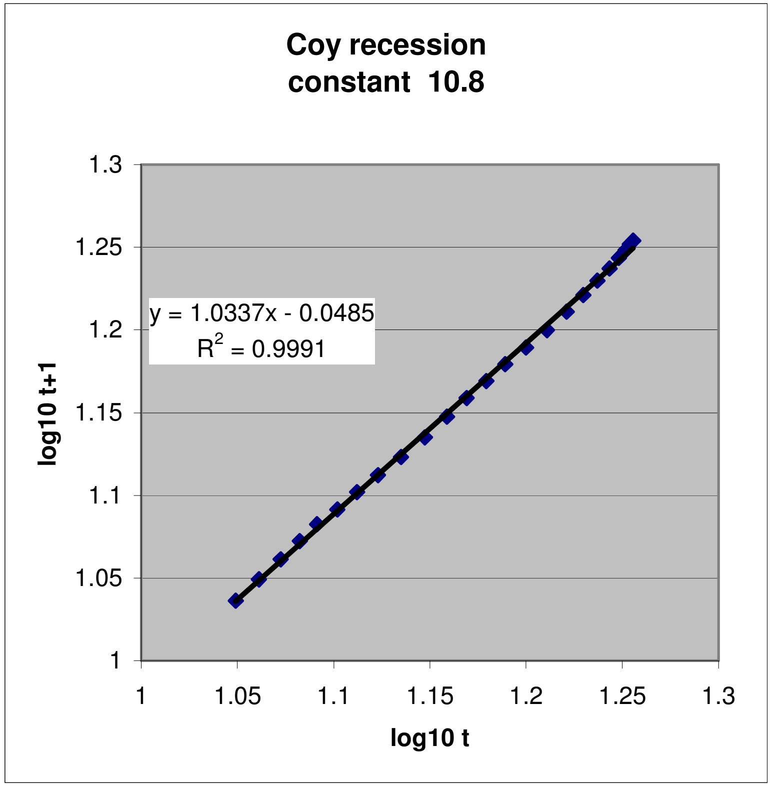


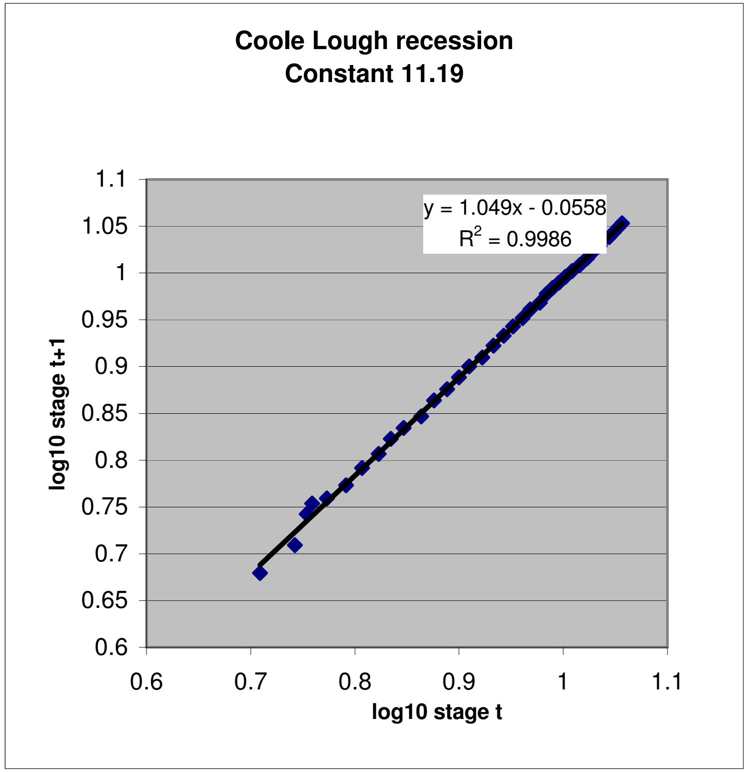
Recession Termon
Constant = 10
y = 1.0001x - 0.0002
R2 = 1
log10 stage t+1
log10 stage t
1.31
1.32
1.33
1.34
1.35

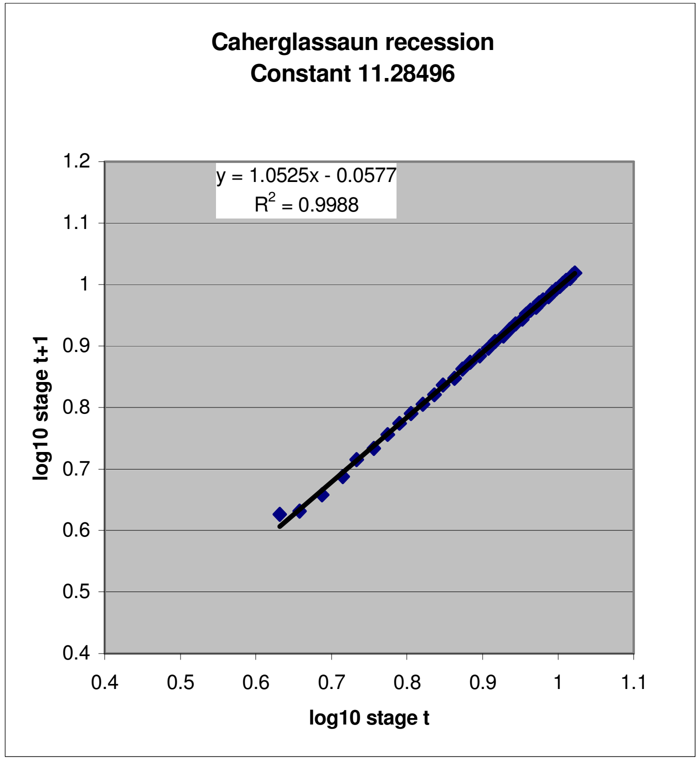


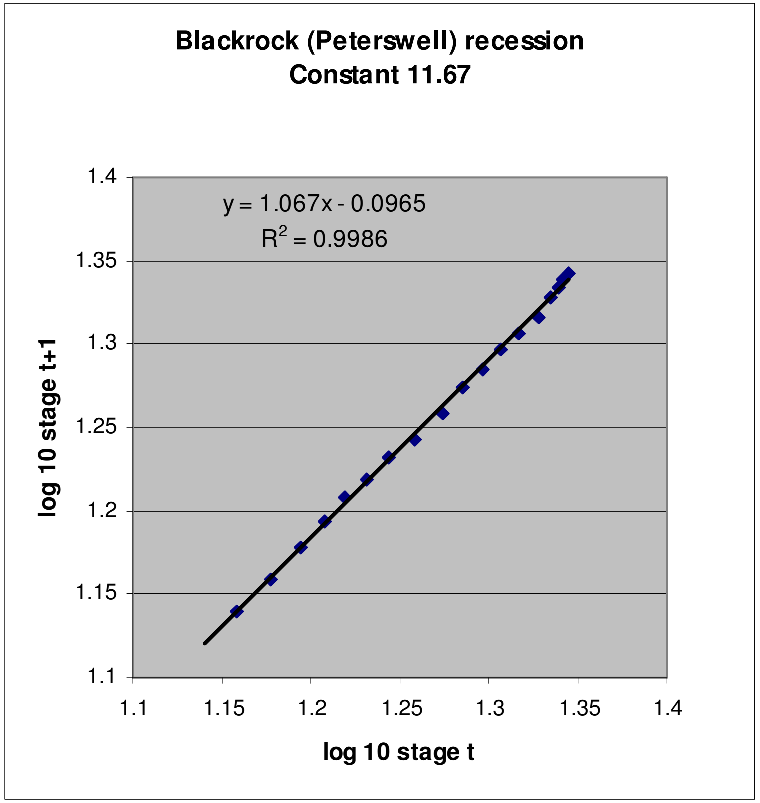
Carranavoodaun recession
Constant 10.02
y = 1.0009x - 0.0012
R2 = 0.9985
log 10 stage t+1
log 10 stage t
1.38
1.382
1.384
1.386
1.388
1.39
1.392


Hawkhill recession
constant 10.25
y = 1.0108x - 0.0241
R2 = 0.9979
log10 stage (t+1)
1
0.9
0.8
0.7
0.6
0.6
0.7
0.8
0.9
1
log10 stage (t)


Coy recession
constant 10.8
y = 1.0337x - 0.0485
R2 = 0.9991
log10 t+1
1.3
1.25
1.2
1.15
1.1
1.05
1
1
1.05
1.1
1.15
1.2
1.25
1.3
log10 t


Coole Lough recession
Constant 11.19
y = 1.049x - 0.0558
R2 = 0.9986
log10 stage t+1
log10 stage t
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.6
0.7
0.8
0.9
1
1.1


Caherglassaun recession
Constant 11.28496
y = 1.0525x - 0.0577
R2 = 0.9988
log10 stage t+1
log10 stage t
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1



Blackrock (Peterswell) recession
Constant 11.67
y = 1.067x - 0.0965
R2 = 0.9986
log 10 stage t+1
log 10 stage t
1.1
1.15
1.2
1.25
1.3
1.35
1.4

APPENDIX 3

GUIDANCE DOCUMENT

WATER FRAMEWORK DIRECTIVE – KARST WORKING GROUP

GUIDANCE ON THE ASSESSMENT OF PRESSURES AND IMPACTS ON GROUNDWATER DEPENDENT TERRESTRIAL ECOSYSTEMS

Risk Assessment GWDTERA2a - Turloughs

WFD Pressures and Impacts Assessment Methodology

GUIDANCE ON THE ASSESSMENT OF PRESSURES AND IMPACTS ON GROUNDWATER DEPENDENT TERRESTRIAL ECOSYSTEMS

Risk Assessment Sheet GWDTERA2a – Turloughs

Paper by the Working Group on Groundwater
Sub-committee on Turloughs

Guidance document no. GW9

This is a guidance paper on the application of an **Assessment of Pressures and Impacts on Groundwater Dependent Terrestrial Ecosystems – Turloughs Methodology**. It documents the principles to be adopted by River Basin Districts and authorities responsible for implementing the Water Framework Directive in Ireland.

REVISION CONTROL TABLE

Status	Approved by National Technical Co-ordination Group	WFD Requirement	Relevant EU Reporting Sheets	Date
Final	March 2005	Pressures and Impacts	N/A	December 2004

Contents

Tables

WFD Pressures and Impacts Assessment Methodology

Guidance on Groundwater Risk Assessment Sheet GWDTERA2a – Risk to Turloughs from Phosphate

Paper by the Working Group on Groundwater: Sub-committee on Turloughs

1 Purpose

This paper sets out guidance on the assessment of risk to turlough GWDTEs from phosphate (risk assessment sheet GWDTERA2a – see Section 8).

2 Background

2.1 Definition of a Turlough

A turlough is defined as:

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.

A relationship exists between the water quality, the flooding regime, the morphology and the substrate of a turlough, and the composition and distribution of its plant and animal communities. Turloughs exhibit a specific range of hydrological, morphological and substrate parameters which are associated with a characteristic range of ecologies.

2.2 Conservation Framework

Turloughs are listed as priority habitats under Annex I of the EU Habitats Directive (92/43/EEC) and, as such, a proportion have been designated as Special Areas of Conservation (SACs). A number of turloughs are also designated as Special Protection Areas (SPAs) for their bird communities under the EU Birds Directive (79/409/EEC). Additional turloughs are likely to be designated as Natural Heritage Areas (NHAs) under the Wildlife (Amendment) Act, 2000. In order to achieve good status under the Water Framework Directive, turloughs must meet their Habitats Directive (HD) objective of "favourable conservation status" where it is dependent on their water needs. This particular risk assessment (GWDTE2a) is designed to achieve the combined objectives of the WFD and HD in terms of water quality. For the purpose of the Article 5 Report, it has been decided to report only on turloughs designated as part of the Natura 2000 Network (i.e. SACs and SPAs). Therefore, only designated turloughs will be subject to the risk assessment procedure before March 22nd 2005. A total of 43 SACs have been designated for turloughs. Some SACs contain more than one turlough within their boundaries, bringing the total number of turloughs designated under the HD to 70 (Table 4). Five of the 70 turloughs are also designated as SPAs (Table 5).

2.3 Distribution

Work carried out by Coxon (1987), suggests that turlough distribution in Ireland is most strongly controlled by the occurrence of well-bedded, pure limestone (they occur almost exclusively on the Dinantian pure bedded limestone rock unit), with turlough frequency also related to degree of karstification. The presence of a thick cover of subsoil is also potentially a controlling factor on turlough distribution. Turloughs designated as SACs/SPAs occur in Counties Donegal, Sligo, Roscommon, Mayo, Galway, Longford, Clare and Kilkenny.

3 Data Limitations

3.1 Data Availability

Whilst a considerable amount of ecological data is available on turloughs (Goodwillie, 1992; Southern Water Global, 1997), data on invertebrates are sporadic. Relevant hydrological data are sparse, however useful summaries are found in Coxon (1986) and Southern Water Global (1997). For instance, a minimum of one year's hydrological data is considered necessary for characterisation of the turlough flood regime and catchment delineation – this is seldom available. Information derived from water tracing experiments within the turlough catchments is also sporadic. There is an almost complete absence of water chemistry data, including phosphorus, for the turlough sites.

Impact data are sporadic – usually applying only to the immediate turlough basin and not to the catchment – and are not consistent, often reflecting the focus of the visiting ecologist rather than being part of a systematic survey.

3.2 State of Knowledge

The link between the ecology of the turloughs, their hydrogeological characteristics and management, has not yet been quantified adequately. This is partly a result of the lack of long-term spatially co-incident data for both aspects. Consequently, there is a high degree of uncertainty associated with predicting impacts from pressures.

4 Risk Assessment

4.1 Risk Assessment Approach

The approach is summarised in risk assessment sheet GWDTERA2a, which is given in Section 8. It involves the following:

1. Delineation of the catchment area of the turlough;
2. Evaluation of pathway susceptibility, using aquifer, soil and vulnerability maps;
3. Estimating impact potential by combining pathway susceptibility with pressure magnitude;
4. Predicting the risk category by combining the receptor sensitivity with the proportion of the turlough catchment with high and moderate impact potential;
5. Adjusting the predicted risk category using available impact data.

4.2 Assessment Area

The area to be included in the risk analysis is the catchment of the turlough. The predictive risk assessment refers only to risk from pressures occurring within the turlough catchment, and not to pressures occurring within the turlough depression. The boundaries of the turlough flooded areas have been supplied by NPWS, based on Goodwillie's vegetation maps. These boundaries will differ from the SAC/SPA boundaries, particularly in large SAC/SPA complexes. Pressures confined to the turlough depression are regulated by the National Parks and Wildlife Service (NPWS) under the Habitats Directive. Available impact data from the turlough depression (Total P/NPWS qualitative impact assessment), or from the catchment (groundwater MRP) enable the predictive risk category to be adjusted.

4.3 Turlough Catchment Delineation

4.3.1 Catchment types

Turlough catchments can be divided into two broad types, based primarily on the depth of groundwater flow and the nature of the karst through which it flows: a) those where groundwater flow is shallow and completely within the epikarst, and b) those where groundwater flows deeper through a more complex karst system.

4.3.1.1 Epikarst Flow Catchments

These catchments are developed within areas where groundwater flows in the weathered upper, approximately 2-5 m, zone, in the epikarst. The epikarst is characterised by having a high proportion of solutionally enlarged fissures (joints, bedding planes, faults and fractures). Storage capacity is low. Locally, groundwater flow may be more-or-less completely disconnected from groundwater flowing at deeper levels within the karst system. Generally, flow will be across the turlough, driven by the hydraulic gradient of the water table, of which the turlough is a surface expression. Recharge is via direct infiltration of rainfall to the outcropping karst. In some instances, recharge reaches the epikarst after percolating through deposits of sand/gravel.

4.3.1.2 Mixed Flow System Catchments

In these catchments, groundwater flows through different types of karst and at different depths. Below the epikarst (exceptionally as low as 40-50 m below ground in the Gort area), major caves and conduits can act as linear flow paths (“conduit karst”). Smaller conduits and solutionally-enlarged fissures and bedding planes transmit groundwater through a less concentrated network (“diffuse karst”). Both types of karst can support very large groundwater flows. In the zone just below the epikarst, the karst may be characterised by major conduits, collapse structures and zones of solutionally-enlarged fissures and bedding planes at depth of 10-15 m below ground level. This type of karstification usually occurs in restricted areas, is typically associated with indirect recharge of the aquifer by surface waters, and can support very large flows.

Groundwater flow in a turlough catchment may flow in one or a combination of these karst types. The flow systems operate as a continuum, with flow being transferred vertically and laterally between them. Shallow, epikarstic groundwater flow will frequently occur in combination (and hydraulic connectivity) with the deeper flow systems.

Recharge to the aquifer occurs through a variety of mechanisms, including:

- Direct recharge via the epikarst, which then transmits water to deeper elements of the flow system;
- Indirect recharge from losing and/or sinking streams;
- Indirect recharge from surface waters generated on non-karst aquifers and which sink in the karstic catchment.

4.3.2 Identifying the catchment type

4.3.2.1 Epikarst Flow Catchments

- Stage recession constants measured for epikarstic turloughs range from 9.76 to 10.72, i.e., they have relatively slow emptying characteristics. It is likely that a recession constant above 10.75 indicates that the turlough is not fed solely by shallow groundwater flowing through epikarst.
- Shallow, epikarstic, systems are characterised by a trophic sensitivity of 1, i.e., an ultra-oligotrophic status, unless their trophic status has been impacted by enrichment. (See Section 4.5.3). Risk category based on predictive risk assessment).

- If the literature and recession constant indicate that a catchment is of this type, but the trophic sensitivity is >1, then the turlough may already be impacted by enrichment. Existing impact data should be consulted to confirm this.

4.3.2.2 Mixed Flow System Catchments

- In a catchment with a trophic sensitivity of 2 or 3 (and which is not an impacted epikarst catchment), most groundwater flows beneath the epikarst in diffuse and/or conduit karst limestones.
- It is probable, though not certain, that a turlough with a trophic sensitivity of 2 has a catchment dominated flow in the transition zone between the epikarst and deeper karstification that is characterised by collapsed conduits.
- A recession constant >11 and/or a trophic sensitivity of 3 (in a non-impacted turlough) is likely to indicate the presence of deep level conduit/diffuse groundwater flow. The catchment may also have groundwater flowing in the epikarst in connectivity with the other flow pathways, though the proportion of flow contributed by the epikarst will be small relatively, resulting in the groundwater flowing through conduit/diffuse karst dominating the trophic sensitivity.

There is a number of probable reasons for the differences in trophic sensitivities between the epikarst (shallow) and mixed (deeper) flow system types. Catchments with mixed flow systems are generally larger, and the flow rates and volumes of throughput are greater, which would tend to deliver more P to the turlough depression, although dilution rates would be higher. In addition, the transport of sediments and, consequently, particulate P would be favoured by the presence of conduit flow.

4.3.3 Methods for delineating the catchment area

4.3.3.1 Epikarst Flow Catchments

- Available reference materials relating to the hydrology/hydrogeology of the catchment were consulted.
- The catchment of the turlough was identified. This exercise was not trivial, since, although groundwater flow is unconfined, the local topography cannot necessarily be used to delineate groundwater divides. This is because topographic highs may be caused by subsoil deposits rather than be underlain by bedrock. Therefore, what is termed the "bedrock catchment" was delineated, using boundaries that are considered to reflect bedrock topography. (Where there is a high degree of confidence that topography is caused by bedrock elevation variations, the local topography can be used to define the catchment directly.) These turloughs are in shallow depressions so may also act as a radial focus for near-surface direct runoff.
- Using water table maps and/or borehole information, the direction of the hydraulic gradient within the bedrock (or topographic) catchment was identified or estimated. The fact that water tables in karst may be discontinuous should be taken into account.
- A catchment area on the up-gradient side of the turlough was delineated within the bedrock (or topographic) catchment previously defined. The top of the up-gradient catchment coincides with the bedrock (or topographic) catchment; the sides are delineated using flow lines, accounting for their curvature due to the 'drain' effect on groundwater flow of the turlough. Hence, the catchment is fan-shaped, albeit with some account being taken of adjacent near-surface radial runoff.

4.3.3.2 Mixed Flow System Catchments

- Available reference materials relating to the hydrology/hydrogeology of the catchment were consulted.
- A water table map of the area, if available, was used, or estimated if sufficient data were available. A sufficiently detailed water table map should identify zones of high conductivity, owing to the influence on the shape of the water table that high permeability zones have. The fact that water

tables in karst may be discontinuous, particularly where flow is concentrated in conduits/conduit-type zones, was taken into account.

- Groundwater flow directions were identified.
- Existing tracing data were used to identify conduits/high transmissivity zones, and the connections between these areas of high conductivity. (It may be necessary to undertake additional tracing.)
- Surface waters that may contribute to groundwater flow, their sources and any sinks were identified. Their overground and underground catchments were included in the overall catchment.
- Where surface waters generated on non-karstic and/or non-limestone aquifers sink in the karstic catchment of the turlough, the full catchment of those surface waters were included in the turlough catchment (i.e., the catchment extends onto the non-karstic areas).
- Groundwater contributing to the turlough via the epikarst was identified. The epikarst catchment was identified with reference to the methodology outlined in Section 4.3.3.1, above.

4.3.4 Additional Issues

4.3.4.1 Partially-contributing catchments

The issue of partially-contributing catchments was addressed in the cases where information was available. Partially-contributing catchments are catchments which contribute a proportion (but not all) of their flow to another turlough under specific stage conditions. In general, the issue of changing catchment boundaries (areas of contribution) with varying stage conditions was addressed wherever possible.

4.3.4.2 Overlapping catchments

Where turlough catchments overlap, then the catchment of each turlough was extended to include the other.

4.4 Pressures

4.4.1 Phosphorus

There is a significant threat to turloughs through enrichment with phosphorus from a variety of diffuse and point sources. Phosphorus in turlough water influences plant species composition, abundance and productivity. Invertebrate species are impacted via the primary producers.

4.4.2 Abstraction

Abstraction within the catchment, local abstractions and arterial drainage can impact upon the quantitative status of the turlough and, consequently, upon the species composition, distribution and extent of plant and invertebrate communities. Over-wintering and breeding bird populations may also be impacted. Risk Assessment from these pressures is carried out as a general assessment for GWDTEs, including turloughs. Further details are given in Groundwater Risk Assessment Sheet GWDTERA1.

4.4.3 Other Pressures

Other pressures have been identified, but not included due to lack of knowledge of the pressure-impact relationship and/or lack of data. These may be added to the risk assessment at a later date when appropriate information becomes available. These include:

- Changes in water chemistry due to urban (including road) run-off.
- Changes in flood regime due to urban (including road) run-off, and climate change.
- Changes in turlough ecology as a result of increased nitrogen concentrations (including the possibility of nitrogen limitation in the aquatic phase of turloughs).

- Changes in turlough ecology resulting from increased sediment loads due to changes or intensification in land use. Sediment can reduce water clarity and, consequently, impact on aquatic photosynthesis and productivity as well as having physical impacts on plants and animals. Sediment can also increase nutrient concentrations, through particulate forms of P.

4.5 Risk Assessment Matrix for Phosphorus

4.5.1 Pathway Susceptibility

The pathway susceptibility matrix is given below. Further information on the risk assessment approach is given in Guidance report GW8 (Methodology for Risk Characterisation of Ireland's Groundwater) (GWWG, 2004).

<table>
<tr><td colspan="4" rowspan="2">PATHWAY SUSCEPTIBILITY</td><td colspan="4">Flow Regime (horizontal pathway)</td></tr>
<tr><td colspan="2">Karst aquifers</td><td colspan="2">Poorly productive and/or fissured aquifers contributing surface waters to turlough catchment**</td></tr>
<tr><td rowspan="6">Vertical pathway</td><td colspan="3">Soil & contributing area</td><td>Dry soil</td><td>Wet soil</td><td><50 m from a stream channel</td><td>Remainder of catchment area</td></tr>
<tr><td rowspan="5">Vulnerability</td><td rowspan="2">Extreme</td><td>0-1 m soil & subsoil</td><td>E</td><td>E</td><td rowspan="5">E</td><td rowspan="5">H</td></tr>
<tr><td>1-3 m soil subsoil</td><td>E</td><td>E*</td></tr>
<tr><td colspan="2">High</td><td colspan="2">M</td></tr>
<tr><td colspan="2">Moderate</td><td colspan="2">L</td></tr>
<tr><td colspan="2">Low</td><td colspan="2">L</td></tr>
</table>

n/a = not applicable
* This ranking allows for bypass of the soil/subsoil at swallow holes; where swallow holes are absent, the appropriate ranking is 'H'. However, the default ranking is 'E'.
** Poorly productive and/or fissured aquifers may contribute surface waters onto a karst aquifer. These may continue as surface water stream flow on the karst or sink into the karst at the aquifer boundary.

4.5.2 Impact potential

Impact potential is a combination of Pathway Susceptibility and Pressure Magnitude, as shown in the matrix below.

	IMPACT POTENTIAL	Pathway Susceptibility			
		Extreme	High	Moderate	Low
Pressure magnitude	>2.0 LU ha^{-1}or >33% tillage Heavily fertilized forestry on peat* Q value < 4** in surface water	High	High	Low	Low
	1.5-2.0 LU ha^{-1} or 18-33% tillage	High	Moderate	Low	Low
	1.0-1.5 LU ha^{-1} or 3-18% tillage	Moderate	Low	Low	Low
	0.5-1.0 LU ha^{-1} or <3% tillage	Moderate	Negligible	Negligible	Negligible

* Heavily fertilized forestry (on peat) corresponds almost completely to sitka spruce. This measure is taken to be a surrogate measure of associated nutrient load from forestry.
** Q value of surface water contributed by poorly productive and/or fissured aquifers and/or of any surface waters within the catchment area. A Q value of ≥4 corresponds to <30µg/l MRP

The pressure magnitude is considered to depend on the density of livestock, the presence of tillage and forestry, and on the water quality of surface water flowing onto/or as surface water on the karst aquifer.

Individual impact potential maps are derived for each of the four types of pressures. For any given area within the catchment, the highest impact potential resulting from among the four pressures is assigned to the area.

4.5.3 Risk category based on predictive risk assessment

The predicted risk category is derived by combining the Impact Potential and Receptor Sensitivity, as shown below.

RISK CATEGORY		Proportion of turlough catchment with high and moderate impact potential					
		>40%	*25-40%*	*15-25%*	*10-15%*	*5-10%*	*<5%*
Receptor Sensitivity	Extreme sensitivity*	1b	1b	1b	2a	2a	2b
	High sensitivity	1b	1b	2a	2a	2b	2b
	Moderate sensitivity	1b	2a	2a	2b	2b	2b

*Extreme, high and moderate receptor sensitivity classes were defined by NPWS using turlough vegetation data.

The impact potential is categorised according to the proportion of the area of the turlough catchment having high or moderate impact potential

Receptor sensitivity is based on the trophic sensitivity of the receptor turlough and the assumption that the higher the trophic sensitivity of the turlough, the greater it's sensitivity to enrichment by PO_4.

The trophic sensitivity of a turlough is based on the extent of selected plant communities, as mapped and classified by Roger Goodwillie (Goodwillie 1992, Southern Water Global 1997 and NPWS 2004). Ellenberg Fertility Scores were assigned to each turlough plant community by averaging the Ellenberg Fertility Scores for the frequently occurring species. Frequently occurring species were those which occurred in a community in >10% of turloughs surveyed. The turloughs were then 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 4 or less indicates that a site is in the range of intermediate fertility to extreme infertility (Hill *et al.*, 1999).

The following table shows the proportion of the plant communities in each turlough which have Ellenberg Fertility scores ≤4, together with the associated Trophic Sensitivities.

Proportion of communities in turlough with Ellenberg N <= 4	**>50% ??**	**>25%and <50%**	**<25%**
Trophic sensitivity	1	2	3
Receptor Sensitivity class	Extreme	High	Moderate

Trophic Sensitivity for each turlough is listed in Table 4 (List of Turlough SACs and their Trophic Sensitivities), under the heading **Current Trophic Sensitivity**. Vegetation communities were not mapped for seven of the 70 turloughs; these are indicated by italics in Table 4. These seven turloughs were assigned a provisional current trophic sensitivity based on best professional judgement. Where these result in a Groundwater Body being placed "probably at significant risk" (1.b), these sensitivities will be investigated under "further characterisation". It is important to note that the NPWS do not consider all the SACs currently to have favourable conservation status, and that this trophic sensitivity does not constitute a reference condition. Under the heading Natural Trophic Sensitivity, NPWS used expert judgement to indicate what they consider the natural, un-impacted status of a turlough to be.

4.5.4 Risk category of turlough catchment adjusted using available impact data

Adjustments can be made to the turlough catchment predictive risk category, as shown in the table below, based on two sources of impact data: turlough water phosphorus data and groundwater phosphorus data. In both cases a set of risk adjustment thresholds are set for measured phosphorus, according to whether the receptor has an extreme or high/moderate sensitivity. Turloughs with extreme trophic sensitivity are considered more vulnerable to nutrient enrichment and as such have been assigned lower impact thresholds. Type of phosphorous measured and thresholds are detailed in the risk analysis summary sheet.

Adjustments for turlough catchment						
Predictive Risk Category	**Turlough data criteria***			**Groundwater data criteria*****		
	*High/moderate sensitivity receptors***	*Extremely sensitive receptors*	*Adjusted Risk Category*	*High/moderate sensitivity receptors***	*Extremely sensitive receptors*	*Adjusted Risk Category*
1b	Total P > 30 $\mu g\ l^{-1}$	Total P >10 $\mu g\ l^{-1}$	1a	MRP >30 $\mu g\ l^{-1}$	MRP >10 $\mu g\ l^{-1}$	1a
2a	Total P 20-30 $\mu g\ l^{-1}$		1b	MRP 20-30 $\mu g\ l^{-1}$		1b
2b	Total P 10-20 $\mu g\ l^{-1}$	Total P <10 $\mu g\ l^{-1}$	2a or 1b depending on confidence in the monitoring data	MRP 10-20 $\mu g\ l^{-1}$	MRP <10 $\mu g\ l^{-1}$	2a or 1b depending on confidence in the monitoring data
	Total P <10 $\mu g\ l^{-1}$		2b	MRP <10$\mu g\ l^{-1}$		2b

* Mean TP of turlough water, based on a mean of monthly sampling during the flood period, but excluding the extreme beginning and end of the flood period. Thresholds are based on the Phosphorus Regulations' standards for total phosphorus (TP) in lakes, which indicate that when mean TP ≤10 $\mu g\ l^{-1}$ the lake is oligotrophic and >10 to ≤20 $\mu g\ l^{-1}$ mesotrophic (McGarrigle *et al*., 2002, Appendix I).

** Sensitivity of receptor (turlough) is that defined by NPWS from turlough vegetation studies, as shown on Table 4.

*** Groundwater data are expressed as median unfiltered Molybdate Reactive Phosphorus (MRP). As many turloughs are conduit fed it is assumed that there will be very little attenuation in phosphorus concentrations in groundwater discharges to the turlough. For this reason it was considered more appropriate to use lake rather than river phosphorus regulation standards. See note (*) above.

4.5.5 Expert Review Recommendations

Expert review of the outcome of this risk assessment is recommended by EPA staff with field experience of the catchment area of the GWDTE and knowledge of surface water impacts.

Final expert review is recommended by National Parks and Wildlife Service staff who may recommend upgrading of the risk category based on available impact data and local knowledge of the SAC/SPA involved.

5 Actions arising from Risk Categorisation

Where a turlough catchment is categorised as being 'at risk' (category 1.a or 1.b), the catchment area will be designated as a new groundwater body. Where a turlough catchment is categorised as 2.a, 'not at risk', but for which confidence in the available information being comprehensive and reliable is low, a new water body will not be designated. Work will be focused on appropriately improving the quality of information on pressures and their likely environmental effects in time for the second pressures and impact analysis due to be completed in 2013.

6 Membership of the Working Group on Groundwater Sub-committee on Turloughs

Organisation	**Representative(s)**
Geological Survey of Ireland	Donal Daly Coran Kelly
National Parks and Wildlife Service, Department of the	Áine O' Connor

Environment, Heritage and Local Government	Deirdre Lynn Jim Ryan
Environmental Protection Agency	Jim Bowman Micheal MacCarthaigh
Environment and Heritage Service, Dept. of the Environment, Northern Ireland	Imelda O'Neill
National University of Ireland, Galway	Dr. Michael Gormally James Moran Eugenie Regan Dr. Micheline Sheehy Skeffington Dr. Marjoleine Visser
O'Neill Groundwater Engineering	Shane O'Neill
Trinity College, Dublin	Catherine Coxon David Drew Paul Johnston Sarah Kimberley Julian Reynolds Suzanne Tynan Stephen Waldren
Shannon Pilot River Basin – EPA (TCD) Research Fellow	Garrett Kilroy
Consultant Ecologist	Roger Goodwillie

7 References

Coxon, C.E. (1986) *A study of the hydrology and geomorphology of turloughs*. Dublin, Trinity College.

Coxon, C. E. (1987) The spatial distribution of turloughs. *Irish Geography*, **20**, 11-23.

Goodwillie, R. (1992) *Turloughs over 10ha: Vegetation survey and evaluation*. A report for the National Parks and Wildlife Service and the Office of Public Works.

Hill, M.O., Mountford, J. O., Roy, D.B. and Bunce R.G.H. (1999) *Ellenberg's indicator values for British plants* ECOFACT Volume 2, Technical Annex. Publ. Department of Environment, Transport and the Regions for HMSO, Norwich.

McGarrigle, M. *et al*. (2002) Water quality in Ireland 1998-2000, EPA

Southern Water Global (1997) *An investigation of the flooding problems of the Gort-Ardrahan area of south Galway.* Final Report to the Office of Public Works, April 1997.

Working Group on Groundwater (2004) Guidance Document GW8: *Methodology for Risk Characterisation of Ireland's Groundwater*, 70 pp.

8 Groundwater Risk Assessment Sheet

Summary details on pressures, receptors and WFD objective

RA Sheet	GWDTERA2a
Receptor type	Groundwater Dependent Terrestrial Ecosystems: Turloughs
Pressure type	Diffuse – low mobility inorganics (PO_4)
WFD objective	Chemical status
Assessment area	Catchment area of GWDTE

A. Pathway susceptibility

Catchment area of the turlough

The RA applies to the area contributing water to the GWDTE. Therefore, the catchment area of the GWDTE must be delineated, even if only approximately. The boundaries must be based on the conceptual understanding of the area and on hydrogeological boundaries to flow. For turlough catchments this will include an assessment of the flow types in the catchment i.e. epikarstic, conduit type, or a combination thereof, and identification of dominant flow routes. Delineation will then include one or more of topographic, bedrock or groundwater catchment delineation.

<table>
<tr><th colspan="4" rowspan="2">PATHWAY SUSCEPTIBILITY</th><th colspan="4">Flow Regime (horizontal pathway)</th></tr>
<tr><th colspan="2">Karst aquifers</th><th colspan="2">Poorly productive and/or fissured aquifers contributing surface waters to turlough catchment.</th></tr>
<tr><td rowspan="6">Vertical pathway</td><td colspan="3">Soil & contributing area</td><td>Dry soil</td><td>Wet soil</td><td>Within 50 m of a stream channel</td><td>Remainder of catchment area</td></tr>
<tr><td rowspan="5">Vulnerability</td><td rowspan="2">Extreme</td><td>0-1 m soil & subsoil</td><td>E</td><td>E</td><td rowspan="5">E</td><td rowspan="5">H</td></tr>
<tr><td>1-3 m soil subsoil</td><td>E</td><td>E*</td></tr>
<tr><td colspan="2">High</td><td colspan="2">M</td></tr>
<tr><td colspan="2">Moderate</td><td colspan="2">L</td></tr>
<tr><td colspan="2">Low</td><td colspan="2">L</td></tr>
</table>

n/a = not applicable

* This ranking allows for bypass of the soil/subsoil at swallow holes; where swallow holes are absent, the appropriate ranking is 'H'. However, the default ranking is 'E'.

B. Impact potential

	IMPACT POTENTIAL	Pathway Susceptibility (from Table A)			
		Extreme	*High*	*Moderate*	*Low*
Pressure magnitude	>2.0 LU ha^{-1} or >33% tillage Heavily fertilized forestry on peat* Q value < 4** in surface water	High	High	Low	Low
	1.5-2.0 LU ha^{-1} or 18-33% tillage	High	Moderate	Low	Low
	1.0-1.5 LU ha^{-1} or 3-18% tillage	Moderate	Low	Low	Low
	0.5-1.0 LU ha^{-1} or <3% tillage	Moderate	Negligible	Negligible	Negligible
	<0.5 LU ha^{-1}	Low	Negligible	Negligible	Negligible

* Heavily fertilized forestry (on peat) corresponds almost completely to sitka spruce. This measure is taken to be a surrogate measure of associated nutrient load from forestry.
** Q value of surface water contributed by poorly productive and/or fissured aquifers and/or of any surface waters within the catchment area. A Q value of ≥4 corresponds to <30µg/l MRP

C. Risk category based on predictive risk assessment

RISK CATEGORY		Proportion of turlough catchment with high and moderate impact potential					
		>40%	*25-40%*	*15-25%*	*10-15%*	*5-10%*	*<5%*
Receptor Sensitivity	Extreme sensitivity*	1b	1b	1b	2a	2a	2b
	High sensitivity	1b	1b	2a	2a	2b	2b
	Moderate sensitivity	1b	2a	2a	2b	2b	2b

*Extreme, high and moderate receptor sensitivity classes were defined by NPWS using turlough vegetation data.

D. Risk category of turlough catchment adjusted using available impact data

Adjustments for turlough catchment						
	*Turlough data Criteria**			*Groundwater data criteria****		
Predictive Risk Category	*High/moderate sensitivity receptors***	*Extremely sensitive receptors*	*Adjusted Risk Categeory*	*High/moderate sensitivity receptors***	*Extremely sensitive receptors*	*Adjusted Risk Category*
1b	Total P > 30 µg l^{-1}	Total P >10 µg l^{-1}	1a	MRP >30 µg l^{-1}	MRP >10 µg l^{-1}	1a
2a	Total P 20-30 µg l^{-1}		1b	MRP 20-30 µg l^{-1}		1b
2b	Total P 10-20 µg l^{-1}	Total P <10 µg l^{-1}	2a or 1b depending on confidence in the monitoring data	MRP 10-20 µg l^{-1}	MRP <10 µg l^{-1}	2a or 1b depending on confidence in the monitoring data
	Total P <10 µg l^{-1}		2b	MRP <10µg l^{-1}		2b

* Mean TP of turlough water, based on a mean of monthly sampling during the flood period, but excluding the extreme beginning and end of the flood period. Thresholds are based on the Phosphorus Regulations' standards for total phosphorus (TP) in lakes, which indicate that when mean TP ≤10 µg l^{-1} the lake is oligotrophic and >10 to ≤20 µg l^{-1} mesotrophic (McGarrigle *et al.*, 2002, Appendix I).

** Sensitivity of receptor (turlough) is that defined by NPWS from turlough vegetation studies.

*** Groundwater data are expressed as median unfiltered Molybdate Reactive Phosphorus (MRP). As many turloughs are conduit fed, it is assumed that there will be very little attenuation in phosphorus concentrations in groundwater discharges to the turlough. For this reason it was considered more appropriate to use lake rather than river phosphorus regulation standards. See note (*) above.

E. Additional Impact data

In addition to the type of phosphorus data described in Table D above, 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. These data may be used to adjust the risk category of the turlough catchment, with the proviso that the data apply only to the immediate turlough basin and not the catchment, and that the data may not be consistent, as they reflect the focus of the visiting ecologist.

F. Expert Review Recommendations

Expert review of the outcome of this risk assessment is recommended by EPA staff with field experience of the catchment area of the GWDTE and knowledge of surface water impacts.

Final expert review is recommended by National Parks and Wildlife Service staff who may recommend upgrading of the risk category based on available impact data and local knowledge of the SAC/SPA involved.

Table 4 List of Turlough SACs and their Trophic Sensitivities

SAC Site Code	SAC Name	Site Name	Proportion of communities with Ellenburg score <=4	Current Trophic Sensitivity[1 2]	Natural Trophic Sensitivity [1]	SPA Site Code	County	National Grid X	National Grid Y
000051	LOUGH GASH TURLOUGH SAC	Lough Gash	0	3	3		Clare		
000054	*MONEEN MOUNTAIN SAC*	*Gortboyheen Lough*	*?*	*1 or 2*	*?*		*Clare*	*127575*	*205315*
000054	MONEEN MOUNTAIN SAC	Muckinish Lough	0	3	2		Clare	127565	208750
000218	COOLCAM TURLOUGH SAC	Coolcam Turlough	0.27	2	2		Galway/Roscommon		
000238	CAHERGLASSAUN TURLOUGH SAC	Caherglassaun Turlough	0.05	3	3		Galway		
000242	CASTLETAYLOR COMPLEX SAC	Caranavoodaun Turlough	0.93	1	1		Galway		
000252	COOLE-GARRYLAND COMPLEX SAC	Coole & Doo Turloughs	0.06	3	3	004107	Galway	143025	204251
000252	COOLE-GARRYLAND COMPLEX SAC	Garryland Turlough	0.13	3	3	004107	Galway	141580	203988
000252	COOLE-GARRYLAND COMPLEX SAC	Hawkhill Turlough	0	3	2	004107	Galway	141144	202341
000252	COOLE-GARRYLAND COMPLEX SAC	Newtown Turlough	0.44	2	1	004107	Galway	142590	202662
000255	CROAGHILL TURLOUGH SAC	Croaghill Turlough	0.02	3	2 to 3		Galway		

Table 1 Notes

1. Trophic Sensitivity: 1 = extremely high sensitivity to enrichment, 2 = high, 3 = medium. See text in Section 4.5.3 for an explanation of the Ellenburg Score and Trophic Sensitivity.
2. Current Trophic Sensitivity: Where no vegetation community data were available an assessment was made by NPWS, using best professional judgement.
3. National Grid references are provided for individual turlough sites within a turlough. For single turlough SACs the centroid of the turlough as occurs in NPWS GIS data is taken as the grid reference.

SAC Site Code	SAC Name	Site Name	Proportion of communities with Ellenburg score <=4	Current Trophic Sensitivity[1 2]	Natural Trophic Sensitivity [1]	SPA Site Code	County	National Grid X	National Grid Y
000268	GALWAY BAY COMPLEX SAC	Ballinacourty Turlough	0.15	3	?		Galway/Clare	136351	219116
000268	*GALWAY BAY COMPLEX SAC*	*Ballyvelaghan Lough*	*?*		*?*		*Clare*	*128051*	*211426*
000295	LEVALLY LOUGH SAC	Levally Lough	0.70	1	1		Galway		
000296	LISNAGEERAGH BOG AND BALLINASTACK TURLOUGH SAC	Ballinastack Turlough	0.44	3	2		Galway		
000301	LOUGH LURGEEN BOG/ GLENAMADDY TURLOUGH SAC	Glenamaddy Turlough	0.22	3	2		Galway		
000318	PETERSWELL TURLOUGH SAC	Peterswell/Blackrock Turlough	0.03	3	3		Galway		
000322	RAHASANE TURLOUGH SAC	Rahasane Turlough	0.09	3	3	004089	Galway		
000407	THE LOUGHANS SAC	The Loughans	0.24	3	2		Kilkenny		
000448	FORTWILLIAM TURLOUGH SAC	Fortwilliam Turlough	0.45	2	1 to 2		Longford		
000461	ARDKILL TURLOUGH SAC	Ardkill Turlough	0.13	3	2		Mayo		
000463	BALLA TURLOUGH SAC	Balla (Pollaghard) Turlough	0.81	1	1		Mayo		
000475	CARROWKEEL TURLOUGH SAC	Carrowkeel (Pollelamagur Lough) Turlough	0.32	2	1 to 2		Mayo		
000480	CLYARD KETTLE-HOLES SAC	Thomastown Turlough	0.03	3	?		Mayo	123372	260971
000492	DOOCASTLE TURLOUGH SAC	Doocastle Turlough	0.25	2	2		Mayo		
000503	GREAGHANS TURLOUGH SAC	Greaghans Turlough	0.01	3	3		Mayo		
000504	KILGLASSAN/CAHERVOOSTIA TURLOUGH COMPLEX SAC	Caheravoostia Turlough	0.38	2	2		Mayo	126811	264449

SAC Site Code	SAC Name	Site Name	Proportion of communities with Ellenburg score <=4	Current Trophic Sensitivity[1 2]	Natural Trophic Sensitivity [1]	SPA Site Code	County	National Grid X	National Grid Y
000504	KILGLASSAN/CAHERVOOSTIA TURLOUGH COMPLEX SAC	Kilglassan Turlough	0.09	3	2		Mayo	127817	264547
000525	SHRULE TURLOUGH SAC	Shrule Turlough	0.72	1	1		Mayo		
000541	SKEALOGHAN TURLOUGH SAC	Skealoghan Turlough	0.51	1	1		Mayo		
000588	BALLINTURLY TURLOUGH SAC	Ballinturly Turlough	0.22	2	2	004138	Roscommon		
000606	LOUGH FINGALL COMPLEX SAC	Ballinderreen Turlough	0.84	1	1		Galway	140401	215910
000606	LOUGH FINGALL COMPLEX SAC	Carraghadoo Turlough	0.76	1	1		Galway	142132	215084
000606	LOUGH FINGALL COMPLEX SAC	Cuildooish Turlough	0.53	1	1		Galway	141253	215837
000606	LOUGH FINGALL COMPLEX SAC	Frenchpark Turlough	0.94	1	1		Galway	141131	214929
000606	LOUGH FINGALL COMPLEX SAC	Lough Fingall	0.76	1	1		Galway	141708	214917
000606	LOUGH FINGALL COMPLEX SAC	Tullaghnafrankagh Lough	0.49	2	1		Galway	143208	215339
000609	LISDUFF TURLOUGH SAC	Lisduff Turlough	0.30	2	?2		Roscommon		
000610	LOUGH CROAN TURLOUGH SAC	Lough Croan	0.24	3	2	004139	Roscommon		
000611	LOUGH FUNSHINAGH SAC	Lough Funshinagh	0.30	2	2		Roscommon		
000612	MULLYGOLLAN TURLOUGH SAC	Mullugollan Turlough	0.31	2	2		Roscommon		
000637	TURLOUGHMORE (SLIGO) SAC	Turloughmore (Sligo)	0.41	2	?		Sligo		
000996	BALLYVAUGHAN TURLOUGH SAC	Ballyvaughan Turlough	0.08	3	2		Clare		

SAC Site Code	SAC Name	Site Name	Proportion of communities with Ellenburg score <=4	Current Trophic Sensitivity[1 2]	Natural Trophic Sensitivity [1]	SPA Site Code	County	National Grid X	National Grid Y
001285	KILTIERNAN TURLOUGH SAC	Kiltiernan Turlough	0.05	3	2		Galway		
001321	TERMON LOUGH SAC	Termon Lough/South	0.62	1	1		Galway/Clare	140941	197346
001321	TERMON LOUGH SAC	Termon North	0.07	3	?		Galway	141914	197694
001637	*FOUR ROADS TURLOUGH SAC*	*Four Roads Turlough*	*?*	*3*	*?*	*004140*	*Roscommon*		
001926	EAST BURREN COMPLEX SAC	Carran Turlough	0.44	2	1 to 2		Clare	128342	198561
001926	EAST BURREN COMPLEX SAC	Castle Lough	0.50	1	1		Clare	134519	198252
001926	*EAST BURREN COMPLEX SAC*	*Coolreash Turlough*	*?*	*1 or 2*	*1*		*Clare*	*132881*	*174471*
001926	EAST BURREN COMPLEX SAC	Knockaunroe Turlough	0.83	1	1		Clare	131317	193982
001926	EAST BURREN COMPLEX SAC	Lough Aleenaun	0.04	3	2		Clare	124800	195369
001926	*EAST BURREN COMPLEX SAC*	*Lough Gealain*	*?*	*1*	*1*		*Clare*	*131502*	*194828*
001926	EAST BURREN COMPLEX SAC	Lough Mannagh	0.51	1	1		Galway, Clare	140347	201649
001926	EAST BURREN COMPLEX SAC	Poulroe Turlough	0.56	1	1		Clare	137294	195278
001926	EAST BURREN COMPLEX SAC	Roo West Turlough	0.57	1	1		Galway, Clare	138627	202214
001926	EAST BURREN COMPLEX SAC	Travaun-Skaghard Turlough	0.39	2	1		Clare	135547	196765
001926	EAST BURREN COMPLEX SAC	Tulla Turlough	0.15	3	2		Clare	136673	201887
001926	EAST BURREN COMPLEX SAC	Turloughmore	0.03	3	2		Clare	134742	199803

SAC Site Code	SAC Name	Site Name	Proportion of communities with Ellenburg score <=4	Current Trophic Sensitivity[1 2]	Natural Trophic Sensitivity [1]	SPA Site Code	County	National Grid X	National Grid Y
002117	LOUGH COY SAC	Lough Coy	0.10	3	2 to 3		Galway		
002293	CARROWBAUN, NEWHALL AND BALLYLEE TURLOUGHS SAC	Ballylee River Turlough	0	3	3		Galway	147864	206395
002293	CARROWBAUN, NEWHALL AND BALLYLEE TURLOUGHS SAC	Carrowbaun East Turlough	0.11	3	2		Galway	148177	207478
002293	CARROWBAUN, NEWHALL AND BALLYLEE TURLOUGHS SAC	Newhall Turlough	0.39	2	2		Galway	147322	206640
002294	CAHERMORE TURLOUGH SAC	Cahermore Turlough	0.07	3	2		Galway		
002295	BALLINDUFF TURLOUGH SAC	Ballinduff Turlough	0.31	2	?		Galway		
002296	WILLIAMSTOWN TURLOUGHS SAC	Curragh Lough	<0.25	3	2		Galway	156382	267733
002296	*WILLIAMSTOWN TURLOUGHS SAC*	*North Gortduff Turlough*	*?*	*3*	*?*		*Galway*	*157386*	*269163*
002296	WILLIAMSTOWN TURLOUGHS SAC	Polleagh Lough	<0.25	3	2		Galway	157207	268422
002303	DUNMUCKRUM TURLOUGHS SAC	Lugnanav or Dunmuckrum	0.35	2	2		Donegal		
002339	*BALLYNAMONA BOG AND CORKIP LOUGH SAC*	*Corkip Lough*	*?*	*3*	*2*		*Roscommon*		

Table 1 Notes

1. Trophic Sensitivity: 1 = extremely high sensitivity to enrichment, 2 = high, 3 = medium. See text in Section 4.5.3 for an explanation of the Ellenburg Score and Trophic Sensitivity.
2. Current Trophic Sensitivity: Where no vegetation community data were available an assessment was made by NPWS, using best professional judgement.
3. National Grid references are provided for individual turlough sites within a turlough. For single turlough SACs the centroid of the turlough as occurs in NPWS GIS data is taken as the grid reference.

Table 5 List of Turlough SPAs

SPA Site Code	SPA Name	Site Name	County	SAC Site Code
004107	COOLE-GARYLAND SPA	Garryland Turlough	Galway	000252
004107	COOLE-GARYLAND SPA	Newtown Turlough	Galway	000252
004107	COOLE-GARYLAND SPA	Coole Turlough and Doo Lough	Galway	000252
004107	COOLE-GARYLAND SPA	Hawkhill Turlough	Galway	000252
004089	RAHASANE TURLOUGH SPA	Rahasane Turlough	Galway	000322
004138	BALLINTURLY TURLOUGH SAC	Ballinturly Turlough	Roscommon	000588
004140	FOUR ROADS TURLOUGH SAC	Four Roads Turlough	Roscommon	001637
004139	LOUGH CROAN TURLOUGH SAC	Lough Croan	Roscommon	000610