Tellus Border

WETLAND PROJECT: AN ECOHYDROLOGICAL INVESTIGATION OF WETLANDS IN THE BORDER REGION OF IRELAND

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Executive Summary

Wetlands are areas of land that are saturated with water throughout much of the year and occur where the water table is at or near the surface of the land or along transitional habitats between dry land and a deep water environment. Water is, therefore, the primary factor determining the functioning of these systems, which may be dependent on inputs from groundwater, surface water or both for maintaining correct ecosystem functioning. Wetlands are geologically and physio-graphically complex and varied and are important environmental resources. They typically support a diverse ecology, are important stores of carbon, and are an important recreational and cultural resource. However, they are fragile and prone to damage from a range of human activities including drainage, pollution from industrial, domestic and agricultural activity and over exploitation of groundwater resources.

With increasing recognition of the value of wetlands, there is an increased need to acquire information on the current status of wetlands and assess the level to which they are being impacted by human activities. There are numerous national and international legislation and policy relating to the protection of wetlands, principle among which include the Water Framework Directive and the Habitats Directive. In order to fully meet our obligations under these Directives, there is a need to develop our understanding of the relationship between hydrogeological and ecological characteristics of wetland systems, particularly those which are dependent on groundwater.

This project aimed to investigate the water delivery mechanisms and water requirements (notably water levels and hydrochemistry) of different types of regional wetlands across the counties on both sides of the border. To do this the project used a combination of data collected as part of the Tellus Project (2004 – 2007) and the current Tellus Border Project (2001 – 2013), in conjunction with a range of geochemical and geological data already available from a variety of sources along with newly-collected field data collected from selected case-study wetland sites. This was done in order to describe and characterise the biological communities within these wetland systems with emphasis placed on synthesising data and methods from different fields of sciences (e.g. ecology and hydrology) in order to develop a more holistic understanding of wetland systems.

The first phase of this project involved a desk-based review of wetland systems which included the development of a baseline report on the occurrence of wetlands in relation to key geochemical and geological parameters across the border region of Ireland. The data gathered on wetland habitats throughout the border counties was then used as a base to short-list wetland sites for further assessment. This short listing process allowed initial wetland characterisation of case-study sites and the identification of key knowledge gaps which helped to define the wetland monitoring activities over the remainder of the project. An eighteen month monitoring program of five shortlisted case-study wetland sites was then conducted and data collected on a range of hydrochemical, hydrological and biological processes occurring within the site. This information allowed the development of a working hypothesis describing key environmental processes, which formed the basis for the development of conceptual diagrams for shortlisted sites describing the current understanding of the mechanisms of water delivery, pressures acting on the site and ecosystem processes.

The experience of setting up a monitoring protocol and the lessons learned throughout this process has led to the development of a framework for the assessment of wetland habitats, which is applicable to the objectives of the Water Framework and Habitats Directives. The provision of baseline data on the occurrence of wetland habitats in the border region of Ireland is an important first step to the development of a comprehensive inventory of wetlands in Ireland. In addition, the site specific data collected over the course of the project and the methodologies developed will provide valuable baseline data on the response of wetland systems to hydrological and hydrochemical variations. This will assist in addressing the data requirements necessary for successful implementation of European Directives. Additionally, it will allow for improved understanding of integrated ecosystem processes which will address key knowledge gaps on the current status of wetlands and the degree to which they are being degraded. This will, therefore, provide the basis for maintaining the ecological functioning of wetland habitats and will ensure the sustainable use of their resources.

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1. Introduction

1.1 Background

Wetlands are defined as areas that are periodically or permanently inundated by surface or groundwater and support vegetation adapted for life in saturated soil. Consequently they are sensitive to changes in both of these supply systems. Wetlands are geologically and physio-graphically complex and varied and are important environmental resources. They typically support a diverse ecology, are important stores of carbon, and are an important recreational and cultural resource.

Wetlands are fragile and prone to damage through factors such as drainage for agriculture, pollution from industrial, domestic and agricultural activity, over exploitation of groundwater resources and peat extraction and are considered to be among the most highly threatened ecosystems on the planet. In 1995, the European Environment Agency (EEA) estimated that around 25 % of the most important wetlands in Europe were threatened by groundwater over-exploitation.

The objectives of the Water Framework Directive (WFD, 2000/60/EC) include achieving both good ecological and chemical status for surface waters and good chemical and quantitative status for groundwater. The objectives for wetlands are less explicit, but nonetheless, important. Good groundwater chemical status is set out in Annex V (Section 2.3.2) under Article 2 (25), and includes preventing a significant deterioration of the ecological or chemical quality of associated surface waters, or any significant damage to terrestrial ecosystems which depend directly on groundwater. The Water Framework Directive requires a comprehensive understanding of both groundwater dependent terrestrial ecosystems (GWDTEs) as well as surface water dependent wetlands in order achieve 'good status'.

Extensive research has been conducted on the ecology of specific wetland habitats. However, there remains limited understanding about how anthropogenic and climactic induced hydrological pressures impact on these local wetland systems. In addition, there is a lack of baseline data for the full range of Irish wetlands and the EPA has identified a need to

develop our understanding of the relationship between hydrogeological and ecological characteristics of groundwater dependent ecosystems.

Following from the Tellus Project in Northern Ireland (2004 – 2007), the Interreg IVA funded Tellus Border Project produced seamless maps of key physical properties and of soil and surface water chemistry across the border area of Ireland. This project used this cross-border data in conjunction with existing data and newly-collected field data from selected case-study sites, to investigate the water delivery mechanisms and water requirements (notably water levels and hydrochemistry) of different types of regional wetlands across the counties on both sides of the border, in order to describe and characterise the biological communities within these wetland systems. Emphasis was placed on developing an understanding of the relationships between hydrogeology, hydrology and ecology allowing a more holistic understanding of wetland systems. By synthesising data and methods from different fields of sciences (i.e. ecology and hydrology) new insights into the functioning of ecosystems can be obtained. The research objectives of this project are centred on understanding fundamental processes, with an explicit objective of evaluating how these natural processes could be incorporated into water management programs.

1.2 The importance of Wetlands

The term wetland can be used to describe a large number of diverse and often complex habitats that often traverse the transitional zone between aquatic and terrestrial environments (Blackwell *et al.*, 2002). Wetland habitats can range from freshwater rivers, lakes, floodplains, fens, bogs and marshes through to coastal lagoons, saltmarshes, tidal mudflats and other littoral marine environments. Whilst wetlands can provide significant economic value (Costanza, 1997; Schuyt and Brander, 2004; De Groot *et al.,* 2006), they can also be perceived as wastelands that should be drained or in-filled due to their inaccessibility, their often poor agricultural value and because of unpleasant smells that may be produced (Otte, 2003).

Wetland ecosystems cover more than 1,280 million hectares globally and wetland habitat loss and degradation is a significant global challenge, and one that is likely to continue into the future as a result of increased pressures such as population growth, increasing economic and

infrastructure development, land conversion, water abstraction, eutrophication, pollution, over-exploitation of resources, and the introduction of alien species (Millennium Ecosystem Assessment, 2005). This loss and degradation of wetlands is also likely to be exacerbated by global climate change (Gitay *et al.*, 2011).

Wetlands across international, national and local scales provide major ecosystem services, which are considered to be those functions of natural systems perceived as beneficial to human society (Cairns, 1993; Table 1.1). Nevertheless, as a result of the inadequate identification and valuation of their benefits, major wetland habitat loss has occurred both in the UK and Ireland (UKNEA, 2011), and throughout the rest of the world (Millennium Ecosystem Assessment, 2005). Despite the difficulties in undertaking economic valuations of specific habitats or biomes, a number of studies have attempted to value wetland ecosystem services, but these estimates vary widely due to differing analyses and data availability, and range from between US$4.9 trillion (Costanza, 1997) to as much as US$14 trillion annually (De Groot *et al*., 2006). Despite the variation in estimates between these studies, it is nevertheless evident that wetlands contribute significant worth to the global environment and economy. In Ireland, the biodiversity value of wetlands has been estimated to be worth €385 million per year (DOEHLG, 2008). Attempting to place an economic value on the ecosystem services provided by wetland ecosystems can be a useful tool in evaluating the benefits derived from wetland ecosystems services and ensuring that this is taken into account during decision making processes. An economic evaluation such as this was conducted on behalf of Monaghan County Council in 2010 using estimates derived from the literature for six case study areas within the county. Based on the data collected as part of this study it was estimated that the value of the case study wetlands over 50 years from the smallest to the largest wetland sites would range from €10,000 to €2.9 million, respectively (Eftec, 2010).

Increasingly, the assessment of ecosystem services provided by wetlands is regarded as an important consideration in informing policy and management decisions (de Groot *et al*., 2006; McInnes, 2007). Wetlands can affect the hydrological cycle and hence the supply of water for both drinking water and irrigation (Kingsford, 1999). Wetlands also have an important role in flood mitigation with floodplains, lakes and reservoirs capable of reducing the impact of floods. Consequently, the degradation or loss of these wetland habitats can

increase the risk of floods occurring. Biogeochemical processes occurring within wetland ecosystems can play an important role in nutrient cycling and attenuation (Reddy and DeLaune, 2008). Wetlands are, therefore, generally regarded as natural filters and have an important role in reducing water borne pollution, potentially improving the quality of potable water supplies at source. In addition, supplies of fresh water for human consumption are sourced from a number of different freshwater sources including lakes and rivers, in addition to shallow groundwater aquifers. In Ireland an estimated 25 % of the population are dependent on groundwater for their supply of water (Hayes *et al*., 2013). Many wetlands help recharge groundwater aquifers. This complex relationship between different wetland types and their link with groundwater can play an important role in water supply. Wetlands also have a key function in the global carbon cycle and are estimated to hold approximately 30 % of global terrestrial carbon pools and are also estimated to be responsible for approximately 20 - 25 % of global methane emissions but are, nevertheless, considered to act as overall carbon sinks (Mitsch *et al*., 2012). However, degradation of certain wetland habitats such as peatlands, which in Ireland account for 53% of all stored soil carbon (Tomlinson, 2005), is of concern, as this will release carbon stores and may offset the gains made through carbon sequestration (Wellock *et al*., 2011). Finally, wetlands can also provide significant cultural, aesthetic and educational benefits. They are important locations for tourism and are important for activities such as fishing and walking. Wetland biodiversity, including habitat, species and genetic diversity is crucial as it underpins the provision of a wide range of ecosystem services. Impacts on biodiversity affecting changes in biotic interactions, loss of key species or introduction of non-native species may reduce the capacity of the ecosystem to adjust to changing environments affecting ecosystem stability, resilience or resistance and, consequently, their ability to provide ecosystem services.

Table 1.1 Examples of economic benefits provided by wetlands (from Foss *et al.*, 2011, adapted from Barbier *et al*., 1997).

USE BENEFITS			NON-USE BENEFITS
Direct Use Benefits	**Indirect Use Benefits**	**Option Benefits**	**Existence Benefits**
Recreation **- Boating** **- Birding** **- Wildlife viewing** **- Walking** **- Angling** **Trapping/Hunting** **Commercial Harvest** **- Nuts** **- Berries** **- Grains** **- Fisheries** **- Peat** **- Forestry**	Nutrient retention Water filtration Flood control Shoreline protection Groundwater recharge External ecosystem support Micro-climate stabilization Erosion control Associated expenditures, e.g. travel, guides, gear, etc.	Potential future uses (as per direct and indirect uses) Future value of information, e.g. pharmaceuticals, education	Biodiversity Culture Heritage Archaeology Non-use Bequest value

1.3 Legislation and Conservation Designations

There are numerous international legislation and policy relating to the protection of wetlands which include the Convention on Biological Diversity (COB) and the 'Convention on Wetlands of International Importance especially as Wildfowl Habitat (1971; known as the Ramsar Convention), which more specifically deals with wetland habitats. Ireland is a signatory of the Ramsar Convention, which aims to promote the wise use of wetlands, ensuring conservation and vigilance in planning. However, it is non-regulatory agreement and consequently, there are no punitive sanctions associated with any violations. The Republic of Ireland (RoI) has a total of 45 designated Ramsar Wetlands of international importance, covering a spatial area of 66,994 hectares. In comparison, the United Kingdom has a total of 168 Ramsar sites covering 1,274,323 hectares, of which 18 sites covering 86,894 hectares occur in Northern Ireland (NI).

The Habitats Directive (Directive 92/43/EEC), the Birds Directive (Directive 79/409/EC) and the Water Framework Directive (WFD; 2000/60/EC) are the key legislative instruments that assist in the protection and conservation of wetland habitats within the European Union. Sites protected through the Habitats and Birds Directives encompass the Natura 2000 network and are designated solely on ecological aspects. However article 2 of the Birds Directive and Article 2(3) of the Habitats Directive state that economic, social and cultural requirements must be taken into account during the designation process. Although wetlands are not specifically addressed in the Habitats Directive, a number of wetland habitats and wetland species are listed under Annexes I and II, respectively. Article 4(2) of the Birds Directive states that '*Member States shall pay particular attention to the protection of wetlands and particularly to wetlands of international importance'*. This, therefore, has implications for Member States to protect all wetlands that provide significant habitat for birds, particularly migratory birds or priority species listed under Annex II of the Habitats Directive, regardless of their conservation status.

According to the Habitats Directive, Member States must carry out assessment at a national level of each habitat or species specified in Annex I and Annex II of the Directive. Important sites are designationed Special Areas of Conservation (SACs), Special Protected Areas (SPAs) or National Heritage Areas (NHAs). Any proposed development or activity within a designated site must be assessed to determine that there will be no significant adverse impact to the site. The ultimate objective of the Habitats Directive is to protect, maintain or restore to favourable conservation status selected species and habitats of importance, and to ensure a coherent network of special areas of conservation. Ireland has a total protected area coverage of 17,500 Km^2 (representing 20.73% of the total land area). An additional 8,452 Km^2 have been identified as proposed National Heritage Areas, but are yet to be formally designated (NPWS, 2013). In comparison, in 2010 the UK had a total terrestrial protected area coverage of 64,851 Km^2, representing 26.35% of the total land area (WDPA, 2011).

The main objective of the WFD is the achievement of good ecological and chemical status for surface waters and good chemical and quantitative status for groundwater by 2015. The Directive was transposed into Irish law in 2003 by the European Communities (Water Policy) Regulations, 2003 (S.I. No. 722 of 2003). The WFD provides a framework for integrated river basin management and, therefore, offers a platform to address wetland-related issues.

The WFD does not explicitly set out environmental objectives for wetlands. Nevertheless, in Article 1(a) of the WFD it states that the Directive will '*prevent 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*.' Protection of wetlands is, therefore, implicit within the WFD as a consequence of their association with other waterbodies, both surface and ground. Preventing the degradation of groundwater bodies for instance, will require the protection of wetlands where they are connected to groundwater bodies (e.g. fed by groundwater as is the case for groundwater dependant wetlands; GWDW). If chemical or quantitative pressures on a groundwater body results in 'significant damage' to a GWDW, then the groundwater body will be classified as being at 'poor status'. It is, therefore, necessary to identify the key hydrogeological and ecological indicators of significant damage at GWDW systems.

The objectives of the Habitats/Birds Directive and the WFD are closely related. The WFD provides a framework for a more holistic approach to water management compared to previous legislation, including a focus on interactions between groundwater, surface water and ecological receptors. Implementation of the WFD across Ireland has led to an increased need for decision makers to understand the links between nutrient sources, pollution pathways (water delivery mechanisms), and the ecological health of receptors. The Habitats Directive also requires an integrated understanding of the ecological requirements of habitats and species so as to develop and implement appropriate conservation measures. The objectives of the directives are, therefore, closely related and particular attention must be taken to coordinate their implementation. In certain situations, a programme of measures which is implemented in order to achieve good ecological status under the WFD may also assist in the achievement of favourable conservation status under the Habitats Directive as the entire ecosystem will benefit rather than specific species or habitats. However, unlike the Habitats Directive, the WFD does not aim to protect particular species (as listed under the Habitats Directive), but rather to maintain or return a system to good ecological status. Member States are bound by the provisions of the WFD and the Habitats/Birds Directive and, therefore, need to meet all of their objectives. Achieving the objective of one directive, does not necessarily imply achieving the objectives of the other. However, when measures are taken under a particular directive, care must be taken to assess whether they could impact on the objectives of the other directive. The WFD contains provisions which requires that

conservation objectives for legally protected areas must also be achieved (e.g. favourable Conservation Status under the Habitats Directive). Consequently, for example, in situations where a more stringent parameter value is required to achieve a site's conservation objectives than is required to meet good ecological status under the WFD, then the more stringent value should be implemented. It is, therefore, necessary that managers determine which objective should be applied given that the objectives of both Habitats Directive and WFD are defined differently. These objectives should be aligned in order to assess which measures should be taken (EU Commission, 2011).

1.4 Threats to wetlands

Key threats to wetland habitats include habitat destruction and further fragmentation of existing wetlands (Hume *et al*., 2008), hydrological changes through drainage and abstraction (Holden *et al*., 2004; Koc, 2008; Zhang *et al*., 2010b; Cohen-Shacham *et al*., 2011; Suislepp *et al.*, 2011), diffuse and point source pollution (e.g. Verhoeven *et al*., 2006), land use and land cover change (e.g. Houlahan *et al*., 2006), the spread of invasive species (Brinson and Malvárez, 2002; Hume *et al*., 2008) and climate change (Hartig *et* al., 1997; Gitay *et al*., 2011). Agriculture activities were identified by Finlayson and Spiers (1999) as the principle cause for wetland habitat loss throughout the world, with an estimated 56-65% of available wetland being drained for intensive agriculture in Europe.

The impacts of invasive species can vary, ranging from minimal impact at vegetation community levels (Mills *et al*., 2009), through to causing extensive economic and ecological damage (Pimental *et al.,* 2005), although the impacts of multiple non-native invaders can depend on the trophic level of each invader (Preston *et al*.,2012). Invasive species in wetlands can include vegetation (Houlahan and Findlay, 2004; López-Rosas and Moreno-Casasola, 2012), amphibia (Govindarajulu *et al*., 2005), fish (Ho *et al*., 2013; Conallin *et al*., 2012), molluscs (Maguire and Sykes, 2004; Karatayev *et al*., 2009; Caffrey *et al*., 2011), and crustacea (Gallardo and Aldridge, 2013; Dick *et al*., 2013).

Wetlands are likely to be impacted by climate change in a number of ways through changes in hydrologic regimes caused by variations in temperature and precipitation (Hartig *et al*., 1997), salinization of coastal freshwater wetlands as a result of sea level rise and greater

intensities of storms (Finlayson *et al.*, 2013), and changes in species distribution and the facilitation of invasive species (Hellman *et al.*, 2008). The exacerbation of these pressures through climate change is likely to increase the potential for near-irreversible changes to the ecological state of some wetlands (Finlayson *et al.*, 2013). Projected impacts of climate change in Ireland include increasing average temperature, more extreme weather conditions including storm surges and rainfall events, an increased likelihood of river and coastal flooding, water shortages, changes in types and distribution of species and the possible extinction of vulnerable species (DOECLG, 2012). Each potential impact has the possibility of affecting Irish wetland habitats in different ways, either singularly or in combination with other impacts. For example an increase in rainfall events may result in a greater surface water flow through an upland wetland, potentially causing erosion of sediment whilst in a downstream lowland wetland potentially causing an increase in sedimentation, an increase in submergence period due to flooding, an increase in groundwater levels and saturation period of the root zone, and potentially facilitating the downstream dispersal of invasive species.

The shallow hydrologic environment of wetlands creates unique biogeochemical conditions that distinguish wetlands from other aquatic and terrestrial environments (US EPA, 2008). Modifications to the hydrological conditions of wetlands can, therefore, affect their structure, function, spatial extant, distribution, and ecological character whilst influencing many abiotic factors such as spatio-temporal flow pattern, redox potential, organic matter decomposition, subsidence rates, salinity and nutrient dynamics (Litaor *et al.*, 2008). Drainage of wetlands for conversion to agricultural land, which impacts both surface water and groundwater flows within the wetland system and their catchments, accounts for a significant proportion of wetland decline throughout the world (Zedler and Kercher, 2005). Wetland vegetation is innately coupled with the dynamics of soil moisture and water table levels, with shallow water tables influencing oxygen and nutrient availability and supplying water to plants through the root zone, whilst in turn vegetation can affect soil dynamics through transpiration and growth dynamics (Muneepeerakul *et al.,* 2008; Chui *et al*., 2011). Wetland flora are particularly vulnerable to changes to hydrological regimes due to the balance between the rainfall, temperature and evapotranspiration that govern their physiology. Therefore drainage or abstraction of water from wetlands can lead to fundamental changes in vegetation and other taxonomic groups that make up the ecological character of a wetland.

Wetlands are also sensitive to water quality pollution from a range of contaminants such as heavy metals (Harikumar *et* al., 2009; Alhashemi *et* al., 2011; Su *et* al., 2011; Schaller *et al*., 2013), hydrocarbons (Obot *et al*., 1992; Liu *et al*., 2011), herbicides (Angier *et al*., 2002), insecticides (López-Flores *et* al., 2003; Qu *et al*., 2011) and nutrients (e.g. Carpenter *et* al., 1998; López-Flores *et* al., 2003; Withers and Haygarth, 2007). Pollutants can contaminate aquatic environments through point sources, for example wastewater effluent discharge and diffuse sources such as agricultural run-off and run-off from failed septic systems (Carpenter *et al*., 1998). Increasing inputs of nutrient, such as nitrogen (N) and phosphorus (P), from both diffuse and non-diffuse sources can have significant impact wetland habitats (Bedford *et al*., 1999) and are considered to be the major threat facing wetland habitats in Ireland. Wetlands respond in varying ways to increased nutrient loading, with general responses usually indicated by changes in plant community type across broad nutrient gradients and declines in species richness (Bedford *et al*., 1999). It is generally observed that following a strong increase in nutrient load rates, wetlands characterised by low productivity and high plant diversity (dominated by slow growing, nutrient conserving species), shift to systems dominated by large, fast-growing helophytes with the degree of response dependent on the natural nutrient richness of the system (Verhoeven *et al*., 2006). The influence of nutrient loads entering wetlands is likely to be variable depending on the surrounding land use, catchment area, soil chemistry and also geographical location (Withers and Hogarth, 2007).

Wetlands have been shown to be able to improve the quality of surface and subsurface waters by retaining and transforming nutrients through the processes of sedimentation, plant uptake, microbial immobilisation and adsorption and precipitation reactions with clay, aluminium, iron and calcium minerals (Hogan *et al*., 2004). However, changes to the hydrological regime of a wetland, such as repeated drying and rewetting events, can cause the substantial release of phosphate that may continue if the water table is returned to the original level (Song *et al*., 2007). It has been found that natural and created wetlands have a removal capacity between 28-98% P removal and 56 - 100% N removal efficiency (Blackwell *et al*., 2002). The processes of P and N removal can vary between wetland with factors such as temperature, moisture and seasonality of temperature and moisture acting to control wetland microbial activities resulting in changes to key biogeochemical cycles (Gutknecht *et al*., 2006).

1.5 Wetlands in Ireland

The distribution of Irish wetlands is dependent on climate, relief, drainage and geology as well as anthopogenic intervention (Ó Criódáin and Doyle, 1994). A standard scheme for describing habitats in Ireland was produced by The Heritage Council in order to provide consistent and complimentary data and best practice for identifying, describing and classifying habitats (Fossitt, 2000). The scheme covers natural, semi-natural and artificial habitats of terrestrial and freshwater environments, inshore marine waters and urban and rural areas. The habitat categories outlined by Fossitt (2000) are arranged within a series of ordered groupings to produce a hierarchical framework that operates on three levels, with identifying codes given to categories at each level:

- Level 1: Eleven broad habitat groups
- Level 2: 30 habitat subgroups; and
- Level 3: 117 separate habitats

A summary of what has become known as the Fossitt Classification is shown in Table 1.2 and includes corresponding Habitat Directive Annex I habitats, where applicable. The majority of freshwater and terrestrial habitats are classified on the basis of vegetation characteristics, supplemented by references to physical environment or management aspects. Detailed descriptions of each of the habitats, including key vegetation species and physical components are provided by Fossitt (2000).

Table 1.2 Summary of Irish wetland habitats above the high spring tide mark (from Fossitt, 2000) and corresponding EU Annex I Habitats from the Habitats Directive. * indicates priority habitat types. Note that correspondence is approximate in many cases.

Fossitt Habitats			EU Annex I Habitats (Natura code)
FL *Lakes and Ponds*	**FL1**	Distrophic Lakes	Natural dystrophic lakes and ponds (3160)
	FL2	Acid oligotrophic lakes	Oligotrophic waters containing very few minerals of sandy plains (Littorelletalia uniflorae) (3110)
			Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorea and/or of the Isoëto-Nanojuncetea (3130)
	FL3	Limestone/marl lakes	Hard oligo-mesotrophic waters with benthic vegetations of *Chara* spp. (3140)
	FL4	Mesotrophic lakes	
	FL5	Eutrophic lakes	Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation (3150)
	FL6	Turloughs	*Turloughs (3180)
	FL7	Reservoirs	
	FL8	Other artificial lakes and ponds	
FW *Watercourses*	**FW1**	Eroding/upland rivers	Watercourses of plain to montane levels with the Ranunulion fluitantis and Callitricho-Batrachion vegetation (3260)
	FW2	Depositing/lowland rivers	Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation (3270)
	FW3	Canals	
	FW4	Drainage Ditches	
FP *Springs*	**FP1**	Calcareous Springs	*Petrifying springs with tufa formation (Cratoneurion) (7220)
	FP2	Non-calcareous springs	
FS *Swamps*	**FS1**	Reed and large sedge swamps	
	FS2	Tall-herb swamps	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels (6430)
GS *Semi-natural grassland*	**GS4**	Wet Grassland	*Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (Molinion caeruleae) (6410)
GM *Freshwater marsh*	**GM1**	Marsh	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels (6430)
HH *Heath*	**HH3**	Wet Heath	Northern Atlantic wet heaths with *Erica tetralix* (4010)
	HH4	Montane Heath	Alpine and Boreal heaths (4060)
PB *Bogs*	**PB1**	Raised Bog	*Active raised bogs (7110) Degraded raised bogs still capable of natural

			regeneration (7120)
			Depressions on peat substrates of the Rhynchosporion (7150)
	PB2	Upland blanket bog	Blanket bog (*if active bog) (7130)
	PB3	Lowland blanket bog	Depressions on peat substrates of the Rhynchosporion (7150)
	PB4	Cutover bog	Depressions on peat substrates of the Rhynchosporion (7150)
	PB5	Eroding blanket bog	
PF *Fens and Flushes*	**PF1**	Rich fen and flush	*Calcareous fens with *Cladium mariscus* and species of the Carision davallianae (7210)
	PF2	Poor fen and flush	
	PF3	Transition mire and quaking bog	Transition mires and quaking bogs (7140)
WN *Semi-natural woodland*	**WN4**	Wet pedunculate oak-ash woodland	*Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (Alno-padion, Alnion incanae, Salicon albae) (91E0)
	WN5	Riparian woodland	
	WN6	Wet willow-alder-ash woodland	
	WN7	Bog woodland	*Bog woodland (91D0)
CD *Sand Dune Systems*	**CD5**	Dune slacks	Dunes with *Salix repens* ssp. *argentea (Salicon arenariae*) (2170)
			Humid dune slacks
	CD6	Machair	Machairs (*in Ireland) (21A0)

1.6 Theoretical Context

To date, the majority of research relating to wetlands has focused primarily on wetlands as habitats for wildlife. However, wetlands are increasingly recognised for their importance in terms of the provision of ecosystem services, or in other words, the economic and social benefits these ecosystems provide (McInnes, 2007). As such, there is an increased need for a

more holistic understanding of these systems which include an understanding of the interaction between hydrogeological and biogeochemical processes, in addition to their biological value. In this way it will be possible to gain a more complete understanding of how these systems function in terms of hydrological services such as flood mitigation, supply of freshwater, groundwater recharge and regulation of global climate change through the release and sequestration of carbon (Mitsch, 1994). As previously discussed, there are a number of international agreements and European Directives which aim to manage and conserve wetland resources. As such four principal targets for wetland protection have been identified:

- Improving water quality (trapping and transformation of nutrients and pollutants).
- Restore or protect wetlands as habitats for plants and animals.
- Water management (flood control, water supply).
- Recreation.

(Davidson *et al*., 2007)

With increasing recognition of the value of wetlands, there is an increased need to acquire information on the current status of wetlands, and to assess the degree to which they are being degraded. Improved strategies for managing wetlands require knowledge relating to the ecological character of wetlands, the extent of wetland loss, the implementation of monitoring strategies and an evaluation of their success following implementation. In turn, this baseline information should be linked directly to the principal legislative and policy drivers in order to facilitate meeting Ireland's obligations in this regard, and to guarantee successful integration with management processes. This will provide the basis for maintaining the ecological functioning of a wetland and will ensure the sustainable use of their resources.

1.7 Overall aims and specific objectives

The principal aim of this project to investigate the hydroecological processes and pressures at wetland sites in the border counties of Ireland by examining the environmental supporting conditions required to maintain the ecosystem in a favourable state. As such this project aims to address a number of key knowledge gaps in the area of wetland research on the island of Ireland, which include the need for more baseline field data describing key hydrological characteristics and to integrate research combining the disciplines of hydrogeology,

hydrology and ecology, with particular emphasis placed on the requirements of both the WFD and the Habitats Directives. Specifically, the project aims to:

- Acquire a better understanding of the link between the hydrogeological, hydrochemical and ecological characteristics at selected case-study wetland sites, which will facilitate more intelligent and cost-effective monitoring of wetland systems and allow for more effective management measures to be put in place.
- Elucidate the locations and extent of wetland habitats in the border region by drawing on data collected during the Tellus Project in Northern Ireland and new data collected as part of the current project (Tellus Border Project), in addition to other data sources, and to create a database relating the occurrence of various wetland habitats to specific geochemical and geological environmental factors.
- Develop a working hypothesis describing key environmental supporting conditions of case-study wetlands which are required to maintain individual wetland communities, thereby allowing their sensitivity to particular anthropogenic pressures such as those associated with land use to be evaluated. This will provide a working hypothesis for the development of generalised conceptual site model (CSM) for the case-study wetlands.

1.8 Report outline

This report provides a succinct overview of the outputs of this project which addresses specific project deliverables as outlined in Table 1.1. The project involved two phases; the first of these involved a desk-based review of wetland systems which included the development of a baseline report describing the occurrence of wetlands across the border counties of Ireland. The second phase involved an intensive monitoring programme of a set of case-study wetland sites aimed to establish the hydrological and ecological dynamics within each system. These two phases of this project have been broken down into a series of tasks designed to meet project deliverables. This report aims to provide an outline of the data collected and how it was used to meet these deliverables. Additional outputs and benefits of the project are also discussed, with particular emphasis placed on the benefits for improved management and protection of wetland systems and additionally providing recommendations on future research and monitoring needs which will improve understanding of the hydroecological processes of wetlands in Ireland and further meet the requirements for implementation both the WFD and Habitats Directive.

Project Deliverable	Section	Page Number	How the deliverable has been met
A GIS database and report providing baseline data describing the extent and locations of wetlands across the border counties of Ireland.	**2**	**24-32**	• Data collated from DOENI, NPWS and Wetland Surveys Ireland to produce GIS map of wetland locations and descriptions of habitat types present at each location. • Assessed bedrock geology, groundwater vulnerability and CORINE data sets within a 1.5Km radius of either wetland point (RoI) or wetland boundary (NI). • Geological (GSI and GSNI maps) and soil geochemical data (Tellus and Tellus Border surveys) summarised for key parameters for each wetland habitat type occurring throughout border counties.
A review of the major the major threats to the quality of wetlands in the border region.	**1**	**7 - 19**	• Compiled dataset of all known surveyed wetlands in the border region of the RoI and all ASSIs containing wetland habitats in NI. Data relating to potential impacts collated for these data sets. • Current state-of-knowledge on anthropogenic activities which could potentially impact wetland systems were collated and a brief summary included in literature review. • Conceptual models of case-study wetlands includes identification of possible impacts.
A database categorising existing literature on wetlands	**1**	**7 - 19**	• Reference literature stored within electronic database. • Summary information provided in literature review
A written description of each of the selected sites with an assessment of the site quality, vegetation communities, faunal assemblages and associated hydrochemical and hydrology information.	**4**	**42 - 133**	• 14 months of hydrological, hydrochemical and ecological monitoring at each of five shortlisted representative wetland sites. • Detailed description for a set of case study sites are summarised in this report.
A system for identifying, surveying, describing sampling and identifying hydroecological processes and pressures at wetland sites which can be rolled out across the border counties.	**5**	**132 - 140**	• A framework for wetland assessment has been developed. This can be used to assist and inform monitoring programmes and supports co-ordination between the objectives of the WFD and Habitats Directive.
A generalised conceptual site model (CSM) for a set of selected case-study wetlands.	**4.5**	**106 - 131**	• Hydrological and ecological data collected over the monitoring period for case-study sites was used to inform the development of conceptual models for each of the sites. These models aim to summarise the complex interactions occurring at each site, and provide a summary of the current understanding of the processes occurring. • Conceptual Site Models for the case study sites are summarised in this report.
Contribute to UK, Irish and European wetland research and improve public understanding of this important resource.	**8 & 9.3**	**150 – 152, 155 - 156**	• The research undertaken provides baseline data on the hydroecological process and pressures at wetlands sites in the border counties of Ireland. Data collected on a series of case study sites allowed the development of a working hypothesis

			describing key environmental processes and represents one of the few intensive hydroecological monitoring of wetland sites within Ireland which integrates the disciplines of hydrology, geology and ecology. Emphasis has been placed throughout this project on disseminating the outcomes to scientists, stakeholders, policy makers and the public through a range of methods, including both oral and poster presentations at both national and international events, attendance at scientific workshops and symposium, face to face meetings with relevant stakeholders, landowner consultation, media articles and online blogs and participation in a variety of public outreach events.
Provide support to policy makers in dealing with increasing anthropogenic pressures on wetlands which will inform development of consistent trans-jurisdictional policies	**6**	**141 - 145**	• Key deliverables from this project include the provision of information on the occurrence of wetlands in relation to a range of geochemical and geological characterisation in the border region, the development of a framework for the assessment of wetland habitats which will support meeting the RoIs and NIs obligations with regards the implementation of the WFD and Habitats Directives and the provision of baseline data on the current status of wetlands and as assessment of the degree to which they are being degraded and adds to baseline data which needed on the full range of Irish wetlands.
Recommendations on future research and monitoring needs to improve understanding of the hydrogeological processes of wetlands in Ireland.	**7**	**146- 149**	• Key recommendations and guidance for policy makers, water managers and other stakeholders are set out in this report. • In addition knowledge gaps have been identified which can form the basis of future work.
Development of teaching material for undergraduate and postgraduate teaching programmes	**9.2**	**154 - 155**	• Building capacity and expertise was an important part of the activities of this project. Data collected during the course of this project formed the basis of a number of postgraduate and undergraduate research projects both in QUB and DkIT. • In addition, course material relating to wetland habitats based on the data collected over the course of the project and the field instrumentation set up at a number of sites has been included in the newly developed Wildlife and Habitat Ecology module forming part of the BSc. in Applied Bioscience programme.

2. Overview of wetlands in the Border Region

Wetlands occur over large areas of the RoI and NI and are generally located where high water table or high rainfall create either permanently or frequently water logged conditions. The type of wetland which develops in a particular landscape setting will be determined by a range of factors, including underlying geological and geochemical conditions.

Geochemical data generated through the INTERREG IVA-funded Tellus Border project and its predecessor the Tellus Project (2004-2007) was used, in conjunction with a range of data already available from a variety of sources (e.g. soil and subsoil data from Teagasc and the Agri-food and Bioscience Institute (AFBI), bedrock geology data from GSI and GSNI) to relate the occurrence of different wetland types in the border region of Ireland to various geological and geochemical conditions. The Tellus Border geochemical survey collected samples of soil, stream water and stream sediment from random locations every 3.5 km^2 across the border region of the RoI between 2011 and 2012. The samples were then analysed for a range of elements and inorganic compounds using X-ray fluorescence spectrometry and inductively-coupled plasma spectrometry (ICP -OES/-MS) following *aqua regia* digestion for stream sediments and topsoil samples, respectively (details of which are available at (www.tellusborder.eu/). Loss on Ignition (LOI) was measured as a proxy for carbon content following combustion at 450 °C. The Tellus samples were collected between 2004 and 2006, with soil and subsoil and stream sediment samples taken every 2 km^2 and analysed using X-ray fluorescence spectrometry and ICP. This Tellus Border and Tellus geochemistry data set was used to assess key geochemical parameters occurring within a 1.5 km radius of over 2,000 known wetland habitats within the border counties of Ireland. The distribution of these wetlands can been seen in Fig. 3.1 in Section 3 of this report. The data used in this analyses for NI and the RoI can be accessed via the following links; http://bit.ly/TB77jZ and http://bit.ly/1kagvEV, respectively.

Wetland habitats within the border counties were found to occur over a range of different geological and geochemical environmental conditions and were particularly influenced by their underlying geology. For example in the Northern Ireland data set, marl lakes occurred only in areas where limestone and sandstone/slates/shales occur. Other more frequently encountered habitats such as wet heath and wet grassland are present over a wider range of underlying geology (Fig. 2.1).

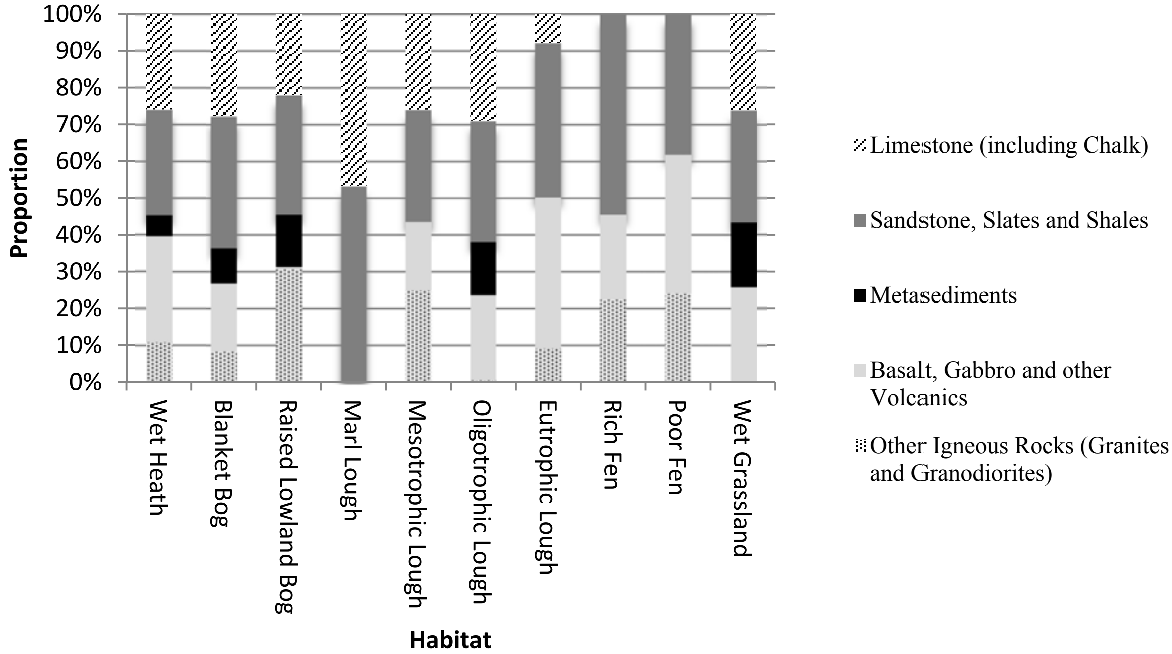


Fig. 2.1 Summary of underlying bedrock for a number of wetland habitat types that exist within Areas of Special Scientific Interest in Northern Ireland.

The occurrence of wetland habitats in the border region in relation to topsoil geochemical parameters showed significant difference among wetland habitats in their occurrence in relation to the geochemical characteristics. For example, as expected, the highest LOI values in the RoI data sets were observed in bogland habitats such as blanket bogs and raised bogs, as did habitats which are typically associated with peatland environments (such as poor fen, dystrophic lakes and wet heath) (Fig. 2.2). Nevertheless, blanket bog and raised bog differed significantly in LOI content, pH, aluminium (Al), manganese (Mn) and phosphorous (P) content of their topsoils, despite the fact that both are acidic bogland habitats, with raised bogs occurring in areas with lower LOI content and higher values of pH, Al, Mn and P than blanket bogs.

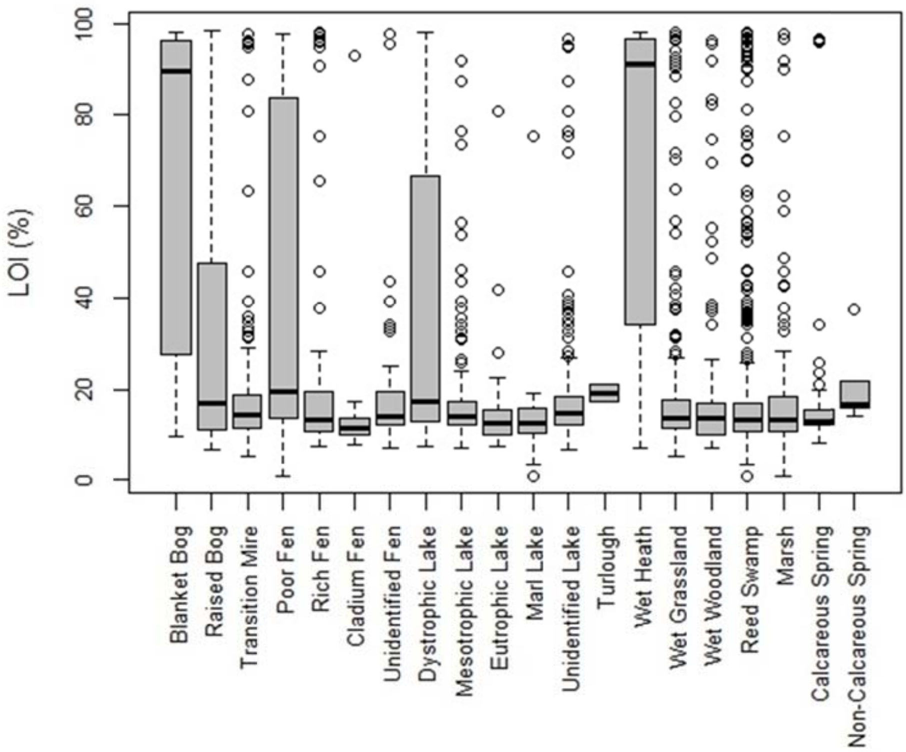


Fig. 2.2 Comparison of topsoil loss on ignition (LOI) across different wetland habitat types in the Republic of Ireland border counties using the Tellus Border geochemical dataset. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

Habitats such as marl lakes, cladium fen and rich fen, which are typically alkaline and where higher calcium concentrations would be expected, did not necessarily occur in areas with higher Ca values compared to other wetland types apart from blanket bog and wet heath habitats (Fig. 2.3). Other habitats typically found in limestone and alkaline environments, such as cladium fens and turloughs occurred in regions with the highest topsoil pH values (Fig. 2.4). Interestingly, there were relatively low pH values recorded within 1.5 Km of marl lake habitats despite the generally alkaline bedrocks underlying marl lake environments, with particularly low pH values observed in Co. Sligo in comparison to other counties in the border region. Calcareous springs and turloughs, however, tended not to differ significantly in any parameter from other wetland habitats, which was likely due to the small sample size for these two habitats, with only one turlough recorded in the RoI border counties.

Aluminium concentrations show wide variation across all habitats and are generally highest for cladium fen and transition mire habitat and lowest for wet heath (Fig. 2.5). Topsoil iron (Fig. 2.6), manganese and phosphorous (Fig. 2.7) content are typically significantly lower for acidic habitats such as blanket bog, poor fen, and wet heath than other habitats.

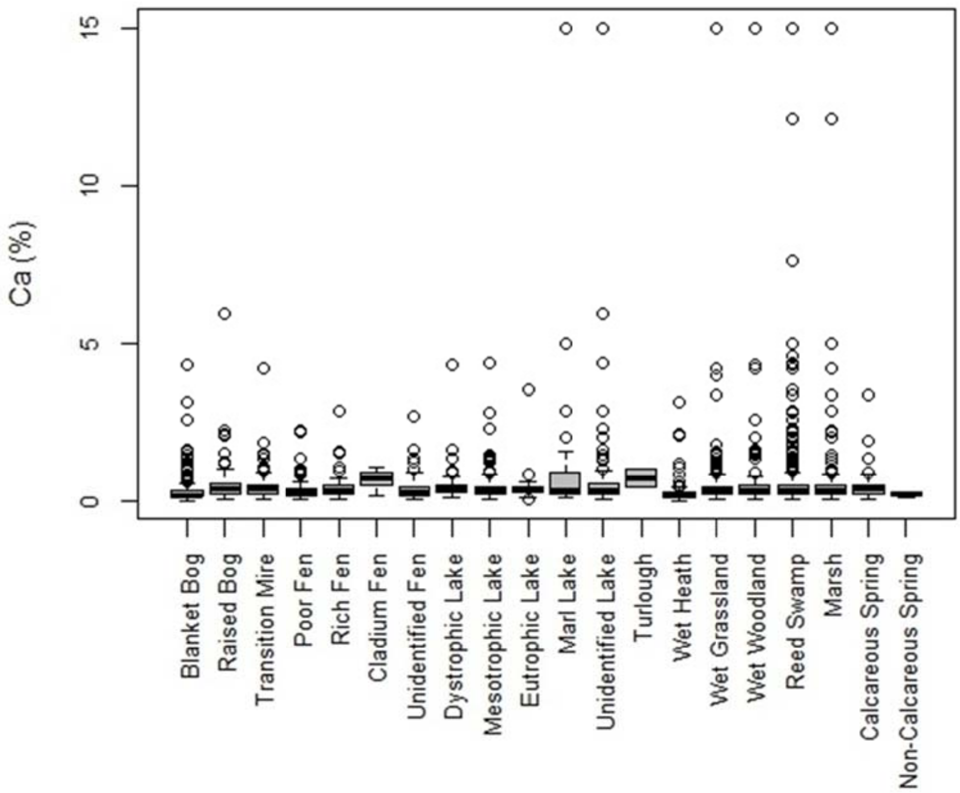


Fig. 2.3 Comparison of topsoil calcium (Ca) across different wetland habitat types in the Republic of Ireland border counties using the Tellus Border geochemical dataset. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

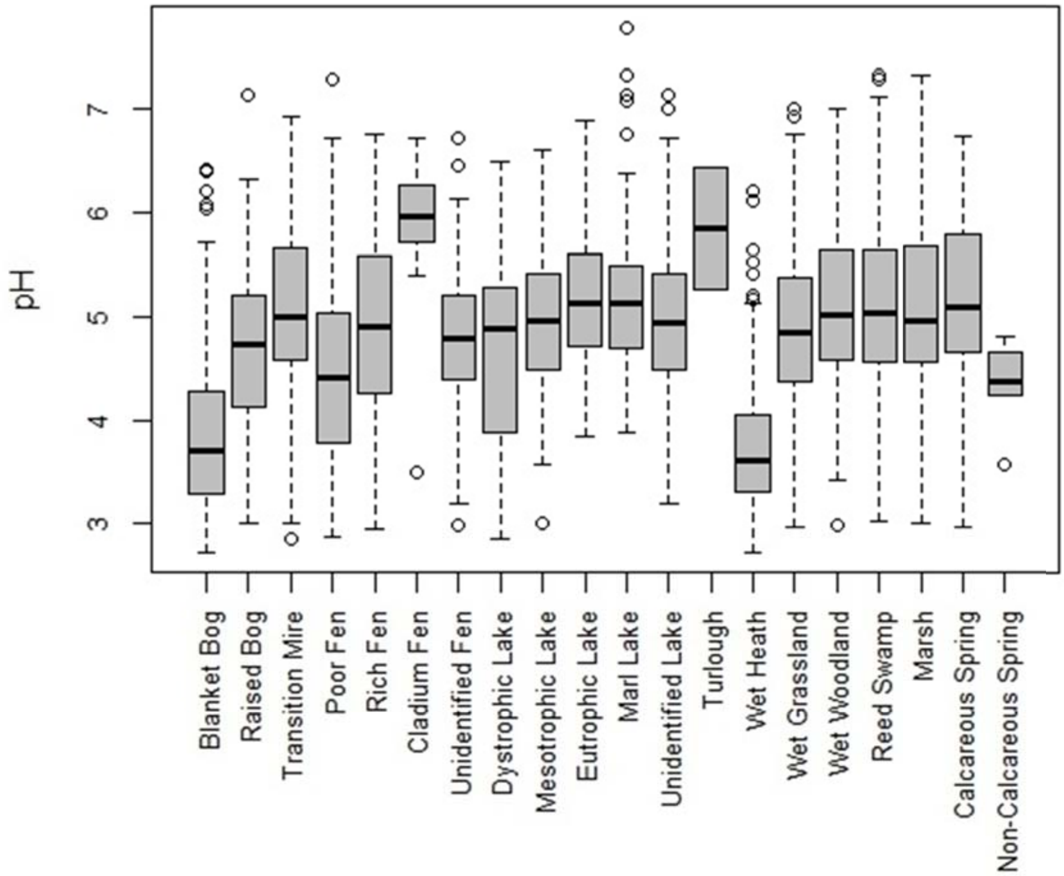


Fig. 2.4 Comparison of topsoil pH across different wetland habitat types in the Republic of Ireland border counties using the Tellus Border geochemical dataset. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

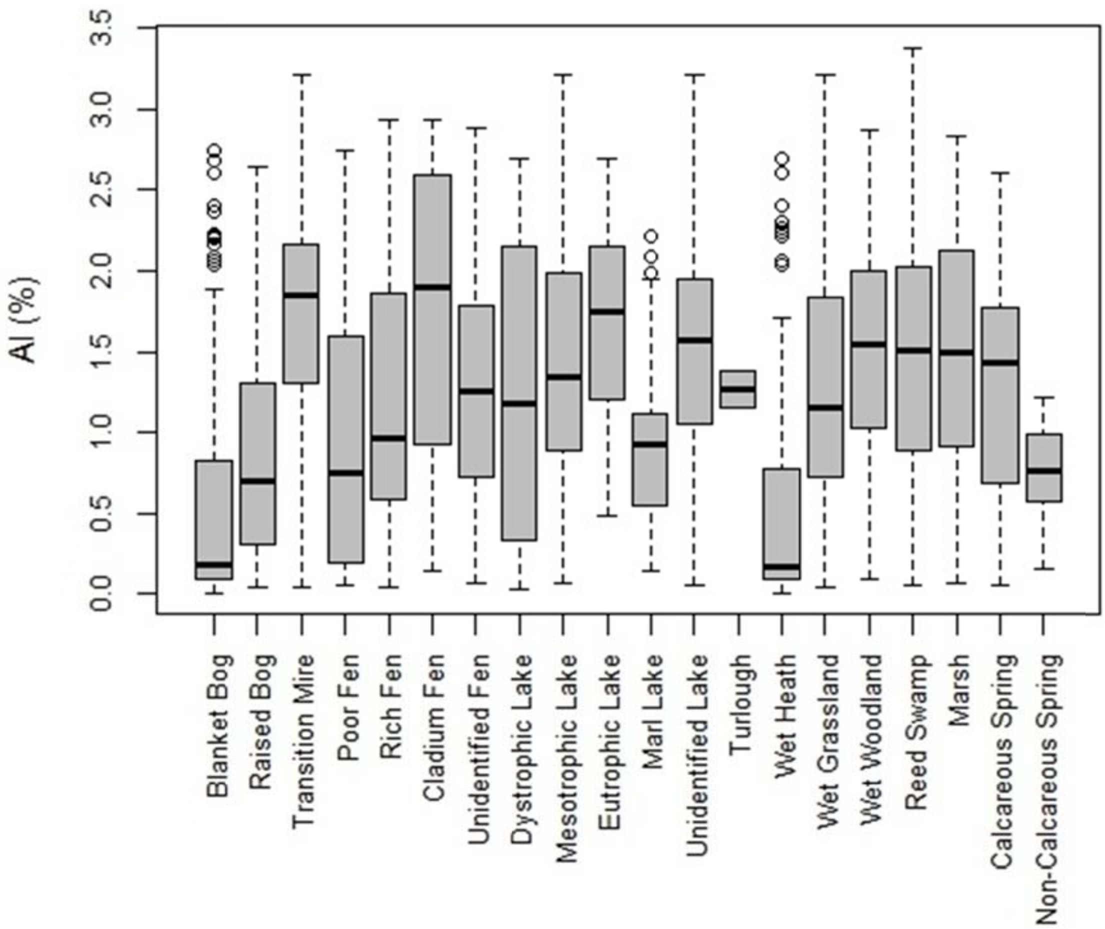


Fig. 2.5 Comparison of topsoil aluminium (Al) across different wetland habitat types in the Republic of Ireland border counties using the Tellus Border geochemical dataset. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

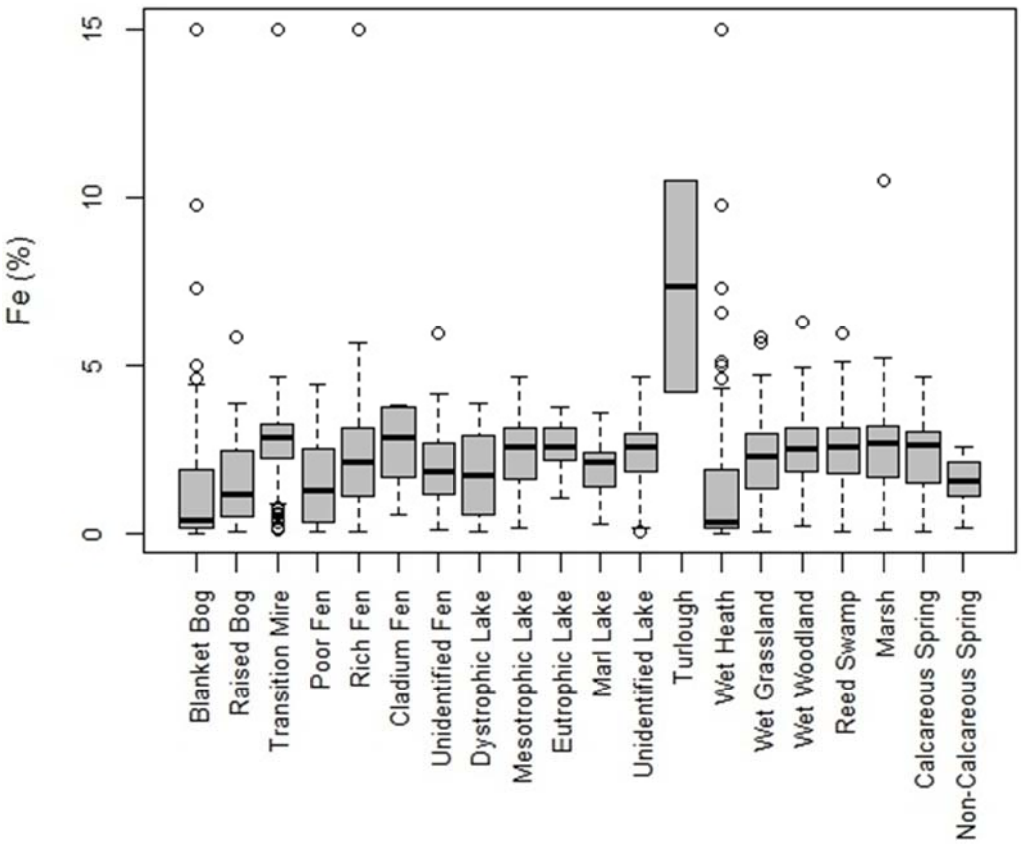


Fig. 2.6 Comparison of topsoil iron (Fe) across different wetland habitat types in the Republic of Ireland border counties using the Tellus Border geochemical dataset. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

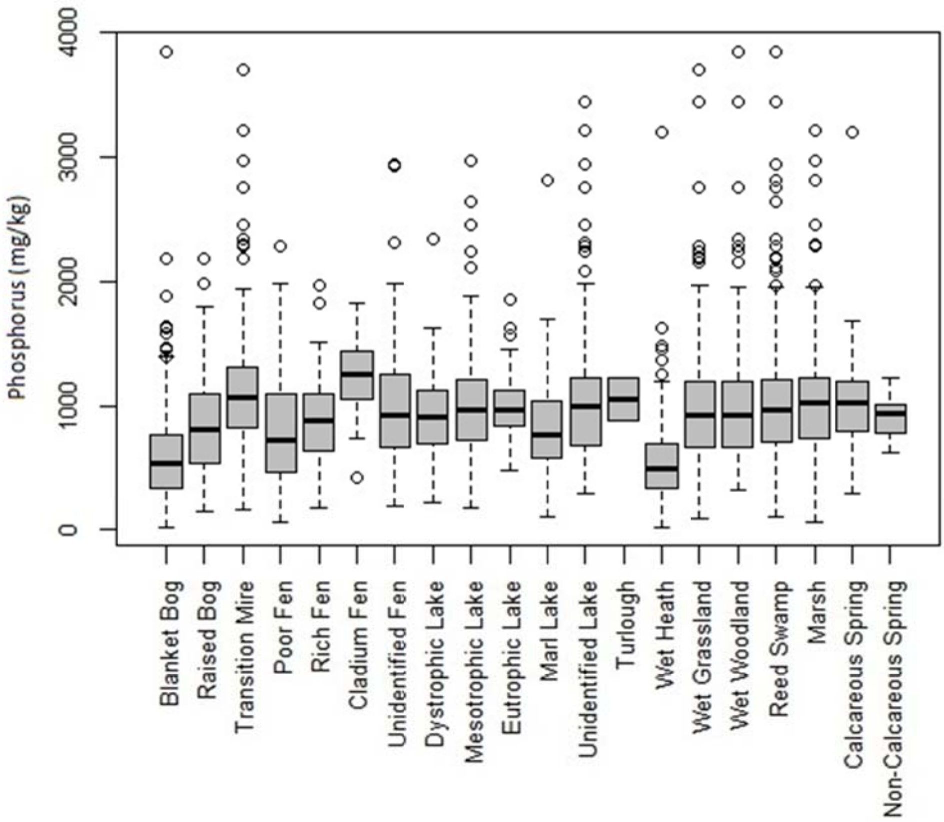


Fig. 2.7 Comparison of topsoil phosphorous (P) across different wetland habitat types in the Republic of Ireland border counties using the Tellus Border geochemical dataset. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

In addition, topsoil geochemistry was assessed for specific wetland habitats occurring within individual counties of the border region. A regional variation in topsoil geochemistry was observed for given wetland habitat types, with generally significant differences observed between counties for the vast majority of geochemistry parameters for all wetland habitats. Typical patterns observed are the general increase in values of geochemical parameters with geographical location from Donegal and Sligo in the northwest/west, to Louth in the East. The only parameter that did not generally follow this geographical pattern is LOI in which Donegal frequently had the highest values, particularly for more acidic habitats such as blanket bog and transition mire. As an example, in blanket bog habitats in the RoI border counties, Al and pH levels were highest in counties Louth and Monaghan, whilst these counties have the lowest median values of LOI for the same habitat type (Fig. 2.8).

In the RoI border counties, for wetland habitats that are relatively common, such as wet grassland, there was a greater variation in geochemical parameters across geographical region, reflecting the wide variety of soil types within which these habitats likely occur. For less common habitats such as marl lakes and calcareous springs, there was less variation. Indeed, non-calcareous springs were only recorded in Co. Sligo and values of the majority of geochemical parameters are typically lower for this habitat in comparison to calcareous springs.

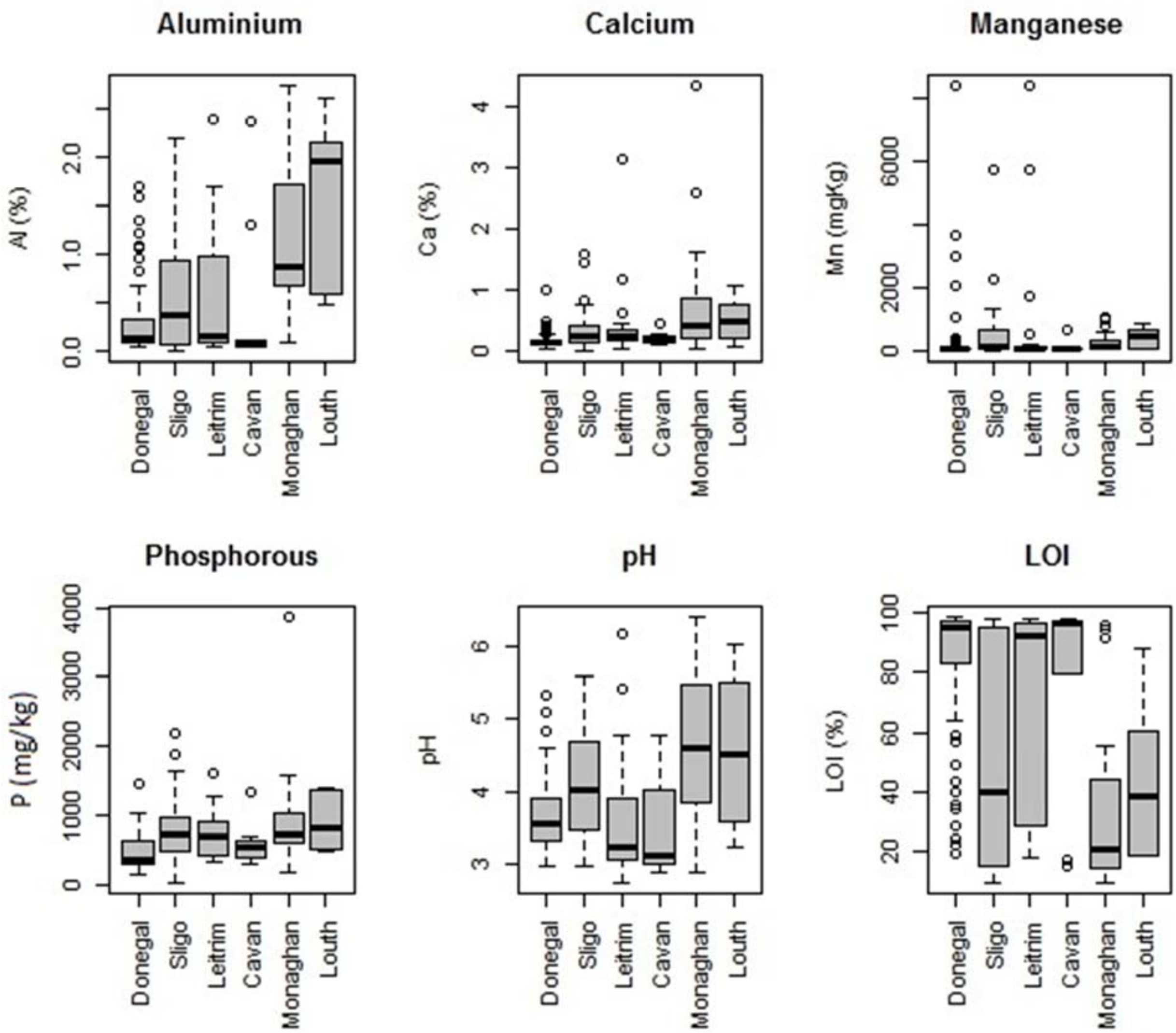


Fig. 2.8 Levels of key topsoil geochemical parameters present within 1.5 Km Ireland blanket bog habitats in each of the border counties in the Republic of Ireland. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

3. Site Selection of Case Study Sites

A number of specific sites considered to be suitable for further investigation and considered representative of the main wetland types in the border region were selected for intensive monitoring. Sites for further investigation were selected from a range of protected sites including Special Protected Areas (SPAs), Special Areas of Conservation (SACs), Areas of Special Scientific Interest (ASSIs: Northern Ireland only) and National Heritage Areas (NHAs: Republic of Ireland only) (Fig. 3.1), and any other sites which had previously monitored or surveyed, but did not necessarily have designated status. This included sites which had been surveyed as part of Local Authority wetland survey programmes. Data was collated for over 2,000 known wetland habitats, and a selection matrix applied to shortlist wetlands for further investigation.

Table 3.1 Final five wetland sites shortlisted sites selected for further investigation.

Site Name	Site Code	County	Coordinates	Site Area (Ha)	Wetland Habitat Type
Kilroosky Lough	KL	Fermanagh/ Monaghan	24º 95' 64'E, 32º73'75'N	23.53	Marl Lough
Greenan Lough	GL	Down	31º 18'79'E 32º32'79'N	18.24	Mesotrophic Lough
Loughaveely	Ly	Armagh	29º54'67'E, 31º41'57'N	4.73	Fen
Windy Gap	WG	Louth	31º30'96'E 31º33'82'N	5.48	Cutover Blanket Bog
Rockmarshall	Rock	Louth	31º16'27'E 30º82'07'N	23.00	Transition Mire and Fen

Following this shortlisting process approximately 34 sites were selected for preliminary scoping visits and samples taken where necessary to assess their suitability as potential sites. The availability of historical baseline data from previous scientific or monitoring programmes was a major consideration in site selection. A number of other criteria were also used in the site selection process including significance of the site with respect to its conservation designation, consideration of known damage or potential for impact from anthropogenic activities where poor water quality issues may have previously arisen, consideration of the possible presence of sensitive habitats or species at the site. The final selection of sites including the number and range of types investigated was dependent on input from the Technical Advisory Group (TAG). On completion of the site selection process which is summarised in Fig. 3.1, five sites with a range of habitat types were selected (Table

3.1; Fig. 3.2). A summary of the CORINE landuse categories within each of their catchments provided in Table 3.2.

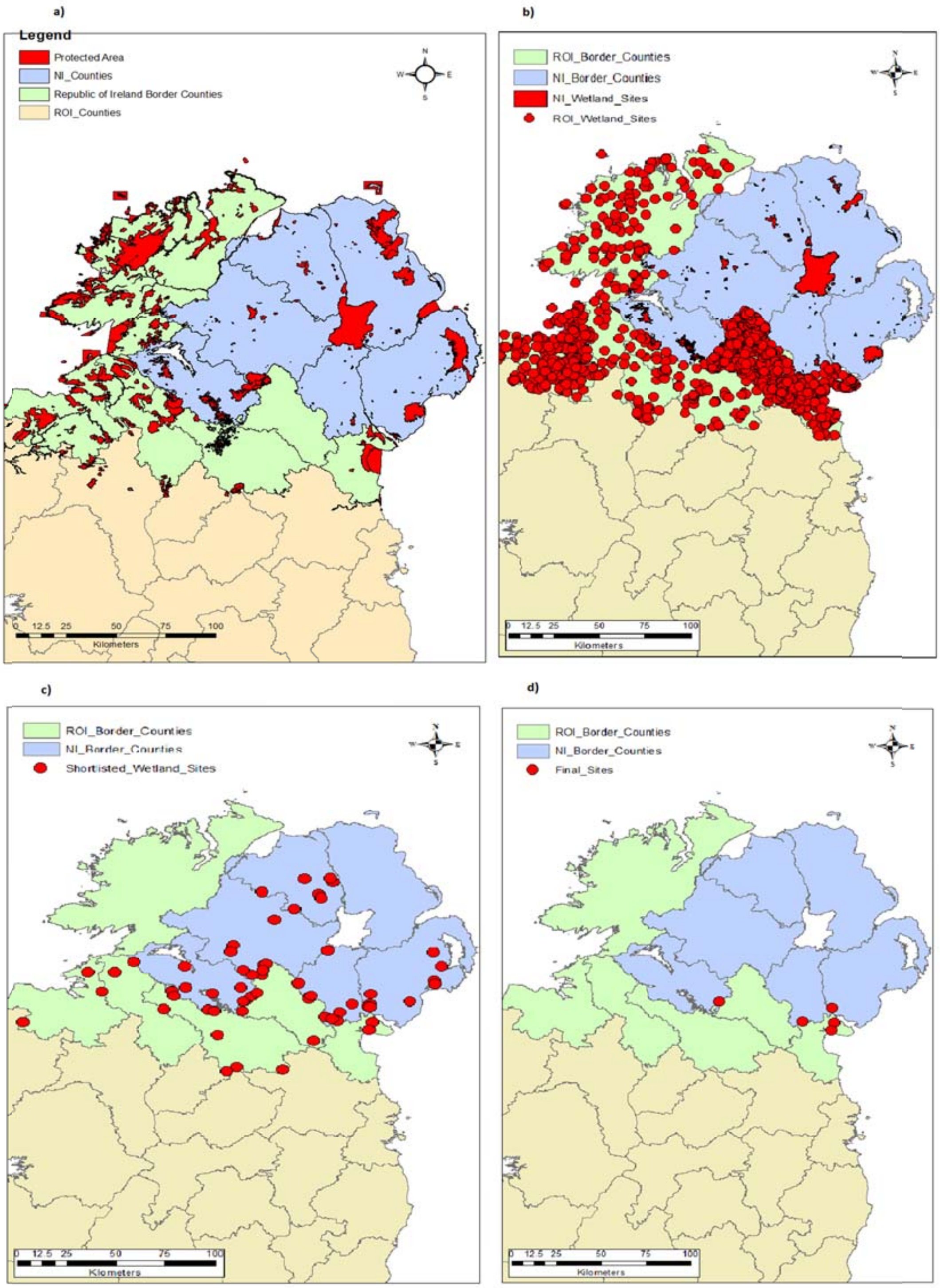


Fig. 3.1 The process of shortlisting wetland sites for further investigations; a) shows all protected areas in the Republic of Ireland (RoI) and Northern Ireland (NI) border counties, including Special Protected Areas (SPAs); Special Areas of Conservation (SACs); Areas of Special Scientific Interest (ASSI) and National Heritage Areas (NHAs) b) includes all ASSI sites in NI containing wetland habitats and all known/surveyed wetland habitats in the RoI border counties, c) 60 sites were included for potential further investigation and the second phase of shortlisting, d) final five sites chosen for further investigation. Data collated from the DOENI, NPWS and Wetland Surveys Ireland.

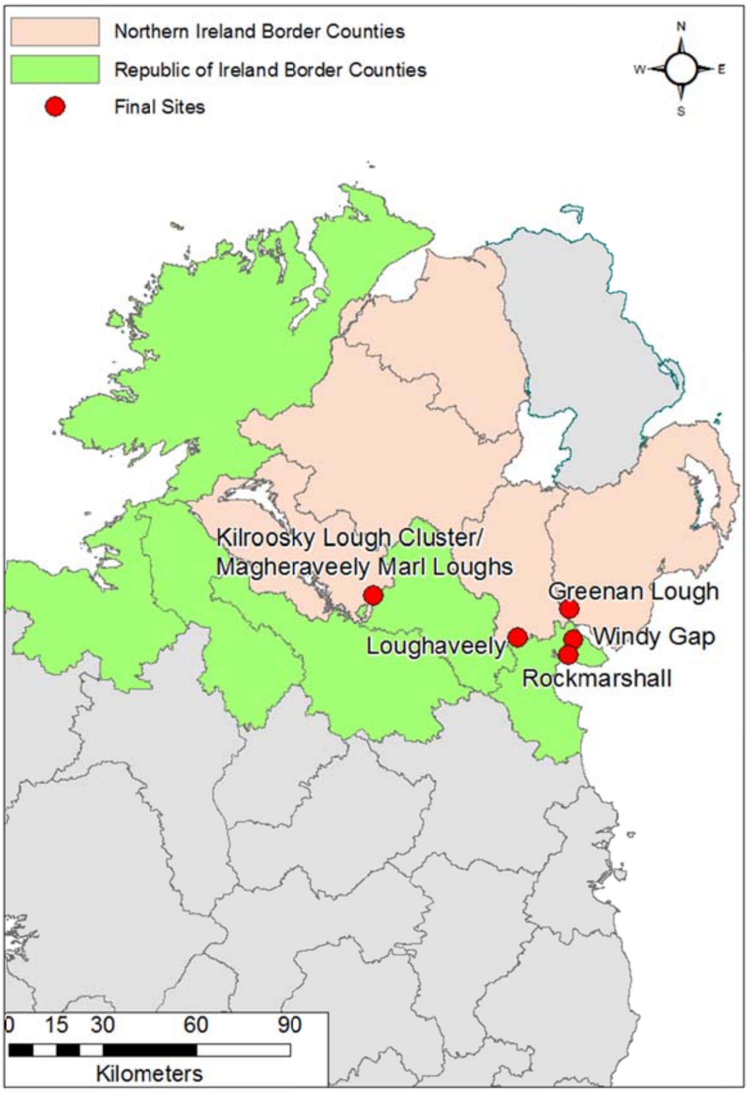


Fig. 3.2 Location of five sites Selected for further investigation.

Table 3.2 CORINE land use within the catchments of the final five shortlisted sites.

Site	Catchment Area (Ha)	Proportion of CORINE Land Use Category: Pasture	Other significant CORINE Land Use Categories within catchment (%)
Kilroosky Lough	55.77	100	NA
Greenan Lough	197.83	100	NA
Loughaveely	150.98	100	NA
Windy Gap	119.67	0	Natural Grasslands (67.61) Peat Bogs (32.39)
Rockmarshall	427.31	31.53	Coniferous Forest (29.81) Peat Bogs (18.70) Complex Cultivation Patterns (16.30)

4. Case Study Wetland Sites

4.1 Field and Laboratory Sampling and Analyses Methodology

4.1.1 Surface Water Sampling

All five case study sites were monitored once a month, between June 2012 and August 2013. Samples of surface water for phyiso-chemical characteristics were collected at each site from inflow points, outflow points and standing water (where present). The number of surface water samples, therefore, varied depending on the hydrological features of the site. A handheld GPS was used to record the location of each of the sampling sites, which are summarised in Section 4.2. Stream and river grab samples were obtained from mid-stream and mid-depth. Flow velocities were measured at each site using a current meter (FP101-FP201 Global Flow Probe, Global Water®). At standing water sites, samples were obtained from the open water zone beyond the edge area dominated by emergent vegetation using a weighted 5 litre plastic bottle which was attached to a rope and thrown from the shore. Conductivity, pH and dissolved oxygen were measured on-site during sampling using a YSI® multiprobe (Model 556 MPS). All samples were collected in 1 L acid washed, deionised water-rinsed polypropylene containers transported to the laboratory in cooled insulated boxes and stored at 4 °C before analyses within 48 hours of collection.

4.1.2 Groundwater Sampling

Groundwater was monitored on a monthly basis at the Rockmarshall site in Co. Louth which is a groundwater dependent transition mire and fen from November 2012 to August 2013. In October 2012, piezometers were installed throughout the site at locations considered suitable for hydrogeological assessment and which were considered likely to follow groundwater flow based on typological features of the site. As such, a group of three piezometers (piezometers GW1 - GW9) were installed in each of the three liner wetland habitats, so as to determine the horizontal direction of groundwater flow, which requires water level measurements for three or more wells to the same level in the ground. A graphical method can then be applied in order to determine horizontal gradient and the direction of groundwater flow within the area surrounded by the three wells. At a later date (January 2013), a further four piezometers (piezometers GW10 – GW13) were installed in order to elucidate a number of queries which had arisen following initial examination of the data. Consequently, piezometer GW12 was installed adjacent to the stream which runs through the site in order to examine groundwater

and surface water interactions and piezometers GW11 and GW12 were located near the northern boundary of the site to examine potential input of nutrients entering the site via shallow groundwater flow, which may have arisen from nearby domestic onsite wastewater treatment systems. The locations of these piezometers are shown in Section 4.2.5 of this report (Fig. 4.19). The piezometers were installed by drilling boreholes of varying diameters (5 cm, 6.3 cm and 7.5 cm) using a window sampler gouge driven by a percussion hammer to a depth of approximately 1 – 2 m below the top of the saturated zone. Into these boreholes, rigid high-density 24 mm diameter polyethylene tubing was inserted. A closed point was fitted at the bottom and a removable cap at the top. The annulus separating the walls of the borehole and the perforated lower part of the tubing was filled with clean filter sand. The void around the upper portion of the tubing was sealed with bentonite to prevent the direct ingress of surface water through the borehole. Each piezometer was covered at ground level with a re-sealable cap and covered with a cavity concrete block to protect it from damage by machinery or grazing animals. A schematic detail of a piezometer installation is provided in Fig. 4.1. Depth to the water table from the land surface was measured over the sampling period in each well just before pumping using an electrical water level meter to determine the seasonal fluctuation of water in the vicinity of each system.

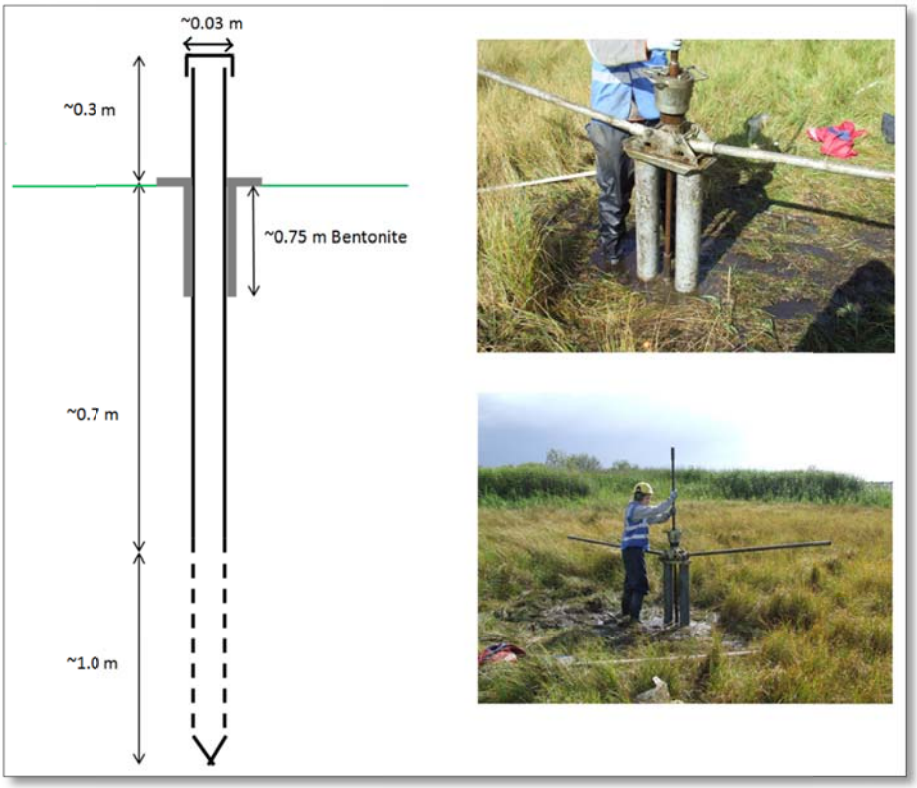


Fig. 4.1 Installation of piezometers at Rockmarshall, showing schematic detail of a typical piezometer.

Shallow groundwater samples were extracted from the piezometers using a peristaltic pump. To ensure representative samples were obtained, all piezometers were purged of approximately two well volumes prior to sample collection. Samples were collected in 1 L acid washed, deionised water-rinsed polypropylene containers and transported to the laboratory in cooled insulated boxes and stored at 4 °C before analyses within 48 hours of collection. Pump tubing was replaced with either new or sterilised silicon and polyethylene tubing between individual well sampling. Conductivity, pH and dissolved oxygen were measured on-site during sampling using a YSI® multiprobe (Model 556 MPS).

In addition, gauge boards were installed at three locations in Rockmarshall and were used to monitor the surface water level in the stream (RockS2), and two of the three saturated wetland areas at the site (Wetland 1 and Wetland 3). Three level and temperature minidivers were installed into piezometers (GWS3, GWS6 and GWS9 in January 2013 to monitor fluctuations in the water table level. One baro diver which is designed to measure the atmospheric (barometric) pressure for a particular area was installed into GWS9 in January 2013, and used in combination with the minidiver data to more accurately record water level readings. A summary of the equipment installed at Rockmarshall and an estimate of the overall costs using the techniques described above are given in Table 4.1.

Table 4.1 Summary of costs associated with instrumenting Rockmarshall, Co. Louth to assess groundwater and surface water interactions.

Equipment	Cost
Drill Rig	€14,800
Weather Station	€700
Piezometers	€318
Divers: 3 x Mini Diver 1 X Baro Diver Readout Unit Readout Cable DiverMate	 €2,148 €400 €266 €157 €347
Labour (installation 2 person X 3days)	€1,500
Total	**€19,086**

4.1.3 Wetland Biota

Sampling for macroinvertebrates was carried out on four occasions each year corresponding to Spring, Summer, Autumn and Winter seasonal periods. Macroinvertebrates were collected from the littoral zone of the open water areas of the wetlands and from a number of

stream/river locations at each site. Therefore, the number of macroinvertebrate samples varied per site depending on individual site characteristics.

A hand-held pond net with a 1 mm mesh size was used to collect the samples at a maximum depth of 10 – 40 cm deep. 1 minute sweep sampling was used to catch a representative sample of fauna, by disturbing the sediment beneath the samplers feet and sweeping the net sideways back and forth through the disturbed path. Samples were stored in 90 % industrial methylated spirits (IMS) in labelled storage bottles. Samples were then sorted in the laboratory and individual organisms removed from the sample and stored in sample vials containing 90 % IMS and grouped according to their taxonomic Order. The animals were subsequently identified under dissection microscope to the lowest taxonomic level possible using Freshwater Biological Association (FBA) taxonomic keys.

Zooplankton were collected from the open water at each site on a monthly basis using a 53 µm mesh size net. The net was thrown from the shore as far as possible and drawn horizontally through the water. After collection zooplankton were transferred to a 500 ml storage jar and narcotised and stored in 90 % IMS. Zooplankton taxa were identified under a dissecting microscope. The mean of four well-mixed 5 ml sub-samples were taken from a known volume of sample using a wide-bore pipette (Bottrell *et al.*, 1976) and placed on a Ward Counting Wheel and identified to the lowest taxanomic level possible following Scourfield & Harding (1966), Harding & Smith (1974), Ruttner-Kolisko (1974), Pontin (1978) and Reddy (1994).

Data for vegetation analyses have been derived from two sources depending on the data availability for different sites. For sites occurring whole or in part in Northern Ireland (Kilroosky Lough, Greenan Lough and Loughaveely), data on species presence is available from the UK National Biodiversity Network Gateway (https://data.nbn.org.uk/).

Data for the Republic of Ireland sites (Windy Gap and Rockmarshall) were collected through quantitative vegetation surveys undertaken by Dr. Peter Foss and Dr. Patrick Crushell through Wetland Surveys Ireland on behalf of the Tellus Border Wetland Project conducted between the 20 and 21 September 2013. These quantitative surveys represent the first detailed vegetative surveys undertaken at each of these sites. The distribution and extent of the

vegetation types were mapped using quadrats (relevés) 2 x 2 m in size, of different vegetation types on the site which were recorded digitally on a field computer. Cover and abundance values were recorded using Domin cover abundance scale (1 to 10) outlined in Table 4.2. A photographic record of each quadrat was taken. Plant species nomenclature followed Stace (1997) and Parnell and Curtis (2012) for vascular plants, Smith (2004) and Atherton (2010) for mosses and liverworts and Dahl (1968) and Whelan (2011) for lichens.

Table 4.2 Domin scale used to record vegetative cover and abundance.

Scale	Description
1	<4 % cover, with few individuals
2	<4 % cover, with several individuals
3	<4 % cover, with many individuals
4	4 – 10 % cover
5	11 – 25 % cover
6	26 – 33 % cover
7	34 - 50% cover
8	51 – 75 % cover
9	76 – 90 % cover
10	91 – 100 % cover

4.1.4 Weather Data

Records of air temperature and total precipitation were obtained from a Met Éireann weather station located in Ballyhaise, Co. Monahgan.

4.1.5 Estimation of nutrient loading

Land use pressure in wetland catchments were determined by estimating diffuse nutrient loading from the surrounding catchment (McKernan, 2013). This was done by collated data on livestock density per District Electoral Division (DED) in the RoI (CSO, 2000) and livestock density per electoral Ward in NI (Northern Ireland Statistics and Research Agency), which provided an indication of the loads from grazing. The data on livestock units were directly applied to areas of 'grazing' identified through CORINE (2000) land use data. To account for the nutrient production rates from these diffuse sources of nutrients, estimates of excretion levels from sheep, beef cattle and dairy cows were obtained from the literature (Teagasc, 2010; Good Agricultural Practice for Protection of Waters, 2010) and multiplied by the total number of cattle and sheep in each DED/Ward. In a similar way estimates of annual nutrient application rates (Teagasc, 2010) to cereal and root crops were multiplied by the total

area of arable land identified through CORINE (2000) data. Further information on the methodology applied to these calculations can be found in McKernan (2013).

4.1.6 Laboratory analyses

All water samples were analysed within 48 hours of collection. Dissolved nutrient analyses (soluble reactive phosphorus (SRP) and dissolved inorganic nitrogen (DIN; nitrate (NO_3^--N) + nitrite (NO_2^--N) + ammonia (NH_3^+-N)) were made on water filtered through 0.45 µm Whatman® membrane filters. Phosphorus and nitrogen analyses were carried out colometrically using a flow injection auto-analyser (Lachat Quickchem®, Lachat Instruments, Loveland, Colorado, USA). Nitrate and nitrite, SRP and ammonia were determined following QuickChem® Methods 10-107-04-1-R, 10-115-01-1-V and 10-107-06-2-L, respectively. Samples for total phosphorus (TP) were analysed after digestion under pressure with potassium peroxide sulphate ($K_2S_2O_8$) and analysed following QuickChem® Methods 10-107-04-4-B and 10-115-01-4-J, respectively.

Sulphate (SO_4^{2-}) and chloride (Cl^-) concentrations were determined by ion chromatography (Clesceri *et al.*, 1989) using a Dionex® ICS-2000 system (electrochemical suppressed conductivity system with an anion exchange column). Sodium (Na^+), potassium (K^+), iron (Fe^{2+}) and calcium (Ca^{2+}) concentrations were measured by atomic absorption (Clesceri *et al.*, 1989). Alkalinity was analysed on 50 ml of an unfiltered sample of water by Gram titration according to Mackereth *et al.* (1978). Suspended solids and suspended particulate organic matter were obtained following Allen (1989). Dissolved Organic Carbon was analysed on samples filtered through 0.45 µm Whatman® membrane filters and analysed using a UV promoted persulfate oxidation method detected on a TOC analyser (Sievers® 5310C Laboratory TOC Analyzer), using a nondispersive infrared detector following Potter and Wimsatt (2005). Chlorophyll *a* analyses were carried out on 1 L triplicate samples from each of the open water samples at each site filtered through Whatman® GF/C filters and extracted with methanol (Standing Committee of Analysts, 1983), with absorbance read on a spectrophotometer at 665 and 750 nm in a 5 cm cell.

4.1.7 Quality control

For all phosphorus and nitrogen analyses, quality control (QC) samples of known concentration were used to assess the performance of the analytical methods employed.

Standard solutions for use as QC samples in N and P analyses were prepared with reagents which were independent to those used for the construction of standards, and therefore provided a degree of quality assurance as well as QC. For nitrate, nitrite and ammonia analyses a QC with a concentration of 0.5 mg L^{-1} as N was prepared, for phosphorus analyses a QC concentration of 0.2 mg L^{-1} PO_4-P was used. All quality assurance values were within acceptable ranges (± 3 %).

4.2 Overview of Geological and Geochemical Setting of Case Study Sites

The five sites selected for further investigation covered a range of wetland habitat types with varying underlying bedrock geology and soil geochemical settings and landuse practices in the surrounding catchment.

4.2.1 Kilroosky Lough

Kilroosky Lough (Fig. 4.2 and 4.3) is a marl lough situated approximately 2 km north of the town of Clones, County Monaghan (24º 95' 64'E, 32º73'75'N), and is bisected by the border of Northern Ireland and the Republic of Ireland. The lake is situated in the Erne catchment, which drains into Upper Lough Erne. The site is located within a designated SAC in the Republic of Ireland and an ASSI in Northern Ireland and is protected as a result of its physiography and its associated wetland flora and fauna (DOENI, 1985). The lake is predominantly spring-fed with calcium-rich water which is reflected in the vegetation communities occurring within the site. An extensive stonewort (Charophyte) community exists within the lake and the white-clawed/atlantic stream crayfish (*Austropotamobius pallipes*) is also present. Large floating stands of yellow water lily (*Nuphar lutea*) and white water lily (*Nymphaea alba*) also occur. The emergent vegetation includes a fringe of common club-rush (*Schoenoplectus lacustris*) backed by a tall swamp of common reed (*Phragmites australis*), great fen sedge (*Cladium mariscus*) and tufted sedge (*Carex elata*). Several rare plant species occur, including marsh helleborine (*Epipactus palustris*), fen pondweed (*Potamogeton coloratus*), fen bedstraw (*Galium uliginosum*) and the bee orchid (*Ophris apifera*) (DOENI, 1985).

Fig. 4.2 Kilroosky Lough from the southern shore.

The bedrock underlying the catchment of Kilroosky Lough consists of Ballyshannon Limestone and Drumgesh Shale (Fig. 4.4). The soils are predominantly derived from limestone and limestone till with fen peat and bog also contributing. The cross border position of the site and the different classifications of soil types used on either side of the border make it difficult to draw comparative summaries of the site (Fig. 4.5). Formatting errors in ArcGIS resulted in an inability to calculate subsoil/superficial soil proportions within the catchment. However, the subsoils/superficial soils are predominantly fen peat and till derived from limestone in the RoI, and Diamicton Till in NI (Fig. 4.6). In the RoI the aquifer bedrock is classified as a locally important aquifer within a generally productive bedrock and in Northern Ireland as highly productive, fracture flow with a karstic element (Fig. 4.7). Groundwater vulnerability on both sides of the border is classified as Moderate.

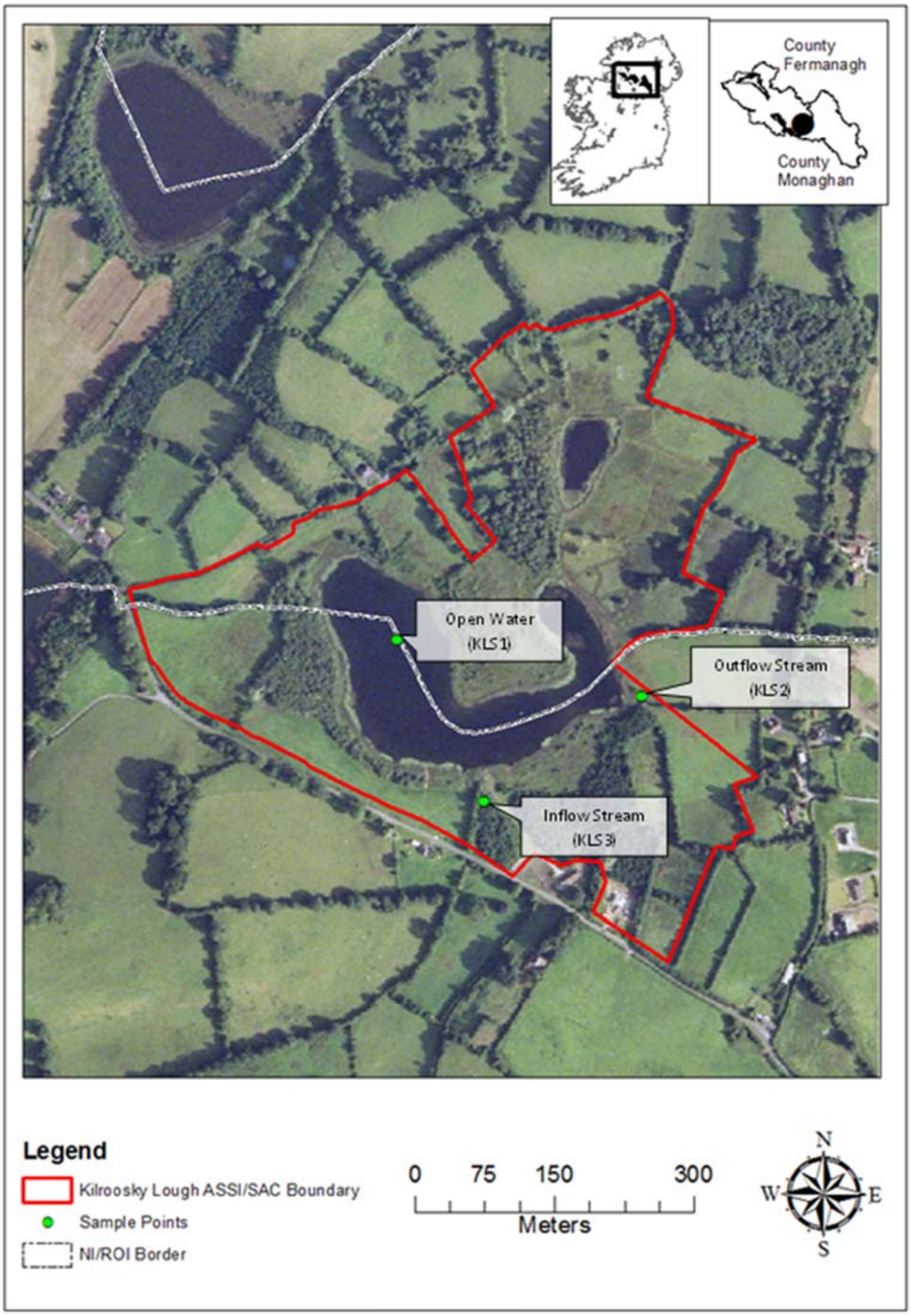


Fig. 4.3 Kilroosky Lough site, County Monaghan/Fermanagh showing locations of surface water sampling points.

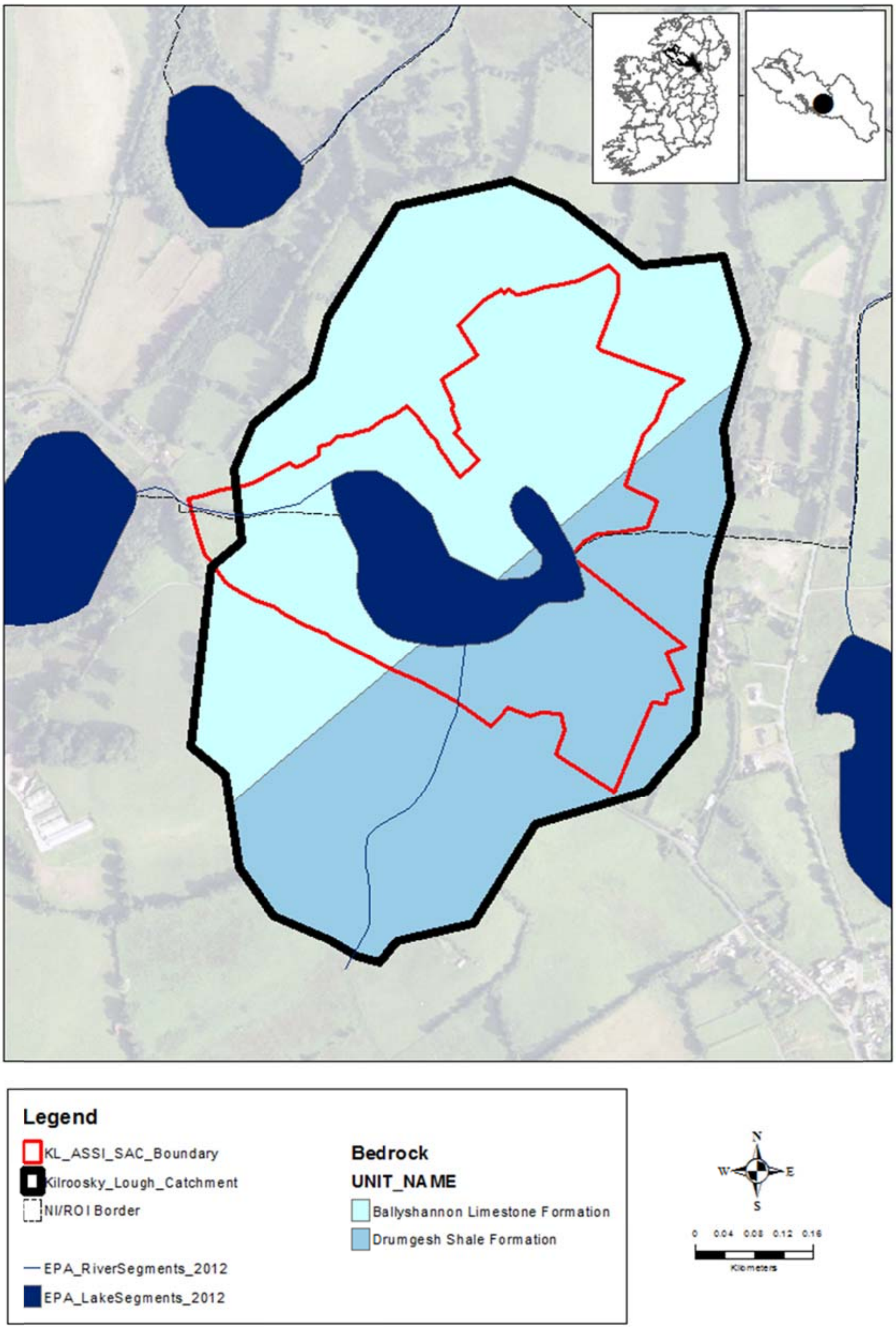


Fig. 4.4 Geological bedrock categories within the Kilroosky Lough catchment, Co. Monaghan.

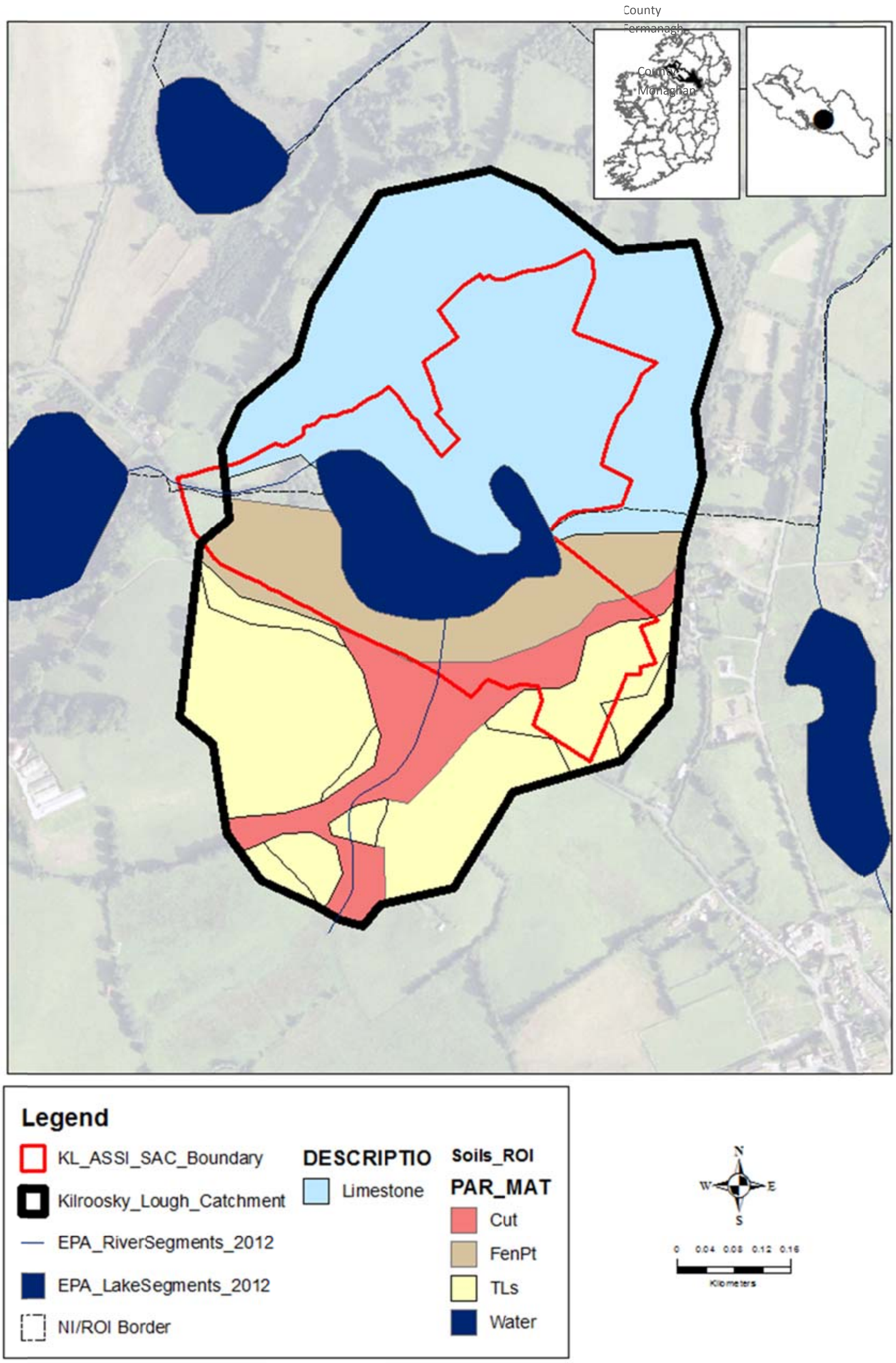


Fig. 4.5 Soil categories existing within the Kilroosky Lough catchment. Classifications reflect those used within respective jurisdictions.

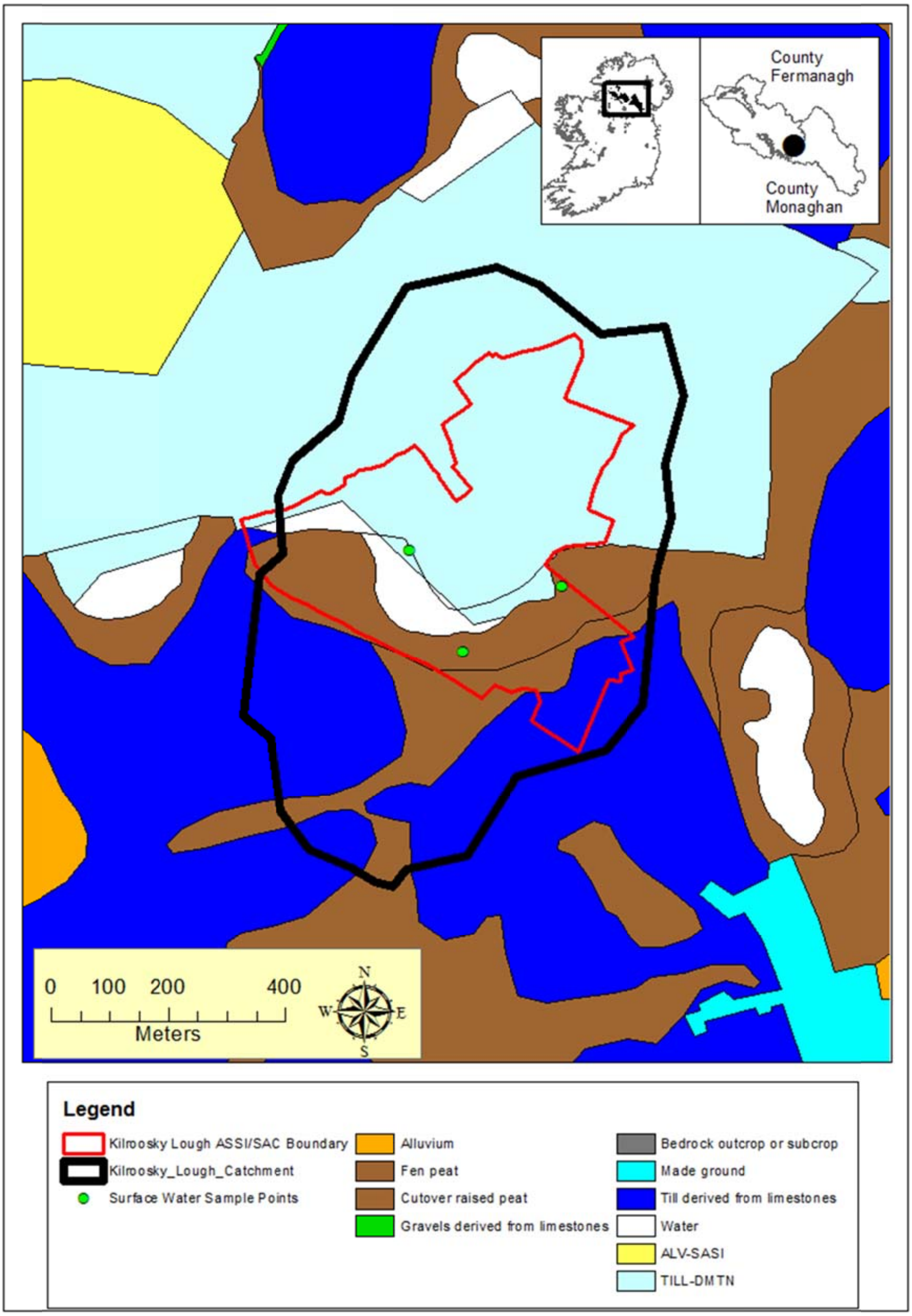


Fig. 4.6 Subsoil/superficial soil categories existing within the Kilroosky Lough catchment. Classifications reflect those used within respective jurisdictions.

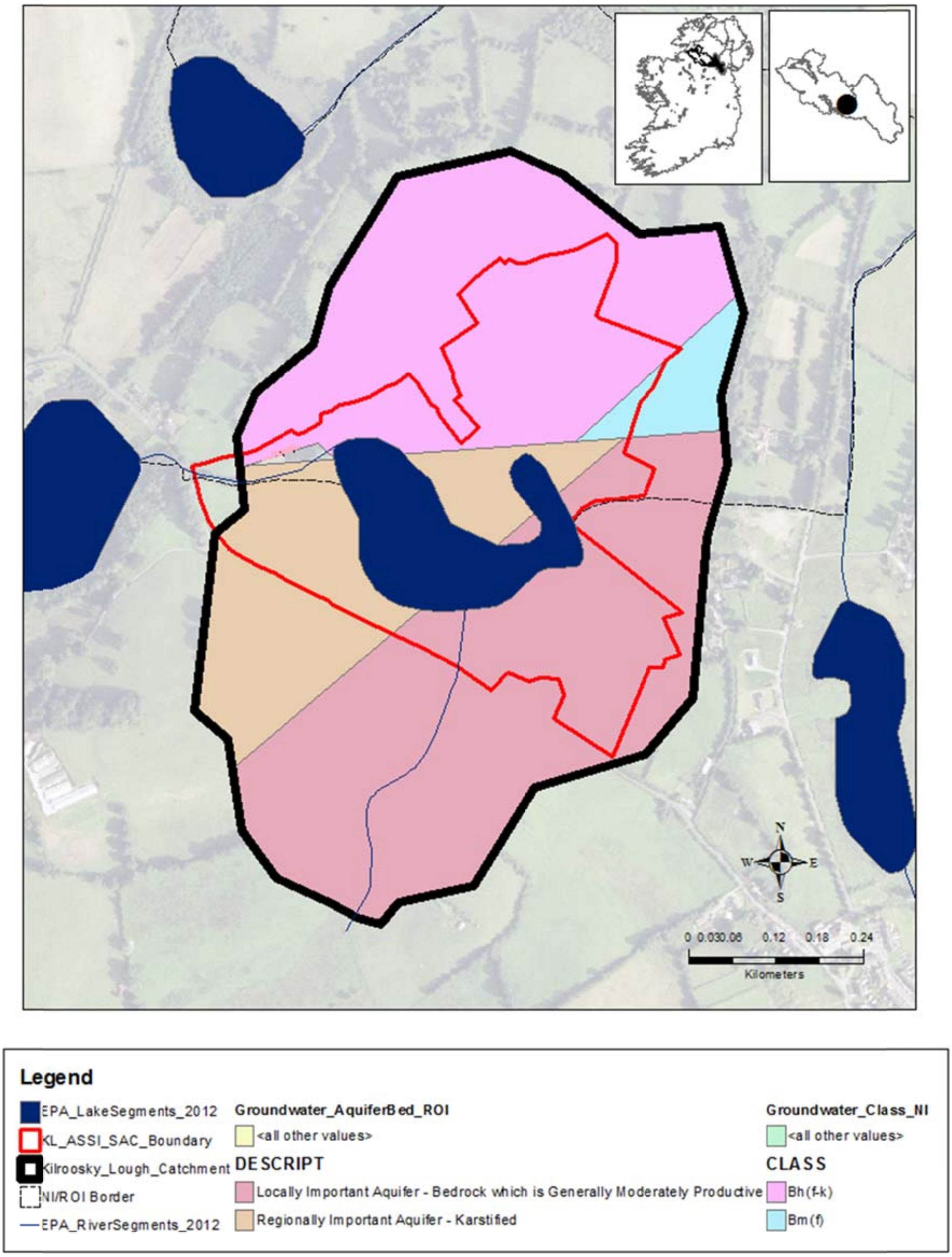


Fig. 4.7 Aquifer groundwater class categories within the Kilroosky Lough catchment, Co. Monaghan.

4.2.2. Greenan Lough

Greenan Lough in Co. Down (31º 18'79'E, 32º32'79'N) is an ASSI, protected as a result of its wetland flora and fauna (Fig. 4.8 and 4.9). The site is situated in an area surrounded by steeply sloping hills and consists of two open water basins with a fen situated to the north of the main basin. Habitats include species-rich fen meadow, fen, grassland and scrub woodland. No inflow streams have been observed at this site, suggesting the lough is groundwater fed. An outflow stream flows southwards from the smaller basin. The catchment area of the lough covers approximately 198 hectares (Fig. 4.7). Greenan Lough ASSI contains a number of vascular plants with a restricted distribution in the British Isles including many-stalked spike rush (*Eleocharis multicaulis*), blunt-flowered rush (*Juncus subnodulosus*), floating club-rush (*Eleogiton fluitans*), fen bedstraw (*Galium uligonosum*) and marsh St. John's wort (*Hypericum elodes*) (DOENI, 1998). In recent years, strands of common club-rush (*Shoenoplectus lacustris*) and common reed (*Phragmites australis*) have developed along the shore. These reeds have markedly ingressed into the lake waters over the past number of years (Geraldine McGovern, *pers.comm*).

Fig. 4.8 The main basin of Greenan Lough from the western hillside.

The bedrock within the Greenan Lough catchment is predominantly Hawick Group Sandstone and Newry Granodiorite (Fig. 4.9). Soils are derived primarily from shale with granite-based soils occurring predominantly in the north and the west of the catchment (Fig. 4.10). Superficial soils that occur within the catchment are derived from Diamicton Till, with bedrock at the surface occurring within 24% of the catchment area (Fig. 4.11). The aquifer class within the Greenan Lough is of limited productivity with fracture flow (Fig.12). The

majority (61%) of the catchment's groundwater is classed as having moderate vulnerability, with 24% being classed as most extreme vulnerability, due to lack of superficial cover.

Fig. 4.8 Greenan Lough site, County Down showing locations of surface water sampling points.

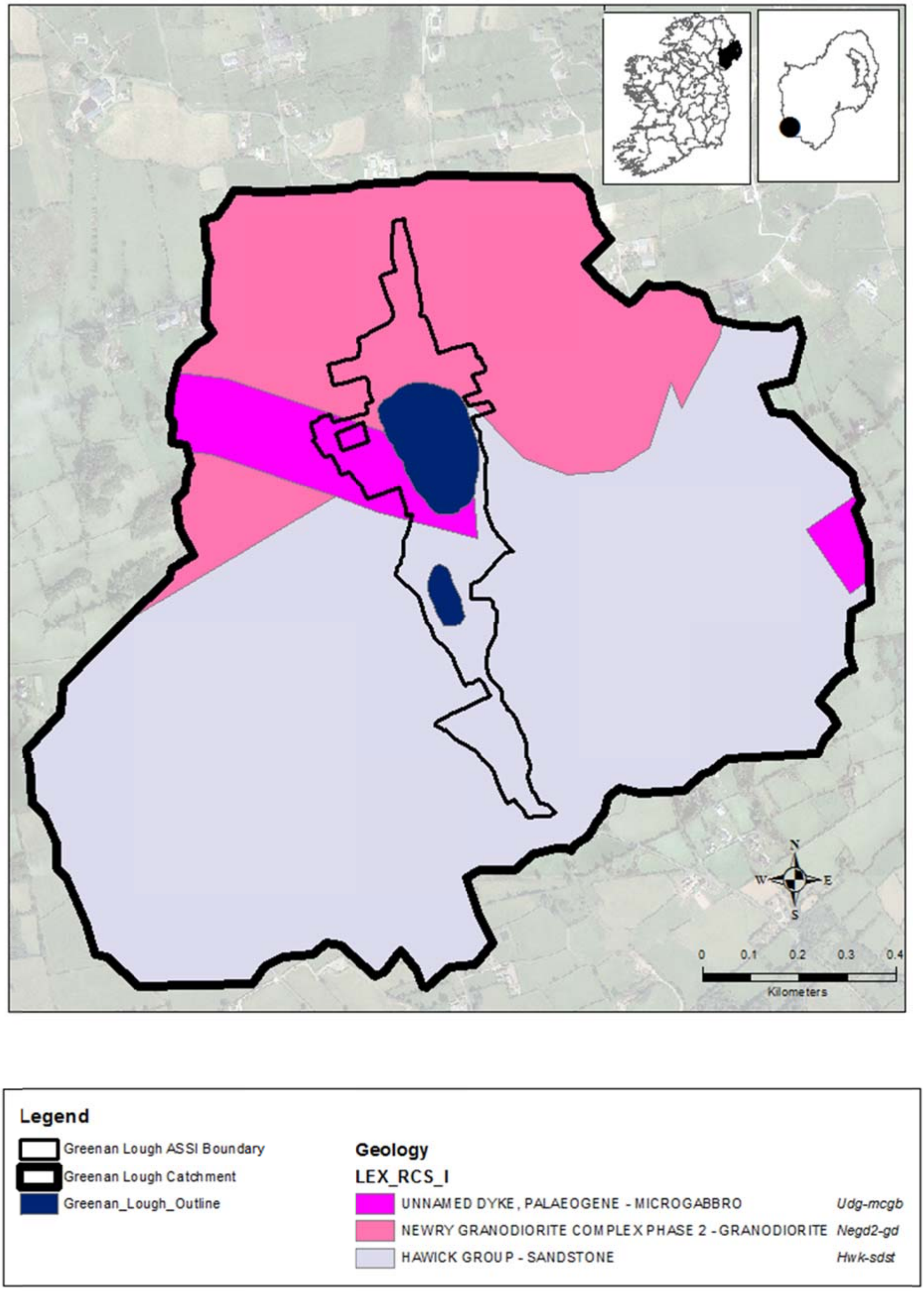


Fig. 4.9 Geological bedrock categories within the Greenan Lough catchment, Co. Down.

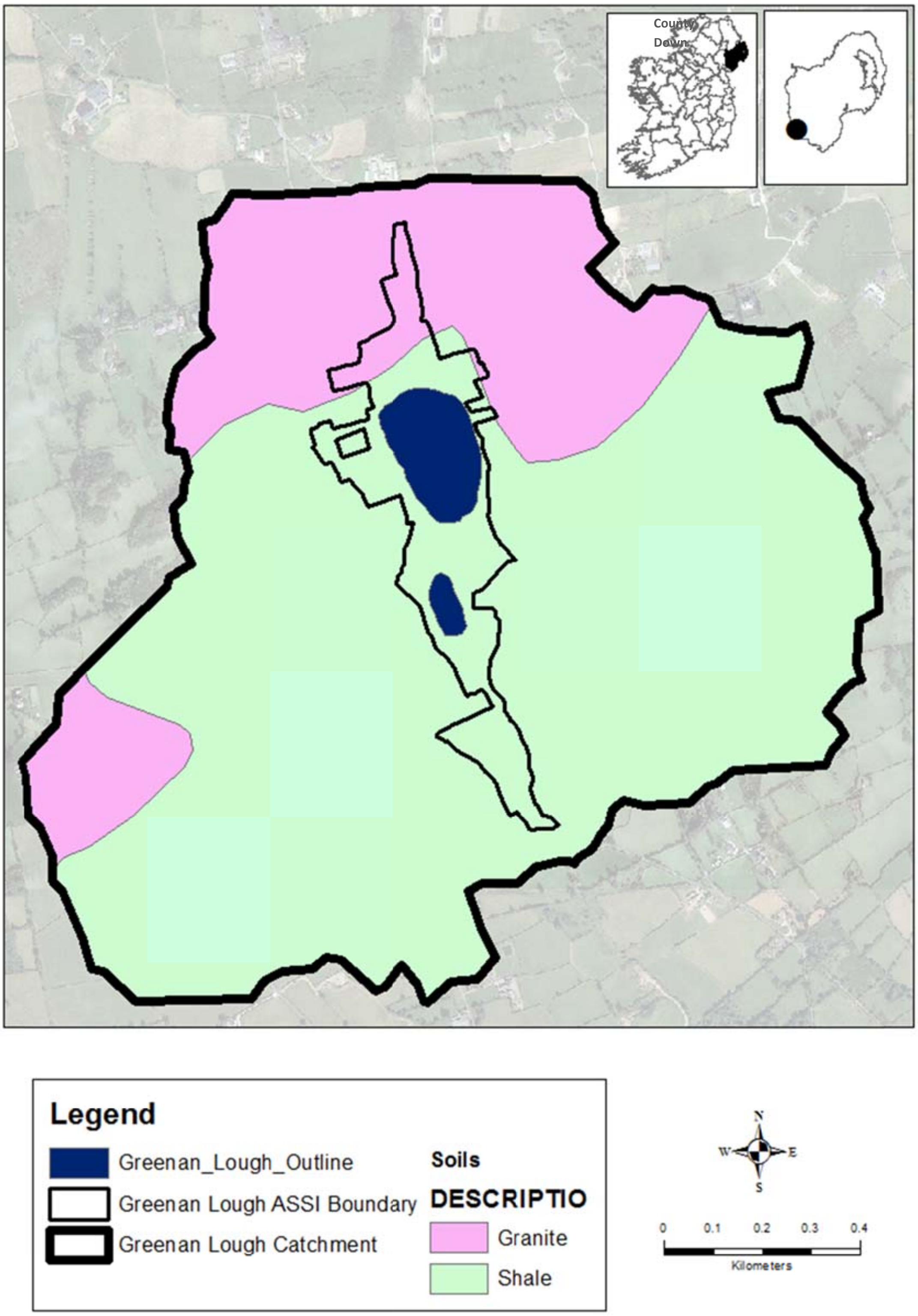


Fig. 4.10 Soil categories within the Greenan Lough catchment, Co. Down.

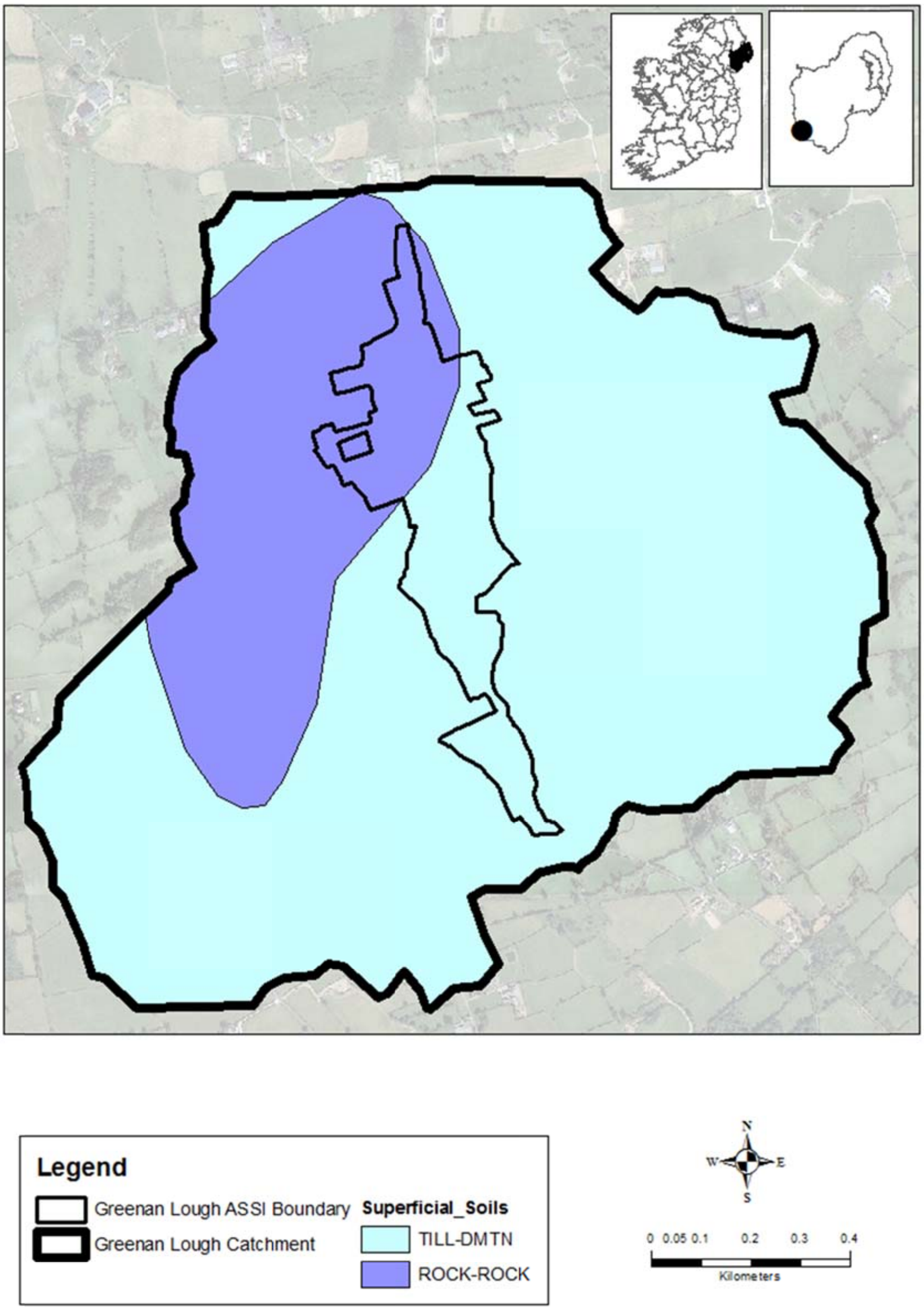


Fig. 4.11 Superficial soil categories within the Greenan Lough catchment, Co. Down.

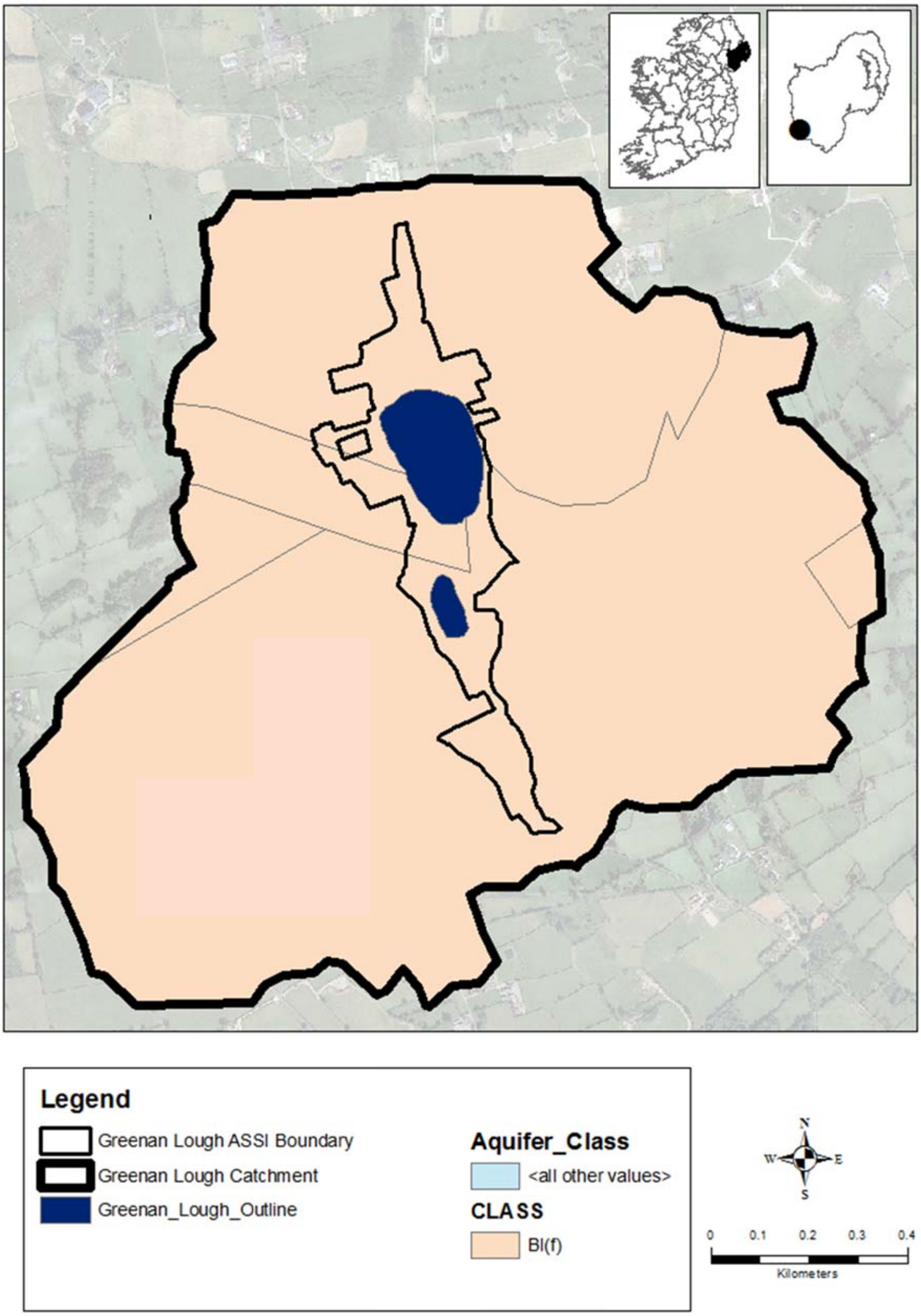


Fig. 4.12 Aquifer class within the Greenan Lough catchment, Co. Down.

4.2.3 Loughaveely

Loughaveely in Co. Armagh (29º54'67'E, 31º41'57'N) is an ASSI protected as a result of its wetland flora and fauna (Fig. 4.13 and 4.14). Loughaveely occurs in an extended basin which is bisected by a minor road. Much of the eastern part of the site contains small pools formed by past peat cutting whilst the large pool in the western section appears to be more natural in formation. A small drain links the two sections of the site and a stream flows from north to south through the eastern section of the site. Loughaveely is a relatively small but diverse site with several wetland plant communities ranging from poor fen vegetation to swamp and open water. The open water of the west section of the site is surrounded by a number of different fen types. A floating mat of vegetation occurs around the western and southern edge of the pool, is dominated by bogbean (*Menyanthes trifoliate*) and the rare sedge species, bog sedge (*Carex limosa*) and lesser tussock-sedge (*Carex diandra*). Elsewhere, the fen vegetation is characterised by species such as water horsetail (*Equisetum fluviatile*), water mint (*Mentha aquatica*), marsh cinquefoil (*Potentilla palustris*), common cottongrass (*Eriophorum augustifolium*), bottle sedge (*Carex rostrata*) and sharp-flowered rush (*Juncus acutiflorus*). Additional habitat diversity is provided by wet grassland dominated by the soft rush (*Juncus effusus*), patches of dry grassland, thickets of bramble (*Rubus fruticosus*) and scrub. A number of scarce plants such as cowbane (*Cicuta virosa*) and the moss *Calliergon cordifolium* are also present within the site (DOENI, 1999). Previous assessments of the site have noted the presence of the bulrush species *Typha latifolia*, which was noted as a possible indicator of a source of pollution near the site which could lead to eutrophication (DOENI, 2005).

Fig. 4.13 Loughaveely, Co. Armagh looking west towards the main pool.

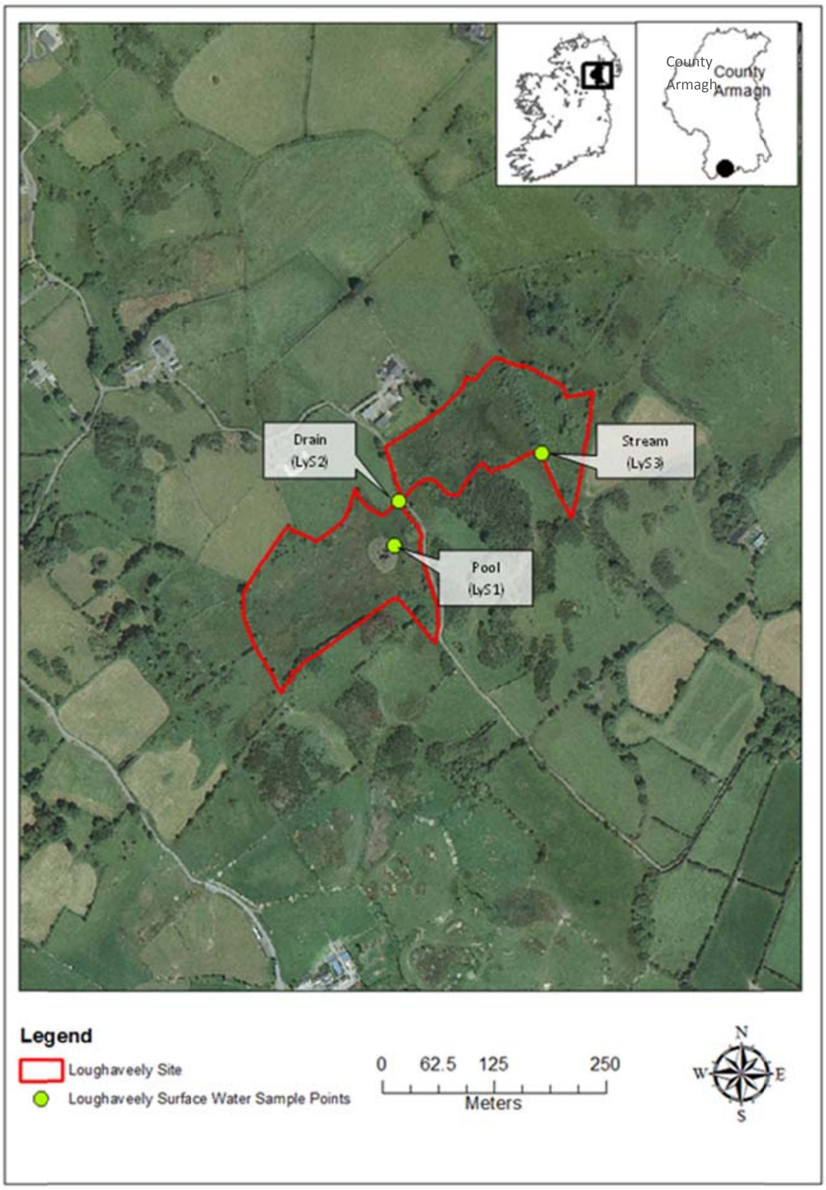


Fig. 4.14 Loughaveely site, County Armagh showing locations of surface water sampling points.

The bedrock underlying the catchment of Loughaveely is Gala Group Sandstone, with a small microgabbro dyke protruding into the southern section of the site (Fig. 4.15). Soils are solely derived from shale (Fig. 4.16), although peat and diamicton till superficial soils exist within the margins of the catchment. The majority of the catchment superficial soils could not be determined as a result of a data gap in the larger NI superficial soils dataset (Fig. 4.17). Aquifer groundwater class within the catchment is entirely classified as being fracture flow of limited productivity (Fig. 4.18). The groundwater vulnerability within the catchment is predominantly classified as mostly extreme.

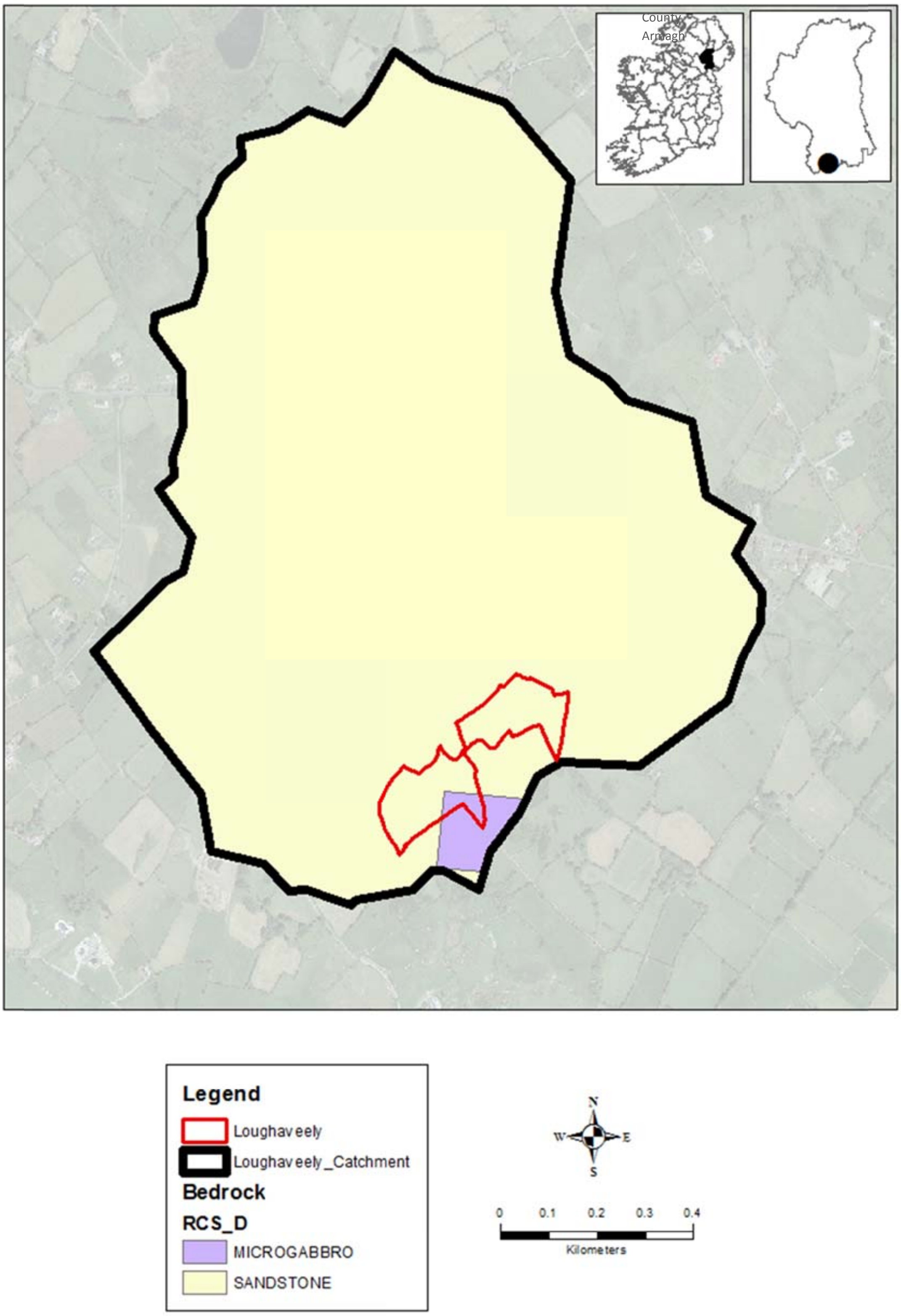


Fig. 4.15 a) Geological bedrock categories underlying the Loughaveely catchment, Co. Armagh.

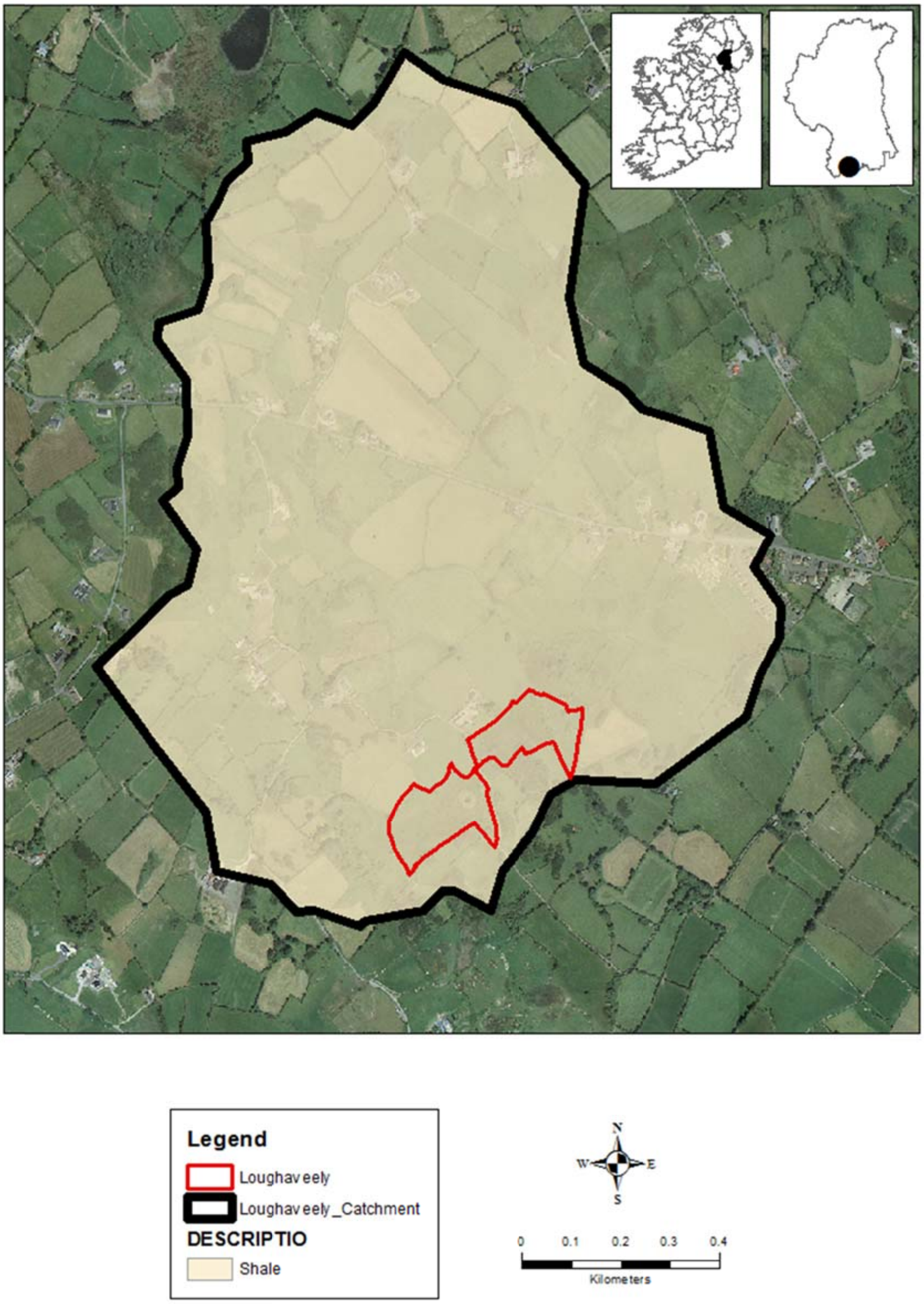


Fig. 4.16 a) Soils underlying the Loughaveely catchment, Co. Armagh.

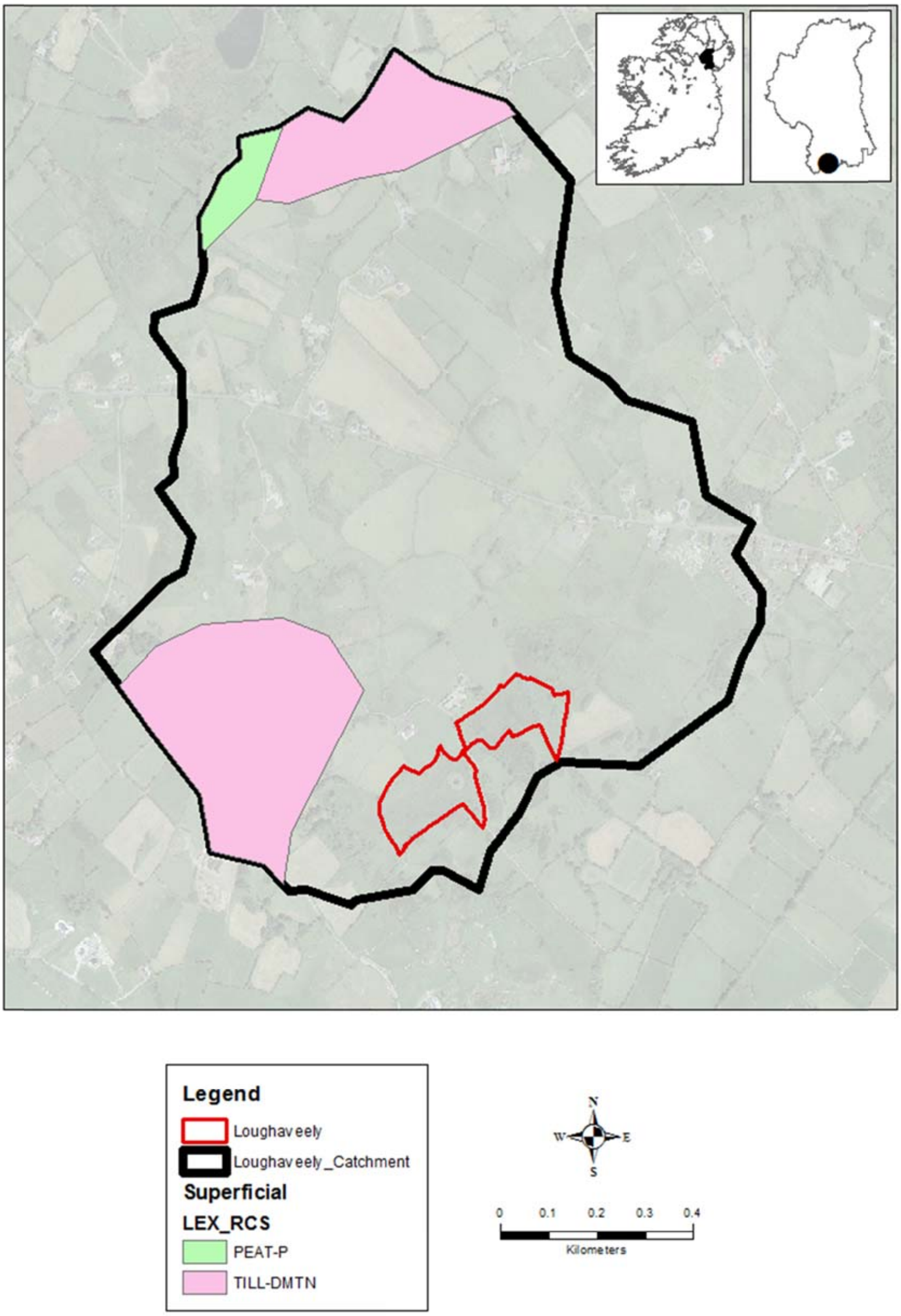


Fig. 4.17 Superficial soils underlying the Loughaveely catchment, Co. Armagh. A gap in the larger Northern Ireland subsoil/superficial soil dataset is evident, resulting in the lack of summary data for the Loughaveely catchment.

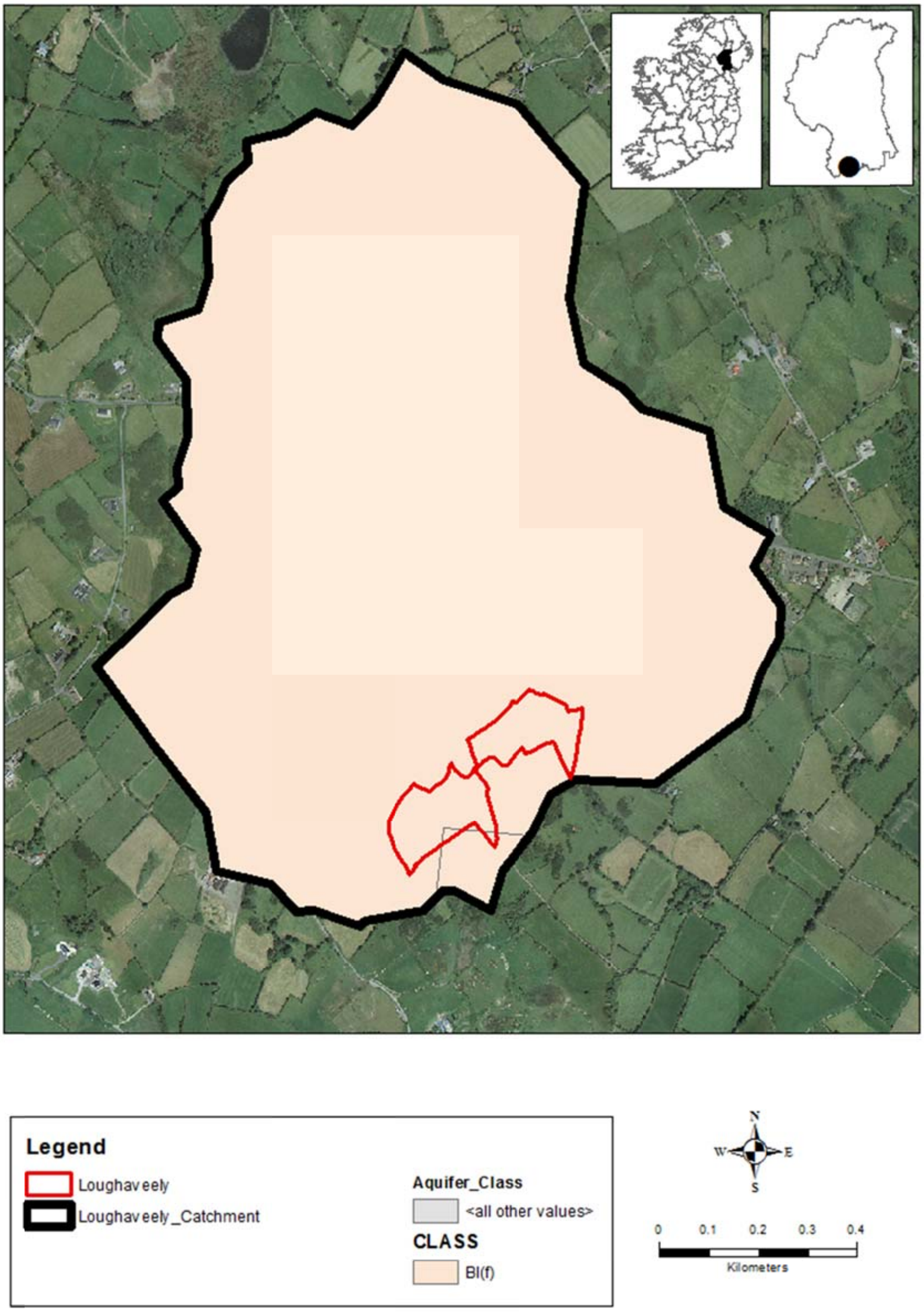


Fig. 4.18 Aquifer groundwater class underlying the Loughaveely catchment, Co. Armagh.

4.2.4 Windy Gap

Although Windy Gap (31º30’96’E, 31º33’82’N) holds no specific conservation designation as an individual wetland, it is situated on the border of the Carlingford Mountain SAC and is, therefore, protected as a result of this larger designation (Fig. 4.19 and 4.20). The wetland is a cutover blanket bog and poor fen, which is situated at an altitude of 179 m and is surrounded by upland heathland and a section of conifer forestry to the northeast. The site consists of large cut out pools dominated by secondary poor fen vegetation. These pools probably arose as a consequence of historical peat extraction at the site, or alternatively arising from extraction of clay deposits following drainage of the site. Peat ridges elevated above the pool areas and are dominated by *Molinia caerulea* wet grassland vegetation. Although the site exists within the Carlingford Mountain SAC, it does not have any habitats present at the site corresponding to any habitats listed under Annex I of the EU Habitats Directive (Foss *et al*.,2011; Foss and Crushell, 2013b).

Fig. 4.19 Photograph of Windy Gap taken from the northern end of the site from the Omeath Road that runs parallel to the site on its western side.

Bedrock within the Windy Gap catchment is equally split between Granophyre and Layerd Gabbro, with a potential boundary between the two rock types existing through the centre of the site (Fig 4.16). Soils within the catchment are predominantly mainly shallow, non-calcareous peaty mineral soil of undefined drainage, with blanket peat occurring throughout the majority of the wetland site (Fig. 4.17). Blanket peat is the dominant subsoil soil classification within the wetland site (Fig. 4.17). The Windy Gap catchment aquifer groundwater class is classified as a poor aquifer with bedrock that is generally unproductive

except for local zones (Fig. 4.16). Groundwater is classified as extremely vulnerable for much of the catchment as the rock is close to the surface. Within the wetland site, groundwater vulnerability is classified as extreme in the western and northern areas and high in the southern area.

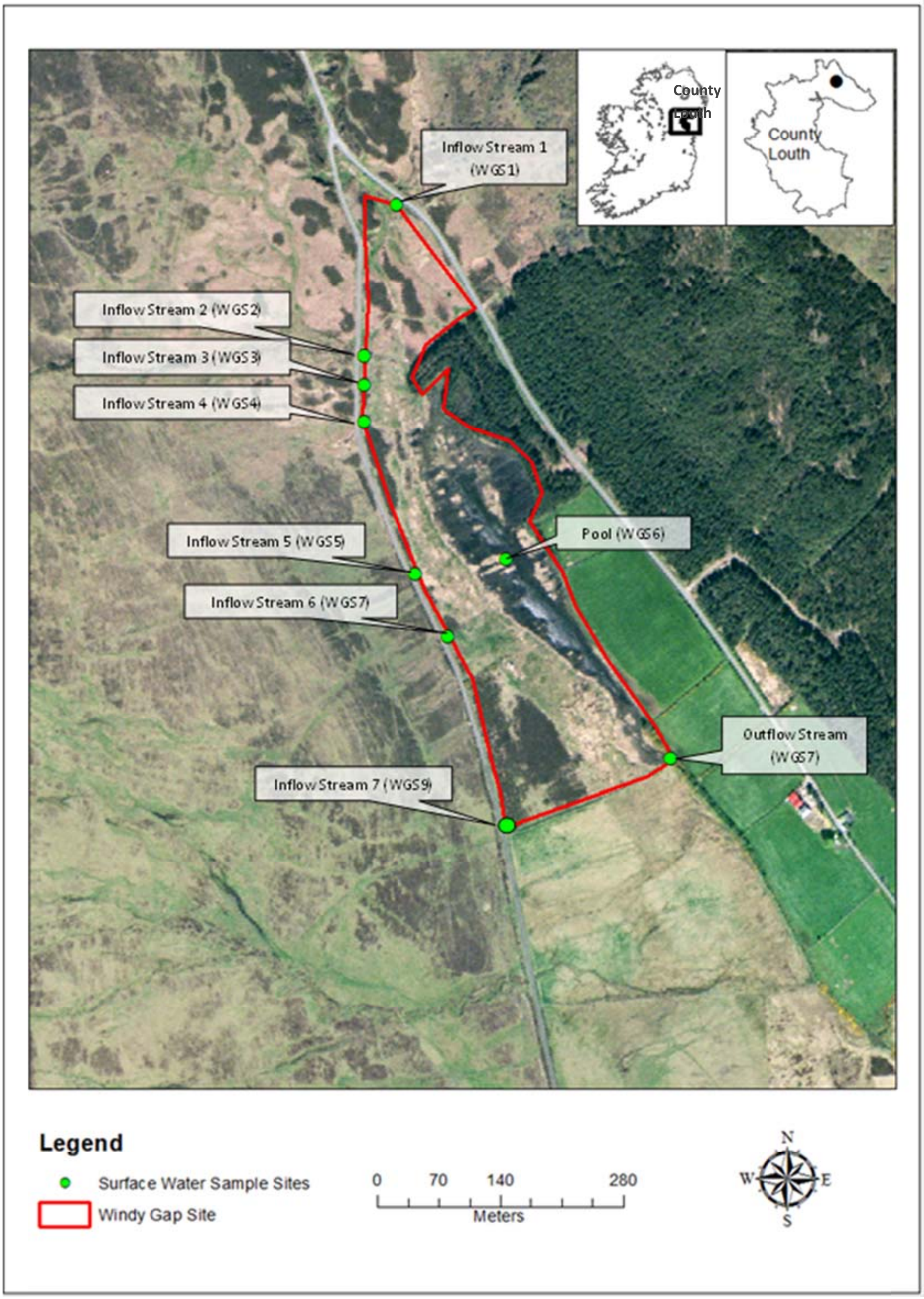


Fig. 4.20 Windy Gap site, Co. Louth showing locations of surface water sampling point.

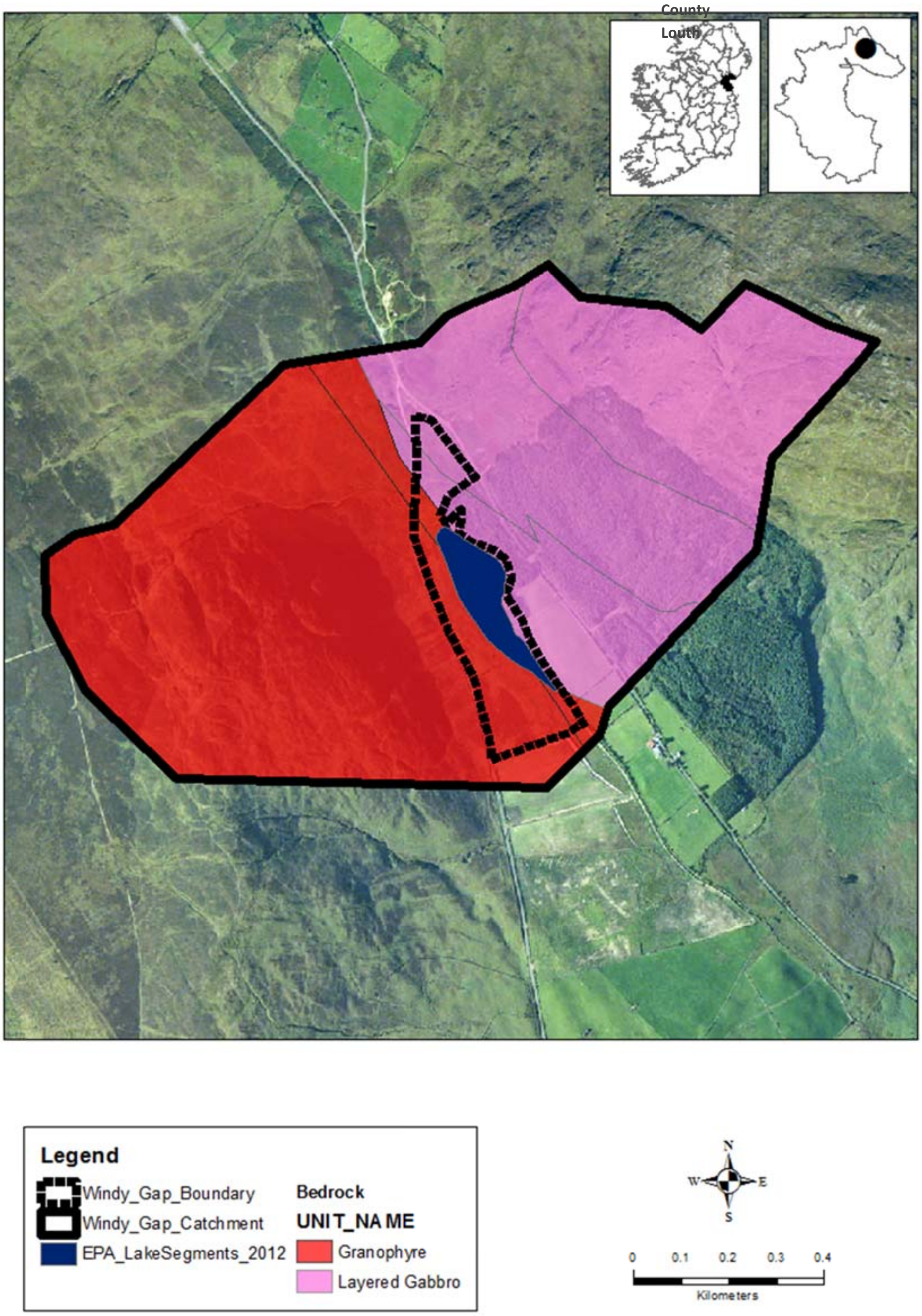


Fig. 4.21 Geological bedrock categories underlying the Windy Gap catchment, Co. Louth.

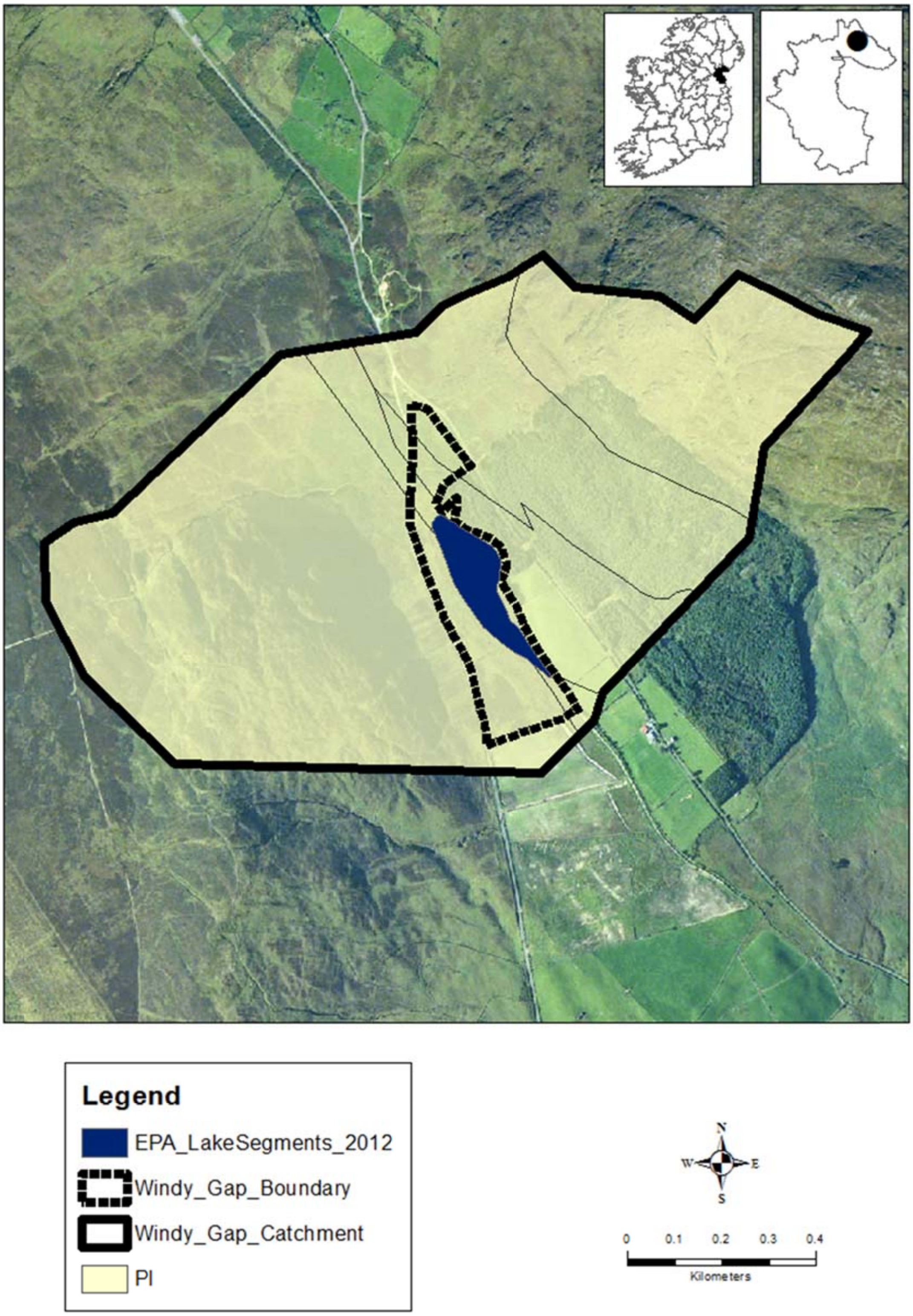


Fig. 4.22 Aquifer bedrock/groundwater class underlying the Windy Gap catchment, Co. Louth.

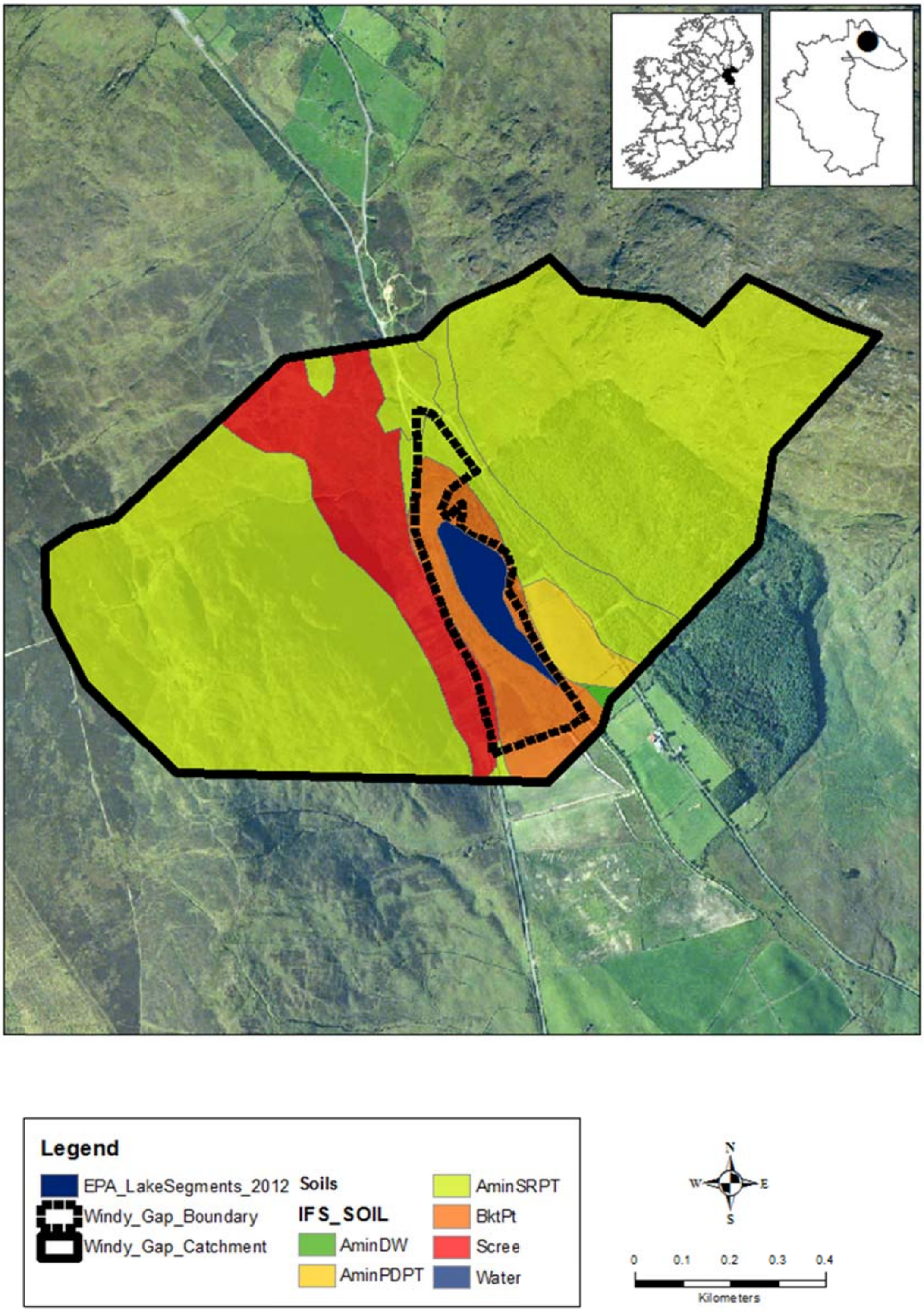


Fig. 4.23 Soils underlying the Windy Gap catchment, Co. Louth.

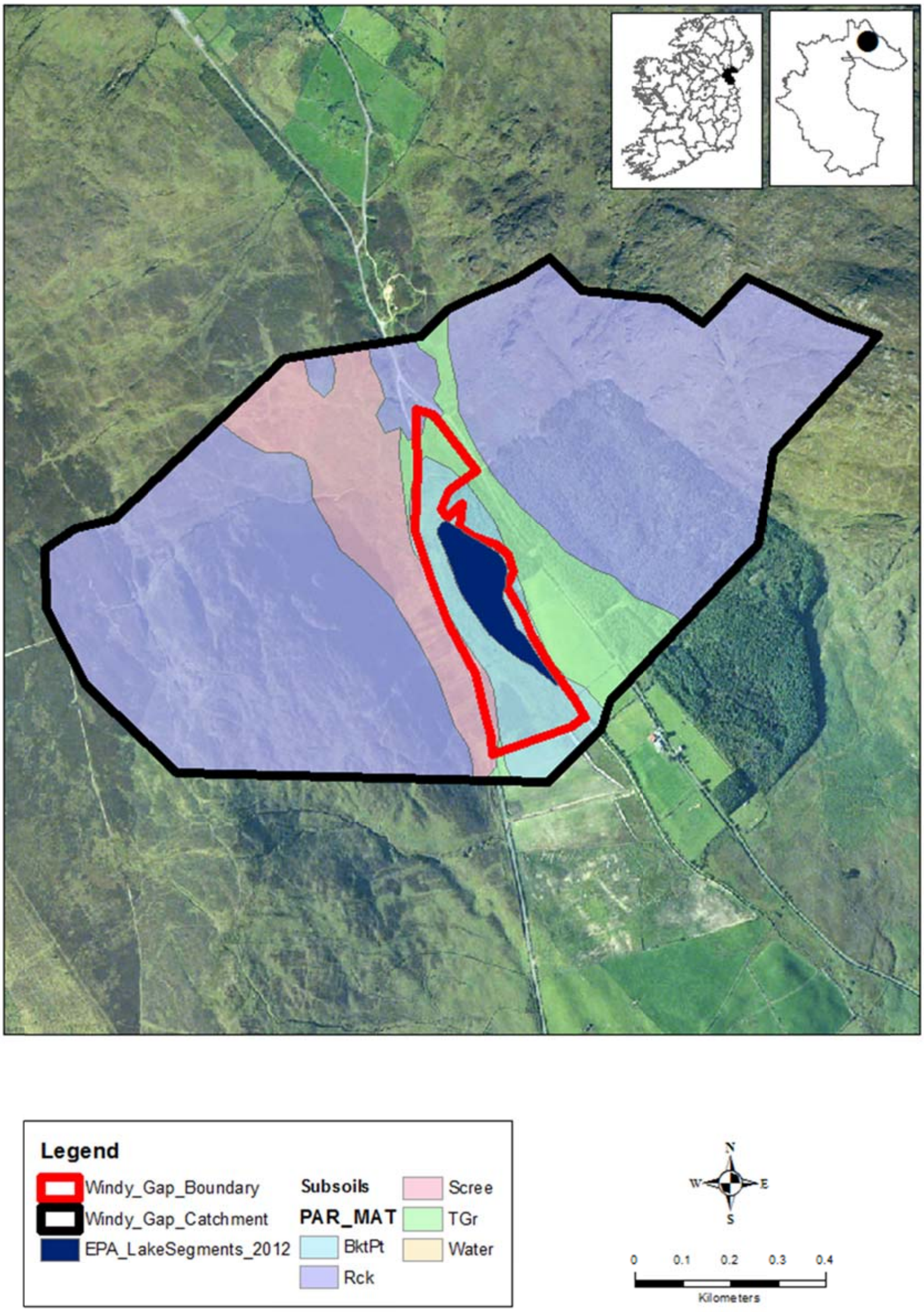


Fig. 4.23 Subsoils underlying the Windy Gap catchment, Co. Louth

4.2.5 Rockmarshall

Rockmarshall (31°16’27’E, 30º82’07’N) is a raised beach and wetland located approximately 6 km northeast of Dundalk on the southern side of the Cooley Peninsula (Fig. 4.24 and 4.25). The site has three linear wetlands areas (designated Wetland 1 – 3 for the purposes of this study) between dry grassland ridges on former raised shingle beaches. Wetland areas include wet grassland, transition mire, reed swamp and scattered patches of willow scrub along drain edges and within the transition mire and reed bed areas. There is a particularly interesting transition from wetland to dry grassland communities. The dry grassland is extensively grazed by sheep year-round. A stream that springs in Upper Jenkinstown in the Cooley Mountains flows through the site before discharging into Dundalk Bay. A number of drains have previously been constructed in each of the linear wetlands, and also to the north of the stream that bisects the site. The site does not currently have any conservation status but as part of the initial survey in 2011, Rockmarshall was rated as being internationally important due to parts of the site potentially corresponding to the EU Annex 1 habitat ‘Transition Mires and Quaking Bogs (7140) (Foss *et al*., 2011).

Fig. 4.24 Rockmarshall wetland from the northern section of the site, on top of an old shingle dune ridge looking southwards towards Dundalk Bay and overlooking two of the linear wetland areas (Wetland 2 in the foreground and Wetland 1 in the distance). The two wetland areas are separated by a dry grassland ridge that is heavily grazed by sheep.

Granophyre contributes to the highest proportion of bedrock within the Rockmarshall catchment, although within the wetland site itself undifferentiated Dinantian Limestones dominate (Fig. 4.26). A large number of soils occur within the catchment, with deep, well drained non-calcareous mineral soil and mainly shallow, non-calcareous peaty mineral soil of undefined drainage contributing the highest proportions (Fig. 4.27). Subsoil in the catchment

are dominated by till derived from granites and rock (Fig. 4.28). The majority of the catchment is classed as a poor aquifer that is generally unproductive except for local zones. However, within the Rockmarshall site itself, the aquifer groundwater is classified as a locally important aquifer that is generally moderately productive (Fig. 4.29). The groundwater vulnerability within the catchment is predominantly classed as extreme, although it is classed as high within the Rockmarshall site boundary.

Fig. 4.25 Rockmarshall site, County Louth showing locations of surface water and groundwater sampling points.

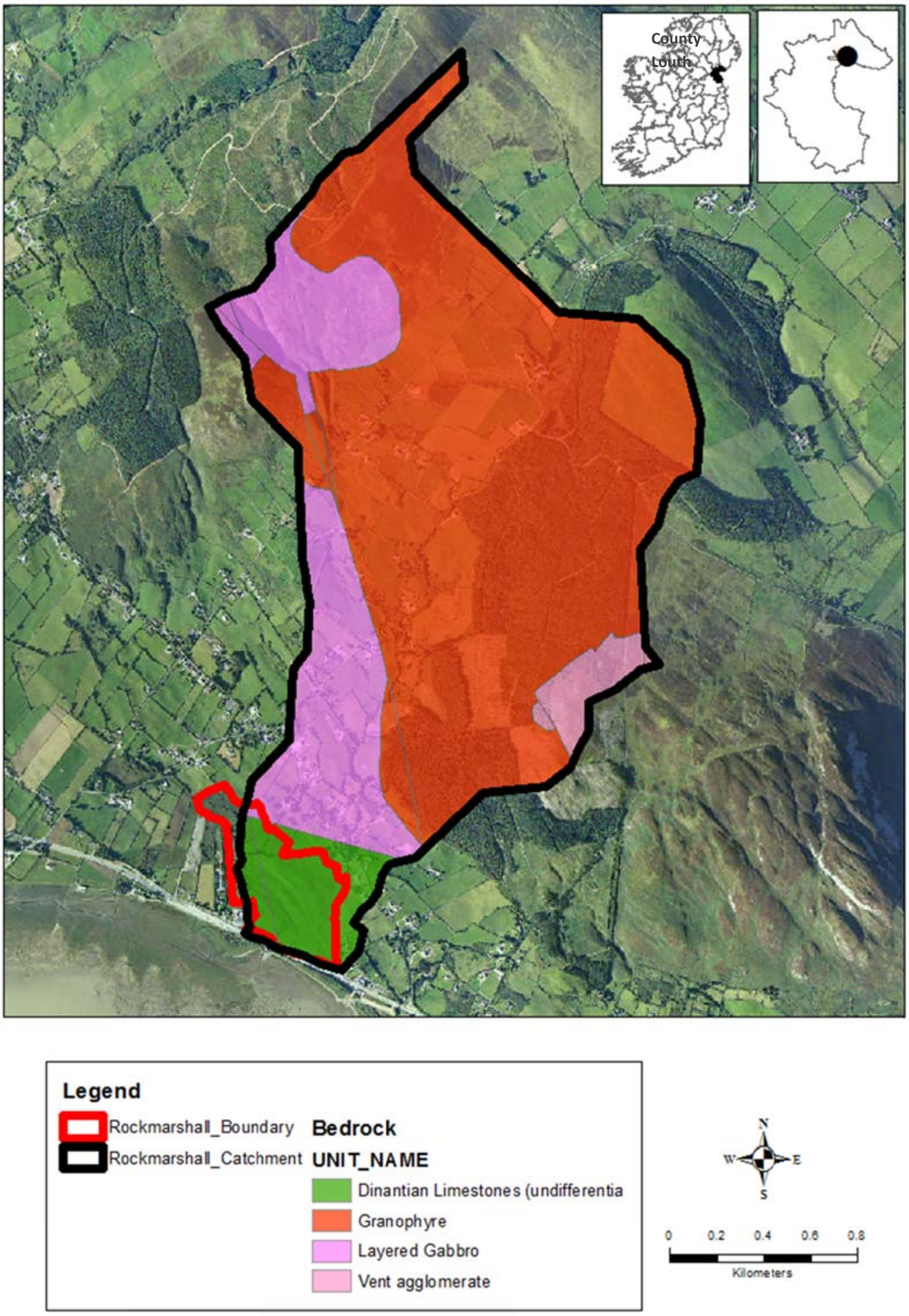


Fig. 4.26 Geological bedrock categories underlying the Rockmarshall catchment, Co. Louth.

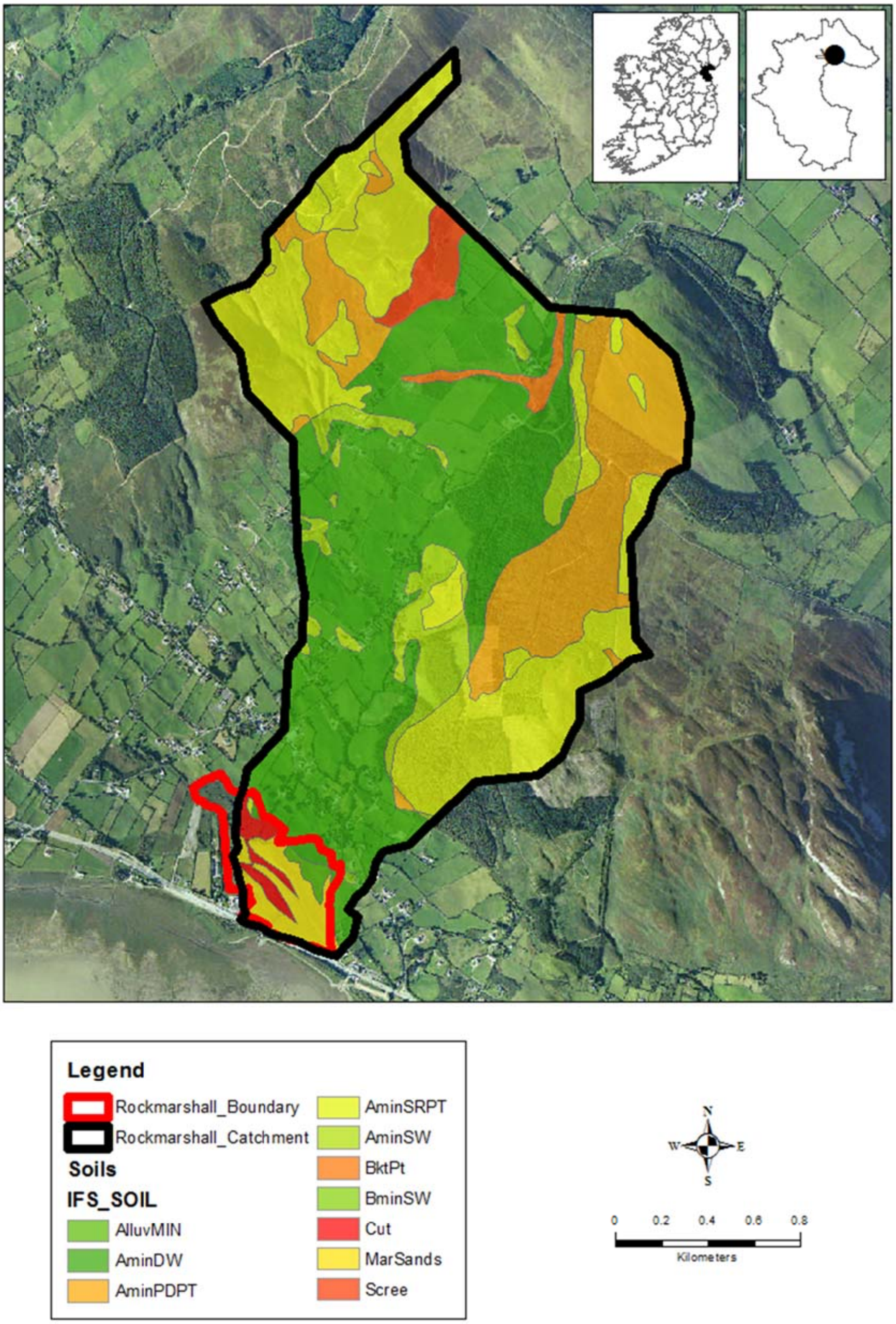


Fig. 4.27 Soil classifications underlying the Rockmarshall catchment, Co. Louth.

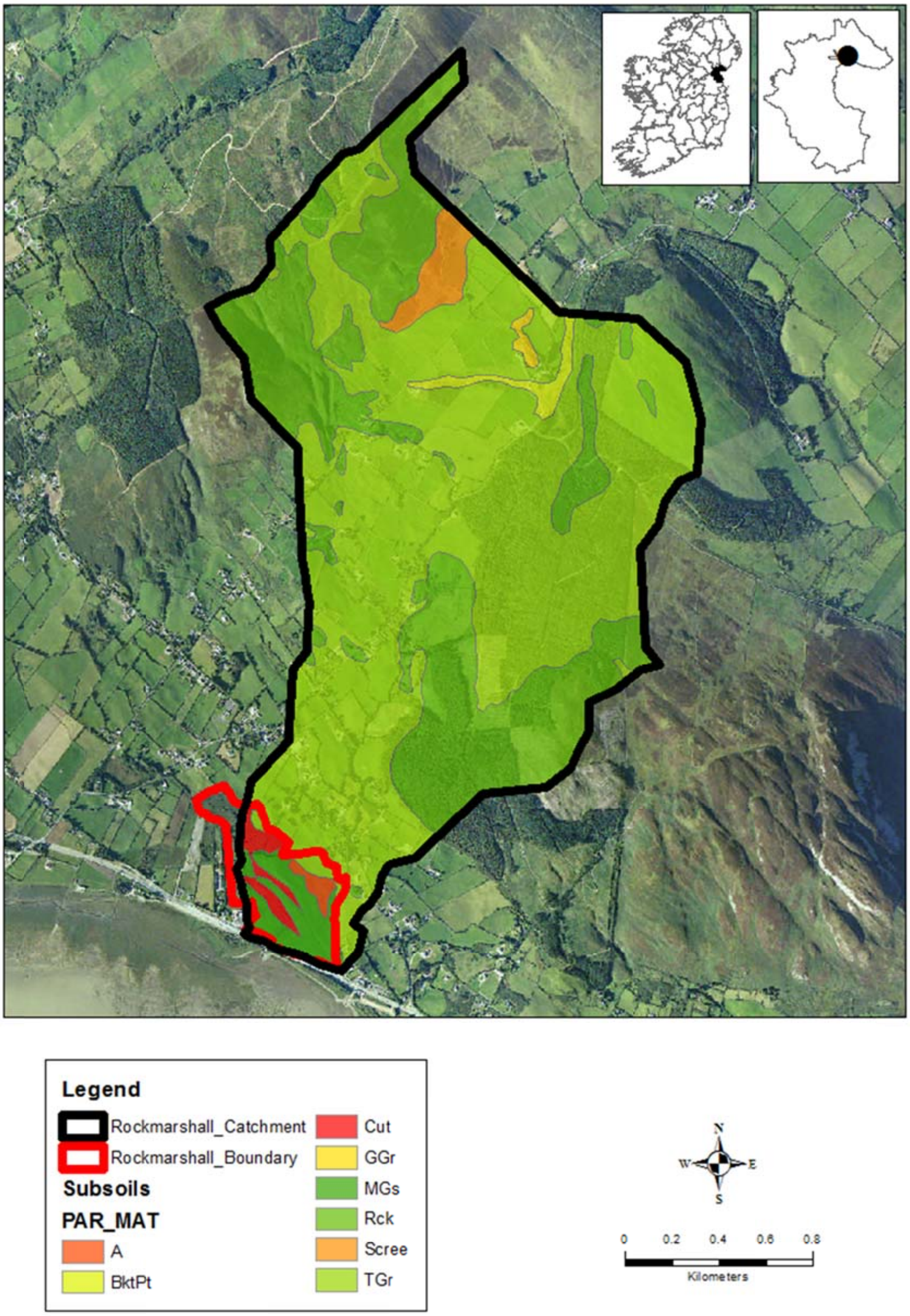


Fig. 4.28 Subsoil classifications underlying the Rockmarshall catchment, Co. Louth

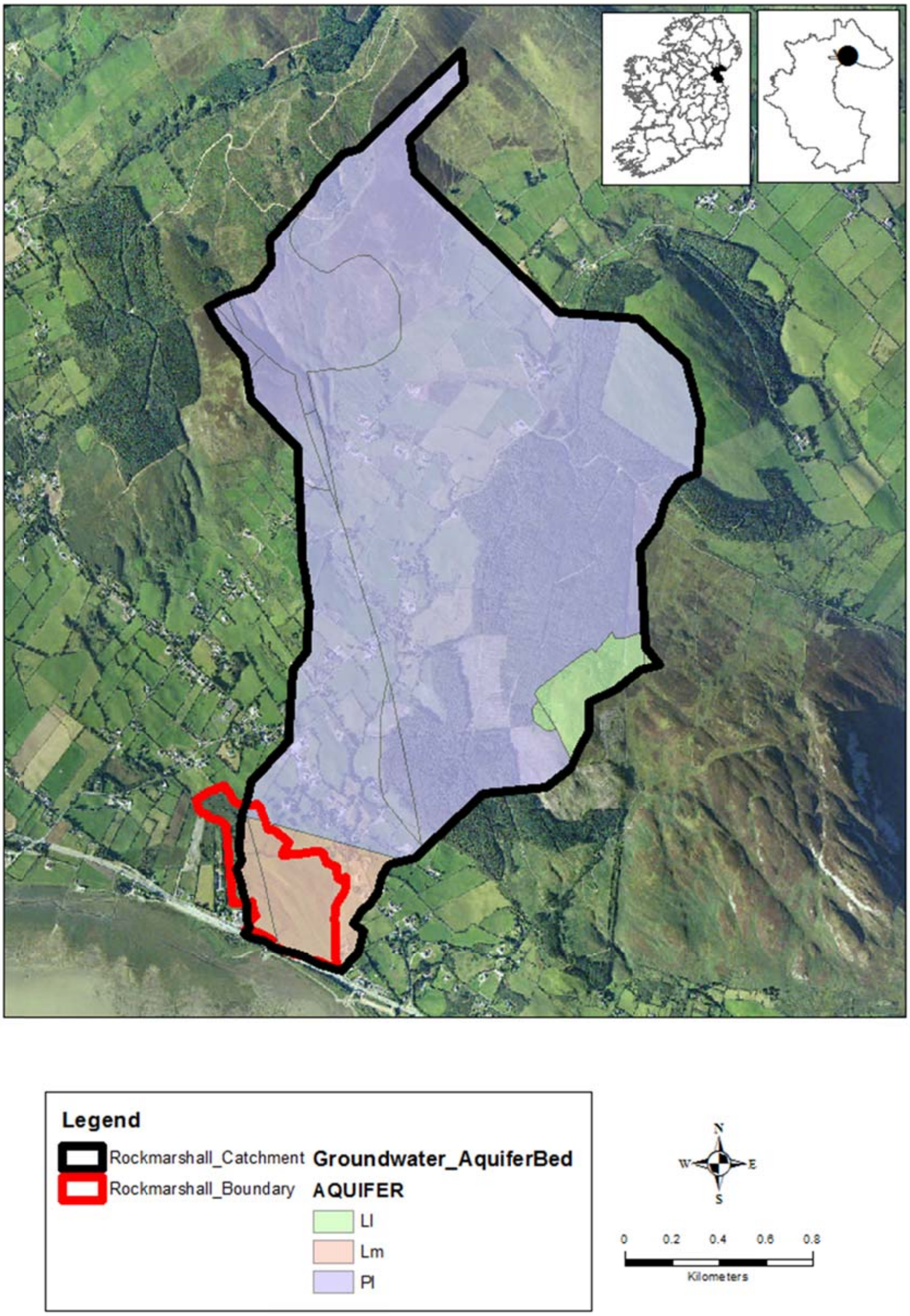


Fig. 4.29 Aquifer groundwater class underlying the Rockmarshall catchment, Co. Louth.

4.3 Comparison of Field Site Hydrochemistry

4.3.1 Alkalinity, pH and Conductivity

There was significant difference observed in alkalinity concentration between case-study wetland sites (Fig. 4.30). Kilroosky Lough had significantly higher alkalinity than all other sites, with a mean ± S.E. (mean values throughout this report are given as mean ± S.E.) across all sampling locations and sampling dates within the site of 130 ± 7.8 mg L^{-1} $CaCO_3$. In contrast, Windy Gap had significantly lower alkalinity values which than all other sites, with a mean value across all sampling locations and sampling dates at this site of 8.48 ± 0.32 mg L^{-1} $CaCO_3$. There were no significant differences between Greenan Lough, Loughaveely and Rockmarshall, with moderate alkalinity values generally less than 50 mg L^{-1} $CaCO_3$, although Rockmarshall had a higher variation in alkalinity values than Greenan Lough or Loughaveely. These differences in alkalinity are generally reflective of their geological and geochemical setting of each of these wetlands, with Windy Gap located within the catchment dominated mainly by shallow, non-calcareous peaty mineral soil and blanket peat occurring throughout the majority of the site and with Kilroosky located within a catchment in part underlain by limestone.

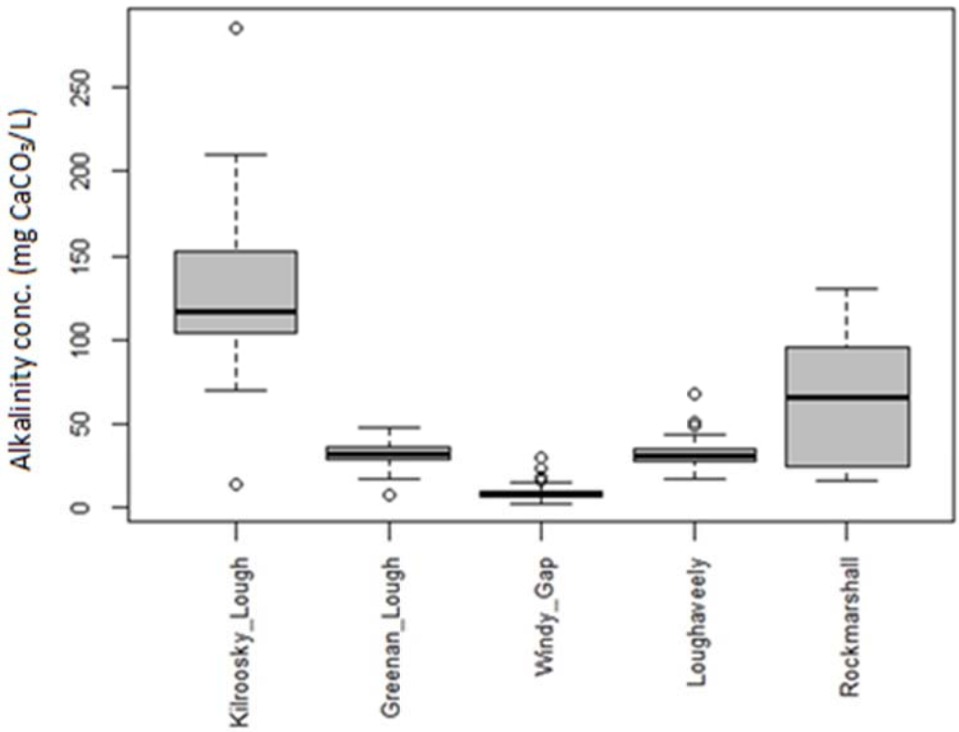


Fig. 4.30 Comparison of alkalinity concentrations (mg L^{-1} $CaCO_3$) of the five case-study wetland sites. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

Nevertheless, pH values across all sites were very similar (Fig. 4.31), with Windy Gap recording relatively high pH values (median pH value of 7.20), considering its peaty soil and low alkalinity status. Windy Gap, however, did record the lowest conductivity values with a mean of 66.3 ± 1.5 µS cm^{-1} compared to the highest mean conductivity value of 477 ± 24.8 µS cm^{-1} observed at Kilroosky Lough. Windy Gap also generally recorded the highest DO values, with very low values recorded at Rockmarshall compared to other sites. However, these low values of dissolved oxygen (DO) at Rockmarshall, were generally recorded at the sampling location ROCK S1, which was a drain located to the south of Wetland 1, and had slow flowing water, which often became quite stagnant.

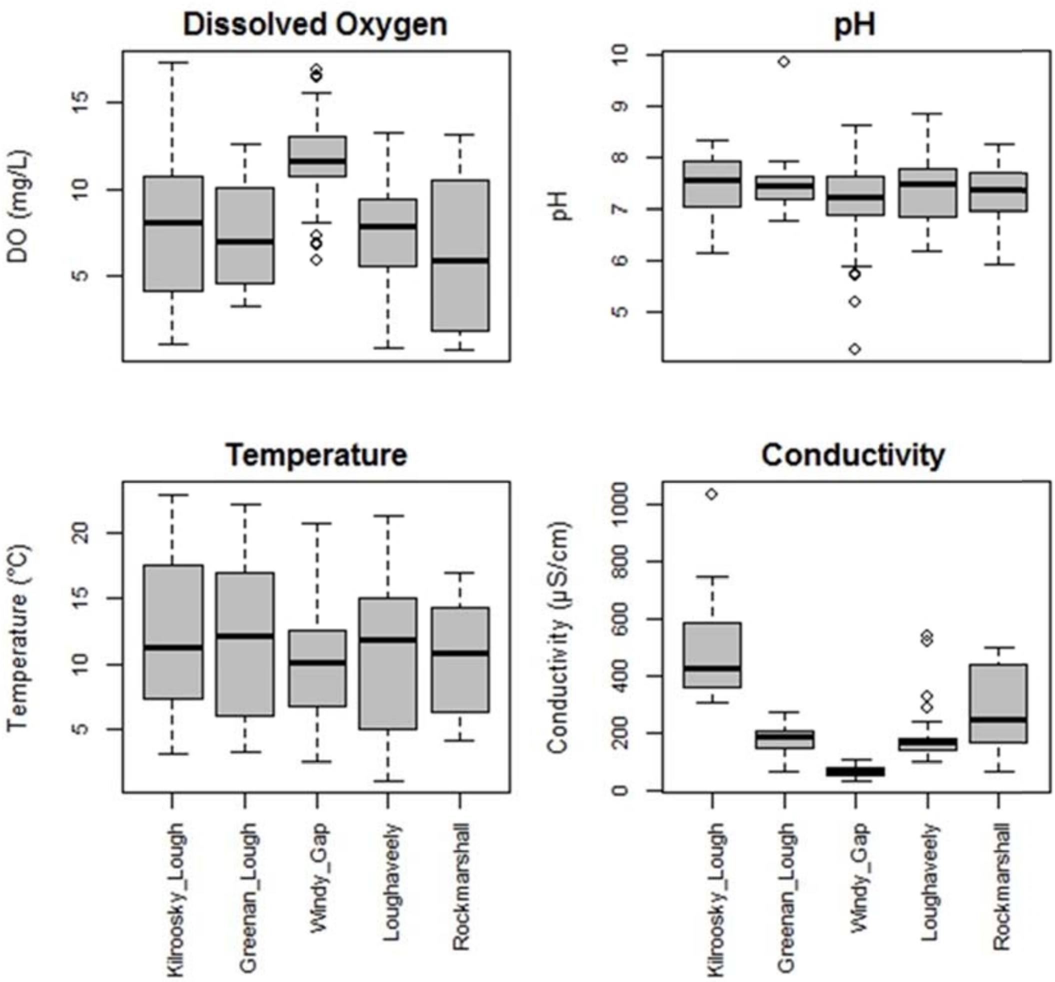


Fig. 4.31 Comparisons of surface water environmental parameters (Dissolved Oxygen (mg L^{-1} DO), pH, temperature (°C) and conductivity (µS cm^{-1}) between each of the five shortlisted sites. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

4.3.2 Dissolved Organic Carbon and Suspended Solids

Despite its location within a peaty catchment, Windy Gap had relatively low mean dissolved organic carbon (DOC) concentrations in comparison to the other four sites. In addition, Windy Gap also recorded low suspended solids concentrations with a mean of 4.42 ± 0.87 mg L^{-1} in comparison to Kilroosky Lough which recorded the highest mean concentration of suspended solids with a value of 16.8 ± 4.28 mg L^{-1} (Table 4.3), with a particularly high outlier of 125 mg L^{-1} recorded in June 2012.

Table 4.3 Mean (± SE) of surface water dissolved organic carbon (DOC) and suspended solids (SS) from five case-study wetland sites, June 2012 – August 2013.

Site	DOC (mg L^{-1})	Suspended Solids (mg L^{-1})
Greenan Lough		
Mean ± SE	6.26 ± 0.05	6.06 ± 2.21
Range	0.49 – 12.47	0.30 – 58.7
Loughaveely		
Mean ± SE	11.08 ± 0.49	11.8 ± 2.05
Range	6.85 – 18.43	0.40 – 53.0
Windy Gap		
Mean ± SE	4.17 ± 0.34	4.42 ± 0.87
Range	6.76 – 23.0	0.10 – 61.4
Kilroosky Lough		
Mean ± SE	9.92 ± 0.57	16.8 ± 4.28
Range	4.76 – 16.6	0.1 - 125
Rockmarshall		
Mean ± SE	7.14 ± 0.71	7.57 ± 2.85
Range	2.57 – 18.27	0.80 – 78.4

4.3.3 Nutrients

Excess nutrients entering a water body such as a lake or wetland may lead to excessive growth of algae, which can reduce oxygen availability for other aquatic biota. In addition, increased nutrient loading may also increase turbidity and ultimately lead to eutrophication or over-enrichment of the system. Phosphorus can be present in water bodies in a number of forms. Orthophosphate is considered to be the most readily available form of phosphorus for plant and algae growth, although phosphorus may also be bound in colloidal suspension or adsorbed onto particulate matter. Analysis of total phosphorus, therefore, is considered to be a more complete determination of the element phosphorus within a water body, and is representative of all of the phosphorus which is actually present in the water course and is particularly meaningful with regard assessing the likelihood of eutrophication. Orthophosphate and total phosphorus concentrations were significantly higher at

Rockmarshall compared to the other case study sites (Table 4.4; Fig. 4.24). Notwithstanding the high phosphorus concentrations recorded at Rockmarshall, the catchment area of this site, nevertheless, had the lowest estimated catchment loading of phosphorus of all the sites (Table 4.5), which were calculated based on CORINE landuse data and livestock numbers within the catchment area. Similar total phosphorus concentrations to those recorded at Rockmarshall were also recorded at Loughaveely, despite generally low values of orthophosphate recorded at this site. There was also a degree of in site variation at Loughaveely with the stream running along the boundary of the site (LYS3) recording higher total phosphorus concentrations (mean of 0.15 ± 0.04 mg L^{-1}-P) compared with the open water pool at the site (mean of 0.04 ± 0.01 mg L^{-1}-P). In contrast to Rockmarshall, however, the high total phosphorus concentrations at Loughaveely corresponded to high estimated catchment loadings of phosphorus. In general mean total phosphorus concentrations at all sites were above the threshold value of 0.06 mg L^{-1}-P considered to be indicative of eutrophication (EPA, 2001), apart from Windy Gap, which consistently recorded the lowest values of all nutrient fractions and is reflective of its high altitude location in an area with relatively low landuse pressures from agricultural activities. Nevertheless, median orthophosphate values were generally found to be below those considered indicative of pollution (Toner *et al.*, 2005), and apart from some sampling locations at Rockmarshall and the outflow point at Kilroosky (KLS2) were generally within the range categorised as unpolluted by the EPA Q-value system (< 0.03 mg L^{-1}-P).

Table 4.4 Mean (± SE) of surface water dissolved nutrients parameters from five case-study wetland sites, June 2012 – August 2013. * = below the detection limit.

Site	Ammonia (NH_3^+-N) (mg L^{-1})	Nitrite (NO_2 -N) (mg L^{-1})	Nitrate (NO_3^--N) (mg L^{-1})	Orthophosphate (PO_4^{3-}-P) (mg L^{-1})	Total Phosphorus (mg L^{-1}-P)
Greenan Lough					
Mean ± SE	0.11 ± 0.01	0.03 ± 0.0	0.97 ± 0.15	0.03 ± 0.0	0.07 ± 0.02
Range	0.01 – 0.20	0.0 – 0.08	0.01 – 2.58	0.0 – 0.08	* – 0.40
Loughaveely					
Mean ± SE	0.09 ± 0.01	0.02 ± 0.0	0.38 ± 0.06	0.02 ± 0.0	0.09 ± 0.02
Range	0.03 – 0.32	0.01 – 0.08	0.01 – 1.60	0.01 – 0.09	* – 0.40
Windy Gap					
Mean ± SE	0.08 ± 0.01	0.03 ± 0.0	0.35 ± 0.02	0.02 ± 0.0	0.02 ± 0.01
Range	0.03 – 0.29	0.01 – 0.21	0.01 – 0.94	0.01 – 0.11	* – 0.65
Kilroosky Lough					
Mean ± SE	0.11 ± 0.02	0.06 ± 0.03	0.60 ± 0.09	0.03 ± 0.0	0.06 ± 0.01
Range	0.03 – 1.74	0.01 – 1.79	0.01 – 2.58	0.01 – 0.25	* – 0.36
Rockmarshall					
Mean ± SE	0.15 ± 0.06	0.03 ± 0.01	0.93 ± 0.10	0.05 ± 0.01	0.09 ± 0.04
Range	0.03 – 2.51	0.01 – 0.37	0.04 – 2.71	0.1 – 0.53	* – 1.60

As already stated there was within site variation in phosphorus concentrations at some of the sites such as Loughaveely and Kilroosky. Additionally, the outlflow at Greenan lough (GLS2) had consistently higher orthophosphate and total phosphorus concentrations than the open water site (GLS1) as did the stream at Rockmarshall (Rock S2) compared with the other surface water sampling locations at this site.

Table 4.5 Estimated loadings of nitrogen and phosphorus from case study wetland site catchments.

Site Name	Nitrogen Loading Kg/Ha	Phosphorus Loading kg/Ha
Greenan Lough	317.5	52.0
Kilroosky	259.6	40.2
Loughaveely	365.5	56.4
Rockmarshall	213.8	37.9

Nitrogen entering a wetland will generally be in either organic or inorganic forms proportionally determined by the source of the water. Particulate fractions usually settle and are buried, while inorganic forms are regulated by various biogeochemical reactions occurring within the system which include nitrification, denitrification, ammonia volatilization and uptake by plants. Ammonia concentrations in surface water above 0.1 mg L^{-1}-N can be considered to be indicative of nearby sources of sewage (EPA, 2001). At the sites of this study, mean NH_3^+-N concentrations were generally below this value, apart from Rockmarshall. Nevertheless, maximum values at the majority of sites often exceeded this value and generally mean values of NH_3^+-N were greater than 0.065 mg L^{-1}-N, which is the threshold environmental quality standard for 'good status' under the WFD (EPA, 2001). However, since most direct inputs of NH_3^+-N will undergo nitrification, most of the nitrogenous content of diffuse and point sources would be expected to appear in surface waters as nitrate (EPA, 2001), and high nitrate concentrations can be indicative of past pollution events from point sources, or alternatively significant run-off from agricultural activities. However, mean levels of nitrate were below the threshold value of 0.9 mg L^{-1} NO_3-N for high status in surface waters (EPA, 2001), with the highest mean value recorded in both Greenan Lough and Rockmarshall, although both were still below values considered indicative of pollution. Nevertheless, throughout the year nitrate values at some sites were high with maximum values as high as 2.28 mg L^{-1} NO_3-N recorded in Greenan Lough and Kilroosky Lough and 2.71 mg L^{-1} NO_3-N in Rockmarshall (Table 4.4; Fig. 4.32). Within-site

variation in nitrate concentration was also apparent at a number of sites including Kilroosky, where higher nitrate values were consistently recorded in the inflow (KLS3) with a mean of 1.1 ± 0.1 mg L^{-1} NO_3-N compared with the open water and outflow sampling points which has similar values (mean of 0.04 ± 0.01 mg L^{-1} NO_3-N for KLS1). For much of the year the outflow at Greenan Lough also had higher nitrate values than the open water sampling site (a mean of 1.3 ± 0.2 mg L^{-1} NO_3-N and 0.6 ± 0.2 mg L^{-1} NO_3-N, respectively).

Overall high concentrations of dissolved inorganic nitrogen (DIN; ammonia + nitrite + nitrate) at Greenan Lough corresponded to high estimated nitrogen loading within the catchment. However, the lowest estimated nitrogen loading was calculated for the Rockmarshall catchment, which had similarly high mean DIN values to those recorded in Greenan Lough.

The ratio of dissolved inorganic nitrogen to total phosphorus (DIN:TP) can be used to provide an estimate of the limiting nutrient for phytoplankton as recommended by Morris and Lewis (1988). They considered these fractions of N and P representative of the bulk of available N and P to phytoplankton. Values greater than 27 (molar) were taken as an indicator of P-limitation, and values below 2 (molar) an approximate indicator of N-limitation. Both Loughaveely and Windy Gap had DIN:TP values > 27 for much of the year (between November and March and all times of the year apart from July and August, respectively), indicating that the phytoplankton community was potentially P limited for much of the year. Ratios of DIN:TP in Greenan Lough fluctuated between values indicative of P limitation between September and March and values indicative of N limitation during the summer months of June and July. Kilroosky showed little indication of either P or N limitation throughout much of the year apart from March 2013 when the DIN:TP ratios rose to a maximum value of 37.

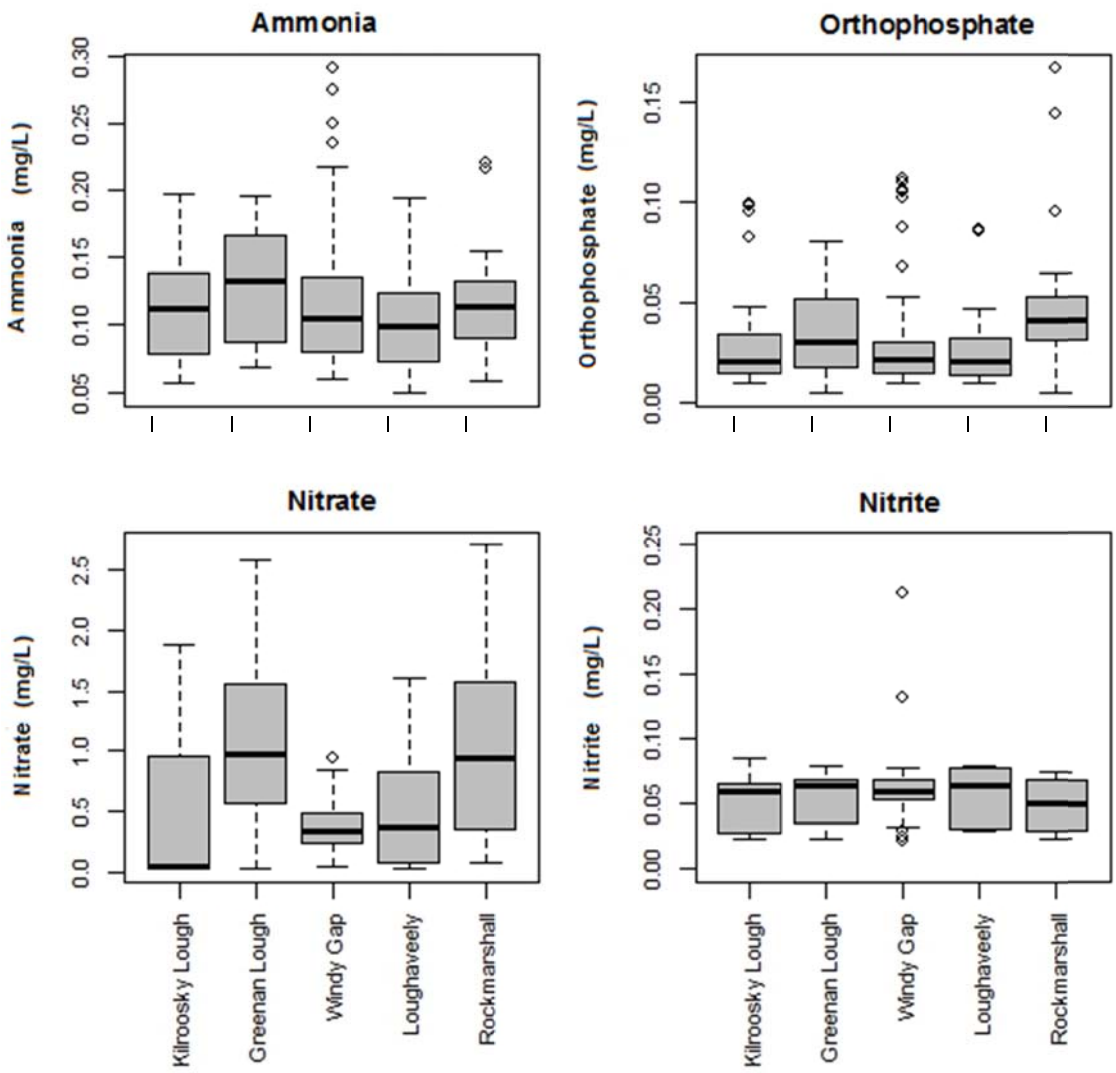


Fig. 4.32 Comparisons of surface water nutrients (ammonia, phosphate, nitrite and nitrate) between each of the five shortlisted sites. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

4.3.4 Major Ion Analyses

The surface water at each wetland was analysed for a range of ions, principally chloride (Cl^-), sulphate (SO_4^{2-}), iron (Fe), potassium (K), calcium (Ca) and sodium (Na). Windy Gap frequently had the lowest values for each of these ions (Fig. 4.33). The highest Cl^- concentrations were found at Rockmarshall with a mean of 22.4 ± 1.1 mg L^{-1}, followed by Kilroosky Lough, which had a number of high outlier values. Values of Cl^- in the study sites remained largely within the normal range of 15 – 35 mg L^{-1} expected for freshwater systems. Kilroosky Lough and Greenan Lough had the highest SO_4^{2-} concentrations with a mean of 11.7 ± 0.9 mg L^{-1} and 9.5 ± 2.9 mg L^{-1}, respectively, although the spread of values were

much grater at Rockmarshall with a maximum SO_4^{2-} value of 25.3 mg L^{-1} compared to 15.7 mg L^{-1} at Greenan Lough. These variations in anoin concentrations between sites are likely reflective of groundwater influences and underlying geology as well as their location in realtion to the coast line, with coastal sites such as Rockmarshall likely to be particularly influenced by sea spray. For example at Kilroosky Lough, higher concentrations of Cl^- were recorded at the inflow stream (KLS3; with a mean of 27.4 ± 4.3 mg L^{-1}), which flows from a spring, compared to the open water (KLS1) and outflow stream (KSL2) at this site which had very similar values throughout the year with mean values of approximately 15.5 ± 0.37 mg L^{-1}. As expected, concentrations of Ca were highest at sites such as Kilroosky Lough and Rockmarshall, which also had the highest alkalinity values, with Windy Gap showing lowest overall Ca values. Similar concentrations of iron were observed across all sites with mean values ranging from 0.009 ± 0.002 mg L^{-1} at Kilroosky compared to the highest mean value of 0.08 ± 0.02 mg L^{-1} at Rockmarshall. The highest within site variablity in Fe concentrations was observed at Windy Gap.

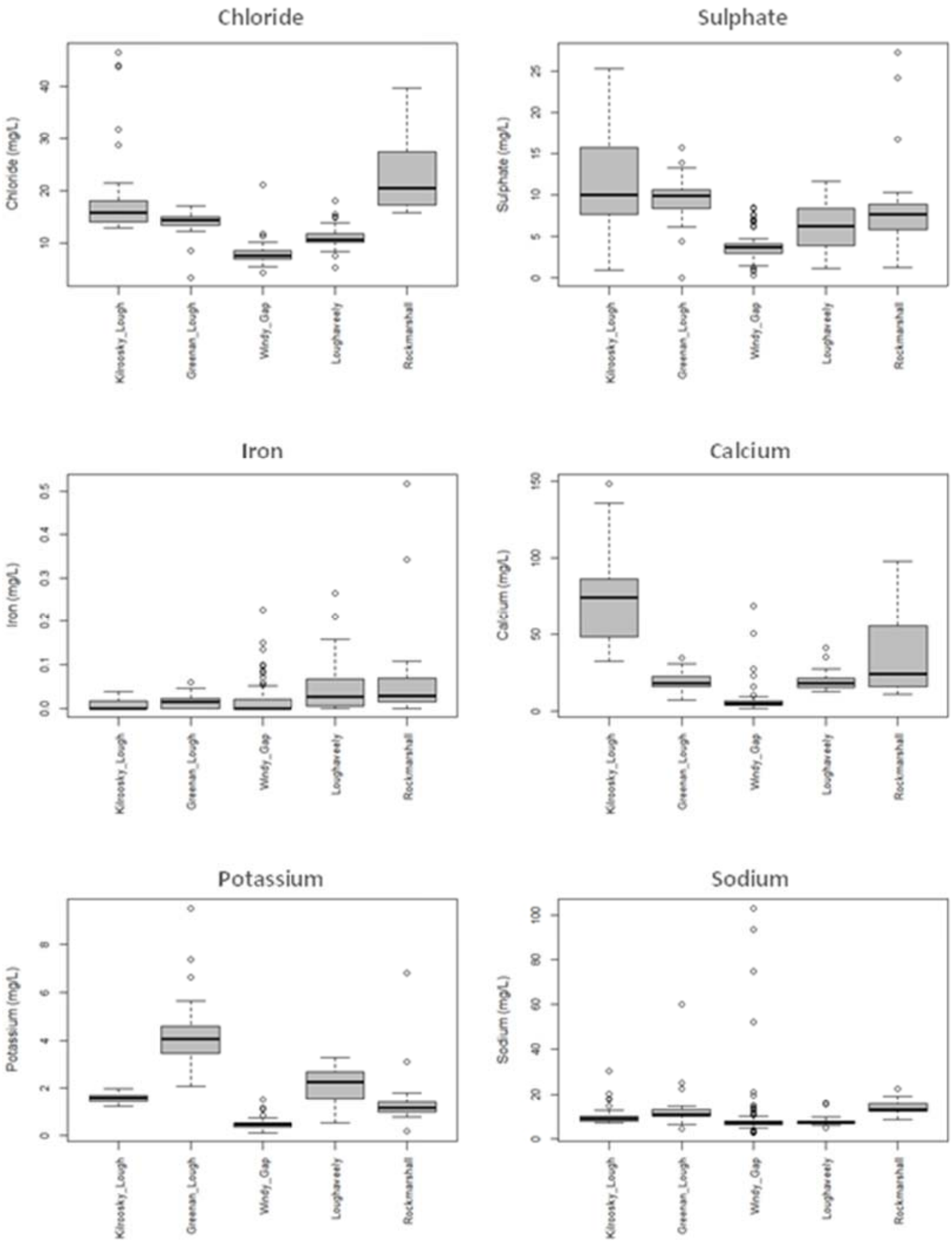


Fig. 4.33 Boxplots showing the concentrations of major ions (chloride, sulphate, iron, calcium, potassium and sodium) in the surface water at each of five wetland sites. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

4.4 Comparison of Field Site Biota

4.4.1 Macroinvertebrates

Macroinvertebrate are any aquatic invertebrate with a body length greater than 0.5 mm. They are a taxonomically diverse group of organisms and are known to have varying responses and sensitivities to environmental conditions. Wetland function and ecosystems health are reflected by the biological components of the system and macroinvertebrates themselves play an important role in the system by decomposing organic matter and vegetation and are, therefore, involved in recycling and transforming nutrients. A total of 83 distinct taxonomic groups of macroinvertebrate were identified across all five case study wetland sites, with each organism identified to lowest practicable taxonomic level. The largest number of taxonomic groups (44) were recorded in Rockmarshall and the lowest in Greenan Lough (27).

Combining all sampling events and reducing the taxonomic classification to taxonomic Class, significant differences were observed between sites for a number of taxonomic groups (Fig. 4.34). Abundances of Mollusca and Annelida differed significantly between sites and both taxonomic groups were absent from Kilroosky Lough. The absence of Mollusca from Kilroosky is surprising given its high alkalinity status and high levels of calcium. Loughaveely observed significantly more Malacostraca (a group which was dominated at all sites by both the amphipod *Gammerus spp*. and the isopod *Asellus sp*), than Rockmarshall, Greenan Lough and Windy Gap, with the lowest recorded numbers of Malacostraca recorded at Windy Gap. There were no significant differences in abundance of Insecta between sites. Insect communities were dominated by species of fly and midges (Diptera) at each site (Fig. 4.35). Stonefly (Plecoptera) were only present (and in small proportions of the overall community) at the stream sampling location at Rockmarshall, the Windy Gap outflow stream and the stream at Loughaveely. Dragonfly species (Odonata) were generally only present in the lake or pool sample locations of Kilroosky Lough, Greenan Lough, Windy Gap and Loughaveely and abundances were generally greatest in July 2012 and October 2012 sampling events. Mayfly taxa (Ephemeroptera) were absent from both Greenan Lough sampling locations (except for June 2012) and Rockmarshall drain (Rock S2) and abundances were very low at Loughaveely, whereas caddisfly larvae (Tricoptera) were present in varying proportions at each site. Hemiptera, which include the Corixidae (water boatmen), typically had greatest mean abundances at sampling locations consisting of open standing water habitats, and were frequently at very low abundances or were absent from lotic habitats with

flowing water. The Annelida Class was dominated by Oligochaeta at all sampling locations except Loughaveely Pool (LYS1) which was dominated by leeches (Hirudinea), which were completely absent from Kilroosky Lough.

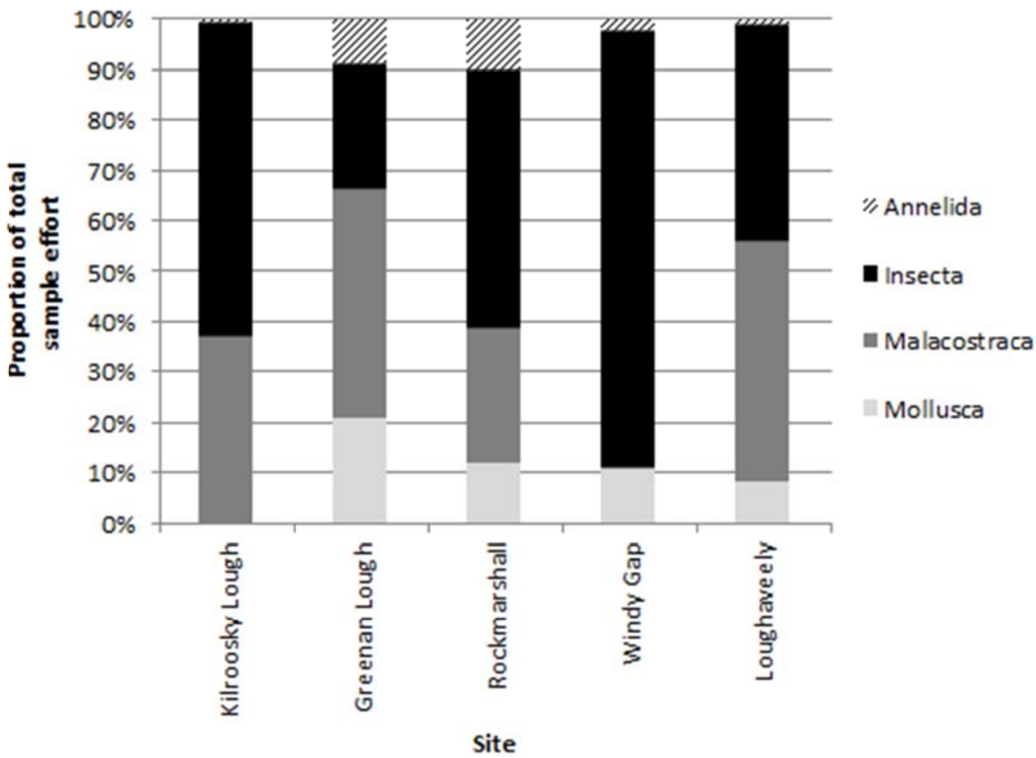


Fig. 4.34 Abundance of key macroinvertebrate taxonomic groups as a proportion of total sample effort for each of five case-study wetland sites.

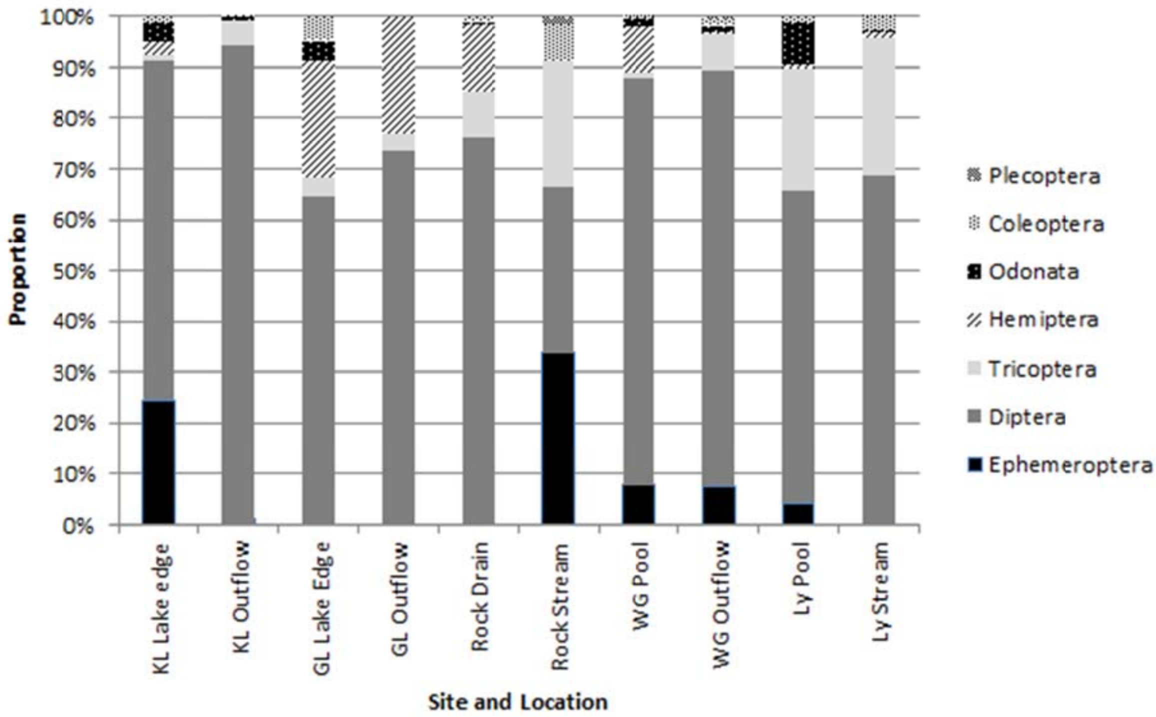


Fig. 4.35 Proportion of taxonomic Orders within the Insecta macroinvertebrate community at each sample location and site.

Both Rockmarshall and Greenan Lough have a more even spread of abundance across the four taxonomic groups in comparison to Windy Gap and Kilroosky lough. Loughaveely and Rockmarshall had the highest mean number of taxonomic groups and mean number of individuals recorded over the entire sampling period, while Greenan Lough had the lowest. However, these differences between sites were not significantly different apart from a difference between Greenan Lough and Loughaveely in the mean number of taxonomic groups recorded (Fig. 4.36).

Mean macroinvertebrate diversity was estimated using a range of diversity indices which are quantitative measures that indicates how many different taxonomic groups there are in a dataset. Diversity is composed of two main factors, richness (or the number of species in a given area), and evenness (or how relative abundance or biomass is distributed among species) (Wilsey and Stirling, 2007). There was a significant difference in both the Simpson's Index and the Shannon Diversity Index (*H'*) between sites (Fig. 4.36), with Rockmarshall showing significantly higher mean Shannon Diversity (*H'*) than Kilroosky Lough, Greenan Lough and Windy Gap (One-Way ANOVA: df=4; F=3.78; P<0.05; Tukey's Post Hoc Test).

This indicates that Rockmarshall has a more diverse macroinvertebrate community than the other three sites (in terms of Shannon Diversity Index).

Rockmarshall had a significantly higher mean Evenness index (*J'*) than both Kilroosky Lough and Windy Gap (One-Way ANOVA: df = 4; F = 3.11; $P < 0.05$; Tukey's Post Hoc Test), indicating that Rockmarshall has significantly more even macroinvertebrate communities (in terms of numbers of different taxonomic groups) than Kilroosky Lough and Windy Gap.

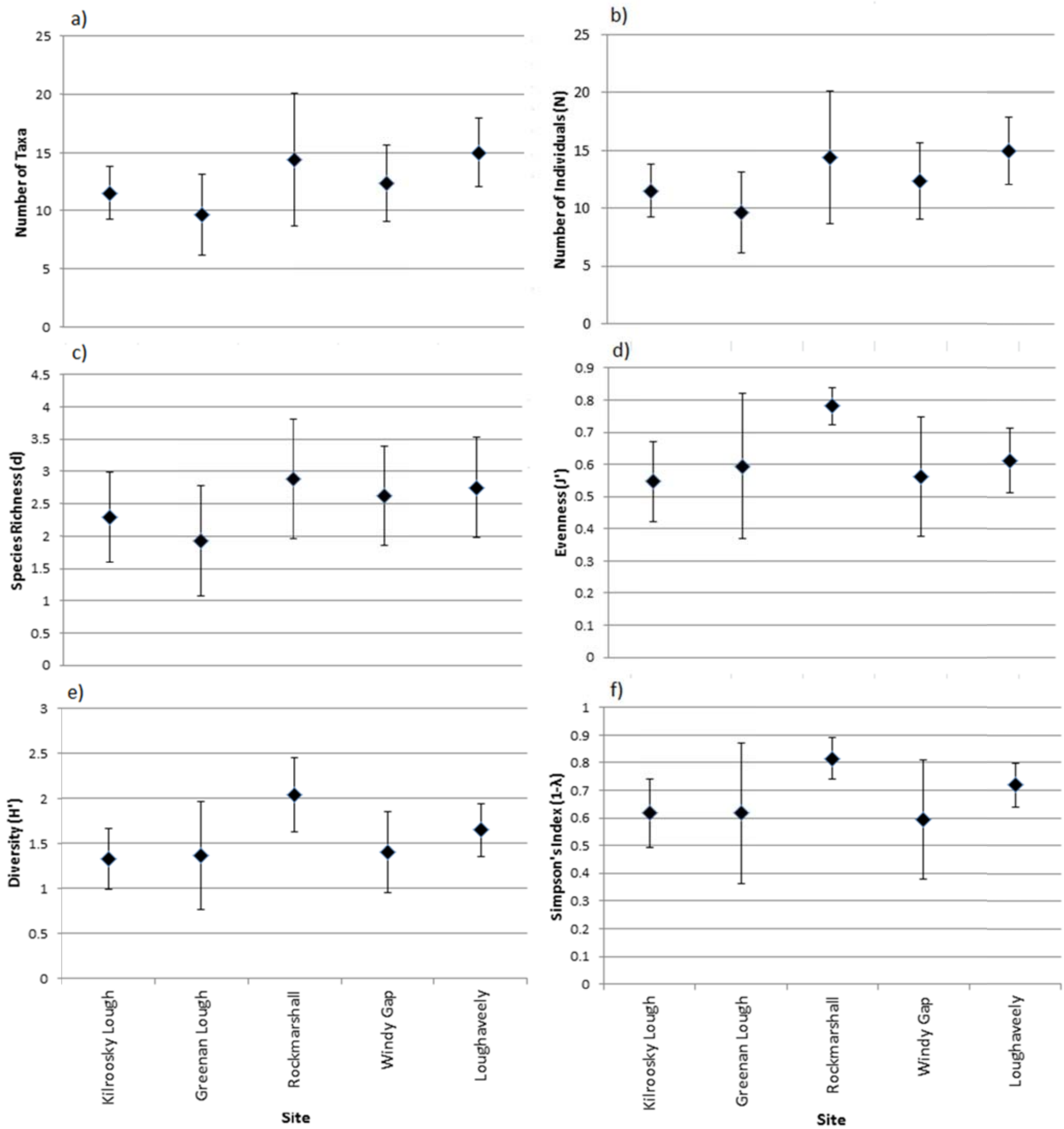


Fig. 4.36 (a) Number of taxonomic groups, (b) number of individuals, (c) species richness, (d) species evenness, (e) Shannon diversity index and (f) Simpson's diversity index calculated on mean number of taxonomic groups per site for all sampling events combined.

There was a significant difference in macroinvertebrate communities between sites (all sampling events combined, ANOSIM Test: Global R = 0.417; $P < 0.01$), except between Greenan Lough and Rockmarshall. The similarity of macroinvertebrate communities across the case-study sites, sampling location and sampling time was assessed using

multidimensional scaling analyses (MDS; Fig. 4.37). Note that the stress value of 0.21 for this analysis indicates a poor fit of the data into this two-dimensional representation, resulting in some distortion of the data. Therefore, care must be taken when interpreting the results of this MDS analysis and the results presented can only be used as an indication of the levels of similarities between points rather than an exact representation of similarities. The further apart points are in the two-dimensional space of an MDS plot, the more dissimilar the macroinvertebrate communities are in terms of diversity and abundance. Green circles enclosing points represent how similar (in terms of macroinvertebrate community diversity and abundance) points within each circle, or cluster, are to each other. In Fig. 4.29, the level of similarity of points within each cluster is 40%.

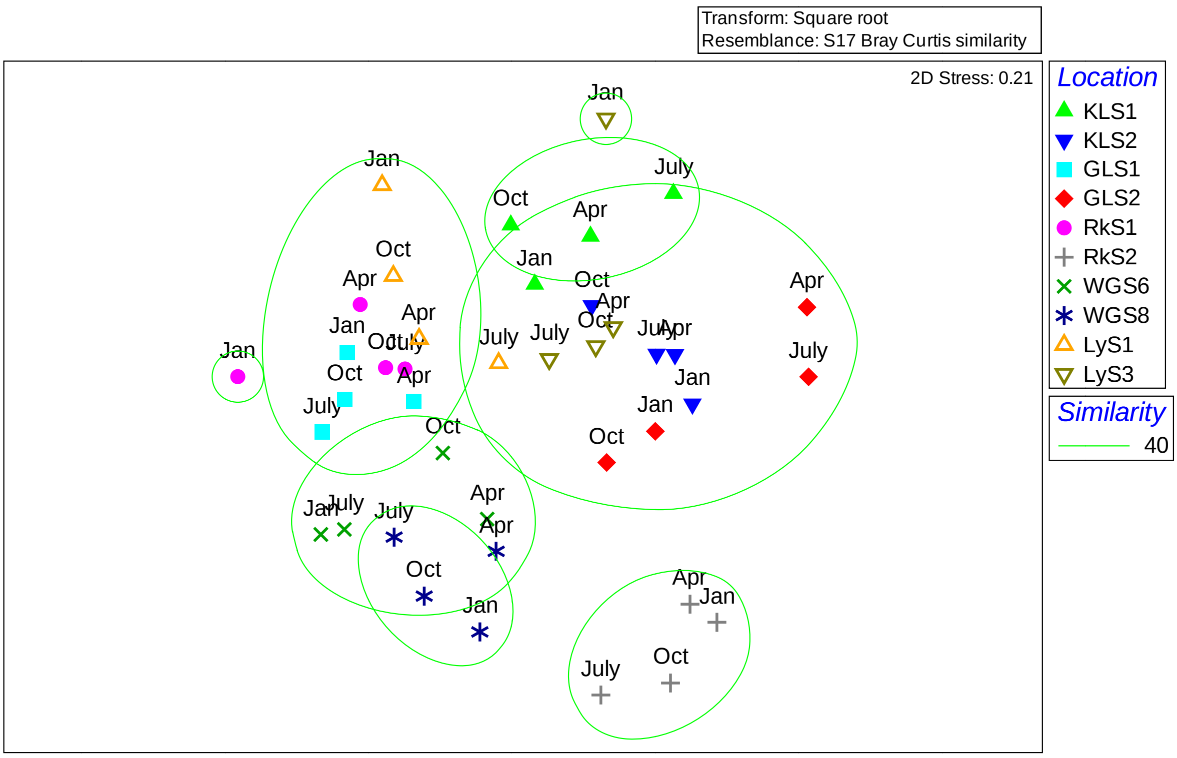


Fig. 4.37 Non-metric Multi-Dimensional Scaling (MDS) diagram showing the relationship between sites, sampling location and sampling occasion in terms of macroinvertebrate community diversity and abundance. Note that the high level of 2D stress indicates that the results observed here can only be used as an indication of similarity between points.

Using SIMPER analysis, it is possible to represent the proportional contribution of individual taxonomic groups to the macroinvertebrate communities at each site or sampling location. Table 4.6 shows the results of SIMPER analysis for each site, with only the top three taxonomic group contributors (in terms of proportional contribution) listed. Four taxonomic groups were consistently among the top three proportional contributors to the

macroinvertebrate community at each site, Chironomidae, Tubificidae, *Gammarus pulex* and *Asellus aquaticus*. At Rockmarshall, a second gammarid species, *Gammarus duebeni*, contributed 7.53% to the community. At Windy Gap, two molluscs contributed high proportions to the macroinvertebrate community, the gastropod *Radix balthica* and the mollusc *Pisidium sp*. This is despite the low alkalinity and low calcium concentrations recorded at this site. The low cumulative total of the top three contributors at Rockmarshall indicates a contribution of a larger diversity of taxonomic groups in comparison to the highest cumulative contribution observed at Kilroosky Lough.

Table 4.6 Proportional contribution of the top three species contributors of the macroinvertebrate community at each site.

Taxonomic Group	Average Abundance	Contribution (%)	Cumulative Contribution (%)
Kilroosky Lough			
Gammarus pulex	7.27	34.94	34.94
Chironomidae	9.09	33.29	68.23
Asellus aquaticus	3.93	14.79	83.02
Greenan Lough			
Chironomidae	4.77	31.92	31.92
Gammarus pulex	5.70	17.08	49.00
Naididae	3.00	12.24	61.23
Rockmarshall			
Chironomidae	5.37	25.19	25.19
Naididae	4.12	22.77	47.97
Gammarus duebeni	3.68	7.52	55.49
Windy Gap			
Chironomidae	9.18	44.04	44.04
Radix balthica	3.34	15.44	59.47
Pisidium sp.	2.02	9.71	69.18
Loughaveely			
Asellus aquaticus	9.84	29.04	29.04
Chironomidae	8.91	21.72	50.75
Gammarus pulex	6.41	10.19	60.94

Environmental pollution can alter macroinvertebrate communities. Community characteristics such as diversity and abundances and assessing the occurrence of ecologically sensitive taxa can, therefore, be used to assess impact on a wetland system. Different taxa can vary in their sensitivity to a range of environmental variables. In order to discover which abiotic variables best explain the pattern in macroinvertebrate community structure, patterns in biotic variable were matched to the patterns in the distribution of the physical and chemical variables using the BEST analysis in Primer v.6. Combining all sampling locations and sample periods, BEST analysis finds that the combination of orthophosphate (PO_4^{3-}), nitrate

(NO_3^-), potassium (K) and suspended solids have the highest correlation value of 0.65, which indicates that this combination of parameters are best able explain the macroinvertebrate distributions and abundance across all sites for all sampling times. The addition of total organic carbon to these BEST environmental variables results in a correlation value of 0.64, which is very similar to the highest correlation value stated above. The two parameters NO_3^- and TOC in isolation result in a correlation of 0.63.

It has previously been found that macroinvertebrate abundances and diversity is negatively affected by high turbidity and nutrient concentrations in the water column in addition to low oxygen concentrations (Spieles and Mitsch, 2000; Van de Meutter *et al*., 2005; Sharma and Rawat, 2009). As was observed here, macroinvertebrate community composition was related to suspended solid concentrations. Suspended inorganic and organic particles are known to affect macroinvertebrates by interfering with their respiration, feeding and reproduction (Van de Meutter *et al*., 2005). Filter feeders whose feeding appendages are disrupted will need to expend more energy collecting food. In addition, high levels of suspended solids may begin to settle covering rocks and vegetation, which will affect movement, feeding, habitat and reproduction of some macroinvertebrates. Distribution of macroinvertebrates was also explained at the five case study sites of this study by the nitrogen and phosphorus concentrations whose effect on the macroinvertebrate community is likely indirect as increased input of nutrients from agricultural spreading of organic and inorganic fertilisers increases algae growth. Excessive growth of algae can cause declines in dissolved oxygen availability. In these conditions, macroinvertebrate community diversity is usually reduced but there is generally an increase in the abundance of a few tolerant taxa who can exploit the conditions. The relationship with potassium at the five case study sites is also likely to be as an indirect consequence of the relationship with increased nutrient inputs, as potassium is often a key component of inorganic fertilizers applied to land which also contain nitrogen and phosphorus.

Macroinvertebrates have traditionally been used as a bioassessment technique to assess the health of aquatic ecosystems, owing to their characteristic changes in community structure in response to levels of organic pollution. Therefore, community characteristics, including diversity and abundance of known ecologically sensitive taxa and their relative proportions to taxa known to be tolerant to pollution within a macroinvertebrate community can allow for an

assessment of potential ecological impact within a site. There was a general lack of taxa to which are considered most sensitive to pollution such as stonefly (Plecoptera) and certain species of mayfly (Ephemoptera) across all sampling sites and sampling periods. These taxa have high requirements for oxygen and are, therefore, considered sensitive to environmental stress. Furthermore, proportional taxa abundance at each site (Table 4.6) was generally dominated by the more tolerant taxa such as Chironomidae, which are considered good competitors under conditions which inhibit other taxa, and Oligochaeta of which the family Naididae (formerly Tubificidae) are very tolerant to pollution and are capable of surviving anoxic conditions.

In Ireland the most commonly applied macroinvertebrate biotic index is the EPA Q-value system, which has been used in Ireland to assess the water quality of streams and rivers since the 1960s and is currently used as part of the WFD monitoring programme. This index was applied to a subset of the macroinvertebrate sampling points from this study which had flowing water. Nevertheless, the values produced must be viewed with caution given that the Q-value system was not designed for stream beds with mud or sand substrate or sluggish water. The stream at Greenan Lough (GLS2) had the lowest Q-value, which is indicative of a seriously polluted system. The outflow at Windy Gap (WGS8) had a low Q-values of Q3 which suggested moderate levels of pollution, although during the autumn and winter sampling periods this did improve slightly, but was still suggestive of slight levels of pollution. Rockmarshall observed the highest overall Q-value of Q-3-4, but this is still not classed as satisfactory condition (Table 4.7).

Table 4.7 Irish EPA Q-values for the three sampling locations whose habitats were closest to the riffle habitats for which Q-value assessments were designed. The Q-value is as follows; Q5, Q4-5*, Q4 = unpolluted water; Q3-4 = slightly polluted; Q3, Q2-3 = moderately polluted; Q2, Q1-2, Q1 = seriously polluted water in unsatisfactory condition. *The intermediate values denote transitional conditions (Clabby *et al*., 2004).

Site	**Location**	**Q-value**				
		July 2012	**Oct 2012**	**Jan 2013**	**April 2013**	**Overall**
Greenan Lough	GLS2	Q3	Q2	Q2	Q2	Q2
Rockmarshall	Rock S2	Q3	Q3-4	Q3-4	Q3-4	Q3-4
Windy Gap	WGS8	Q3	Q2-3	Q3-4	Q3	Q3

It is also worth noting that the white-clawed crayfish (*Austopotamobius pallipes*) was present at Kilroosky Lough. The sampling technique employed for this study was not suitable for

assessing their abundance accurately, however, they were easily observed during every visit to the site. The white-clawed crayfish is one of four crayfish species indigenous to Europe and is the only crayfish species found in Ireland. It was classified as vulnerable in the 2010 IUCN Red List of threatened animals and listed under Annex II and V of the EU Habitats Directive. Ireland is, therefore, required to designate Special Areas of Conservation (SACs) for the species under Natura 2000 and to monitor the status of the crayfish populations on a regular basis. Crayfish generally occur in regions dominated by limestone geology (Reynolds *et al*., 2010), and as Ireland is thought to have some of the best stocks of this species in Europe, these Irish stocks are of considerable conservation importance (Reynolds, 1998). The white-clawed crayfish are vulnerable to the build-up of silt and suspended solids, which can easily clog their gills and they are not generally found to occur in areas covered by mud or silt (Reynolds *et al*., 2010).

The common newt (*Lissotriton vulgaris;* formerly *Triturus vulgaris*) was also observed at the at the Rockmarshall site. They are considered native to Ireland and are the only species of newt, and one of only three species of amphibian which occur in Ireland (Marnell, 1996). The newt is listed in Annex III of the Berne Convention. Newts breed in ponds and areas of standing water with vegetation cover close by, they are, therefore, particularly vulnerable to drainage and habitat damage. Other fauna of note recorded at Rockmarshall over the course of the monitoring period include a skullcap sawfly (*Athalia scutellariae*) which was recorded during the vegetative survey feeding on the skullcap plant, which was new county records for this species (see section 4.3.3.2.2). In addition, numerous species of bird were observed such as the common snipe (*Gallinago gallinago*), pheasant (*Phasianus colchicus*) and the curlew (*Numenius arquata*), which was also recorded during the vegetative survey.

4.4.2 Plankton

4.4.2.1 Phytoplankton

Chlorophyll *a* is a measure of the concentration of photosynthetic chlorophyll pigment and is commonly used as a proxy of phytoplankton biomass. Consequently, measurements of chlorophyll *a* are an important parameter for assessing aquatic systems, as phytoplankton growth is strongly linked to nutrient availability and excessive nutrient inputs can promote the excessive growth of phytoplankton, particularly those species which are particularly

adapted to alteration in the ratio of nitrogen to phosphorus availability, such as cyanobacteria which can develop into harmful algal blooms.

Windy Gap had significantly lower chlorophyll *a* concentrations than all other sites (Fig. 4.38; Table 4.8), with the highest concentrations generally recorded at Kilroosky. Maximum chlorophyll *a* values at Kilroosky (Fig. 4.39) and Greenan Lough were within the range (25 – 35 µg L^{-1}), which is considered indicative of moderate levels of eutrophication based on the modified Organisation for Economic Cooperation and Development [OECD] trophic classification scheme utilised in Ireland by the EPA (EPA, 2001). Windy Gap remains within the oligotrophic range (< 8 µg L^{-1}) suggesting no pollution impact, and Loughaveely within the mesotrophic range (8 – 25 µg L^{-1}), which indicates low levels of pollution.

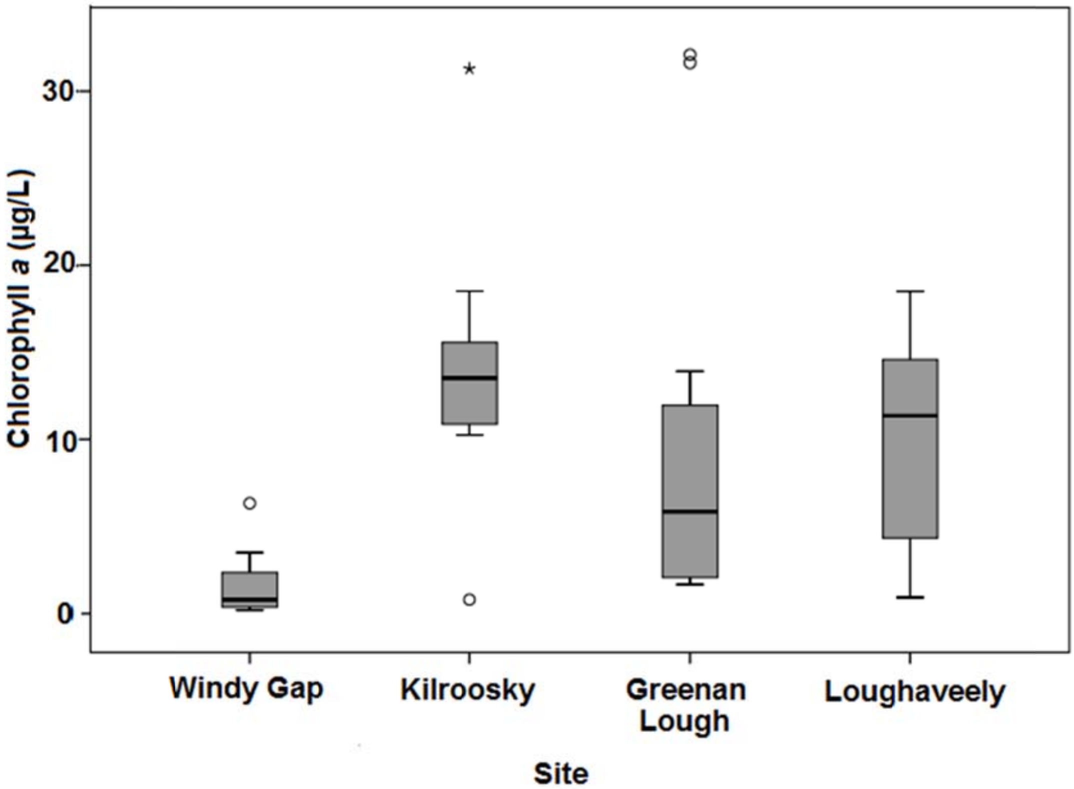


Fig. 4.38 Comparisons of surface water Chlorophyll *a* concentration between each of the shortlisted sites containing open water habitat. The boxplots show the median, 75th and 25th percentile, whiskers delineate the data value less than or equal to 1.5 times the inter-quartile range outside the quartile, o = outlier data value less than or equal to 3 times and greater than 1.5 times the inter-quartile range outside the quartile.

There was no statistically significant relationship between chlorophyll *a* and nutrient concentration at either Kilroosky Lough or Windy Gap. However a negative relationship was

observed between orthophosphate and chlorophyll *a* concentration at Loughaveely and Greenan Lough (Pearson's, $r = -0.62$, $P \leq 0.05$, n = 12 and $r = -0.69$, $P \leq 0.05$, n = 12, respectively). This would suggest that phytoplankton growth at these sites may be P limited, and orthophosphate is consumed rapidly as phytoplankton biomass increases.

Table 4.6 Chlorophyll *a* concentrations for each of the five study sites.

Site	Greenan Lough ($\mu g\ L^{-1}$)	Loughaveely ($\mu g\ L^{-1}$)	Windy Gap ($\mu g\ L^{-1}$)	Kilroosky Lough ($\mu g\ L^{-1}$)
Mean ± SE	9.17 ± 0.1	9.11 ± 0.38	1.47 ± 1.19	13.4 ± 2.39
Range	1.6 – 32.1	0.92 – 18.5	0.09 – 6.32	0.81 – 31.3

Fig. 4.39 A plankton sample collected from Kilroosky Lough in March 2013, which corresponded to a maximum in Chlorophyll *a* concentration recorded at the same time.

4.4.2.2 Zooplankton

Zooplankton species hold a central location in pelagic food-webs and are typically regulated by a combination of predation and food limitation. At certain times of the year, zooplankton grazing can have a major role to play in reducing total phytoplankton biomass and productivity. In addition, zooplankton can also stimulate phytoplankton growth by recycling nutrients back into the system. Compared with the multitude of species commonly found in the phytoplankton community of freshwater systems, the zooplankton community is relatively species poor and is dominated by three main groups comprising the rotifers,

copepods and cladocerans. The rotifers are small animals less than 1 mm in length, and owing to their small size, generally constitute only a relatively minor part of zooplankton biomass. They are, however, a considerably important component of the community owing to their rapid turnover and metabolism, and often have a major role in the processes of nutrient cycling and energy transfer in open water systems (Makarewicz and Likens, 1979). The copepods are crustaceans and are composed of two principle open water groups, the calanoid copepods and the cyclopoid copepods. Copepods consist of herbivorous, carnivorous and parasitic forms. The calanoids generally collect their food by filtration, whereas cyclopoids tend to macerate their prey, however, there are many exceptions and a variable diet is common (Dussart and Defaye, 1995). The Cladocera encompasses an eclectic group of organisms, most of which live in the open water, although some live on surfaces such as macrophytes or among sediments. During optimum conditions, populations are dominated by females who reproduce asexually, however, during environmental stress such as food limitation, oxygen depletion or overcrowding production of males can triggered and the population enters a phase of sexual reproduction. The majority of cladocerans are generalist filter feeders, but some species can be carnivorous, feeding on protozoa, rotifers, and small crustaceans.

Highest zooplankton biomass was recorded in Kilroosky and Greenan Lough with peak in biomass occurring at all sites, apart from Windy Gap, in March 2013. This corresponded to the observed peaks in phytoplankton biomass, as indicated by high chlorophyll *a* concentrations which were observed at most sites during this period. The zooplankton community structure of both Greenan Lough and Kilroosky were dominated by rotifer species with cladocerans and copepods contribute just a small fraction to overall abundance (Fig, 4.40). Windy Gap and Loughaveely had a more even distribution of across taxa groups (Fig. 4.40) with cladoceran and copepod species making a larger contribution to total zooplankton abundance. It would be expected that given the small body size of rotifers that they would contribute less to the community in terms of biomass, however, following conversion to biomass, rotifers still remained the dominant component of the zooplankton community of both Greenan Lough and Kilroosky, whereas, copepod and cladocerans contributed a greater proportion of overall biomass at Windy Gap and Loughaveely (Fig 4.41). This is despite the fact that previous studies have reported low numbers of large, calcium dependent taxa such as *Daphnia* in low-alkalinity lakes (Hessen *et al.*, 1995;

Wærvågen *et al*., 2002). Additionally, previous studies have found increasing abundances of rotifers with decreasing alkalinity (Tessier and Horwitz, 1990). Nevertheless, a study of six lakes in Ireland observed a positive relationship between rotifer abundance and alkalinity (McCarthy and Irvine, 2010), which corresponds to observations at the case study sites of this study. In addition, presence of zooplankton taxa believed to require relatively high levels of calcium for growth and reproduction at Windy Gap, which was found to have low-alkalinity and Ca concentrations, corresponds to what was also observed for the macroinvertebrate community at this site.

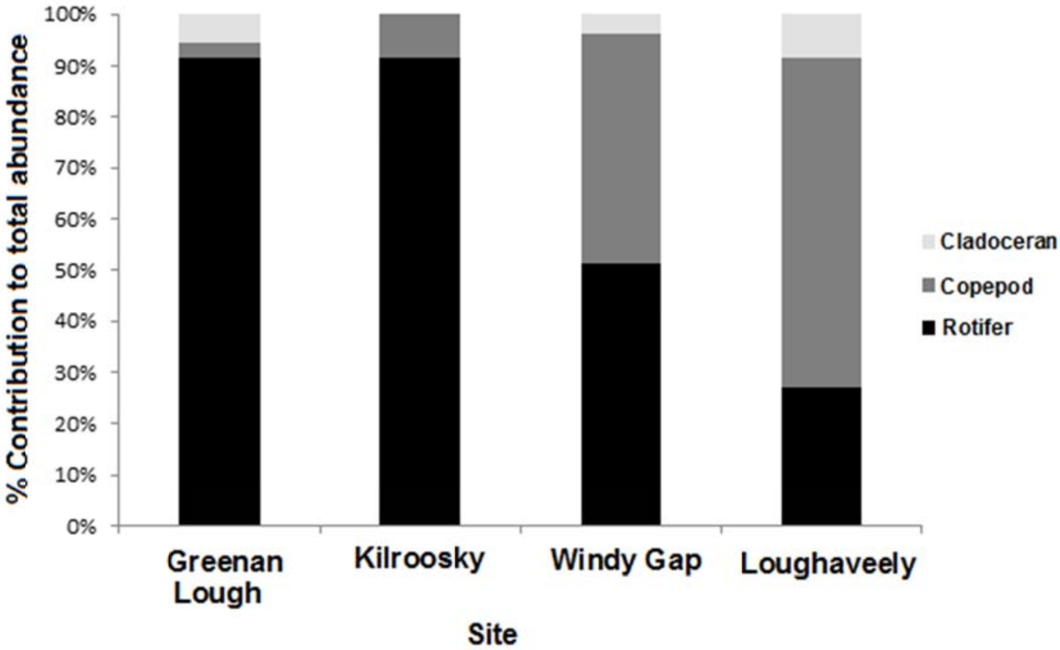


Fig. 4.40 Percentage composition of zooplankton community abundance at each of the four case-study sites which contained open water.

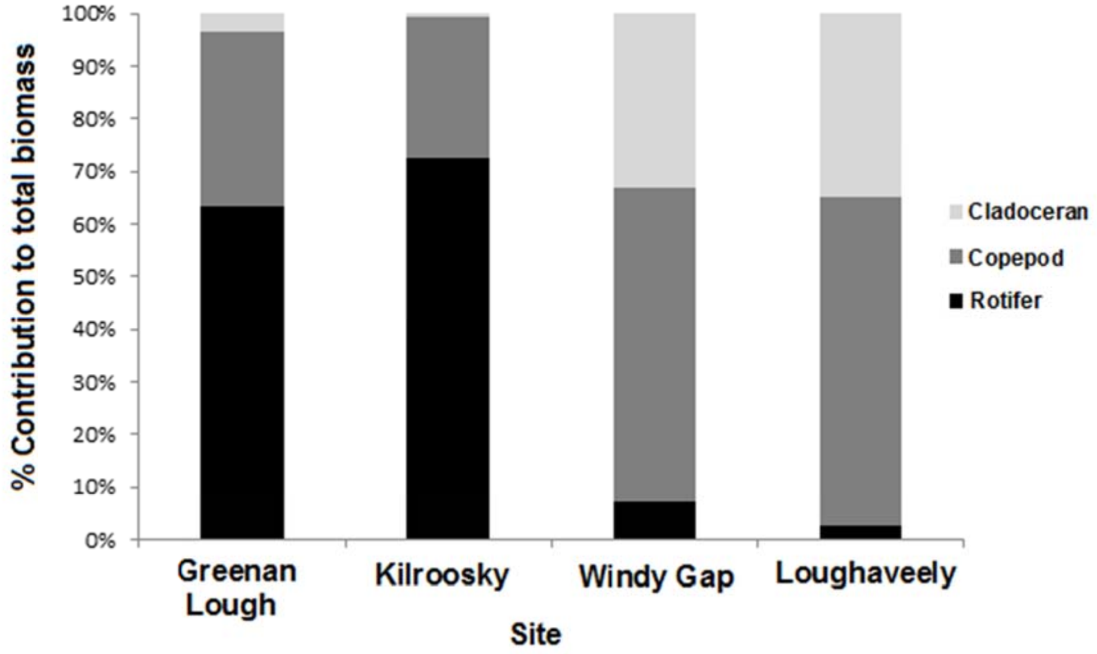


Fig. 4.41 Percentage composition of zooplankton biomass at each of the four case-study sites which contained open water.

4.4.3 Vegetation

4.4.3.1 Presence/Absence comparison across sites

Data for vegetation analyses have been derived from two sources depending on the data availability. Data on species presence from the UK National Biodiversity Network Gateway (https://data.nbn.org.uk/) is available for sites occurring either entirely or partially in NI (Kilroosky Lough, Greenan Lough and Loughaveely). This provides presence/absence data which was collated for each site following routine monitoring of protected areas. Data for the sites in the RoI (Windy Gap and Rockmarshall) were collected through quantitative vegetation surveys undertaken by Dr. Peter Foss and Dr. Patrick Crushell through Wetland Surveys Ireland on behalf of the Tellus Border Wetland Project. These quantitative surveys represent the first detailed vegetative surveys undertaken at each of these sites.

Greenan Lough had the highest number of species (229), followed by Kilroosky lough (87), Loughaveely (63), Windy Gap (58) and Rockmarshall (50), however, this may be representative of survey effort, survey methodology and the specific areas assessed. In order to compare the vegetation community across all case-study wetlands a cluster analysis (Fig. 4.42) was carried out which found that Greenan Lough has a distinct vegetation community in comparison to the other sites. Rockmarshall and Windy Gap have the most similar vegetation communities, diverging at approximately the 50% similarity level.

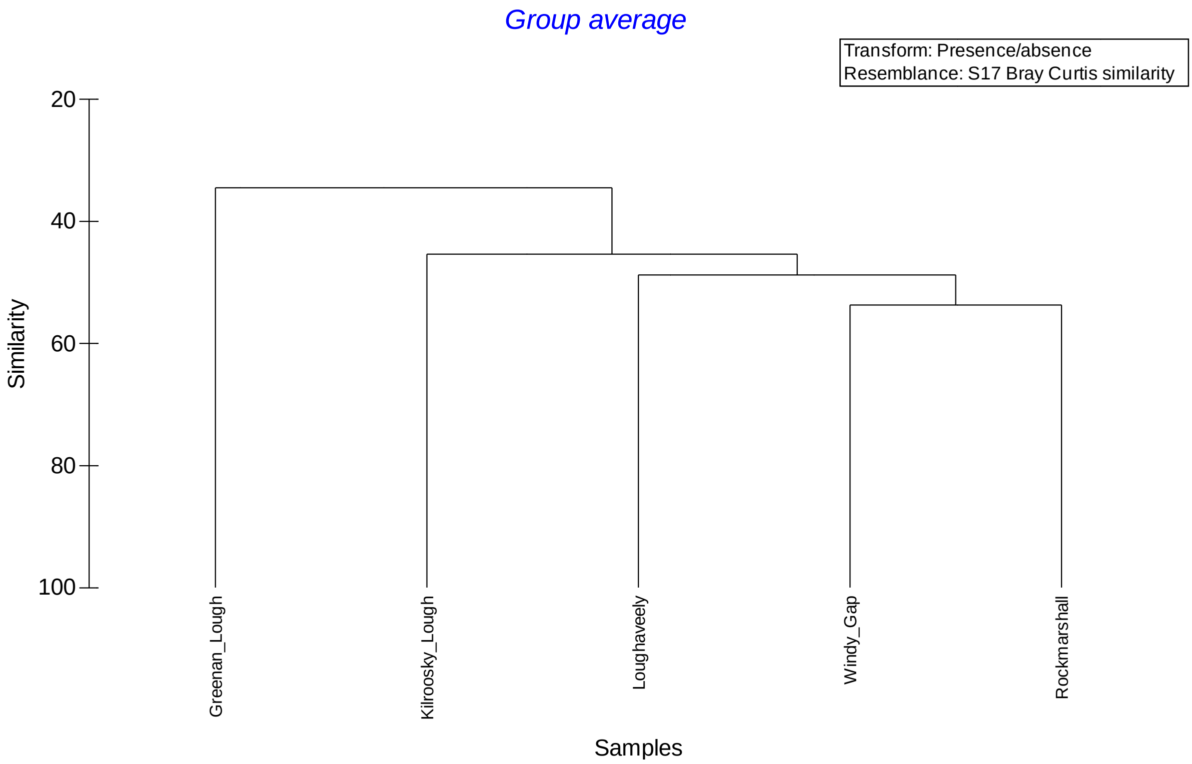


Fig. 4.42 Cluster analysis showing the levels of similarity between vegetation communities at different sites.

4.4.3.2 Quantitative Vegetation Survey

4.4.3.2.1 Windy Gap

The main wetland habitat types occurring on Windy Gap are wet grassland, poor fen, heathland and cutover bog areas dominated by secondary poor fen vegetation (Table 4.9; Fig. 4.32). In general, the secondary fen vegetation occurring on the site appears to be subject to a degree of enrichment from inflow or groundwater. The poor fen on the site has a low bryophyte cover in general, with few *Sphagnum* species and patchy brown mosses distribution. Dry/humid acid grassland, poor fen and flush, wet grassland and dry heath represent the major vegetation types present at Windy Gap (Table 4.9). Dense bracken and dystrophic pools cover a small proportion of the site.

A series of linear remnant peat ridges, running in an almost east west direction, and elevated above the surrounding wet hollows and pool areas, occur throughout the site. These ridges are dominated by *Molinia caerulea* wet grassland vegetation. The ridges are up to 50 cm taller than the surrounding wetter hollows. A similar fringe of *Molinia* dominated grassland vegetation occurs around the edge of the site, in particular on the western side, between the acid grassland/heath vegetation on the slope and the wetland in the base of the valley. The

Molinia grassland along the western edge of the wetland is associated with a steep bank some 80 to 200 cm in height where the transition to the wetland in the valley floor occurs.

A total of 10 vegetation quadrat descriptions (relevés) were recorded at the Windy Gap site. The Poor Fen and Flush community occurs throughout the Windy Gap wetland within hollows and in large cut out bog pools. The peat substrate depth recorded within these quadrats was in excess of 150 cm and the ground was extremely soft and quaking throughout the site. Surface water was at or close to the surface in the quadrats recorded. The vegetation is characterised by the occurrence and significant cover of *Carex rostrata, Eleocharis multicaulis, Equisetum fluviatile, Carex panicea* and *Menyanthes trifoliata*. Vegetation cover varied from 80 to 95% in the quadrats. The occurrence of a number of brown mosses indicates that the vegetation may be influenced by groundwater. A high cover of algae on the bare peat substrate or on mosses in the ground layer was noted in a number of locations supporting this vegetation type.

Table 4.9 The main vegetation types and their extent recorded during the 2013 survey and calculated from the GIS at Windy Gap, County Louth.

Habitat Type	Fossitt Habitat Code	Area covered in ha based on 2013 survey data	Area covered in ha based on aerial photographic interpretation	Vegetation type
Poor fen and flush	PF2	2.24	1.45	*Carex rostrata* dominated poor fen
Upland eroding stream	FW1		-	NA
Wet Grassland	GS4	1.37	-	*Molinia* dominated wet grassland
Dystrophic Lake	FL1	0.13	0.92	With sparse surface and submerged vegetation; *Carex rostrata* is the main species present
Dry heath	HH1	1.55	-	
Dense bracken	HD1	0.12	-	
Dry / humid acid grassland	GS3	4.92	-	
Cutover bog	PB4	2.24	-	Not mapped, as secondary wetland habitats now dominate former cutover bog areas

The vegetation community of a number of dystrophic pools created as a result of former peat cutting activities was characterised by the sparse growth of *Carex rostrata* and *Equisetum fluviatile* with a limited number of other aquatic species occurring which included *Eriophorum angustifolium, Eleocharis multicaulis, Menyanthes trifoliata*, *Myriophyllum alterniflorum*, *Ranunculus flammula* and *Potamogeton natans*. The vegetation at the edge of pools covered 20 - 25 % of the surface area of quadrats, and declined in cover towards the open water areas in the centre of pools. Following the vegetation survey, the area covered by the dystrophic ponds was estimated to be relatively small, reflecting the occurrence of at least some sparse poor fen vegetation around the edge of these pools, and were mapped accordingly with open water areas on the site covering 0.13 ha and poor fen estimated to cover 2.24 ha (Fig. 4.43). However, Fig. 4.44 shows the extent of open water areas as seen on recent aerial photography, taken during the winter months, when the poor fen vegetation has died back and more extensive open water areas are revealed. The open water area on this map version covers 0.92 ha. Applying this value for the area of open water, the extent of poor fen would only cover an estimated 1.45 ha of the site (Table. 4.9).

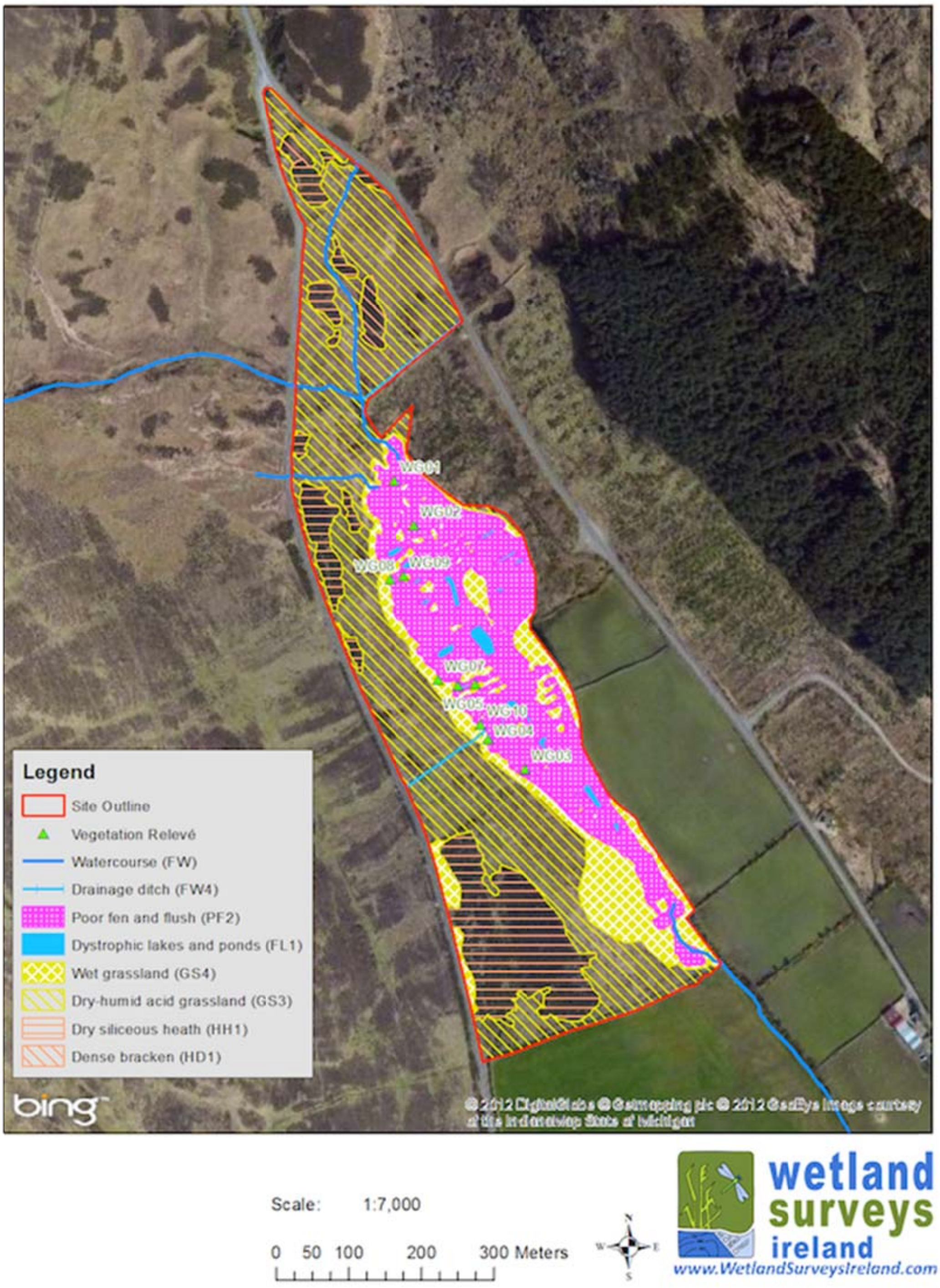


Fig. 4.43 Map of the vegetation types and hydrological features at Windy Gap, Co. Louth based on the 2013 survey.

(Photographic copyright Bing Maps).

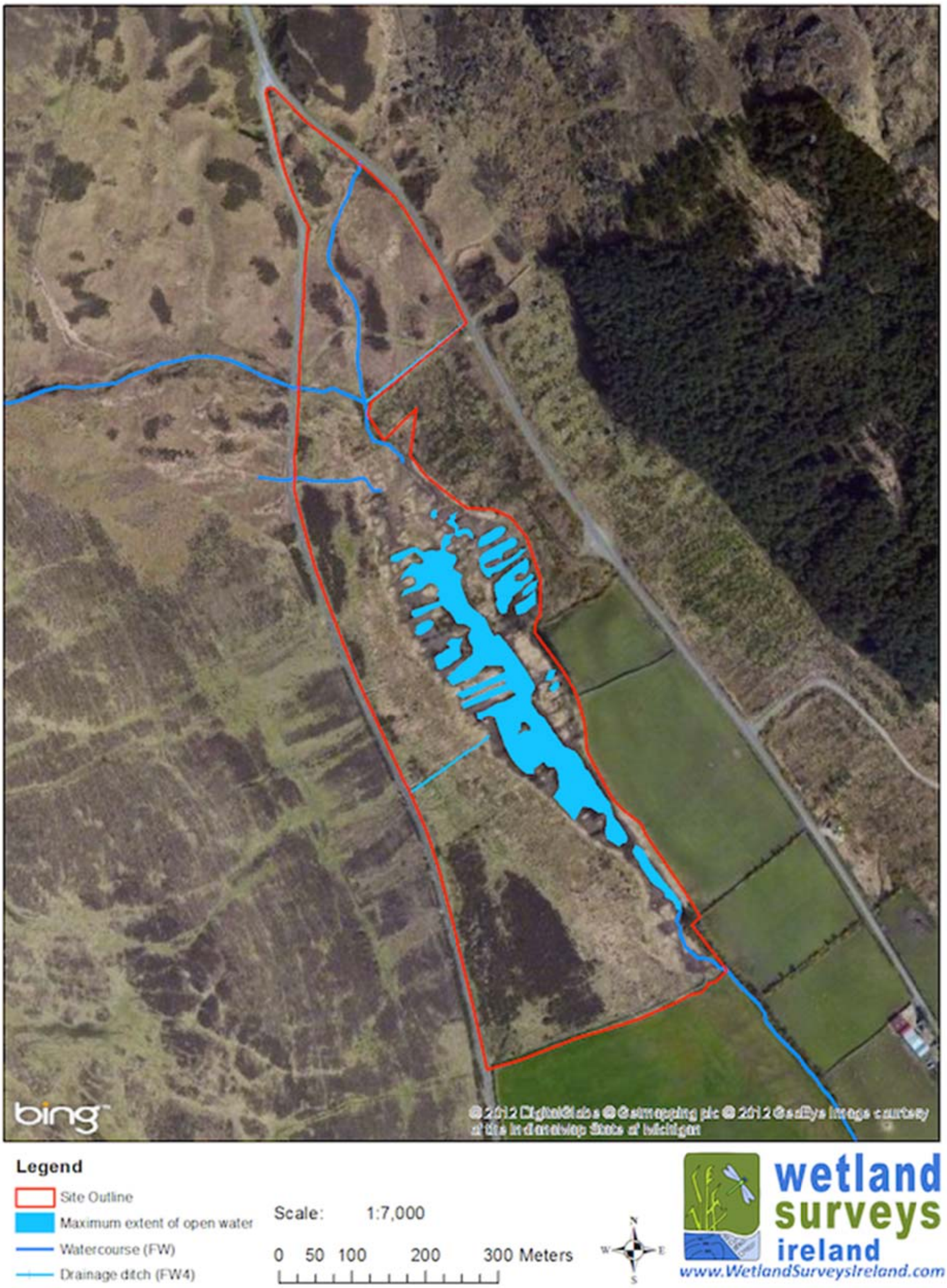


Fig. 4.44 Map showing maximum pool extent on Windy Gap, Co. Louth based on winter aerial photographic interpretation.

(Photographic copyright Bing Maps).

4.4.3.2.2 Rockmarshall

A total of 11 vegetation quadrat descriptions (relevés) were recorded at the Rockmarshall site. The main wetland habitat types recorded were transition mire, reed bed, wet grassland and some willow scrub areas on fen at the southern end of Wetland 1 (SW1) and Wetland 2 (SW2) (Table 4.10), and along the central drains, which run through each of the three linear wetland areas, in particular on Wetland 1 and Wetland 2. Wetland 1 and Wetland 2 are the wettest of the linear features and contain all of the wetland habitats described above. In the case of Wetland 3, the largest of the linear wetland features, only wet grassland was recorded (Fig. 4.45). A deep drainage ditch running through the centre of Wetland 3 (SW3) may be having a significant effect on the potential wetland community that could occur on this wetland. Based on the surveyors observations of vegetative cover, all of the drains appear to have been in situ for a considerable period, many are semi in-filled and may no longer be functioning at peak efficiency.

Table 4.10 The main vegetation types recorded at Rockmarshall, County Louth.

Habitat Type	Fossitt Habitat Code	Area covered in ha or length in m	Vegetation type
Transition mire & quaking bog	PF3	1.01 ha	*Carex rostrata* dominated transition mire
Reed and large sedge swamp	FS1	0.36 ha	*Phragmites* dominated reed swamp
Wet Grassland	GS4	4.77 ha	*Juncus* dominated wet grassland
Scrub/transitional woodland: Scrub	WS1	Not mapped	Scattered *Salix* areas on wet grassland, transition mire or reed swamp
Drainage ditches	FW4	1138 m	-

The vegetation at Wetland 1 and 2 is characterised by the occurrence and significant cover of *Carex rostrata*, *Juncus acutiflorus*, *Ranunculus flammula*, *Calliergonella cuspidata, Carex disticha, Carex nigra, Galium palustre, Cardamine pratensis* (which may be under recorded in quadrats due to the time of sampling, which was late in the growing season), *Menyanthes trifoliate* and *Hydrocotyle vulgaris*. *Phragmites australis* although present within the transition mire tends to be scattered (reaching no more than 1 m in height) and generally has a low cover abundance. Vegetation cover varied from 95 to 100% in the transition mire quadrats. The peat substrate depth varied from 30 cm to 70cm and was firm to quaking in parts. Surface water was present in all but one of the quadrats recorded. In the north west end

Fig. 4.45 Map of the vegetation types of Rockmarshall, Co. Louth.

of Wetland 1, a spring was noted by the surveyors. There was a steady flow of water from the spring which exhibited a rusty appearance. However, it is very likely that this was in fact a continuation of the drain which opens at the sampling point ROCK S1. With the aid of a walking probe it was noted that there was a 90 cm hole below the opening of this drain which was surrounded by a small area of transition mire. The wet grassland community at Rockmarshall occurred on the edges of Wetlands 1 and 2 and dominated the entire Wetland 3. The Wet Grassland community at Rockmarshall was generally dominated by a mixture of *Juncus* species including *J. conglomeratus, J. acutiflorus, J. effusus*, together with a range of grass and herb species. These wet grassland areas were tussocky in appearance with the intermediate hollows between tussocks being grazed by sheep. The vegetation varied in height from 50 cm to 100 cm. The ground was generally firm with no surface water present. Soil were generally mineral rich or with only a shallow peat layer present.

The Reed swamp community at Rockmarshall occurred on Wetlands 1 and 2. The Reed swamp community was characterized by the dominance of *Phragmites australis* with few other species recorded within the centre of the reed bed (Fig. 4.46). In general other species were rare, and occurred only as scattered individual plants for a distance (50 cm to 75 cm) into the *Phragmites* stand at which point the closed canopy and high degree of shade prevented the growth of other species. The reed swamp was 240 cm in height, surface water was generally present. The peaty substrate was up to 50 cm deep and was soft and quaking.

Fig. 4.46 Appearance of *Phragmites australis* reed swamp at the northern end of Wetland 2. The vegetation in the foreground is dry grassland, grading into wet grassland and transition mire adjacent to the reed swamp.

Scutellaria galericulata (Skullcap) (Fig. 4.47) was recorded at Rockmarshall during this survey, which was a new County record for the species. The record has been submitted to the National Biodiversity Centre. Identification of this member of the Labiate family was confirmed by Dr. Tom Curtis, who reported that "it is usually a species of fens and rich marshes whereas the other species (*Scutellaria minor*) is a bog flush/poor fen inhabitant".

Fig. 4.47 *Scutellaria galericulata* (Skullcap), Rockmarshall, Co. Louth. This is a new County record for Louth.

4.5 Seasonal and spatial dynamics and Conceptual Site Model (Case Study Sites)

Intensive monitoring of groundwater and surface water at each of the five case-study sites provided detailed information on the hydrological, hydrochemical and biological processes occurring at each site over the sampling period. Summary information from a number of these case-study field sites is provided here which demonstrates the methodological approach used in this study at chosen field site locations. These detailed site investigations allowed for the development of conceptual site models showing an understanding of the potential sources of contamination, migration pathways, and ecological receptors which represents a working hypothesis about the site characteristics. The process is represented here for a sub-set of the case-study sites with the most well developed supporting information. The models are presented as a diagrammatic representation with accompanying text describing the key features and main impacts at the site.

4.5.1 Case Study Site Rockmarshall, Co. Louth

4.5.1.1 Seasonal and spatial dynamics, Rockmarshall, Co. Louth

A range of surface water and groundwater sites were monitored over a one year period both within and outside Rockmarshall site in Co. Louth. Sampling locations situated outside the boundary of the site were included in the sampling regime in May 2013 so as to allow the surface water contribution to be better assessed at this site.

Water levels in piezometers located within each of the three linear wetlands remained fairly constant throughout the sampling period and there was generally no significant relationship observed between rainfall and groundwater levels (Fig. 4.48), apart from groundwater levels in piezometer GWS6 located in wetland 2, which showed a positive relationship with rainfall for the period between January and May 2013. The diver in this piezometer was subsequently moved to an adjacent piezometer within the same wetland and there was no relationship observed between water levels and rainfall thereafter.

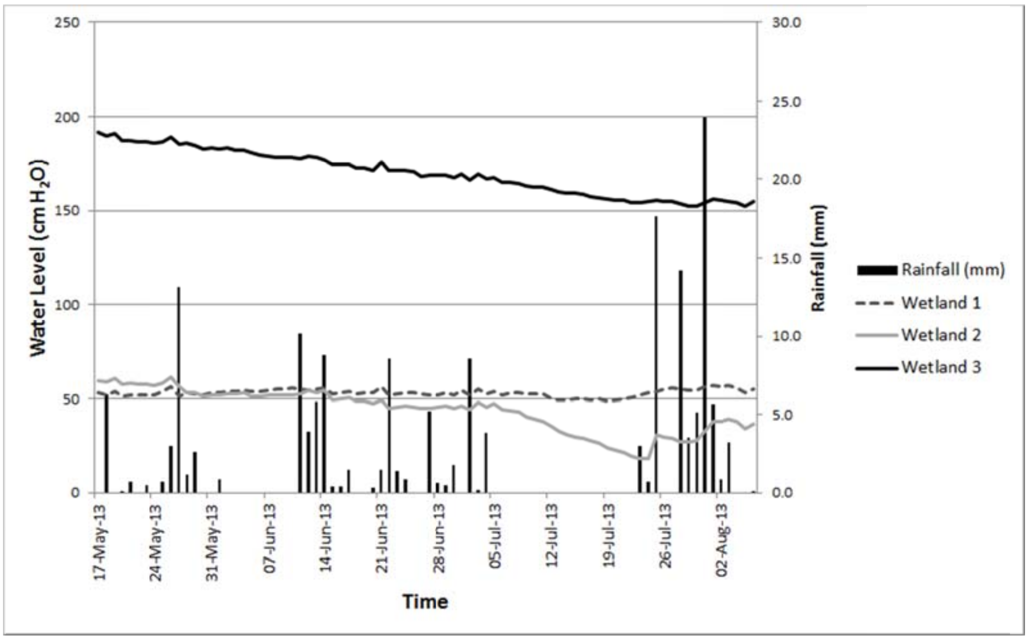


Fig. 4.48 Water levels at piezometers located in Wetlands 1, 2 and 3 at Rockmarshall, Co. Louth and rainfall levels from data collected at Ballyhaise, Co. Monaghan.

There were clear spatial differences in groundwater hydrochemistry between the three linear wetlands at this site. Piezometers located within Wetland 3 (GWS7, GWS8, GWS9), showed higher mean values of ammonia (NH_3-N) throughout the year compared to piezometers located in Wetland 1 and 2 (Table 4.11). In contrast, lower concentrations of nitrate (NO_3-N) were recorded throughout the year at Wetland 3 compared to Wetland 1 and 2 (Table 4.11; Fig. 4.49). In addition, there was generally consistently lower values of chloride (Cl^-) (Fig. 4.12), sulphate (SO_4^{2-}), calcium (Ca) and conductivity levels at the piezometers located in Wetland 3 and lower values of pH in Wetland 3, ranging from 6.2 – 6.3 compared with values ranging from 7.1 – 7.2 in piezometers located within Wetlands 1 and 2. Iron (Fe) and manganese (Mn) were the only other parameters, apart from ammonia, which showed consistently higher concentrations in the groundwater samples from Wetland 3 (mean iron concentrations, of 4.0 ± 1.9 mg L^{-1} and 3.2 ± 1.2 mg L^{-1} in GWS7 and GWS8, respectively), compared with mean values < 0.1 mg L^{-1} recorded in the remaining piezometers. Mean values of manganese in groundwater samples were detected at Wetland 3 (mean 0.04 ± 0.2 mg L^{-1}), but was generally not detected in any other the other wetland piezometers.

Table. 4.11 Mean concentrations of groundwater hydrochemical parameters taken from piezometers located within each of the three wetland areas of Rockmarshall, Co. Louth (Wetland 1 = GWS1, GWS2, GWSD3; Wetland 2 = GWS4, GWS5, GWS6; Wetland 3 = GWS7, GWS8, GWS9), Nov 2012 and Aug 2013.

Site	Ammonia (mg L^{-1}-N)	Nitrate (mg L^{-1}-N)	Phosphate (mg L^{-1}-P)	Chloride (Cl^-) (mg L^{-1})	Sulphate (SO_4^-) (mg L^{-1})	Calcium (Ca) (mg L^{-1})	Cond. (µS cm^{-1})
GW Wetland 1 Mean ± SE	0.09 ± 0.05	4.48 ± 0.41	0.09 ± 0.09	31.5 ± 1.9	20.5 ± 3.3	72.9 ± 17.9	473 ± 57
GW Wetland 2 Mean ± SE	0.07 ± 0.03	6.36 ± 0.79	0.08 ± 0.07	29.9 ± 2.9	17.3 ± 3.5	69.8 ± 20.3	462 ± 52
GW Wetland 3 Mean ± SE	1.19 ± 0.48	0.57 ± 0.68	0.11 ± 0.08	18.0 ± 2.1	6.3 ± 3.26	39.3 ± 4.4	295 ± 52

There was no statistically significant difference in groundwater phosphate concentration between wetlands, with similar concentrations recorded in all piezometers ranging from 0.01 mg L^{-1} to 0.55 mg L^{-1}. Similar seasonal patterns and fluctuations were also observed in phosphate concentration across all piezometers at the site, with values increasing over the winter months between December and February. No seasonal patterns were evident in any of the other measured groundwater parameters, although fluctuations in concentrations over time were similar across all piezometer for the majority of measured parameters.

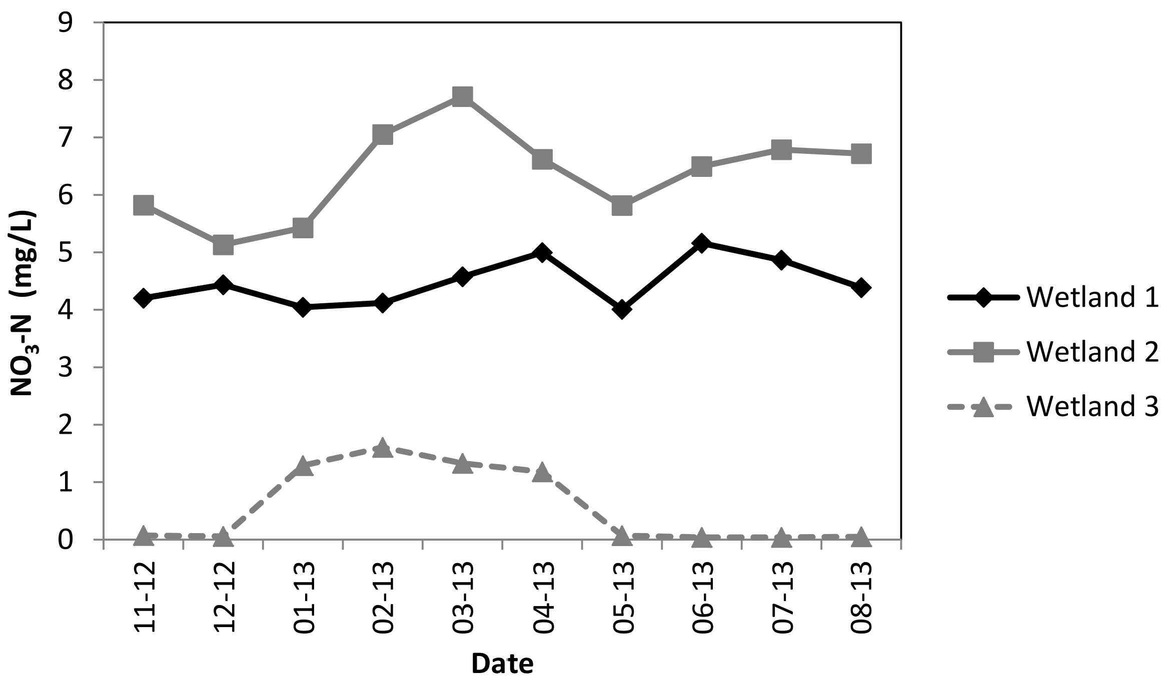


Fig. 4.49 Mean nitrate (NO_3-N) concentrations of piezometers located in each of the three linear wetland habitats located at Rockmarshall, Co. Louth, Nov 2012 – Aug 2013.

In a similar way to groundwater, there was also clear spatial differences observed in surface water hydrochemistry at Rockmarshall. Both ammonia and nitrate concentrations were significantly higher in the surface water sampled at Wetland 3 over the sampling period than at any other two linear wetlands (Table 4.12). In addition, higher iron and sulphate were recorded in Wetland 3 (although these variables were only measured on a once off basis), compared with the other two wetlands. However, lower calcium concentrations were recorded in Wetland 3 (Table 4.12). In general, lower concentrations of surface water hydrochemical parameters were detected in the samples collected from the stream running through the site than the values recorded at the linear wetlands within the site (Table 4.13).

Table 4.12 Mean concentrations of surface water hydrochemical parameters from each of three wetland areas at Rockmarshall, Co. Louth, May 2013 and Aug 2013.

Sampling Location	Ammonia (mg L^{-1}-N)	Nitrate (mg L^{-1}-N)	Phosphate (mg L^{-1}-P)	Chloride (Cl^-) (mg L^{-1})	Calcium (Ca) (mg L^{-1})
SW Wetland 1 **Mean ± SE**	0.67 ± 0.3	0.20 ± 0.1	0.06 ± 0.01	36.4 ± 1.6	98.5 ± 4.0
SW Wetland 2 **Mean ± SE**	0.55 ± 0.5	0.04 ± 0.02	0.06 ± 0.01	34.9 ± 0.7	70.1 ± 11.7
SW Wetland 3 **Mean ± SE**	5.5 ± 0.4	2.13 ± 2.0	0.06 ± 0.02	29.2 ± 2.9	33.2 ± 22.2

Similar ammonia and phosphate values were recorded at all stream sampling locations, however, spatial differences in some of the other parameters were evident. Nitrate for example, showed a considerable degree of variation along the full length of the stream (Fig. 4.50; Table 4.13) with lower nitrate values recorded at Rock ST1 and the upper stretches of the river, before increasing further down-stream as the stream enters the site. A similar pattern in chloride was also evident (Table 4.13). Low values of conductivity and pH were also recorded at Rock ST, but with a high level of variability over time. In addition, low levels of calcium were also recorded at this sampling location compared to other locations, although there was little variability elsewhere, and iron was not detected above the lower limit of detection at this point at all, which was generally low at all sampling locations, apart from RockST2, which had a mean iron concentration of 0.15 ± 0.05 mg L^{-1}.

Table 4.13 Mean concentrations of surface water hydrochemical parameters at Rockmarshall, Co. Louth, May 2013 and Aug 2013.

Sampling Location	Ammonia (mg L^{-1}-N)	Nitrate (mg L^{-1}-N)	Phosphate (mg L^{-1}-P)	Chloride (Cl^-) (mg L^{-1})	Conductivity (µS cm^{-1})
Rock ST1 Mean ± SE	0.07 ± 0.04	0.40 ± 0.1	0.04 ± 0.01	10.5 ± 0.3	150 ± 44
Rock ST2 Mean ± SE	0.08 ± 0.04	0.82 ± 0.2	0.05 ± 0.02	15.2 ± 0.7	145 ± 11
Rock ST3 Mean ± SE	0.04 ± 0.006	2.09 ± 0.5	0.05 ± 0.01	17.6 ± 1.0	173 ± 7.3
Rock ST4 Mean ± SE	0.07 ± 0.03	2.05 ± 0.46	0.06 ± 0.01	17.7 ± 1.1	168 ± 6.0
Rock ST5 Mean ± SE	0.05 ± 0.01	1.43 ± 0.3	0.03 ± 0.001	18.8 ± 1.2	187 ± 4.9
Rock ST6 Mean ± SE	0.10 ± 0.03	2.40 ± 0.4	0.05 ± 0.01	18.9 ± 1.3	192 ± 2.3

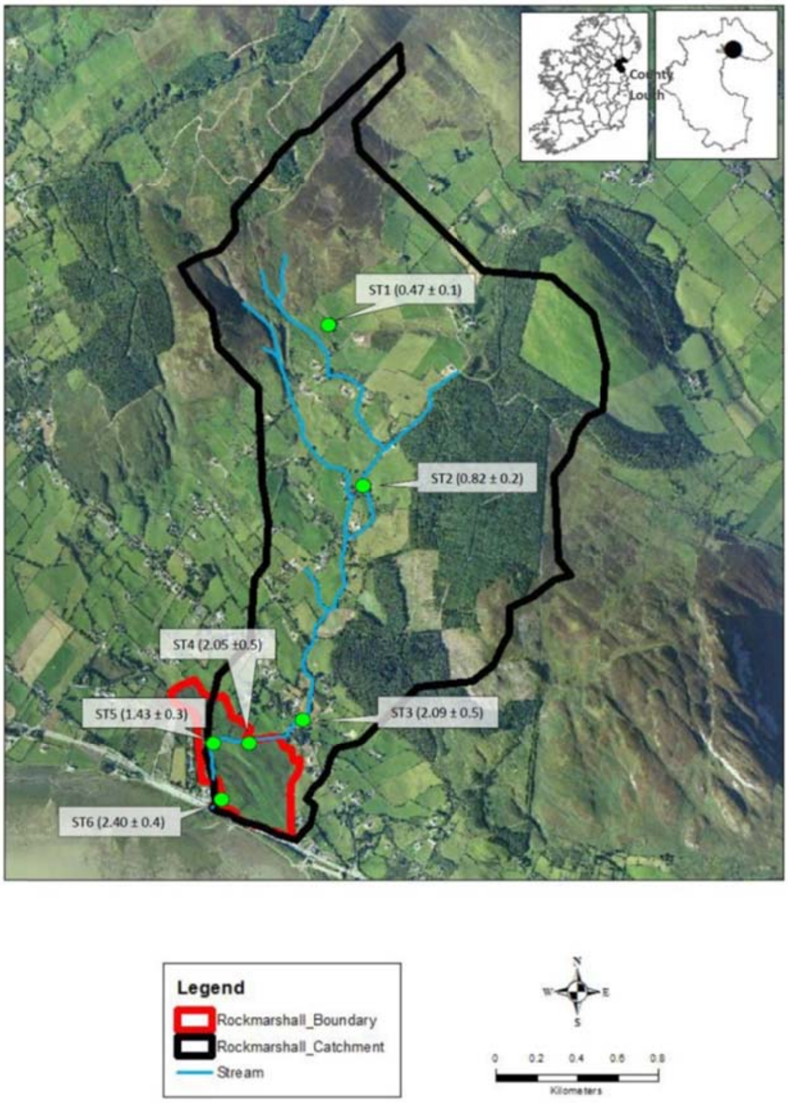


Fig. 4.50 Nitrate variation in surface water stream samples at Rockmarshal, Co. Louth, May 2013 – Aug 2013.

4.5.1.2 Conceptual Site Models, Rockmarshall, Co. Louth

Rockmarshall is a raised beach which has three linear wetlands areas located between dry grassland ridges on former raised shingle beaches. A stream that originates from a spring in Upper Jenkinstown in the Cooley Mountains, flows through the site before discharging into Dundalk Bay (Fig. 4.50). The three wetland habitat types differ, with transition mire and reed dominating in Wetland 1 and Wetland 2, which are the wettest of the linear features. However, Wetland 3 which is the largest of the linear wetlands is composed of wet grassland. Drainage ditches are located in each of the three wetland areas and following the vegetation survey it was suggested by the surveyors that the deeper drainage ditch running through the centre of Wetland 3 may be influencing the wetland community which can develop at this location.

The site is located within a catchment area dominated by agricultural pasture land, with a small percentage of forestry located to the North East of the catchment boundary. In addition, there were a number of one-off houses, with on-site wastewater treatment systems, located within the catchment, which are estimated to account for approximately 3% of total nutrient loading reaching the wetland ecosystems (McKernan, 2013). There is also direct sheep grazing pressure taking place within the site itself, with sheep recorded on the site throughout much of the spring and summer period.

There was a high level of spatial variation at this site with regards both surface water and groundwater hydrochemical variables. The groundwater samples within Wetland 3 generally had higher ammonia concentrations, but lower concentrations of nitrate. This suggest a direct source of contamination within the vicinity of this wetland possibly arising from the houses located on the northern boundary of the site and travelling along shallow interflow pathways through the alluvium. This shallower groundwater also contained relatively high concentrations of iron and manganese relative to that recorded at groundwater monitoring sites elsewhere at the site. High concentrations of ammonia were also recorded in the surface water sampled at Wetland 3, in addition to high levels of nitrate, suggesting that nitrification was occurring within the wetland which is converting the ammonia rich groundwater to nitrate.

In comparison low concentrations of ammonia, but high levels of nitrate, were recorded in the groundwater of the other two wetlands. In addition, high calcium concentrations were also recorded in the groundwater piezometers located in Wetland 1 and 2, which indicates that deeper groundwater is delivering nitrate and calcium rich water to Wetland 1 and 2. The calcium is likely derived from the underlying limestone bedrock, however further calcium may enter the system as the water passes through the marine sands and gravels. The high concentrations of nitrate detected in the groundwater did not, however, correspond to high levels of nitrate in the surface water at these two wetland locations. On the contrary low levels of nitrate recorded in the surface water in these wetlands suggests nitrogen retention either via plant uptake or alternatively through the process of denitrification which involves the degradation of nitrate by heterotrophic microorganisms to nitrogen gas in the presence of organic carbon. This process is dependent on the oxidation state of the soil.

High nitrate levels were also recorded in the surface water of the stream which passes through the site, particularly upstream in the Rockmarshall catchment. Water loss from the stream to the groundwater occurs as the stream enters the Rockmarshall site owing to the hydraulic connectivity between the stream and the groundwater at this point, thereby, contributing nutrients to the system. However, within 500 m of this point there is no longer any hydraulic connectivity between the stream and groundwater. Nevertheless, it is still likely that diffuse nutrients may enter the site from its eastern edge through groundwater flowing beneath the stream. High nitrate concentrations recorded at the stream sampling location RockST5 are likely to have arisen from a field drain which is flowing from the eastern side of the site and joins the stream at this point. High nitrate and ammonia concentrations at RockST6, are likely contributed by groundwater flowing from the site towards the stream, which at this point is no longer hydraulically isolated and is receiving groundwater flow from nearby Wetland 1. A full summary in provided in Fig. 4.51.

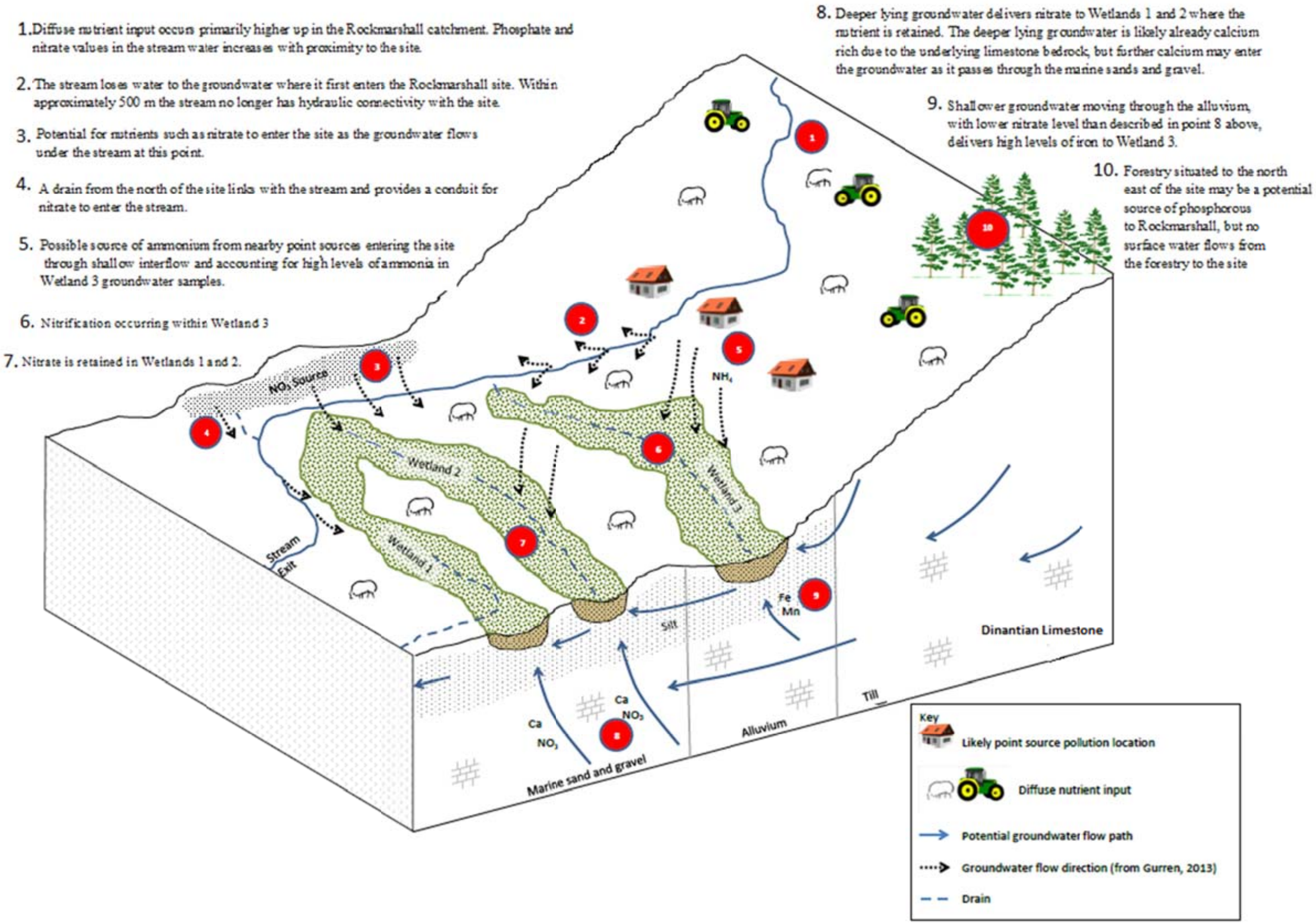


Fig. 4.51 Conceptual Site Model for Rockmarshall, Co. Louth.

4.5.2 Case Study Site Kilroosky, Co. Monaghan

4.5.2.1 Seasonal and spatial dynamics, Kilroosky, Co. Monaghan

Surface water from a number of locations as shown in Fig. 4.43, were monitored over a one year period at Kilroosky in Co. Monaghan. These monitoring locations corresponded to an open water sample (KLS1), a sample from the principle surface water inflow (KLS3) and a sample from the outflow (KLS2).

In general there was clear variation in nutrient concentration between sampling site locations, with the open water sampling location (KLS1) generally showing lower concentrations of the majority of indicator parameters compared to the other sampling locations. At sampling location KLS1, Chlorophyll *a* concentrations, which are indicative of phytoplankton growth, were generally recorded ranged from 8 – 25 µg L^{-1} (Fig. 4.52), which is within the mesotrophic range based on the OECD modified trophic classification scheme (EPA, 2001). However, two significant peaks in concentration occurred in January and March 2013 of 31.6 µg L^{-1} and 31.2 µg L^{-1}, respectively. Both of these peaks in chlorophyll *a* occurred during periods of ice cover on the open water (there was no sample collected in December 2012 owing to substantial ice cover at this time), and were high enough to bring the overall trophic status of the system into the eutrophic category, as the classifications in Ireland is based on annual chlorophyll *a* maxima.

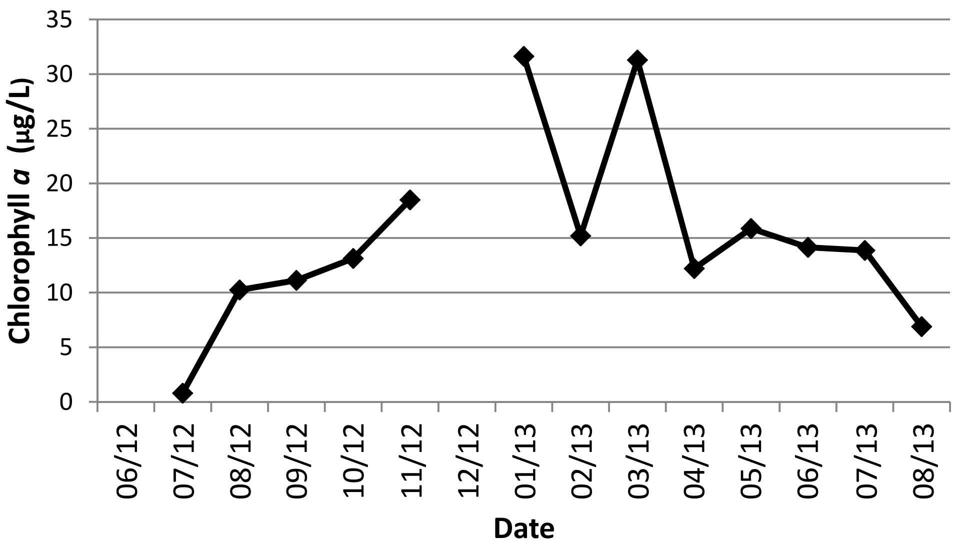


Fig. 4.52 Chlorophyll *a* concentrations at the KLS1 sampling location, Kilroosky, Co. Monaghan, June 2012 – August 2013.

It has generally being observed that the growth and composition of the phytoplankton communities throughout the year are related to a number of factors including the availability of light and temperature and the supply of nutrients, particularly phosphorus and nitrogen, from point and diffuse sources within the catchment. In Kilroosky, the first peak in chlorophyll *a*, occurred in January 2013 which was a period of low water temperatures (temperatures ranged from 3.5 ºC to 4.8 ºC between November 2012 and March 2013), and thin ice cover, which is likely to reduce light availability. Consequently, increased chlorophyll *a* levels in Kilroosky at this time were more likely to be related to increased nutrient availability. Levels of phosphorus, including orthophosphate and TP generally increased over the winter period, with increasing values of TP recorded from August 2012 through to February 2013 (Fig. 4.53). Nutrient concentrations in lakes often increase over the winter owing to increased loading from the catchment as a consequence of rainfall events flushing nutrients into lakes. This can be particularly evident in areas dominated by diffuse sources of pollution (Bowes *et al*., 2008). Phytoplankton growth during ice-cover has previously been recorded where flagellated chlorophytes and chrysophytes have concentrated near the surface and given rise to late winter blooms (Jones, 1991).

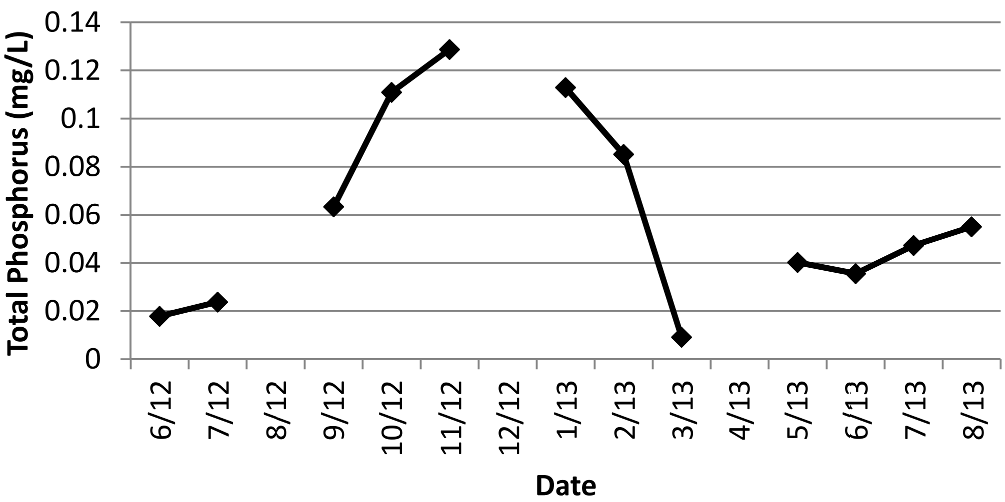


Fig. 4.53 Total phosphorus (TP) concentrations at the KLS1 sampling location, Kilroosky, Co. Monaghan, June 2012 – August 2013.

The peak in phytoplankton which occurred in January 2013 in Kilroosky Lough is, therefore, likely a consequence of increased availability of nutrients, particularly phosphorus. This is backed-up by the correspondingly high concentrations of dissolved organic carbon (DOC)

and suspended solids both of which peaked over the winter months at sampling location KLS1. This is also likely a consequence of increased flushing from the surrounding catchment. There was also a peak in orthophosphate in January 2013, which is the fraction of P that is immediately available for phytoplankton growth. The second peak in chlorophyll *a* which occurred in March also occurred during a period of low temperature and thin covering of ice. During this period, however, P concentrations declined with lower recorded concentrations of both TP and orthophosphate. The highest ratio of DIN:TP was also recorded at this time. This high value DIN:TP is both a consequence of reduced P availability at this time and the relatively high concentrations of available N which were also recorded (DIN concentrations of 0.15 mg L^{-1}-N were recorded). The DIN:TP at this time was greater than 27 and was, therefore, indicative of P limiting conditions, within the system, suggesting that the growth of phytoplankton biomass at this time was capable of reducing P availability within the system.

In contrast to the open water sampling location KLS1, the remaining two sampling locations within the site generally had higher concentrations of the majority of indicator parameters. The inflow sampling location (KLS3) had particularly high concentrations of parameters such DIN throughout the year (Fig. 4.54; Table 4.14). The high concentrations of DIN at KLS3 were, principally driven by nitrate with accounted for between 42- 98 % of DIN at this site. This high nitrate also corresponded to high concentrations of parameters such as conductivity, chloride, and sulphate at this sampling location (Table 4.14). It is, therefore, likely that groundwater rich in calcium, nitrate, sulphate and chloride is delivered into Kilroosky Lough by the inflow which originates from a spring. However, flow at this location was low and intermittent and always < 0.1 m^3 sec^{-1}. Consequently the loading of nutrients to the lough from this inflow point would have generally been quite low.

In contrast, TP, orthophosphate and DOC values were generally recorded at lower concentrations throughout the year at the inflow sampling location (KLS3), compared to the outflow (KLS2), which also had a very low flow for much of the year (generally < 0.1 m^3 sec^{-1}). A particularly high peak in TP (0.36 mg L^{-1}) and orthophosphate (0.33 mg L^{-1}) as well as DIN (seen in Fig. 4.54), were recorded at the outflow sampling location (KLS2) in July 2013, which may have been a consequence of a recent input of organic pollution to the system, particularly as the bulk of this DIN was composed of ammonia and nitrite (95 % of

the DIN). The presence of ammonia and nitrite in high concentrations relative to nitrate is generally considered indicative of a recent pollution event, since ammonia is readily converted to nitrate in aerobic conditions and is likely linked to nearby sources of contamination arising from agricultural activities within the vicinity of the drain. However, in this case, there was no measurable flow in the outflow drain at this time. This would have led to a poorly oxygenated environment which is also likely to have contributed to the higher ammonia values that were recorded at this time.

Table 4.14 Mean concentrations of surface water hydrochemical parameters at the three sampling locations at Kilroosky, Co. Monaghan, June 2012 - Aug 2013. DIN = dissolved inorganic nitrogen, DOC = dissolved organic carbon, cond. = conductivity. * Data unavailable.

Sampling Location	DIN (mg L^{-1}-N)	Phosphate (mg L^{-1}-P)	DOC (mg L^{-1})	Cond. (µS cm^{-1})	Chloride (Cl^-) (mg L^{-1})	Sulphate (SO_4^{2-}) (mg L^{-1})
KLS1 Mean ± SE	0.14 ± 0.01	0.04 ± 0.01	10.9 ± 0.92	396 ± 18.1	15.5 ± 0.44	8.77 ± 1.01
KLS2 Mean ± SE	0.30 ± 0.12	0.09 ± 0.02	10.7 ± 0.9	390 ± 18.0	15.5 ± 0.60	9.79 ± 1.07
KLS3 Mean ± SE	1.37 ± 0.21	0.03 ± 0.01	7.72 ± 1.03	681 ± 36.6	27.4 ± 4.3	18.1 ±1.71

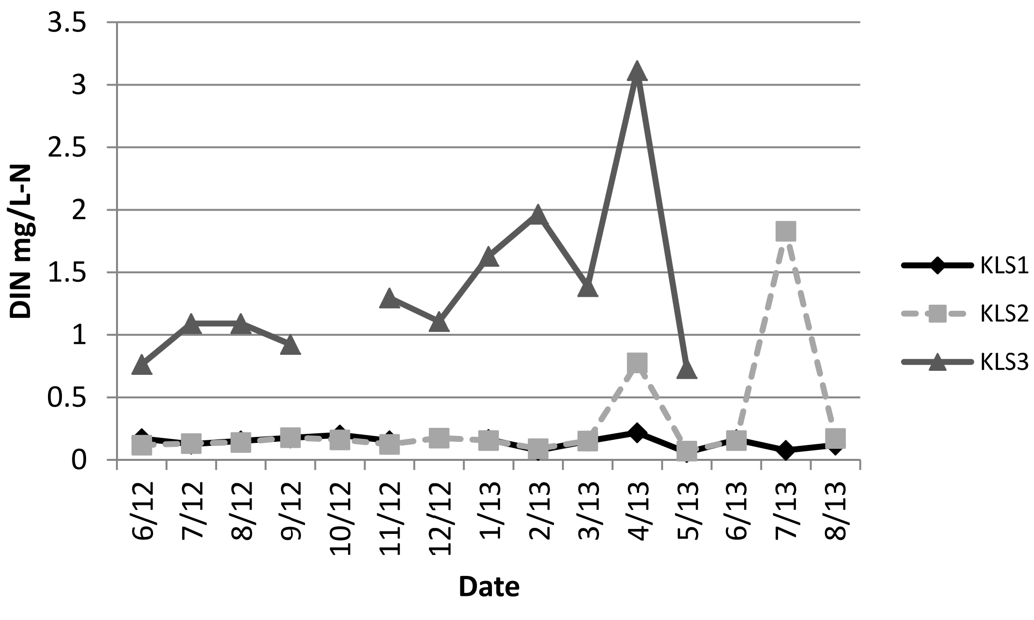


Fig. 4.54 Dissolved inorganic nitrogen (DIN) concentrations at surface water sampling locations, Kilroosky, Co. Monaghan, June 2012 – August 2013.

The biogeochemical processes regulating the functions of the ecosystem are important for evaluating nutrient impacts in wetland systems. Phosphorus retention within wetlands, for

example, can be regulated via biological processes, such as phytoplankton uptake, or via physical processes such as immobilization in sorption reactions with iron and aluminium oxides in acidic conditions and precipitation reactions with calcium carbonate ($CaCO_3$) in alkaline conditions. Sediments are, therefore, extremely important long term nutrient stores in wetland systems (Mustafa *et al*., 2009). A set of ten sediment samples were taken from Kilroosky Lough and analysed for a range of elemental parameters including iron, calcium and TP (Fig. 4.56). The content of iron, calcium in particular were highly variable within sediment samples across Kilroosky Lough (Table 4.15). It was generally found that iron concentrations were low in areas where calcium concentrations were particularly high and there was a direct correlation between iron and organic matter content of the sediment (Pearson's $r = 0.79$, $P \leq 0.01$, n = 10). Additionally, high calcium concentrations within the sediment were found to be related to high concentrations of TP (Pearson's, $r = 0.97$, $P \leq 0.001$, n = 10). This suggests that calcium has an important role to play in terms of P immobilization in Kilroosky. Nevertheless, the patchy and variable nature of the elemental content of the sediment implies that these processes are not likely to occur in a uniform manner throughout the site. In addition, previous studies have demonstrated that long-term retention of P in marl lakes is more dependent on iron than $CaCO_3$ (Golterman, 1988; Hobbs *et al*. 2005). This is because although P immobilisation with $CaCO_3$ is likely to occur during the growing period through elevated coprecipitation and high pH, P release is more likely during the winter as a result of $CaCO_3$ dissolution (Gonsiorczyk *et al*., 2001). Consequently, increased TP observed in the water column at Kilroosky may be a result of internal P release from calcium bound P.

Table 4.15 Percentage content of calcium (Ca), iron (Fe) and total phosphorus (TP) in surface sediments at Kilroosky, Co. Monaghan, June 2012. Sample numbering system relate to sample locations in Fig. 4.56.

Sediment Sample	% Ca	% Fe	% TP
1	0.83	5.6	0.03
2	0.21	43.4	0.006
3	0.72	9.45	0.03
4	0.22	7.15	0.01
5	0.84	6.15	0.19
6	0.18	42.6	0.01
7	0.24	40.3	0.03
8	0.83	4.17	0.18
9	0.29	44.4	0.02
10	0.81	8.29	0.23

Fig. 4.56 Location of sediment sampling points (labelled 1 – 10), Kilroosky, Co. Monaghan, June 2012 – August 2013.

4.5.2.2 Conceptual Site Models, Kilroosky, Co. Monaghan

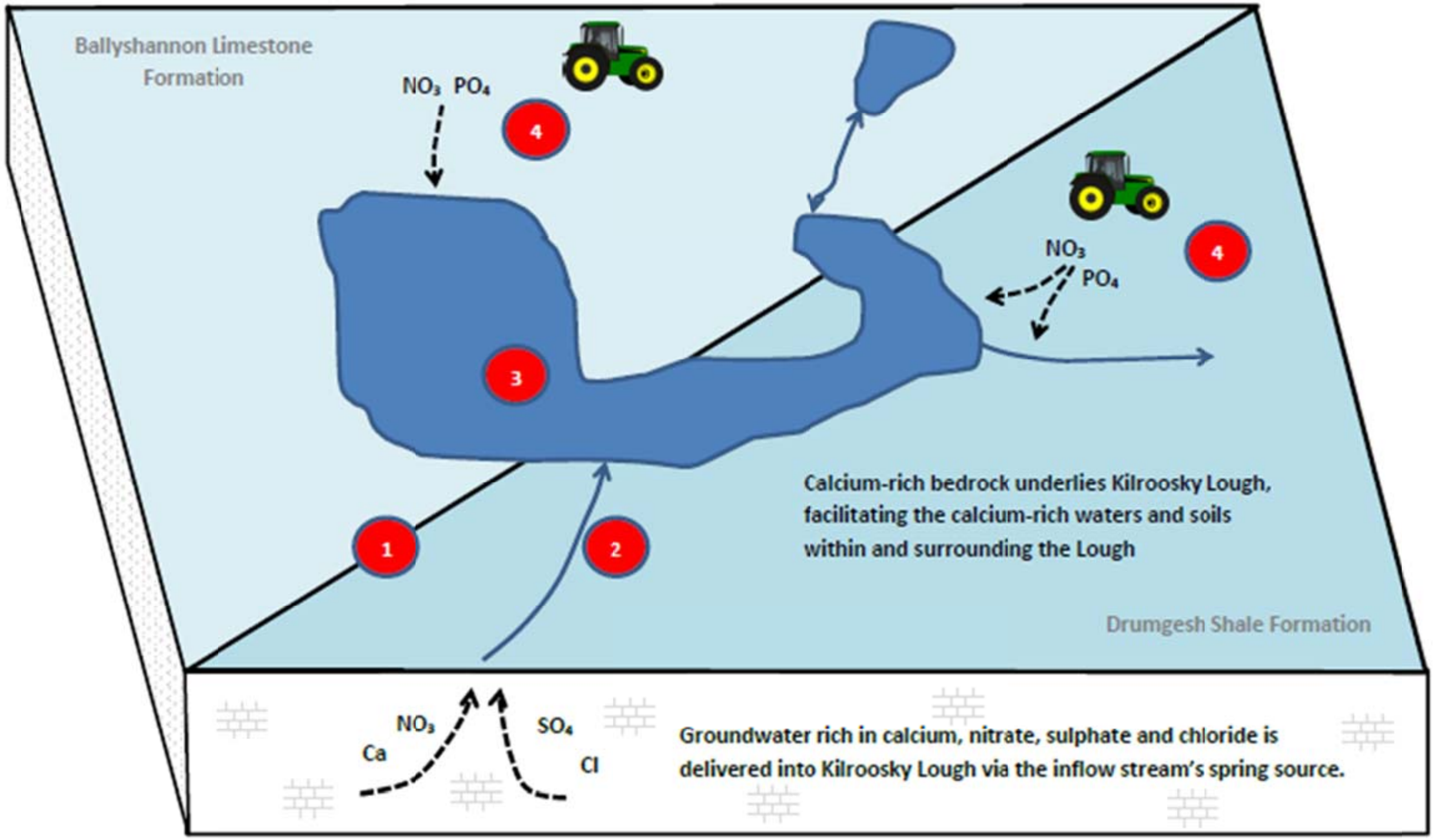
Kilroosky is a marl lough with fringing alkaline fen habitat and is located within a cluster of hard-water marl lakes with adjacent fen vegetation largely linked by small streams. There are two principal surface water inflows to Kilroosky, one to the west of the site and the other to the south of the site, both of which have low to intermittent flow. The lake is groundwater fed, with the southern inflow, labelled KLS3 in this study, originating from a spring. Additionally, there is a drain which is the principal outflow of lough located to the west of the site and there is anecdotal evidence that this drain was recently widened by the landowner (*pers. comm.*). Kilroosky is a high alkalinity system whose chemical composition is consistent with the underlying Lower Carboniferous limestone and shale bedrock and the surface glacial till in this area. The lough exhibits a natural succession from open water to terrestrial vegetation types. The site is bounded by improved and semi-improved grassland, with evidence of livestock access to the site throughout. The site to the south is bounded by a public road, with a single house located to its south western shore.

Marl loughs are characterised by very clear water and low nutrient status and are buffered against phosphorous enrichment to a certain extent as a result of phosphorous immobilisation

in marl formations (DOENI, 2005). However, phosphorus may be released if the buffering mechanism is disrupted and the lake 'switches' to a eutrophic state. The high concentrations of dissociated calcium carbonate drives the precipitation of marl in these systems, which occurs most often during the summer as a result of high photosynthetic activity as a consequence of plant growth, which removes carbon dioxide from the water column. In Kilroosky Lough, high levels of both phosphorus and nitrogen were recorded, within the open water. High concentrations of nitrate were observed throughout the year at the inflow stream to the south of the site (KLS3). These high levels of nitrate were also associated with high concentrations of other parameters such as chloride, conductivity, sulphate and calcium which were all recorded at this sampling location and is suggestive of nutrient groundwater source from which the stream flows intermittently. Both of the principal inflows to the lough had very low or absent flows, but values of nitrate recorded at the southern inflow (which had the largest flow of the two principal inflows) were consistently above the threshold value of 0.9 mg L^{-1} NO_3-N for high status surface waters (EPA, 2001), although concentrations of phosphorus remained low at this sampling point throughout the year.

Within the open water itself, however, values for nitrate were generally below the threshold value for surface water, suggesting biological uptake. In contrast, concentrations of TP within the lough were generally high and above the threshold value of 0.06 mg L^{-1} P considered indicative of eutrophication (EPA, 2001). Levels of phosphorus increased significantly during the winter months, which is indicative of increased flushing of diffuse nutrients into the lake from the surrounding agricultural land. This also corresponded to increased concentrations of orthophosphate and a consequence of increased phytoplankton biomass, which reached high levels indicative of eutrophic conditions on at least two occasions during this period, despite the low temperatures and partial ice cover at the time, which would have also reduced light availability. The increased growth of phytoplankton is, therefore, likely to be a response to high nutrient availability, despite nutrient ratios suggesting that limiting conditions for phytoplankton growth generally do not exist within the system. High orthophosphorus concentrations recorded at the outlet of the site (KLS2), which is susceptible to considerable pulses in concentration not seen to the same extent at the other sampling locations at the site also suggests that adjacent agricultural practices are facilitating the diffuse input of nutrients into the surface waters at this site, with low flow conditions not allowing for sufficient flushing of these nutrients at some points throughout the year.

Surface sediment composition within the lough was found to be highly variable resulting in differing phosphorus sorption processes throughout the lough, with areas high in calcium associated with high sediment TP concentrations compared to the areas rich in organic matter, with high percentage iron content. This variability indicates that the P attenuation processes within the site are not uniform throughout, or may be short-term given the strong association between calcium and TP content of the sediment. Consequently, Kilroosky may be more sensitive to nutrient enrichment than would generally be expected from a marl forming system such as this. A summary of the site is provided in Fig. 4.57.



1. The geological boundary between the Drumgesh Shale and Ballyshannon Limestone formations likely facilitate the delivery of nitrates, calcium and other parameters directly into the main body of the Lough
2. Nitrate and other contaminants are delivered into the Lough by the intermittently-flowing inflow stream
3. Varying chemical composition results in differing phosphorus sorption capacities of the sediments throughout the Lough.
4. Agricultural practices facilitate the diffuse input of nitrates and phosphates into the Lough and outflow stream

Fig. 4.57 Conceptual Site Model for Kilroosky, Co. Monaghan.

4.5.3 Case Study Site Greenan Lough, Co. Down

4.5.3.1 Seasonal and spatial dynamics, Greenan Lough, Co. Down

Surface water samples at Greenan Lough were monitored for just over a one year period from the open water (KLS1) and from its outflow (KLS2), as shown in Fig. 4.8.

In general there was clear variation in nutrient concentration between sampling site locations, with the open water sampling location (KLS1) generally showing lower concentrations of the majority of indicator parameters compared to the outflow sampling locations (KLS2). Concentrations of chlorophyll *a* remained below 5 µg L^{-1} between June and December 2012, which is within the oligotrophic range (< 8 µg L^{-1}; EPA, 2001). However, a very high peak of 31.6 µg L^{-1} occurred in January 2013, which is considered indicative of moderate levels of eutrophication, and remained relatively high thereafter, peaking again to similar levels in June 2013 (Fig. 4.58).

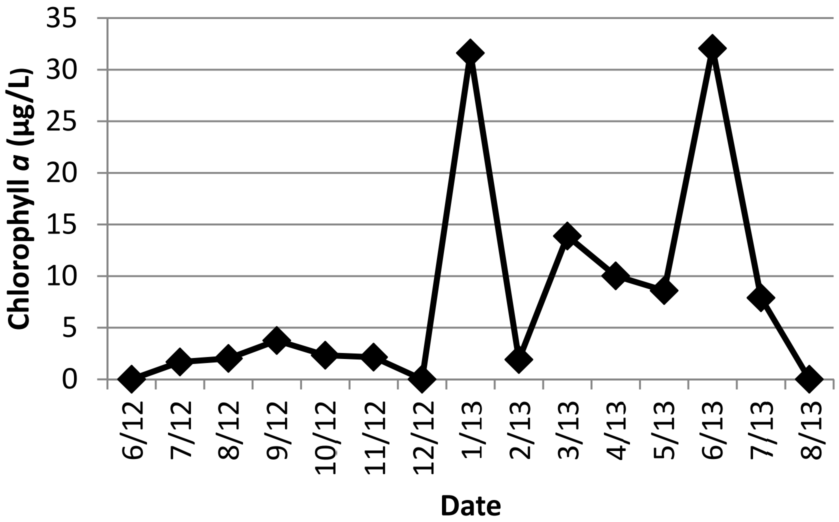


Fig. 4.58 Chlorophyll *a* concentrations at the GLS1 sampling location, Greenan Lough, Co. Down, June 2012 – August 2013.

Peaks in phytoplankton biomass as represented by the chlorophyll *a* concentration, corresponded to reduced concentrations of orthophosphate at the open water sampling location, particularly during the spring and summer growing period (Fig. 4.59). A similar reduction in orthophosphate during this period was not observed at the outflow sampling site (GLS2), despite fluctuations in orthophosphate remaining relatively similar between the two sampling locations at other times of the year (Fig. 4.59).

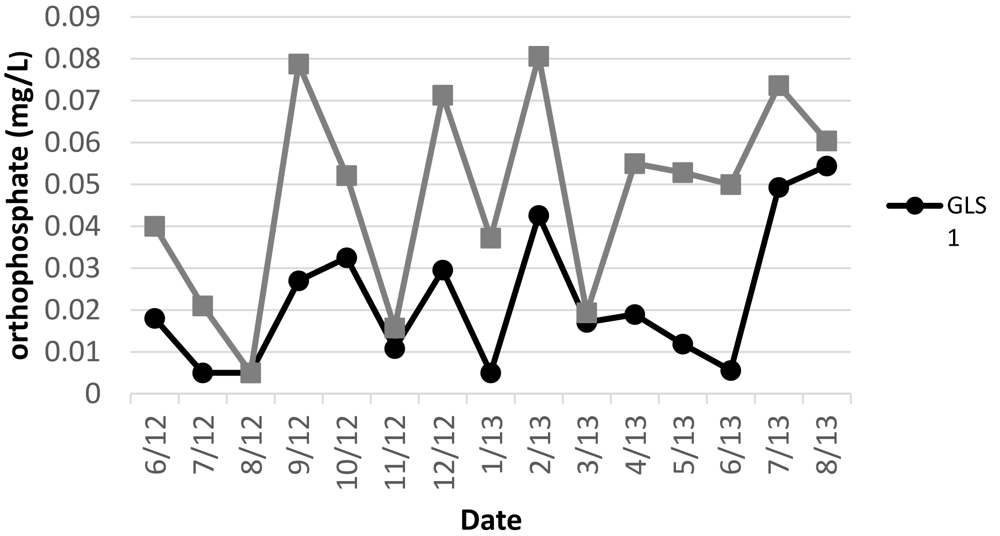


Fig. 4.59 Orthophosphate concentrations at the open water sampling location (GLS1) and outflow sampling location (GLS2), Greenan Lough, Co. Down, June 2012 – August 2013.

A decline in the availability of DIN was also observed at GLS1 during the spring and summer period of 2013, corresponding to increased phytoplankton growth at this time, however a similar decline in DIN at the outflow (GLS2) was not observed, despite both sites generally following similar seasonal patterns, with increased DIN recorded between January and February 2013, declining thereafter (Fig 4.60). As with orthophosphate, concentrations of DIN were generally higher at sampling location GLS2, although the difference was not as great as that observed for orthophosphate. At sampling location GLS2, the bulk of DIN was composed of nitrate for most of the year ranging from 73 – 97% of total DIN. There was a greater variation in the composition of DIN at sampling location GLS1, however, with a higher proportion of the nitrate fraction between November 2012 and April 2013 of between 82.7 – 98.7 %, compared to values which generally remained below 40 % for the remainder of the year, during which time ammonia and nitrite constituted the remaining 60% of DIN.

In general concentrations of dissolved nutrients were generally high at this site (Table 4.16). This was particularly so at the outflow (GLS2), where concentrations of orthophosphate were generally higher than 0.03 mg L^{-1}-P which is considered indicative of pollution (Toner *et al*., 2005), and values of nitrate greater than the threshold quality standard of 0.9 mg L^{-1} NO_3-N (EPA, 2001). In addition, nitrate concentrations often exceeded this value in the open water sampling location, particularly over the winter months and corresponded to relatively high concentrations of chloride and sulphate. However, conductivity values remained relatively

low at this site, compared to other case-study sites which also had high nitrate concentrations such as Rockmarshall and Kilroosky Lough.

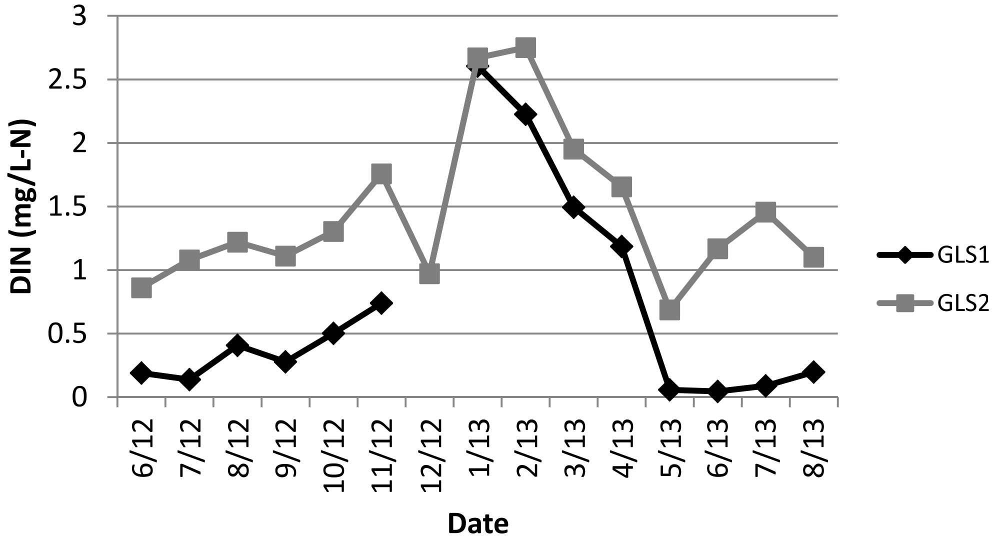


Fig. 4.60 Dissolved inorganic nitrogen (DIN) concentrations at the open water sampling location (GLS1) and outflow sampling location (GLS2), Greenan Lough, Co. Down, June 2012 – August 2013.

Table 4.16 Mean concentrations of surface water hydrochemical parameters at the two sampling locations at Greenan Lough, Co. Down, June 2012 - Aug 2013. DIN = dissolved inorganic nitrogen, DOC = dissolved organic carbon, cond. = conductivity. * Data unavailable.

Sampling Location	DIN (mg L^{-1}-N)	Phosphate (mg L^{-1}-P)	DOC (mg L^{-1})	Cond. (µS cm^{-1})	Chloride (Cl^{-}) (mg L^{-1})	Sulphate (SO_4^{2-}) (mg L^{-1})
GLS1 Mean ± SE	0.72 ± 0.22	0.02 ± 0.004	6.87 ± 0.81	162.6 ± 11.7	12.5 ± 10.8	8.99 ± 0.90
GLS2 Mean ± SE	1.45 ± 0.16	0.05 ± 0.006	5.65 ± 0.57	190.7 ± 13.4	15.2 ± 0.29	10.0 ± 0.66

4.5.3.2 Conceptual Site Models, Greenan Lough, Co. Down

Grennan Lough is an open water lough, with associated wetland vegetation types including reedbeds, scrub woodland and sparse carr woodland. In addition species-rich fen meadow and fen communities with a high cover of grasses also occur. A second smaller open water pool is also located to the south of the main basin.

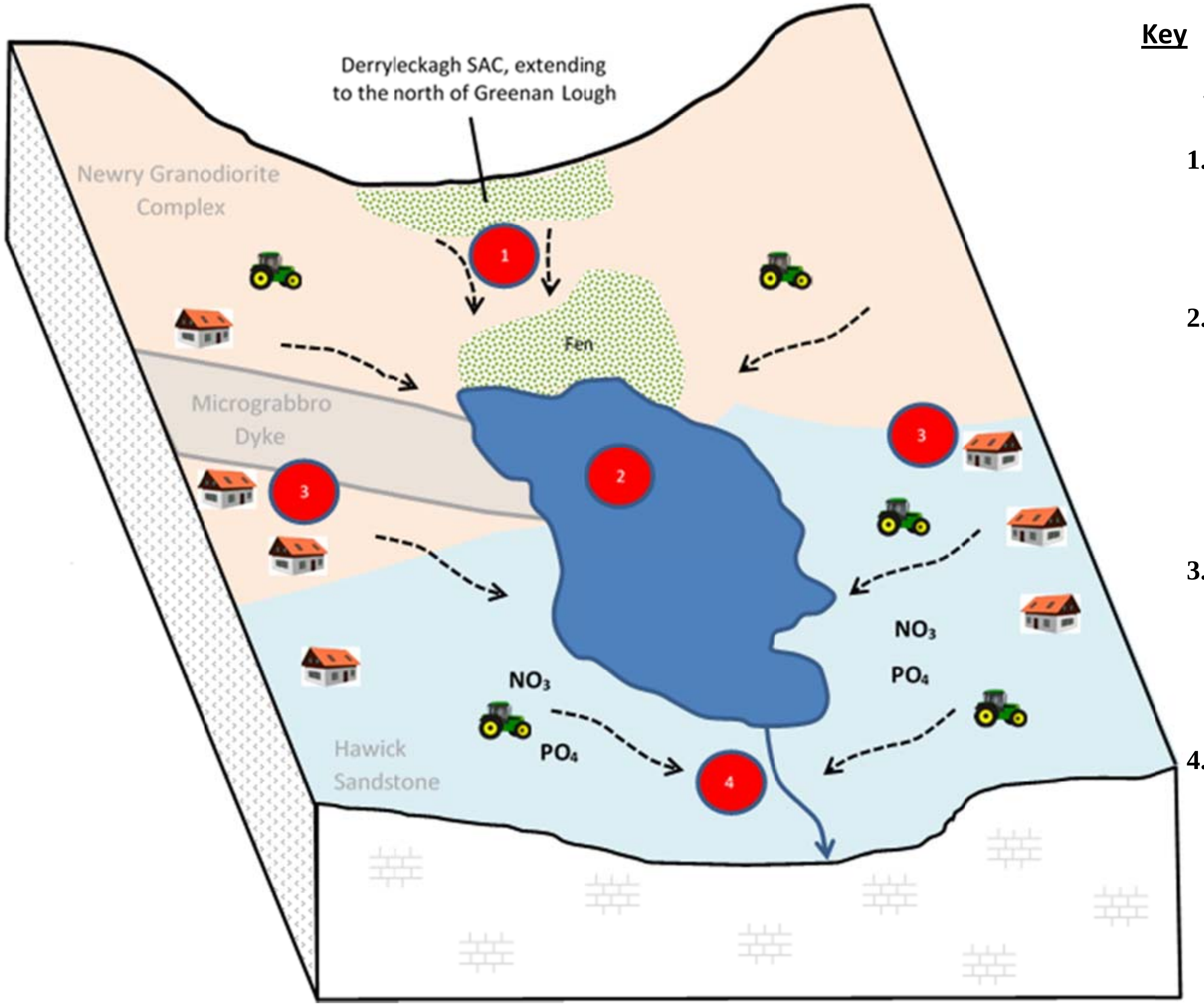
The lough is located in a valley with steep sloping sides. No inflow to the site has been identified suggesting that the lough is groundwater fed. A small outflow flows from the south of the basin. Derryleckagh Bog lies to the north of the site, which is also a designated SAC consisting of large transitional valley mire in the valley floor and a small section of

base-rich woodland. Groundwater is likely to flow from Derryleckagh SAC towards Greenan Lough. In addition, the geological boundary of the Newry Granodiorite complex and the Hawick Sandstone group, in addition to the presence of a Dyke which runs through the main body of Greenan Lough, potentially facilitates the delivery of groundwater and associated contaminants to the lough.

The surrounding landuse is principally dominated by agricultural pasture land, and given the steeply sloping nature of the land immediately adjacent to the site, there is the potential for contaminants to reach the site through diffuse run-off. Additionally, there is a small number of one-off houses with associated on-site wastewater treatment systems located adjacent to the site, which could also facilitate delivery of contamination to the lough via shallow groundwater flow.

Unlike some of the other case-study sites, Greenan Lough did not show a large degree of within-site variation. However, in general it was found that nutrients and some ions such as chloride and sulphate occurred at higher concentrations in the outlet of the site than within the open water. This was particularly the case for orthophosphate, which showed consistently higher values in the outflow, but nevertheless generally showed very similar fluctuations to that observed in the open water, apart from the spring and summer period where phytoplankton uptake of orthophosphate reduced its concentrations in the open water, but not in the outflow. There was, no clear pattern orthophosphate concentrations during the year, with values increasing and decreasing at various times, not necessarily consistent with seasonal changes. An early peak in chlorophyll *a* also occurred in January 2013, which in a similar way to that observed in Kilroosky corresponded to a period of low temperature. This January peak in chlorophyll *a* reached similar concentrations to those observed in June 2013 despite these low temperatures. The January peak in chlorophyll *a* also corresponded to a sharp decline in orthophosphate concentrations, consistent with phosphorus up-take by phytoplankton at this time. Dissolved Inorganic Nitrogen concentrations, were high at both sampling locations within the sites, although again were generally slightly higher at the outflow than within the open water. Nevertheless, they generally followed similar seasonal patterns with a large peak occurring in January and declining gradually thereafter until April. However, from this point onwards, concentrations of DIN reduced to extremely low levels at the open water sampling location, but remained much higher in the outflow sample, which is

again consistent with phytoplankton growth and uptake of this nutrient. At both sampling locations the bulk of the DIN was composed of nitrate, which always constituted more than 73 % of the DIN at the outflow point, but fell to less than 5 % in the open water site from May to July, which again points towards uptake of nitrate during the growing season. Concentrations of nitrate at this site were high and generally above the threshold value of 0.9 mg L^{-1} NO_3-N, which is the threshold for good water quality status in surface waters (EPA, 2001), particularly at the outflow. Given that there are no surface water inflows at this site, the bulk of this nitrate is likely to be of groundwater origin and corresponds to relatively high chloride and sulphate concentrations relative the other sites.



Key

- - - - - -▸ Likely groundwater flow direction

1. Groundwater likely flows southwards from Derryleckagh SAC into the fen area adjoining the northern margins of Greenan Lough.

2. The geological boundary of the Newry Granodiorite Complex and the Hawick Sandstone Group, in addition to the presence of a Dyke, runs through the main body of Greenan Lough. This boundary potentially facilitates the delivery of groundwater and associated contaminants to the lough.

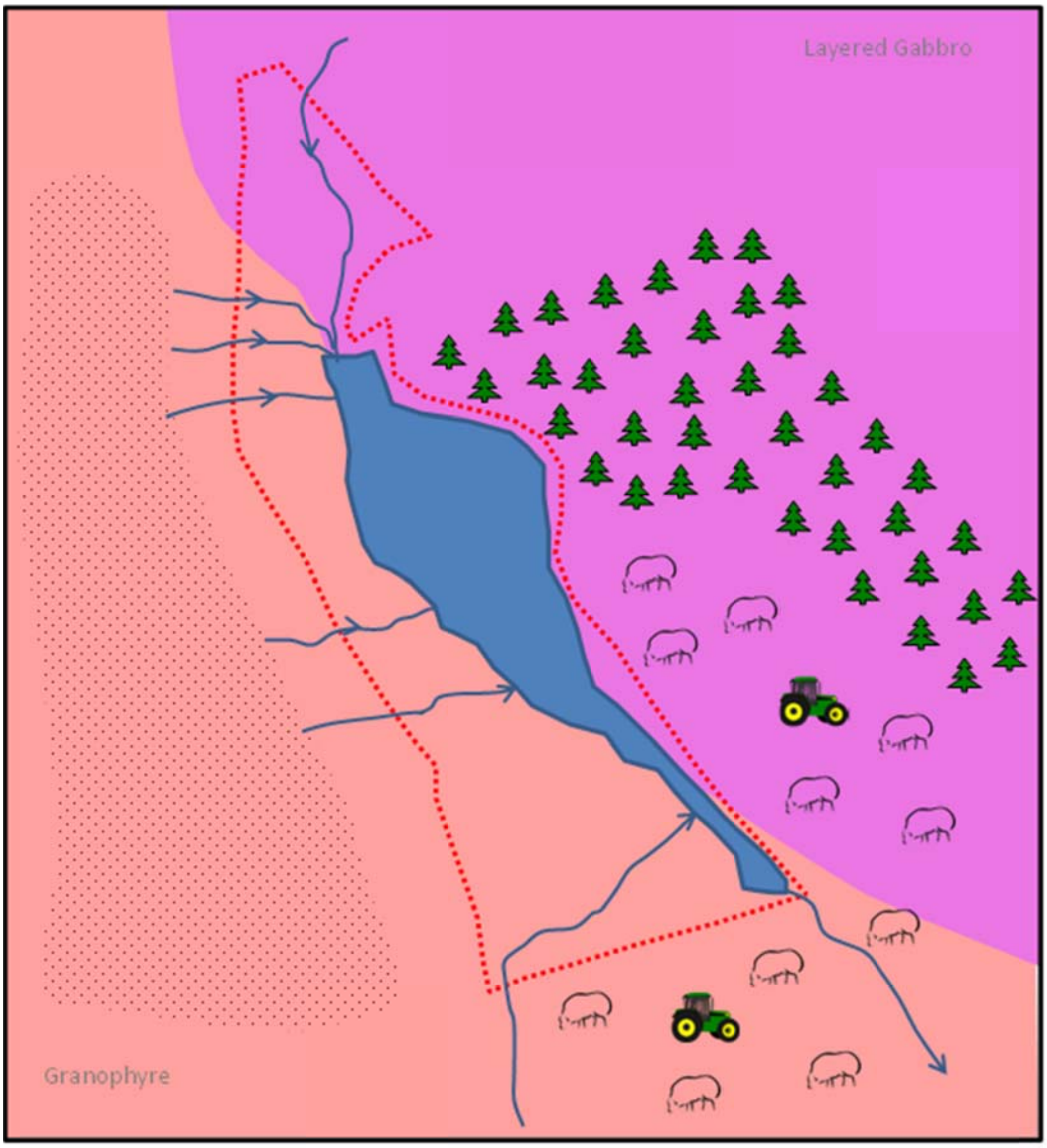
3. The steeply sloping hills surrounding Greenan Lough facilitate the potential for contaminants from on-site waste water treatment systems of local dwellings to be delivered into the lough.

4. Agricultural practices on land surrounding Greenan Lough facilitate diffuse delivery of nitrates and phosphates to the lough, with nutrient levels in the outflow stream typically higher than the main lough water body.

Fig. 4.61 Conceptual Site Model for Greennan Lough, Co. Down.

4.5.4 Summary Conceptual Site Models

Conceptual site models are provided below for the remainder of the case-study sites. A similar process of data analyses and exploration of data on the hydrological, hydrochemical and biological processes occurring over the sampling period was carried out as outlined in section 4.5.1, 4.5.2 and 4.5.3 above, and used to develop the models, which are outlined below for Windy Gap, Co. Louth (Fig. 4.62) and Loughaveely, Co. Armagh (Fig. 4.63).



Boundary of wetland area.

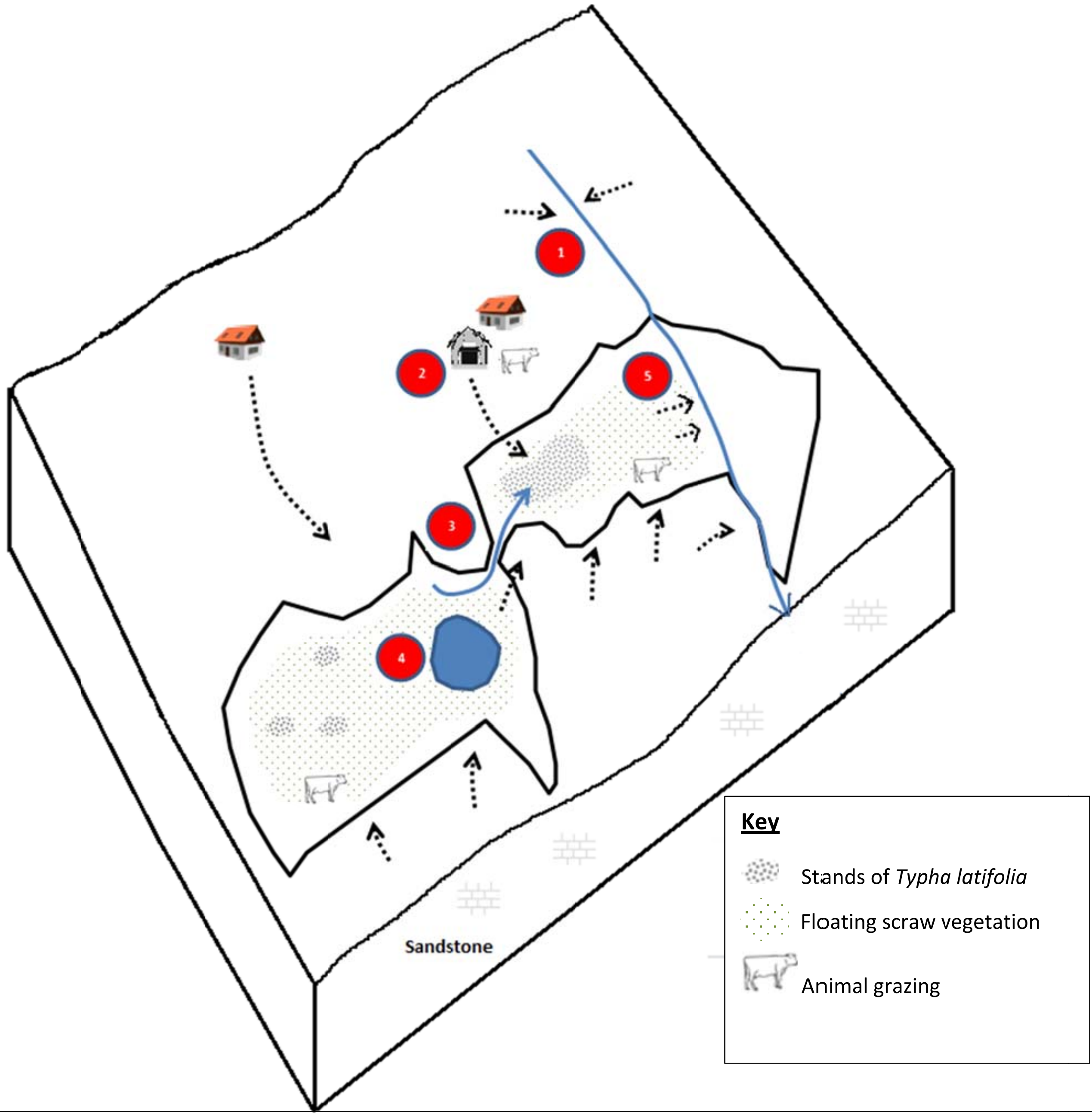
1. Mountain streams deliver water low in conductivity, alkalinity and nutrients to the main pool area.

2. The main pool area supports a comparatively diverse macroinvertebrate community containing relatively high proportions of bivalves and gastropods that are unexpected in a typically acidic cutover bog environment. Higher than expected pH values suggest the possibility of groundwater contribution facilitated by the geological boundary that runs directly through the pool area.

3. The forestry area to the east of the wetland area has the potential to deliver nutrients and sediment into the water body during periods of felling.

4. Agricultural practices to the east and south of the wetland area have the potential to diffusely deliver nutrients to the southern area of the wetland.

Fig. 4.62 Conceptual Site Model for Greennan Lough, Co. Down.



1. Diffuse nutrient input enters the stream that flows through the site from higher up in the catchment.
2. Point source nutrient input is likely from a slatted house situated on top of a small rise, below which a large stand of *Typha latifolia* is growing, a typical indicator of enriched nutrient status. A second potential point source location is a residential septic tank situated at the top of the drumlin that overlooks Loughaveely to the north of the site.
3. A drain links the two sections of the site, flowing from the west to the east. Diffuse nutrient inputs entering the western section of the site can flow through to the eastern section via this drain. The drain flows into the large *Typha latifolia* stand in the eastern section.
4. The main pool is surrounded by floating scraw vegetation. Groundwater may flow into the pool and surrounding scraw, delivering potentially nitrate and iron rich water to the site particularly in late winter/early spring for nitrate and late summer/early autumn for iron.
5. Water flows from the site towards the stream that flows through the site.

Fig. 4.63 Conceptual Site Model for Loughaveely Lough, Co. Armagh.

5. Framework for Monitoring

Wetland assessment is essential in order to understand threats, risks and likelihood of change to hydrological and ecological character of wetland habitats. The assessment can be undertaken in a number of ways, from initial low-cost desk-based, data and literature gathering assignments through to large scale, multi-stakeholder, multi-year, high investment research and monitoring projects. As such, wetland assessment is typically resource limited in terms of budgets, time and personnel.

At the international level, The Ramsar Secretariat provides a framework for inventory, assessment and monitoring of Ramsar wetlands (Ramsar Convention Secretariat, 2010). The framework defines wetland inventory, assessment and monitoring as:

- **Wetland Inventory:** *The collection and/or collation of core information for wetland management including the provision of an information base for specific assessment and monitoring activities.*
- **Wetland Assessment:** *The identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities.*
- **Wetland Monitoring:** *The collection of specific information for management purposes in response to hypotheses derived from assessment activities and the use of these monitoring results for implementing management.*

In order to achieve the key tasks of the Tellus Border Wetland Project, a combination of wetland inventory, wetland assessment and wetland monitoring has been undertaken. The wetland inventory process was undertaken through the site shortlisting process, gathering information on wetland habitats throughout the border counties, and using this information as a base to shortlisting wetlands for further assessment. Further desk-based data collection on the shortlisted sites resulted in an initial wetland characterisation that identified key knowledge gaps which helped to define the wetland monitoring activities over the course of the Tellus Border Project. The information and data collected through the wetland monitoring phase has informed the development of conceptual diagrams for shortlisted sites which indicate the current understanding of the mechanisms of water delivery and ecosystem function to the site along with pressures acting within the site.

The experiences and lessons learned through this Tellus Border Project have been collated to produce a framework for wetland monitoring that is applicable not only at the border county scale, but also nationally and internationally. Importantly, the scale at which assessment has to take place and the varying requirements of competing legislation and policy that are driving assessment provide significant challenges to developing a framework that is applicable across geographical, spatial, hydrological and ecological variation.

The framework (Fig. 5.1) adopts a five-phased approach with a number of tasks identified within each phase. The level of expertise required to complete each phase is identified, but is it important to note that within all five phases managers are able to provide significant personal development and up-skilling opportunities to lower-level staff in order to increase the knowledge and skill base within their organisations. For this framework, expertise has been divided into three levels:

- *Basic* – Junior staff members or research assistants with no or limited knowledge of wetland habitat assessment capable of undertaking task;
- *Moderate* – More senior/experienced staff members with reasonable knowledge of wetland ecosystems and their monitoring and assessment should undertake the task;
- *Expert* – Staff that are expert in wetland ecosystem function and processes and their monitoring and assessment should undertake the task. Typically senior field staff, managers and academics are able to provide input at this highest level.

Phase I: Collation of background and baseline information

The initial phase of the framework is a desk-based data gathering exercise that can be undertaken by personnel at the lower (basic) expertise level, with the aim of collating all known information available on the wetland habitat or site. This first phase is divided into three distinct tasks:

Task 1: The identification of any legislative requirements that are driving the assessment of the wetlands. It is likely that these legislative requirements are already known and have, therefore, identified the need for further work to be undertaken on a wetland habitat or site.

Task 2: To identify which wetland habitats and or wetland sites are of interest. This can also be driven by the legislative requirements, for example GWDTEs may be the focus as a result of requirements of both the Water Framework and Habitats Directives. If necessary,

particularly if working at the larger scale (for example national scale), a full wetland inventory process as identified by the Ramsar Convention Secretariat (2010) may be required.

Task 3: Assembling all available background and baseline information on the wetland habitat and/or site(s) to develop an initial characterisation of the wetland. If the habitat or site is protected under current legislation then much of this information will already have been gathered by the respective responsible government agency. Background/baseline information for the initial characterisation should include, but not be restricted to:

- Site location
- Habitats present (provide habitat maps if possible)
- Underlying geology
- Soils present
- Subsoils present
- Aquifer classification and groundwater vulnerability
- Delineation of catchment area
- Delineation of Zone of Contribution if groundwater dependent
- CORINE data within the catchment
- Hydrological data for both surface water and groundwater
- Ecological data (e.g. vegetation, macroinvertebrate and bird surveys)
- Hydrochemical and geochemical data – regional baseline and site specific
- Potential threats to the hydrology and ecology of the habitat/site
- List of stakeholders (and contact details) associated with a specific habitat or site, e.g. Government agency officer(s), community groups, landholders

Phase II: Review of Objectives and Gap Analysis

Before any specific investigations are undertaken, a clear understanding of the management and conservation objectives of the habitat and/or site is required. A moderate skill level is required at this stage, but junior staff members can be encouraged to participate in up-skilling and personal development. There are four tasks outlined in Phase II:

Task 1: To identify the management and conservation objectives for the site(s) of interest. If the site has conservation designation under national or international legislation or policy, then

it is likely that these objectives have already been determined and are available for review. If there are currently no objectives for the site then it is recommended that they are developed in consultation with the key stakeholders of the site (see Task 3, Phase I, above). If a key legislation change is likely in the near future then it may be prudent to wait for the legislation change before altering the objectives, however this must be assessed against current timeframes and the pressing need for gathering further information.

Task 2: Undertake a review of current objectives. Are they suitable for the habitat or site? Are the objectives being met by current management and conservation practices? Are there likely to be any changes to the objectives in the near future as a result of any alteration in legislation or management practices? If the objectives are not determined to be suitable, or changes to the objectives are likely in the near future, then it is recommended that updated objectives are developed in consultation with the key stakeholders of the site (see Task 3, Phase I, above).

Task 3: Assess the risks and likelihood of not achieving the objectives. This involves examining the management and conservation practices at the site, the potential threats to the site and undertaking a basic risk assessment, inclusive of likelihood scores, of the objectives not being achieved.

Task 4: If the objectives are not being met, then there will be key knowledge gaps that need to be filled in order to move towards achieving the objectives. These knowledge gaps may include, among others, the lack of baseline data or unsuitable management practices that may require some form of change. The identification of these knowledge gaps allows the assessment of the suitable tier level of data collection required as outlined in Phase III below.

Phase III: Tiered approach to the collection of new information

The level of investigation that is required can be determined following the identification of key knowledge gaps and also an examination of resources. Budgets, personnel and time are the limiting factors associated with the collection of new information and, therefore, a four-tiered approach has been developed that reflects these limitations:

Tier 1: Desk-based collation and summary of current information.

- Timeframe: Short-Medium.
- Cost: Low.

- Expertise level: Basic to Moderate.

The background/baseline information that was collected in Task 3, Phase I, needs to be collated and analysed/summarised in order to develop a more holistic understanding of the wetland habitat or site being assessed. This analysis or summary can be used to further determine the suitability of the current management and conservation objectives and also provide baseline information for the subsequent tiers for information collection.

Tier 2: Site visit and walkover assessment.

- Timeframe: Short term.
- Cost: Low.
- Expertise level: Moderate to Expert, with opportunities for up-skilling of less expert staff members.

Site walkovers are an exceptionally valuable tool to gather an in depth understanding of the hydrology and ecology of a wetland habitat or site. Personnel require an expert knowledge of hydrology and/or ecology and should be suitably qualified, however, there exists an excellent possibility for providing up-skilling and personal development opportunities, particularly in sharing methodologies and knowledge with the expert staff in attendance. The walkover should aim to confirm: 1) The hydraulic connectivity and hydraulic interactions and within and immediately outside the site; 2) Key aspects of the site's ecology and any potential indicators of a change in ecological character from that for which the site is protected or described (if there is no conservation designation). Walkovers should include, but not be limited to:

- Recording surface water inflow and outflow locations.
- Estimating surface water levels, inflow and outflow rates and stream morphology.
- Identification of any barriers to surface water inflow/outflow.
- Taking spot measurements of conductivity, pH, temperature and dissolved oxygen in both inflows and outflows, but also wherever standing water is present within the wetland. Conductivity and temperature can be useful indicators of potential groundwater contribution.
- Observations of any iron precipitates or staining within standing surface waters (indicating potential groundwater contribution).
- Observations of distinct habitat areas within the site.

- Observations of any indicators of nutrient enrichment (e.g. presence of green algae in surface waters, presence of *Typha latifolia* particularly in large swards).
- Observations of the general topography.
- Observations on any potential pressures to the habitat/site (e.g. potential point source locations such as cattle yards or possible septic tank locations, farming practices within and external to the site).

The information collected during the site walkover can be used to inform conceptual models (see Phase IV), updating any site characterisations as well as informing the design of monitoring and/or research programmes (Tiers 3 and 4).

Tier 3: Design and implementation of a short-term monitoring programme

- Timeframe: Short to medium.
- Cost: Moderate.
- Expertise level: Moderate to Expert.

In order to fill key knowledge gaps, a short-term (less than one year) monitoring programme may be required. Monitoring programmes should be designed to achieve SMART objectives, answer key questions and be aligned (if feasible) with any current legislative objectives and monitoring programmes.

Tier 4: Design and implementation of a longer-term monitoring or research programme

If resources allow, it may be necessary to initiate a longer-term (greater than one year) monitoring or research programme in order to fill the key knowledge gaps. Again, the aim should be to achieve SMART objectives and answer key research questions, with specific timeframes allocated to specific tasks. It is likely that additional funding will be necessary and, therefore, funding options available through national and international bodies and programmes should be investigated as well as the possibility of leveraging additional funding from industry and academia. In-kind contributions from governmental bodies, NGOs, academia and community groups as well as other stakeholders can assist in reducing potentially high costs. Community monitoring activities should be considered if a suitable group and skills base is available.

Phase IV: Analysis and understanding of new information

The information collected through application one of the four tiers outlined in Phase III must be analysed and interpreted. This generally requires an expertise level of medium to expert, but some basic assessments may be undertaken by more junior level staff. There are four tasks outlined in Phase IV:

Task 1: Undertake qualitative or quantitative analysis of new data or information. Following the initial desk-based summary outlined in Tier 1, Phase III, characterisation documents and maps may need to be completed or updated. Following a site walkover outlined in Tier II, Phase II, habitat maps may need updating, along with the addition of any previously unknown hydraulic input/output. Spot measurements and observations can be recorded in characterisation documents. Both the short- and longer-term monitoring/research programmes outlined in Tiers 3 and 4, Phase II, will likely result in complex quantitative data that will require statistical analysis and graphical representation and may involve complex interpretation.

Task 2: Following the analyses undertaken in Task 1, the data or information should be interpreted to build or update the conceptual understanding of the wetland habitat or site. The conceptual understanding can take the form of a number of models or diagrams and should aim to follow the processes outlined by Wilkinson *et al*. (2007a and b). It should be noted that the Wilkinson *et al*. (2007a and b) framework was developed in South Australia and therefore is directed towards the aquatic environments found in that locality. Nevertheless, the fundamental processes described are applicable globally and represent a framework for conceptualising aquatic systems which is currently absent in Ireland.

Task 3: Following the conceptualisation of the wetland habitat or site, it is important to go back to review the original management and conservation objectives, knowledge gaps and monitoring/research questions with regard to the newly collected data or information. Have the monitoring/research questions been successfully answered? If not, what is required to answer them fully? Have the key knowledge gaps been filled? Are the objectives achievable and do they need updating? Revisions of management and conservation objectives should be undertaken in consultation with key stakeholders identified in Task 3, Phase I. Outputs from this task may also include the identification of further activities required to achieve objectives

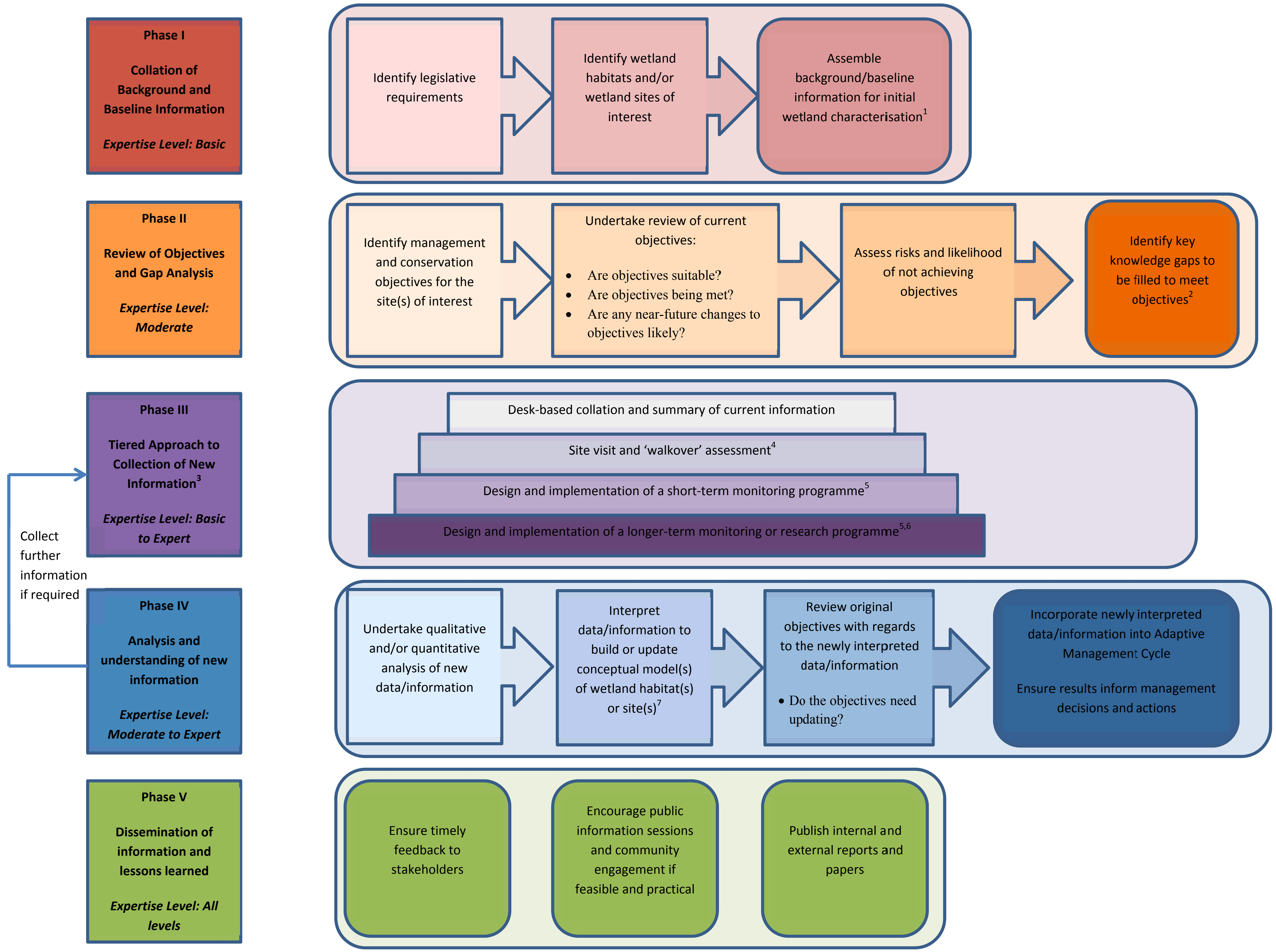
or fill knowledge gaps that may include the collection of further information (i.e. a return to Phase III).

Task 4: All newly interpreted information and data must be incorporated into an adaptive management cycle to ensure that management decisions and actions are informed by the most up to date information available. Communication of the data and information is, therefore, very important.

Phase V: Dissemination of information and lessons learned

Incorporating new information into an adaptive management cycle critically relies on the clear communication of that information. Communication will be important across a number of levels from senior management through to the engagement of community groups. Therefore communication can be undertaken in a number of forms both orally and written through published reports, papers and presentations, formally through official management and funding reporting structures and informally through casual meetings and conversations. The three tasks outlined in Phase V encourage the dissemination of information collected:

- *Task 1:* Ensure timely feedback to stakeholders.
- *Task 2:* Encourage public information sessions and community engagement if feasible and practical.
- *Task 3:* Publish internal and external reports and papers.



[1]Background/Baseline information should include, but not be restricted to: 1). Underlying geology; 2). Soils; 3). Subsoils; 4). Aquifer classification and groundwater vulnerability; 5). Delineation of catchment area(s); 6). CORINE data; 7). Hydrological data for both surface waters and groundwaters; 8) Ecological data (e.g vegetation, macroinvertebrate and bird surveys); 9). Hydrochemical data.
[2]Methods for filling knowledge gaps include 1). Desk-based studies and literature reviews; 2). Field-based surveys; and 3). Networking with external bodies and agencies (national and international).
[3]This four-tiered approach is resource limited in terms of both budget, time and personnel.
[4]A site walkover assessment should be undertaken by a suitably qualified ecologist and hydrologist in order to confirm: 1) Hydraulic connectivity and interactions to, from and within the site; and 2). Key aspects of the ecology and any potential indicators of a change of ecological character from that for which the site is protected or described (if no conservation designation).
[5]Monitoring programmes should be designed to achieve SMART objectives, answer key questions and be aligned (if feasible) with any current legislative objectives and monitoring programmes.
[6]Additional funding and research collaborators are likely necessary to implement longer term (>1 year) monitoring and research programmes. National and International funding bodies and programmes will be important, in addition to the leveraging of additional funding from industry, academia and in-kind contributions from governmental bodies, NGOs and community groups and other stakeholders.
[7]Conceptual model building for wetland habitats should aim to follow the processes outlined by Wilkinson *et al*. (2007a and b): A best practice framework for the monitoring and evaluation of water-dependent ecosystems: a) Framework; and b) Technical Resource.

Fig. 5.1 Framework for the assessment of wetland habitats and sites.

6. Conclusion and Benefits

With increasing recognition of the value of wetlands, there is an increased need to acquire information on the current status of wetlands, and to assess the degree to which they are being degraded. Improved strategies for managing wetlands require knowledge relating to the ecological character of wetlands, the extent of wetland loss, the implementation of monitoring strategies and an evaluation of their success following implementation. In turn, this baseline information should be linked directly the principal legislative and policy drivers in order to facilitate meeting Ireland and Northern Ireland's obligations in this regard, and to insure successful integration with management processes, which will provide the basis for maintaining the ecological functioning of a wetland, thereby ensuring the sustainable use of their resources. The research undertaken over the course of the project provided baseline data on hydrological and ecological aspects on a range of wetland habitats in the border region. The outputs and benefits of the project, some of which are of particular relevance to national and EU regulations and policy frameworks (Table 6.1), can be summarised as follows:

- In order to improve wetland management it is necessary to acquire information on the occurrence and distribution of wetlands. The information which was produced as part of this study on the occurrence of wetlands in relation to a range of geological and geochemical characteristics in the border region of Ireland is an important first step in the development of a full inventory of wetland habitats for both jurisdictions and highlights the role that Tellus and Tellus Border datasets could play in providing data useful for regional studies of this type. A comprehensive inventory of wetlands will be an important tool for successful wetland management as it will provide a clear means of assessing rates of wetland loss and degradation and will, therefore, additionally provide a means of promoting awareness of wetland function and conservation value.
- A framework for the assessment of wetland habitats was developed (applicable both to the WFD and Habitats Directives). This can be used to assist and inform monitoring programmes and supports co-ordination between the objectives of the WFD and Habitats Directive, particularly in the case of GWDTEs. Monitoring is crucial in helping to understand where and why habitats form. Long-term monitoring plays an essential role in assessing the ecological status and function of wetland systems and allows changes through time to be documented. In addition, monitoring

allows the impact of various land management decisions and the effect they have on the ecosystems as a whole, or on a group of target species or habitats, to be assessed.

- Monitoring data collected as part of this project, in addition to other desk based data collated over the course of the project has provided information on the principal threats to wetland habitats in the border region of Ireland. Hydrochemical and biological data collected at case study sites indicate that a number of sites may be impacted by excessive inputs of nutrients. This was particularly evident in the biological communities, with high annual maximum chlorophyll *a* concentrations representative of high phytoplankton biomass recorded at some of the sites, particularly Kilroosky. In addition, macroinvertebrate taxa considered to be tolerant to high levels of pollution were found to dominate communities at case study sites, with a corresponding absence of the most sensitive taxa at the majority of sites. Nevertheless, values of dissolved nutrients were generally below levels considered indicative of pollution, which is likely a consequence of important biogeochemical processes which are occurring within the system, such as retention within sediments or uptake by the vegetation. Phosphorus can be immobilized through sorption and precipitation reactions with iron and calcium. In this study the calcium concentration within the sediments of Kilroosky Lough were found to be correlated with phosphorus levels within the sediment. The importance of biogeochemical effects in mitigating the impact of dissolved nutrients was also evident at Rockmarshall, with low surface nitrate concentrations occurring in locations where high groundwater nitrate levels were recorded. This suggests that biogeochemical processes within the system are also important for the retention of nitrogen through denitrification or plant uptake.
- High inputs of nutrients at wetland sites did not necessarily correspond to impacts on vegetative communities. At Rockmarshall, for example, high inputs of nitrate from groundwater flowing into the site did not result in an observed impact on the vegetative communities at Wetland 1 and 2 or high levels of surface water nitrate. This suggests that there was a degree of nitrogen retention within the system. However, the poor development of the vegetation at Wetland 3 may be accounted for by the elevated levels of ammonia in the groundwater samples from Wetland 3 which also had high surface water nitrate and ammonia concentrations compared to the other linear wetland features. This suggests the possibility that elevated nutrient input, likely arising from nearby point sources, is impacting the development of the

vegetative community, or alternatively the vegetation may be affected by the deeper drainage ditch at this wetland, resulting in dryer conditions compared to the other two linear wetlands.

- Nevertheless, observations of *Typha latifolia* at Loughaveely, which can be an indicator of high nutrient levels, suggests vegetative impacts at this site. Detailed spatial monitoring at Loughaveely indicates elevated surface water concentrations of nitrate (3.91 mg L^{-1} NO_3-N compared to mean nitrate values of 0.38 ± 0.06 mg L^{-1} NO_3-N), within the vicinity of the *Typa* bloom. It is very likely that the high nitrate concentrations at this location originated from the nearby farmyard and slatted house situated less than 200 m up-gradient of the area of *Typha* growth. At this site, as elsewhere in this study, it was found that investigation of spatial variation in hydrochemical parameters within sites was instrumental in assisting with the identification of possible sources of contamination within a site. In addition to the high nitrate levels associated with possible contamination arising from a slatted house at Loughaveely, additional high nitrate was also recorded adjacent to a land drain and cattle feeder located on the site.
- Drainage on wetlands is often carried out to make the land more suitable for agricultural activities. However, it can have wide ranging effects on the water budget of a site and is, therefore, extremely important. At Loughaveely towards the end of the project study period, a drain running through the site was widened and deepened. Unfortunately, the impact of this drainage on the habitat could not be observed within the life span of this project. In addition, there was also anecdotal evidence of historical drainage events at some sites, such as Kilroosky Lough, with drainage activities at the outflow reportedly resulting in a drop in the water level of the Lough by nearly a metre leading to terrestrialisation of the lake margins (local landowner, *pers. comm.*). In the absence of historical data, it is difficult to verify this observation or to assess the corresponding impact on ecosystem function, particularly on the important lake edge habitat preferred by the white-clawed crayfish. This highlights the importance of improved monitoring programmes which can assess the impact of anthropogenic activities on the ecosystem function.
- At a number of sites notable vegetative and macroinvertebrate communities were identified which support SAC and ASSI listings, such as the presence of the white clawed crayfish at Kilroosky. In addition, some of the sites showed interesting

biological communities such as Windy Gap, which had relatively high abundance and diversity of species of snail despite its low alkalinity and low calcium concentrations. In addition, the high pH values recorded at Windy Gap were greater than expected for a cutover bog system. This was possibly a consequence of the inflowing streams having limited contact with peat, or alternatively points towards a potential for groundwater input to the site.

- Assessing the environmental supporting conditions of groundwater dependent wetlands (GWDTEs) in Ireland is limited by the lack of evidence-based information on groundwater level, flow and hydrochemistrky which are required to maintain the ecosystem in a favourable condition. This project provides detailed site specific data on GWDW habitats and species (including the detailed instrumentation at Rockmarshall, Co. Louth), which directly assesses their response to water levels and quality variations. Information on environmental supporting conditions required to maintain an ecosystem in a favourable state will allow managers to better determine impact or significant damage at a wetland site, particularly GWDTEs. The site specific data may also provide much needed baseline data on a range of GWDW habitat types. In the United Kingdom (UK), Trigger Values (TVs) have been developed for a range of GWDW habitats (UKTAG, 2012), and work has previously been undertaken to develop TVs for caladium fen habitats in Ireland (Kimberley and Coxon, 2013). However, the lack of baseline data in Ireland has made development of TV values for the full range of GWDW categories difficult. Trigger values are used in the assessment of nutrient inputs from groundwater bodies to GWDTEs. Exceedance of a TV at a groundwater monitoring point which is linked to a GWDW can trigger further investigation of that site to determine if there has been resulting impact to the wetland ecosystems. However, the UKTAG recognise the necessity to investigate further the relationships between elevated nitrate concentrations and wetland condition in lowland settings. In addition, further research is required to establish the relationship between phosphate in groundwater and wetland condition. The methodologies employed in this project, in addition to the site specific investigations of this project will provide data which may assist in addressing the data requirements necessary for successful implementation of the WFD particularly in relation to Irish GWDTEs.

Table 6.1 Tellus Border Wetland Project contribution to national and EU regulations and policy frameworks.

Policy Drivers	Key Stakeholder	Specific Project Output	How can it be used
Water Framework Directive Habitats Directive	Environmental Protection Agency (EPA), Local Authorities, Ireland Environment Agency (NIEA), Geological Survey Northern Ireland (GSNI), Gelogical Survey Ireland (GSI), National Federation of Group Water Schemes (NFGWS). National Parks and Wildlife Services (NPWS) Ireland, Environment Agency (NIEA).	A Framework for the assessment of wetland habitats . Baseline data describing the locations and extent of wetlands in the border counties of Ireland in relation to their underlying geological and geochemical characteristics. Detailed site specific data on GWDW habitats and species.	This can be used to assist and inform monitoring programmes and assists with co-ordinating the WFD and Habitats Directive objectives for GWDTEs in particular. Providing a better understanding of where various wetland habitats are likely to occur. Providing baseline data which is lacking in Ireland and has prevented the development of Trigger Action Values.

7. Recommendations and Future Work

This research was undertaken to provide baseline data on the hydroecological processes and pressures at wetland sites in the border counties of Ireland. Data was collected on a series of case-study sites which allowed the development of a working hypothesis describing key environmental processes. In addition, data was collated on the occurrence of wetlands in relation to key geochemical and geological parameters across the border region of Ireland. Following completion of the project a number of recommendations and knowledge gaps have been identified which can form the basis of future work in this area:

- A significant body of work was conducted as part of this project in collating information on the occurrence wetlands in the border region of Ireland. This task was complicated by the variations in the manner in which this information has been collected and stored. There is a need to collate and integrate all of the available data on wetlands throughout the country. This will enable the data which has already been collected on wetland systems to be used to its full potential and will permit more targeted approach to monitoring and the assessment of impacts and pressures on wetland ecosystem functioning. Integration of this knowledge and development of conceptual models which assimilates current scientific understanding of key components of specific habitats will be crucial in allowing knowledge gaps for further research and monitoring programmes to be identified. Synthesis of complex data in this way, in addition to improved co-operation and data sharing between various sectorial groups, will allow more effective communication of vital information relating to complex processes in a more effective manner.
- This project benefited greatly from the multidisciplinary approach taken, in which hydrologist, ecologists and geologists worked closely together in developing the monitoring programme and subsequent analyses of data and development of conceptual models. Co-operation between hydrogeologists and ecologists is vital so as to ensure that scare resources are not needlessly exhausted through repetitive sampling, which often fails to integrate conceptual understanding from the full range of hydrogeological, hydrochemical, geochemical and biotic factors affecting ecosystem function. It is also important that when planning monitoring programmes that that hydrologists and ecologists operate within the same scale (e.g. catchment, wetland site, within wetland site), so that ecological effects can be measured. By taking this multidisciplinary approach it will also be possible to improve understanding of the links between groundwater and ecological

communities particularly in GWDW, thereby allowing a more holistic approach to water resource management (Hancock *et al.*, 2009). The methodologies used throughout this project can provide a methodological framework for similar multidisciplinary studies to be conducted over a wider range of wetland habitats types, so as to provide an integrated approach to data collection and consequentially improved understanding of integrated ecosystem processes.

- Improved education of the general public and policy makers is also extremely important for protecting wetland systems and improving management of these systems. As increased understanding of their ecological and economic value will improve outcomes of the decision making process. The approach taken to public outreach in this project involved a combination of direct communication with the public, particularly landowners and participation by project members in a range of outreach events, predominantly those focused on primary and second level students. These activities were vital for developing goodwill amongst the landowners involved in the project. However, these actions could be developed further, particularly in relation the direct involvement of the public in conservation or monitoring activities. Local or regional conservation activities that involve field visits or workshops can greatly improve the public's understanding of issues relating to wetland management and highlight their importance both economically and recreationally. The 'BioBlitz' campaign, managed by the National Biodiversity Database, is an excellent example of a national initiative that aims to improve public awareness of issues relating to biodiversity conservation. Similar events carried out on a more site specific or regional basis may be equally successful in shaping attitudes relating to wetland loss and damage, which may ultimately succeed in garnishing support from higher level policy makers. In addition, highlighting or focusing on the monitoring of 'flagship species' which are rare, nationally important, or high profile, can be used to assist in gaining publicity and support for monitoring or research activities ultimately benefiting a range of other species, or the habitat as a whole.
- Adopting an ecosystem approach (a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way (Millennium Ecosystem Assessment, 2005)) to wetland monitoring could provide an overarching framework for the development of local and strategic management plans for wetland ecosystems. Wetlands provide major services, but their benefits are inadequately identified resulting in habitat losses. Although not necessarily a straight forward process,

measuring or placing a value on ecosystem services is integral for the development a management framework which aims to maintain ecosystem structure and function, and is vital for ensuring informed decision making (Barbier *et al*., 1997). There remains, however, uncertainty about how ecosystems services are related to factors such as habitat type, size, extent, structure or ecosystem function. Current monitoring programmes which aim to fulfil requirements of the WFD, for example, are focused on accumulating data relevant to describing the state of the systems, without necessarily addressing ecosystem processes or services. Monitoring programmes which collate data on potential pressures such as drainage or nutrient inputs and assess present and potential future impacts may also be used to make inferences about how the system may function to remove nutrients through its biogeochemical processes and can, therefore, be used to assess a range of ecosystem services in this regard (McInnes, 2007). Ensuring good inter-disciplinary cooperation will also assist in the process, particularly if social scientists and economists are used to link data on wetland ecosystem functioning to socio-economic valuation (Mode *et al*., 2002). Further research is needed to fully establish the links between ecosystem process and services, and how this can be incorporated into a wetland monitoring programmes.

- Monitoring programmes which aim to address both the requirements of the WFD and Habitats Directives should be encouraged, and will ensure more cost effective use of limited resources. Although the scope of the two directives differ, it is, nevertheless, possible to integrate monitoring programmes by including biological quality elements which are needed for both Directives, or including elements required for both Directives in the same programme allowing an assessment to be made based on a common data sets. The importance of long term monitoring sets must also be considered as they allow assessments of ecosystem change to be monitored over time, providing evidence of the impact of landuse change or other management decisions on ecosystem processes. This is particularly significant as implementation of both the Habitats Directive and the WFD require the identification of threshold hydrochemical and hydrological conditions. These thresholds can be difficult to define in complex systems particularly as they may vary over time, and this variability may be necessary to maintain system stability or resilience. There is, however, a lack of long-term data sets. Research such as this must be carried out in conjunction with more widespread surveys of wetland condition in relationship to potential impacts, so as to ensure that ecohydrological dynamics are fully understood. Cross-

jurisdictions co-operation should also be encouraged, particularly in cases where sites are situated on the border, such as Kilroosky Lough in this study.

- Within-site variability was evident at the majority of sites sampled as part of this study. Selecting the appropriate scale of spatial sampling will be important in developing monitoring programmes, which aim to assess potential risk and subsequent impacts on wetland ecosystem functioning. Further research is required, which is cable of identifying the processes underpinning within site spatial variations in order to fully characterise the relationship between threshold nutrient levels and wetland ecosystem functioning.

8. Dissemination of Research

The activities of this project were disseminated to the wider scientific community, research participants, stakeholders, and the public through a variety of methods aimed at meeting the needs of the target audience in an appropriate manner.

8.1 Poster and Oral presentations

- McKernon, R., O'Leary, A., McCarthy, V., Rolston, A., Jordan, C., Higgina, A. and Flynn, R. *Assessing the risk of nutrient enrichment in groundwater dependent ecosystems: The role of geochemistry*. Poster presentation. Geoscience 2013, Dublin Castle, Ireland. 26th November 2013.
- McKernon, R., O'Leary, A., McCarthy, V., Rolston, A., Jordan, C., Higgins, A. and Flynn, R. *Can Tellus geochemical datasets assist in assessing the risk of nutrient enrichment in groundwater dependent ecosystems?* Poster presentation. Chartered Institute of Ecology and Environmental Management, Dublin, Ireland. 19-19th November 2013.
- McKernon, R., O'Leary, A., McCarthy, V. Rolston, A. Jordan, C., Higgins, A. and Flynn, R. *Geochemical datasets assist in assessing the risk of nutrient enrichment in groundwater dependant ecosystems?* Poster presentation. Chartered Institute of Ecology and Environmental Management, Dublin. 13th November 2013.
- Rolston, A. and McCarthy, V. *Ecohydrological characterisation of wetlands in the border region of Ireland*. Oral and Poster presentation. Tellus Border Project Showcase, Monaghan, Ireland. 24th October 2013.
- McCarthy V. *Applications of the Tellus and Tellus Border data to Environmental Sector*. Oral presentation. Tellus Border Project Showcase, Monaghan, Ireland. 24th October 2013.
- Rolston, A. and McCarthy, V. *Assessment of ecohydrological character of Irish border county wetlands*. Oral presentation. Society of International Limnology (SIL) Conference. Budapest, Hungary. 5th-9th August 2013.
- McCarthy, V., Rolston, A., O'Leary, A., McKernan, R. and Flynn, R. *The influence of geological and geochemical setting on nutrient delivery mechanisms to*

groundwater dependent wetland systems. Poster presentation. Society of International Limnology (SIL) Conference. Budapest, Hungary. 5th-9th August 2013.

- Rolston, A. *Simplified approach to wetland monitoring.* Invited oral presentation. International Association of Hydrogeologists – Irish Group. Annual Groundwater Conference: 'Groundwater and Catchment Management'. 24th April 2013.
- Rolston, A. *Tellus Border Wetland Project*. Invited oral presentation: GeoScience 2012, Dublin Castle**.** 19 April 2012.
- McCarthy, V., Rolston, A. and Linnane, S. *Ecohydrological characterisation of wetlands in the border region of Ireland*. Poster presentation, ENVIRON 2012, University College Dublin, 7 – 9th March, 2012.

8.2 Workshops

A number of workshops relating to wetlands and groundwater dependent ecosystems were attended by the Tellus Border Wetland project team at DkIT. These events hosted a wide range of individuals from a broad spectrum of disciplines and included representatives from stakeholder groups such as the EPA, Local Authorities and conservation groups as well as academics. These events were as follows:

- Integrated Catchment Management field trip and workshop led by Donal Daly of the EPA to the Knappagh and Lough Bawn Catchment, County Monaghan, 20th September 2013. This field trip underlined the complexity of water catchments and the need for a multi-layered approach to protecting water bodies.
- Action for Biodiversity Conference – "Working Together for Biodiversity", Crowne Plaza Dundalk, Green Park, Dundalk, Co Louth, Wednesday 1st May 2013. This event, attended by over 160 participants from, from local authorities, environmental charities and non-governmental organisations. It was hosted by Action for Biodiversity which was a project part-funded through INTERRG IVA aims to deliver a regional and cross-border Biodiversity Framework for the region.
- Special session on Groundwater Dependent Terrestrial Ecosystems (GWDTEs) hosted by the EU Working Group C Groundwater on behalf of the Irish Presidency, Aviva Stadium, Dublin, 16th April 2013. The project team was invited to this workshop, which was attended by approximately 70 delegates mainly from a groundwater

background during which Member States outlined the progress that is being made regarding actions on GWDTE required for implementation of the WFD. This was intended to provide guidance which would enable all countries to make progress on in this regard for WFD implementation.

- Geological Society of London Workshop on Groundwater Dependent Ecosystems, Birmingham and Midland Institute, 27th February 2013. The delegates consisted of a range of researchers and representatives from stakeholder organisations during which current research activities relating to GWDTE were presented and issues surrounding current and future research and policy challenges were discussed. A guest blog summarising this event was prepared by the Tellus Border Wetland Project team member which was posted on the Geological Society of London website.
- End-of-project workshop for the EPA-STRIVE funded project titled *Environmental Supporting Conditions for GWDTEs,* Trinity College Dublin, 30th May 2012. This workshop was attended by representatives from the EPA, SEPA, NPWS, GSNI, GSI, UK EA as well as numerous academics during with the determination of groundwater nutrient threshold values and quantitative action values for groundwater dependent terrestrial ecosystems (GWDTEs) in Ireland was discussed including progress, challenges and recommendations.

9. Added value for the project

9.1 Leveraged funding

The data obtained over the course of this two year project in addition to the considerable instrumentation installed in at least one site, has provided the project team with an opportunity to further develop upon and enhance the outputs of this project by securing additional funding from other sources. This will lead to an increase in the project scope, allowing additional issues and research questions relating to wetlands to be addressed and developed, with particular emphasis placed on GWDW, which is a priority area owing to current legislative needs under the WFD.

Thus far, the team at DkIT have leveraged funding from a number of different sources and will continue to apply for additional funding as it is made available. The funding obtained to date has built on previous highly successful collaborations between DkIT and Queen's University Belfast (QUB) and, therefore, has enhanced mutually beneficial long-term cross border links along the strategic M1 Dublin-Belfast corridor. In addition, leveraged funding will insure maximum scientific output from the current project, and will broaden the overall impact of the work carried out to-date. The funding leveraged is summarised as follows:

- 2013, €23,000, Tellus Border Research Tender, *Tellus Investigation of Wetland Ecology and Geochemistry* (TIWEG), *Collaborators*: QUB.
- 2012-15, €41,800, DkIT Collaborative Research Programme, *An investigation into the ecology and hydrology of Groundwater Dependent Habitats*. Supports a PhD student for a period of three years, *Collaborators*: QUB.
- 2012, €1,300, DkIT Summer Undergraduate research programme, *Assessment of macroinvertebrate communities within freshwater wetlands in the border counties*. Provided funding to support and undergraduate student in gaining research and laboratory experience over a six week period.
- Further proposals in progress, building on cross border collaborations.

9.2 Training and development of Expertise

Building capacity and expertise within DkIT in the area of wetland research was core to the activities of the project team. As such the activities of the project have been used to develop and augment both undergraduate and postgraduate teaching programmes within the Department of Applied Sciences at DkIT. Additionally, work experience placements and job opportunities created over the course of the project have provided training and development opportunities which have enhanced individual skill sets and career prospects. Positions made available as a consequence of the project include:

- One Postdoctoral researcher position, two year fixed-term contract.
- One Research Assistant position, nine month fixed-term contract.
- PhD student, undertaking wetland research in the border counties of Ireland, 3 year fully funded studentship.
- Two interns under the FÁS JobsBridge National Internship Scheme.
- Summer Undergraduate Bursary Students, six week long fully funded student bursary awarded by DkIT.

In addition, the project outputs and activities were used at both undergraduate and postgraduate as follows:

- As part of the Programmatic Review process carried out within the School of Health and Science at DkIT in 2013, a newly developed module on Wildlife and Habitat Ecology was introduced to the BSc Applied Bioscience programme. The indicative content of this module was informed by the activities of the Tellus Border Wetland Project. Wetland habitat and management now forms an important component of the module, with field sites such as Rockmarshall providing an excellent case study site for field investigations showing hydrological and ecological monitoring and instrumentation set up and sampling procedures.
- Three final year research projects were conducted under BSc (Hons) in Environmental Biology programme which were integrated into the activities of the Tellus Border Wetland Project as follows:
    - Student: Leanne Corduff; Thesis Title: *To assess the phosphorus (P) sorption capacity of the sediments of two different wetlands using a Langmuir*

Isotherm, and to analyse the sediment characteristics at Kilroosky lough and Greenan Lough.

    - Student: Ronan Maguire; Thesis Title: *Aspects of zooplankton species distribution and abundance in wetlands.*
    - Student: Bibishan Rai; Thesis Title: *Macroinvertebrate spatial distribution within wetland habitats.*

- Two MSc theses produced through collaboration with QUB (Raymond Flynn) as follows:
    - Student: Ruaidhrí McKernan; Thesis Title: *An investigation into the human and geological factors impacting Groundwater Dependent Ecosystems (GWDEs) in the Republic of Ireland-Northern Ireland border area using GIS.*
    - Student: Michael Gurren; Thesis Title: A hydrological investigation of a Groundwater Dependent Ecosystem (GWDE) in the Republic of Ireland.
- PhD project: *An investigation into the ecology and hydrology of Groundwater Dependent Habitats.*

9.3 Outreach and Knowledge Transfer

An important aspect of the Tellus Border Wetland Project activities was to promote awareness of issues relating to wetland conservation and protection among the general public, in addition to policy makers and managers. It is anticipated that improved public knowledge on the societal benefits of wetland habitats and their management will engender a greater interest and understanding of the issues. This will improve public discourse and encourage informed responses by decision makers. Outreach activities ranged from direct contact with landowners and local authorities to attendance at educational outreach events, and are summarised as follows:

- Attendance as Judges by Tellus Border Wetland Project team members at SciFest events at DkIT (2 years running). SciFest is a series of one-day science fairs for second-level students hosted locally in schools and at regional level in the Institutes of Technology.
- Dr. Alec Rolston is Chair of Loughs Agency Community Environmental Forum. This is a stakeholder interest group with almost 50 representatives.

- Extensive landowner consultation was undertaken throughout the life-span of the project. Particular emphasis was placed on effectively engaging with landowners from the five case-study sites, so as to keep them informed at every stage of the process and ensure a good working relationship with the project team.
- During the early stages of the Tellus Border Wetland Project, team members met with individual Local Authorities within the border counties in both NI and the RoI in order to inform them of the proposed activities and outcomes of the project. Their assistance and recommendations, in particular, were an important part of the site selection process.
- In September 2013, a field visit took place to the Rockmarshall site, Co. Louth by a group from the Irish section of the International Association of Hydrogeology (IAH). There were approximately 15 delegates in attendance and they were provided with a summary of the project and field survey techniques.
- In Aug 2012, stakeholder (EPA) site visit took place to the Rockmarshall site, Co. Louth.
- A guest blog summarising a Geological Society of London Workshop on Groundwater Dependent Ecosystems, held at the Birmingham and Midland Institute was prepared by the a Tellus Border Wetland Project team member which was posted on the Geological Society of London website: (http://blog.geolsoc.org.uk/2013/05/10/groundwater-dependent-ecosystems-event-summary/).

9.4 Collaborations

Strategic cross border collaborations have been established over the course of this project, with particular emphasis placed on the need for multidisciplinary approaches to the project and the consequently need for input from a wide range of scientific disciplines. As such, on-going collaboration between DkIT and QUB have been developed. Hydrogeological expertise on this project was provided by Dr. Raymond Flynn, SPACE, QUB. This collaboration, has led to the development of a number of other research proposals. In addition, collaboration with members of the Tellus Border Soil Carbon Project who carried out ground penetrating radar (GPR) and electrical resistivity surveys of the Rockmarshall site. Additional, electrical conductivity surveys were carried out by Shane Donohoe of QUB. Links were also

established with Tiernan Henry and Eve Daly from NUI Galway, to discuss potential synergies between the Tellus Border Wetland Project activities in the Dundalk Bay region, which includes the site at Rockmarshall, and the project funded under the Tellus Border Research Tender entitled ‘Groundwater and Land resources in Tellus Border coastal zones.’

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